Mariculture Committee

ICES CM 2002/F:04
Ref. ACME

REPORT OF THE

Working Group on Environmental Interactions of Mariculture

ICES Headquarters
8–12 April 2002

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

Palægade 2–4 DK–1261 Copenhagen K Denmark

TABLE OF CONTENTS

1 OPENING THE 2002 MEETING

The 2002 meeting of the Working Group on Environmental Interactions of Mariculture (WGEIM) began at 9.00 hours on 8 April 2002 at ICES headquarters in Copenhagen, Denmark. The meeting was opened by the Chair, Edward Black.

The meeting was attended by twelve members from six countries. Hans Ackefors (Sweden), N. Connolly (Ireland), Jackie Doyle (Ireland), Thomas Landry (Canada), Peter Burbridge (United Kingdom), and Eva Roth (Denmark) sent their apologies that they were unable to attend this year's meeting. The complete list of attendees is attached as Annex 1. Dr Eva Roth provided verbal comments for consideration of the Working Group.

2 ICES WELCOME TO COPENHAGEN HEADQUARTERS

Mr David Griffith, ICES General Secretary, welcomed the group to its first meeting at ICES headquarters. He presented an overview of the role of the Working Groups in the ICES structure and the pivotal role they play in creating advice that the Council supplies to Member Countries.

3 ADOPTION OF THE AGENDA

After small alterations, the agenda was accepted and included as Annex 2 of this report. No additional items were added under the agenda item “Other Business”.

4 ARRANGEMENTS FOR THE PREPARATION OF THE REPORT

As in previous meetings of the WGEIM, it was explained that it would be necessary to reach agreement on the recommendations and main points of the report before closing the meeting. Unlike previous meetings, the period between the end of the meeting and delivery of the report to the Mariculture Committee (30 April 2002) was very short, leaving almost no opportunity for substantive changes to the document once the meeting was closed.

5 COLLATE AND REVIEW INFORMATION ON PRODUCTION PATTERNS BASED ON REPORTS PREPARED BY WORKING GROUP MEMBERS AND COLLECT AND ASSESS INFORMATION ON THE METHODOLOGY FOR THE COLLECTION OF STATISTICS ON PRODUCTION AND FEED UTILIZATION FOR FINFISH CULTURE WITH A VIEW TO HARMONIZING METHODS

Participants provided national reports (Annex 3) on production levels and trends. A summary is presented below.

Canada

Mariculture continues to expand in Canada. Finfish culture grew by 6 % between 1999 and 2000, while shellfish production grew by 20 % in the same period. There has been a moratorium on the issuance of new aquaculture site licenses on the Pacific coast. Issuance of new licenses is expected to begin in 2002 and this should significantly expand finfish and shellfish production by 2004. A detailed country report may be found in Annex 3 (Section 3.1).

France

Shellfish production in 2000 has declined marginally (approximately 5 %) since 1998. During the same period, French finfish production has remained essentially unchanged. A detailed country report may be found in Annex 3 (Section 3.2).

Germany

With the exception of shellfish, mariculture is not a significant activity along the German coasts. A few small-scale cage farms continue to grow rainbow trout in sea and brackish water. Extensive shellfish farming fluctuates from year to year depending on spatfall success, while the mussel beds have remained unchanged in size and number. A detailed country report may be found in Annex 3 (Section 3.3).

Ireland

Production of finfish was relatively static in the years under review but the production of Atlantic salmon represented an increase of approximately 15–20 % relative to the production in 1998 previously reported. Rope mussel production was also relatively static and the decrease in output recorded in 2000 was mainly the result of prolonged closures of production areas due to the presence of biotoxins. There was a significant increase in the output of bottom-cultured mussels in 2000 relative to previous years.

A detailed country report may be found in Annex 3 (Section 3.4).

Norway

Growth in production of salmon has slowed due to softening market demand, however, cod and blue mussel production continues to expand. A detailed country report may be found in Annex 3 (Section 3.5).

Scotland

The production tonnage of salmon in sea water increased by 1.8 % in 2000, due mainly to an increased average weight of individual fish produced. The estimated number of smolts put to sea in 2000 was 50.2 million, which would indicate an increased harvest in 2001 and 2002. The estimated harvest forecast for 2001 is 158,479 tonnes, an increase of 23 % on the 2000 total. The production of all species of shellfish has shown considerable variation from year to year. However, considered over a 10-year period (1991–2000), there has been a steady increase in the production of mussels. The main areas of expansion have been Strathclyde, Shetland, and Highland Region. Production in the Western Isles may now be increasing again, while there is now no production in Orkney. A detailed country report may be found in Annex 3 (Section 3.6).

5.1 Methodology for Determining Production Patterns, Fishmeal and Fish Oil Use

There is no consistent pattern in the methodology used to collect information for statistics on finfish and shellfish production. In some countries (Norway and France) individual producers must report their annual production and the information is summarized by a government agency. Reporting in this fashion may be less reliable than desired, when the farmer feels he may be taxed based on his level of production. In other countries, like Canada, production statistics are arrived at by a number of methodologies. In some areas, regional industries determine their production and report it en mass to the federal government. In other areas, the Provincial government receives information which it then forwards to the federal government. Individual producers may or may not identify their production to the federal government depending on the region in which they reside.

Where production reporting is mandatory, most production reporting is tied to site licensing and monitoring. With differences in the administration of site licensing and monitoring existing between countries and even between regions within a country, the potential for easily harmonizing the methodology for the gathering of production statistics is limited.

Most countries do not have a mechanism or requirement for acquiring or reporting consumption of commercial aquaculture feeds. Norway is an exception. This limitation however may not, for many analyses, be of critical importance. For farmers the cost of feed is critical to their ability to compete in the market place. Consequently, for all farmers viable commercial production depends on achieving the lowest currently feasible feed conversion ratio. Thus, for most farmers there is a narrow range of sustainable feed conversion efficiencies and this does not vary much from farm to farm. The surrogate of production itself can therefore be used in most analyses, as is done in the following discussion on sustainability of fish feeds as currently formulated. However, where direct monitoring of farm sites for sediment build up is not routine, it may be useful to be able to track feed consumption on a site-by-site basis to identify those sites which could possibly be affected by the substrate in an undesired manner.

5.2 Analysis of Sustainability of Feed for Aquaculture Production

Recently it was suggested that a contributing factor to the collapse of fisheries stocks worldwide was associated with the use of fishmeal in mariculture diets (Naylor *et al.*, 2000). The authors also state that with the increase in mariculture, ever increasing amounts of small pelagic fish would be caught for use in aquafeed. On the other hand, the amount of fishmeal and fish oil used for aquafeed was reported to be a small percentage of the total world production of fishmeal and fish oil (Tidwell and Allan, 2001). Also, with the advent of alternate sources of protein and lipid, as well as the utilization of discarded by-catch, the impact on capture fisheries may be insignificant. In this report, production data from FAO statistics[1] were used to identify production patterns for major mariculture products since the mid-1970s. The objective was to identify the impact of changes in the mariculture industry on production with special emphasis in the ICES area.

In this report, fish and crustaceans (generic term "fish" used in this document) include the following species: Atlantic salmon (*Salmo salar*), sea bass (*Dicentrarchus labrax*), seabream (*Sparus auratus*), shrimp (*Paeneus vannamei*), and turbot (*Scophthalmus maximus*). The production figures of these species are considered as one since aquafeed is used in their culture (Figure 5.2.1). Another major production group for mariculture is shellfish. The shellfish group includes the common edible cockle (*Cerastoderma edule*), Pacific cupped oyster (*Crassostrea gigas*), American cupped oyster (*Crassostrea virginica*), northern quahog (*Mercenaria mercenaria*), Mediterranean mussel (*Mytilus galloprovincialis*), blue mussel (*Mytilus edulis*), European flat oyster (*Ostrea edulis*) and Japanese carpet shell (*Ruditapes decussatus*). Shellfish production has been fairly constant and production has always been in excess of 500×10^3 metric tonnes (mt). On the other hand, the containment-based mariculture of fish in net pens, tanks and recirculating systems started to increase in the mid-1980s. The volumes of production for shellfish (833×10^3 mt) and finfish (737×10^3 mt) were very similar in 1998.

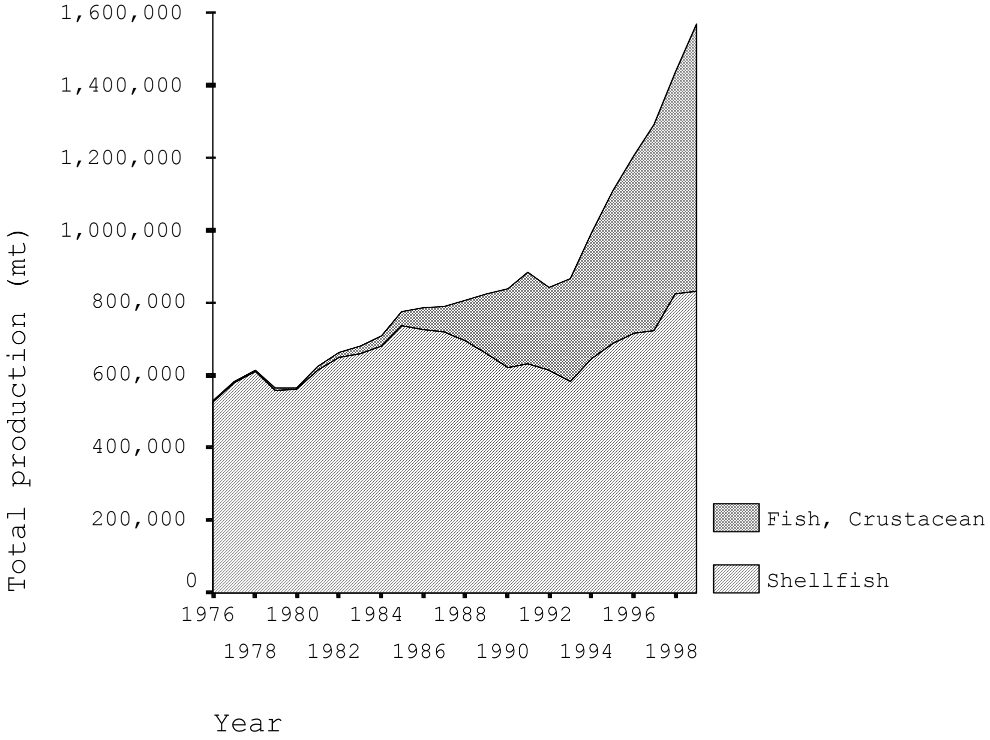


Figure 5.2.1. Total mariculture production (mt) in ICES Member Countries, as compiled from the statistical data of FAO.

The annual growth rates (AGR) in the total production of shellfish by mariculture is characterised by a sequence of ups and downs (Table 5.2.1), but there has been an increase of about 30 % over the last two decades. Blue mussel is the main product from shellfish mariculture (Figure 5.2.2), followed by Pacific oysters. The major blue mussel producing countries are Spain, the Netherlands, France and Germany (Table 5.2.2). The stable production observed may be due to market factors, production factors (environment), and/or regulatory constraints. Future growth may be slow due to limited availability of suitable sites; however, advances in large-scale offshore facilities may contribute significantly to the future growth of shellfish production.

---

[1] FAO, Fishstat plus 2.30.0020, data for Europe and North America: aquaculture production (1970–1999), commodities (1976–1999).

Table 5.2.1. Mariculture production and annual growth rate of production (AGR) in ICES Member Countries, as compiled from the statistical data of FAO. All values are given as metric tonnes (mt).

Year	Fish and crustacean production	%AGR	Shellfish production	%AGR
1976	1,651		527,906	-10.57
1977	2,277	37.92	580,678	10.00
1978	3,956	73.74	609,657	4.99
1979	4,967	25.56	558,729	-8.35
1980	5,054	1.75	560,225	0.27
1981	9,819	94.28	615,031	9.78
1982	13,304	35.49	648,660	5.47
1983	20,476	53.91	659,446	1.66
1984	27,173	32.71	679,872	3.10
1985	39,221	44.34	735,503	8.18
1986	60,195	53.48	726,776	-1.19
1987	68,944	14.53	720,199	-0.90
1988	112,052	62.53	695,379	-3.45
1989	165,837	48.00	658,607	-5.29
1990	217,123	30.93	620,434	-5.80
1991	252,350	16.22	630,234	1.58
1992	229,725	-8.97	612,536	-2.81
1993	283,581	23.44	582,623	-4.88
1994	348,893	23.03	644,587	10.64
1995	421,959	20.94	686,709	6.53
1996	492,350	16.68	715,896	4.25
1997	566,027	14.96	724,211	1.16
1998	610,827	7.91	824,451	13.84
1999	736,775	20.62	832,598	0.99

The growth of fish mariculture was more dramatic during the last two decades and the annual growth rate was greater than 50 % on several occasions. In contrast to shellfish production, a decrease in production for fish was observed only once, in 1992 (Table 5.2.1). Fish production has increased 55 times. By 1999 production reached 737 × 10^3 mt, and fish farming in the ICES area is now a significant consumer of aquafeed and, consequently, of fishmeal and fish oil.

Atlantic salmon (*S. salar*) currently dominates fish mariculture in the ICES countries (Figure 5.2.3). The 646 × 10^3 mt of Atlantic salmon that was produced in 1999 accounted for 90 % of the mariculture fish production in the ICES area. Two newcomers, sea bass (*D. labrax*) and seabream (*S. auratus*), produced between 37 × 10^3 and 48 × 10^3 mt per year. Whiteleg shrimp (*P. vannamei*), a newly cultured species since 1984, represents a minor industry (2 × 10^3 mt in 1999). Similarly, turbot (*Scophthalmus maximus*) was first cultured in 1984 and production for 1999 was 3.7 × 10^3 mt.

The annual growth rates for salmon production were consistently high and from 1995 to 1999 production increased on average by 15 % per year. It is unlikely that this trend will continue due to market constraints. In some regions, salmon mariculture will be limited by the availability of suitable sites (Scotland, Atlantic Canada). On the other hand, Norway and Pacific Canada have plenty of suitable sites that will allow for sustainable and environmentally acceptable expansion of net pen aquaculture. Cod (*Gadus morhua*), haddock (*Melangrammus anglefinus*) and Atlantic halibut (*Hippoglossus hippoglossus*) mariculture will certainly increase in the near future. Norway is likely to produce 15 × 10^3 – 20 × 10^3 mt of cod in the year 2005. This may add to the need for low-fat and high protein aquafeed. The development of alternative aquafeeds containing vegetable proteins may improve protein availability, especially if these diets are enriched with essential amino acids. In summary, salmon farming may show only moderate growth, while cod and other marine fish culture will certainly increase. For example, sea bass and seabream mariculture had annual growth rates for 1995 to 1999 of 25 % and 35 %, respectively. However, this increase was followed by a rapid decline in farm gate prices, similar to that observed previously with salmon. This suggests that growth in the culture of these two species will continue at a slower rate.

Table. 5.2.2. Mariculture production of blue mussels (*Mytilus edulis*) in ICES Member Countries, as compiled from the statistical data of FAO. All values are given as metric tonnes (mt).

Year	Canada	France	Germany	Ireland	Netherlands	Norway	Portugal	Spain	Sweden	United Kingdom
1970	100	32,500	9,600	3,500	86,000			150,000	200	
1971	200	30,900	5,600	4,600	95,700			140,000	100	
1972	200	34,600	8,100	5,200	116,200			154,500	<05	
1973	100	26,000	10,400	3,000	113,000			160,300	<05	
1974	78	27,727	15,860	3,465	98,719			166,000	58	
1975	98	48,374	17,042	3,652	112,126			160,000	32	
1976	81	36,385	22,692	3,971	73,310			177,500	42	
1977	75	46,644	11,154	3,501	109,328			183,000	30	
1978	118	45,061	11,760	3,018	118,485			224,000	45	
1979	40	56,482	3,422	2,939	97,414			194,000	41	
1980	190	67,128	10,760	4,558	76,972			192,000	39	
1981	178	74,761	10,566	4,658	109,448			200,000	557	
1982	192	66,989	16,967	5,282	130,271			210,000	1,548	
1983	244	56,583	31,634	5,739	119,643			213,000	1,580	
1984	876	49,289	59,311	13,717	60,149			230,000	1,278	1,003
1985	909	49,073	20,818	10,358	116,252			245,655	415	1,204
1986	2,062	52,959	29,939	10,575	85,896	170		246,995	325	1,561
1987	1,740	52,312	25,926	14,892	98,367	127		245,455	2,556	2,185
1988	2,045	45,762	29,725	12,648	77,596	87		243,010	858	2,124
1989	3,391	34,296	18,556	13,560	107,000	43		193,010	241	2,278
1990	3,598	46,642	20,237	18,380	98,845	77	1	173,300	1,163	2,044
1991	3,956	45,783	29,977	15,300	49,254		11	195,220	1,643	4,826
1992	4,877	47,423	50,800	13,822	51,223		61	138,910	1,353	3,880
1993	5,141	55,000	24,666	13,657	65,981		59	91,461	737	4,211
1994	6,866	48,413	4,868	12,967	104,952	542	136	142,687	2,095	4,017
1995	8,626	49,194	17,782	11,000	79,772	388	380	182,250	1,521	5,801
1996	9,832	49,962	38,028	14,500	94,496	184	136	188,462	1,821	8,347
1997	11,449	52,350	22,330	16,094	93,244	502	455	188,793	1,425	13,127
1998	14,920	50,800	31,213	19,096	113,185	267	310	261,062	455	8,956
1999	17,339	51,600	37,912	16,111	100,800	701	286	261,969	954	9,535

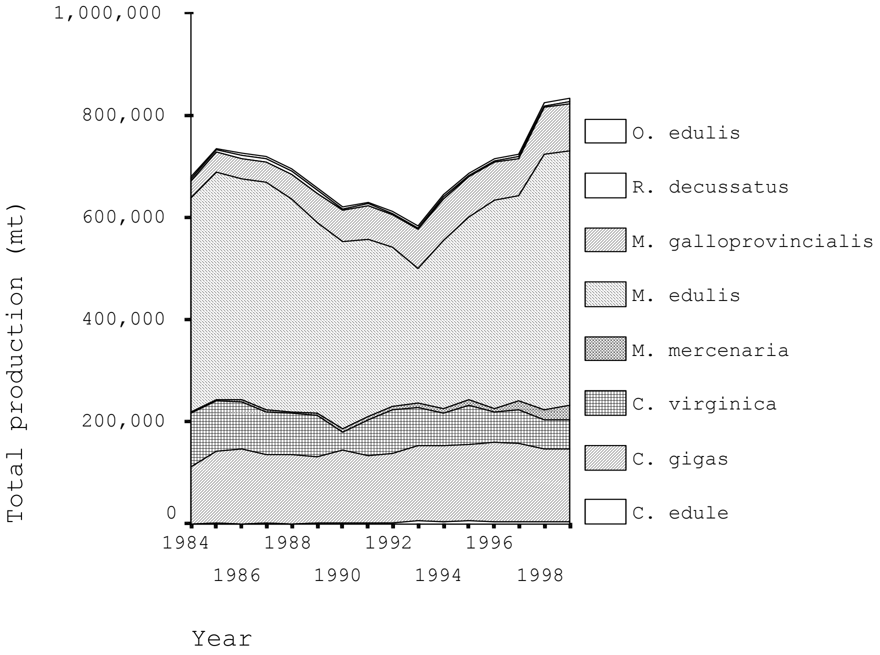


Figure 5.2.2. Shellfish mariculture production in ICES Member Countries as compiled from the statistical data of FAO.

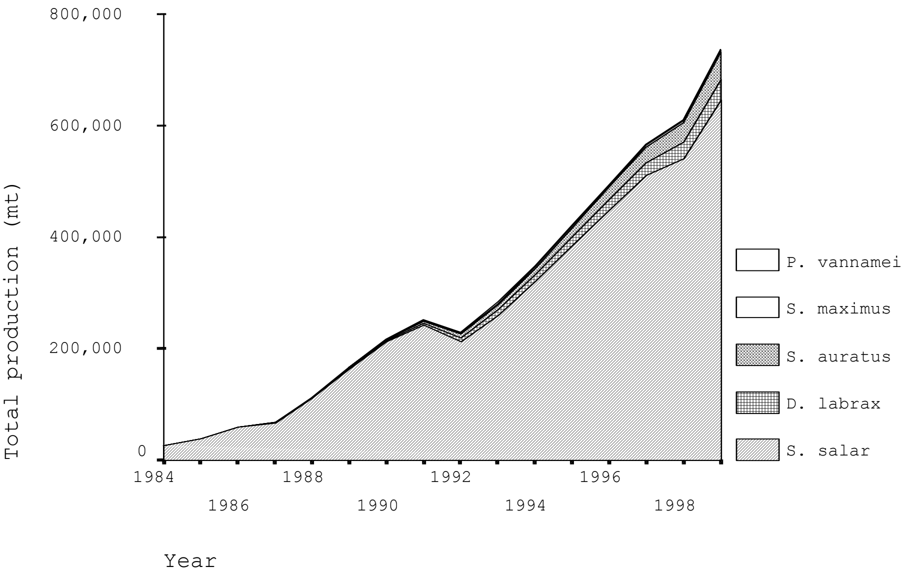


Figure 5.2.3. Fish and crustacean mariculture production in ICES Member Countries as compiled from the statistical data of FAO.

In conclusion, fish and crustacean mariculture in ICES Member Countries is dominated by species high in the food chain and has a strong dependence on the fishing sector that supplies high grade raw materials (marine fishmeal and fish oil) to the aquafeed industry.

The production figures for fish and crustacean mariculture were summarised for different species to estimate the use of fishmeal and fish oil by mariculture operations in the ICES area. Based on production data, the total amount of aquafeeds was calculated assuming FCRs[2] of 1.2, 1.8, 1.8, 1.8, and 2.0 for Atlantic salmon (*S. salar*), sea bass (*D.*

---

[2] Food Conversion Ratio.

labrax), seabream (*S. auratus*), turbot (*S. maximus*), and whiteleg shrimp (*P. vannamei*), respectively. Further, it was assumed that the diet is composed of 45 % fishmeal and 25 % fish oil for Atlantic salmon and 50 % fishmeal and 15 % fish oil for sea bass, seabream and turbot. The diet for shrimp was assumed to be 30 % fishmeal and 2 % fish oil. These assumptions were used to estimate the total amount of fishmeal and fish oil used in the culture of fish (Table 5.2.3).

Table 5.2.3. Mariculture production of fishes and crustaceans in ICES Member Countries: the estimated use of fishmeal and fish oil, and the percentage share of the total world production as reported by FAO in the commodities statistics.

	Total production of fish	**Total fish meal used**	**Total fish oil used**	**Total fish meal production in the world**	**% fishmeal in production of fish**	**Total fish oil productionin theworld**	**% fish oil in production of fish**
1976	1,651	892	495	3,601,544	0.02%	850,904	0.06%
1977	2,277	1,230	683	3,895,518	0.03%	835,474	0.08%
1978	3,956	2,136	1,187	3,738,156	0.06%	924,134	0.13%
1979	4,967	2,684	1,490	4,059,107	0.07%	973,848	0.15%
1980	5,054	2,735	1,516	4,143,475	0.07%	1,022,523	0.15%
1981	9,819	5,311	2,945	4,131,475	0.13%	983,684	0.30%
1982	13,304	7,201	3,990	4,538,703	0.16%	1,080,681	0.37%
1983	20,476	11,083	6,141	4,776,662	0.23%	1,076,912	0.57%
1984	27,173	14,727	8,107	5,393,912	0.27%	1,257,171	0.64%
1985	39,221	21,337	11,729	5,517,477	0.39%	1,195,375	0.98%
1986	60,195	32,796	17,877	5,580,315	0.59%	1,283,085	1.39%
1987	68,944	37,558	20,348	5,630,457	0.67%	1,219,158	1.67%
1988	112,052	60,952	33,324	5,791,982	1.05%	1,221,035	2.73%
1989	165,837	90,375	49,509	5,706,565	1.58%	1,221,995	4.05%
1990	217,123	118,808	64,777	5,417,877	2.19%	1,122,115	5.77%
1991	252,350	139,194	75,053	5,453,566	2.55%	1,142,994	6.57%
1992	229,725	129,619	67,944	5,125,032	2.53%	800,456	8.49%
1993	283,581	160,939	83,659	5,302,666	3.04%	830,314	10.08%
1994	348,893	198,023	103,356	5,992,290	3.30%	914,601	11.30%
1995	421,959	240,755	125,258	5,804,485	4.15%	909,315	13.77%
1996	492,350	281,535	146,068	6,157,244	4.57%	857,749	17.03%
1997	566,027	325,292	167,866	5,659,423	5.75%	741,643	22.63%
1998	610,827	354,743	180,663	4,963,820	7.15%	648,460	27.86%
1999	736,775	430,023	217,817	5,814,176	7.40%	724,523	30.06%

During the early development of mariculture, i.e., until 1985, only an insignificant amount of fishmeal and fish oil was used. Today almost 9 % of the fishmeal production and 40 % of the fish oil are used in the European and North American mariculture industry. However, even during periods of high annual growth rates in mariculture production, the increase in fishmeal and fish oil demand by the mariculture industry in Europe and North America is not reflected by an increase in total world production of fishmeal and fish oil (Figure 5.2.4). By 2010, the total requirement of fishmeal for mariculture is estimated to be 3.5 million tonnes, which would represent 60 % of the world production. The 1.2 million tonnes of fish oil required would be 92 % of the world production. These figures take into account some substitution of fishmeal and fish oil with vegetable sources. With the demand for fish oil for pharmaceutical/nutrimental products (up to 10 %), supplies will be barely adequate as 2010 approaches. This issue was discussed in the 2002 meeting of the Working Group on Marine Fish Culture. It was noted that consumers have concerns about food safety in general and about contaminants in fishmeal and fish oil. The high prices and the lack of opportunities to expand the capture fishery make it imperative that alternate protein and lipid sources be developed for use in aquafeeds.

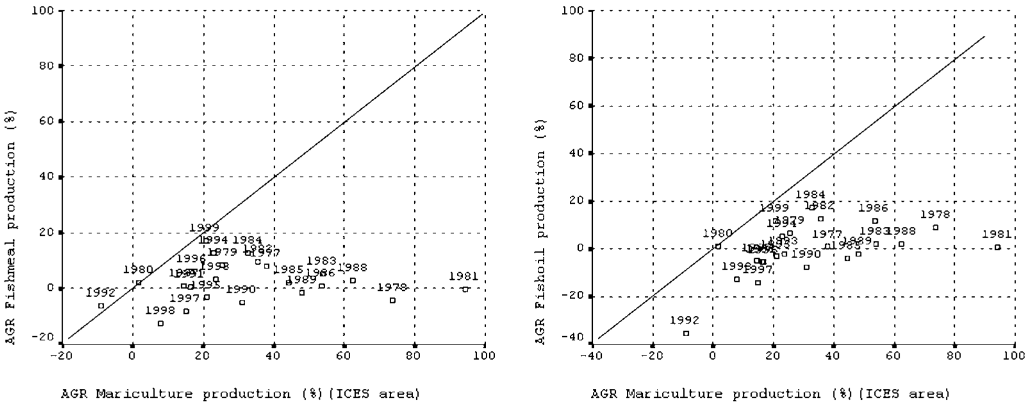


Figure 5.2.4. Annual growth rates for fishmeal production, fish oil production, and mariculture production in North America and Europe based on the statistical data of FAO.

5.3 References

Naylor, J. M., Goldberg, R. J., Primavera, H.J.H., Kautsky, N., Beveridge, M.C., Clay, J., Folk, C., Lubchenco, J. Mooney, H., and Troell, M. 2000. Effect of aquaculture on world fish supplies. Nature, 405(1): 17–1024.

