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

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[1] The geographic scope of this report is Europe, with a particular focus on Denmark, Iceland, Norway, Spain, Russian Federation, United Kingdom, Faeroe Islands, Sweden, France, Germany, Greenland,Ireland, Italy, Netherlands, Poland, Portugal and Ukraine.

SUMMARY

The intensive production of mainly carnivorous species in Europe uses fish feeds with a high content of fishmeal and fish oil, currently consuming around 615 000 tonnes of fishmeal and 317 000 tonnes of fish oils per year, thus requiring around 1.9 million tonnes of feedfish. While the capture and processing of feedfish provides only a small contribution to European fisheries-related employment (0.5 percent) and value added (2.8 percent), they help support an important aquaculture industry that has been dependent upon regional fishmeal and fish oil production to sustain its growth. With a conservatively estimated rise of European aquaculture production of 2 percent per year, fishmeal and fish oil use are likely to rise to 629 000 tonnes and 343 000 tonnes, respectively, by 2015, despite the greater use of vegetable-based substitutes and the greater efficiencies in feeding and nutrition.

The main sources of these feedfish are the small pelagic stocks of northern Europe, the Peruvian anchovy and jack mackerel of South America, and the fishmeal produced from trimmings and the bycatch of food fisheries. Due to the small size and low age of these feedfish, the stocks are difficult to manage on a multi-annual basis like many stocks in Europe. While their high fecundity allows stocks to recover from depletion fairly rapidly, there is concern over the impact of fishing pressure on predator-prey relationships in already stressed ecosystems.

Although quality and price are the main determinants for fishmeal purchasers in the aquafeeds industry, the sustainability of feed-fish sources is beginning to become more important. As yet there is no fully independent comprehensive analytical framework that integrates target stock assessment with the wider ecosystem linkages. To a degree this exists with the development of ecosystem models and approaches such as the Marine Stewardship Council (MSC) criteria for "responsible fishing". Once such a framework has been created and is accepted as a suitable benchmark by the aquafeed industry and its detractors, then it will be easier for purchasers to purchase only from sustainable feed-fish stocks. This process will inevitably have consequences, such as greater pressure on those stocks deemed as sustainable, as well as possible effects on market economics.

The various feed fisheries targeted for fishmeal in Europe have little alternative uses. However some fisheries such as blue whiting, capelin, anchovy, herring and sprat, can be used for direct human consumption. The portion that goes for human consumption is not determined by technical limitations but depends largely on economic and cultural factors, which are more difficult for the industry to address directly. Despite the relatively low cost of products originating from small pelagic fisheries, they are not considered to contribute significantly to ensuring the food security of any part of Europe, due to the ready availability of other nutritional options.

This report concludes with a number of issues that are considered to be of particular regional significance. These, together with the recommendations, are summarized briefly below:

- Improved management of European feed fisheries is needed through a combination of greater political will and the gradual adoption of the ecosystem approach as implementation mechanisms evolve.
- Technical and other assistance to feed fisheries outside European waters, in particular to South American and Antarctic resources, should be provided through greater cooperation and the strengthening of relevant regional fisheries management organizations.
- Barriers to the sourcing and use of sustainable fishmeal and fish oils should be addressed by (i) adopting well-structured feed-fish fisheries sustainability criteria to guide buyers; (ii) improving traceability of materials, especially if blended during manufacture or distribution; (iii) encouraging sustainable purchasing

strategies through the use of formal environmental management systems; and (iv) premium branding of aquafeeds and aquaculture products produced using sustainable raw materials.

- Markets for European feedfish and their by-products in Eastern Europe and the Far East should be investigated. These markets currently absorb between 60 000–100 000 tonnes of Icelandic capelin per year (60–85 percent of the total), which might be increased.
- Food products for direct human consumption should be developed from species that are currently reduced to fishmeal and fish oil. These products should be economically competitive, appeal to European and export markets and be resistant to the cyclical nature of fishmeal and fish oil commodity pricing.
- Further development of plant-based substitutes for fishmeal and fish oil inclusion in aquafeeds is needed. These substitutes must be able to provide cost-effective alternatives to fish-based products, be acceptable to consumers and not raise sustainability issues in their own right. Much of the required research has already been completed to effect significant levels of substitution, but various commercial and consumer issues also need to be addressed.

1.INTRODUCTION[2]

1.1 Background

The fishmeal and fish oil industry started in northern Europe at the beginning of the twentieth century. Initially based mainly on surplus catches of herring from seasonal coastal fisheries, this was essentially an oil production activity, with fish oil finding industrial uses in the lubrication of machinery, leather tanning, and in the production of soap, glycerol and other non-food products. The residue was originally used as fertilizer, but since the turn of the twentieth century it has been dried and ground into fishmeal for animal feed. The fishmeal and fish oil sector has now developed into a major supplier of raw material for animal and fish feeds.

The demand for aquafeeds continues to increase, yet the overall global supply of fishmeal and fish oil is relatively fixed (SEAFeeds, 2003). This implies that there will be increased pressure on the fisheries that supply these commodities unless alternatives become both available and acceptable. While there is no real reason why feed fisheries should not continue to supply the aquaculture industry in the future, adequate sustainability assurances need to be in place.

2. OVERVIEW OF AQUACULTURE SYSTEMS AND PRACTICES IN EUROPE

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

2.1 Current status and trends

Aquaculture is the farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated (FAO, 2009)[3]. Although freshwater aquaculture has been practiced in Europe for many centuries, full-cycle aquaculture in brackishwaters and marine waters is a more recent phenomenon. Large-scale mariculture first started in the 1970s with the Atlantic salmon (*Salmo salar*), whose large eggs and simple juvenile nutrition permitted the straightforward production of fingerlings for on-growing. Over the same period, research was being conducted into the breeding and feeding of other marine species with smaller, pelagic eggs. This has now led to the widespread production of seabass and seabream in the Mediterranean Sea and increasing volumes of more temperate species such as Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), Atlantic halibut (*Hippoglossus hippoglossus*) and turbot (*Psetta maxima*), which are being produced as technological constraints are gradually overcome and their farming becomes economically viable.

An examination of salmonid (salmon and trout) production in Europe (Figure 1) shows that the production of Atlantic salmon still dominates European mariculture in terms of volume, although growth is slowing as a result of softening prices and competition from Chile. European salmon production is largely based around the deepwater bays (lochs and fjords) of western Scotland, Ireland, Faeroe Islands and Norway. Salmon farming is almost exclusively conducted in sea cages with good tidal flushing, with a trend for larger cage systems with deeper moorings increasingly offshore.

[2] This review, which covers the period from 1995 to 2005, is essentially a desk study based on secondary sources of information and data derived from published literature and unpublished reports. Where possible, primary source data/information has also been collected through consultations with those associated with reduction fisheries and aquaculture practices in the region.

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

Seabass and seabream aquaculture has developed more recently and the production of both species groups has tripled over the last decade, reaching around 80 000 tonnes and 97 000 tonnes, respectively, in 2005 (Figures 2 and 4, Table 1). Based mainly in Greece, Turkey and Italy, seabass farming expanded rapidly in the late 1990s but has steadied since 2000. Seabream farming, principally of the gilthead seabream (*Sparus aurata*), also showed a brief plateau in the early 2000s but continues to increase, largely due to the rapid growth of Turkish production. Both species groups are mainly farmed in sea cages in sheltered areas, although land-based units are also used in France and Spain. Italy traditionally used the "vallicoltura"[4] system but has also moved towards intensive production in land-based operations and marine cage farms. Without tidal flushing, cage-farm units in the Mediterranean Sea tend to be smaller than salmon cage farms in the Atlantic.

The production of other marine fish such as turbot, halibut and cod is increasing steadily as technical constraints are overcome (Figures 2 and 4, Table 1). Turbot and Dover sole (*Solea solea*) are mostly produced in land-based farms on the Atlantic coasts of Spain and France, while cod, halibut and

FIGURE 1
Atlantic salmon and trout production in Europe, 1999–2005

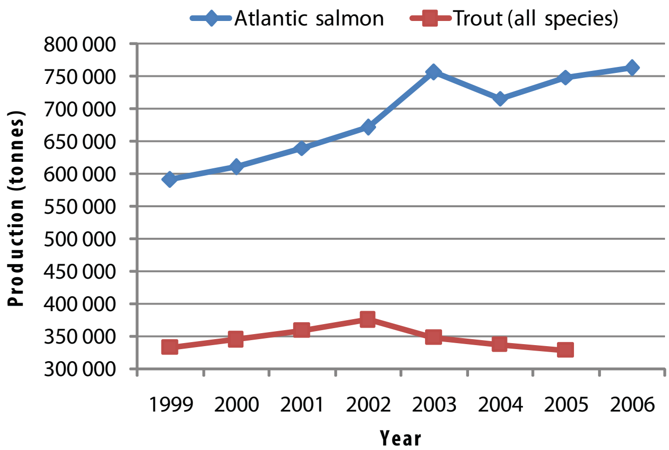

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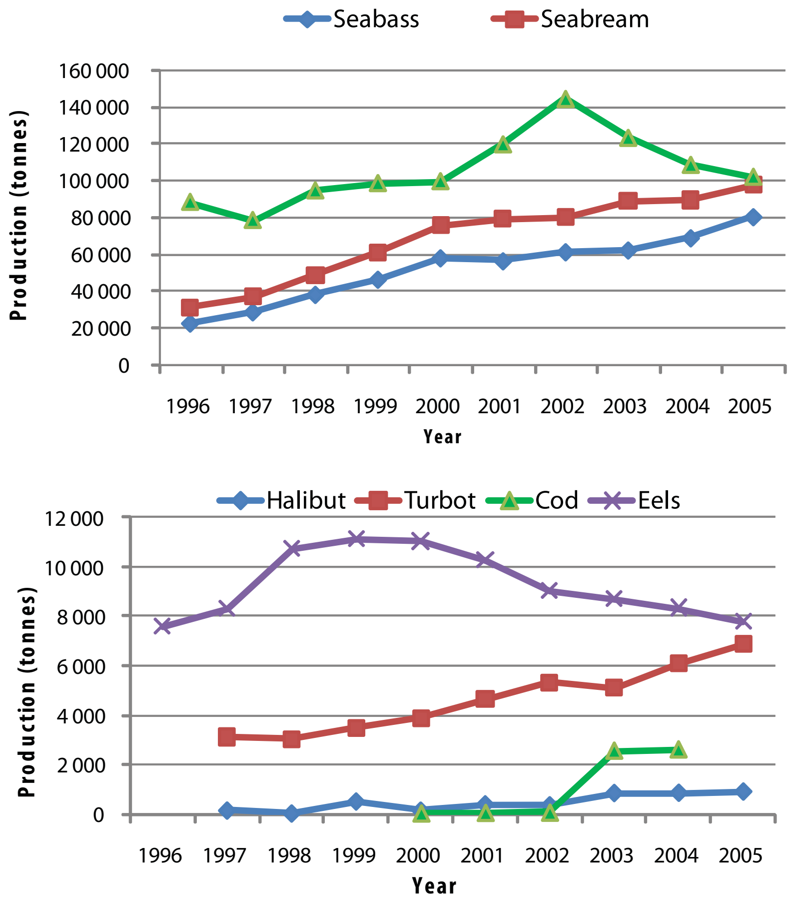
FIGURE 2
Marine finfish production in Europe, 1996–2005



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

[4] Traditional extensive lagoon-based fish culture

TABLE 1
Marine finfish production in Europe, 1996–2005 (tonnes)

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Seabass	22 334	28 433	37 939	46 157	57 811	56 162	61 093	62 060	68 679	80 161
Seabream	31 132	36 843	48 450	60 831	75 232	79 003	79 767	88 340	88 922	97 060
Salmon	403 284	452 702	502 361	591 068	610 947	640 777	671 655	756 744	717 831	712 271
Sea-grown trout	87 941	78 025	94 250	98 219	99 282	119 431	144 270	122 987	108 198	101 680
Halibut	–	138	20	503	135	389	350	845	855	905
Turbot	–	3 118	3 035	3 466	3 873	4 640	5 320	5 107	6 086	6 865
Cod	–	–	–	–	16	41	50	2 550	2 600	n/a
Eels	7 594	8 293	10 738	11 109	11 033	10 284	9 033	8 715	8 340	7 800
Total	**552 285**	**607 552**	**696 793**	**811 353**	**858 329**	**910 727**	**971 538**	**1 047 348**	**1 001 511**	**1 006 742**

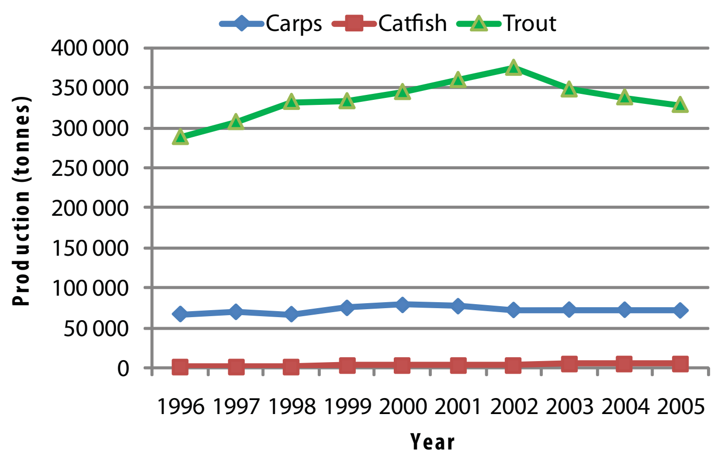
n/a: Data not available
Source: www.feap.info/feap/aquaculturedata/default_en.asp

haddock are farmed in cages in the colder waters of Norway, Iceland and the United Kingdom. Halibut juveniles are reared in land-based tanks until they are 30–40 g before they are stocked into sea cages. Unlike salmon, they prefer sheltered areas with little current movement.

In Europe, eel farms can be found in countries such as Sweden, the United Kingdom, the Netherlands, France, Spain, Denmark, Italy and Greece. Due to the complexity of their life cycle, no one has yet managed to successfully breed European eels (*Anguilla anguilla*). Instead, eel farms rely on using young eels returning from the Sargasso Sea to grow. Eel culture or farming involves catching juvenile (glass) eels when they enter freshwater and growing them to a marketable size. While 95 percent of eels are grown in freshwater, Italy, the United Kingdom, France and Germany culture eels in brackishwater (4.5 percent of production) and full seawater (0.5 percent). The three main techniques for culturing eels include the use of ponds, accelerated temperature facilities and recirculation systems.

The fattening of bluefin tuna (*Thunnus thynnus*) has expanded rapidly in the Mediterranean Sea over the last five years. The Mediterranean Sea farmed tuna production in 2004 was approximately 23 000 tonnes (FAO, 2005b), of which around 95 percent was exported to Japan, although the International Commission on Conservation of Atlantic Tuna (ICCAT) reports that there is currently cage capacity of around 41 000 tonnes (for a six-month growing period). This is mostly in Spain (29 percent), Turkey (23 percent), Croatia (16 percent), Malta (15 percent) and Italy (11 percent), with lower levels of production in Greece and Portugal.

FIGURE 3
Freshwater finfish production in Europe, 1996–2005



In freshwaters, two species groups predominate, trout and cyprinids (Figures 3 and 4, Table 2). Trout farming is carried out commercially in 23 European states, with annual production exceeding 60 000 tonnes in Norway and 35 000 tonnes in Denmark, Italy, France and Spain, while Finland, Germany, Poland and the United Kingdom each produce

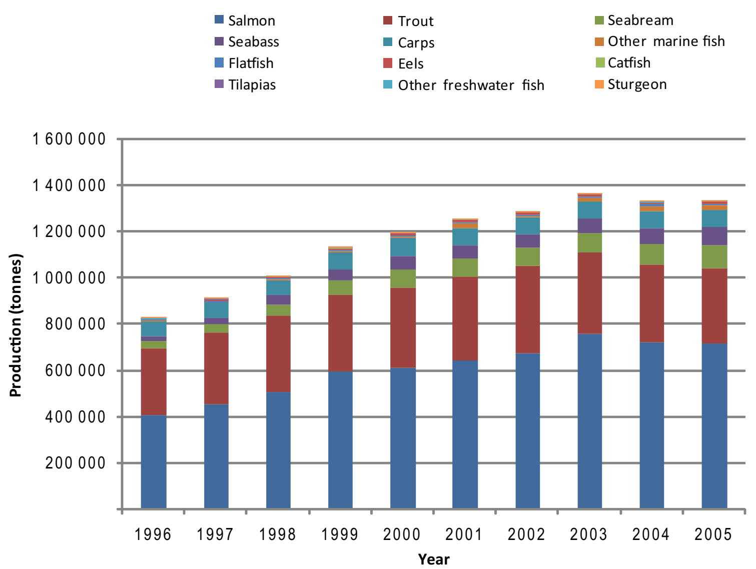
TABLE 2
Freshwater finfish production in Europe 1996–2005 (tonnes)

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Trout	288 483	307 316	332 616	333 473	344 969	360 035	375 346	348 137	338 258	328 816
Carps	67 494	70 343	67 300	75 329	79 300	77 664	72 743	73 265	73 039	72 090
Bighead carp	n/a	n/a	*450*	–	–	–	–	–	–	–
Silver carp	n/a	n/a	*2 062*	*3 648*	*3 379*	*3 195*	*2 580*	*2 777*	*3 747*	*3 950*
Common carp	n/a	n/a	*62 550*	*70 144*	*73 121*	*71 669*	*67 616*	*68 282*	*67 936*	*66 740*
Grass carp	n/a	n/a	*2 238*	*1 587*	*2 800*	*2 800*	*2 547*	*2 206*	*1 356*	*1 400*
Catfish	2 067	2 208	2 565	3 359	4 490	4 071	3 756	5 458	5 510	5 470
Tilapias	250	300	300	200	150	150	150	450	450	550
Other freshwater fish	453	568	546	619	595	420	496	528	481	495
Sturgeon	642	572	463	544	265	196	200	230	275	332
Total	**359 389**	**381 307**	**403 790**	**413 524**	**429 769**	**442 536**	**452 691**	**428 068**	**418 013**	**407 753**

n/a: Data not available.
Source: www.feap.info/feap/aquaculturedata/default_en.asp

between 10 000 and 25 000 tonnes. The main species is rainbow trout (*Oncorhynchus mykiss*), although there is limited production of brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*), and growing interest for arctic char (*Salvelinus alpinus*). European trout production has been in decline over the last three years, from a high of 375 000 tonnes in 2002 to 329 000 tonnes in 2005. During the same period, the value to trout farmers slipped from €2.26/kg to €2.03/kg for portion-size trout, while large trout rose in value from €2.40/kg to €2.50/kg. The overall first sale value fell from €805.2 million to around €700 million. With a few exceptions, trout production in Europe is poorly organized and is operated by a large number of small, independent farmers. This has led to a production-led rather than a market-led industry, with fragmented sales and decreasing returns to farmers.