Tidwell, J. H., and Allen, G. L. 2001. Maintaining and managing the wealth from the seas. EMBO Reports 21: 958–963.

6 REVIEW INFORMATION ON TECHNOLOGICAL CHANGES IN MARICULTURE, INCLUDING THE UTILIZATION OF NEW SPECIES, WITH PARTICULAR EMPHASIS ON THE CONSEQUENCES FOR PRODUCTION AND THE ENVIRONMENT

6.1 Introduction

Although traditional aquaculture has a long history on several continents, modern mariculture technology is relatively new. Innovations in aquaculture technology are driven by (i) economic forces, (ii) technology improvement, and (iii) biological constraints, but rarely by ecological issues, with the exception of those imposed by government to comply with new regulations. Recently, the industry has become more proactive by adopting various codes (Code of Practice, Code of Conduct) and global improvement strategies (e.g., the Chilean industry, which includes environmental certification). This section reports on technology and species changes at the production level that could occur within the next few years and impact on the environment.

6.2 Changes in Technology

The majority of European shellfish and finfish aquaculture is located in sheltered areas within two miles of shore. With increased tourism and urban uses, coupled with competition for aquaculture sites in environmentally complex coastal areas, it is understandable that there is a need to exploit the space differently. Changes are occurring in the ways described below.

6.2.1 Onshore controlled systems (finfish)

Status - The most promising system is the "Recirculating System" (ICES, 2000) to pre-grow and grow finfish that reuses wastewater. Many applications have been developed in the EU (France, UK, Germany, Italy) and North America for various species, including particle separation devices, ammonia oxidation into NO_3 biofilter design, bacterial load control, heat control, etc. (see descriptions in Waller, 2000). Scaling up these systems from laboratory to marine hatchery scale is under way in Europe (see National Report for France in this report). Initial studies are very promising economically for large facilities (Blancheton *et al.,* 2002) and they may be of interest globally.

Environmental aspects – Controlled systems have many advantages: lower water demands, limited space requirements, possible shift away from the sea front, reduced water discharge, predator exclusion, independence from external conditions, isolation from the natural environment, avoidance of escapees, improved biosecurity because of isolation from external contamination and possible water treatment at the outlet, and limited chemical use.

These systems have no environmental constraints although they require high capital investment and are energy demanding. The present technology concentrates effluents, but does not remove all the nitrogen (to transform NO_3 into gaseous N_2 is energy consuming), and they are released nearshore undiluted. The transformation of soluble compounds into particulate matter demands space (e.g., treatment through algae pond in a secondary loop), and solids, in the form of sludge, have to be disposed of on land. Phosphates and heavy metals accumulate in this system and are difficult to remove, limiting the use of this organic material for crops (Moretti, 2001) until new specific feed has been developed.

Pre-growing shellfish using groundwater was developed in western France (see National Report for France in this report). The major impacts are concerned with the use of non-renewable fossil water, the loading of nutrients and phytoplankton in the area, and the thermal discharge at the outlet.

6.2.2 Offshore systems

Sea cages

Status – While carrying capacity is at present not the limiting factor in some countries involved in coastal cage farming, this is certainly the case in others. A driving force towards moving to more exposed or even offshore sites is due to the fact that there are increasing pressures on coastal habitats from many resource users, making site acquisition for mariculture development increasingly difficult. Offshore space for mariculture expansion appears to be unlimited to many in the industry. There are, however, a number of other constraints that require a long lead-time and large-scale investment in R&D before truly offshore systems become a routine business. Very few commercial-scale offshore developments have occurred so far. High cost of both the system purchase and its operation are critical factors. World-wide, there is a tendency towards larger production unit sizes and at a gradually increasing distance from the shore. The present trend is towards more exposed sites rather than to truly offshore systems. The main reasons for such gradual exploration of more exposed waters rather than open-ocean waters are that operating and infrastructure costs as well as the infrastructure support systems are similar to existing inshore farming systems. The initial investment costs may even be similar to those presently encountered for re-circulating systems. Pilot-scale experiments and commercial operation for more exposed cage systems developed out of conventional cages through step-by-step enlargement and structural improvements have been reported from Ireland, Norway and Italy. Tuna farming in Spain rears large fish (> 50 kg). Attempts to use submersible cages there have been successful.

There are a number of reasons for moving to offshore sites. It is claimed that such operations mitigate environmental effects otherwise encountered inshore with units at identical scale. Species-specific requirements may also lead to the development of offshore systems. For example, tuna farming requires large systems and these occupy large spaces often not easily available inshore, and therefore they must move further offshore. Tuna farming has been reported to be successful in Spain. It involves large fish (> 50 kg) and during the cultivation process little intervention is practised except for harvesting. Some recent attempts to utilise submersible cages have been technically successful and are under further development, including free-drifting (non-moored) systems. For such systems, vast areas must be allocated exclusively for the operation to allow back and forth (controlled) drifting with currents. Temporary submersion allows the position of the cages in the water body top be adjusted so as to position the cages in water bodies which move in the opposite direction of the surface currents, thereby returning the cage to their point of original placement.

Although numerous new opportunities seem to arise for offshore sea cage farming, a new set of constraints occurs, which are not at all encountered by nearshore sea cages: (a) the minimum size for juvenile fish to be stocked in such systems may be much larger than for inshore cages, (b) rearing constraints may stem from the need for much more sophisticated technology as to sorting, handling and harvesting of the fish, and (c) construction materials and operational procedures may have to take into account the species-specific behavioural requirements and peculiarities, adding to operational costs (e.g., maintenance issues, weather conditions and material resistance, better surveillance techniques and remote control of feeding).

Environmental aspects – Open sea farming encounters very different hydrodynamics, providing much better water exchange within cages and also much improved and rapid dispersion of wastes. In that sense, qualitative impacts from offshore fish farming on the water body would be much more diffuse and negligible considering the vast areas involved. However, considering the immediate vicinity of the water mass around cages, the environmental load is likely to be qualitatively and quantitatively equivalent to other cage farming systems. The real difference between offshore versus inshore systems relates to reduced benthic deposition, with the actual benthic loading so small that measurable differences in terms of biodiversity indices may not be detectable. The local impacts near inshore cage farming systems have been well documented in shallow water (0–20 metre depth) and are reported to vary with the environmental conditions (temperature, substrate, light, hydrodynamic regime). Studies on faecal pellet deposition in deep sea show a low rate of mineralization. It is debatable whether specific studies on the impact of offshore farming on the benthos in very deep waters need to be addressed.

Another potential impact would come from the FAD ("Fish Attracting Devices") effect of cage structures. Offshore cages can induce a positive effect by decreasing particulate organic matter that is consumed by wild fish accompanying the cages, or a negative one by modifying the behaviour of pelagic fish and inducing consequent changes in biological conditions such as predatory pressure. Positive effects of mussel offshore longline cultivation on fish nursery grounds by increasing polychaete biomass and their availability as food for imported commercial species have been reported (Tenore *et al.*, 1982). However, oxygen depletion and increased turbidity within the culture system may induce stress to the fish. Being far from the shore, the offshore structures need land-based support systems (for cleaning, maintenance, stocking the food) and in this respect they are no different from nearshore conventional cage farming systems, leading to similar environmental considerations. The high priority R&D needs for the appropriate future development of offshore farming systems are summarised in the recommendations of this report. (N.B.: some offshore mussel farming for longline operations is under development in southern France. This development is threatened by heavy predation by seabream. This is an original example of environmental impact because those stocks did not exist before.)

Further areas of high priority are summarised in the Recommendations section of this report.

Sea Ranching and Stock Enhancement

Status - These techniques have been used successfully with both exotic and native shellfish in marine environments. Species that have reached commercial level include scallops (*Pecten maximus*) in France, lobster (*Homarus americanus*) in Canada, and Atlantic salmon in Iceland. In the case of lobster, restocking was stopped due to improved stock management and better natural recruitment. In Iceland, Atlantic salmon restocking ceased due to poor economic return. Very few attempts at marine fish restocking programmes have occurred (Hansson *et al.*, 1997). The most successful programmes involve red seabream (*Pagrus major*) stocking in Japan, where a number of hatcheries at strategically important points within the Seto Inland Sea are operated cooperatively, supporting local stocks up to year-class two when fish are still largely non-migratory. To be successful, restocking programmes for marine species require preliminary studies in the following areas: resistance to the local flora and fauna, trophic compatibility, releasing strategies, tagging and capture methodology.

Environmental aspects – Most information on environmental impacts from population enhancement is theoretical. The major predictable environmental impacts are genetic aspects (see below) and trophic competition between wild and cultured populations within a given carrying capacity. There may be an effect of artificial reefs and wind farms (WGEIM Report 1999) on the natural carrying capacity of an area. Coupling artificial reefs with offshore sea cages may have positive effects by accelerating organic matter processing, decreasing the benthic impacts and increasing wild fish populations, as observed in the bay of Eilat (Rosenthal, pers. comm.). A beneficial effect has been reported by Hansson *et al.* (1997) regarding pikeperch (*Stizostedion lucioperca*) stocking in the Baltic on the functioning of the ecosystem despite the very high fishing pressure. Several stock enhancement programmes for marine benthic fish populations are presently under scientific investigation and test trials are under way along the coasts of some New England States of the U.S. The results remain to be evaluated in the years to come.

6.2.3 Integrated systems

Status - Integration of mariculture into a managed mix of coastal resources use can be envisaged in several ways. One approach is at the biological level through co-culture between species, including fish and/or shellfish and/or micro/macro algae, and in various combinations of species at different trophic levels. Another option is to combine various mariculture technologies, for example, onshore culture systems (e.g., flow-through or recirculation systems) to produce either juveniles and/or market-sized fish (most likely medium-sized specimens for specific markets) in conjunction with nearshore or offshore sea cages for on-growing and fattening to much larger-sized products which can target different markets (vertical integration).

Attempts to decrease the potential impact of fish farming by linking fish farm effluents (e.g., rearing turbot or sea bass) with polishing pond operation in order to produce phytoplankton used to feed oysters downstream have proved to be an interesting concept, however, the management and economic constraints incurred still require improvement. The GENESIS demonstration project is aimed at associating sea bass production with cupped oyster and *Salicornia* culture units in a partially recirculating system, including sedimentation ponds, foam separation and phytoplankton production, in order to convert and recapture released nutrients and organic material. It may also include secondary and/or tertiary system loops to assimilate as much of the energy in terms of nutrients and wastes as possible.

Environmental aspects – These systems have several advantages: they reduce nutrient releases (through consumption by algae) and particulate organic content of the effluent (through sedimentation ponds and consumption by filter feeders); they decrease the energy and water requirements by reusing water; they increase the global feed conversion efficiency of the whole system; they participate in reducing soil erosion, and allow the preservation of lands that would have been lost (ancient salt marshes).

Environmental constraints are also imposed: by demanding space (100 to 350 m^2 of *Ulvae* per tonne of fish produced, up to 2500 m^2 of diatoms plus oyster plus artificial wetland in the GENESIS project) and they may modify the visual aesthetics. Algae produced are enhanced by the addition of silicate, for diatom production, which is released to the environment instead of nutrients. Settled organic matter and mud utilisations remain problematic. In some areas, pond aquaculture is reported to have increased the salinity of underground freshwater. Converting natural wetlands or salt ponds to aquaculture may impact on wild bird populations (Beveridge, 2001).

6.3 Technological Improvements

Within the existing system, technological improvements have occurred regularly. It is beyond the scope of this report to review them all. Recently the quality of the final product and ethical questions (ecological labelling, animal welfare) have been of concern; consequently, some technological changes have been directed towards addressing these.

6.3.1 Floating cage technology and practice

There are few significant technological improvements to report. Better estimates of standing biomass by using acoustic estimation have been tested to improve feeding ratios, but they are not available on the market. Globally, better husbandry, including improved handling and transportation, has decreased mortality and improved the health of reared fish.

In Norway, better netting and mooring, predator control, as well as improved fish handling practices, have decreased the number of escapees per tonne of fish produced from 4 to less than one from 1993 to 2000 (i.e., an overall 20×10^6 rainbow trout and Atlantic salmon during year 2000).

Opportunities for establishing new marine sites for salmon farming are becoming more difficult to find in some countries (e.g., in Scotland, France). Production continues to increase, but this is mainly through expansion at existing sites rather than development of new sites. In most cases, salmon sites are currently located in sheltered or semi-sheltered sites in sea lochs and similar inlets. The more open coast has been considered too exposed for cages of normal design. In the past year, several small (100 tonnes) experimental sites have been established in exposed locations in Shetland. These sites use cone-shaped nets, with surface flotation collars. The cones are heavily weighted, which keeps the netting under tension. Preliminary observations indicate that these cages are resistant to the weather and wave conditions found at these more exposed conditions. If these cages prove economically successful, they could open considerable new areas of coastal waters to salmon cultivation.

Antifouling compounds provide the classic example of a chemical associated with construction materials that can have profound effects on both the cultured animal and the surrounding indigenous biota. Tributyltin (TBT) compounds are the classical example. It was subsequently shown to cause reproductive failure or growth abnormalities in molluscs and has a high toxicity to many other forms of marine life. The use of TBT in aquaculture is now prohibited, and the International Maritime Organization has prohibited the application of TBT paints to large vessels after 2003.

Currently, various approaches are taken to control fouling on marine fish cages. Frequent replacement of fouled nets is always an option. In some cases, mechanical cleaning can be undertaken, or nets can be partially raised to allow fouling communities to desiccate and die. However, many farms now use copper-based antifouling preparations on nets, in some cases with the addition of booster organic biocides such as dichlofluanid and 2,4,5,6-tetrachloro isophthalonitrile. These give rise to new environmental concerns from the elevated concentrations of copper found in sediments around these farms, and the potential for both the copper and booster compounds to inhibit primary production in the surrounding waters. Antifouling compounds are considered as biocides and, therefore, fall under the EU Biocides Directive.

6.3.2 Feed and feeding

Status - Currently, no progress has been made on artificial feeding of filter feeders. Efforts have focused on decreasing the cost of feed for finfish by better understanding fish nutritional requirements. Technically and biologically, it is feasible to replace 50 % of salmonid fishmeal with plant material. Increased demand from aquaculture production has increased the demand for replacement of fish protein and fish oils with plant substitutes (see also Section 5 of this report). At present, any reduction in their use occurs solely as a result of market prices for these products relative to that of fishmeals. Replacing protein by fat as the energy source in fish feed does not alleviate the problem as it increases the demand for fish oil, the supply of which is more limited than is fishmeal protein. This is because fish oil substitutes generally lack some of the essential poly-unsaturated fatty acids (see also Section 6 of this report) required for good fish nutrition. The presence of PCBs and dioxins in fish oils (and consequently in fishmeals) is also of concern to the feed industry. Replacing *Artemia* with artificial pellets as feed for larvae is currently under development and will affect the supply of *Artemia*.

Major issues concerning aquaculture sustainability (Hasan, 2001) include: the availability and cost of feed resources, the development of aquafeeds, the competition for resources with other users (e.g., livestock production), forecasting the global supply and demand, and the reduction of the potential environmental impact.

Environmental aspects - Fish metabolism is highly dependent on food characteristics and the metabolic loadings from fish farms. The consequent environmental impact of fish feeding varies depending on these aspects. Documented effects of nutrient and organic loadings can be classified as follows:

- Local impact: organic content and sediment particle size in relation to the benthos can possibly lead to oxygen depletion, etc. Through fallowing, it is possible to increase recovery mineralisation turn-over by bacteria (the same strains used in bacterial filtration). This is subject to ongoing investigations (EU BIOFAQ project).
- Large-scale impact: eutrophication due to nutrient release (ammonia, phosphate, CO_2), plankton response, wild fish population response. Polyculture, associating shellfish and algae culture with fish culture, may be a part of the solution.
- Global impact: use of natural resources at a high level in the food chain, and of fossil energy (pumping, processing). Research is ongoing in Norway to replace these resources with resources from lower down on the food chain (zooplankton, krill).

Considerable improvements have occurred in the salmon industry over the last ten years to decrease metabolic outputs (i.e., uneaten pellets, faeces from un-digestible fraction, ammonia, phosphate). This has been achieved through a better understanding of metabolic requirements of fish, cyclical nature of fish appetites, modification of feed requirements with fish age, environmental conditions, physiology, improving feed distribution devices (reward/demand system), improvement of rearing conditions to improve FCR (e.g., in the Norwegian salmon industry it decreased from 1.5 to 1.1 in the last ten years), analysis of the actual digestibility (for organic matter, protein and phosphorus) of foodstuff and use of enzymes to improve it (e.g., phytase in case of plant phosphorus), pre-treatment of feed ingredients to improve their availability (e.g., pre-cooked starch, low temperature fishmeal), evaluating the energy to protein ratio, determining the level of protein sparing effect by fat (i.e., decreasing nitrogen content of feed), the amino acid balance, and micro-nutrient requirements (vitamins, heavy metals), decreasing the phosphorus content of feed (e.g., decreases from 1.5 to 0.7 in salmon feed in Scotland), and genetic improvement for feed efficiency (Dosdat, 2001). Further attention is needed on the digestibility of plant foodstuff in order to support the future levels of production.

These improvements will need to be adapted to emerging and new species. FCRs are still very high in sea bass farming in Greece, amounting 2.0 on average, when values of 1.2 have been observed at experimental scale (Dosdat, personal communication).

6.3.3 Genetics

All new developments in genetics will not be reviewed in this report (see 2001 report by WGAGFM). There are four different methods and tools: (i) genetic selection, (ii) polyploidy and gynogenesis, (iii) sex manipulation and hybridisation, and (iv) gene transfer. Those techniques are available for both fish and shellfish.

Status - (i) Concerning genetic selection, less than 1 % of aquaculture production is based on genetically improved strains. Genetic selection and improvement are the major tools used to obtain the economic sustainability of the aquaculture sector (competing with other animal production sectors). Its basis is the genetic variation (biodiversity) of a single species, and selection within that variability to promote interesting/useful characters. Domestication results in lower diversity and loss of genes. Selection is primarily for body weight and growth (salmonids, trout, sea bass, seabream, cupped oyster), resistance to disease (Furunculosis and IPN in salmonids, *Bonamia* in flat oyster, sealice in Atlantic salmon). More recently, flesh quality and yield indexes have been integrated into selection processes. Sometimes, undesired correlated responses may appear (e.g., decreased diseases resistance when selecting for body weight).

(ii) Polyploidy (triploidy) is widely used to obtain sterile progenies that allow diversion of energy from gonadic to somatic growth and ensure a constant quality of the flesh. It has been applied commercially to culture of rainbow trout and Pacific oysters (using a cross-breeding between tetraploids and diploids) and on a pilot scale with sea bass and Atlantic salmon. Experimentally gynogenetic fish have been produced using the same techniques for the creation of homogeneous and cloned populations.

(iii) Sex manipulation techniques are used to produce sexual dimorphic characteristics. It is used mainly on rainbow trout, for the creation of all female populations.

(iv) Molecular genetics for marine species is still in its infancy and very few of these techniques have been applied on an industrial scale. Salmon that are transgenic for a growth hormone allele are being produced at a pilot scale in Canada. Work is under way to investigate the effects that these gene constructs might have on other heritable traits.

Environmental aspects – In contrast to other farmed animals, domesticated fish have wild conspecifics with which they can easily reproduce. The impact of domesticated strains, hybrids, or genetically engineered fish on genetic variation, population numbers and fitness of conspecifics is under debate. Little scientific research exists on these interactions (cf. Recommendation in this report). It is known that farmed species can interbreed (even in the case of triploid production, e.g., oyster) with other species under open-culture systems. From a genetic and environmental point of view, a genetically improved species or strain (including GMO fish) is considered to be analogous to an exotic strain. With respect to escapees, three scenarios specific to genetic issues are likely (Dunham *et al.*, 2001):

- **Adding or reducing genetic diversity, and introducing novel genotypes**. Potential significant negative effects include increased vulnerability to environmental changes and decreased production and fitness of wild populations. In some cases (e.g., when over-fishing of wild stocks selects against size and reduces variability), artificial genetic diversity could increase fitness in endangered species. Introgression levels have been modelled (Kanaiwa and Harada, 2000) and seem to rapidly stabilise depending on the number of escapees on an annual basis, their reproductive fitness and sex ratio.
- **Replacement of wild populations.** The long-term survival of a population of escapees required to replace the wild population seems unlikely in the marine environment, given the available space, the discontinuous flow of accidental escapement, and the low survival rate of escapees (see 1999 report of the WG on North Atlantic Salmon). Very low occurrence of escaped Atlantic salmon has been reported in eastern Canada (0–1 %; WGNAS, pers. comm.). Nevertheless, Atlantic salmon escapees in some rivers in Norway outnumber wild salmon and there is a risk of threatening wild populations even if escapees have a lower reproductive fitness. It is assumed that interactions would be more pronounced for salmon than for sea bass or seabream.
- **Co-existence of escapees with no interbreeding.** This is the case in Western Canada and Chile, where Atlantic salmon are breeding in small numbers. In Chile, where the numbers are much higher than in Western Canada, local fisheries are reported to control escapee expansion (Sotto *et al.*, 2001). The presence of escapees, however, may alter predation pressure on wild stocks, increase competition for feeding resources with wild conspecifics, affect reproductive behaviour (e.g., sterile fish minimizing reproductive features), transfer pathogens, or establish a new population in ecosystems outside their natural range. In some cases (e.g., sea bass), gametes can be released from the rearing unit.

Genetic impacts on local endemic populations can be controlled or avoided by: improved physical containment for all life stages (e.g., improved netting and mooring, use of recirculation technology); improved husbandry practices during fish transfer and sorting (i.e., use of Code of Practice such as the one developed by NASCO and the International Salmon Farmers Association as well as the requirement for an escape contingency plan as part of the consenting of all new and modified farm developments in Canada and Scotland); developing techniques for escapee recovery; use of sterile fish (triploids); use local stock or population, particularly for new species; and maintaining high numbers of wild fish in the production areas.

6.3.4 Animal health technologies

Status - Increased fish disease transfers may occur as a result of hatchery development (fish and shellfish), where broodstock are recruited from the wild, and juveniles or broodstock are moved between the hatchery and on-growing sites. In addition, the ornamental fish trade has played a significant role in spreading disease (see the review by Blanc, 2001). This is of particular concern, as a disease tends to spread rapidly in areas where wild fish have not been previously exposed to the disease.

Diseases are classified into two groups – Infectious diseases are broadly divided into those that are known by the OIE (Office International des Epizooties) and considered to have socio-economic or public health importance. These must be declared and reported annually. New or emerging local diseases are generally treated as a farm management issue and are not reported.

Non-infectious diseases are also important. They are usually the result of bad husbandry management, bad water quality, inappropriate feeding and nutrition, exposure to pollutants, or self-pollution, and require more focus on the animals' nutritional and containment conditions.

Fighting pathogens includes the use of both preventive/prophylactic and medicinal tools. Very powerful diagnostic techniques, based on immunological and molecular tools, have been developed recently. They still remain costly, technically complex and are some times difficult to interpret (PCR evidence may, at times, be misleading unless combined with other evidence in determining the health status of a population). Diagnostic kits need to be improved to increase their relevance. Under regulatory incentives and constraints, "disease-free zones" are being defined and better communication of fish disease status is occurring. A number of new vaccines have been developed in recent years (against Furunculosis, vibriosis, cold-water vibriosis, yersiniosis, IHN, VHS, VNN, etc.). Vaccines for viruses are still experimental and require further field validation. A significant benefit of the development of vaccines can be seen in the Norwegian salmon farming industry, where there has been a dramatic decrease in the use of antibiotics since the start of extensive use of the use of cold-water vibriosis and furunculosis vaccines in 1993.

The use of chemicals against parasites and bacterial infections occurs primarily in fish farming. Numerous chemicals are available (see *ICES Cooperative Research Report* "Chemicals used in mariculture" by I. Davies *et al.*, 2002, in draft). Effective chemotheraputant sealice treatment remains a necessity for salmon farming; however, other uses of chemotheraputants is generally a sign of poor husbandry. For years, sealice infestations have been the most significant fish health problem in salmon farming. An important development over the last 2–3 years has been the increased availability of alternatives to the "traditional" treatments by dichlorvos or hydrogen peroxide (and, in limited circumstances, ivermectin). Bath treatments now employ cypermethrin or azamethiphos as active ingredients. Possibly more significantly, in-feed treatments containing teflubezuron and emamectin are becoming increasingly popular in the industry. These compounds offer the prospect of improved efficacy and greater ease of treatment. In turn, this raises the possibility of more strategic approaches being taken to parasite control. Better knowledge about the biology of reared animals and of the rearing system has proved to be a very efficient tool for disease occurrence prevention, and reduction of the use of chemicals. Chemotherapy has value in preventing and controlling animal diseases, but must be utilised as the last means to prevent epizooty.

<u>Environmental aspects</u> – The bulk of the reported environmental effects concern the impact of chemicals (parasiticides, anti-bacterials, anti-fungals) on endemic fauna. The major impact of antibiotics is on benthos, given the very low intake and digestibility of the products that are usually given in feed. Strains of benthic bacteria resistant to various antibiotics have been reported and associated with bacterial changes on the benthos (i.e., modifying the mineralisation process). Residues or by-products may remain for a long time in the environment as well as in the fish tissues (see also Section 10 of this Report and the Cooperative Research Report on "Chemicals used in mariculture"). These chemicals currently must be submitted for government authorisation. That process typically includes an evaluation of their effects on specified species. The number of these chemicals has increased over time but the registration process has also tended to increase the cost of the product. In consequence of that, very few new products have been put into use these last few years. While this causes some concern about our ability to control disease outbreaks should they occur, vaccines and improved husbandry methods have reduced these outbreaks and, thus, chemotheraputant use is gradually decreasing in ICES Member Countries.

Sealice treatment remains the single most common health-related issue in salmonid aquaculture. Almost all the product is released into the water environment as most treatments are done using baths (oral treatments are less efficient). However, the range of therapeutic and husbandry strategies that are now available may provide the necessary combination of efficacy and flexibility to allow a significant step forward in controlling sealice.

The other major impact is spreading disease. Around 100 new disease occurrences have been reported in Europe (Blanc, 2001) over the decades. *Gyrodactylus,* a viral gill disease, is an example, which began with the introduction of foreign stocks of the Pacific oyster *(Crassostrea gigas)* that destroyed the Portuguese oyster (*Crassotrea angulata)* stocks in Europe. The occurrence of Viral Nervous Necrosis (*Nodavirus*) in sea bass is suspected to be due to uncontrolled juvenile transfer. Additional regulation on live fish transport is important and Specific Pathogen Free seed from the hatchery (see the national Report for France) should be encouraged. In case of Nodavirus, modifications made in the farming processes decreased mortality. Land-based farms and hatcheries have wastewater treatment at the outlet and the inlet and it is possible to avoid disease transmissions. This opens the door to the concept of biosecurity that can decrease use of chemical treatments and disease transmission.

6.3.5 Current status in the development of new species

Marine finfish and shellfish aquaculture is based on a very small number of species and there is interest worldwide in increasing the number of domesticated species. The species that are presently reared very often have been selected for biological/economic reasons (e.g., egg size, growth rate) that may be difficult to agree with the ecological constraints of sustainability. Very few projects have been designed to go through a sound selection process based on a multi-criteria analysis, including variable weight. Canada (Le François *et al.*, 2000) and France (Quemener *et al.*, 2002) have tentatively evaluated the potential of a variety of marine species based on biology and market demand and have concluded that there is limited knowledge on which to base our selection of species for development. Cod appears to be the most promising species and, surprisingly, tope shark (*Galeorhinus galeus*). Further research is still needed to confirm their potential. For a complete list see also WGMAFC 2002 Report.

Fish

Sole (*Solea solea*)

Culture trials for restocking has been done in Belgium. The project (1999–2001) assessed the feasibility of restocking sole in Belgian coastal waters, an important species in the Belgian fisheries. The project involved conditioning broodstock; collecting gametes and egg incubation; rearing larvae to metamorphosis; rearing juveniles; conditioning of juveniles to natural conditions; tagging and release of juveniles and processing recapture data.

Tuna (*Thunnus thynnus*)

Bluefin tuna (BFT) farming began in the 1970s in Japan and Canada and in the 1990s in Spain. It was based on catching BFT in the wild and growing them in large cages located offshore. Since the late 1980s, BFT farming has spread to other parts of the world - the Mediterranean (Spain, Croatia, Morocco, Malta), Portugal, Mexico, Panama, and Australia. Spain sold 10000 tonnes in 2001 with a net production of 2000 tonnes. However, some farming was stopped because BFT were not available, rearing knowledge was limited and there was a shortage in financial funding.

A networking group has been established under the support of the EU (DOTT project, see also web site http://193.187.190/thunnus/). Its objective is to lay the foundation for cooperative research and development and basic and applied scientific disciplines to domesticate tuna. An R&D plan will define the needs for establishing a long-term and sustainable farming industry. The major environmental constraints come from the unknown trophic impacts from metabolic wastes and uneaten fish (FCR is around 30 in this species), the impact on the trash fish fishery to supply feed (no artificial feed is available), and the effect on fishery and fishing effort on wild tuna juveniles.

Cod (*Gadus morhua*)

The high prices for cod has led to a high fishing intensity for several decades. As a result, the main stocks are overexploited, and it will take years of strict regulations and reduced catches to rebuild them. There will, therefore, be a demand for cod in the market, and this demand can only be met with cultivated fish.

Fry production

Based on early fry production trials in Arendal, Norway in the 1970s, the first attempts at large-scale fry production started in the late 1980s. These were macrocosm experiments where cod larvae were placed in enclosed natural systems with natural plankton as starter feed. Production increased steadily and reached a peak of 600,000 fry in 1989, but as critical factors were not controlled, production was seasonal and unpredictable. Norway has a high priority to develop intensive fry production and methods similar to those used in the production of sea bass and seabream are being adapted, including light manipulation of the broodstock. In 2001 about 1 million fry were produced in Norway, and according to the prognosis, a production of 50–60 million cod fry per year is expected in five years.

Grow-out production

The grow-out production of cod uses net cages developed for the production of rainbow trout and salmon. Cod feed must be leaner compared to salmon feed, with a higher protein content. Feed producers are planning to produce cod feed. Competition for cheap, raw protein material is to be expected between cod and salmon feed production.

The grow-out production in 2001 was based on the fry generated in 1999 and reached about 300 tonnes in Norway. An increase in production is expected to reach 1500 tonnes in 2002 and 10,000 tonnes in 2005. This raises important issues concerning feed quality, market, siting, genetics and diseases.

A current expansion is reported for cod in Scotland, which produced 5 tonnes in 2000 and 189 tonnes in 2001. In Canada, the first commercial operation is expected in 2002.

Haddock (*Melanogrammus aeglefinus*)

Initial experiments for culturing haddock have been promising and research will continue. Main topics will be to prevent early maturation and to develop a larger liver.

In Canada, the first commercial operation will produce fish in 2002, after mastering the haddock reproduction cycle. In Norway, the main stocks of haddock are low as they are for cod, but the price of the fish is high. The losses due to vibriosis at early stages have been high, and vaccines are being developed.

Halibut (*Hippoglossus hippoglossus*)

The scaling-up of halibut culture has been hampered by the difficulty in producing fry. Two methods of fry production are used: semi-intensive and intensive. In the latter, the larvae are kept in smaller units under controlled conditions and production is independent of the season. In 2001 about 450,000 fry were produced in Norway, 90 % by the intensive method. Problems initially experienced with viral infections (VER and IPN) have been reduced, partly as a result of improved water quality, and fry production is increasing.

The objective for grow-out production is to harvest 5-kg fish 30 months after hatching. This has not yet been achieved for groups of fish, although it is being reached for individual fish. Reasons for depressed growth for groups of fish include poor quality of fry, sub-optimal temperature and environmental conditions, and early maturation of males.

On-growing halibut farms should be located in areas with relatively high winter temperatures and low summer temperatures (< 15 °C). As the fish need bottom area rather than volume of water, the biomass per area will be less than in salmon farms. It is thus possible that halibut farms can be located at sites with less holding capacity than salmon farms. In 2000 Norway harvested a little over 400 tonnes of halibut, a small decrease from 1999. A manual for halibut cultivation, which covers all aspects of halibut cultivation, is available in Norwegian on the Internet (http://www.imr.no/kveite/).

Halibut culture in Scotland produced 16 tonnes in 2000 and 41 tonnes in 2001.

Meagre (*Argyrosomus regghius*)

This new species has been reported in the Mediterranean Sea, but resides predominantly in the Atlantic. It is being developed in the French Mediterranean, where a pilot scale project at a French private hatchery has developed the technology to produce fry (150,000 in 2000). It is a very promising species with interesting biological features, that can be reared in the same sea cages as sea bass and seabream. A Demonstration Project supported by the EU will be launched in 2002 to design and build a hatchery dedicated to this species. Major problems remain in broodstock conditioning, management, and in control of reproduction.

Fish Species Under Development

Attempts are under way to develop a variety species for aquaculture: wreck fish (*Polyprion americanus*), red mullet (*Mullus barbatus*), cod (*Gadus morhua*), pollack (*Pollachius pollachius*) and red drum (*Scianops ocellatus*) in France, lemon sole (*Microstomus kitt*), lumpsucker (*Cyclopterus lumpus*), and haddock (*Melanogrammus aeglefinus*) in Scotland, wolffish (*Anarhicas* sp.) in Norway, and winter flounder (*Pseudopleuronectes americanus*) in Canada. Some sparids (*Dentex dentex, Pagrus pagrus, Puntazzo puntazzo)* are being cultivated in the Mediterranean region, from egg to egg, while attempts to raise amberjack (*Seriola dumerili*) from wild juveniles and groupers have been made in Italy (CIHEAM, 1999). Investigations are concerned with reproductive potential of captive broodstock and initial larval development. Concerns about wild fish utilisation or importation of broodstock may limit the feasibility of the developments.

Shellfish And Others

Scallop (*Pecten maximus*)

From 1982 to 1998, a programme was developed in Brittany to maintain and support the scallop fishery in the Bay of Brest, where wild scallop stocks had declined dramatically. Stock enhancement was used to restore this traditional fishery. The minimum size for scallops used for stock enhancement as hatchery spat was determined to be 30 mm, and juvenile scallops were spread on the bottom in an allocated site in order to sustain the feral breeding population. Increased wild spat production will sustain the adult fishery, hence a management system, financed by fishermen, will enable a production of 400 t per year in the Bay (50 t was produced in the early 1980s). Competition for space and resource use in the Bay of Brest is limiting the development of the sector. Again, the environmental impact on the Bay basin threatens the juveniles (pesticides, salinity variations, eutrophication) and in 2001, unexplained mortality was reported.

Since 1997, one hatchery in Norway has had an annual production of about two million scallop seed. There have been some difficulties in stabilising the production, problems related to the environment, and management that are not yet resolved. A second hatchery to scale-up seed production is being considered. A new law on sea ranching in 2000 has given sea ranching of scallops an improved regulatory and commercial framework.

Sea ranching—from bottom culture to the final product—still has a long way to go for stable production and commercialisation. Results are encouraging, and last year results improved by fencing in the area to prevent crab (*Cancer pagurus*) predation. One company obtained an increased survival up to 90 % after 15 months with an average shell market size of 10 cm in 2001. The market for scallops is steadily increasing and the harvest of wild stock reached 600 tonnes in 2001.

Pecten jacobeus

Projects are anticipated that will integrate sea ranching and artificial reefs in the French Mediterranean using artificial propagated spat.

Sea urchin (*Paracentrotus lividus*)

An EU project has developed a unique polyculture model for cultivation of sea urchins alongside salmon cages. The potential for sea urchins to bioaccumulate an anti-sealice agent is being addressed. Artificial feed seems to be the major problem in developing a controlled maturation process (only the gonads are eaten). From hatchery-reared juveniles five tonnes were produced by Ireland in 2001, and 10 tonnes are expected in 2002, (See also EU projects FAIR-CT96–1623.) The technology is also available in Canada, based on collection of wild juveniles, but faces market constraints.

Abalone

No information was reported from the only farm, in Guernsey. Some experimental work is being done on the development of juvenile rearing on Canada's West Coast.

Softshell clams (*Mya arenia*)

Wild juveniles are caught on sandy grounds on the East Coast of Canada and are restocked in production sites. Estimated production is about 10 tonnes per year. Apart from the collection of wild spat and pressure on wild stock, other environmental concerns are the suspension of particulate matter and benthic communities when harvesting juveniles.

Algae

Cultivating the red seaweed, *Palmaria palmata,* has only been reported under the FAIR-CT97–3828 project. A combined project including kelp is under evaluation in Eastern Canada.

6.4 Environmental Aspects

Globally, breeding and rearing new species will have the same types of environmental effects that have been previously referred to in this Section. In addition to those, particular attention should be given to:

- Choosing a good candidate species, i.e., the metabolic status of the fish (e.g., tuna, a partial thermo-regulator), herbivorous/omnivorous/carnivorous status of the fish (e.g., is it able to utilise plant energy and plants proteins). The two studies cited previously did not integrate these aspects in their contingency matrix;
    - Major modifications of commercial feed formulations are required species to species to minimise metabolic outputs;
    - Transfer of non-endemic species/populations has to be considered with great care. Among potential consequences is the establishment of non-endemic populations or possible gene flow in the case of movement of endemic populations. Translocation also brings the risk of diseases (bacteria, virus, parasites) spreading and should consequently incorporate the use of a sound Code of Practice for such activities (e.g., following the ICES Code of Practice on the introduction and Transfers of Marine Organisms, 2002). This should incorporate identification of the potential for accidental transfers of exotic species (e.g., macro and micro algae from the Pacific introduced with cupped oysters (*Crassostrea gigas*) in Thau lagoon (Verlaque, 2001)).
- As a first step in development, there is a need to, on a cost-benefit basis, extend the use of improved containment systems (nets, land-based systems, recirculating systems, etc.). Utilisation of local stocks for genetic improvement programmes could reduce the risk of interbreeding and enhance artisanal fishing of escapees.
- When the whole biological cycle of the candidate species is not mastered, the effect of fishing wild juveniles on wild stock depletion (case of tuna, mullet, amberjack, eel, softshell clam) has to be considered.
- When possible, either by coupling algae culture with sea cages or recirculated/integrated onshore systems, it is worthwhile to consider the capacity of algae to counteract the enrichment effect of growing fish. In that sense, their use should be encouraged.

6.5 References

Beveridge, M.C.M. 2001. Aquaculture and wildlife interactions. Proceedings of the seminar of the CIHEAM Network on Technology of Aquaculture in the Mediterranean, Zaragossa, 17–21 January 2000. Cahiers Options Méditerranéennes, 55: 57–66.

Blancheton, J.P. *et al.* 2002. Recirculation systems for Mediterranean fish production: state of the art and prospects. EAS Workshop on “Better use of water, nutrients and space”, Trondheim, Norway, 7 August 2001. 15 pp.

CIHEAM, 1999. Marine finfish species diversification: current situation and prospects in Mediterranean aquaculture. Cahiers Options Méditerranéennes série B, 24. 139 pp.

Costello, M.J., *et al.* 2001. The control of chemicals used in aquaculture in Europe. J. Applied Ichthyology, 17: 173–180.

Dosdat, A. 2001. Environmental impact of aquaculture in the Mediterranean: nutritional and feeding aspects. Proceedings of the seminar of the CIHEAM Network on Technology of Aquaculture in the Mediterranean, Zaragossa, 17–21 January 2000. Cahiers Options Méditerranéennes, 55 : 23–36.

Dunham, R.A., *et al.* 2001. Review of the status of aquaculture genetics. *In* R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery and J.R. Arthurs, Eds. Aquaculture in the Third Millenium. Technical proceedings of the Conference on Aquaculture in Third Millenium, Bangkok, Thailand, 20–25 February 2000. pp 137–166.

Funge-Smith, S., and Phillips, M.J. 2001. Aquaculture systems and species. *In* R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery and J.R. Arthurs, eds. Aquaculture in the Third Millenium. Technical proceedings of the Conference on Aquaculture in Third Millenium, Bangkok, Thailand, 20–25 February 2000. pp 129–135.

Gimenez Casalduero, F. 2001. Integrated systems: environmentally clean aquaculture? Proceedings of the seminar of the CIHEAM Network on Technology of Aquaculture in the Mediterranean, Zaragossa, 17–21 January 2000. Cahiers Options Méditerranéennes, 55 : 139–145.

Hansson, S., *et al.* 1997. Benefits from fish stocking experiences from stocking young of the year pikeperch (*Stizostedion lucioperca*) to a bay in the Baltic Sea. Fish. Res., 32: 123–132.

Hussenot, J. 2002. Proposals to manage effluents in marine fish-culture farms located in European coastal wetlands. Aquaculture Interchange Program – Management of Aquaculture Effluents. Honolulu, 6–9 May 2002, 15 pp.

ICES, 2000. Report of the Working Group on Environmental Impacts of Mariculture (WGEIM). ICES CM 2000/F:02.

Kanaiwa, M., and Harada, Y. 2000. Theoretical analysis of introgression between released fish and wild populations considering sex differences. Fisheries Sci., 66: 686–694.

Le François, N., *et al.* 2000. Potentiel aquicole de différentes espèces de poissons marins à des fins de développement de la mariculture au Québec. Université du Québec à Rimoulski. 345 pp.

Moretti, A. 2001. New developments in waste treatment: filtration and thickening systems for inland farms. Proceedings of the seminar of the CIHEAM Network on Technology of Aquaculture in the Mediterranean, Zaragossa, 17–21 January 2000. Cahiers Options Méditerranéennes, 55: 129–137.

Quemener *et al,* 2002. Selection methods for finfish aquaculture: the case of French Atlantic, the Channel and the North Sea coasts. Aquatic Living Resources (in press).

Sotto, D., *et al.* 2001. Escaped salmon in the inner seas, southern Chile: facing ecological and social conflicts. Ecological Applications, 11: 1750–1762.

Subasinghe, R.P. *et al.* 2001. Aquaculture development, health and wealth. *In* R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery and J.R. Arthurs, Eds. Aquaculture in the Third Millennium. Technical proceedings of the Conference on Aquaculture in Third Millennium, Bangkok, Thailand, 20–25 February 2000. pp 167–191.

Tenore, K., *et al.* 1982. Coastal upwelling in the Rias Bajas, NW Spain: contrasting the benthic regimes of the Rias de Muros. J. Marine Res., 40: 701–772.

Verlaque, M. 2001. Checklist of the macroalgae of Thau Lagoon (Hérault, France), a hot spot of marine species introduction in Europe. Oceanologica Acta, 24: 29–49.

Waller, U. 2000. Tank culture and recirculating systems. *In* Environmental Impacts of Aquaculture, K.D. Black Ed, CRC Press. pp 99–127.

Youngson A.F. *et al.* 2001. Genetic interactions between marine finfish species in European aquaculture and wild conspecifics. J. Applied Ichthyology, 17: 153–162.

7 REVIEW NEW RESEARCH AND MONITORING PROGRAMMES, TAKING INTO ACCOUNT THE PROCEEDINGS OF THE 1999 ICES SYMPOSIUM “ENVIRONMENTAL EFFECTS OF MARICULTURE” AND OTHERS AS APPROPRIATE

Mariculture has a wide range of potential environmental interactions ranging from aesthetic impacts, ethical aspects of animal welfare, effects on wild populations to the impacts of a variety of effluents. These impacts can be harmful to the mariculture operation, as well as to the surrounding environment, and it is a prerequisite for a sustainable industry that the impact is kept within environmentally safe limits. Monitoring of environmental impacts is crucial and must fulfil the needs of the operator, as well as the needs of the regulator and the general public.

GESAMP (1996) has provided a working definition for monitoring in relation to aquaculture, as “the regular collection, normally under regulatory mandate, of biological, chemical or physical data from predefined locations such that ecological changes attributable to aquaculture wastes can be quantified and evaluated”. GESAMP (1996) also emphasises that in order to have efficient regulatory tools, monitoring programmes must be integrated with simulation models that can predict the impact of a given operation and respond with remedial action if the threshold levels for environmentally acceptable impact are breached.

Appropriate monitoring programmes are essential for achieving and maintaining an environmentally friendly mariculture industry. Monitoring and regulating the production process and the extent of the operation are also a prerequisite to the integration of mariculture into coastal zone planning. It is only when adequate data are available that environmental and mariculture needs can be formulated securely. It follows, therefore, that integration will be successful when all participants (end-users of their coastal resources) are able to identify their environmental needs and impacts while demonstrating a high level of credibility in their assessment. Only then can mariculture achieve acceptance among stakeholders. This will safeguard all users beyond the initial threshold levels agreed by consensus. To increase the public confidence and build trust in the mariculture industry, it is strongly recommended that results from ongoing monitoring programmes are accessible to the public.

Setting threshold levels for environmental impacts or environmental quality standards (EQS) requires a close cooperation between authorities that can define what impact is acceptable, and scientists who understand what this means in measurable parameters. In many countries, the task is determined by environmental quality objectives (EQO) from which EQS values are derived. An EQO/EQS system is highly recommended since it will contribute to transparent regulatory systems that are based on political decisions and public acceptance. This approach opens the possibility of defining zones with different allowable impacts, and accordingly, different EQS values (Ervik *et al.*, 1997; Henderson and Davies, 2000; Hansen *et al.*, 2001).

Monitoring programmes must concentrate on the main impacts of mariculture. Hansen *et al.* (2001) suggest that the following criteria should be used to select the impacts on which to put the main emphasis:

- The sum of the impacts must have relevance for both the environment and the mariculture operation, including consumer safety.
- The impact must be convenient for monitoring, e.g., routine analytical methods must be available and the signals must be distinguishable from background levels.
- Scientific information must be available to set adequate EQS.
- The monitoring must be cost efficient, as most aquaculture operations are small enterprises.

The EU Water Framework Directive (WFD) will be the primary EU driver for the improvement of groundwater and surface water quality over the next decades. Under the Directive, definitions of good ecological quality will be agreed upon for a wide range of water body types covering all surface waters in the EU. Good ecological quality will be the target for improvement guidelines to be adopted by member states and their environmental agencies.

Aquaculture is not specifically mentioned in the Directive. However, it will be viewed as a source of environmental pressures with the potential to adversely affect the primary indices of ecological quality in the transitional and coastal water bodies where mariculture operations are located. As such, it is likely that such areas will be subject to operational monitoring, as defined under the WFD. Fish farms will be assessed as potentially affecting benthic, phytoplankton and angiosperm communities, and also hydrochemical conditions such as nutrient and dissolved oxygen concentrations.

The implications for fish farming are as yet difficult to predict. The first critical factor will be the approach taken by national authorities in delineating the boundaries of water bodies. It currently seems likely that water bodies will be defined on the basis of hydrographic and physiographic factors and may be on the scale of individual sealochs, fjords, or estuaries. Questions then arise as to how the ecological status of such bodies will be determined, taking into account the wide range of seabed, water depth, plant and animal community types present.

The MARAQUA project evaluated the scientific principles underlying environmental impact monitoring of aquaculture in Europe (Fernandes *et al.,* 2001). The authors recommended a set of regulations for environmentally friendly mariculture. It is recognized that aquaculture requires a framework of regulations to ensure an environmentally acceptable industry and to minimize potential environmental impacts. As part of good environmental management, mariculture operations must be monitored with regard to potential changes in pelagic and benthic systems. The monitoring practice must therefore be adapted to the natural environment as well as to the character of the farming operations. MARAQUA provided a comprehensive overview of different monitoring systems and techniques (Fernandes *et al.,* 2001) and recommended that the following factors be taken into account:

- Aquaculture methodology (extensive, semi-intensive, intensive or integrated);
- Aquaculture technology (flow-through, open cage, or closed systems, land- or sea-based);
- The type of environment (coastal zone, semi-enclosed systems like the Mediterranean and the Baltic, Norwegian fjords, offshore conditions, deep sea);
- Uses and users of the environment (e.g., nature conservation, fisheries, tourism, recreation, navigation).

In addition, new topics like animal welfare and consumer safety are getting increasing attention. Mariculture is important socioeconomically in many rural districts and management processes, including monitoring, should be transparent, simple, efficient and cost effective.

MARAQUA (Rosenthal *et al.,* 2000) found that mariculture is monitored in most European countries; however, there is no overall system of monitoring and control that is widely applicable throughout Europe. In contrast, there are large differences in consistency, sophistication and complexity of regulations, control and monitoring procedures. The potential deleterious effects of mariculture are well documented, and it is widely accepted that such impacts could be minimized or negated by adopting environmental safeguards, including regulatory control and monitoring procedures. MARAQUA suggested that research and development conducted in some European countries could be applied to harmonize regulatory, control and monitoring in the EU by creating a Best Practice Code. Despite the differences in development in countries like Canada, US, Norway and Scotland that seem to have established the most comprehensive regulatory, control and monitoring systems, the applied strategies are remarkably similar.

References

Ervik, A., Hansen, P.K., Aure, J., Stigebrandt, A., Johannessen, P., Jahnsen, T. 1997. Regulating the local environmental impact of intensive fish farming. I. The concept of the MOM system (Modelling-Ongrowing-Monitoring). Aquaculture, 158: 85–94.

Fernandes, T.F., Eleftheriou, A., Ackefors, H., Eleftheriou, M., Ervik, A., Sanchez-Mata, A., Scanlon, T., White, P Cochrane, S., Perason, T.H., Read, P.A. 2001. The scientific principles underlying the monitoring of environmental impacts of aquaculture. J. Appl. Ichythol., 17: 181.

GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). 1996. Monitoring the Ecological Effects of Coastal Aquaculture Wastes. Scientific Aspects of Marine Environmental Protection. Reports and Studies GESAMP 57. FAO, Rome, Italy, 38 pp.

Hansen, P.K., Ervik, A., Aure, J., Schaanning, A., Johannessen, P., Aure, J., Jahnsen, T., and Stigebrandt, A. 2001. Regulating the local environmental impact of intensive marine fish farming. II. The monitoring programme of the MOM system (Modelling-Ongrowing fish farms-Monitoring). Aquaculture, 194: 75–92.

Henderson, A.R, and Davies, I. M. 2000. Review of aquaculture, its regulation and monitoring in Scotland. J. Appl. Ichthyol., 16: 200–208.

Rosenthal, H., Schnack, D., Hilge, V., Read, P.A., Fernandes, T.F., Miller, K.L., Davies, I.M., and Rodger, G.K., 2000. Monitoring and regulation of marine aquaculture in Europe, Proceedings of the 1st Workshop. (University of the Algarve, Portugal, 6–8 September 1999) J. Appl. Ichthyol., 16(4, 5).

8 REVIEW MONITORING ACTIVITIES AND DEVELOP GUIDELINES FOR THE PREPARATION OF ENVIRONMENTAL IMPACT STATEMENT/ASSESSMENT DOCUMENTS FOR LARGE-SCALE SHELLFISH FARM DEVELOPMENTS AND APPROPRIATE MONITORING PROGRAMMES

A variety of different shellfish species are cultured throughout the ICES area. These can be divided broadly into the following taxonomic groupings and culture methods. The culture methods and locations reflect the broad biological requirements (e.g., infaunal or epifaunal) and the physiological tolerances of the species concerned.

- Mussels
    a. Rope culture - (subtidal)
    b. Bottom culture - (subtidal/intertidal)
- Oysters
    a. Bottom culture (intertidal and subtidal)
    b. Trestle culture (intertidal)
    c. Suspended culture (subtidal)
- Clams

    a. Net culture (intertidal)
    b. Pen culture (intertidal)
    c. Beach culture (intertidal, subtidal)
- Scallops
    a. Suspended culture (subtidal)
    b. Pens (subtidal; on-bottom)
    c. Bottom culture (specified areas, not penned)

Studies of the environmental impacts of these activities have been published in numerous peer-reviewed publications and were reviewed briefly by WGEIM in 2000. A number of studies have clearly shown that the sedimentation of faeces and pseudofaeces beneath mussel farms leads to organic enrichment and thus alters macrofaunal communities (Mattson and Linden, 1983; Kaspar *et al.,* 1985; Chamberlain *et al.*, 2001). Impacts on the water column appear to be related to the filtering capacity of shellfish species, which can minimize eutrophication effects by grazing on phytoplankton (Rice, 2000, 2001). Other impacts on phytoplankton community structure have been proposed. For example, bivalve excretion and the subsequent increase in nutrient fluxes from the enriched sediments underlying bivalves in suspension or on the bottom may enhance local primary productivity over that of ambient conditions (Archambault *et al.,* 1999; Kaiser, 2000). Some research also suggests that harmful algal blooms may result from an imbalance in nutrients brought about by intensive bivalve aquaculture (Bates, 1998; Bates *et al.*, 1998). Bivalve aquaculture can also influence the composition of zooplankton communities (Lam-Hoai *et al.,* 1997) and possibly decrease the abundance of larvae of commercially important invertebrate and fish species (Davenport *et al.,* 2000). However, the importance of these effects and their cascading effects on the rest of the ecosystem is largely unknown.

8.1 Guidelines for preparation of EIA

In EU Member States, Environmental Impact Assessment (EIA) is the subject of an EU Directive, Council Directive 97/11/EC amending Council Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment. The aim of the Directive is to ensure that competent authorities are provided with relevant information to enable them to make a decision on a specific project's potential impact on the environment. EIA is an open and transparent process, which ensures that all relevant information is considered. The process involves public consultation to ensure that all the relevant concerns are addressed. This facilitates decision making to the benefit of the regulator, the developer, if approval is given, and concerned parties.

The Directive defines "intensive fish farming" as an Annex II project, thereby permitting individual Member States to determine, on a case-by-case basis or by setting thresholds or other criteria, whether projects should be subject to the EIA process. To date most EU Member States have determined that only finfish aquaculture projects should be subject to EIA and few shellfish projects, regardless of scale, have been subject to EIA. The MARAQUA concerted action recommended, however, the adoption of the EIA process for **all** aquaculture operations.

In Canada, the Canadian Environmental Assessment Act (C-15.2) stipulates that an EIA is required for new activities that would result in harmful alteration of the marine environment. Proposed shellfish culture projects may fall into this category. However, while some shellfish and finfish projects have completed EIAs, the number of projects that have carried out a full EIA is unclear. It seems that written guidelines are not available and that each component of the proposal (e.g., fisheries, navigation) is evaluated separately and any one of these evaluations can trigger an EIA.

WGEIM reviewed the information required by Environmental Impact Statements (EIS) for salmon farms in Ireland and Scotland and derived a proposed list of information that may be relevant to EIS for marine shellfish farms (Table 8.1.1).

Table 8.1.1. Proposed information to be included in an EIS for shellfish farming.