FIGURE 4
Finfish aquaculture production in Europe, 1996–2005



Source: www.feap.info/feap/aquaculture/default_en.asp

Five cyprinid species share the European scene, being the common carp (*Cyprinus carpio*), the silver carp (*Hypophthalmichthys molitrix*), the bighead carp (*Aristichthys nobilis*), the grass carp (*Ctenopharyngodon idellus*) and the tench (*Tinca tinca*). Carp farming is mainly in extensive or semi-intensive pond-based systems, the latter being predominantly typical in Central and Eastern Europe. There is a big difference in the production characteristics of Western Europe and Central/Eastern Europe, the latter contributing 76 percent of European cyprinid production in 2005. The total European production dropped from 158 000 tonnes in 1988 to 72 000 tonnes in 2005, the biggest reductions being seen in the early 1990s and in the major production countries. Part of the reason for these circumstances was the social and economic change occurring in Central and Eastern Europe. However, there are only limited market opportunities available, particularly given the rising availability of other inexpensive food products.

2.2 Future outlook

Despite ongoing supply problems and rising prices, the consumption of fish and seafood is forecast to increase in all the major European markets. This is attributed to a number of factors, including the well-documented move towards healthy eating and lifestyles, the recent scares over meat safety, and the increased added-value opportunities for fish and fish products due to demographic and societal changes. Before looking at the outlook for aquaculture production, it is important to understand how demand for seafood might change due to changes in the European population, per capita demand for seafood, and the supply from capture fisheries.

2.2.1 Population growth in Europe

The population of the European Union (EU) is likely to fall significantly by 2050, even allowing for inward migration. Deaths will begin to outnumber births across the EU in the next five years, and a collapse in childbirth rates and increased emigration has already caused populations to start shrinking in several of the former communist countries of Eastern and Central Europe that joined the EU in 2004. Eurostat models suggest that by 2013 the population of Italy will start to fall, joined a year later by Germany and Slovenia and, in 2018, by Portugal. The population of Britain will continue to grow, peaking in 2040, followed by 10 years of gentle decline. Overall, the total population of the EU is expected to rise by more than 13 million between now and 2025, although after 2010 that increase will be entirely the result of immigration. By 2025, net migration will not be able to counteract the falling birth rates of the continent, and by 2050 the population of the EU will be 450 million, a decrease of more than 20 million people from the peak. The share of the population over the age of 65 will increase considerably in the EU – the old age dependency ratio (persons aged 65 years and over compared with persons 15–64 years-old) is expected to approximately double by 2050 from the initial 25 percent in 2004. There are rare exceptions: the populations of Ireland, Cyprus, Luxembourg, Malta and Sweden will continue to grow even after 2050.

2.2.2 Per capita food consumption

The per capita consumption of seafood in Western Europe has increased steadily over the last few decades and is set to rise further by 2030 (Ye, 1999), reaching around 36 kg/person/year (Table 3). Consumption in the Nordic countries, which is higher than elsewhere in Europe, is also likely to increase, but not as much as in Western Europe. In the ex-centrally planned economies (CPEs) of Eastern Europe,

TABLE 3
European per capita seafood consumption (historical and predicted)

Area/Year	Historical per capita fish consumption (kg/person/year)							Forecast		Increase 1995–2030	
	1965	1970	1975	1980	1985	1990	1995	2015	2030	%	kg
Western Europe	18.2	18.4	17.4	17.4	19.9	22.2	22.1	26.7	30.1	+36.2	+8
Nordic countries	27.9	30.8	31.7	32.4	32.5	34.0	35.6	38.8	41.7	+17.1	+6.1
Eastern Europe	16.1	20.2	24.3	22.3	25.1	20.6	10.7	25.4	30.8	+187.9	+20.1
Europe average	17.4	19.6	21.1	20.1	22.7	21.7	16.8	26.3	30.8	+83.3	+14.0

Source: Ye (1999)

consumption dropped dramatically over the 1990s but is expected to increase quickly to nearly 31 kg/person/year.

Per capita fish supply figures from the Food and Agriculture Organization (FAO) of the United Nations (Delgado *et al.*, 2002) for the period 1999–2001 indicate that the 15 EU countries have a per capita supply of 24.2 kg/year; the new EU states, 10.7 kg/year; other countries of Western Europe (The Faroe Islands, Iceland, Norway and Switzerland), 29.9 kg/year; and the countries of Eastern Europe, 3.1 kg/year. The areas of the former Union of the Soviet Socialist Republics (USSR) have a per capita supply of 16.9 kg/year.

TABLE 4
Predicted production from capture fisheries and aquaculture (million tonnes)

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

Source: *FAO (2002); **FAO (2006a); ***FAO (2005c); ****Failler (2005)

2.2.3 Supply from capture fisheries and aquaculture

According to FAO, total global fish production (capture fisheries plus aquaculture) might increase from 131 million tonnes in 1999/2001 to 146 million tonnes in 2010 and then to 179 million tonnes by the year 2015 (Table 4). This means that growth in global fish production is projected to decline from the annual rate of 2.7 percent of the last decade to 2.1 percent per year between 1999/2001 and 2010 and to 1.6 percent per year between 2010 and 2015. Global capture production is projected to stagnate, while global aquaculture production is projected to increase substantially, albeit at a slower rate than in the past. Out of the expected increase of 48 million tonnes in total global fish production from 1999/2001 to 2015, 73 percent would come from aquaculture, which is projected to account for 39 percent of global fish production in 2015 (up from 27.5 percent in 1999/2001).

TABLE 5
Regional share of total food-fish production %, 1973–1997 (actual) and 2020 (projected)

Region	Actual annual production (%)			Projected (%)
	1973	1985	1997	2020
Europe (subtotal)	30	23	11	9
EU-15	13	9	6	5
Eastern Europe and former USSR	17	14	5	4
China	10	13	36	41
Other Asia	17	19	21	21
Latin America	5	6	7	7
West Asia and northern Africa	1	2	2	2
Sub-Saharan Africa	4	4	4	5
United States of America	4	6	5	4
Japan	17	14	6	4
Other	12	13	8	7
Total	**100**	**100**	**100**	**100**

Source: Delgado et al. (2002)

Within these global figures, the proportion of fisheries production from Europe is of particular interest. The International Food Policy Research Institute (IFPRI) has projected that the total European share of food-fish production will drop from 30 percent in 1973 to 9 percent in 2020 (Delgado *et al.*, 2002). Of this, the relative importance of capture fisheries production in the EU-15 Member States is projected to drop from 79 percent in 1997 to 71 percent in 2020 (Table 5).

2.2.4 Outlook for European aquaculture

Aquaculture is now a maturing industry in Europe, especially for the established species such as salmon and trout. Past sectoral growth has been driven by the development of breeding and grow-out technologies for new species and their adoption by the commercial sector. A brief look at Figure 4 shows the steady climb in production up until 2003 and the apparent plateau in production to date. This flattening in production reflects (i) a decline of around 45 000 tonnes of United Kingdom and Faroese salmon production and (ii) a similar decline in trout production since 2002. Other species, especially seabass and seabream, continue to expand as more eastern Mediterranean countries adopt the technology, and prices recover from a slump in 2002–2003.

Delgado *et al.* (2002) forecast that the pre-2004 accession EU Member States would see a growth rate approximating that of global output but this appears optimistic. Brugère and Ridler (2004) forecast that growth from 2000 to 2020 would be less than 1 percent for most of Western Europe, with the exception of Norway, which is committed to its aquaculture sector as a means of maintaining isolated communities (Table 6). While these figures must be used with some caution, they do emphasize that aquaculture expansion in Europe will not continue at historical rates.

TABLE 6
Historical and forecasted aquaculture output in Europe

Country	Historical output (tonnes)		Actual annual growth rates (%)		Forecast 2000–2020	
	2000	2004	1980–1990	1990–2000	Output 2020 (tonnes)	Annual growth (%) 2000–2020
Spain	315 321	363 181	0.4	3.8	361 017	0.7
France	261 216	243 907	2.0	0.8	307 497	0.8
Italy	213 054	117 786	7.1	3.5	279 363	1.0
United Kingdom	159 267	207 203	30.0	11.5	168 241	0.3
Europe-15	1 314 017	–	4.0	3.5	1 539 664	0.8
Norway	493 111	637 993	31.1	13.2	1 620 000	6.3
Europe	2 067 068	2 205 649	6.9	3.2	3 557 000*	4.8*

*author's estimate
Source: Brugère and Ridler (2004)

Based on a regression analysis of trends of growth in European aquaculture, this study has projected European aquaculture production in 2015 (Table 7 and Figure 5). Two scenarios are given, one (S1) based on trends over 1996–2005 and the second (S2) on trends over 2001–2005.

Both scenarios broadly agree on the species that show a constant trend since 1996 but differ where there has been a sharp up or down trend in production over the last five years. In particular, salmon and trout have both shown a slowdown over the last five years, and this is reflected in scenario 2 (S2). Based on this latter scenario, which is considered to be the most realistic, European aquaculture is likely to reach production of 1.57 million tonnes by 2015, an overall increase of 2 percent per year. This seems reasonably realistic, although it may be an underestimate if Norwegian production increases at a greater rate than the rest of Europe. Other studies are more optimistic than this study – an estimate based on Brugère and Ridler (2004) indicates an increase of 4.8 percent, mainly driven by an increase in Norwegian production.

TABLE 7
Past, current and predicted European aquaculture production (tonnes)

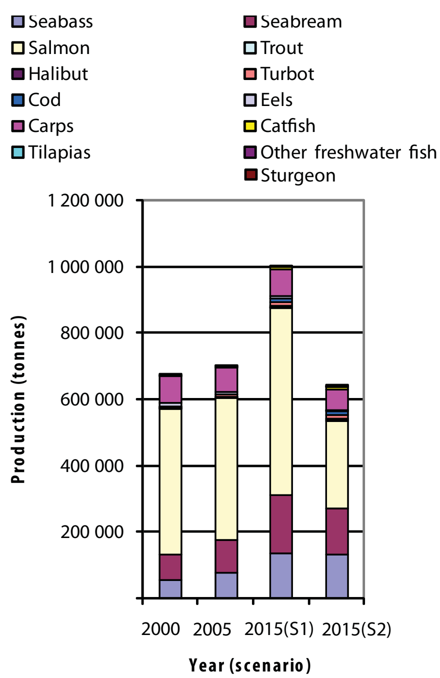
Species	2000	2005	2015			
			S1		S2	
	Tonnes	Tonnes	Tonnes	Increase**	Tonnes	Increase**
Seabass	57 811	80 161	136 968	171%	132 332	165%
Seabream	75 232	97 060	175 589	181%	140 941	145%
Salmon	610 947	712 271	1 149 081	161%	926 852	130%
Trout	444 251	430 496	567 256	132%	264 112	61%
Halibut	135	905	1 970	218%	2 513	278%
Turbot	3 873	6 865	11 349	165%	11 863	173%
Cod	16	2 600*	11 031	424%	14 032	540%
Eels	11 033	7 800	7 984	102%	2 041	26%
Carps	79 300	72 090	79 929	111%	60 738	84%
Catfish	4 490	5 470	9 957	182%	10 315	189%
Tilapias	150	550	677	123%	1 670	304%
Other freshwater fish	595	495	444	90%	646	131%
Sturgeon	265	332	-255	-77%	663	200%
Total	**1 288 098**	**1 417 095**	**2 151 979**	**152%**	**1 568 718**	**111%**

*2004 data ** Increase /decrease from 2005.
Source: Delgado *et al.* (2002)

Sustaining growth is a challenge, as there are a number of key constraints that may limit expansion of aquaculture. These are briefly reviewed below:

- *Environmental:* The major constraint to the expansion of aquaculture is the lack of suitable sites for new development and the need to ensure that existing sites are used in a sustainable manner. In many northern European countries, such as the United Kingdom and Denmark, gaining planning permission for both coastal and freshwater sites is increasingly difficult in a highly regulated environment. This has led to investigation into new cage technologies for deeper, more exposed sites, larger production units and improved diets with greater digestibility and less waste. There is also a trend towards less intensive farming techniques that are compatible with maintaining wetlands important for nature conservation at a favourable conservation status. Another emerging restraint is the need to use genetically benign species that will not impact on local fish populations if they escape.
- *Market*: Achievable ex-farm prices are critical to determining the economic viability of farming ventures and thus the uptake of evolving and often increasingly expensive aquaculture technology. It is important to understand the extrinsic factors that affect European aquaculture economics, such as competition from Chilean salmonid production. The

FIGURE 5
Past, current and predicted European aquaculture production (tonnes)



Source: Delgado *et al.* (2002)

markets for farmed fish have also been affected by persistent negative publicity over the safety of farmed fish, e.g. the possible health risks associated with high levels of persistent organic pollutants (POPs) in salmon cultivated in Europe (Hites *et al.*, 2004).

- *Raw material:* Allied to the last point above, variability in raw material costs and availability are increasingly important in dictating aquaculture viability. The main input is fish feed, especially for the high-protein diets that are required for over 95 percent of European finfish production. The demand for fishmeal and fish oils from developing economies such as China has a profound impact on feed prices as they operate within a commodity market. A shortage of fishmeal imports into the United Kingdom during 2003 and 2004 was one of the primary reasons for the dip in salmonid production over those years.
- *Implications for food security and poverty alleviation*: As discussed above, the demand for seafood products from Europe will remain strong, and with most capture fisheries reaching or exceeding their sustainable yield, aquaculture is expected to provide an increasing proportion of raw material for human consumption. However, when compared with developing regions, aquaculture in Europe does not make a strong contribution to food security or poverty alleviation. In terms of food security, the vast majority of aquaculture products (e.g. salmon, trout, seabass, seabream) are relatively high-value species that reflect the high cost of their high-protein dietary requirements and, therefore, cannot be considered as a "basic" food commodity[5]. Essentially, they are luxury items that compete with other similarly placed products in the market. It is possible that as aquaculture contributes a greater proportion of seafood products in Europe, the cost of production might fall to allow greater economic access to aquaculture products, but this is unlikely to contribute to improved food security on an individual basis. However, it might mean a reduced need to source fish products from outside of Europe and thus contribute to food security on a world level.

Regarding poverty alleviation, the intensive nature of European aquaculture means that there is only a minor contribution to improving the economic well-being of poor communities. Despite this, there is no doubt that aquaculture does have an important role to play in rural communities, both for remotely located intensive aquaculture (e.g. the highlands and islands of Scotland) and for the low yield, semi-extensive aquaculture practiced in places such as the Po River delta[6] in Italy. There are also upstream and downstream employment dependencies in feed fisheries and processing, respectively, with the latter providing opportunities to replace those lost as white fish processing contracts.

3. USE OF FISH AND OTHER AQUATIC SPECIES AS FEED FOR AQUACULTURE AND ANIMAL FEEDS IN EUROPE

In Europe, there are three main sources of marine-based raw material for aquaculture and animal feeds:

- feedfish caught in European waters for reduction into fishmeal;
- feedfish caught outside European waters for reduction into fishmeal; and
- trimmings, fish off-cuts, offal and landed bycatch for reduction into fishmeal.

The only direct use of whole, unprocessed fish for aquaculture (i.e. "trash fish") is

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[5] "All people at all times have both physical and economic access to the basic food they need." (FAO Committee on World Food Security).