Location and dimensions of proposed farm

Location of proposed farm and reasons for its selection

Description of Project:

- Dimensions of proposed licence area
- Projected production and maximum biomass
- Type and number of structures (e.g., longlines, trestles)
- Proposed layout, dimensions, orientation, materials and colours of all structures on the farm
- Arrangement of moorings
- Need for, and proposed location of, any shore-based facilities

Site Characteristics

- Location
- Landscape
- Natural Features
- Archaeological features
- Water depths
- Currents (speed and direction)
- Wave climate
- Sediment type - particle size, organic content, physical appearance
- Redox profiles
- Benthic flora and fauna, including in particular any fragile taxa
- Location of main freshwater inputs
- Temperature / Salinity
- Occurrence of water column stratification
- Turbidity, Particulate Inorganic Matter (PIM) and Particulate Organic Matter (POM)
- Dissolved oxygen - especially near bottom
- Chlorophyll
- Bacteriological Classification of water body
- History of harmful algal events
- Location of existing finfish farms in the area
- Location of existing shellfish farms in the area
- Fishing activity in the area (gears used)
- Recreational activity in the area (e.g., recreational fishing, sailing)
- Navigation channels and anchoring areas
- Location of piers and harbours
- Access roads
- Special Protection Areas (SPA)
- Special Areas of Conservation (SAC)

Production process

- Production model
- Economic and commercial aspects
- Source of seed
- General site management
- Waste management
- Harvesting method
- Timing of harvest
- Fallowing periods
- The proposed development in the context of Integrated Coastal Zone Management initiatives.
- Plans to deal with accidents and emergencies (e.g., failure of moorings, storm damage to structures, mass mortalities)
- Shore-based facilities required
- Boats and service craft

Potential Impacts

It should be emphasized that the estimation of potential impact is best performed by modelling the functioning of a farm, both from an ecological and an economic point of view.

- Estimate of the amount of solid waste produced
- Sediment loading
- Estimate of the extent of area of sediment impacted by solid waste
- Potential impacts on:
    - – Benthic flora and fauna
    - – Water quality
    - – Existing aquaculture operations
    - – Fishing activities
    - – Navigation
    - – Tourism
    - – Recreational activities
    - – Wildlife, including birds, cetaceans and other marine mammals
    - – Existing infrastructure (e.g., traffic, use of piers and harbours)
    - – Visual impact
    - – Social interaction

Mitigation measures

Description of measures to mitigate adverse impacts of the project while taking into account:

- Existing Regulations
- Codes of practice (e.g., sediment management)
- Carrying capacity considerations (e.g., stocking density)

Monitoring

- Monitoring of the benthic environment
- Water column monitoring
- Monitoring for validation of models (as required)
- Other monitoring activities, e.g., quality of shellfish, toxic algae (if not at institutional stage)

Difficulties in completion of EIS

- Lack of baseline data?
- Model uncertainty?
- Uncertainty in prediction of impacts?

Consultation

- List of individuals/representative bodies and organisations consulted
- Responses of consultees

WGEIM noted that the preparation of an EIS as part an EIA can be expensive and time consuming. In the EU, if an EIA is required, then legally the process must comply with the requirements outlined in the Directive. EU Member States are required to adopt the necessary measures to ensure that the developer supplies the information specified in Annex IV of the Directive (97/11/EEC) in an appropriate form.

There are significant cost implications in carrying out a full EIA for new developments, particularly for smaller operators that dominate the industry in many ICES Member Countries, such as France and Ireland. Such a situation may be resolved somewhat, by implementing a "scaled down" version of an EIA for proposed developments. As an alternative to a full EIA, Fernandes *et al.* (2001), as part of the MARAQUA project, recommended that in some instances environmental studies of a more limited nature could be carried out and the results provided to the regulatory authorities in the form of an "Environmental Report" when making an application for a shellfish farming permit. Any environmental information and data compiled will provide a background against which any future data and information can be compared.

WGEIM reviewed the type of information that could be included in environmental reports and concluded that the report should focus specifically on the list in Table 8.1.2. The WGEIM noted that the preparation of such reports should ideally be done on a case-by-case basis and the information should be relevant to the specific site and local conditions.

Table 8.1.2. Proposed information to be included in an Environmental Report.

Location and dimensions of proposed farm
- Location of proposed farm and reasons for its selection

General Description of Project (to include):
- Dimensions of proposed licence area
- Projected production and maximum biomass
- Type and number of structures (e.g., longlines, trestles)
- Proposed layout, dimensions, orientation, materials and colours of all structures on the farm
- Arrangement of moorings
- Need for, and availability of, any shore-based facilities

Site Characteristics
- Location
- Water depths
- Currents (speed and direction)
- Sediment type - particle size, organic content, physical appearance*
- Turbidity levels
- Bacteriological Classification of water body
- Location of existing shellfish farms in the area
- Navigation considerations
- Conservation Status of area and occurrence of fragile species

Production process
- Source of seed
- Waste management
- Harvesting method*
- The proposed production in the context of ICZM initiatives

Potential Impacts

It should be emphasized that estimating the potential impact is best performed by modelling the functioning of a farm, both from an ecological and an economic point of view.
- Sediment loading
- Estimate of extent of area of sediment impacted by solid waste

Mitigation measures
- Description of measures to mitigate adverse impacts of the project

Monitoring

It is suggested that some form of monitoring of the activity be implemented, however, without being able to fully realise the impacts activity – monitoring may have to be considered on a case-by-case basis.

Difficulties in completion of Report
- Lack of baseline data?
- Model uncertainty?
- Uncertainty in prediction of impacts?

Consultation
- List of individuals/representative bodies and organisations consulted

*Mostly relevant to bottom culture methods where the risk of severe disturbance of the sea floor is highest

Shellfish production in most ICES Member Countries is carried out by small-scale operators producing relatively small volumes in small licensed areas. WGEIM noted that in certain areas there can be many licensed operators working in close proximity. For the most part, regulatory authorities have tended to consider license applications in isolation and cumulative impacts of many small operators have not been fully addressed. WGEIM considered that the cumulative impacts of many small operations could be significant and that appropriate management and regulatory strategies need to be developed to minimise these impacts. Such strategies will require the development of carrying capacity models, and the setting of Environmental Quality Objectives (EQO) and Environmental Quality Standards (EQS), which ideally should be part of a science-based Integrated Coastal Zone Management system. The development of EQO and EQS is fundamental to the establishment of "acceptable" levels of impact.

The species chosen, method of culture and production schedule may have a significant bearing on the information required for assessment in an environmental report. For example, rope mussel culture will have different environmental requirements as well as impacts than a bottom culture operation.

The EIA Directive (97/11/EEC) dictated that when setting thresholds, criteria, or examining projects on a case-by-case basis for the purpose of determining which projects should be assessed based on their significant environmental effects, Member States should take into account the selection criteria set out below.

1. Characteristics of projects
The characteristics of projects must be considered, particularly:
- the size of the project,
- the cumulation with other projects,
- the use of natural resources,
- the production of waste,
- pollution and nuisances,
- the risk of accidents, having regard in particular to substances or technologies used.

2. Location of projects
The environmental sensitivity of geographical areas likely to be affected by projects must be considered, with regard to:
- the existing land use,
- the relative abundance, quality and regenerative capacity of natural resources in the area,
- the absorption capacity of the natural environment, paying particular attention to the following areas:

(a) wetlands;
(b) coastal zones;
(c) mountain and forest areas;
(d) nature reserves and parks;
(e) areas classified or protected under Member States' legislation; special protection areas designated by Member States pursuant to Directive 79/409/EEC and 92/43/EEC;
(f) areas in which the environmental quality standards laid down in Community legislation have already been exceeded;
(g) densely populated areas;
(h) landscapes of historical, cultural or archaeological significance.

3. Characteristics of the potential impact
The potential significant effects of projects must be considered in relation to criteria set out under 1 and 2, above, and having regard in particular to:
- the extent of the impact (geographical area and size of the affected population),
- the trans-frontier nature of the impact,
- the magnitude and complexity of the impact,
- the probability of the impact,
- the duration, frequency and reversibility of the impact.

It is evident that the selection criteria are general in nature and apply to many different types of projects and developments covering both terrestrial and marine environments. However, such generic criteria may not be appropriate for specific projects, such as large-scale shellfish culture. WGEIM acknowledged that there is a need for the refinement of these criteria to suit shellfish operations explicitly and recommended that further work be carried out to determine appropriate the threshold or criteria to determine which type of shellfish projects should be subject to:

(i) an EIA,
(ii) an environmental report,
(iii) no environmental assessment,

in order to obtain appropriate statutory permissions.

WGEIM considered that, as with salmon farming, careful and informed site selection, considering both ecological and environmental criteria, is critical in order to minimise adverse impacts on the environment and other resource users. In addition, early and widespread consultation with all stakeholders is important. These consultations, when carried out in the early stages of the project, can identify potential conflicts with other users, which may be overcome by modification of the project. Consultation at an early stage is strongly recommended to avoid delays caused by requests for further information and expedite the processing of an application.

The cumulative impacts of these activities on the environment are of critical importance. They have been partially addressed in some ICES Member Countries by single bay management processes (Area Management Agreements, Scotland, Appendix 4: Coordinated Local Aquaculture Management Systems in Ireland) involving all resource users where possible. These initiatives provide a forum for dealing with specific issues on a system-wide basis and are consensus based. In relation to system-wide issues, WGEIM concluded that licence applications should not be approved without considering cumulative impacts. WGEIM concluded that since baseline information is lacking in many areas hydrodynamic and environmental capacity models to determine loading should be generated. This carrying/environmental capacity information would form the basis of management plans for discrete areas.

Environmental capacity is defined by GESAMP (1986) as "a property of the environment and its ability to accommodate a particular activity or rate of an activity…without unacceptable change". In relation to large-scale shellfish farms, this may include the rate of organic flux to the benthos without major disruption to natural benthic processes, but also the reduction in scenic value (visual impact), reduction of natural habitat and reduction in amenity value.

The environmental capacity can be estimated by assessing cumulative or combined impacts and acceptable levels of environmental change compatible with the goals of coastal management. The estimate of total capacity can be allocated among different uses of the environment and among users within each category of use. GESAMP (2001) noted that the approach has not been implemented widely in relation to finfish and shellfish aquaculture, largely because of the lack of quantitative information about causal links between aquaculture wastes and their environmental effects, and the large costs of obtaining such data. Ideally the environmental capacity of the whole coastal resource system, including effects of all developments, should be addressed.

Quantifying environmental capacity in relation to visual impact is, at least, partly subjective and establishing methods and criteria to determine the visual impact of shellfish farming is becoming increasingly important in areas of high scenic value and tourism potential. In this regard, WGEIM noted the recent publication in Ireland of "Guideline for Landscape and Visual Impact Assessment of Marine Aquaculture" (Department of the Marine and Natural Resources, 2001).

Review of Monitoring Activities

Monitoring of shellfish culture activities typically has considered the activity from a human health, not an ecological or environmental health, perspective. Typically, regulatory monitoring programmes of shellfish culture have included the sampling and analysis of toxic and harmful algal species, the presence of biotoxins in shellfish, bacteriological quality of shellfish growing waters and shellfish flesh, as well as trace metal and contaminants in shellfish. Additional assessments of growth rates, mortality rates and biofouling levels have been used by producers to monitor crop performance. The WGEIM 2000 report highlighted the fact that environmental monitoring programmes similar to those in place for salmon aquaculture (in place in most Member Countries) did not exist for shellfish culturing activities. This situation has not changed in the interim.

The WGEIM 2000 report outlined the objectives of monitoring programmes for finfish culture; however, the same report highlighted the fact that shellfish culture will have an impact on the environment. Some member states (Canada, Scotland, France and Ireland) have expressed the need to establish shellfish monitoring programmes that should focus primarily on benthic impacts. This supposition, that benthic impacts are the most appropriate measures, is examined further in this report.

In Ireland, environmental monitoring programmes specifically related to the environmental impacts of shellfish aquaculture have not been developed or implemented to date. However, a Working Group has been established and met for the first time in February 2001 to discuss the issue. The ultimate goal of the Working Group is to make appropriate recommendations to the Department of Marine and Natural Resources based on sound scientific principles to establish an environmental monitoring programme. An outline of a monitoring programme may be prepared. A set of actions has been identified that includes a review of the shellfish culture practices in Ireland, an assessment of the potential impacts, a comprehensive literature review of research carried out to date and, finally, identification of gaps in knowledge that may be the focus of future research activities.

In France, there are several ongoing studies investigating the impacts of shellfish culture on benthos. Some are part of a research programme studying interactions between fisheries and shellfish culture. These studies examine the impact that organic material and silt sedimentation from shellfish culture operations may have on the community structure of the benthos. Positive responses, in terms of fishery production, have been identified by an increase in available food for juvenile flatfish in the vicinity of the culture operation being studied. This study will be completed in two years. In addition, a national benthic habitat survey (REBENT) is currently under way with the goal of characterising trends in benthic communities in coastal areas. Several sites have been chosen within shellfish culture areas and the gathered information will allow the impacts of shellfish aquaculture to be assessed. These surveys will form the basis for the development of a monitoring plan.

Developing Guidelines to Monitor Large-Scale Shellfish Cultures

Historically, marine aquaculture was viewed as a benign activity with limited environmental impacts. However, with the rapid development of the industry, the negative impacts on the areas surrounding the farms became evident (e.g., Grant *et al.*, 1995; Duplisea and Hargrave, 1996). For finfish culture, many countries have established monitoring programmes to ensure that impacts are limited to prescribed boundaries. With the advent of intensive culture of molluscs, it is now evident that they may have a significant impact on the environment (Prins *et al.,* 1998). To date, no countries have required that monitoring programmes be established for bivalve aquaculture. The purpose of this discussion is to outline some features that are important in considering the establishment of monitoring programmes for bivalve aquaculture. This topic is also addressed in Section 8.

This review is largely based on the recent papers by Read *et al.* (2001) and Fernandes *et al.* (2001) and expands on some of the subjects already discussed therein. Although these papers were largely about aquaculture of finfish, the recommendations may be extrapolated to the bivalve system. Fernandes *et al.* (2001) point out that any monitoring programme must address the needs of the scientists, operators, regulators, and the general public. At the simplest level, monitoring is needed to keep the integrity of the culture sites and to ensure that production does not surpass the capacity of the site. This will ensure sustainable development of the industry and help in integrated management of the coastal zones (IMCZ).

Considerations - This review will address the following points:

1. What is monitoring?
2. What does “large-scale” mean?
3. Scientific and other considerations

1. What is monitoring?

According to GESAMP (GESAMP 1996), monitoring may be defined as “the regular collection, generally under regulatory mandate, of biological, chemical or physical data from predetermined locations such that ecological changes attributable to aquaculture wastes can be quantified and evaluated.” This review will consider this definition to include an initial sampling programme to determine baseline information about the study site (see below). Further, this review will only consider effects within grow-out sites.

2. What does “large-scale” mean?

The importance of most ecological processes is a function of the scale at which they are measured (Levin, 1992). Variables measured at one spatial scale may not be important at another. For example, populations and communities in soft sediments may be less variable at small (~1 m) rather than at larger (10 m–10 km) spatial scales (Lindegarth *et al.,* 1995; Li *et al.,* 1996), whereas the converse may be true in rocky habitats (Underwood and Chapman, 1996; McKindsey and Bourget, 2001). Likewise in bivalve aquaculture, the scale at which variables are measured may greatly influence the ability to interpret the results of studies, the importance of a given aquaculture site to the local environment, or the outcome of monitoring programmes. In bivalve aquaculture, “large” may refer to surface area over which the farming is occurring, the cumulative production of a site, or the density of animals within a site. Any combination of these three possibilities may be considered “large-scale”.

3. Scientific and other considerations

The purpose of any monitoring programme is to be able to detect whether a given aquaculture activity has changed a site beyond that which is acceptable. Of course, this assumes that the baseline (historic) and spatial data exist for comparison. Typically, a large number of variables need to be measured in an EIA or similar exercise before the aquaculture site is operational in order to determine the variables that may be important for the given location. The initial evaluation also identifies any "special" features that may be present at the proposed site. There are a number of criteria about the culture species, grow-out methods, and proposed site that should be considered when selecting the appropriate variables to measure; these are considered below.

1) Species differences

Different species can differ greatly in their basic ecology and physiology such that effects associated with the culture of some species may not be seen with other species. For example, different bivalve species produce pseudofaeces at different rates. Thus, accumulation of biodeposits under mussel longlines may be greater than that under suspension culture for oysters, for example.

2) Grow-out conditions

The same species grown under different conditions may also have different impacts. For example, oysters grown on trestles may have a greater effect on the underlying sediments than do oysters growing in bottom culture or those in suspension. This also includes production cycles (seasonal, inter-annual, fallowing periods, etc.).

3) Depth

All else being equal, depth will modify the extent to which by-products from bivalve culture will be spread and thus the area over which we might expect to find an effect of the culture operation.

4) Bottom type

Hard bottoms may be predicted *a priori* to experience greater impacts from bivalve culture because a hard substrate will likely be replaced by a soft-sediment substrate, with concomitant changes to the associated plant and animal assemblages.

5) Hydrography

Hydrography is in part a function of 3) and 4), above; hydrography is also influenced by, among others, weather, larger-scale hydrological processes, and topography. Of course, these differences are largely related to factors other than the one being discussed and there are usually cascading effects of one factor on the others. This serves simply to highlight the point that most of these factors are important and interact in countless ways such that each case should be evaluated on its own merit.

6) Site history

This considers whether or not the site is currently being farmed or has been in the past and, if so, in what capacity. Also, the geographic location of the site with respect to other similar and/or competing uses for the same resource (other industries, recreation, etc.).

7) Scale/Area of impact

Briefly, this questions the magnitude of the impact (e.g., everything dead or replaced) and over what spatial and/or temporal scale the impact of the culture activity is detected.

Variables

The variables that may be measured to detect impacts and routine monitoring fall into three broad categories: Physical, Chemical, and Biological (Table 8.1.3). A further possibility is the development of indices of biotic integrity (IBI) that, although usually based on communities of a given group of species (Weisberg *et al.,* 1997; Karr and Chu, 1999; Smith *et al.,* 2001), can be extended to include aspects of all three of these large groups. Typically, biological measurements are the most expensive indices to measure because of the cost involved in processing samples (for population and community-level variables, due to the actual cost of sorting and then taxonomic identification) or in the time and equipment necessary for other biological indices.

Table 8.1.3. Variables commonly used in detecting environmental impacts and monitoring (modified from Fernandes *et al.,* 2001).

Physical	Chemical	Biological[b]
Biotope mapping	Redox potential	Species abundance, richness, diversity
Hydrological aspects	Dissolved oxygen[a]	Biomass
Sedimentation	Nutrients[a]	Health/physiology
Erosion/accretion	Particulate/Dissolved organic matter	Productivity (1° and 2°)
	Suspended solids	Population/Community structure
	Chemicals (metals, antibiotics, etc.)[a]	Trophic interactions
		Rare and threatened species
		Habitat mapping

[a] indicates that this applies to both the water column and benthos.

[b] may be measured for phytoplankton, zooplankton, benthos (micro, meio, and macro), fishes, birds, etc.

Sampling design

Regardless of the factors deemed most appropriate for monitoring, of fundamental importance is the robustness of the sampling design to reliably detect differences between culture sites and the appropriate control location(s). Emphasis should be placed on the quality of the sampling programme such that it should be able to show that the value of a given variable falls within prescribed acceptable levels rather than not differing from acceptable levels (McDonald and Erickson, 1994), as is done when testing pharmaceuticals. The former requires precise and sufficient sampling while the latter benefits from less rigorous sampling with large variances.

Inherent in developing an appropriate sampling/monitoring programme is the ability to analyse the information generated and interpret the output in a meaningful manner. The most appropriate statistical procedure to be used is obviously a function of the variables determined as being the most appropriate to monitor. Basically, the types of approaches fall into two large classes: univariate (i.e., one variable at a time) and multivariate (i.e., multiple variables at a time, parametric and non-parametric methods are commonly used). Numerous authors have outlined various statistical methods and discussed the merits of numerous analytical software.

An approach to developing a monitoring programme favoured by Fernandes *et al.* (2001) and Henderson *et al.* (2001) is to first model the system in order to determine the likely spatial and temporal implications of any potential impact to guide any future monitoring programme. In the absence of scientifically robust carrying capacity models, it may be appropriate for both regulators and shellfish producers to consider surrogate methods of predicting impact. As an example, the growth parameters in the cultured organism may be monitored. Significant decreases in growth rate may reflect over-stocking and reductions in stocking density may result in optimisation of yield and minimisation of impacts.

References

Archambault, P., McKindsey, C.W., and Bourget, E. 1999. Large-scale shoreline configuration influences phytoplankton concentration and mussel growth. Estuar Coast Shelf Sci, 49:193–208.

Bates, S.S. 1998. *In:* Anderson, D. M., Cembella, A.D., and Hallegraeff, G.M. (Eds.). Physiological Ecology of Harmful Algal Blooms. Springer-Verlag, Heidelberg, pp. 405–426.

Bates, S.S., Garrison, D.L., and Horner, R.A. 1998. *In:* Anderson, D.M., A.D. Cembella, and G.M. Hallegraeff (Eds.). Physiological Ecology of Harmful Algal Blooms. Springer-Verlag, Heidelberg, pp. 267–292.

Chamberlain, J., Fernandes, T.F., Read, P., Nickell, T.D., and Davies, I.M. 2001. Impact of biodeposits from suspended mussel (*Mytilus edulis* L.) culture on the surrounding surficial sediments. ICES Journal of Marine Science, 58: 411–416.

Davenport, J., Smith, R.J.J.W., and Packer, M. 2000. Mussels *Mytilus edulis*: significant consumers and destroyers of mesozooplankton. Mar Ecol Prog Ser, 198:131–137.

Department of Marine and Natural Resources. 2001. Guidelines for landscape and visual impact assessment of marine aquaculture. Dublin, Ireland 65pp.

Duplisea, D.E., and Hargrave, B. 1996. Response of meiobenthic size-structure, biomass and respiration to sediment organic enrichment. Hydrobiologia, 339:161–170.

Fernandes, T.F., Eleftheriou, A., Ackefors, H., Eleftheriou, M., Ervik, A. Sanchez-Mata A, Scanlon T, White, P.S., Cochrane, S., Pearson, T.H., and Read, P.A. 2001. The scientific principles underlying the monitoring of the environmental impacts of aquaculture. J Appl Ichthyol, 17:181–193.

GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on Scientific Aspects of Marine Environmental Protection). 1986. Environmental capacity. An approach to marine pollution prevention. Rep. Stud. GESAMP, 30: 49p.

GESAMP. 1996. Monitoring the ecological effects of coastal aquaculture wastes. (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection), Reports and Studies, GESAMP, 57. 36 pp.

GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on Scientific Aspects of Marine Environmental Protection). 2001 Planning and management for sustainable coastal aquaculture development. Rep. Stud. GESAMP (68) 90 pp.

Grant, J., Hatcher, A, Scott, D.B., Pocklington, P., Schafer, C.T., and Winters, G.V. 1995. A multidisciplinary approach to evaluating impacts of shellfish aquaculture on benthic communities. Estuaries, 18:124–144.

Henderson, A., Gamito, S., Karakassis, I., Pederson, P., and Smaal, A. 2001. Use of hydrodynamic and benthic models for managing environmental impacts of marine aquaculture. J Appl Ichthyol., 17: 163–172.

Kaiser, M.J. 2000. Ecological effects of shellfish cultivation. In: Black KD (ed) Environmental Impacts of Aquaculture, pp 51–75.

Karr, J.R., and Chu, E.W. 1999. Restoring life in running waters: better biological monitoring. Island Press, Washington.

Kaspar, H.F., Gillespie, P.A., Boyer, I.C., and MacKenzie, A.L. 1985. Effects of mussel aquaculture on the nitrogen cycle and benthic communities in Kenepru Sound, Marlborough Sounds, New Zealand. Marine Biology, 85:127–136.

Lam-Hoai, T., Rougier, C., and Lasserre, G. 1997. Tintinnids and rotifers in a northern Mediterranean coastal lagoon. Structural diversity and function through biomass estimations. Mar Ecol Prog Ser, 152:13–25.

Levin, S.A. 1992. The problem of pattern and scale in ecology. Ecology, 73:1943–1967.

Li, J., Vincx, M., Herman, P.M.J., and Heip, C. 1996. Monitoring meiobenthos using cm-, m- and km-scales in the southern bight of the North Sea. Mar Environ Res, 43:265–278.

Lindegarth, M, André, C., and Jonsson, P.R. 1995. Analysis of the spatial variability in abundance and age structure of two infaunal bivalves, *Cerastoderma edule* and *C. lamarki*, using hierarchical sampling programs. Mar Ecol Prog Ser, 116:85–97.

Mattson, J., and Linden, O. 1983. Benthic macrofauna succession under mussels, *Mytilus edulis* L. (Bivalvia) cultured on hanging long lines. Sarsia, 68: 97 –102.

McDonald, L.L., and Erickson, W.P. 1994. Testing for bioequivalence in field studies: has a disturbed site been adequately recaimed? *In:* Fletcher DJ, Manly BFJ (Eds.) Statistics in Ecology and Environmental Monitoring: Otogao Conference Series. University of Otago Press, Dunedin, University of Otago, pp 183–197.

McKindsey, C.W., and Bourget, E. 2001. Body size and spatial variation of community structure in subarctic intertidal boulder fields. Mar Ecol Prog Ser, 216:17–30.

Prins, T.C., Smaal, A.C., and Dame, R.F. 1998. A review of the feedbacks between bivalve grazing and ecosystem processes. Aquat Ecol, 31:349–359.

Read, P.A., Fernandes, T.F., and Miller, K.L. 2001. The derivation of scientific guidelines for best environmental practice for the monitoring and regulation of marine aquaculture in Europe. J Appl Ichthyol, 17:146–152.

Rice, M.A. 2000. A review of shellfish restoration as a tool for coastal water quality management. Environ Cape Cod 3:1–8.

Rice, M.A. 2001. Environmental impacts of shellfish aquaculture: filter feeding to control eutrophication. *In:* Halvorson HO (ed) Workshop on Aquaculture and the Marine Environment: A Meeting for Stakeholders in the Northeast, University of Massachusetts Boston, pp 1–11.

Rosenthal, H., Schnack D., and Hilge, V. 2000. MARAQUA: The Monitoring and Regulation of Marine Aquaculture in Europe. Proceedings of the 1st workshop held at the University of Algarve, Faro, Portugal, 6–8 September 1999. Issued as a special issue of Journal of Applied Ichthyology (Vol 16(4–5)).

Smith, R.W., Bergen M., Weisberg S.B., Cadien, D., Dalkey, A., Montagne, D., Stull, J.K, and Velarde, R.G. 2001. Benthic response index for assessing infaunal communities on the Southern California Mainland Shelf. Ecol App, 11:1073–1087.

Schmidt R.J., and Osenberg, C.W. 1996. Detecting Ecological Impacts: Concepts and Applications in Coastal Habitats. Oxford University Press, Oxford.

Underwood A.J., and Chapman, M.G. 1996. Scales of spatial patterns of distribution of intertidal invertebrates. Oecologia, 107:212–224.

Weisberg, S.B., Ranasinghe, J.A., Dauer, D.M., Schaffner, L.C., Diaz, R.J., and Frithsen, J.B. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. Estuaries, 20:149–158.

9 REVIEW ISSUES OF SUSTAINABILITY IN MARICULTURE INCLUDING INTERACTIONS BETWEEN MARICULTURE AND OTHER USERS OF RESOURCES IN THE COASTAL ZONE

9.1 Introduction

The role of Integrated Coastal Zone Management (ICZM) for mariculture development and fisheries has been considered on several occasions by the Working Group and, in particular, the reader is referred to the Working Group reports of 1995–2000. It seems appropriate to refer to these documents, in particular to the updated version on the subject in the 1999 report that reflects the management approaches to be taken. In revisiting the issue, the Working Group welcomes the initiatives of the EU in recent years to foster demonstration projects on Integrated Coastal Zone Management as there is an important need to incorporate all activities in coastal areas with serious consideration of social and economic factors. WGEIM reiterates the need for cross-sectorial management approaches that link mariculture, fisheries, tourism, shipping, rural development and other disciplines to achieve ICZM objectives. However, the present structure of the ICES community seems not yet well equipped to deal with multidisciplinary, non-biological management tasks and methodologies.

In light of the need to prepare ICES for the required outreach and cross-linking, WGEIM reconfirmed the content of the ICZM chapter in the 1999 WGEIM Report (Appendix 9). Specifically, the Concept of Integrated Coastal Zone Management was addressed. Two major dimensions of the process were highlighted:

- vertical integration of governance in the form of policies, management arrangements from national to local levels of government, including community-based approaches, and
- horizontal integration of policies, management arrangements and development plans across national, district, or local levels of government as well as among different stakeholders with common interests in coastal areas and resources.

The Appendix emphasises the need to create a shift in emphasis away from management that controls solely the end-use of resources derived from coastal ecosystems towards a more balanced approach. Emphasis is given to maintaining the health and productivity of coastal ecosystems so that they can continue to supply flows of resources that sustain different forms of activity, including mariculture.

Several EU-projects (outlined in EU FAIR 1994–98 Synopsis of projects, EUR 18949 EN) are presently under way or have recently been completed to assist in developing scientific criteria for sustainable resource use including aquaculture. These projects cover the following subject areas:

a) the development of recirculation systems to minimize environmental impact of mariculture (FAIR-CT98–4160);
b) risk assessment of antimicrobial agent use in aquaculture (FAIR-CT96–1703);
c) studies on the physiological and behavioural mechanisms affecting the performance of introduced and escaped fish (FAIR-CT97–3498); and
d) effects of shellfish culture and options for sustainable exploitation (Essense FAIR-CT98–4201).

The CIHEAM Network on Technology of Aquaculture in the Mediterranean (TECAM) has recently published the proceedings on "Environmental impact assessment of Mediterranean aquaculture farms" (Uriarte and Basurco, 2001). This addresses, among other aspects, the issues of wild-cultured species interactions, tools for impact assessment of aquaculture activities on marine communities, aquaculture interaction with tourism, recreational activities and special protected areas, the development of monitoring guidelines and modelling tools for environmental effects from Mediterranean aquaculture, and mitigation strategies for inshore finfish cage farming through the deployment of specifically designed "filters" or "artificial reefs" (a project called: BIOFAQs = BioFiltration and AQuaculture).

A series of symposia, including the ICES Symposium on Environmental Effects of Mariculture (Wildish and Heral, 2001), a symposium in Dartmouth, Nova Scotia in 1994 (Silvert and Hargrave, 1995), Plymouth, UK (1996) and Boston, MA in 2001 (Silvert, 2001) addressed a number of issues related to environmental assessment. In particular, the ICES Symposium received papers on:

- Benthic and water column monitoring at fish farms;
- Regional aspects of environmental impact of fish farming;
- Benthic effects of shellfish cultivation, including modelling;
- The design of monitoring programmes;
- Chemical analysis relevant to aquaculture;
- Behaviour of escaped fish;
- Remote sensing approaches to monitoring;
- Effects of fish farm waste on algal growth.

A major undertaking to assess the status of monitoring and management of marine aquaculture in Europe was covered by the EU Concerted Action MARAQUA (Monitoring and Regulation of Marine Aquaculture in Europe). The results of MARAQUA contain contributions of all member countries and are published in two special issues of the Journal of Applied Ichthyology.

Based on the status of WGEIM knowledge and elaborations, the Working Group decided to deal with more practical and biological aspects of mariculture in the 2002 report that can be considered as components of a larger integrated management approach while contributing to its sustainable development.

9.2 Estimating Site Potential

A critical issue in the management of mariculture is estimating the potential productivity of proposed sites, both in terms of their ability to support a commercially viable level of production and in ensuring that the environmental impact of the sites will be sustainable at an acceptable level.

9.2.1 Shellfish and algae

The productivity of shellfish sites is normally limited by availability of planktonic food, although environmental impacts are increasingly being recognised, especially for large sites. While these sites produce significant quantities of faeces and other wastes, much of their environmental impact arises from physical disturbance associated with the lines, rafts and other structures, and these impacts can be evaluated only on a site-by-site basis. In addition, the importance of shellfish farms in depleting plankton levels that might otherwise be consumed by wild components of the ecosystem is very site-specific.

Furthermore, shellfish culture may be considered as a simple modification of the use of the ecosystem. Contrary to finfish farming, no food or chemicals are added in the field. The reared species, or their biogeographic equivalent, is already part of the ecosystem. Assessing the impact of shellfish cultivation should therefore be considered by estimating the changes due to human action on the way the ecosystem works. The use of models aiming at describing the functioning of ecosystems, in terms of carbon fluxes, should be simulated whenever it is possible on a local basis. Some of these models are available (ECOPATH, inverse analysis) and may prove to be useful in describing the impact of shellfish culture on the ecosystem. However, their use cannot be generalised, as they require a good knowledge of ecological compartments in a given area. Other models can be used to improve our knowledge about the impact of shellfish culture, such as DEPOMOD, as modified for the biodeposition arising from shellfish farms, or hydrodynamic models. Another interesting use of these models is allowing predictions to be made of the importance of other ecosystem compartments, which otherwise may vary strongly within the population.

Similarly, the farming of plants, both planktonic and macroalgal, depletes nutrients and lowers light levels, but there exists no general model for how much these changes affect natural systems that can be used to set threshold levels for development.

9.2.2 Finfish

The area that has received the greatest attention to date, and for which models currently exist, is in estimating safe limits to finfish production. Because finfish farming requires the introduction of large quantities of nutrients in the form of feed to the ecosystem, the risk of serious environmental damage is significant and must be carefully evaluated in the licensing procedure.

9.2.2.1 Benthic impacts

The impacts which are generally perceived as most serious, and which have received the greatest attention, are changes in the benthos due to carbon loading (nutrients and physical disturbance are also significant causal factors, but are generally less important than carbon loading). While low levels of carbon loading can increase benthic productivity, the higher levels usually associated with fish farms generally lead to low biodiversity and a shift of benthic production to bacteria. This can create hypoxic or even anoxic conditions and possibly the production of hydrogen sulphide and other toxic gases immediately under the cages. A halo of increased productivity around this zone may to some extent compensate for the loss of production in the heavily impacted zone.

Several models for the prediction of carbon loading exist, but fortunately they are all variants of the same basic underlying theory and are consistent with each other, other than in the range of effects which they include. While further development in this area is to be expected, the basic structure is as follows:

- Faecal production can be calculated from physiological budgets that depend on the type of fish, quantity and quality of feed, and environmental variables such as temperature and photoperiod.
- Deposition of faeces on the seabed can be calculated on the basis of the current regime (typically the tidal currents), given the density and drag coefficients of the faecal matter. This depends on the type of feed, and while some fish produce particulate faeces, others (particularly salmonids) regularly produce stringy mucosoid faecal strings which not only sink slowly and are easily transported by currents, but also tend to get caught in the framework of the fish pens.
- Material that has settled on the seabed may be resuspended and transported either on a regular basis by tidal currents or episodically by storms.

These models are complicated by the fact that some assume a flat bottom while others allow for realistic bathymetry, and many do not take resuspension into account – however it is possible to obtain a good general representation by combining the best features of the many published models, as some authors have attempted to do.

It is also important to recognise that not all of the information necessary to evaluate and predict potential benthic impacts needs to come from models in the usual sense; for example, it is very difficult to model benthic resuspension and bedload transport, but examination of the seabed and identification of erosional and depositional areas in the vicinity of the site can provide equivalent useful information.

9.2.2.2 Nutrient loading

The effect of releasing nutrients into the water column is less well understood, in part because the rapid dispersion of dissolved substances generally makes this a regional rather than localised effect. The environmental impact is consequently more the effect on total production in the region (inlet, estuary, etc.) rather than that due to a single farm. This means that decisions about new licenses depend on how many sites and other sources of nutrification are in the region – this makes the decision process politically difficult, especially when several applications are made within a short period of time.

One of the major obstacles to dealing with nutrient loading is the difficulty of determining the capacity of an inlet to assimilate additional nutrients without deleterious effects. Low levels of nutrification normally lead to enhanced primary production. In fact, it may be possible to combine shellfish and finfish mariculture so that the increased primary production can be utilised by the shellfish. However, there is also an increased risk of harmful algal blooms, and of course excessive algal production can lead to anoxia if there is not enough secondary production to utilise the plant material before it decomposes. It is relatively easy to determine how much nutrification will occur from a fish farm, but at the present time we have limited ability to specify threshold values which can be used for regulatory purposes.

9.2.2.3 Biological oxygen demand

Biological Oxygen Demand (BOD) can be modelled in much the same way as nutrification, and in fact BOD can be treated as a negative nutrient.

9.2.2.4 Other effects

There are numerous other effects associated with fish farms that are not normally considered in determining site potential. For example, there is a risk of disease transmission between farms, but this is normally dealt with by regulations which specify a minimum spacing between lease sites, and these regulations do not generally relate the spacing to the size of the farms. Oxygen uptake associated with fish respiration is another consideration, but because this is very localised it is often treated as a husbandry issue rather than a matter for regulation.

9.2.3 Using models

While there are many models in the scientific literature which address many of the potential environmental impacts of mariculture, these models are of little direct use to farm managers and regulatory agencies as they require considerable scientific expertise and understanding to use correctly. For this reason, there has been increasing interest in the development of Decision Support Systems (DSS). DSS is a type of expert system that provides an effective interface between the models and people who need to use the models, but who do not have the scientific background to run and interpret the models in the form in which they are normally developed.

9.2.3.1 DSS, GIS, and ICZM

A typical DSS might work as follows: consider a fish farmer who applies to a regulatory authority for a new lease. He specifies the exact location of the site and further information about the farm operation, which the regulator enters into the DSS, presumably implemented as a program running on a computer. The DSS program then retrieves additional information from a GIS (Geographical Information System) database to determine relevant data for the site, such as water depth, current regime and bottom type, as well as any additional factors relating to other uses that might come into conflict with the proposed farm – these could include many aspects such as transportation use, effluent discharges in the locality, and recreational facilities. Based on this information, the DSS can then provide basic guidance to the regulator that can be used in formulating a decision.

The inner workings of the DSS include two basic components: first, it needs to be able to access a GIS database for the information associated with the site, and second, it can provide a user-friendly front end for using these data to run the models that predict environmental impacts.

The chief advantages of a DSS are two-fold – first of all, the incorporation of GIS means that it serves as a central repository for all of the geographically indexed information that is available for evaluation of mariculture licenses, as well as for other coastal zone uses. Secondly, the ability to include complex mathematical models within the framework of an easily manipulated user interface means that scientific knowledge and information that might otherwise be ignored can be included in the decision-making process.

In some cases a DSS can provide a conclusive answer, although this is likely to be rare – for example, if the data in the GIS show that the proposed site is illegally close to a sewage outfall or lies in a designated transport channel, then the application would have to be rejected. In many cases the output of the program would be only suggestive, and the regulator would have to make a decision based on further information. However, a properly designed DSS can provide guidance in determining what more needs to be known, which can safeguard applicants against having to provide masses of costly data much of which are likely to prove irrelevant, and can incorporate these added data in a more refined evaluation of the application and of the site potential.

Consider, for example, information about currents, which is of critical importance in evaluating the probable impacts of a fish farm (in addition to being essential for the design of moorings, pen configuration, and other structural features of the farm). No GIS is likely to provide completely reliable information on the current regime at a specific location, unless by chance that location was the site of one of the moorings used to construct the database. A DSS can therefore make a best guess at the currents at the site, using either smoothing of existing observations in the database or by running a physical model if one exists. The preliminary site evaluation would then contain a caveat that it was based on inadequate current data. The regulator could then inform the applicant of the results of the analysis and explain that a final decision would require that the applicant obtain and provide current data for the site.

The applicant could in turn decide whether to invest in the additional cost of providing this information on the basis of the preliminary evaluation. If the initial output of the models is favourable this would probably be worthwhile, but if it is very negative the applicant might decide on that basis to withdraw the application.

The concepts of Decision Support Systems, Geographical Information Systems, and Integrated Coastal Zone Management are closely tied together. The complexity of ICZM makes decision support without the technical features and computing power of an automated DSS impractical. The need for coordination of large amounts of geographically indexed data means that without the use of GIS it would be almost impossible to handle all the information needed for reliable decision-making. These technical tools can play a major part in dealing with mariculture issues, in integrating it with other coastal zone issues, and in coastal zone management in general.

9.2.4 Fuzzy logic approaches

In 1998, WGEIM considered alternative approaches to decision-making based on fuzzy logic, which is well suited for characterising the types of issues that arise when considering mariculture issues. Typical fuzzy characterisations would be that "The presence of the fish farm changed the appearance of the inlet from <u>beautiful</u> to <u>ugly</u>" or "the area <u>close</u> to the processing plant smells <u>bad</u>", where the fuzzy terms are underlined. While these terms sound very subjective and scientifically unsatisfactory, they are in a sense the original data – these are what some of the stakeholders may actually say – and they are difficult to quantify in any meaningful way. Economists have developed methods for expressing all value judgements in financial terms, typically through utility analysis where they ask people how much they would accept as recompense for something they do not like or what they would pay to remove it. However, there are many disadvantages to applying this to real or perceived aquaculture impacts. If, for example, a wealthy landowner says that he would expect $1,000,000 in compensation for the loss of his view of a pristine inlet, that would effectively block mariculture development in a way that can hardly be considered fair to the proponent. The advantages of using fuzzy logic in this context are that it retains the true characterisation of the conflict without converting subjective judgements into misleadingly precise monetary or other quasi-quantitative terms. It also provides the mathematical tools necessary to resolve conflicts and social optimisation in socio-political, rather than strictly economic, terms.

9.2.4.1 Fuzzy rule-based decision support systems

One can use fuzzy logic to develop decision support systems (DSS) which are based on rules of the form

IF a THEN b

where a is some fuzzy Boolean expression and b is the outcome, namely the decision that should be made (or recommended). Fuzzy rules can be used both for purely scientific decision-making and for the kinds of socio-political decisions associated with ICZM. A typical scientific rule might be,

> IF the water is shallow OR (the current is low AND the bottom is depositional)
> THEN the lease application should be rejected,

while some socio-political rules might be

> IF nutrient release is high AND seagrasses are nutrient-limited THEN there is a risk of offensive beach detritus
> IF the region is used for recreation THEN offensive beach detritus should be avoided.

Of course, a complete DSS would contain many such rules along with prescriptions for resolving conflicts between them.

9.2.4.2 Combining fuzzy rules

To construct a full DSS one needs to combine several fuzzy rules, which may conflict with each other, in a reasonable way. For example, the rule given above,

> IF nutrient release is high AND seagrasses are nutrient-limited THEN there is a risk of offensive beach detritus

may trigger a conflict with the following rule that says

> IF the region is used for recreation THEN offensive beach detritus should be avoided

We resolve these conflicts by quantifying the fuzzy terms through the use of membership functions. We can usually define a range of nutrient fluxes such that below this range the nutrient release is not high and above it the nutrient release is definitely high, and within the range we may call the rate of release, say, 40 % high. We can also quantify the degree to which seagrasses are nutrient-limited. However, it is difficult to quantify what we mean by “used for recreation”, which for some people might mean casual strolling on the beach and for others implies development of tourist facilities.

The formal theory of how to combine fuzzy Boolean operators and rules will not be covered in this report, but the general approach is based on fuzzy control theory. In the above example, if nutrient release was quite high and the seagrasses were only marginally nutrient-limited, we might assign a membership of 60 % to the first Boolean operator (nutrient release is high AND seagrasses are nutrient-limited). On the other hand, we might assign a membership value of only 20 % to the variable in the second rule (the region is used for recreation). The first rule sets off the second, but by balancing the membership functions a 60 % risk factor (which is not necessarily the probability of generating detritus, since the degree of offensiveness can also be factored in) coupled with only a 20 % degree of recreational use, means that there can be problems. However, they will probably not be serious enough to mitigate against the development of mariculture.

It is important to recognise that the apparent subjectivity of the fuzzy logic approach reflects the underlying subjectivity of many of the issues that are raised about mariculture, and attempts to convert these into quantitative measures that appear more objective and scientific can be very misleading. Furthermore, there is often a high degree of uncertainty about many of the factors involved, since mariculture development often involves totally new uses of marine systems, the results of which cannot be inferred from statistical analysis of historical data. The power of fuzzy set theory for dealing with uncertainty makes it an exceptionally valuable tool.

As an initial step toward developing decision support for ICZM that includes mariculture, it would be worthwhile to initiate a project to develop a model based on fuzzy rules, the output of which could be compared with actual decision-making in the field. Validation of such a model could be the basis for expanding it into a working prototype of a decision support system for ICZM.

9.3 Mariculture and Sustainability

The Working Group discussed briefly the issue of sustainability and concluded that sustainable development is certainly a desirable political objective for any human activity. However, in order to derive methodologies to achieve this goal, well-defined objectives have to be identified, and scientific criteria need to be developed that allow objective assessment to be made of the sum of interactions across all activities in a given area, jurisdiction or larger ecosystem. The reader is referred to general definitions as outlined by UNCLOS (Agenda 21) or more specific (more aquatic resource oriented) ones as formulated by Barg, 1992; Muir, 1996, and Goodland and Daly, 1996.

Whatever definition is employed, it has to be realized that sustainability is not a fixed set of conditions. Because types and intensity of resource use constantly change, as do our constraints, achievement of sustainability depends on adequate adjustments to constant change in the resource use system, the competing pressure among users of the same or interdependent resources and changes in the market place. To achieve sustainability, therefore, involves a dynamic and adaptive management approach to environmental, economic, and social demands. Over the years, WGEIM has demonstrated in its reports how progress in a number of areas has contributed to sustainability of the industry. These include – among others – (a) the better understanding of species-specific needs leading to improved husbandry and reduced culture stress; (b) improved methods of preventing disease outbreaks through appropriate development of vaccines and their mass application; (c) improved predictive modelling of benthic impact and nutrient release, thereby permitting estimates of site-specific carrying and holding capacity; (d) improved hatchery and broodstock management to produce healthy and disease-resistant strains; (e) restrictive measures on use of antimicrobials and other chemicals; and (f) improved site selection criteria and monitoring programmes which help safeguard the environment and the industry both from itself and other users. Along these lines, the Working Group considered a number of new developments and research findings that have additional bearing on further improvements to our ability to achieve sustainability of mariculture.

9.3.1 Case studies

In the Netherlands, the family of COSMO-models (COastal zone Simulation MOdel) has been developed and modified for a number of applications. The main aim of the set of models and subroutines is to foster the decision-making process by developing conflict scenarios and visualising the potential interactions and threats between various developments that have been developed. The modules allow an interactive operation with communities, local authorities and regional planners. Although initially a training tool, several modules with specific applications have been developed. One especially useful element is helpful in creating awareness of potential long-term effects of sea level rise on nearshore economic activities and is, therefore, useful in training decision-makers in multiple-effect considerations. Long-term planning involving site selection and changes in system dynamics may benefit from such tools, while also being linked to more general DSS systems as described in the section on “multi-objective optimisation”.

Another expert system that contains elements useful for consideration in evaluating resource use interactions is the IterWad monitoring and environmental management DSS for assessing seabird population status in relation to coastal economic activities. Again, this system (developed in the Netherlands) does not contain a specific model linking with mariculture needs. Since seabirds and mussel beds in the Wadden Sea are ecologically and economically linked, it would be advisable to promote this and similar systems to develop modules that particularly link to mariculture needs and interactions. The potential for developing this tool further should be evaluated as it is designed to collect data on the Wadden Sea in general.

Reference is also made to the RamCo development, a modelling tool for rapid assessment of the coastal zone that also was developed by several Dutch experts to prepare site-specific scenarios on general coastal habitat changes in the face of climate change (e.g., sea level rise). The RamCo methodology does not claim to be a decision support system (DSS), but can be utilized in support of such systems, in particular, when considering long-term investments and their fate in face of global climate change.

A dynamic DSS has been developed with the Sim-Coast Fuzzy Logic Expert System, which follows a structure similar to other such DSS used in areas such as control and consumer electronics, decision support in medicine, business and finance decision support, market vulnerability analysis and forecasting.

As already reported earlier (WGEIM Reports 1998, 1999), the conceptual basis of SimCoast is a two-dimensional multi-zoned transect onto which key features such as ports, laws, mangroves, wetlands, aquaculture sites and other activities such as fisheries, tourism and rural coastal development can be mapped, evaluated and linked to processes. These evaluations are the result of consensual expert rules and examples of such role formulation are presented in Section 9.5.2, below.

There are a number of tools presently under development for use in planning and management that have direct utility in ICZM. These are based on GIS applications, satellite imagery and combinations of these, particularly suitable for site selection, monitoring and prediction of harmful algal blooms, water quality and changes in coastal topography. Such methodologies have been described recently for acoustic classification of marine habitats in coastal waters (Anderson *et al.*, 2002). GIS tools have been described for inspecting trawl survey data (Fortunati *et al.*, 2002), automated acoustic logging systems for commercial fishing vessels and data visualization (Melvin *et al.*, 2002), and visualisation of spatio-temporal data for fisheries management purposes (Kemp and Meaden, 2002).

9.3.2 Multi-objective optimisation and development of Decision Support Systems (DSS)

Decision Support Systems (DSS) that include other economic and socio-economic elements as well as mariculture need to be developed. The ICES WGEIM membership feels that in order to work towards such systems, the development of specific modules restricted to biological and ecological issues may be all that can presently be prepared for incorporation into ICZM systems. At present, we are aware of a number of EU projects and of national initiatives that already prepare development tools that can be incorporated into ICZM management schemes.

9.4 Mariculture Systems, Environmental Interactions, and Escapees

9.4.1 Technology improvements

As presented in Section 6, technology improvements have greatly contributed to the reduction of site-specific impacts. These include:

- Improved automated feeding and nutritional requirements and formulations (thereby reducing feed loss);
- Development of integrated farming systems, including artificial reefs near cages in order to assist in effective nutrient recovery and conversion;
- The continued development of effective vaccines that help to reduce the overall use of antimicrobial compounds;
- The trend towards co-culture with species of different trophic levels;
- The utilization of more exposed sites to defray environmental loads and pressures from competing resource uses in nearshore habitats;
- The development of recirculation systems to move towards onshore production;
- The inclusion of new species into mariculture.

9.4.2 Environmental interactions and environmental management

In order to minimize environmental impacts, the development of Codes of Conduct (Codes of Practice) for responsible aquaculture has started in several regions. Following the FAO initiative to develop a Code of Conduct for Responsible Fisheries, several countries have, over the past few years, developed specific codes for the aquaculture industry in coastal waters. It is recommended that ICES Member Countries not yet equipped with such codes for their industries should consider the benefits that can be derived from such an international benchmarking exercise. Suitable subjects for codes include:

- various guidelines for production systems, environmental guidelines;
- aesthetic/landscape/scenic issues;
- animal welfare issues;
- disease management;
- waste disposal practices;
- harvesting procedures;
- interactions with algal blooms;
- eco-labelling and organic farming;
- improved control and management schemes to reduce impacts;
- technical aspects and opportunities for developing farms in less sheltered areas, or offshore areas.

Possible interactions between fish farms and the occurrence of harmful algal blooms are of considerable current environmental and public interest in several countries. There are few research projects clearly directed at this proposed linkage. A project AQUATOXSAL has recently been carried out in Chile to investigate possible links between aquaculture and harmful algal events.

The overall objective of the project was to provide management tools for the sustainable development of aquaculture in the South of Chile. The rapid exponential growth of the fish-farming industry during the last ten years produced important socio-economic benefits. The salmon production during the year 2000 was around 250,000 tonnes, placing Chile second in the world after Norway. This industry is, however, adversely affected by recurring noxious phytoplankton blooms in coastal waters throughout the region. The implications are relevant to human and fish health, as well as social and economic effects. The accumulated actual annual losses in the Chilean industry, due to toxic algal blooms in fishfarming, is greater than $12 million USD. The potential losses for the industry due to recurring events are estimated to be greater than $50 million USD, and these figures exclude risks for human health and life.

The specific objectives of the project were to estimate the ecological impact of fish farming on coastal seawater quality and on benthos disturbance, and to determine primarily how these impacts relate to harmful phytoplankton blooms. To achieve these objectives, a number of sub-projects were realized:

- *in situ* measurements to the describe the pelagic environment in three different areas, including water quality criteria, particular benthic conditions used in predictive modelling of carbon deposition under and around farms;
- *in situ* and laboratory experiments on physiological responses of phytoplankton species to environmental change in order to identify parameters related to aquaculture and involved in algal populations imbalance (likely responsible in bloom evolvement). The effects of animal excretion products on phytoplankton growth (e.g., fish excreta, bivalve mucus release and effects of uneaten fish feed on microalgal species performance) were experimentally tested while the effects of aquacultural wastes on phytoplankton community structure were studied *in situ*. Additionally, the potential contribution of atmospheric disturbance (UV) to microalgal physiology and performance was also studied in the Patagonian country.

The results of the above studies are brought together synthetically in order to derive recommendations for aquaculture management. These include the development of impact indices, a predictive dispersion model to be used in the benthic domain while also considering harmful bloom assessment. The full report is included in Annex 5.

9.4.2.1 Interaction of mariculture with other resource users

9.4.2.1.1 Sustainability of feed resources (fishmeal and fish oil)

As aquaculture grows, there will be a need to replace fishmeal and fish oils in farmed fish diets since they are limited and have to be shared with other end users, including elements of terrestrial agriculture. Over the years, numerous research projects have shown that it is possible, when growing salmonids as carnivorous species, to partially replace fishmeal (e.g., early studies during the 1970s and 1980s tested the re-use of feather meal from the poultry industry successfully) or totally replace animal protein by plant protein without losing growth or quality (Dabrowski *et al.*, 2001). Most studies were undertaken on experimental and not on commercial scales.

Numerous projects are presently under way in several ICES Member Countries to better understand the use of alternative energy and protein sources for fishmeal in commercial aquaculture diets. Among these are also several EU projects that have been recently clustered to gain momentum. These include the following projects in the EU Quality of Life, Framework 5 portfolio:

PEPPA: Perspectives of Plant Protein usage in Aquaculture. QLRT-1999–30068 (www.fishbiology.net/peppa.html);

GUTINTEGRITY: Gastrointestinal Functions and Food Intake Regulation in Salmonids: Impact of Dietary Vegetable Lipids. QLRT-1999–31656 (http://vivaldi.zool.gu.se/Personal/Pages/ThrandurB/Research_GUTINTEGRITY.html);

FPPARS: Cloning and functional analysis of fish peroxisome proliferator activators: transcriptional control of lipid metabolism in cultivated fish. QLRT-1999–30360;

PUFAFEED: Feed for aquatic animals that contains cultivated marine microorganisms as alternatives for fish oil. QLRT-1999–30271; and

RAFOA: Researching Alternatives to Fish Oils for Aquaculture. QLRT-1999–30058.

The projects started in January 2001, and will each run for three years.

It has been argued recently (e.g., Naylor *et al.*, 2000) that mariculture of carnivorous species acts to increase the pressure on natural fish stocks. Consequently, cultivation of carnivorous species should be limited. However, the development of mariculture is not resource limited but demand limited, as alternatives for feed ingredients will become available as the demand for them increases and therefore active limitation of aquaculture is not necessary.