[6] Valliculture (vallicoltura) was developed by the upper Adriatic populations to exploit the seasonal migrations of some fish species from the sea into the lagoon and delta areas, which were more suitable for their growth. Large brackish areas were enclosed to prevent the fish returning to the sea and complex permanent capture systems (fish barriers) were developed to catch the adults. Many such systems are now supported by artificial hatcheries.

in tuna fattening in the Mediterranean Sea. This section examines the nature and source of the raw materials used as well as the subsequent utilization of fishmeal and fish oils in Europe.

3.1 Landing of fish and other aquatic species destined for reduction

Fish destined for reduction into fishmeal and fish oil for use by the European aquaculture industry originate from either (i) the feed fisheries within European waters themselves or (ii) external fisheries, such as the anchovy and chub mackerel fisheries of South America or to a lesser extent, the Antarctic krill fisheries. The choice of where aquafeed compounders purchase their fishmeal depends largely upon the following:

- *Price*: Fishmeal is a global commodity whose price is interlinked with that of its main competitor, soybean meal. The level of substitution within fish feeds is limited, however, and varies between different dietary formulations (i.e. for starter, grower and finisher diets). Therefore, feed manufacturers can increase or decrease fishmeal incorporation levels within predefined limits.
- *Quality:* Quality is an important factor that also has an influence on price. The quality of fishmeal depends upon its freshness (measured by its volatile nitrogen content at conversion), the process used (e.g. processing temperature) and the stabilization techniques used.
- *Specification*: Fishmeal from North Atlantic stocks tends to be higher in protein content (68–71 percent) than southern hemisphere fishmeal (65–68 percent), reflecting the species used. Northern hemisphere fishmeal tends to have higher levels of digestibility – for instance, an Icelandic 71 percent protein meal from capelin/herring with a digestibility of 92 percent gives 65.2 percent digestible protein (DP) as against only 58.8 percent DP from the best Chilean sardine meal. Certain fishmeals (e.g. high performance feeds for some species/growth stages) might be selected to achieve a particular amino acid profile.
- *Contamination levels*: POPs accumulate in oily fish and have become a major food safety issue in Europe. Fishmeal sources from oceanic pelagic stocks in South America tend to have less POPs that those from the continental shelf stocks in the northeastern Atlantic. Although the resultant meals have to be within legal limits – and the technology exists to reduce them further through filtration – this may have an influence on purchasing.
- *Usability*: Individual feed producers' machinery characteristics can rule out the use of fishmeal from some origins.

There are no published figures on the proportion of fishmeal used for European aquaculture that is sourced from South America rather than from Europe's own feed-fish stocks. A recent report on the sustainability of feeds for the Scottish fish-farming industry (Huntington, 2004) suggests that around 54 percent of feed fish-derived fishmeal is currently derived from northern hemisphere sources, 28 percent from southern hemisphere sources and the balance from whitefish trimmings and pelagic offal (Table 8).

Table 8 examines the recent (2003) and predicted (2010) use of fishmeal and fish oil by Scottish aquaculture. These figures, which have been produced by the industry, indicate a number of interesting trends:

- A small (5 percent) increase is predicted in the southern hemisphere proportion of fishmeal by 2010.
- The relative contribution of trimmings and offal to fishmeal and fish oil production will remain around the same.
- Oilseed and legume-derived meals will increase from 17 percent to 24 percent of the total fishmeal protein source contribution, mostly at the expense of northern hemisphere fishmeal.

TABLE 8
Current and predicted fishmeal and fish oil utilization by Scottish aquaculture (tonnes)

A. Fishmeal and protein

Year	Whole fishmeal						Protein derivatives			
	Northern hemisphere		Southern hemisphere		Trimmings and offal		Oilseeds and legumes		Gluten	
2003	53 140	38%	27 600	20%	16 900	12%	24 400	17%	19 250	14%
2010	44 500	29%	30 100	19%	16 000	10%	38 000	24%	27 200	17%

B. Oils

Year	Fish oil						Vegetable oils	
	Northern hemisphere		Southern hemisphere		Trimmings and offal			
2003	41 200	65%	10 600	17%	11 000	17%	300	0.5%
2010	31 300	41%	13 000	17%	12 000	16%	20 000	26%

Source: J Nelson, Agricultural Industries Confederation (AIC), personal communication, 2004

- The relative contribution of southern hemisphere oil supplies will remain unchanged.
- Vegetable oils will become an important source of oils in Scottish aquafeeds, accounting for nearly a quarter of the total by 2010, again at the expense of northern hemisphere feed-fish supplies.

The main species used are primarily small pelagic species that are characterized by early maturation and high fecundity. Their populations respond quickly and strongly to changes in environmental conditions, which increases the uncertainty of stock forecasts, especially in eastern Pacific waters that are vulnerable to the "El Niño" effect.

The main species used for fishmeal reduction from European stocks are capelin, blue whiting and sand eel and lesser volumes of Norwegian pout (Figure 6). Landings of these species by the different European countries are shown in Table 9. In addition, the table shows data for a number of other species that are used for both feedfish and for direct human consumption. Peruvian anchovy and Chilean jack mackerel are both imported from South American sources for use in European fish feed, and Poland and Ukraine both use Antarctic krill as a fishmeal source.

3.1.1 European fish species reduced for fishmeal and fish oils

Blue whiting (Micromesistius poutassou): The blue whiting is a pelagic gadoid (i.e. of the cod family), which is widely distributed in the eastern North Atlantic. Its biology is reasonably well known, and a management plan has been formulated and accepted, with annual quotas set in December 2005. However, fishing mortality remains unacceptably high, far above sustainable rates; populations have only been sustained by recent good year classes, and the International Council for the Exploration of the Sea (ICES) currently considers this fishery to be harvested unsustainably. The dispute over catch allocation has led to the last quota of 650 000 tonnes set by the North East Atlantic Fisheries Commission being exceeded four-fold; fishers caught 2.3 millon tonnes in 2003. It should be argued that until the management plan is implemented and total allowable catches (TACs) fall within the agreed level, this species cannot be recommended as a component stock of fishmeal or fish oil. This issue with blue whiting is recognized by the fishmeal industry, which fully supports implementation of the proposed management plan, yet has relatively little influence in the progression of its adoption (A. Chamberlain, FIN, personal communication, 2006).

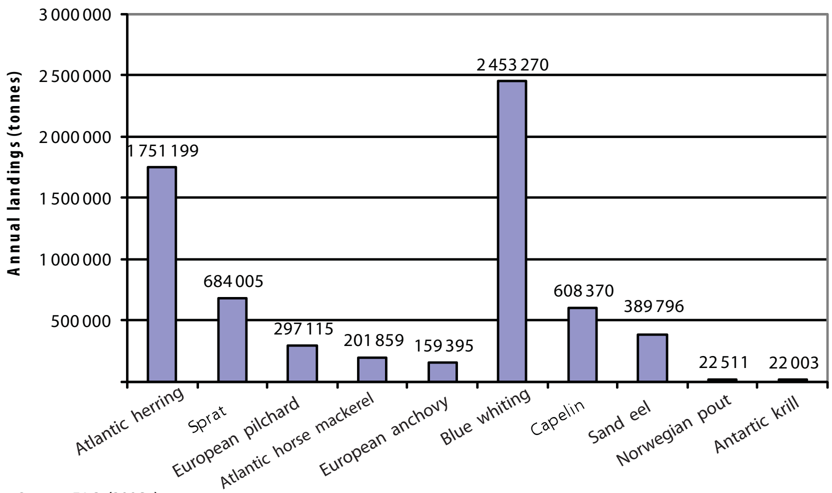
Capelin (Mallotus villosus): The capelin is a small pelagic species whose biology is reasonably well known. There are two main stocks in the Barents Sea and Iceland.

TABLE 9
Landings of European feed-fish species in 2004 (tonnes)

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

Source: Derived from FAO capture fisheries data (FAO, 2006a)

FIGURE 6
Landings of European feed-fish species, 2004



Source: FAO (2006a)

The fishery is based upon maturing capelin of ages 3 and 4, and the abundance of the immature component is difficult to assess before recruitment to the adult stock at ages 2 and 3. Given that recruitment is highly dependent upon environmental variables, its high spawning mortality and its importance as a forage fish, a precautionary approach to capelin management is required. Given that immature capelin were absent in autumn 2004 and winter 2005 surveys, the Icelandic quota for the 2005/2006 season was 194 000 tonnes, compared with 803 000 tonnes for the previous year of 2004/2005. The Norwegians closed the capelin fishery entirely for 2006.

Sand eel (Ammodytes spp.): The main elements of sand eel ecology and population structure in the North Sea have been well researched, although the nature of local subpopulations may be less well described. The high natural mortality of sand eel populations and the few year classes make stock size and catching opportunities largely dependant upon incoming year classes, which complicates forward-looking management. The linkages between feed fisheries and non-target species have been investigated, but the complex nature of marine ecosystems means that there is still only a partial understanding of the relationships and interactions, thus indicating a need to be precautionary in the management of this stock. The fisheries are implemented under strictly controlled conditions with high compliance levels. The fishery has a high number of participants that constrains the level of reinvestment but does assist in the redistribution of wealth within the sector and restricts efforts into other fisheries. Most of the vessels and fishmeal plants are operated within a share system. At present, the North Sea sand-eel stocks are considered by ICES to have reduced reproductive capacity and the EU Fisheries Council has set an effort limit of 20 percent of the 2004 effort.

Norwegian pout (*Trisopterus esmarki):* Fishing the stocks in the North Sea and Skagerrak-Kattegat Seas directed fishery was banned over 2005 (extended into 2006) except for when caught as unavoidable bycatch, as the stock biomass is below the sustainable limit reference point (B_{lim}). Catches in ICES Area Via (West Scotland) of small-meshed Danish vessels are highly variable and the state of the stock is unknown. The directed fishery has a history of bycatch of blue whiting, haddock, whiting and herring (ICES, 2005), and Norwegian pout is itself vulnerable as a bycatch to the blue whiting fishery.

Atlantic horse mackerel (*Trachurus trachurus):* The Atlantic horse mackerel has three main stocks – North Sea, western and southern. Most of the catch destined for fishmeal is bycatch from other pelagic fisheries, although there is a directed fishery in western waters. The stock is dependent upon infrequent and very high recruitment pulses, the last major one being in 1982. The current TAC is considered to be too high to sustain the fishery, especially in combination with high levels of juvenile mortality from fishing. Information on the Atlantic horse mackerel's interactions with other species is limited, but it is known to be an important predator of juvenile herring.

3.1.2 Non-European fish species reduced for fishmeal and fish oils for use in Europe

Given that South American fishmeal represents an important component of European aquafeed, it is appropriate that the two main feed-fish species, Peruvian anchovy and Chilean jack mackerel, are included in the species listed for consideration, as is Antarctic krill.

Peruvian anchovy (Engraulis ringens): There is considerable research into the stock ecology and biology and the impacts of fishing, but much of the resulting information is contained in grey literature, difficult to compile and subject to quality assessment. There are also apparent gaps in the information on the effects of fishing on the different stocks' reproductive capacity. Funding limitations have also severely restricted the ability of resident researchers to examine the wider ecosystem implications for stock removal and the impacts on non-target species. In addition, compared with the Danish sand-eel fishery, it is difficult to assess the success of Peruvian monitoring efforts, and compliance levels are less well documented. In the absence of this information, it is difficult to conclude whether the fishery is currently sustainable or not. The recently introduced Individual Tradable Quota (ITQ) system, together with 100 percent sampling of landings by an independent certification company, has induced rationalization into the previously unconstrained fleet structure, and further reductions in capacity are expected. A recent international conference (Lankester, 2005) concluded that the efforts by the Peruvian authorities to control the fishery have been under-reported, although further work was needed to integrate the socio-economic effects of the fishery, as well as ecosystem components, into stock management.

Chilean jack mackerel (Trachurus murphyi): Recruitment into this stock is highly subject to environmental and climatic conditions (in particular the El Niño event) and is thus difficult to assess. However, this stock it is generally considered to be overfished, with an increasing proportion of smaller fish being caught. It is recovering from previous overfishing and has still to recover to previous (1996) levels, despite tight controls on effort.

Antarctic krill (Euphausia superba): In the Antarctic, both Ukrainian and Polish vessels fish Antarctic krill (often as third-parties to Japanese ventures), of which 70 percent is destined for reduction into fishmeal. Krill is central to the Antarctic marine food web, as most organisms are either direct predators of krill or are just one trophic level removed. Traditional, single-species fisheries management principles are not applicable to the Antarctic krill fishery due to the key role of this species in the southern ocean food web. A multi-species management approach is necessary to take into account potential impacts on krill-dependent predators and the Antarctic marine environment as a whole, in case of an expansion of the krill fishery. Although krill catches in the southern ocean are currently well below Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) catch limits, there is potential for a rapid expansion of the fishery in future years, as krill processing technology develops and demand for krill products increases (CCAMLR, 2004). There is also concern over the impact of global warming, as this could affect krill recruitment and krill stock size in the long term.

3.1.3 Trash fish and other fishery by-products

Use in production of fishmeal and fish oils: In Europe, trimmings from other fisheries represent around 33 percent of the total supply of raw material to the fishmeal and fish-body oil industry (IFFO, 2002). It is estimated that 80 percent of the trimmings from fish processing enter the fishmeal and fish-body oil industry in Denmark, although the figure is only 10 percent in Spain. In the United Kingdom, Germany and France, between 33 and 50 percent of fish trimmings enter the fishmeal and fish body oil industry (Table 10).

TABLE 10
Raw material sources for fishmeal and fish body oil in the EU-15, 2002

Country	Feedfish (tonnes)	Trimmings (tonnes)	Total raw material supply (tonnes)	Utilization of trimmings (%)
Denmark	332 000	33 200	365 200	10
United Kingdom	7 800	42 500	50 300	84
Spain		42 000	42 000	100
Sweden	18 750	6 250	25 000	25
France		25 000	25 000	100
Ireland	8 800	13 200	22 000	60
Germany		17 000	17 000	100
Italy		3 000	3 000	100
Total	**367 350**	**182 150**	**549 500**	**33**

Source: Adapted from IFFO (2002)

The United Kingdom and German dependence on whitefish trimmings has fallen. This is in response to a decline in whitefish supplies and a reduction in “black fish”. In contrast, a greater proportion of supplies are now derived from pelagic trimmings, where the state of raw material supply is healthy. Salmon also increasingly provides an added source of supply to United Kingdom fishmeal plants, but this fish can no longer be allowed to re-enter the food chain for aquaculture. The introduction of a number of animal by-products regulations[7] by the European Commission (EC), together with the feed industry’s own initiatives, have constrained the use of fishmeal and fish-derived waste in both aquaculture and agriculture feeds as a result of concerns over the cross-species transmission of pathogens.

Direct use in tuna farming: In most Mediterranean countries, the tuna farming season extends for about six to seven months, starting typically in June. ICCAT routinely uses a default 25 percent factor for the back calculation of farm inputs from tuna farm production figures – on the assumption that 25 000 tonnes of bluefin tuna were put in cages during 2004, for a feeding period of 180 days and a daily ration of 5 percent, it is estimated that 225 000 tonnes of feedfish were used on tuna fattening farms in the Mediterranean Sea over 2004. A large percentage of the fish feed utilized in the Mediterranean tuna farming industry is imported frozen from outside the region (over 95 percent of total baitfish in the case of Turkey; Lovatelli, 2003). The precise specific composition of feedfish is not known in most cases, but Lovatelli (2003) lists the small pelagic species used as including sardine (*Sardina pilchardus*), round sardinella (*Sardinella aurita*), herring (*Clupea* spp.), mackerel (*Scomber scomber*) and horse mackerel (*Trachurus* spp.). These fish originate mostly from the North Sea/Baltic region and the West African upwelling system.

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

3.2 Fishmeal and fish oil production and trade

3.2.1 Production

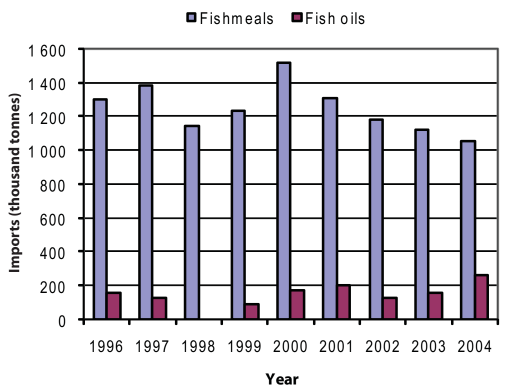
In Europe, fishmeal and fish body oils are derived from directed fisheries for feedfish (providing 67 percent of raw material) and trimmings produced as by-products of processing fish for human consumption (providing 33 percent of raw material). Fishmeal is produced by cooking the fish, before pressing them to remove water and body oil, and finally drying them at temperatures of between 70 to 100 °C depending upon the meal type manufactured. After extraction from the fishmeal, fish body oils are purified through centrifugation. Fish oil represents around 5–6 percent of the total raw material body weight.

In Europe, around 1.1 million tonnes of fishmeal are produced per year (Table 11). Denmark is the largest producer (30 percent), followed by Iceland (23 percent) and Norway (10 percent). Denmark also produces more than half of Europe's fish oil (51 percent), with Norway being the only other significant producer (27 percent).

3.2.2 Imports

Europe is a net importer of fishmeal (~1.6 million tonnes) and fish oil (~240 000 tonnes), although this is a rather simplistic interpretation, as there are significant international product flows based on product specification and price (Figure 7). Norway imports almost half of total European exports (Table 11) and 52 percent of its own net usage. The United Kingdom is the largest importer of fishmeal, of which Iceland (22 percent), Norway (16 percent) and Denmark (12 percent) are the main European sources, and imports represent around three-quarters of all fishmeal usage. South American fishmeal currently accounts for around 19 percent of the United Kingdom's imports, but the amount can vary from year to year and may occasionally increase to around 30 percent. Likewise, Germany only produces a small fraction (7 percent) of its own usage. Norway and Denmark are major European fishmeal producers but also import 64 percent and 41 percent, respectively, of their fishmeal needs. In total, fishmeal imports and consumption are known to have fallen markedly in 2003 and 2004 and are down 18 percent against the preceding years. This is as a result of the ban on the use of fishmeal in ruminant feed.

FIGURE 7
European imports (net) of fishmeal and fish oil, 1996–2004



Source: FIN (2004)

3.2.3 Exports

Denmark exports around 30 percent of its product to the southern countries within the EU (Greece and Italy) and a further 15 percent to Norway. The remaining 55 percent is exported to a number of Far Eastern countries where there is a high demand for high-quality meal and oils. Denmark exported an average of 269 886 tonnes of fishmeal over 2001–2003 and 92 536 tonnes of fish oil (Table 11). The main European exporters of liver oils in 2003 were Norway (1 820 tonnes), Spain (1 940 tonnes) and Portugal (311 tonnes). Most of these oils are cod liver oils. Spain also exports between 900 and 2 500 tonnes of high grade "industrial" shark oils, which are exported to Japan. This is equivalent to 4 500 to 14 000 tonnes of shark (live weight).

TABLE 11
Import, production and export of fishmeal, fish oil and fish waste by European countries (2001–2003 average)

Country	Imports						Production				Exports (including re-exports)					
	Fishmeal		Fish oil		Fish waste		Fishmeal		Fish oil		Fishmeal		Fish oil		Fish waste	
	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%
Bulgaria	4 445	0	3	0	16	0		0		0		0	–	0		0
Croatia	11 398	1	5	0	13	0	510	0	18	0		0	14	0		0
Denmark	142 036	11	30 046	7	531 574	53	350 356	30	114 605	51	269 886	34	92 536	60	52 658	9
Estonia	2 973	0	5	0	34	0	3 600	0		0	3 791	0	23	0	4 271	1
Faroe Islands	151	0	2 710	1	79 838	8	40 950	4	994	0	40 936	5	994	1	137 917	24
Finland	20 358	2	3 158	1	25 174	3		0		0	23	0	4	0	141	0
France	54 621	4	36 340	8	10 061	1	32 350	3	4 433	2	19 560	2	18 539	12	7 191	1
Germany	195 347	15	11 843	3	55 095	5	14 148	1	5 857	3	199 890	25	6 600	4	3 961	1
Greece	85 474	7	9 235	2	2 028	0	2 635	0		0	2 635	0	146	0	18	0
Iceland	37	0	177	0	138 561	14	267 750	23	1 540	1	51 892	7	7 200	5	76 524	13
Ireland	8 711	1	51	0	12 999	1	17 867	2	4 167	2	17 805	2	1	0	6 731	1
Italy	73 161	6	18 595	4	1 681	0	3 361	0		0	5 253	1	97	0	1 330	0
Latvia	3 319	0	1	0	3 402	0	5 432	0	21	0	5 389	1	677	0	63	0
Lithuania	16 027	1	622	0	1 892	0	10 169	1		0	10 169	1	514	0	13	0
Malta	1 519	0	9	0	17	0		0		0		0		0	8	0
Netherlands	78 576	6	44 737	10	3 184	0		0		0	15 474	2	12 790	8	9 267	2
Norway	140 411	11	209 615	48	100 271	10	220 967	19	59 100	27	93 900	12	2 244	1	221 956	39
Poland	16 369	1	1 082	0	689	0	1 231	0		0	15 961	2	1	0	2 379	0
Portugal	12 437	1	553	0	412	0	2 918	0	95	0	978	0	902	1	115	0
Romania	20 306	2	16	0	3	0	277	0		0	11	0		0		0
Russian Federation	114 673	9	958	0	3 052	0	37 471	3	1 940	1	5 507	1	321	0	18 453	3
Spain	95 573	7	21 101	5	5 095	1	101 822	9	14 614	7	20 373	3	3 351	2	6 150	1
Sweden	1 642	0	377	0	7 819	1		0	4 571	2	3 336	0	5 076	3	19 111	3
Ukraine	6 365	0	34	0	21	0		0		0	1 625	0	11	0	114	0
United Kingdom	203 375	16	43 718	10	19 768	2	48 800	4	10 600	5	10 096	1	1 327	1	6 261	1
Total	**1 309 303**	**100**	**434 991**	**100**	**1 002 698**	**100**	**1 162 614**	**100**	**222 555**	**100**	**794 491**	**100**	**153 366**	**100**	**574 631**	**100**

Source: FAO (2005a)

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

Table 12 examines the situation in Europe over the last few years and illustrates that overall fishmeal consumption has decreased over the five years between 2002 and 2007. Despite the growth in aquaculture in the region, fishmeal use in aquafeeds has reduced slightly due to its replacement with alternative, mainly vegetable, proteins (A. Jackson, International Fishmeal and Fish Oil Organisation (IFFO), personal communication, 2009). However, as a percentage of fishmeal usage in the region, the proportion used for aquaculture rose from 39 to 50 percent. Fishmeal usage in pig diets has continued to decline, as has its use in poultry diets. The continued ban on feeding fishmeal to ruminants (see Section 6.3) has meant that there has been reduced overall consumption of fishmeal in Europe. If this ban were to be lifted, unlikely in the short term, there could be significant increase in Europe's demand for fishmeal.

TABLE 12
Average annual fishmeal consumption in Europe, 2002 and 2007

Use	Annual consumption (thousand tonnes)	
	2002	2007
Use for aquaculture	552 (39.3%)	537 (49.6%)
Use for pigs	653 (46.5%)	426 (39.4%)
Use for poultry	149 (10.6%)	69 (6.4%)
Other uses, including pet food	50 (3.6%)	50 (4.6%)
Total consumption in Europe	**1 404 (100%)**	**1 082 (100%)**

Source: A. Jackson, IFFO, personal communication, 2009

Two supporting comments should be made with respect to the above points:

a) The ban on feeding meal to ruminants has had a very significant effect on the sales of fishmeal to the United Kingdom (down 70 000 tonnes), Italy (down 35 000 tonnes), the Netherlands (down 20 000 tonnes) and Germany. The United Kingdom and Danish meal manufacturers have borne the brunt of this impact, in particular Denmark, mainly because Italy represented one of its largest export markets. Germany has also suffered particularly badly, as many of its small meal manufacturers used fishmeal as an integral ingredient in their feed supplies for the agricultural sector.

b) The United Kingdom, being the largest single EU market for fishmeal, has seen a significant reduction in imports. Meal manufacturers that once used fishmeal as a component of their product have now eliminated it. The dedicated United Kingdom producers, while suffering from a reduction in the market, have been able to sustain product sales largely because of demand from the aquaculture sector and increased demand from the pig and poultry sector.

3.3.1 Fishmeal and fish oil use in aquafeeds

In contrast with much of aquaculture production in Asia and Africa, European production is focused on the intensive rearing of carnivorous fish such as salmon, seabass and seabream. With the exception of the on-growing of tuna in the Mediterranean Sea, farms use compounded meals that have been optimized for their performance, digestibility and cost-effectiveness.

These feeds vary highly in their protein and oil levels, and use depends upon the species being fed and the stage at which the feeds are given. It can be seen from Table 13 that starter diets are typically rich in protein and lower in oil than grower feeds. Smaller fish also have different nutritional requirements that might favour the use of particular fishmeal, such as the histidine-rich South American feeds. It should also be remembered that starter feeds represent a smaller volume than grower feeds, as it is the latter that are mainly used to contribute to stock biomass.

Fishmeal

Based on the current trends in production discussed in the previous section, a tentative forecast can be made of likely fishmeal usage by European aquaculture over the next ten years (Table 14). This table indicates that fishmeal usage will increase from the present level of around 615 000 tonnes to about 630 000 tonnes in 2015.

TABLE 13
Typical composition of the main feeds used in European aquaculture

Feed type		Protein %	Oil %	Typical FCR*
Salmon starter diets		50–55	14–23	0.90–1.00
Salmon grower diets		34–50	22–38	1.20–1.30
Trout starter diets		50–57	14–22	0.80–0.95
Trout grower diets		38–50	8–33	0.90–1.30
Other finfish diets	Marine fish	50–60	12–24	1.10–1.40
	Freshwater fish	31–55	7–18	

*Food conversion ratio.
Source: J Nelson, Agricultural Industries Confederation (AIC), personal communication, 2004

The increase in demand for fishmeal is not particularly dramatic and is at a lower pace than the predicted increase in production, mainly due to increased efficiencies in fishmeal and fish oil usage that result from improved feed formulation and delivery. The rate at which fishmeal is included in aquaculture diets is expected to drop over the next decade as increasing levels of substitution with vegetable proteins and oils occurs. In addition, continued research into the dietary requirements of particular species reared under particular conditions will refine formulations and improve feed delivery that, with the increased use of automated feeding and consumption monitoring systems, will lead to potential improvements in food conversion ratios (FCRs).

Fish oil

The use of fish oil by European aquaculture is predicted to rise at a slightly higher rate than the use of fishmeal (8 percent as opposed to just over 2 percent), as inclusion rates are set to increase slightly (Table 15). This table indicates that European demand for fish oils for aquaculture will rise to almost 343 000 tonnes by 2015 from the current level of almost 305 000 tonnes.

3.3.2 Fishmeal and fish oil use in agriculture

The agriculture sector uses predominantly Peruvian and Icelandic fishmeal, with fishmeal from Morocco and other minor sources making up the balance. With fishmeal and fish oil production predicted to remain stable over the next decade and the proportion being utilized by aquaculture increasing considerably, there is likely to be a fall in the proportion used by agriculture (Table 16).

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

TABLE 14

Past, current and predicted fishmeal use by European aquaculture, 2000–2015

Species	FCR*	2000			2005			2015		
		Production (tonnes)	Fishmeal (%)	Fishmeal use (tonnes)	Production (tonnes)	Fishmeal (%)	Fishmeal use (tonnes)	Production (tonnes)	Fishmeal (%)	Fishmeal use (tonnes)
Seabass	1.3	57 811	55	41 335	80 161	50	52 105	132 332	45	77 414
Seabream	1.3	75 232	55	53 791	97 060	50	63 089	140 941	45	82 451
Salmon	1.3	610 947	40	317 692	712 271	35	324 083	926 852	30	361 472
Trout	1.3	444 251	30	173 258	430 496	28	156 701	264 112	25	85 836
Halibut	1.4	135	45	85	905	42	532	2 513	40	1 407
Turbot	1.4	3 873	45	2 440	6 865	42	4 037	11 863	40	6 643
Cod	1.4	16	45	10	2 600	42	1 529	14 032	40	7 858
Eels	2.0	11 033	50	11 033	7 800	45	7 020	2 041	42	1 715
Carps	2.0	79 300	5	7 930	72 090	4	5 767	60 738	3	3 644
Catfish	1.5	4 490	3	202	5 470	2	164	10 315	2	309
Tilapias	1.7	150	7	18	550	5	47	1 670	4	114
Other freshwater fish	1.7	595	10	101	495	7	59	646	5	55
Sturgeon	1.5	265	25	99	332	20	100	663	18	179
Total		**1 288 098**		**607 995**	**1 417 095**		**615 232**	**1 568 718**		**629 097**

*Food conversion ratio

Source: Federation of European Aquaculture Producers (FEAP) (www.feap.info/feap/aquaculturedata/default_en.asp)

TABLE 15

Past, current and predicted fish oil use by European aquaculture, 2000–2015

Species	FCR*	2000			2005			2015		
		Production (tonnes)	Fish oil (%)	Fish oil use (tonnes)	Production (tonnes)	Fish oil (%)	Fish oil use (tonnes)	Production (tonnes)	Fish oil (%)	Fish oil use (tonnes)
Seabass	1.3	57 811	10	7 515	80 161	11	11 463	132 332	12	20 644
Seabream	1.3	75 232	10	9 780	97 060	11	13 880	140 941	12	21 987
Salmon	1.3	610 947	25	198 558	712 271	22	203 710	926 852	20	240 982
Trout	1.3	444 251	15	86 629	430 496	15	83 947	264 112	15	51 502
Halibut	1.4	135	20	38	905	18	222	2 513	15	528
Turbot	1.4	3 873	20	1 084	6 865	18	1 682	11 863	15	2 491
Cod	1.4	16	20	4	2 600	18	637	14 032	15	2 947
Eels	2.0	11 033	5	1 103	7 800	8	1 170	2 041	10	408
Carps	2.0	79 300	0	–	72 090	0.5	721	60 738	1.0	1 215
Catfish	1.5	4 490	1	67	5 470	0.5	41	10 315	0.5	77
Tilapias	1.7	150	1	3	550	0.5	5	1 670	0.5	14
Other freshwater fish	1.7	595	5	51	495	5	42	646	5	55
Sturgeon	1.5	265	15	60	332	12	60	663	12	119
Total		**1 288 098**		**304 892**	**1 417 095**		**317 580**	**1 568 718**		**342 968**

*Food conversion ratio

Source: Federation of European Aquaculture Producers (FEAP) (http://www.feap.info/feap/aquaculturedata/default_en.asp)

TABLE 16
Fishmeal and fish oil use in world agriculture, 2002 and 2010 (predicted)

A. fishmeal usage (2002 and 2010 (predicted))				B. Fish oil usage (2002 and 2010 (predicted))			
Consumer	Fishmeal use (thousand tonnes)			Consumer	Fish oil use (thousand tonnes)		
	2002	2010	Change in use (%)		2002	2010	Change in use (%)
Poultry	1 755	975	-44	Edible	375	175	-53
Pigs	1 885	1 430	-24	Industrial	150	88	-41
Ruminants	65	–	-100	Pharmaceutical	25	–	-100
Others	585	975	67	**Total**	**550**	**263**	**-52**
Total	**4 290**	**3 380**	**-21**				

Source: Barlow (2002)

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

The use of fishmeal in ruminant diets[8]

Although sheep and cattle consume diets that are predominantly forage-based, there is increased use of concentrate diets and supplements at times of increased productivity, such as during pregnancy and lactation and during rapid growth. The use of fishmeal in these situations has considerable advantages over other protein sources such as soybean meal and bone meal in supplying RUP at times when metabolizable protein requirements may be greater than those that can be supplied by microbial protein synthesis and forage RUP.

Use of fishmeal in diets of non-ruminants

Fishmeal use in pig diets accounts for approximately 20 percent of total fishmeal use, and it is recognized as a key protein source with a good balance of essential amino acids. Pigs' diets containing fishmeal show improved feed conversion efficiencies and generally produce leaner carcasses (Wood *et al*., 1999). The protein is well tolerated in pigs of all ages and has a high digestibility. As with fishmeal used in ruminant diets, however, processing has a significant impact on protein quality in pig diets. Excessive heat treatment results in a significant reduction in digestibility and biological value, due mainly to loss of lysine, a key limiting amino acid in growing pigs. One major environmental benefit in the use of fishmeal in pig diets is the high digestibility of the added protein, resulting in an improved efficiency of dietary protein use with a concomitant reduction in the production of high N-containing effluent.

Use of fishmeal in diets of poultry

As with diets for mammalian species, fishmeal is considered a natural, balanced ingredient for poultry diets with a high protein, high mineral and high micronutrient

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

content. The protein in fishmeal is readily digested by poultry, and it contains all the essential amino acids necessary for adequate growth and production, especially the growth-limiting amino acid lysine. However, as with pig diets, the quality of the fishmeal can seriously affect protein digestion and biological value. Inclusion of fishmeal in poultry diets at about 4 percent results in improved feed conversion efficiency and growth rates. Laying performance is also improved by feeding fishmeal.

3.4 Contribution of feed fisheries to the European economy

3.4.1 Direct employment

The industrial fishing sector is economically very small relative to the EU fisheries as a whole. It accounts for only 0.5 percent of the sector's employment and 2.1 percent of the sector's value added (Megapesca, 1998). Table 17 summarizes the economic significance of the fishmeal and oil sector within the EU. The sector contribution to EU gross value added is €137 million. Approximately 2 220 people are employed directly in the sector. More specifically, the level of economic dependency (value added) on feed-fish fisheries accounts for €137 million or 87 percent of the total and as such is significantly greater than the economic value generated from fish offal.