This area has been explicitly discussed in a position paper prepared by various experts around the world (Roth *et al.*, 2001, see Annex 4) in an attempt to bring the discussion on “farming up and fishing down the food web” back to realistic grounds. Additionally, Barlow and Pike (unpub. available on www.ifoma.com) commented on the same issue and addressed questions concerning whether the fish resources utilised for fishmeal production are exploited in a sustainable manner, with particular reference to mariculture and aquaculture feed production in general. They write that most feed fish stocks are fished to remain fully sustainable. In Europe, quotas exist for most species of fish including sand-eel. Blue whiting currently is probably the only exception in northern European waters. These authors further state that "Sandeels.... were the subject of much publicity" when the industry was accused of over-fishing. Yet catches had always been well within stock sustainability. Indeed the quota subsequently set confirmed this – the quota has only once been reached. Another issue raised was "sensitive areas" where seabirds breed and where fish stocks can be critical for successful breeding. This issue has been resolved in Europe through ICES: fishing in sensitive areas is suspended if seabird breeding success [for whatever reason] falls. Kittiwakes are the "indicator" species, with a limit set on 0.5 fledglings reared per nest. Below this, fishing is stopped until breeding success reaches 0.75 fledglings per nest (ICES, 2000).

In reviewing the literature further, members of the Working Group concluded, in accordance with many statements made recently by other experts worldwide, that there is no evidence for the suggestions made by Naylor *et al.* (2000) that aquaculture is increasing the pressure on wild fish stocks for feed manufacture (see http://response.home.sapo.pt). Further growth of the aquaculture industry is unlikely to have a negative impact on the sustainability of wild feed fish resources, as exploitation of these resources is tightly controlled and usage will be diverted from other users where the value of fishmeal uses is lower. Replacements will become available on a commercial scale in the near future, while studies show that, for short-term rearing, there is no negative effect on feed conversion and fish health. However, replacing fishmeal with vegetable protein will increase the waste output of carbon and settling faeces.

With respect to fish oils, potential replacements exist, though they are more costly. However, the potential side-effects on fish quality and fish health are not yet fully understood. As Barlow and Pike (2001) rightly point out, there seem to be few adverse effects when fish oils are partially substituted, in particular in relation to fat composition of fish (increase in omega-6 PUFAS instead of omega-3 PUFAS), flavour of the meat and disease susceptibility. It is in this area that intensified research is needed to be able to understand the effects of fish oil substitution and to provide better advice to the industry on what levels of substitution might be recommended in the future. Such research is urgent, as it is estimated that by 2010 the total amount of fish oils needed for aquaculture will be around 1.2 million tonnes. This represents about 92 % of the world production. Barlow and Pike (2001) note that this estimate already included allowance for some fish oil substitution. Research is also required to develop new technologies that may provide options for utilization of additional marine lipid resources from marine plants and other trophic levels.

Much more critical aspects relate to the ongoing discussion on dioxins in fishmeals and fish oils originating from the northern and southern hemispheres. It is clear that fish oils from the northern hemisphere contain higher concentrations of dioxins, and dioxin-like CBs, than do fish oils from the southern hemisphere. The feed industry is already adopting strategies to limit the concentrations of these compounds in the formulated feeds for farmed fish. However, this process inevitably reduces the flexibility available to the industry, and may restrict options for the reallocation of the utilisation of fish oil resources between industrial sectors. Recent information on the concentrations of dioxins and dioxin-like CBs in raw feed materials is given in Annex 6.

9.4.2.1.2 Interactions involving the space requirements for mariculture

Mariculture is currently conducted in coastal waters, and often competes with other activities, such as fishing, navigation, recreational activities, and conservation. These activities are all major competitors for space, as are the coastal fisheries. Coastal areas also support several species of fishes that depend on the shallow waters for their feeding or reproduction. Many fish nursery areas are located in these shallow waters. Development of aquaculture may contribute to reducing the space available for these nurseries. On the other hand, mariculture may constitute a physical obstacle for fishing activities (cages, offshore longlines, etc.) and therefore contribute to protecting highly sensitive nurseries from fishing pressure. Aquaculturists also need to access local harbour facilities for their support vessels, and in some cases this can create additional pressure on fishing vessels during unloading of catches.

To solve spatially-related competition between coastal activities, the spatial requirements for mariculture should be taken into account in the process of ICZM, in common with the requirements of other activities. Therefore, a spatial analysis of the requirements for the different users using GIS should be considered a prime objective of coastal management. Such analysis can also help to identify opportunities for further development of aquaculture in coastal waters.

9.4.2.1.3 Interactions with coastal nursery grounds

Aspects of the interactions of wastes from mariculture operations with coastal ecosystems have been discussed by WGEIM on many occasions, and a full review is not attempted here. The waste products from cultivated species are the basis of many ecological interactions in the coastal areas. The main impact is currently encountered on the sea bottom, where an excess of organic materials, from faeces and waste food, accumulate beneath installations, thus leading to possible sediment degradation and changes in the infaunal composition. Species composition may also be affected, and increased biomass of meiofauna has been reported. Changes in the characteristics of the benthic faunal community are classically observed, with a decline of bivalves and an increase in several classes of polychaetes (Pearson and Rosenberg, 1978). Several species of fishes may be attracted by this input of new potential food. Tenore *et al.* (1982) have pointed out that the transport of organic-rich sediment from mussel culture to coastal areas may enhance inshore fisheries. Juvenile stages may benefit first from these faunal changes, as they are able to consume harpacticoid copepods or annelids favoured by the organic enrichment.

As part of any monitoring programme, it is necessary to evaluate the changes in benthic fauna provoked by the deposition of wastes coming from aquacultural installations. Furthermore, the complex interactions between mariculture and fish populations should be investigated with regard to the occurrence of new pathways in food webs related to the development of mariculture, the role of potential food available for fishes on aquaculture installations (biofouling), including the attractive potential of aquaculture sites to attract fish and other organisms, such as eider ducks.

Mariculture operations inevitably lead to emissions of various substances and ecological interactions in the coastal zones. These include processes that are mediated through food chains, as well as intra- and inter-species competition at different levels. This requires a holistic approach, in which the interactions are clarified and quantified, and appropriate EQOs and EQSs are developed to safeguard the environment as well as the mariculture operations.

9.4.2.1.4 Social interactions

Mariculture tends to provoke negative public perceptions because of its very visible and exposed nature and because of a general tendency to feel concern about any new intrusion on natural ecosystems, no matter how benign. It is commonly the case that the aquatic component of the coastal zone is in public ownership and subject to various uses (unlike land, which is usually under private ownership before it is developed); the potential for conflict is always present, even if at a superficial level. Furthermore, inlets suitable for mariculture are almost always multiple-use areas, supporting capture fisheries, both commercial and recreational boating, and they are often places where the human tendency to prefer living in sight of the water attracts housing. It is therefore inescapable that mariculture must be considered in the context of coastal zone planning and is therefore a natural component of ICZM.

While standard economic theory offers several tools for dealing with conflicts of this sort, such as Pareto optimisation, it is not clear that they can easily be applied to many of the types of conflicts that arise with mariculture. Most of these procedures are based on assigning value to different components of the system, but many of the issues that involve mariculture involve subjective considerations such as loss of scenery and recreational opportunities. Scientific confusion and misinformation often confound the situation. For example, if any unpleasant phenomena are found in the vicinity of a fish farm, such as smelly, rotting vegetation along the shoreline or a harmful algal bloom, then many people automatically blame the fish farm. There also can be unusual political situations – whereas many conflicts about industrial development pit wealthy industries against poor people who live close to factories, in the case of mariculture one often finds small fish farmers under attack from wealthy individuals who own attractive waterfront property. The usual political and legal structures for dealing with development, where an army of well-paid lawyers takes on a large but poorly funded citizenry, are not appropriate when under-capitalised fish farmers are under attack from rich home owners and agencies which promote recreational tourism. For this reason, it is not always feasible to apply traditional methods of conflict resolution and multi-objective decision-making to ICZM when mariculture issues are involved.

Conflicts often arise within and between social groups exploiting the coastal area. For example, a conflict between fishermen and oystermen around a shellfish culture project in subtidal areas of the Bay of Marennes Oleron (which are currently fished) has been documented in the framework of a research programme (LITEAU programme, French Ministry of Environment). This programme includes a social analysis, dealing with the rationale and behaviour of actors concerned with what is perceived to be tremendous changes. The purpose of the project is to analyse the causes that lead the stakeholder groups to react, in some cases, in negative ways.

Aiming to better understand the perception of threats felt by the different actors competing for space and resources in coastal areas, *the WGEIM recommends that* emphasis should be given to research in the social sciences to help establish a consensus among users in the coastal zone (e.g., within the framework of an ICZM initiative (e.g., Section 7, consensus-building)).

9.4.2.1.5 Escaped fish and interactions with wild populations

The issue of escaped fish and their potential interaction with native stocks has previously been addressed by the WGEIM and by the Working Group on the Application of Genetics in Fisheries and Mariculture. Recently, additional information has become available from long-term studies in Chile, following the 1994–1995 large accidental losses of farmed salmon species in heavy storms (Soto *et al.,* 2001). The uniqueness of the observations in Chile relates to the fact that none of the species is a native species, so that their performance can be directly compared. The number of escaped salmon was sufficient to have created reproductive populations in the wild, but most of the escapes probably did not survive long enough to spawn. However, the large number of escapes (possible more than 4,000,000 fish of around 1 kg weight) became an attractive target for artisanal fisheries. 40–80 % of the recaptured Coho salmon (at the appropriate time of year) were found to have sexually matured. By contrast, only 15 % of the rainbow trout were mature, while no mature Atlantic salmon were found. The Atlantic salmon appeared to have performed relatively poorly at feeding in the wild. The authors concluded that the escapes would only have a significant impact on native species if they were able to form reproducing populations. They considered this to be rather unlikely, as the salmon were strongly targeted by the artisanal fisheries.

WGEIM received two short presentations from members of the WG on North Atlantic Salmon on escapes, and the working paper WGNAS WP 01/09 on the causes of farmed Atlantic salmon escapes from sea cages in North America. Available data suggest that the most important cause of escapes in North America are failures of cages during storm events. Escapes are a continuing concern in other salmon-farming countries. Current data indicate that the proportion of farmed fish in wild catches is about 1 % in Scotland, but generally around 20–25 % in Norway. In Scotland, better containment is being encouraged and an Industry Code of Practice was introduced in 2000. The Scottish Executive monitors compliance with key elements of the Code. Under the Environmental Impact Assessment regulations, escape contingency plans are required as part of the consenting of all new and modified farm developments. Proposals have also been made to introduce compulsory reporting of escapes. This will be supported by inspections of aspects of cage integrity, in recognition of the joint NASCO/International Salmon Farmers Association Code on Containment. Discussions are also in progress with the industry to develop procedures that will permit efforts to be made to quickly recapture escapees close to the site of the escape.

In Scotland, and other Northern European countries, there was relatively little obstruction to escaped salmon joining wild runs into spawning rivers. Prof. Andrew Ferguson, Queen's University, Belfast and Dr Philip McGinnity, Dept of the Marine, Ireland, have undertaken research over the past 10 years, partly EU funded. They have studied the lifetime fitness of farm fish, wild fish, and farm x wild hybrids. This showed that farm fish were only 1–2 % as fit from egg to egg as wild fish in the situation studied (Burrishole river system, Eire). F1 hybrids and F2 backcrosses were intermediate in approximate proportion to the relative proportion of farm and wild ancestry they had. They also showed that a transplanted wild stock from a neighbouring river system was only 20 % as fit as the native fish. The differences were highly significant statistically. An implication of this work is that a small proportion of escapes interbreeding with native wild stocks in rivers can have an adverse effect on the fitness of the wild population.

It should be noted that the issues of escaped/wild fish interactions thus far addressed in the ICES community pertain solely to salmonids which show a specific migration and homing pattern. However, new species are presently emerging in marine aquaculture and there is an urgent need to study the potential risks associated with escapes of non-migratory species with native localized populations, the number of which may exceed the native local population by orders of magnitude once the industry becomes established. The MARAQUA reports (Youngson *et al.*, 2001) contained some discussion of the likely consequences of sea bass cultivation in the Mediterranean area, where the western stock has been used almost exclusively in cultivation to the probable detriment of the wild eastern stock. There are also concerns over the possible impact of escapes of seabream on wild seabream that breed in a rather limited number of locations.

9.5 Exotic Species

It was not possible to deal with this matter adequately at the current meeting of WGEIM. However, it was noted that there was increased concern over the consequences of transfers of exotic species by commercial aquaculture, the aquarium trade, fisheries and shipping (ballast water).

There are several high-profile recent "arrivals" in the Northeast Atlantic. These include the Kamchatka king crab, which appears to out-compete *Carcinus* and may well give rise to serious effects through predation on shellfish beds. *Pfisteria* has been found, and poses a significant threat to fish farming. These matters are primarily discussed at ICES WGITMO, which has paid particular attention to the transfer of diseases through common commercial practices (see report of 2002 meeting).

9.6 Other Outstanding Issues

As discussed in previous WG meetings, WGEIM reiterated the need to have concern for the impacts that other users of the coastal zone can have on mariculture. However, there was no time to address these questions in any substantive detail. Some issues were mentioned in discussion, but were not elaborated. These included:

- The risk to aquaculture from harmful algal bloom events. What can be done? New approaches to remote sensing, warning systems, forecasting needs, etc.
- Education, public awareness campaigns to raise the profile of aquaculture in relation to coastal zone planning**.** The gaps between research results and application in industrial practice, regulation and planning.
- The need to improve local planning and management procedures to develop mutually beneficial consensus attitudes to the siting and management of aquaculture facilities.

References

ADB (Asian Development Bank)/NACA(Network of Aquaculture Centres in Asia-Pacific). 1998. Aquaculture and the Environment. Report on a Regional Study and Workshop: Aquaculture sustainability and the environment. Bangkok, Thailand IVX, 1–491 pp.

Anderson, J.T., Gregory, R.S., and Collins, W.T. 2002. Acoustic classification of marine habitats in coastal Newfoundland. ICES J. Mar. Sci., 59: 156–167.

Barlow, S.M., and Pike, I.H. 2001, unpub. Sustainability of fishmeal and oil supply. Available on website www.ifoma.com

Black, K.D., Sayer, M.D.J., Cook, E., Angel, D., Spanier, E., Karakassis, I., Malej, A., Colins, K., Pickering, H., Whitmarsh, D., and Lojen, S. 2001. BIOFAQs – BIOFiltration and Aquaculture: an evaluation of substrate deployment performance with mariculture developments. Pp. 205–208. *In:* Uriarte, A., Basurco, B. (Eds.) 2001. Environmental Impact Assessment of Mediterranean Aquaculture Farms. Cahiers Options Méditerranéennes, 55: 1–213.

Boyd, C.E. 1999. Codes of Practice for Responsible Shrimp Farming. Global Aquaculture Alliance, St. Louis, MO, USA 42 pp.

Boyd, C.E., Tucker, C.S., Queiroz, J., and Polioudakis, E. 2000. Implementation Plan of a Global Aquaculture Alliance Responsible Aquaculture Programme. Global Aquaculture Alliance (mimeographed). 19 pp. Plus 7 Appendices.

Bridge, L. 2001. Policy instruments for integrated coastal zone management in selected European countries CoastLink, Maidstone, UK 95 pp. (CoastLink: European Network for Sustainable Coasts and Seas).

EU DG Environment, Fisheries, Regional Policy 1999. Towards a European Integrated Coastal Zone Management (ICZM) Strategy: General principles and policy options. A Reflection Paper. European Communities 1999 31 pp plus maps.

EUROCAT: 2002. European catchments: catchment changes and their impact on the coast. EU funded project, Res Directorate General, EVK1-CT-2000–00044). http//www.iia-cnr.unical.it/EUROCAT/prject.htm

Fishmeal Information Network/Grain and Feed Trade Association (GAFTA). 2000. Fishmeal from sustainable sources. A summary of documentary evidence. GAFTA, Gafta House, 6 Chapel Place, Rivington Street, London EC2A 3SH.

Fortunati, L., Garofalo, G., and Demontis, R. 2002. TSDV: A GIS tool for inspecting trawl survey data. ICES J. Mar. Sci., 59: 168–178.

Gallagher, A. 2001. Putting sustainability into Practice in the Coastal Environment. Coastlink Maidstone, UK, 60 pp. (Coastlink: European Network for sustainable Coasts and Seas).

Gee, K., Kannen, A., and Sterr, H. 2000.- Integrated Coastal Zone Management: what Lessons for Germany and Europe. Christian-Albrecht Univ. Kiel, Report, 21: 1–125.

GESAMP. 2001. Planning and Management for sustainable coastal aquaculture development. Rep. Stud. GESAMP 68: 90 pp.

Gimenez Casalduero, F. 2001. Integrated systems: "Environmental clean" aquaculture. Pp. 139–145. In: Uriarte, A., Basurco, B. (Eds.) 2001. Environmental Impact Assessment of Mediterranean Aquaculture Farms. Cahiers Options Méditerranéennes, 55: 1–213.

Giménez Casalduero, F. 20001. Bioindicators. Tools for the impact assessment of aquaculture activities on the marine communities. Pp. 147–157. *In.* Uriarte, A., Basurco, B. (Eds.) 2001. Environmental Impact Assessment of Mediterranean Aquaculture Farms. Cahiers Options Méditerranéennes, 55: 1–213.

ICES. 1999. Report of the Working Group on Environmental Interactions of Mariculture, ICES CM 1999/F:2. Appendix 9. Pp A9-I-XIV.

ICES. 2000. Report of the ICES Advisory Committee on the Marine Environment, 1999. ICES Cooperative Research Report, 239: 7–10.

Indo-Pacific Fisheries Commission 1994. Proceedings of the Symposium on Socio-Economic Issues in Coastal Fisheries Management, Bangkok, Thailand, 23–26 November 1993. RAPA Publication 1994/8, 422 pp.

Kemp, Z. and Meaden, G. 2002. Visualization for fisheries management from a spatiotemporal perspective. ICES J. Mar. Sci., 59: 190–202.

Lall, S. 2000. Role of nutrition in fish health. International Aquafeed. Issue, 2: 10–14.

Melvin, G., Li, Y., Mayer, L., and Clay, A. 2002. Commercial fishing vessels, automatic acoustic logging systems and 3D data visualisation. ICES J. Mar. Sci., 59: 179–189.

NACA/FAO 2000. Report of the Conference on Aquaculture in the Third Millennium. 20–25 February 2000, Bangkok, Thailand. NACA, Bangkok and FAO, Rome, 120 pp.

Naylor, R. L., Goldburg, G.R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J.F., Olke, C., Lubchenco, J., Mooney, H., and Troell, M. 2000. Effect of aquaculture on world fish supplies. Nature, Vol. 405, 29 June 2000.

Pearson, T.H., and Rosenberg, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Ann. Rev., 16: 229–311.

Rosenthal, H., McGlade, J., and Gollasch, S. 2001. The role of aquaculture in integrated coastal zone management. Bull. Aquacult. Assoc. Canada, 101–1: 5–10.

Roth, E. *et al.* (plus 36 co-authors) 2001. See Annex 4 (http://response.home.sapo.pt).

Soto, D., Jara, F., and Moreno, C. 2001. Escaped salmon in the inner seas, southern Chile: Facing ecological and social conflicts. Ecological Applications, 11(6): 1750–1762.

Tidwell, J.H., and Allan, G.L. 2001. Maintaining and managing the wealth from the seas. EMBO reports. 21(111): 958–963.

Uriarte, A., and Basurco, B. (Eds.) 2001. Environmental Impact Assessment of Mediterranean Aquaculture Farms. Cahiers Options Méditerranéennes, 55: 1–213.

Wildish, D.J., and Héral, M. (Eds.). 2001. Environmental effects of mariculture. ICES J. Mar. Sci., 213: 363–529.

William, S. 2001. Impact on habitats: determining what is acceptable. *In:* Marine Aquaculture and the Environment: A Meeting for Stakeholders in the Northeast, M. F. Tlusty, D. A. Bengston, H. O. Halvorson, S. D. Oktay, J. B. Pearce and R. B. Rheault (Eds.), Cape Cod Press, Falmouth, Massachusetts, p. 16–40.

William, S., and Hargrave, B. 1995. Report on International Workshop on Modelling Environmental Interactions of Mariculture. ICES CM 1995/F:6.

Youngson, A, Dosdat, A, Saroglia, M., and Jordan, W.C. 2001. Genetic interactions between marine finfish species in European aquaculture and wild conspecifics. J Appl Ichthyol., 17, 153–162.

10 UPDATE THE *ICES COOPERATIVE RESEARCH REPORT* #202 ON CHEMICALS USED IN AQUACULTURE

During the meeting, WGEIM was able to make significant progress towards an updated version of *ICES Cooperative Research Report* 202 “Chemicals used in Mariculture”. WGEIM agreed to continue to work on the text intersessionally with a view to having a complete draft for approval during summer 2002.

Table 10.1. Chemicals used in maricuture.

Therapeutant group	**UK**	**Norway***	**Ireland**	**Canada**
Antibacterials	Amoxycillin		Amoxycillin	
	Florfenicol	Florfenicol		Florfenicol
		Flumequin		
		Oxolinic acid		
	Oxytetracycline	Oxytetracycline	Oxytetracycline	Oxytetracycline
	Potentiated sulphonamides (i.e., sulphadiazine – trimethoprim)		Potentiated sulphonamides (i.e., sulphadiazine – trimethoprim)	Potentiated sulphonamides (i.e., sulphadiazine - trimethoprim, and sulphadimethoxine – ormetoprim)
	Sarafloxacin		Sarafloxacin	
Parasiticides (sealice control)	Azamethiphos			Azamethiphos
	Cypermethrin	Cypermethrin	Cypermethrin	
		Deltamethrin		
		Diflubenzuron		
	Emamectin benzoate	Emamectin benzoate	Emamectin benzoate	Emamectin benzoate
	Hydrogen peroxide			
	Teflubenzuron	Teflubenzuron	Teflubenzuron	
Fungicides	Bronopol	Bronopol		
				Hydrogen peroxide
				Formalin
Anaesthetics	Tricaine methanesulphonate			Tricaine methanesulphonate

*In Norway, medicines authorised for use in agriculture may also be used in mariculture. The substances listed are those most frequently used in 1999–2000 (WGEIM report, 2002, Norway country report).

In discussion, WGEIM confirmed the difficulty involved in trying to prepare a comprehensive list of licensed/authorised chemicals in all ICES member Countries. However, Table 10.1 was prepared covering four countries. In most cases, quantitative information on the amounts of these products used is difficult to obtain, since most countries do not have a central system to record/store data. The primary exceptions are Norway (quantities of chemicals used by industry are available in ICES WGEIM reports) and Scotland (information has been collated for the southwest Scotland for most of the last decade).

The centralised system of medicine supply in the Norwegian salmon farming industry allows comprehensive and reliable data on the usage of medicines to be collected. As a result of extensive vaccination programmes and hygienic measures, bacterial diseases now cause only minor problems. This situation is reflected in the current (2002) low consumption of antibiotics by the Norwegian salmon industry (Table 10.2). At present, these drugs are used mainly on broodstock fish (Figure 10.1). Usage of antibiotics was at a maximum in 1987 and passed through a subsidiary maximum in 1990. Since then, usage has declined to low levels, even though production has increased almost continuously over the last two decades.

Table 10.2. Weights of antibiotics used in the Norwegian mariculture industry from 1996 to 2000. Quantities are given as kilograms of active component. Source: Norwegian Directorate of Fisheries.

	Enrofloxacin	Florfenicol	Flumequin	Oxolinic acid	Oxytetracycline	Others	Total
1996	-	64.0	97.0	844.0	19.0	19.8	**1043.8**
1997	-	26.5	71.4	445.5	11.8	0.5	**555.7**
1998	-	128.6	116.8	421.7	4.2	-	**671.2**
1999	-	65.0	7.0	494.0	25.0	-	**591.0**
2000	0.02	146.2	16.8	434.5	2.1	-	**599.6**

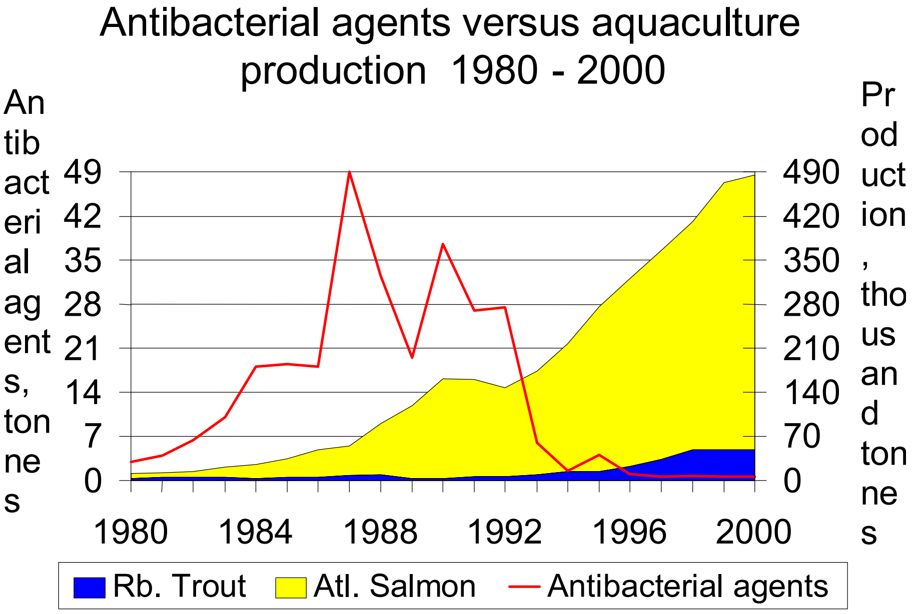


Figure 10.1. Antibiotic consumption from 1980 to 2000 and production of Atlantic salmon and rainbow trout. Source: Norwegian Directorate of Fisheries.

Sealice are still the cause of substantial losses in Norwegian mariculture and the use of parasiticides is an important element in the control of infestations. Table 10.2 shows that there has been a reduction in the quantities of drugs used, partly due to the introduction of the more effective emamectin benzoate.

Table 10.3. Usage (kg) of ecto- and endoparasite drugs in kg active component from 1996 to 2000. **A**=Cypermethrin, **B**=Deltamethrin, **C**=Diflubenzuron**, D**=Emamectin benzoate, **E**=Teflubenzuron. Source: Norwegian Directorate of Fisheries.

	A	B	C	D	E	Others
1996	-	0.1	103.0	-	547.0	968.0
1997	0	0	462.1	-	1429.7	386.4
1998	8.5	28.4	585.1	0	1186.9	128.3
1999	19.0	11.0	50.0	3.5	231.0	14.0
2000	68.7	17.6	12.4	33.6	61.5	-

Southwest Scotland has accounted for around 17–22 % of the total Scottish production of farmed salmon between 1991 and 1999. Data on medicine usage has been supplied by farms to the Scottish Environment Protection Agency.

Five active antimicrobial compounds have been used in Scotland between 1991 and 1999 (Table 10.4). The total weight used per year remained relatively constant from 1991–1996 at 2600–4400 kg, but has declined steeply since then. Usage in 1999 was very low (less than 100 kg).

In the period 1991–1997, the pattern of use of antimicrobial compounds changed gradually. Potentiated sulphonamides contributed a decreasing percentage (from 65 % to 5 %) of the total mass of antimicrobials used, while the percentage of amoxycillin increased from 20 % to 68 % over the same period. There have been dramatic swings in the pattern of use in 1997–1999. In 1998, over 90 % of the mass used was oxytetracycline, while in 1999, only oxolinic acid was used. It is not clear whether this is as a result of greater coordination of medicine use within the industry.