Of the 2 222 workers in the EU dependent upon feed-fish catching and processing, around 64 percent are dependent on feed-fish supplies (fish catching and processing feedfish) and 35 percent on the trimmings sector (Table 18). Employment in the production of feed-fish related meal tends to be less labour intensive than in offal production (Frid *et al.*, 2003).

3.4.2 Interdependence of the catching sector

Table 17 illustrates the relatively low levels of dependency on feed fisheries in the context of the EU fishing fleet. However, some countries, most noticeably Sweden and Denmark, have fleets that are fully or partly dependent on feed fisheries. Reducing feed fisheries in these countries would have a direct impact on a significantly greater number of vessels than those 60 vessels that are strongly dependent on the fishery. The Danish Research Institute of Food Economics (FOI) explored the potential impact on the Danish fishery sector (Andersen and Løkkegaard, 2002) in the event of (a) a ban on sand-eel fishing (scenario 1) and (b) a ban on all industrial fishing (scenario 2). The assessment took account of changes in turnover and costs resulting from a loss of catch and a reduction in fishing effort. Because of the inter-linkages between human and industrial fishing activity, a ban would not only eliminate the 60 dedicated industrial vessels, it would also result in the removal of 125 vessels under scenario 1 and 194 vessels under scenario 2. This would result in a loss of employment of between 479 (scenario 1) and 750 workers (scenario 2). Applying a similar rational for the Swedish fleet would probably see the loss of 88 and 136 jobs, albeit that there are different species dependencies.

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

4.1 Review of the impacts of feed fisheries on ecosystems

4.1.1 Direct effects of feed fisheries

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

TABLE 17

The economic significance of Europe's fishmeal and oil sectors, 2003

Country	Sector	Numbers of employees (FTE)*	Value-added (million €)
Denmark	Fish catching	507	83.0
	Fish processing	395	11.1
Sweden	Fish catching	93	14.0
	Fish processing	35	4.3
United Kingdom	Fish catching	11	1.45
	Fish processing	105	5.0
Ireland	Fish catching	10	1.45
	Fish processing	46	2.5
Spain	Fish catching	0	0
	Fish processing	250	2.6
France	Fish catching	0	0
	Fish processing	270	4.4
Germany	Fish catching	0	0
	Fish processing	62	1.5
Poland	Fish catching	60	2.0
	Fish processing	53	–
Finland	Fish catching	305	3.6
Other	Fish processing	20	–
Total	**Fishmeal**	**2 222**	**136.9**
Total EU fishery sector		**482 374**	**6 416.8**
% Contribution of fishmeal to EU fishery sector		**0.46%**	**2.13%**

*Full time equivalent
Source: Frid *et al.* (2003)

TABLE 18

Employment dependency by producing/processing group, 2003

Sector	Total dependency	
	Number	%
Fish catching	986	45.5
Fish feed processing	417	19.2
Fish trimming and processing	766	35.3
Total	**2 169**	**100**

Source: Frid *et al.* (2003)

Feed-fish stocks

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

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

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

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

Habitats

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

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

Although the impact to the sea bed and benthos by each individual tow may be less than with comparable demersal otter trawling operations, as the gears are lighter, the way the fishery operates suggests that local impact on the sea bed and invertebrate communities may be quite intense. This is because the same trawl path tends to be fished repeatedly over a period of several days by several boats operating in any particular region (Frid *et al.*, 2003). Mitigating against this, however, is the fact that these fisheries are seasonal. The local impact may be intense, but it is followed by long periods of recovery. The fishery for Norway pout occurs primarily through the winter months, with little fishing during the summer, which allows six to eight months of the year for the benthos to recover. The sand-eel fishery is constrained by the hibernation of the species in winter.

4.1.2 Indirect effects of fishing

There are a number of indirect effects of fishing feed-fish stocks, largely due to their foraging low in the food chain and, therefore, being preyed upon by fish, marine mammals and seabirds of higher trophic levels. Changes to specific predator-prey relationships may impact the whole food chain and lead to changes in the composition of biological communities (Greenstreet and Hall, 1996; Rijnsdorp *et al*., 1996; Bianchi *et al*., 2000; Hill *et al*., 2001). Removal of a species' biomass reduces the buffering capacity of the stock and makes the population more vulnerable to poor prey availability or climatic conditions. There are also the genetic effects associated with removing large amounts of the gene pool, which may adversely affect populations over long time periods. Indirect effects may also include ghost fishing resulting from lost fishing gears, which may continue to catch and disturb biological communities and habitats unmonitored (Chopin *et al*., 1996; Laist, 1996).

Bycatch

The incidental catch of non-target species, and in particular the capture of juveniles of commercial species, is one of the most controversial aspects of feed fisheries, as most undersized fish are landed and processed. In North Atlantic waters, juvenile herring are known to shoal with sprat (Hopkins, 1986), while juveniles of other commercial species such as whiting and haddock are known to shoal with industrial teleost feedfish such as Norway pout (Huse *et al.*, 2003; Eliasen, 2003). Bycatch levels are not necessarily high – the bycatch in the Danish and Norwegian North Sea sand-eel fishery (mainly herring, saithe and whiting) has averaged 3.5 percent over 1997–2001 (ICES, 2003a). While levels are low, given the scale of the feed fisheries being prosecuted, actual quantities of bycatch can be significant. In 2002, the Danish sand eel landings accounted for 622 100 tonnes, of which 3.7 percent was considered bycatch, totalling 23 018 tonnes of herring, cod, haddock, whiting, saithe and mackerel. In the same period, the sprat fishery took 27 972 tonnes of bycatch. In 2003, an experimental trawl survey (CEFAS, 2004) used a 16 mm commercial sand-eel net to monitor the whitefish bycatch on the West Dogger sand-eel grounds. Sand eels comprised 50–65 percent of the catch, below that required to meet EU catch composition rules, but sand-eel abundance was exceptionally low in 2003. Adult cod and haddock were not caught in the sand-eel net, which was capable of retaining 0-group gadoids (whiting), but their distribution was patchy, and no juvenile cod were caught.

There is recent evidence of declining bycatch in the sand-eel fisheries and the blue whiting fishery as seen in the Danish feed-fish catches (Table 19). Bycatch is an issue in the sprat fisheries, where increased herring bycatch is largely a result of relative increases in abundance (ICES, 2003b).

The composition and volume of catches from the Norwegian industrial fisheries, which target both blue whiting and Norway pout, was reported by ICES (2003b). Between 2000 and 2002, the average annual landings from the mixed fishery was 109 000 tonnes. Blue whiting formed an estimated 58 percent of this catch, while Norway pout formed approximately 17 percent. The remaining 25 percent, or about 16 000 tonnes, consisted of a range of fish and invertebrates. The six most important bycatch species (in terms of landed catch) were saithe, herring, haddock, Atlantic horse mackerel, whiting and mackerel, each of which represented an annual catch of at least 1 000 tonnes in this fishery. This length distribution analysis suggests that the bycatch of these species consisted primarily of immature individuals.

In the North Sea, this issue has been addressed by closures of part of the North Sea to Norway pout fishing to reduce the bycatch of juvenile commercial species. Similarly, seasonal closures exist for the conservation of fishery resources through technical measures for the protection of juveniles of herring and sprat (EC Regulation 850/98; Council of the European Union, 1998). Bycatch regulations and minimum mesh size are also in place, aimed at reducing juvenile bycatch.

The spatial and temporal distribution of cod bycatch in the herring and sprat fisheries of the Baltic Sea was thought to relate to the co-occurrence of the three species on cod and sprat pre-spawning and spawning grounds. ICES (2001) determined that the share of bycatch in total landings of cod was within the range of 1.3 to 2.0 percent. The bycatch in pelagic fisheries, therefore, appeared to have a minor effect on the cod population.

In a recent study, the majority of haddock and whiting in the bycatch of the industrial fisheries of Denmark and Norway were of age 3 or less (ICES, 2003c). The mortality of haddock caught as bycatch by the industrial fisheries was small for age groups 0 and 1 (less than 1 percent by number and weight), while the mortality percentages of older fish aged 2 and 3 were more varied. The percentages of whiting caught were generally higher. However, the mortality due to industrial fishing was considered small in comparison with the total estimated survivors for the year classes and considering that the natural mortality of haddock and whiting is very high.

Seabirds

Bycatch mortality: The methods for catching fish species depend on the behaviour of the fish. Many fish species shoal, and small-mesh trawls and gillnets are used to capture the shoaling fish. Many of the feed-fish fisheries use trawls, and birds are less likely to be caught by this type of gear (Tasker *et al.*, 2000). A study in the Baltic Sea assessing the bycatch of common guillemot (*Uria alga*) indicated that a small unquantified degree of mortality could be attributed to trawls, but the researchers did not identify the trawls as specifically targeting an industrial fish species (Österblom, Fransson and Olsson, 2002). Bycatch of birds is potentially an issue in the purse-seining for anchovy, but the level of interaction is little researched (Majluf *et al.* 2002), and there are only anecdotal reports of bycatch (S. Austermühle, Mundo Azul, personal communication, 2003).

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

TABLE 19

Landings and bycatch from four Danish North Sea industrial fisheries, 1998–2001 (average) and 2002

Catch species composition	Landings of four industrial feed fisheries (thousand tonnes)							
	Sand eel		Sprat		Norway pout		Blue whiting	
	1998–2001	2002	1998–2001	2002	1998–2001	2002	1998–2001	2002
Sand eel	564.3	622.1	6.1	4.1	0.0	0.0	0.1	0.0
Sprat	6.6	1.0	152.8	140.6	0.2	0.0	0.0	0.0
Norway pout	1.6	0.0	0.4	0.2	53.8	43.2	3.5	3.7
Blue whiting	1.4	0.7	0.0	0.0	2.6	4.7	31.1	21.1
Herring	2.6	1.6	11.2	16.6	1.8	3.2	0.8	0.2
Cod	0.2	0.1	0.0	0.0	0.1	0.0	0.0	0.0
Haddock	0.7	1.2	0.1	0.0	0.9	1.5	0.2	0.1
Whiting	1.8	1.5	1.4	2.5	1.3	1.7	0.1	0.1
Mackerel	0.4	0.4	0.4	0.7	0.1	0.0	0.1	0.0
Saithe	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1
Other species	2.2	1.4	1.8	2.7	0.9	0.4	3.3	1.6
Total	**581.8**	**630.0**	**174.2**	**167.4**	**61.5**	**54.9**	**39.2**	**26.9**
% bycatch	3.0	1.0	12.3	16.1	12.5	21.5	20.9	22.1

Source: Adapted from Frid *et al*. (2003)

Sea sand-eel stocks compared with fish predators (Bax, 1991; Gislason, 1994; ICES, 1997), this relationship is sensitive to the population levels of key predators such as mackerel and gadoids, which are currently low in the North Sea.

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

Marine mammals

Bycatch mortality: The Ecological Quality Objective for bycatch of small cetaceans adopted under the Bergen Declaration[9] requires anthropogenic mortality to be below 1.7 percent per year. No bycatch of marine mammals has been reported in the industrial fisheries (Dalskov, personal communication, 2003), but Huse *et al.* (2003) provide anecdotal evidence that there are occasional bycatches of cetaceans in the North Sea sand-eel fishery. The opportunistic feeding behaviour of cetaceans and pinnipeds in and around trawls means they are vulnerable to becoming trapped (Fertl and Leatherwood, 1997). There is a need for further investigation of the level and spatial and temporal extent of marine mammal bycatch in the North Sea. Should this prove significant in areas or in certain seasons, pingers could prove an effective management measure (Larsen, 1999).

Bycatch of cetaceans is potentially an issue in the purse-seining for anchovy (Majluf *et al*., 2002). The dusky dolphin (*Lagenorhynchus obscurus*) is known to take *E. ringens* as a major component of its diet (McKinnon, 1994), and the species was reported as caught by purse seines before cetaceans were protected in the region (law No. 26585: 1996) (Read *et al*., 1988). Van Waerebeek *et al*. (1997) conducted a survey of Peruvian fishers to estimate mortality on 722 bycaught cetaceans (and direct takes); species reported in multifilament gillnets were 82.7 percent dusky dolphin (*L. obscurus*), with the remainer Burmeister's porpoise (*Phocoena spinipinnis*), long-beaked common dolphin (*Delphinus capensis*) and bottlenose dolphin (*Tursiops truncatus*). Van Waerebeek *et al.* (1997) found that there was no indication of a reduction in dolphin mortality in the industrial purse-seine fisheries, and that large numbers of long-beaked common dolphins are known to be by-caught. Currently, catches are thought to occur, but evidence is anecdotal (S. Austermühle, Mundo Azul, personal communication, 2003).

Availability as prey: Diet composition analyses of cetaceans show the presence of industrial feed-fish species in the diet of harbour porpoise (*P. phocoena*), bottlenose dolphin (*T. truncatus*), white-beaked dolphin (*L. albirostris*), common dolphin (*D. delphis)*, Risso's dolphin (*Grampus griseus*), Atlantic white-sided dolphin (*L. acutus*) and minke whale (*Balaenoptera acutorostrata*) (Fontaine *et al*., 1994; Santos *et al*., 1994, 1995; Couperus, 1997; Olsen and Holst, 2001; Kastelein *et al.*, 2002; Borjesson,

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

Berggren and Ganning, 2003). In some cetaceans, the proportion of feedfish reported in the diet is minimal, but in Scottish waters, sand eels constitute 58 percent by weight of the stomach content in harbour porpoises and 49 percent by weight of the stomach content in the common dolphin. Other feed-fish species, sprat and Norway pout, were less than 1 percent by weight (Santos *et al.*, 1995). In Kattegat and Skagerrak Seas, feedfish (mainly sprat and herring) constitute 13 percent by weight of the contents in juveniles' stomachs and 10 percent by weight in adults' stomachs (Borjesson, Berggren and Ganning, 2003). Sand eels contribute 86.7 percent to the diet by weight of Minke whale in the North Sea and further north, into the Norwegian Sea, the diet of Minke whales is dominated by spring-spawning herring (Olsen and Holst, 2001). The differences in the diet composition reflect the local foraging of cetaceans. Industrial fisheries in the North Sea may, therefore, impact marine mammal populations by altering their food supply in certain areas. It is, therefore, important to consider the local availability of feedfish to cetaceans and their ability to switch to other prey if the stocks are depressed, when assessing the effects of feed-fish fisheries on marine mammals. This, however, has yet to be demonstrated in any cetacean population.

There is some evidence that there is a link with fisheries and grey seal population dynamics. The Effects of Large-scale Industrial Fisheries On Non-Target Species (ELIFONTS) study investigated the grey seal population on the Isle of May, in the North Sea. Grey seals (*Halichoerus grypus*) consumed mainly sand eels (*Ammodytes marinus*), but the greater sand eel (*Hyperoplus lanceolatus*) was also taken. For this study, the proportion of not breeding, but reproductively capable females and the number of breeding failures among marked animals were positively correlated with sand-eel catch per unit effort (CPUE) in the southern North Sea in the years 1990–1997. Effects were only seen when the reproductive performances of known seals were examined in relation to fishery data. It is possible that the reproductive performance of some seals may be more affected by changes in sand-eel availability than that of other seals, reflecting either a tendency to specialize on sand-eels or an inadequacy in hunting behaviour. Also, the body condition of female seals was positively correlated with CPUE for the local stock area. However, the total number of pups increased steadily during the study periods and thus, although there appears to be an interaction between sand-eel abundance and seal breeding success, given the current state of the populations, this interaction does not appear to be a major factor explaining variations in seal populations (Harwood, 1999).

Ecosystem changes

The complexity of marine systems makes it difficult to identify the effects of predator/prey removal on other communities. Marine communities often exhibit size-structured food webs, and changes in the abundance and size composition of populations are likely to lead to changes in the quantity and type of prey consumed (Frid *et al*., 1999). However, these changes may not be predicted by simplistic models of predator-prey interactions, as they do not take into account prey switching, ontogenetic shifts in diet, cannibalism or the diversity of species in marine ecosystems (Jennings and Kaiser, 1998; Jennings, Kaiser and Reynolds, 2001).

Ecological dependence takes account of the ecological linkages in the marine systems. Ecological dependence is already considered in management advice for sand-eel in the Shetland area, and sand eel in Sub-area IV, e.g. the kittiwake/sand eel interaction. ICES (2002) identified several feed-fish stocks for which ecological dependence may need to be considered further in management advice: sand eel in Division IIIa; Norway pout in Sub-area IV and Division IIIa; sand eel in Sub-area IV; Norway pout in Division VIIa and sand eel in Division VIa. However, assessing ecological dependence is problematic, as evidence for the effects of strong ecological interactions on some stocks, e.g. the proposed kittiwake/sand-eel interaction, should not be taken as evidence that they are necessarily a concern to managers of all stocks. ICES (2003c) suggested that the current approaches for assessing ecological dependence could not be widely applied and that fundamental research is needed to develop an appropriate method for assessing and ranking the strength of ecological dependence of species.

Commercial species as predators of feed-fish species

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

The ICES stomach sampling project in 1981 showed that sand eel, Norway pout and sprat provided more than 50 percent of the food of saithe and whiting and between 1 and 30 percent of the food of cod, mackerel and haddock (Gislason, 1994). Greenstreet (1996) investigated the diet composition of the main predators in the North Sea; Table 20, which gives the consumption of industrial species, shows that industrial or feed-fish species are a valuable food resource for predatory fish.

TABLE 20

Diet composition (%) of the main predators in the North Sea

Prey	Predator					
	Cod	Haddock	Whiting	Saithe	Mackerel	Atlantic horse mackerel
Norway pout	7.7	6.3	8.9	32.2	7.3	0.0
Herring	4.1	0.1	6.6	0.6	3.7	8.8
Sprat	2.1	0.3	9.4	0.4	3.2	0.4
Sand eel	7.3	7.2	27.3	9.7	16.6	0.0

Source: Recalculated from Greenstreet (1996)

However, while bioenergetic estimates of sand-eel consumption in the North Sea show that fish are important predators, predation on sand eels is declining (Furness, 2002), as stocks of large gadoid predators are weak and their spawning stock biomass is declining (Sparholt, Larsen and Nielsen, 2002). Sparholt, Larsen and Nielsen (2002) tested the hypothesis that a reduction in consumption of industrial fish by gadoids such as cod, whiting and saithe should lead to a measurable reduction in the predation mortality of their prey (Norway pout) and found the total mortality of Norway pout for ages 1 and 2 had declined between the 1980s and 2000.

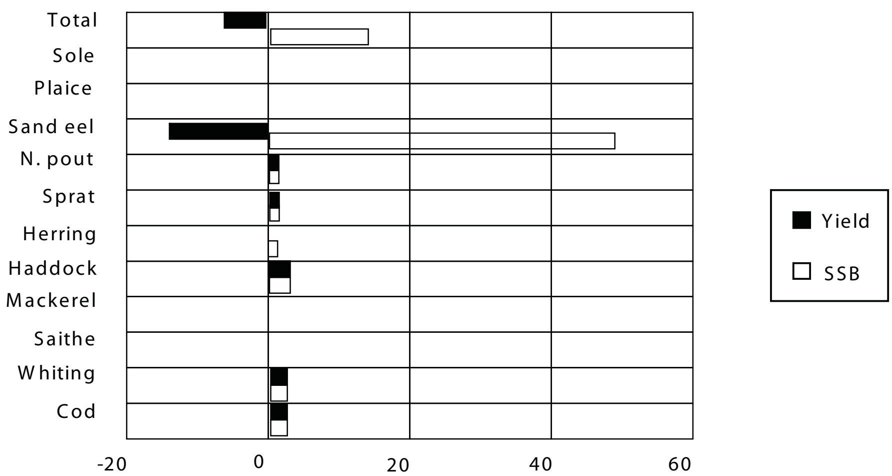
If small pelagic species have become more dominant in marine systems, resulting from a decline in demersal fish predators due to fishing, then there is an argument for management to allow larger harvests of industrial species due to the reduced natural predation pressure on these stocks. However, Naylor *et al.* (2000) argued that in the North Sea, exploitation of sand eel and Norway pout is implicated in the decline of cod. It has been suggested that a reduction in fishing effort on industrial fish stocks will benefit higher trophic predators (including gadoids) (Dunn, 1998; Cury *et al*., 2000; Furness, 2002). The more recent assessments of the Norway pout stocks in ICES

Sub-area IV and Division IIIa (ICES, 2003d) indicate that fishing mortality is lower than natural mortality, and multispecies analyses have indicated that when F (fishing mortality) is below M (natural mortality), the fisheries are not causing problems for their predators on the scale of the stock. It further noted that locally concentrated harvesting may cause local and temporary depletions of predators and, therefore, harvesting should be spread widely across large geographical areas.

The ICES Multispecies Forecast Programme (MSFOR) (reported in Gislason and Kirkegaard, 1998) predicted that if there was a 40 percent reduction in the industrial fishing effort in the North Sea, the harvested yield of sand eel would decrease by

FIGURE 8

MSFOR predictions of the percentage change in yield and spawning stock biomass (SSB) in the North Sea for 11 North Sea species upon a 40 percent reduction in sand-eel fishing



Source: Gislason and Kirkegaard (1998)

19 percent (compared with the prevailing situation), while the spawning stock biomass would increase by more than 50 percent (Figure 8). The model predicted that reducing the fishing mortality of industrial species, and hence increasing the sand-eel stock, would only have a small effect on predatory species. Such modelling must always be interpreted with caution, as models can only make predictions based on the data available. For example, the overfishing of predatory fish may have perturbed the marine system to such an extent that the recovery of these stocks is unlikely even if there is a reduction of the fishing effort on sand eels (Beddington, 1984). The lack of appropriate modelling frameworks for establishing the ecosystem effects of fisheries is well recognized (Robinson and Frid, 2003). However, it appears that fishing mortality due to the sand-eel and Norway pout feed fisheries is sufficiently low to ensure that prey items are available to predatory fish.

Teleost feedfish as predators of commercial species

The survival of the early planktonic phases of the fish life cycle is essential for stock recruitment (Blaxter, 1974; Chambers and Trippel, 1997; Horwood, Cushing and Wyatt, 2000). Even small variations in the mortality rate between egg fertilization and recruitment can have a profound effect on the subsequent adult abundance (Jennings, Kaiser and Reynolds, 2001). Many industrial fish species prey on the eggs and larvae of commercial fish. Sand eel, Norway pout and capelin consume fish eggs and larvae (www.fishbase.org), and sprat and herring prey on cod eggs (Stokes, 1992;

Köster and Möllmann, 2000). Juveniles of saithe, cod and whiting may also experience competitive interactions with Norway pout (Albert, 1994). As the abundance of the larger predatory gadoids has been reduced to low levels, the industrial feedfish that prey on their juveniles and eggs may now be exerting a higher level of mortality than previously, and may potentially affect gadoid stock recruitment and slow recovery. However, it should be noted that such profound trophic impacts are difficult to verify, given the lack of information and the confounding effect of other impacts.

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

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

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

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

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

4.2.1 FIN "Sustainability Dossier"

When most feed manufacturers state that they only procure from "sustainable" sources, this claim is usually based upon the Fishmeal Information Network (FIN) Sustainability Dossier, an annually updated assessment initiated by the Grain and Feed Trade Association (GAFTA) and funded by the United Kingdom Seafish Industry Authority (SFIA). Until recently, this dossier has been limited to examining stock assessment reports and the presence of regulatory frameworks, but it has now been expanded to reflect wider ecosystem impacts based on the latest ICES and FAO advice.

4.2.2 MSC "Principles and criteria" for responsible fisheries

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

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

While the MSC criteria respond well to fisheries and ecosystem issues, they do not provide a specific assessment of the economic or social elements. Huntington (2004) took the basic MSC criteria and adapted them to specifically suit feed fisheries, applying them to the five main fisheries that provide the bulk of fishmeal destined for the Scottish fish-farming industry (Table 21).

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

The advantage of the MSC approach is that it provides a vigorous quantitative approach to assessing the main elements that ensure that a fishery is sustainable. The main question is whether this approach can be successfully applied to feed fisheries, whose main species constitute an important forage prey, unlike many of the top predators that have formed the focus on many fisheries certifications to date. While MSC does look at implications of target species removal on ecosystem structure and function, it has been a challenge to both determine and quantify in practice. With growing interest in ensuring the sustainability of aquaculture products throughout the production chain, the certification of feed-fish stocks has become an urgent priority.

4.3 Sustainable use of available fishery resources for aquafeeds

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

TABLE 21

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

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

Source: Huntington (2004)

4.3.1 Barriers to buying aquafeeds sourced from sustainable feed fisheries

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

- *Lack of recognized criteria for suitability:* At present, there are no feed manufacturing industry standard definitions or criteria for the sustainability of feed fisheries. It currently uses the FIN Sustainability Dossier for guidance, but this is essentially limited to examining stock assessment reports and regulatory frameworks. This dossier does not include some of the elements included in the assessment criteria used in this study, such as non-target species impacts, regulatory compliance levels, availability of key information and knowledge relevant to sustainability, as well as economic and social factors. The MSC-derived framework used by this study is considered an improvement on the FIN Dossier, and one that should be adopted more widely. The setting of sustainability criteria will ultimately enable both fish producer and consumer to purchase selectively, creating a market for a sustainable product.
- *Traceability:* Although the traceability of feed ingredient sources is improving rapidly, it may be difficult to ensure the origin of all fishmeal. For instance, fishmeal is often blended to give constant characteristics of density, flow, digestibility and protein content, and thus species identity tends to be uncertain. Much of the South American fishmeal is blended at the time of loading of tankers (both ship and road) and hence cannot be traced beyond that point. Traceability is high on the feed industry's agenda, and some manufacturers are looking to traceability schemes such as the Universal Feed Assurance Scheme (UFAS) and the Feed Materials Assurance Scheme (FEMAS) to reduce the purchase of feed products where there is not a full traceability chain.
- *Fishmeal nutritional performance:* Restrictions on certain fishmeal stocks may have implications for fishmeal nutritional performance. For instance, smaller fish (i.e. salmon <1 kg) need high levels of amino acid histidine that is found in much higher levels in South American fishmeal – exclusion from these would necessitate much higher fishmeal inclusion levels for European meals and thus higher levels of consumption. There is the potential for substitution with porcine blood meal, but this is likely to meet retail and consumer resistance. Conversely, for larger fish, the use of meals from the northern hemisphere produced at low temperature (LT) is favoured because they are higher in protein and of the highest digestibility. For instance, blue whiting meal is a highly digestible meal and while some users dislike its higher ash level, most processors find it worthwhile using and may be reluctant to reduce its use.
- *Supply assurance:* Should the industry become selective for more sustainable fishmeal stocks, the demand for those stocks will increase. This has a number of implications:
    - o Fishmeal supply may be restricted for reasons outside the control of fishmeal manufacturers and their clients, e.g. the wide inter-annual variability of South American production through the El Niño events.
    - o Connected with the point above, prices may become more variable, with a general shift upwards as the supply base is effectively reduced.
    - o Increased pressure will be put upon sustainable fishmeal stocks. However, this should not be an issue if they are well regulated and controlled (as they should be if deemed as sustainable).
    - o Risk reduction – formulators such as a mix of fishmeals from different sources to reduce the risk of unforeseen quality or contamination problems.

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

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

4.3.2 Recommendations for improving responsible sourcing of aquafeeds

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

- *Better structured feed-fish fisheries sustainability criteria:* The majority of European aquafeed manufacturers use the FIN Sustainability Dossier (FIN, 2003), which is published every year once the EC's annual fisheries management regime has been agreed. As discussed previously, this dossier now includes a review of the wider ecosystem ramifications of feed-fish utilization. To assist this process further, it would be useful to have a formal series of "sustainability criteria" specifically for feed fisheries that could be applied to the main species being sourced and independently verified to provide consumer confidence. This could act as a first stage to pre-assessment and full certification of the more sustainable feed fisheries over the longer term.
- *Improved traceability:* Fishmeal purchasers should request improved information on fishmeal species ingredients, their origin and chain of custody. Such information should be made fully available to the public domain to provide assurance of the industry's transparency.
- *Sustainable purchasing strategies:* Fishmeal purchasers should develop a purchasing strategy that minimizes and, where possible, eliminates the use of those species considered unsustainable. This strategy could be prepared with a number of different timescales:
    - a. *short term*: reduce the purchase of less sustainable species, such as blue whiting or jack mackerel, where possible;
    - b. *medium term:* develop approaches to halting purchases of less sustainable species through a detailed analysis of alternatives; and
    - c. *long term:* develop alternative protein and oil substitutes for fishmeal and fish oil; set a date for and approach to purchasing all fishmeal and fish oils from sustainable fisheries independently verified for "responsible management".

This purchasing strategy could be updated regularly to reflect changes in different fishing practices and the latest "sustainability assessments", together with emerging trends in fish nutrition and alternative feed materials. The use by procurement departments of environmental management systems such as International Organization for Standardization (ISO) ISO 14 001 to ensure that procurement strategies minimize the environmental implications of purchasing should also be considered.

- *Use of non-fish protein and oil:* Greater knowledge should be developed about the options for substituting different fish species with non-fish protein and oil at different times of year to obtain a required fishmeal quality and specification.
- *Premium branding:* European aquaculture, in partnership with its own customers, should seek to develop its premium brand image by encouraging its feed suppliers to move toward targets for achieving sustainable supplies.

5. ENVIRONMENTAL IMPACT OF AQUACULTURE BASED ON FEEDFISH AS INPUTS

While the sourcing of sustainable raw materials for aquafeeds is only just now becoming a serious issue in European aquaculture, the impact of aquafeeds on the environment has been on the agenda for a number of years after the potential magnitude of waterbody eutrophication and other effects of intensive aquaculture were realized. As a result, the content, digestibility and physical structure of pelleted feeds have undergone considerable evolution to minimize wastage and their subsequent effect on the environment.

5.1 Environmental impacts of aquafeed use in Europe

Compounded fish feeds, especially for carnivorous fish such as salmon, trout, seabass and seabream, are now used for over 99 percent of European aquaculture production of finfish. Food-derived waste has four sources (Dosdat, 2003):

- *Uneaten feed.* This is the case with artificial feeding, generally due to poor husbandry, fish diseases or unsuitable environmental conditions.
- *Undigested feed*. This is the case mainly in bivalves when the control of intake and repletion is insufficient. Thus, they ingest more than they can process and release the intact microalgae in the form of faeces called pseudo-faeces.
- *Indigestible compounds*. Complex molecules present in the feed are split into small molecules that either can or cannot cross the intestinal barrier during digestion. Those that cannot, due to their size or their shape, are rejected in the form of particulate matter (faeces).
- *Excreta*. Excretion is the physiological phenomenon by which molecules that come into the body and dissolve in the plasma are released after being processed and degraded. These are soluble compounds that are discharged into the water through particular organs, such as the gills and the kidney. Thus, aquatic animals are directly subjected to the effect of their own waste products.

The impacts of these waste materials can be divided into two main areas of concern:

- *Hyper-nutrification of the waterbody:* Eutrophication is the process of natural or anthropogenic enrichment of aquatic systems with inorganic nutrient elements. The long-term eutrophication of coastal and estuarine waters results from the additions of both dissolved inorganic and organic nutrients and increased biological oxygen demand (BOD). Dissolved inorganic nutrients released by finfish culture and regenerated from sediments enriched with sedimented organic matter may stimulate phytoplankton production and increase oxygen demand. The degree of nutrient enrichment is influenced by the scale of aquaculture, local hydrographic characteristics and the magnitude of other sources relative to aquaculture, and internal processes such as uptake by phytoplankton, algae, internal recycling, resuspension of fine material and uptake by biofouling communities that colonize cage-farming areas. Eutrophication can alter the ratio between essential nutrients (carbon: nitrogen: phosphorus), as well as absolute concentrations by causing a shift in phytoplankton species assemblages. The possible interactions between aquaculture and harmful algal blooms (HABs) are of considerable current environmental and public interest in Europe. This relationship exists on two levels: (i) the role of intensive finfish aquaculture in contributing to HAB events through the ability of fish to input nutrients into the aquatic ecosystem through uneaten food, faecal material and metabolic by-products; and (ii) the impact of HABs resulting from wider anthropogenic and natural sources upon aquaculture systems, especially cultured bivalves. Other studies have looked at the effects of different shellfish and finfish excretion products on phytoplankton growth – shellfish excreta are generally stimulatory; finfish ammonia compounds are also stimulatory, but other metabolic products may have an inhibitory effect (Arzul, Seguel and Clément, 2001).

- *Sedimentation from faecal solids and uneaten food:* Both finfish and shellfish aquaculture produces particulate wastes that mainly result from the undigested organic and inorganic elements of the feed materials. While land-based farms are able to remove these elements from the system through the use of settlement ponds and filtration, they are more difficult to control in cage farms. Particulate loss occurs during finfish feeding, and wastes are usually found directly under the net cages with relatively local impacts. The underlying sediments become enriched with organic matter that degrades more easily than the natural particulates in coastal areas. This may have important consequences for sediment biogeochemistry, especially when microbial activity is engaged. In the marine environment, sulphate reduction is among the most important mineralization processes and is stimulated by enrichment with organic matter. This leads to an increase in the production of sulphides, which may accumulate to levels toxic for benthic fauna. In moderately enriched sediments, opportunistic species may survive, but if enrichment is increased further, the fauna may disappear completely. This leaves the degradation of waste products to microbes only, and such a change is usually followed by increased burial rates of organic matter. It then becomes very difficult for a climax benthic community to re-establish itself. The impact of such sediment deposition may largely be limited to localized effects. However, the change in such coastal benthic faunal communities may have consequences for inshore nursery grounds. These are not necessarily negative, as juvenile stages may benefit from faunal changes, as they are able to consume the copepods or annelids favoured by organic enrichment.

The use of trash fish in European aquaculture is limited to tuna fattening in the Mediterranean Sea. The Worldwide Fund for Nature (WWF) has noted that this has had a number of undesirable impacts, such as increasing the fishing pressure for species that were not previously fished commercially, such as the round sardinella in the western Mediterranean Sea, with possible consequences for one of its main predators, the common dolphin. In addition, they raise the possibility of transmitting viruses from non-endemic feedfish to local wild fish populations, as has been experienced in Australian waters (WWF, 2005).