Table 10.4. Annual production of farmed Atlantic salmon, and use of antimicrobial agents, in SEPA South West area, Scotland, 1991–1999.

Year	Production tonnes	Amoxycillin kg	Furazolidone kg	Oxolinic acid kg	Oxytetracycline kg	Potentiated sulphonamides kg	Total kg
1991	8005	602.2	65.0	272.8	705.3	1401.2	3046.5
1992	6458	992.8	63.0	503.0	1561.4	1315.1	4435.3
1993	8675	842.0	-	673.5	1169.5	1093.8	3778.8
1994	13184	747.0	-	108.7	560.8	1208.6	2625.1
1995	15777	860.3	-	468.2	721.8	750.8	2801.1
1996	17223	2026.7	-	89.1	549.0	503.5	3168.3
1997	17194	845.8	-	151.6	202.0	50.3	1249.7
1998	23722	-	-	79.9	858.0	8.3	946.2
1999	23929	-	-	16.5	-	-	16.5

The treatment dose of antimicrobial compounds differs between active ingredients. From knowledge of the standard treatment doses and durations, it is possible to calculate the weight of fish treated by each medicine each year. The total weight of fish treated has declined from 10,000–12,000 tonnes in 1991–1993, to less than 200 tonnes in 1999.

The ratio between the tonnage of fish treated with antimicrobials and the tonnage produced reached a maximum in 1992 of almost 2. This ratio has subsequently declined by a factor of around 100 to very small values, and indicates that a very significant improvement has occurred in some aspects of fish health, i.e., in conditions treatable by antimicrobial compounds. This is at least part due to the introduction of effective vaccines against furunculosis in the early-to-mid-1990s.

In Norway, the total amount of antimicrobials used declined from 48.6 tonnes in 1987 to 0.7 tonnes in 1997–1998. This is equivalent to 0.04–0.002 kg/tonne of production in the period 1993–1997, a reduction from 0.81 kg/tonne in 1987. Although these figures are not directly comparable since there are differences between Scotland and Norway in the antimicrobial agents used and treatment regimes, the equivalent figures for SEPA South West Area for the period 1996–1999 are 0.18–0.007 kg/tonne, a reduction from 0.69 kg/tonne in 1992.

The active ingredients in the main medicines used to control sealice in Scotland in 1991–1999 were dichlorvos, azamethiphos, hydrogen peroxide and cypermethrin, which are all used as bath treatments (Table 10.5). The use of newer in-feed treatments (such as those containing diflubenzuron or emamectin benzoate) was not yet significant during the period covered by the study. In order to obtain an impression of the total annual usage, it is possible to calculate the volume of water treated each year, assuming compliance with standard treatment concentrations. The volumes range from 1,910,000 m^3 in 1991 to 455,000 m^3 in 1999. The volumes of water treated have declined by a factor of 4, even though the weight of salmon produced was 3 times greater in 1999 than in 1991. Dichlorvos was always the most commonly used treatment, except in 1999.

Table 10.5 Quantities of sealice control medicines used in Atlantic salmon farming in SEPA South West Area, Scotland, 1991–1999.

Year	Azamethiphos kg	Cypermethrin kg	Dichlorvos kg	Hydrogen peroxide kg	Teflubenzuron kg
	-	-	-	-	-
1991	-	-	1914.8	-	-
1992	-	-	1573.4	-	-
1993	-	-	898.7	11118.9	-
1994	-	-	637.0	127569.9	-
1995	-	0.058	396.8	327962.0	-
1996	-	0.037	382.4	193196.2	3.8
1997	-	0.071	809.4	164589.8	-
1998	0.3	0.055	645.3	356470.8	-
1999	0.6	0.923	128.3	203697.0	-

Note: Teflubenzuron is the active ingredient of an in-feed treatment that was used on a trial basis in 1996. Its use did not constitute a significant proportion of the sealice control effort during that year, and is omitted from subsequent calculations.

The volume of water treated per tonne of fish produced has decreased from 240 m^3 in 1991–1992 to 19 m^3 in 1999. This indicates that, in 1999, fish were being treated at only 10 % of the frequency of treatment in 1991–1992 (assuming that stocking densities were similar in the two years). This may indicate a parallel improvement in the prevalence and/or severity of sealice infection.

It is clear that the Norwegian and Scottish industries are showing parallel trends in reductions in the need to use parasiticides. In the period 1993–1997, the volume of water treated per tonne of production in Norway was around 18–37 m^3, and the data suggest similar usage rates in the preceding four years. Since 1997, there has been a marked change in the Norwegian industry away from bath treatments in favour of in-feed treatments. A parallel shift in practice in Scotland started to occur a few years later. It should also be noted that Norwegian farms make more extensive use of species of wrasse as cleaner fish. There are limited stocks of the appropriate species in Scottish waters, and therefore the opportunities for the Scottish industry to adopt the use of wrasse are much more restricted.

Limited data are available on the usage of medicines (and pesticides) in Canadian aquaculture for 1999 (Table 10.6). At this time, the annual production was around 86,000 tonnes for east and west coasts combined.

Table 10.6 Use of medicines and parasiticides (for sealice control) in Canada in 1999.

Antibacterials	kg	Parasiticides	Kg
Erythromycin	6.0	Azamethiphos	10.9
Potentiated sulphonamides	1016.2	Ivermectin	6.1
Oxytetracycline	18345.3	Emamectin benzoate	415.0
Florfenicol	26.1	-	-
Totals	19393.6	-	432.0

The rate of use of antibacterial compounds is equivalent to 0.23 kg/tonne of production. This is rather less than the maxima of 0.7–0.8 kg/tonne observed at the peaks of usage in Scotland and Norway 10–15 years ago, but substantially higher than current usage rates in Norway of 0.002–0.04 kg/tonne. Anecdotal information suggests that antibacterial use is also relatively high in Chile.

It seems that, with respect to sealice bath treatments and antimicrobial medicine use, the salmon industries in Norway and Scotland have followed generally the same path of development and decreasing use of medicines, with the Scottish industry following a few years behind the Norwegian. This pattern may be characteristic of maturing marine fish farming industries. The relatively high use rate (particularly of antibacterials) in the younger industry in Canada is consistent with this interpretation. Disease management strategies develop from attempted cures to preventive approaches as the industry matures, and operators gain access to better information on the priority diseases and more experience of the particular health problems affecting their industries. This interpretation suggests that procedures in the Canadian industry could be improved and usage of antibacterial compounds reduced.

References

Burridge, L E. 2002. Chemical use in marine finfish aquaculture in Canada: A review of current practices and possible environmental effects. Unpub.

Davies, I.M., and Henderson, A. 2002. Use of medicines in the Scottish fish farming industry. In prep.

Norwegian country report. Report of ICES WGEIM 2002.

11 OTHER BUSINESS

No other business was brought forward to the working group.

12 CONSIDERATION AND APPROVAL OF RECOMMENDATIONS, INCLUDING PROPOSALS FOR A FURTHER MEETING

The Working Group on Environmental Interactions of Mariculture [WGEIM] recommends that:

1) Member Countries support research on the performance of new offshore farming systems and on the operational risks and environmental interactions associated with such new farming systems. The Mariculture Committee should through its national members foster the collection of information on national activities in this area to be considered by the working group during the next meeting;
2) ACME, the Mariculture Committee and the Delegates of ICES Member Countries make a serious effort to assure that national representation from countries with major aquaculture activities is provided at the next Working Group meeting;
3) the Working Group on Environmental Interactions of Mariculture [WGEIM] (Chair: E. Black, Canada) meet in Vigo, Spain for five days in March 2003 to:
    a) review the progress towards implementation of Water Framework Directive (WFD) in EU member states, in order to prepare a draft discussion paper to assess the appropriateness of water quality targets for coastal and transitional waters developed under WFD for the sustainability of mariculture in these waters;
    b) prepare a review of the potential impacts of escaped non-salmonid candidates for aquaculture on localized native stocks in order to develop, at an early stage, risk assessment and management strategies. The risk assessment element should include behavioural studies to identify potential methods for effective recovery of escaped fish;
    c) formulate a strategy to protect aquaculture against the harmful effects of external influences arising from other resource users and their environmental impacts, with the aim of gaining better cooperation in developing modern tools to prevent or mitigate negative interactions. An extended draft outline for a discussion paper will be prepared during a special session on the subject at the next meeting;
    d) prepare a report on an evaluation of existing DSS tools, GIS and other expert systems in order to derive strategic advice on the content of a DSS system for mariculture, and also to identify potential linkages to existing tools presently being developed, tested or already used in coastal management schemes;
    e) ICES through ACME and the Delegates bring to the attention of the national regulatory authorities in ICES Member Countries the need for participation of planners, regulators, and stakeholders in mariculture to participate in a special session during the next Working Group meeting to discuss in a broad context the wider issues on marine coastal resource use conflicts with mariculture as the activity potentially at risk and/or in need of safeguarding.

WGEIM will report by 11 April 2002 for the attention of the Mariculture Committee and ACME.

Supporting Information

Priority:	WGEIM is of fundamental importance to the ICES advisory process.
Scientific Justification:	1) Although offshore farming systems are presently under development and several are already being used on a trial basis, there is a long learning process ahead in the needs of the infrastructure for operating such systems. Even though being mainly distant from the coast, there is a need for a land base and for support systems that may require specific developments and control measures to prevent unforeseen hazards. Are the automated monitoring tools presently available adequate to safeguard offshore systems? What control measures and rescue strategies and options exist in extreme situations? Besides these technical aspects, there are a number of biological factors that may be operating at different levels than in inshore farms (e.g., behavioural aspects, biotechnology of sorting, application of counting and measuring techniques, monitoring for mortalities and their recovery, etc. 2) The demand for advice on specific subject items to be given to the ICES clientele and placed on the TORs of the WGEIM is increasing. Excellent expertise is required to respond appropriately to the often complex issues raised. The Working Group cannot fulfil its mandate if the Member Countries with major mariculture activities are not represented. The Working Group wishes to make ICES bodies aware of the risk that in case of severe lack of support from Member Countries, requests on advice from the Working Group coming from within the ICES system may have to be referred back to the respective committee and tasks cannot be fulfilled. 3) a) The EU Water Framework Directive will be the primary EU driver for the improvement of groundwater and surface water quality over the next decades. Under the Directive, definitions of good ecological quality will be agreed for a wide range of types of water body, covering all surface waters in the EU. Good ecological quality will then be the target for improvement measures to be adopted by member states and their environmental agencies. Aquaculture is not specifically mentioned in the Directive. However, it will be viewed as being the source of environmental pressures with the potential to adversely affect the primary indices of ecological quality in the transitional and coastal water bodies where mariculture operations are located. As such, it is likely that such areas will be subject to operational monitoring, as defined under the WFD. Specifically, fish farms will probably be assessed as potentially affecting the quality of the benthic fauna, the phytoplankton and angiosperm communities, and also hydrochemical conditions such as nutrient and dissolved oxygen concentrations. However, the position of aquaculture within the WFD also needs to be viewed from a different direction. Successful aquaculture requires good water quality. As the targets for improvements in water quality will be defined within the WFD system, it is important to assess the relationships between the WFD targets and the requirements of aquaculture. b) In order to foster a sustainable development of coastal and marine aquaculture, there is a need to diversify production and to cultivate new species. A pro-active approach is required to avoid mistakes made previously when salmonid farming was developing. Mitigation strategies based on sound scientific criteria in relation to the species under consideration need to be prepared at an early stage of development. Studies would have

	to consider the status of the natural stocks in the area, the potential genetic, trophic and behavioural interactions, and, foremost and specifically, the development of methods for recovery of escaped fish in the event of large-scale escapements. This subject seems to be of particular importance for non-migratory fish stocks with small localized populations (e.g., sea bass and seabream), or migratory species with different migratory patterns than salmonids (e.g., cod, halibut, turbot, and wolffish and other species). c) With the continued globalisation of markets, shipping is gaining importance worldwide and already today transports about 80 % of the world's cargo. Ships are becoming larger and so are ballast water volumes. There are increasing reports of the transport of viable, and potentially harmful, species in ballast waters, and also documented instances of the establishment of populations of harmful exotic organisms and pathogens. d) A number of technologies and support systems are presently under development, some of which have been outlined in the WGEIM 2002 Report. These should be evaluated and compared, with the aim to prepare a review publication on the requirements for a DSS system tailored to the needs of mariculture, that builds on the state of the art and/or links to existing systems. e) For ICES advice to be effectively utilisable by Member Countries, it is necessary that there is effective, open, and transparent communication with those stakeholders potentially affected by implementation of ICES advice. Towards that end, and the fulfilment of Goal #5 in the ICES Strategic Plan (February 2002), the Working Group feels there is an immediate need for the WG to benefit from the input of stakeholders' perspectives and the subsequent exchange of opinions and viewpoints. Such inputs are essential in making progress on determining the scientific criteria and tools for DSS developments as being suggested under item (d), above.
Relation to Strategic Plan:	Responds to Objectives
Resource Requirements:	None required other than those provided by the host institute.
Participants:	WGEIM members
Secretariat Facilities:	Room for 15–20 required plus meeting support
Financial:	None required
Linkages to Advisory Committees:	ACME
Linkages to other Committees or Groups:	MARC, MHC
Linkages to other Organisations:	HELCOM, OSPAR
Cost share	100 % ICES

ANNEX 1: AGENDA

Working Group on Environmental Interactions of Mariculture [WGEIM]

at ICES Headquarters
Palægade 2–4, Copenhagen, Denmark
from 8 April, 09:00 hrs, to 12 April, 17:00 hrs

1) Opening of the 2002 meeting
2) Welcome to ICES Headquarters
3) Adoption of Agenda
4) Arrangement for the preparation of the report
5) a) collate and review information on production patterns based on reports prepared by Working Group members and, in this connection, b) collect and assess information on the methodology for the collection of statistics on production and feed utilisation for finfish culture with a view to harmonising methods;
6) Review information on technological changes in mariculture, including the utilisation of new species, with particular emphasis on the consequences for production and the environment;
7) Review new research and monitoring programmes, taking account of the proceedings of the 1999 ICES Symposium on "Environmental Effects of Mariculture" and others as appropriate;
8) Review monitoring activities and develop guidelines for the preparation of Environmental Impact Statement/Assessment documents for large-scale shellfish farm developments, and appropriate monitoring programmes;
9) Review issues of sustainability in mariculture, including interactions between mariculture and other users of resources in the coastal zone and, in particular:
10) Update the *ICES Cooperative Research Report* #202 on Chemicals used in aquaculture.
11) Any other business
12) Consideration and approval of recommendations, including proposals for a further meeting.
13) Closure of the meeting

ANNEX 2: LIST OF PARTICIPANTS

Working Group on Environmental Interactions of Mariculture

Name	Address	Telephone no.	Fax no.	E-mail
Edward Black (Chair)	2051 Murphy Avenue Comox, B V9M 1V4 Canada	+1 613–990–0272	+1 613–954–0807	blacke@dfo-mpo.gc.ca
Alain Bodoy	IFREMER-CREMA Place Seminaire B.P. 7 17137 l'Houmeau, France	+33 5 46 50 06 13	+33 5 46 50 06 00	alain.bodoy@ifremer.fr
Ian M. Davies	Fisheries Research Services Marine Laboratory P.O. Box 101 Victoria Road Aberdeen AB11 9DB United Kingdom	+44–1224–876544	+44–1224–295511	daviesim@marlab.ac.uk
Antoine Dosdat	IFREMER Chemin de Maguelone 34 250 Palavas-Les-Flots France	+33 4 6750 4277	+33 4 6768 2885	adosdat@ifremer.fr
Arne Ervik	Institute of Marine Research P.O. Box 1870 Nordnes N-5817 Bergen, Norway	+47–55–238–500	+47- 55–238–531	arnee@imr.no
Kats Haya	Dept. of Fisheries & Oceans Biological Station 531 Brandy Cove Road St Andrews, N.B. ESB 2L9 Canada	+1–506–529–5916	+1–506–529–5862	hayak@mar.dfo-mpo.gc.ca
Chris McKindsey	Dept of Fisheries & Oceans Institut Maurice-Lamontagne 850, route de la Mer C.P. 1000 Mont-Joli, Quebec G5H 3Z4 Canada	+1–418–775–0667	+1–418–775–0718	mckindseyc@dfo-mpo.gc.ca
Terry McMahon	Dept. of the Marine Fisheries Res. Centre Abbotstown Dublin 15, Ireland	+353–1-822–8200	+353–182–05078	terry.mcmahon@marine.ie
Francis O'Beirn	The Marine Institute Galway Technology Park Ballybrit Galway, Ireland	+353–91–730–400	+353–91–730–760	Francis.obeirn@marine.ie
Harald Rosenthal	Institut für Meereskunde an der Universität Kiel Düsternbrooker Weg 20 D-24105 Kiel, Germany	+49–40–700–6514	+49–40–701–02676	
William Silvert	IPIMAR Avenida de Brasilia P-1400 Lisbon, Portugal	+351 919 355 925	+351 213 015 948	wsilvert@ipimar.pt
Uwe Waller	Institut für Meereskunde an der Universität Kiel Düsternbrooker Weg 20 D-24105 Kiel, Germany	+49–431–600–1630	+49–431–600–1631	uwaller@ifm.uni-kiel.de

ANNEX 3: COUNTRY REPORTS

3.1 Canada

Submitted by: K. Haya, St. Andrews Biological Station, St. Andrews, New Brunswick

3.1.1 Production Summary

Table A3.1.1.1 Canadian Aquaculture Production in tonnes and Canadian dollars 1998–2000.

CANADIAN AQUACULTURE PRODUCTION							
				Harvest Fisheries			
	Tonnes			**Tonnes**	**$000 (CND)**		
	1998	**1999**	**2000**	**2000**	**1998**	**1999**	**2000**
Finfish							
Salmon	58,618	72,890	78,495	18,775	349,043	450,084	495,555
Trout	5,962	6,581	6,407		28,058	32,047	31,460
Steelhead	2,354	6,002	5,523		13,014	28,754	24,889
Other	402	595	694	502,712	3,862	5,176	6,770
Total Finfish	67,435	86,150	91,195	521,487	394,859	516,847	559,407
Shellfish							
Clams	704	800	1,000	31,155	3,619	4,200	5,900
Oysters	8,137	8,785	10,024	4,130	11,321	13,278	16,915
Mussels	15,018	17,397	21,287	14,429	18,985	23,244	27,213
Scallops	70	55	59	86,627	488	266	362
Other	47	41	359		235	69	1,775
Total Shellfish	23,976	27,078	32,729	136,341	34,648	41,057	52,165
Total	91,411	113,228	123,924	657,828	429,507	557,904	611,572

1) Details available at http://www.dfo-mpo.gc.ca/communic/statistics/aquacult/Aqua_E.htm
2) The production and values are as of the farm gate for marine sites and excludes hatcheries or value added products
3) Summaries of production pre-1998 were presented at WGEIM 2000.

The Canadian aquaculture industry continues to grow as indicated by increased production between 1998 and 2000. Total production of shellfish and finfish was 124 thousand tonnes, valued at $612M in 2000, an increase of 36 % from 1998.

Growth in finfish aquaculture between 1999 and 2000 is due to increased production of salmon in Atlantic Canada. This is partly due to a recovery from ISA and sealice epidemics due to improved methods of husbandry, site selection and disease control measures that have been adopted by the industry. There has been a moratorium on licensing new sites in British Columbia since the early 1990s, which is expected to end this year. More than 80 % of the salmon cultured in BC is Atlantic salmon, with chinnook and coho making up the rest. Cultured Atlantic salmon production is now more than 4 times that of the wild salmon harvested in Canada. Wild salmon do not include Atlantic salmon because commercial salmon fishing only occurs on the Pacific Coast. However, the total cultured finfish production was only 15 % of the total cultured and wild finfish production of all species in Canada in 2000.

Growth in shellfish aquaculture production is mainly due to the increase in production of oysters and mussels in Prince Edward Island during 1998–2000. The production of cultured mussels and oysters was almost double that of the wild landings for 2000. However the total of all cultured shellfish represents only 19 % of the total production of these shellfish from harvest and aquaculture fisheries. Scallop and clam harvest fisheries account for most of the wild landings of shellfish.

3.1.2 Aquaculture Development

Office of the Commissioner for Aquaculture Development

A temporary organization whose role it is to help government put in place programs that will promote the development of aquaculture in Canada. The term for the Office of the Commissioner for Aquaculture Development (OCAD) has been extended to March 31, 2004. The new mandate of the *Office of the Commissioner for Aquaculture Development* is to develop an awareness of the integration of culture and wild fisheries through the recognition of fisheries based culture and culture-based fisheries. The Commissioner has conducted a legislative and regulatory review and the initial findings were published in March 2001.

Aquaculture Collaborative Research and Development Program (ACRDP)

The ACRDP is a Department of Fisheries and Oceans (DFO) initiative to increase the level of collaborative research and development activity between the aquaculture industry and the Department. ACRDP funding is approximately $4.0 million per year for five years starting in 2000. ACRDP is an industry-driven program that partners industry with DFO researchers. Industry establishes research priorities and helps fund research. The program allocates ACRDP funds to collaborative research projects that are proposed and jointly funded by aquaculture producer partners. Research funding remains within DFO. 38 projects are presently funded. (See Attachment 1).

AquaNet

AquaNet is a network for centres of excellence for academic aquaculture research in Canada. It is funded by the National Science and Engineering Research Council and Social Sciences and Humanities Research Council of Canada. AquaNet supports aquaculture research initiatives across Canada in conjunction with university and industry partners to produce highly qualified personnel, provide educational training and to increase the knowledge base in aquaculture. The overall research goal of AquaNet is to provide research in the natural, applied and social sciences capable of supporting an aquaculture industry that is productive, environmentally sound and acceptable within the context of social, cultural and political values of Canadian society. By using a multidisciplinary approach, drawing on national and international expertise and by collaborating with the private and public Canadian sectors, AquaNet has initiated a dynamic program that focuses on the most significant research challenges facing the Canadian aquaculture industry. AquaNet currently funds thirty-nine research projects (see Attachment 2).

3.1.3 Environmental Interactions Related Activities

In June 2001 the report of the Standing Senate Committee on Fisheries and Aquaculture in Canada’s Atlantic and Pacific Regions was released. The main findings were that more environmental and ecological research is required. The recommendations relevant to WGEIM were a need for more:

- research on the cumulative impact of aquaculture on ecosystems;
- research on the impact of the presence of non-indigenous salmon populations on both coasts;
- research on disease and parasite transfer between cultured salmon and wild fish;
- research on the uptake in the food chain of therapeutants found near salmon cage sites;
- research on marine and land environmental risks are lowest.

DFO and Environment Canada funded research on environmental impacts of aquaculture is listed in Attachment 3.

Chemicals in Aquaculture

A recent study provides an inventory of the substances used by the aquaculture industry, quantities and circumstances of use of these substances and an assessment of risks to habitat, fish and the use of fish with such substances by man. The following were being used in significant amounts in 1999: the antibiotic, Oxytetracycline (Terramycin Aqua®, 6540 kg); the sealice control agents, azamethiphos (10 kg) and emamectin benzoate (415 kg); iodine-based disinfectants; and copper-based antifoulants and preservatives. Included in the report is a bibliography with abstracts of recent publications of relevance.

North American Sea Lice Network

Sealice are the most economically significant ectoparasite for global Atlantic salmon farming. A network of people interested in sealice biology and control was established in Europe from 1997–2000, and has involved some Canadians through attendance at meetings, circulation of the *Caligus* newsletter, and the e-mail list server *Caligus*. A Canadian working group on sealice led by John Smith (Pest Management Regulatory Agency) ceased to operate around 2000, and there has been no coordination or networking on sealice in Canada since. The instigator and coordinator of the European network, Dr Mark J. Costello, took a position at the Huntsman Marine Science Centre, in St. Andrews, NB in September 2000. He called a meeting to assess the potential of a sealice network in North America. The meeting was held in March 2002 to discuss the status, current research and environmental effects of chemicals used in the treatment of sealice infestations in cultured salmon. The recommendations from this meeting were:

1) Establish a network of persons interested in sealice biology and control with the aim of communication of information of mutual interest, and thereby facilitating development of new research activity and better management.
2) Investigate holding in 2002 a 1-day workshop with a few invited speakers and a briefing for industry of advances in sealice research and management.
3) Proceed with planning for an international conference in July 2003 in St Andrews, NB, Canada.

Harmful algal blooms (HAB) and aquaculture

In 1999, a detailed program to monitor harmful algae has tracked algal occurrences at 18 salmon farm sites on the West Coast of Canada. The program was funded by a consortium of fish farming companies and conducted under a collaborative agreement with the Pacific Biological Station of Fisheries and Oceans Canada. Weekly reports, advisory warning notices on presence of harmful species in farming areas as well as detailed annual reports on the phytoplankton and water nutrients were presented to all consortium members. Algal blooms have caused moralities of cultured salmon on both the Atlantic and Pacific coasts in recent years (see Attachment 4).

Attachment 1. Aquaculture Collaborative Research and Development Program

1) Cod aquaculture – strategies for improved hatchery broodstock management;
2) Optimal cage depth for Bay d'Espoir salmonid aquaculture;
3) Furunculosis vaccine efficacy for Atlantic salmon;
4) Literature review of the environmental impacts of aquaculture in Newfoundland;
5) Determine the availability of giant scallop, *Placopecten magellanicus,* seed from two areas in the Gaspé region of Québec;
6) Evaluation of two types of growout cages for suspension culture of giant scallop, *Placopecten magellanicus*, Madeleine Island;
7) Characterization of the sediment of two new sites for growing scallops on the bottom in Madeleine Island;
8) The effect of biological and physical factors on the burrowing of clam (*Mya arenaria*);
9) Evaluate the environmental conditions and feasibility of culturing the Iceland scallop, *Chlamys islandica*, in the Mingan area;
10) Evaluate the impact of hydraulic harvester on clams and on the benthic community in the Baie des Chaleurs;
11) Influence of alternate dietary lipid sources on growth and health of large (2.5 kg) sablefish;
12) Monosex strain development for white sturgeon (*Acipenser tranmontanus*) and salmonids;
13) Sablefish broodstock development;
14) Marine finfish and suspended shellfish aquaculture: water quality interactions and the potential for polyculture in coastal British Columbia;
15) Rapid determination of pigmentation and lipid levels in fish flesh using fibre optic technology;
16) Reducing the impact of *Kudoa thyrsites* in farmed Atlantic salmon in British Columbia;
17) Development of probiotic strain diagnostics for the control of bacterial diseases in hatchery rearing of aquatic species;
18) Evaluation of a polyculture system utilizing several plant species to enhance phosphorus and nitrogen removal from freshwater salmon farm effluent;
19) Atlantic salmon egg research;
20) A genetic-based broodstock management approach in Atlantic halibut;
21) The effect of photoperiod on growth and maturation of Atlantic salmon in the Bay of Fundy;
22) Development of monitoring and assessment tools for adaptive management of salmon aquaculture relative to sensitive marine invertebrate habitat;
23) Development of guidelines for fish health consequences of water circulation patterns in Long Pond Bay, Grand Manan;
24) Identification of virulence specific PCR based markers for teleost pathogens;
25) RT-PCR to identify replicative strands of RNA of ISAV;
26) Evaluation of protocols for selection of key performance characteristics for New Brunswick Arctic charr broodstock development, evaluation and selection program;
27) Fencing scallops on the seabed to protect them from predation by rock crabs and sea star;
28) Development and evaluation of standardized monitoring and data acquisition systems for the management of mollusc culture in Atlantic Canada;
29) Predator and competitor interaction with bivalve culture: development of an effective management approach;
30) Harmful phytoplankton and bivalve aquaculture in a cold ocean environment;
31) Haddock (*Melanogrammus aeglefinus*) broodstock management in Atlantic Canada: improvements to egg quality, production and disinfection technology;
32) Adaptation of virtual population analysis models for quahog (*Mercenaria mercenaria*) bottom culture management in St. Mary's Bay, St. Bernard, Nova Scotia, Canada;
33) Parasites affecting Maritime mussel aquaculture development and movements;
34) Ecosystem experiment to assess environmental impacts of freshwater cage aquaculture;
35) Harmful algae monitoring at salmon aquaculture locations on the Pacific coast of Canada;
36) Circulation and oceanography of the Broughton archipelago;
37) The effect of stressors on the immunocompetence and susceptibility to *Kudoa thyrsites* as a measure of smolt quality;

38) Genetic variation at microsatellite DNA and MHC genes in domesticated Atlantic salmon strains of British Columbia.