5.2 Examples of environmental "best practice"

Intensive aquaculture in Europe has been driven to improve efficiency by a combination of lower economic margins and an increasingly strict regulatory environment. This is reflected by the very low FCRs now experienced in salmonid and seabass/seabream culture, as well as by the gradual adoption of joint area management, where companies operating within an enclosed or semi-enclosed area work to reduce the cumulative impact of their production.

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

- *Modelling of sites to set biomass limits:* Computer modelling can provide assessments of both impacts from nutrient loading on waterbody or regional algal productivity, as well as the benthic effects from sub-cage deposition. The particle tracking model *Depomod* has been extensively used in Europe for determining the theoretical carrying capacity of cage-farming areas as well as assessments of the deposition of organic matter beneath finfish cages and mussel rafts. Depomod is limited to near field predictions through the use of a uniform horizontal flow field – detailed modelling at a waterbody and regional scale requires the capability to represent two or three dimensional flows, depending on the degree to which the waterbody is vertically mixed. Various proprietary models exist, for example *Delft3D* and *Mike21*, that can enable detailed assessments of the cumulative effects from aquaculture activity on water quality, such as nutrients and algal activity, in a waterbody. While numerical flow and water-quality models of this nature require considerable effort to set up and calibrate, and the level of effort required increases with the complexity and scale of the model domain and the water quality processes of interest, they can provide useful predictions on the carrying capacity of sites and thus assist in the planning and consenting of aquaculture development.
- *Setting of EQS:* Environmental Quality Standards (EQS) can be used in assimilative capacity model development. EQS values have to be set for the different environmental quality variables (EQVs) defined by regulators and industry bodies, such as dissolved oxygen concentrations. These then provide the basis for setting environmental quality benchmarks and monitoring targets for aquaculture areas.
- *Joint management of sea, semi-enclosed bay, lake and watershed areas*: In Scotland, the use of Area Management Groups has resulted in greater coordination between different farming interests within a single waterbody that allows joint management actions, such as the complete fallowing of sea areas between aquaculture production cycles. This helps control and reduce the cumulative impacts of intensive aquaculture, especially in areas with limited flushing rates.
- *Waste reduction strategies:* Perhaps the greatest change in intensive aquaculture over the last ten years has been the reduction of wastage through better management and monitoring of feeding. Various approaches have been adopted, including maximizing the bioavailability of feed components through applied research, as well as better feed delivery management using computer-controlled, centralized feeding systems. Feeding rates can be further adjusted by the use of underwater cameras and sensors that detect when feed is passing through cage systems and not being utilized by the stock, thus invoking a reduction in feeding rates.
- *Environmental monitoring:* Intermittent monitoring of the benthos and water column will also provide managers with information on the levels of feed utilization, wastage and impact from aquaculture systems, especially when combined with the EQS approach described above.

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

6.1 Current and alternative uses of feed-fish catches

Europe differs from Asia in that aquaculture depends upon formulated diets that have been made from fishmeal and fish oils from targeted feed fisheries. Around three-quarters of European fishmeal is derived from targeted feed-fish fishery catch, while one-quarter is from either (i) those fisheries where a portion is used for direct human consumption or (ii) bycatch or trimmings that are utilized for fishmeal when no economically preferable alternative is available.

Table 22 shows the ten main species used to produce fishmeal in Europe. Excluded from this analysis are the feed fisheries of South America, which are considered separately within this volume. This table indicates a number of trends and opportunities:

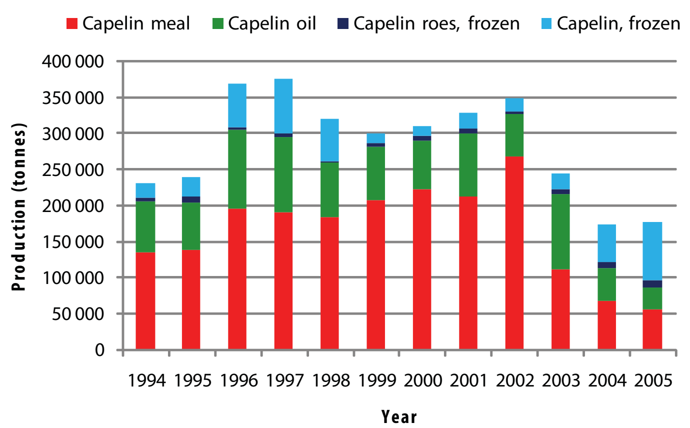
6.1.1 Increased utilization of the feed fisheries for human consumption:

While some of the feed-fish species are too small to use for human consumption (i.e. sand eel and Norwegian pout), others show some potential for direct human consumption, specifically blue whiting and capelin (Table 22).

Blue whiting are unlikely to find a ready market in chilled form, either as whole fish or as fillets – their small size, discoloration due to autolysis and bruising and the presence of parasites all weigh against them in competition with other well established white fish species. However, research some 10–15 years ago (MAFF, undated) showed that skinless fillets can be produced from chilled or frozen whole fish for the manufacture of frozen laminated blocks for finger or portion production. Another possible product form investigated was blue whiting mince prepared from skinless fillets that could also be used to manufacture fish cakes, fish pies and cook-freeze dishes. One possible European export outlet for blue whiting is to Japan as surimi, an intermediate product in mince form used there for the manufacture of *kamaboko*, a speciality product of high value. Uptake of these new technologies has been slow and blue whiting is unlikely to become an important food fish in the near term.

A proportion of capelin is currently used for human consumption (Figure 9). Around 16 percent of the Icelandic catch in 2005 was frozen whole for sale in Japanese and East European markets. Over the early part of the 2006 season, of the 135 000 tonnes reported caught by Icelandic vessels, 58 000 tonnes (42 percent) were frozen for human consumption and 78 000 tonnes (58 percent) were processed into meal and oil. Such low capelin catches favour a higher proportion of these fish going for human consumption – an examination of the trend in Icelandic capelin usage over the last ten years indicates a fairly consistent volume of capelin used for human consumption.

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



Source: FAO (2005a)

6.1.2 Non-target, bycatch or trimmings that are utilized for fishmeal

A number of food-fish species are also used for reduction into fishmeal and fish oil, either whole when market conditions

TABLE 22

Principle European feedfish and their uses, 2004

Species (2004 catch, thousand tonnes)	Main use	Proportion used for fishmeal	Uses		Comment
			Current	Potential	
Blue whiting (2 453)	Fishmeal	>95%	Fresh and frozen whole fish for human consumption	Frozen blocks for “economy” meals, mince, surimi	Unlikely to be accepted in chilled form due to their small size, bruising, autolysis and parasite load.
Capelin (608)	Fishmeal	50–85%	Human consumption (especially roe)	Incorporating oil into food products	Of the 633 000 tonnes of Icelandic capelin landed during the 2004/2005 season, 100 000 tonnes were frozen for consumption in Japanese and East European markets.
Sand eel (390)	Fishmeal	100%	None	None	
Norwegian pout (22)	Fishmeal	100%	None	None	
Antarctic krill (22)	Fishmeal	70%	Boiled frozen krill or peeled krill tail and concentrate powders	Aquafeeds, non-nutritional uses	Attractive as an aquafeed due to high levels of astaxanthin for salmonid feeds.
Atlantic herring (1 751)	Human consumption	<30%	Fresh and frozen for human consumption, tuna farming	Added-value for human consumption	Strengthening frozen herring prices have made this fish less attractive for fishmeal use. Atlanto-Scandinavian use for fishmeal has dropped from 68% to 25% since 2001.
Sprat (684)	Fishmeal and human consumption	<50%	Smoked for human consumption, mink food	Added-value for human consumption	Mainly used for fishmeal except in Latvia and Russian Federation. High dioxin levels may have implications for use in fishmeal/oil.
European pilchard (297)	Human consumption	c. 50%	Canned	Added-value for human consumption	
Atlantic horse mackerel (202)	Human consumption	<20%	Block frozen for Russian Federation and Africa	Added-value for human consumption	
European anchovy (159)	Human consumption	?	Canned	Added-value for human consumption	

Source: Compiled by the author

TABLE 23
Levels of herring processed for fishmeal and human consumption, 2001–2005

Icelandic herring	2001/2002		2002/2003		2003/2004		2004/2005	
	Thousand tonnes	%	Thousand tonnes	%	Thousand tonnes	%	Thousand tonnes	%
Processed on land for human consumption	35	35	28	29	33	26	33	29
Processed at sea for human consumption	21	21	19	20	27	21	37	32
Total processed for human consumption	56	56	47	49	60	47	70	61
Total Processed for fishmeal*	45	45	49	51	66	52	45	39
Total processed	**101**	**100**	**96**	**100**	**126**	**100**	**115**	**100**

Atlanto-Scandinavian herring	2001/2002		2002/2003		2003/2004		2004/2005	
	Thousand tonnes	%	Thousand tonnes	%	Thousand tonnes	%	Thousand tonnes	%
Processed on land for human consumption	7	6	2	2	0	0	3	2
Processed at sea for human consumption	33	26	48	39	47	53	102	73
Total processed for human consumption	40	32	50	41	47	53	105	75
Total processed for fishmeal*	86	68	73	59	42	47	35	25
Total processed	**126**	**100**	**123**	**100**	**89**	**100**	**140**	**100**

* It has been assumed that 50 percent of the catch processed on land will be trimmings that are going to the fishmeal industry.
Source: www.srmjol.is/displayer.asp?cat_id=47&module_id=220&element_id=207, accessed May 2007

make reduction an economically preferable alternative or as trimmings from processing waste.

Atlantic herring stocks are improving and support a number of economically important fisheries. The majority of herring catches are landed as either fresh or frozen whole fish. In the EU, controlled herring fisheries (west of the United Kingdom, the North Sea, the Skagerrak and Kattegat Seas) food grade can only be sent for reduction if there is no market for human consumption. All fish caught in the Baltic Sea can be offered as feed grade.

As shown in Table 23, the proportion of herring processed for fishmeal by the Atlanto-Scandinavian fisheries has decreased from 68 percent in 2001/2002 to 25 percent in 2004/2005 due to a combination of greater land and sea freezing capacity as well as strengthening prices for the frozen whole product for human consumption.

Antarctic krill demand is likely to increase due to its excellent value as a nutrient source for farmed fish and crustaceans (protein, energy, essential amino acids). Other outstanding properties of krill are its natural pigment content (particularly appropriate for salmon farming), its palatability, its low content of pollutants and its likely improvement of larval fish survival. These attributes make krill a more attractive feed than potential competitors such as squid meal, clam meal, artemia soluble and fish soluble (Sclabos, 2004).

The western European catch of sprat has largely been used for fishmeal, but it is a popular food fish in eastern European Baltic states. However, with the increased awareness of dioxin contamination of oily fish in the Baltic Sea, it may be that the demand for human consumption will decrease and a greater proportion will be used for reduction (FAO, 2005b). There is, therefore, the possibility for increased human utilization by the countries of Eastern Europe of the “low-value” feedfish from the cleaner waters of the North Atlantic. However, this potential is likely to be constrained by the continued low demand for low-value fish[10] from this region – in 1985, the regional annual consumption of low-value fish was 2.5 million tonnes but dropped to 150 thousand tonnes by 1997 – and is not predicted to increase to much more than 161 thousand tonnes per year by 2020 (Delgado *et al.*, 2002).

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

6.2 Comparative analysis of use in aquafeeds versus for human consumption

As the section above indicates, there are few alternative uses of feedfish for the main feed fisheries supplying fishmeal production in Europe that are not already being utilized. In European feed fisheries, a more fundamental question is whether it is more ecologically efficient if these feed-fish stocks – which are often prey items for both commercial fish species as well as an integral mid-level component of the food chain in many European seas – are left in the sea. Essentially, is it more effective to harvest low trophic-level species in industrial fisheries and convert the biomass obtained to human consumption fish protein in aquaculture systems, or is it better to leave low trophic-level fish in the sea where they can be consumed by their natural predators, and then to harvest species from higher trophic levels in fisheries for human consumption?

This question was asked of ICES by the EC's DG Fisheries, and its response was published in the annual report of the ICES' Working Group on Ecosystem Effects of Fishing Activities (ICES, 2004). Its conclusions were as follows:

- *Transfer efficiencies in natural marine food webs*: The transfer efficiency of both energy and carbon between trophic levels along a food chain is not 100 percent. Energy is required for metabolism and maintenance, and only a fraction of the food consumed by a predator is actually converted to predator biomass. Transfer efficiencies in the range from 10 to 15 percent are generally accepted for predator-prey interactions involving fish predators in marine temperate shelf-sea food webs (Jennings, Kaiser and Reynolds, 2001).
- *Transfer efficiencies in aquaculture systems:* Taking into account the levels of fishmeal inclusion and food conversion ratios, the total conversion efficiency of, say, a sand eel-derived salmon diet in producing a harvestable biomass is around 10–17 percent, which is much in line with natural food webs.
- *Other energetic factors:* In addition to the above efficiencies, the energy/material "costs" need to be considered. Additional materials are required for production of fish feeds, as well as the energy involved in processing. However, while the trophic energy efficiency in marine food chains may be around 10–15 percent, this does not account for natural mortality due to predation, which may reduce this efficacy considerably.
- *Conclusions:* ICES concluded that "if one is only concerned about the efficiency of converting sandeel biomass to human consumption fish biomass, then the exploitation of sandeels by industrial fisheries for the aquaculture industry is at least as efficient ecologically". ICES then goes on to ask the question as to whether it is of greater benefit to society to exploit lower trophic-level marine fish resources in industrial fisheries and rely on an aquaculture industry to provide mankind's human consumption fish requirements, or is it better to leave these fish to be processed through the natural marine food web and then to harvest fish in the higher trophic levels in fisheries for human consumption?

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

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

6.3 Risks of utilizing feedfish in the food chain

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

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

6.3.1 Persistent organic pollutant (POP) residues

Salmonids, which represent around 80 percent of European aquaculture production by volume, are relatively oily fish that easily bioaccumulate lipophilic POPs such as PCBs, dioxins and polybrominated diphenyl ethers (PBDEs), should they be present in the diet. It is widely recognized that contamination levels of forage fish from the industrialized waters of the Baltic Sea and coastal waters elsewhere in the northeastern Atlantic are higher than those found in Pacific waters, and this may be mirrored in feeds manufactured from fishmeal originating from these waters.

The levels of POPs (PCBs, dioxins, toxaphene and dieldrin) in farmed fish were brought to wide public attention with a much quoted study reported in the journal *Science* (Hites, *et al.*, 2004) that investigated contaminants in a variety of fish feeds and farmed salmon products. Hites *et al.* (2004) concluded that salmon produced in Europe had significantly higher contaminant levels than those produced in both North and South America, reflecting higher contaminant concentrations in forage fish from the industrialized waters of Europe's North Atlantic as compared with forage fish from the waters off North and South America. Indeed, fishmeal and fish oils of European origin have been reported by the Scientific Committee on Animal Nutrition (SCAN) of the European Commission to contain much higher levels of dioxin than those originating from the cleaner waters off Peru and Chile (SCAN, 2000). Such differences in dioxin content not only affect fishmeal and fish oils but also influence the residue levels in wild fish caught for direct human consumption. In a study of European fish cited by Klinkhard (2001), one of the highest dioxin contents found in samples taken between 1995 and 1999 was in wild salmon from the Baltic Sea (Sweden). Of the farmed salmon and trout analysed during this period from Finland, Germany, Norway, Sweden and

TABLE 24

Current limits on dioxins in fishmeal, fish oils and aquafeeds

Product	Maximum level (ng/kg product)	Action level (ng/kg product)
Fishmeal	1.25	1.0
Fish oil	6.00	4.5
Compounded fish feed	2.25	1.5

Source: University of New Castle upon Tyne and Poseidon Aquatic Resource Management Ltd . (2004)

the United Kingdom, the highest level of dioxin reported was only 15 percent of the level found in Baltic wild salmon.

In order to improve food safety, the EU has adopted a two-fold strategy of (i) reducing POP inputs into the environment and (ii) restricting the level of POPs that can enter the human food chain by setting the maximum and action levels[11] of dioxins in fishmeal, fish oil and aquafeeds over the period 2002–2005 as shown in Table 24. These levels are close to the levels found in fishmeal and fish oil of European origin but much higher than the highest levels found in products originating from Chile and Peru.

The comparisons between different sources of fishmeal and fish oil show very low levels of dioxin. SCAN commented that "no adverse effects from dioxins would be expected in mammals, birds and fishes exposed to the current levels of background pollution" (SCAN, 2000). Despite this, a considerable proportion of the population of Europe (and undoubtedly other regions) is exceeding the tolerable weekly intake (TWI) levels for dioxins set by various authorities. As there is a considerable safety factor imposed on TWI, this does not necessarily mean that there is an appreciable risk to individual health. However, exceeding TWI levels erodes the protection of this safety factor.

European exposure to dioxins and PCBs is decreasing (by a factor of about 50 percent over the last 10–15 years) due to improved waste management and restrictions on the use of these materials.

6.3.2 Transmissible spongiform encephalopathy (TSE)

First, it is important to state that there is no epidemiological evidence for the transmission to humans of a variant of CJD caused by prions that use fish or fish products as vectors (GLOBEFISH, 2001).

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

The EU ban on the use of animal proteins includes the use of fishmeal in ruminant feeds but does not ban its use in feeds for pigs or poultry, or its use in aquafeeds. The EU ban on the use of fishmeal in ruminant feeds was initiated because meat and bone meal has unfortunately been used at times to adulterate fishmeal in order to alter its protein content. While the use of fishmeal is not banned in feeds for other animals, including fish, the ban concerning ruminant feeds causes a further problem for feed manufacturers generally. This problem is that cross-contamination may occur between

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

batches of feeds made for one type of livestock and batches made for other types of animals – the current EC regulation has a zero tolerance, and thus manufacturers have been forced to mill ruminant and non-ruminant feeds at different factories. It is possible that the current ban may stay in place for some time. However, the tolerance level has been lifted to 1 percent, which should ease the situation for feed producers.

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

7.1 Issues of regional importance

Given the high level of dependence of European aquaculture on compounded feeds in intensive systems, the issues of regional importance reflect the sourcing of raw materials included in the feeds rather than the environmental impact of their actual use. It is considered that there are three issues of immediate concern:

- *Improved sustainable management of feed-fish stocks:* Feed fisheries, which are largely composed of small, bony pelagic fish, require quite distinct management approaches compared with the often larger and slower-growing fisheries for human consumption. As described earlier in this report, their management needs to recognize the dynamic turnover of the stock and the high degree of inter-annual variability that may depend upon extrinsic, often climate-related factors. Furthermore, they may be highly migratory and, therefore, often shared among more than one fishing nation.

  Within Europe, the majority of the northern feed stocks are managed through the European Commission Common Fisheries Policy (CFP), mainly acting upon the advice of the International Council for the Exploration of the Seas (ICES). Other major fisheries – most notably those managed by Norway and Iceland – are also subject to national, EC and international management agreements. Mediterranean fisheries within EU Member States' waters operate under the CFP as well as within the wider General Fisheries Council for the Mediterranean (GFCM) management regime with the FAO.

  While it is possible to provide science-based precautionary management of feed -fish stocks, political and economic reality may combine to reduce management effectiveness, as typified by the long period in which it took to finalize the joint management of the northern blue whiting stock. Furthermore, the ecosystem linkages between feed fisheries and natural predators such as white fish, tunas, sea birds and marine mammals are still not fully understood, and thus further precautionary thinking is necessary in many cases.
- *Increased utilization of feedfish for human consumption:* As mentioned earlier, while catchs of a number of food fisheries are not suitable for direct human consumption, catchs of other food fisheries are. The main barriers to their direct use are not so much technical but more related to market and other economic or cultural influences.
- *Greater substitution by protein and oil substitutes:* Substitutes for fishmeal protein and marine fish oils are continuously being sought and progress is being made. Protein substitutes are already used in fish feed in the United Kingdom and Norway, with up to 25 percent of the protein in the feed derived from plants. The uptake of fish oil substitutes has been slower. Concerns over the dioxin and PCB levels in the northern hemisphere fish oils have increased the pressure on fish oil manufacturers to produce oils with reduced levels of dioxins. Scottish Quality Salmon (SQS) has revised its Quality Manual (Product Certification Scheme for Scottish Quality Farmed Salmon) to allow up to 25 percent of the oils added to the fish feed to be of plant-based origin. However, the level of substitution of fish-based meals and oils possible is limited by their lack of essential amino acids (such as lysine, methionine and histidine). Substitution at higher levels may limit

grow. Another issue facing the plant meal and oil substitution option in Europe is consumer opinion and the affect that vegetable oil substitutes may have on the continued acceptance of farmed fish as a "high-quality" product similar to its wild counterpart. To produce a product as "near to the wild product as possible", research is also focusing on the "dilution" of vegetable oils in the flesh when fish are fed diets containing 100 percent marine fish oils for six months prior to harvest. In addition, vegetable oil substitutes do not necessarily improve the environmental sustainability of the product (e.g. increased soybean production may lead to further rainforest clearance).

7.2 Ongoing work of interest

7.2.1 Improved sustainable management of feed-fish stocks

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

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

These working groups feed information into the decision-making process through the ICES Advisory Committee on Fishery Management (ACFM). The ACFM meets twice a year (summer and late autumn) to prepare its advice, which is then translated into effective management by the national governments and the EU.

EU fisheries management in the Mediterranean Sea tends to be focused upon coastal fisheries. In general, EU catch limits or quotas are not applicable in the Mediterranean Sea, with the exception of limits on bluefin tuna that have been introduced in response to recommendations by the International Commission for the Conservation of Atlantic Tuna (ICCAT). In contrast, the GFCM's work has focused on shared or straddling stocks, particularly those involving demersal and large pelagic species. GFCM's Sub-Committee on Stock Assessment (SCSA) recently assessed the stocks of 11 small pelagic species, which assessment will result in the development of management programmes controlling the pelagic trawling and purse-seine fisheries exploiting anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*) and sprat (*Sprattus sprattus*) (FAO, 2006b).

The EU is currently finalizing a strategy and action plan to improve scientific advice and research in stock evaluation in the waters of third countries. This strategy will combine actions to (i) improve data collection, management and use; (ii) increase the level of research, especially into ecosystem considerations; (iii) strengthen the role of Regional Fisheries Organization (RFOs) and (iv) provide greater cooperation with European research and advisory organizations, as well as improve the capacity of national fisheries administrations to operate within a regional context.

Ultimately, pressure for improved management of feed-fish stocks must come from both the aquaculture industry and consumers. One of the barriers to the environmental certification of aquaculture in Europe has been the inability of the feed manufacturers to assure the sustainable sources of fishmeal and fish oils in compounded feeds. As mentioned earlier, this has become an increasingly important issue, with feed manufacturers looking to FIN for reassurance (see Section 4.2.1). There has also been growing pressure for independent certification through such schemes as MSC's standard for responsible fishing (see Section 4.2.2).

7.2.2 Impact of fisheries on marine ecosystems

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

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

7.2.3 Increased utilization of feedfish for human consumption

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

7.2.4 Greater substitution with protein and oil substitutes

The potential for including higher levels of non-fishmeal protein sources in aquafeeds has been explored for a number of years with gradual but significant success. As discussed earlier, the proportion of oilseed and legume-derived meals in aquafeeds will increase from 17 percent to 24 percent by 2010, resulting in the reduction of northern hemisphere fishmeal, while vegetable oils will become an important source of oils in salmonid aquafeeds, accounting for nearly a quarter of the oil content by 2010, again resulting in the reduction of northern hemisphere, from the feed-fish supplies.

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

- *Perspectives of Plant Protein Use in Aquaculture (PEPPA) project:* a €2.5 million project over 2001–2004 to (i) replace the greater amount of fishmeal with plant protein sources in fish diets while improving muscle protein growth, fish quality, health, reproductive potential and environmental quality; (ii) understand the metabolic fates of dietary amino acids and carbohydrates as carbon donors and as an energy source; and (iii) strengthen our understanding of the relationships between nutritional factors and endocrine control of muscle growth and adiposity using cellular and molecular approaches.

- *Researching Alternatives to Fish Oil in Aquaculture (RAFOA):* an EU-funded project studying the effect of substitution of fish oils with plant oils on growth performance, fish health and product quality during the entire life cycle of salmon, rainbow trout, seabream and seabass.
- *The Directorate of the Fisheries Institute of Food and Nutrition in Norway* has also conducted research similar to that of the RAFOA project. In addition, a second project, "Fish Oil Substitution in Salmonids" (FOSIS), is currently investigating whether fish oil can be replaced by vegetable oils in the diet without reducing the nutritional value or the growth performance of the fish, while minimizing fat deposition in the flesh.
- *Two EU research projects* are studying the effects of plant oils on fish digestion and metabolism, "GLUTINTEGRITY" and "FPPARS". In addition to vegetable oils, an EU research project "PUFAFEED" is investigating the use of cultivated marine micro-organisms as an alternative to fish oil in feed for aquatic animals.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

European aquaculture differs from aquaculture in other parts of the world in that it is a maturing industry focusing on a limited number of high-value, mainly carnivorous species. As such, the dynamic growth seen over the 1980s and 1990s has slowed, and European aquaculture is now going through a period of consolidation. This said, while growth in salmon and trout farming has slowed, the farming of seabass and seabream, as well as temperate marine species such as cod and turbot, has expanded to take advantage of the strong market as technological barriers are broken. This study considers that, based on recent trends, a cautious growth in production of around 2–5 percent per year is likely, mainly in the production of these "new" marine species.

In Europe, the intensive production of mainly carnivorous species requires a high demand for fishmeal and fish oil. With typical grow-out diets containing between 30 and 50 percent protein and 10 and 25 percent oil, European aquaculture currently uses around 615 000 tonnes of fishmeal and 317 000 tonnes of fish oil per year, thus requiring around 1.9 million tonnes of feedfish[12]. The main sources of these feedfish are the small pelagic stocks of northern Europe, as well as the Peruvian anchovy and jack mackerel of South America. In addition, approximately a third of fishmeal is produced from trimmings and the bycatch of food fisheries. The utilization of fishmeal for aquaculture is likely to fall on a per unit basis as inclusion rates drop through the use of alternative vegetable-based substitutes and greater efficiencies in feeding and nutrition. With the conservative rise of European aquaculture production of 2 percent per year, the use of fishmeal and fish oil is likely to rise to 629 000 tonnes and 343 000 tonnes, respectively, by 2015.

The feed fisheries make a low economic contribution to the fisheries sector as a whole, providing an estimated 0.5 percent of the EU's fisheries-related employment and 2.1 percent of the sector's value added. Nearly half (45 percent) of this employment is in the catching sector, with the remainder in feed-fish processing (19 percent) and fish trimming (35 percent). The adoption of technically advanced catching and processing methods has ensured that feed fisheries-related employment remains low. However, this low level of dependency hides localized relatively high levels of dependency in the fleets of Denmark and Sweden, where feed fisheries are interwoven into a substantive part of the fisheries sector as a whole.

The main impacts of this demand for fishmeal and fishoil are on the feed-fish stocks and linked elements of the food chain. Feedfish are mainly bony small pelagic fish with

[12] This assumes that 66 percent of fishmeal is derived from feed fisheries and that it takes 4.8 tonnes of feedfish to produce 1 tonne of fishmeal.

short lives and a high level of inter-annual variability that may depend upon extrinsic, often climate-related factors. As such, they are difficult to manage on a multi-annual basis when compared with longer-lived stocks for which the state of successive year classes entering the fishery can be monitored in advance. Fortunately the high levels of fecundity allow stocks to recover relatively quickly, and thus they are protected to a certain degree from high levels of exploitation. What is less certain is the consequences of stock variability on natural predators such as gadoids, marine mammals and seabirds, as well as the contribution of fishing mortality to these effects. Recent research suggests that as long as fishing mortality remains below natal mortality, feed fisheries may not cause problems for the predators on the scale of the stock. However, locally concentrated harvesting may cause local and temporary depletions, which might affect subpopulations of species such as sand eel and their natural predators at a local level.

As can be inferred from the above, judging the sustainability of feed-fish stocks is complex. Although quality and price are the main determinants for fishmeal purchasers in the aquafeeds industry, the sustainability of feed-fish sources is beginning to be more important. At present, most buyers depend upon the FIN "Sustainability Dossier" for information on what stocks are "sustainable" or not, but there is a recognized need for a comprehensive analytical framework that integrates target stock assessment with the wider ecosystem linkages. To a degree this exists with the development of ecosystem models and approaches such as the MSC criteria for "responsible fishing". Once such a framework has been created and is accepted as a suitable benchmark by the aquafeed industry and its detractors, then it will be easier for purchasers to purchase only from sustainable feed-fish stocks. This process will inevitably have consequences, such as greater pressure on those stocks deemed as sustainable, as well as possible effects on market economics. This implies that greater use of vegetable-based substitutes will be essential, which in turn may require a change in consumer attitudes towards their inclusion in farmed-fish diets.

There are a number of impacts of compounded feed use, especially in poorly flushed lakes and semi-enclosed waterbodies with limited flushing, with increased nutrient levels leading to limnological change as well as benthic change due to increased sedimentation. However, the high cost of feed, combined with increasingly strict environmental legislation, has meant that European aquaculture must become generally very efficient, with minimum wastage and production being limited to the assimilative capacity of sites. The rapidly expanding use of whole fish, usually small-pelagic species, for tuna fattening also has its problems, with the possible introduction of exotic pathogens into local coastal fish populations and increased pressure on the target stocks themselves.

The various feed fisheries targeted for fishmeal in Europe have little alternative uses. However, some, such as blue whiting, capelin, anchovy, herring and sprat, can be used for direct human consumption. The proportion that goes for human consumption depends largely on economic and cultural factors rather than technical limitations, and these factors are more difficult to address directly by the industry. Despite the relatively low cost of products from small pelagic fisheries, these products are not considered to contribute significantly to ensuring food security in any part of Europe, due to the ready availability of other nutritional options. In particular, while Eastern European markets have shown interest in utilizing feed-fish species such as capelin for human consumption, the volumes used are low and are not likely to grow significantly. However, the potential for greater utilization of feed-fish fisheries stocks by Eastern European consumers warrants further investigation, with a focus on the price sensitivity of these markets and recommendations on how products can be developed that might better utilize this raw material. However, expectations should be limited –the recent reductions in capelin catches due to low stock availability may impact investment opportunities and confidence.

At an ecological level, recent work by ICES questions the immediate assumption that the reduction of fish into fishmeal and subsequent use in aquaculture is less efficient than leaving the fish in the sea to supply predators further up the food chain. It then goes on to state that so long as the food conversion efficiencies are regularly reviewed, then a closely regulated combination of industrial fisheries and fisheries for human consumption fisheries may provide the only solution to the long-term demand for fish protein.

The European aquaculture industry has proven to be vulnerable to health issues arising from contamination of fishmeal and fish oil raw materials – either through the concentration of pollutants through the food chain or via the production and distribution process – that affect consumer confidence in the farmed product. Two potential problems that have become particularly important recently include (i) the presence of dioxin, PCB and other POP residues in human food products of animal origin and (ii) the relationship between meat and bone meal, and the incidence of BSE in ruminants, coupled with the linkage with Creutzfeld-Jacob Disease (CJD). These problems have resulted in a number of pieces of strict legislation that have banned the use of fishmeal in ruminant diets and increased the logistics and costs of feed milling and compounding in order to achieve greater levels of traceability.

In summary, although feed-fish fisheries capture and processing only make a small contribution towards European fisheries-related employment (0.5 percent) and value added (2.8 percent), they help support an important aquaculture industry that has been dependent upon regional fishmeal and fish oil production to sustain its growth. Although the relative contribution of regional feed-fish stocks is likely to fall as alternative protein products become increasingly used, it is considered that they will have a continued role to play in the production of European aquafeeds as part of a balanced strategy of sustainable use and responsibility.

8.2 Recommendations for further action

Based on the above, a number of recommendations can be made to ensure that the moderate forecasted growth in European aquaculture can continue – against a background of increased global demand for fishmeal and fish oils – and yet improve its environmental performance, particularly in regard to the sustainable sourcing of raw materials for aquafeeds. Recommendations include:

- Management of European feed fisheries should be improved through a combination of greater political will and cooperation, as well as the gradual adoption of the ecosystem approach as implementation mechanisms evolve.
- Technical and other assistance should be provided to feed fisheries outside European waters, in particular South American and Antarctic resources, through greater cooperation and the strengthening of relevant regional fisheries management organizations.
- Piloting of innovative management approaches should be done, such as the certification of responsibly managed feed fisheries to provide a market incentive to influence fishmeal and fish oil purchasing.
- Barriers to the sourcing and use of sustainable fishmeal and fish oils should be addressed by (i) adopting well-structured feed-fish fisheries sustainability criteria to guide buyers; (ii) improving traceability of materials, especially if blended during manufacture or distribution; (iii) encouraging sustainable purchasing strategies through the use of formal environmental management systems, and (iv) premium branding of aquafeeds and aquaculture products produced using sustainable raw materials.
- Markets for European feedfish and their by-products in eastern Europe and the Far East should be investigated. These markets currently absorb between 60 000 and 100 000 tonnes of Icelandic capelin per year, which might be increased.

An investigation might focus particularly on the Russian Federation, Romania, Poland and Ukraine, which have traditionally been a keen market for small pelagic products, as well as other emerging markets. Such an investigation would examine why import levels have remained static over the last five years and determine the sensitivity of price, stock availability and other key factors constraining trade. The study should also recognize the recent falls in capelin availability and the likely impact on investor confidence.

- Food products for direct human consumption should be developed from species that are currently reduced to fishmeal and oils. These products should be economically competitive, appeal to European and export markets and be resistant to the cyclical nature of fishmeal and oil commodity pricing.
- Plant and other substitutes for fishmeal and fish oil in aquafeeds should be further developed. These substitutes must be able to provide cost-effective alternatives to fish-based products, be acceptable to consumers and not generate sustainability issues in their own right.

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