Attachment 2. AquaNet Projects, Animal Production Theme

1) Host-Pathogen Interactions: The *Aeromonas salmonicida/Salmo salar* Model System Applied to Non-salmonid Finfish;
2) Nutritional Value and Clinical Role of Dietary Lipid in Fish;
3) Optimisation of Larval Feeding and Digestion in Atlantic Halibut, Atlantic Cod, Haddock and two small Flounder Species;
4) Optimising Metabolic Design for Growth of Fishes at Low Temperature;
5) Factors, Risks and Significance of Emergent Neoplasia Diseases in Cultured and Wild Soft-Shell Clams (*Mya arenaria*) in Atlantic Canada;
6) Development of Winter Flounder and Other Flatfish for Land-based and Inter-Tidal Aquaculture;
7) An Evaluation of Current and New Diagnostic Tests for Infectious Salmon Anemia Virus;
8) Impacts of Sea Ducks on Mussel Aquaculture Operations in Prince Edward Island;
9) Supplemental Algal Feeding for Field-based Oyster Nursery Culture;
10) Enhancement of Production in Broodstock and Post larvae (spat) of Marine Bivalves;
11) Stress in Fish: Diagnostics, Role in Disease, and Management;
12) Shellfish Health: Development of Biochemical Indicators of Stress;
13) Production of Disease Resistant Transgenic Salmonids Expressing Major Histocompatibility Complex (MHC) Genes at all Temperatures;
14) Aquaculture Broodstock and Seed Production: Production of the Next Generation of Genetic Markers;
15) Production of Single-Sex (All-female) Populations of Fish for Aquaculture;
16) Improved Freeze and Stress Resistance with Glycerol;
17) Transgenic Fish with Improved Freeze Resistance by Antifreeze Gene Transfer;
18) Production of Transgenic Tilapia for the Treatment of Diabetes: ES-cell Approach;
19) Genetic and Environmental Factors Affecting Growth and Production of Mussels (*Mytilus edulis* and *M. trossulus*);
20) Immunological Response in Atlantic Salmon, and the Identification of Molecular Markers Associated with an Efficient Immune System.

Environmental Integrity Theme

21) Genetic and Ecological Interactions Between Farm and Wild Atlantic Salmon;
22) Objective Risk Assessment of Interactions among Cultured and Wild Salmonids;
23) Risk and Consequences of Infestation from Salmon Lice;
24) Environmental Requirements for Sustainable Shellfish Aquaculture Development;
25) Development of *in situ* Early Warning Systems for Harmful Algal Blooms and Phycotoxin Monitoring at Aquaculture Sites;
26) Water-Sediment Interactions: The Processes and Effects of Sorption/Desorption of Additives to Aquacultural Systems on Sediment and Water Quality;
27) Intelligent Monitoring Systems for Aquaculture;
28) Sea Lice Resistance to Chemotherapeutants: Diagnosis, Mechanisms, Dynamics and Control;
29) Improving Amino Acid Utilization in Salmonid Fish: A Key Factor to Improving Feed Efficiency and Reducing Waste Outputs in Marine and Freshwater Salmonid Fish Culture;
30) Cultured Salmon: Their Swimming Performance, Energetics and Reproductive Success in Relation to Fish Introductions and Escapements;
31) A Multi-disciplinary Approach with the Integration of Three Trophic Levels (Fish / Shellfish / Seaweed) for the Development of Sustainable Aquaculture Systems;
32) Development of Cold-water Recirculation Systems;
33) Optimisation of Existing Faecal Trap to Reach 99 % Settable Solid Removal in Highly Recirc Systems Through Hydraulic Modelisation.

Socio-Economic Theme

34) The Industrial Economics of Aquaculture Industries;

35) The Institutional and Social Structure of Aquaculture: A Comparative Study of Norway, Chile, the Faeroes and Japan;

36) Law and Policy Project: Towards Principled Access, Allocations and Operations in Aquaculture;

37) The Social Construction of Aquaculture: Risks and Benefits; Work and Community;

38) Dynamics of cooperation, local development and new property rights: bottom-seeding of scallop beds in the inshore community of Botsford;

39) First Nations Involvement in Aquaculture in British Columbia.

Attachment 3: DFO Funded Research

1) Environmental Impact of Chemical Wastes From the Salmon Aquaculture Industry;
2) Environmental Studies for Sustainable Aquaculture;
3) Integrated Ecosystem Studies for Modelling Mussel Aquaculture-Environment;
4) Antibiotic Residues and Microbial Antibiotic Resistance in Marine Sediments Associated with Salmon Farms in Southwest New Brunswick;
5) Endocrine disruption in invertebrates: impacts of emamectin benzoate on molting and egg production in American lobster;
6) Coastal Oceanography and the environmental impacts of salmon aquaculture in the Bay of Fundy.

Environment Canada aquaculture activities:

1) Research on the effect of shellfish and finfish aquaculture on migratory birds;
2) Development of a revised environmental management strategy for salmon farms that included studies on chemicals in sediments and the potential of physical remediation of sediment in depositional zones;
3) Water quality surveys in shellfish harvest and culture areas, developing a method to rank risk of chemicals used in aquaculture;
4) Participation in environmental assessment of proposed aquaculture sites subject to the Canadian Environmental Assessment Act;
5) Preparation of national environmental assessment guidelines.

Attachment 4: Agal Blooms and Aquaculture

Pacific

In 1999, a detailed program to monitor harmful algae began at 18 salmon farms sites on the West Coast of Canada (Figure 1a). The study was funded by a consortium of fish farming companies and conducted under a collaborative agreement with the Pacific Biological Station of Fisheries and Oceans Canada. Based on this program and fish bioassays ichthyotoxic blooms of *Cochlodinium polykrikoides* were demonstrated in Canada for the first time. The following year the program received funding for expanded monitoring around Vancouver Island (Figure 1). Monitoring data indicated marked difference between years in occurrence and distribution of harmful species at specific sites. Phytoplankton biomass was generally higher in the inlets on the west side of Vancouver Island, with dinoflagellates or Raphidophytes (*Heterosigma akashiwo*) dominant in the late summer. Weekly reports, advisory warning notices on presence of harmful species in farming areas and detailed annual reports on the phytoplankton and water nutrients were presented to all consortium members. Monitoring in 2001 (Figure 1) again illustrated inter-annual species diversity and abundance. Clearly inter-annual variance does occur, and is dependent on environmental conditions at these sites.

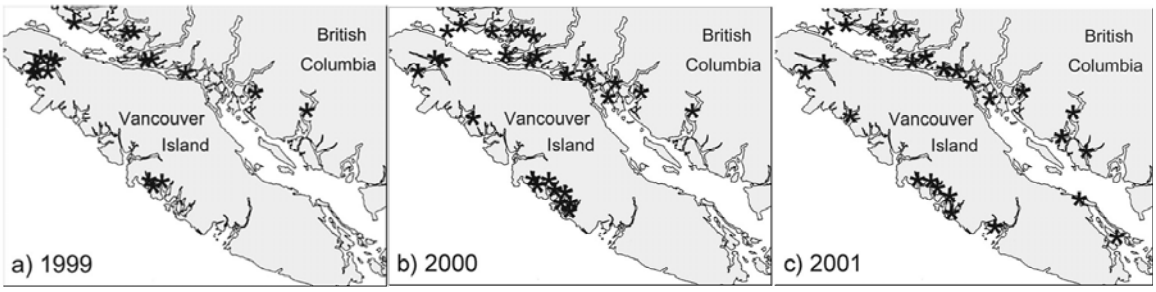


Figure 1. HAMP monitoring sites 1999 to 2001.

2001 was not a typical year for plankton on the west coast of Canada. While there were *Heterosigma akashiwo* blooms, they were generally of short duration, and most fish losses were minimal. Limited blooms of *Cochlodinium polykrikoides* were seen, but no mortalities from these blooms were recorded. Harmful *Chaetoceros* species were present, and caused mortalities in specific areas, in the spring, at concentrations that were extremely high for these species. Other harmful species were seen in association with mortality of farmed fish for the first time in the areas monitored: in early September a *Chrysochromulina* species occurred with kills of fish at a farm on the Northeast side of the island. Another bloom in Kyuquot Sound occurred with mortalities, but was reported too late for identification of the causative algal species. *Rhizosolenia setigera* and *Dictyocha speculum* both bloomed on the southeast side of Vancouver Island, but no mortalities were reported. Other blooms of non-harmful plankton were seen in various areas throughout the sampling season. Percentage biomass of the five constituent groups (diatoms, dinoflagellates, raphidophytes, other flagellates, and microzooplankton) varied from site to site, with sites on the west side of the island generally showing a greater predominance of dinoflagellates, especially in late summer, than those on the east side. Inside waters off Vancouver Island usually contained diatoms as the dominant group, except for sites such as Glacial and Kunechin, which showed generally low phytoplankton biomass throughout the sampling year, with mixed species dominance. Three years of detailed data on distribution and abundance of species together with nutrient (N, P, Si) levels are available for computer modelling to assess predictive capabilities of bloom formation.

Atlantic

During 1998 and 1999 the salmon aquaculture industry in northern Passamaquoddy Bay was impacted by algal blooms for the first time, when low level mortalities were observed. Red tides associated with the organism *Mesodinium rubrum* were observed in Passamaquoddy Bay between the 4th week of August, through to September 17, 1998 and again for one week in August (17–24), 1999. During the red tide events, patches or aggregates of cells were observed drifting through some salmon farms. *M. rubrum* concentrations in samples collected from waters with discolouration exceeded 1 million cells l^{-1}. Some patches were 20–50 m wide and as long as 1–2 km, although they were sometimes broken up into several lobes. In 1998, *M. rubrum* was the dominant organism and represented up to 95 % of the total algal population. Surface water temperature was 18 ^{o}C and salinity was 31.5–32.0 psu. Nutrient levels measured were lower in the red tide area than in a non-red tide area such as Brandy Cove, where concentrations of *M. rubrum* were considerably lower (3,000–6,000 cells l^{-1}), suggesting that *M. rubrum* cells were absorbing significant levels of nutrients. Nutrient levels measured were: nitrate + nitrite, 0.20–0.48 µM in the red tide area and 2.95–4.47 µM at Brandy Cove; ammonia, 2.29–3.88 and 3.86–4.10 µM, respectively; phosphate, 0.66–0.77 and 0.78–1.04 µM; and silicate, 3.97–5.82 and 5.08–6.44 µM.

In 1999, the *M. rubrum* red tide accounted for <50 % of the total phytoplankton population. The diatom, *Chaetoceros socialis*, was abundant in these samples, as well as a number of other species, including other diatoms and dinoflagellates. Surface temperature was 15 ^{o}C; salinity, 31.5–32.0 psu; and fluorescence was 31 µg chlorophyll l^{-1} at a depth of 3 m. Oxygen levels measured between 133 % and 180 % saturation at the depth of 3 m in the red tide. An 18-h sampling period showed that, while cells were observed throughout the water column, they tended to concentrate in the upper 1–3 m during the day. In strong sunlight, cells formed dense aggregations at 3 m; at night, cells tended to disperse vertically and horizontally, but did not seem to migrate to any particular layer or depth. Overnight oxygen levels decreased throughout the water column, with lowest levels (64.5–72.3 % saturation) measured on Aug. 21. Levels increased towards mid-day.

Although *M. rubrum* does not produce a toxin, it is possible for stress and mortalities among aquatic organisms to occur through secondary effects, such as asphyxiation due to oxygen depletion. During the 1998 red tide, the algal blooms drifted through a number of salmonid aquaculture sites resulting in low-level mortalities of salmon. This occurred during late stages of the bloom or during bloom decay. Salmon exhibited symptoms of stress (such as slow swimming, loss of equilibrium, non-feeding), associated with low oxygen levels due to a combination of the red tide, decreased currents and elevated temperatures. In August, oceanographic processes in upper Passamaquoddy Bay consisted of shallow, warm water, with periodic low current speeds and thermal stratification – ideally suited for high primary production and generation of red tides. The phenomenon of water discolouration, as a result of high concentrations of *M. rubrum,* has been observed in both the presence and absence of aquaculture, for example, red water sightings prior to 1998 and 1999 were observed during 1975, 1977, 1979, 1989, and 1993.

3.2 France

Submited by: A. Dosdat, A. Bodoy, J.L. Gaignon, and J.M. Deslous-Paoli, IFREMER, France.

3.2.1 French metropolitan and Overseas Territories Production Figures and Trends

Table 3.2.1. French marine production figures (seed and fry production are given in 10^6 units, production in tonnes).

METROPOLITAN PRODUCTION		**1998**	**1999**	**2000 (t)**	**2000 (value 10^6 €)**	**INCREASE (2000/1998) %**
Cupped oysters	Seed	800				
		153,000	137,000	133,500	220	−13
Flat oysters	Seed	4				
		2,500	2,000	2,000	10	−20
Mussels		60,000	62,500	68,000	83	+13
Algae				60	<1	
Other shellfish		5,000	3,600	3,600	12	−28
TOTAL SHELLFISH		**218,500**	**205,000**	**207,160**	**325**	
S.W. Rainbow trout		200		160	0.5	−20
S.W. Brown trout		600		500	1.7	−16
Salmon		550		200		
Sea bass	Fry	22				
		2,600		3,000	22	+15
Sea bream	Fry	10				
		1,500		1,500	8	+0
Turbot	Fry	2.5				
		1,000		1,100	7	+10
Meagre		40		40	0.2	
Marine fish		6,450	6,690	6,500	40	+0.8
Freshwater fish		53,000	53,000	54,200	140	+2
TOTAL FISH		59,525		58,760	180	
Japanese shrimp	Fry	6				
		30	24	28	0.5	−6
TOTAL METROPOLITAN		225,980				
OVERSEAS PRODUCTION		**1998**	**1999**	**2000 (t)**	**2000 (value 10^6 €)**	**INCREASE (2000/1998) %**
Pearl oysters	Pearls	10	8	12	173	+20
Red drum				25	0.2	
Lates and Tilapia				25	0.1	+20
Shrimp		1,500	1,850	1,800	13	
Freshwater shrimp				70		
TOTAL OVERSEAS				1,932	186.3	

Sources: IFREMER, OFIMER.

Major trends in French aquaculture sector are the following:

- **Cupped oyster production continued to decline**. While production was about 152,000 tonnes in 1995, it was 135,500 tonnes in 2000. It remained the major cultivated species for both production and turnover. The decrease may be explained by the following:
  - reduction in supply due to restructuring in the sector, from poor natural seed collections for the last ten years;

- reduction in consumer demand, following health issues, and consumer habits (young people do not eat oysters).

The two major oyster production areas in the French Mediterranean (Thau and Leucate lagoons) are temporarily A-rated and will be declassified from A to B. Producers will have to use depuration units.

- **Use of triploid oyster strains to avoid gametogenesis.** Two different techniques to produce triploid oysters are now available for the oyster industry. The first one uses the chemical cytochalasine B to induce triploidy, but there are still some difficulties with this technique. The triploidisation level only reached 70–80 % of oysters, leaving reproducing animal in the batches. The second technique, crossing tetraploids with normal dipoids obtains 100 % triploids without use of a highly toxic product. Tetraploid oysters have been produced at the laboratory. All French oyster hatcheries use triploid oysters with about 10 % of the total production from using cytochalasine. While not mandatory, the labelling of triploid oysters will be established in 2002. The transfer of tetraploid oysters to hatcheries for commercial purpose is under evaluation.
- **Mussel production is highly variable due to the inclusion of wild mussel catch.** The large increase observed from 1999 to 2000 is combined mussel catches from aquaculture and fisheries activities.
- **Flat oyster and utilisation of tolerant strains.** Attempts to cultivate flat oysters in the Mediterranean area have been unsuccessful. Heavy infestations by *Martelia* sp. occurred at the end of the first year of growth inducing high mortality rates. In contrast, *Bonamia* sp. prevalence remained low. Under these conditions, flat oyster cultivation is not economically viable. After a 10-year selection process, significant improvements have been obtained with resistant/tolerant strains of the flat oyster at an experimental level. These strains are being tested by industry to confirm that production on the farm will give the same results as seen in laboratory experiments. The challenge lies with producing large numbers of these strains for industry when hatchery production of the flat oyster is already difficult. The first large-scale experiment will be launched in south Brittany (Quiberon area).
- **Marine fish farming is steady with some fluctuation**. Few new farms have been put into production, the variations coming from the enterprise stock variations. The biggest single farm is located in Gravelines, near Dunkerque. Corsican production has been threatened by huge variations in sea bass prices. Specific Germ-Free hatcheries are coming into operation in France. The first French hatchery has begun to operate Germ-Free in 2001, using knowledge from the pig industry. A disease-free Community Area has been established with a strong emphasis on detecting healthy carriers, controlling biological trade-offs with various domesticated stocks, and the development of optimal health management methods. The major interests rely on improved sanitation between farms, limiting environmental interactions between farms and wild populations, reducing chemical usage. This may improve quality for the consumer and increase consumer confidence in aquacultural products.

In 2000, the total aquaculture production in France represented 31 % of the total tonnage of aquatic production including fisheries.

3.2.2 Coastal Zoning Issues

Site availability along the French coast was determined in 2000 according to a standardised process (Dosdat and Deslous-Paoli, 2000) for the Central Administration for Agriculture and Fisheries and distributed to Administrations in charge of aquaculture development (Agriculture and Fisheries, Environment and Planning, Marine Office). These administrations will validate and transform this information into a Management Planning tool to be used when assessing requests for new aquaculture facilities. Local constraints are assessed with respect to natural resources and space. The formal approval of this coastal zoning process is under way before its enforcement. This initiative was also an opportunity for the administration to implement their knowledge concerning the aquaculture development in France and in Europe.

Under of the Directive 2000/60/CE (23/10/2000), the French authorities decided to apply a system of Environmental Quality Criteria to evaluate the status of the coastal environment by using three major sets of parameters: water chemistry, biology, physical environment. Using these parameters, the environmental capacity of a given site is assessed according to potential uses and consolidated to enable sound comparisons over time between different natural environments and will serve as a basis for restoration/management programmes.

3.2.3 Offshore Aquaculture

Shellfish on seabed grounds in Marennes-Oléron bay.

The Bay of Marennes-Oléron has been used extensively for oyster culture for seventy years. Due to high culture densities, growth has decreased along with the profitability of shellfish farms when compared to other areas of France. A research project that is currently under way has established a cultured oyster bed in the outer part of the bay, which is hydrologically independent from the inner bay. Oysters were seeded on a muddy bottom and monitored for growth and conditions. Preliminary results showed that oyster growth is faster than in the intertidal culture, but large infestations of the Polydora annelid affected oyster shells. Shell quality will have to be restored before the oysters can be sold. However, this project is facing a strong opposition from the local fishermen, who fear a possible reduction of their fishing grounds.

Mussel Culture in the Mediterranean

The predation of offshore cultured mussels by seabream is threatening the industry and many mussel farms are closing due to heavy losses. About 20 % of the standing stock was destroyed in 2001 and attempts to use various devices to prevent further destruction of mussel stocks have been unsuccessful. In order to understand the behaviour of these predatory fishes, tagging experiments were performed with telemetry devices on fishes released on mussel longlines. Unfortunately no clear results have been obtained yet from the trajectory of the fishes.

Fish culture in offshore locations (projects)

In order to decrease the pressure of fish farms on the coastal zone, farms are relocated to offshore locations. This has been done successfully by tuna farmers in Spain, and attempts to introduce this technique to other countries/species are underway. Alternative techniques will be needed to produce juveniles capable of growing in those conditions because of water movements, cage size, and difficulties in fish sorting.

3.2.4 Transferred Species

IFREMER introduced red drum (*Scianops ocellatus*) from the French West Indies, under the ICES recommended framework and legal authority for experimental purposes. Rearing the fish in a closed recirculating system reduced the risk of fry escaping (1 g). The experiment tested the feasibility of rearing red drum in a facility designed to grow seabass, given the high metabolic requirements of this fast growing species, and the unknown response at high temperature (25 °C) of bacteria that mineralise organic matter and oxidise ammonia. The results were very encouraging and demonstrated that rearing non-native fish species from tropical areas in environmentally safe facilities is possible. Attempts to introduce this species for commercial purposes are under way.

Slipper limpet's development in Thau lagoon (reported in the WGEIM 2000 report) is controlled through predation by carnivorous snails (*Urosalpinx* sp., *Natica* sp.). Climatic conditions also explained the slow development of this invasive species.

5. New Species

Scallop (*Pecten maximus*) in the Bay of Brest.

From 1982 to 1998, a programme was developed in Brittany to maintain and support scallop fishery in the Bay of Brest where wild scallop stocks had fallen dramatically. Stock enhancement was used to restore this traditional fishery activity. Stocks were initially enhanced using wild spat, then with hatchery production because collecting wild spat was not sustainable. The minimum size needed for stock enhancement from spat was determined to be 30 mm. Juvenile scallops were spread on the bottom in order to sustain the breeder stock and to increase spat production in the wild. In the early 1990s, a pilot scale production was launched that considered the whole cycle, from aquaculture spat to commercial size. Hence, a management system financed by fishermen and managed by their fishermen organisation produced 400 t per year instead of 50 t as in the early 1980s. Since 1998, the system is regulated through voluntary licensing. Funds are devoted to the hatchery and pre-growing operating costs (10 million post-larvae were produced in 2000) and licenses allow an individual quota. However, competition for space and resources in the Bay of Brest is limiting development and environmental impacts threaten juveniles (pesticides, salinity variations, and eutrophication). In 2001, an unexplained mortality was reported. This is a good example of the length of time needed to implement such management concepts and tools (about 20 years) and the need for a more global approach.

Meager (*Argyrosomus rhegius*) in southern France.

This new species is under pilot development in the French Mediterranean where a private hatchery has developed the technology to produce fry (150,000 individuals in 2000). It is a very promising species and can be reared in the same sea cages as sea bass and seabream. A Demonstration Project supported by the EU is to be launched in 2002 to design and build a hatchery dedicated to this species.

Other fish

Various candidate species for culture include: wreckfish (*Polyprion americanus*), red mullet (*Mullus barbatus*), cod (*Gadus morhua*) and pollack (*Pollachius pollachius*). Research is focused on the reproductive potential of captive broodstocks and larval development.

Sanitary constraints, induced by either wild fish utilisation or imported individuals for broodstocks constitution, are pending and limit the feasibility of those programmes.

3.2.6 Implementation of EIA for Finfish Farming

In France, an EIA is necessary for every fish farm producing more than 20 tonnes per year (Dosdat and La Pomélie, 2000). A Methodology Guide to evaluate the environmental impact of finfish farming in the Mediterranean southeast coast has been proposed by IFREMER to the fish farmer association (Deslous-Paoli *et al.,* 2002). This guide provides practical methods to evaluate the impact of fish farming, sound monitoring measures, models for calculations and data presentation, and includes a database on the impact of sectoral activities in the Region. It proposes criteria and thresholds to adapt the size of the EIA to environment requirements and sensitivity. This guide will be available to other Regions. Given its objectives to improve the quality of EIA in France, discussions are under way to apply it to the whole French sector. It will be adapted for all end users, including a formal adoption by the various administrative bodies (particularly the Ministry for Agriculture and Fisheries and the Ministry for Environment and Regional Planning). This tool will become a consensual framework to implement sound EIAs.

3.2.7 Water Reuse Systems and Integrated Aquaculture

Fish

Laboratory and small-scale pilot experiments that study recycling wastewater within production systems are enforced in the European fish farming industry. Two projects in France that study this are supported by the European Union.

The first one is aimed at integrating sea bass from nurseries into an existing fish farm (Aqua-Maki, Eureka). Evaluating the global technical-economic ratios was the objective of the project (Blancheton *et al.,* 2002). Increased growth rates and fish density were achieved by improving water quality through coupling ozonation and UV reactors and modifying the physical properties of the faeces. Provisional results indicate that biological results and production costs were similar in recirculating systems and in traditional flow-through raceways. The coupling of a recirculation unit for pre-growing purposes with a traditional system decreased sea bass production cost by 15 % and increased annual production by 30 % without modifying the on-growing unit. This concept could be applied to offshore cage fish farming. The project also raised several issues requiring investigation on fish growth and nutrition improvements at higher density, water quality treatments (particles, accumulating substances) and integrating algae and shellfish production.

The second experiment is a joint France-Iceland project on cost-efficient mass production in a closed system for marine aquaculture (Mistral Mar) aimed at scaling up water treatment systems based on bacterial transformation of ammonia and on residual organic matter oxidation with biofilters. It is coupled with sea bass production. Emphasis has been on socio-economic advantages/disadvantages of the production system to improve cost effectiveness of rearing procedures (particularly hydrodynamics of rearing tanks), animal welfare, monitoring and control of systems to reduce risks and improve productivity, and the dissemination of results.

A private farm operates in Northern Brittany using these technologies to produce 100 tonnes of turbot per year.

Shellfish

Land-based Mollusc Culture on the West Coast of France

The artificial cultivation of microalgae has been established for seventy years. Nutrient and light composition and concentrations are now clearly defined and microalgae are cultured at different stages from the laboratory to industry. However, the cultivation of algae to feed molluscs is costly and developed only in the laboratory or commercial hatcheries. Growing molluscs on cultured food would result in production costs that cannot compete with extensive shellfish culture.

It may be possible to obtain nutrients (ammonia, phosphates, silicates, and iron) at a very low cost in flat coastal areas of western France, where fossil, marine groundwater can be found 2 to 15 metres deep. This water could be used to promote phytoplankton blooms in large (1000 m^3) concrete tanks. The tanks are filled with the ground water and some natural sea water as an inoculum (all these facilities remained near the shore and have access to natural sea water) to produce a diatom-dominated bloom. Very often the prominent species is *Skeletonema costatum*, and the culture becomes monospecific. At this stage, there is no need to remove excess iron salts, but dilution may be necessary for feeding molluscs, as the precipitate may clog the gills. As the quantity of food may be strictly controlled, optimum growing conditions result in faster growth.

Oysters have been reared in this way, but these fast-growing oysters have thin shells. For marketing reasons, a hardening stage in the field is needed. The groundwater may be used on oysters that were cultivated in the traditional way at the end of the culture cycle. The high density of food allows a “fattening” stage to improve the quality of the flesh (glycogen as energy storage) before selling. Other molluscs species have been cultivated, e.g., clams, and flat oysters. The production of large quantities of algae has led to the development of land-based mollusc hatcheries (which utilise the algae for conditioning the breeders), and nurseries producing seed for oyster farmers. Many seeds of flat oysters now come from this technique.

The development of inland aquaculture of molluscs is limited by the availability of groundwater which is strictly controlled. The same water is being used by inland fish farms for thermal control. The water temperature is 14 °C and heats during winter and cools during summer. Because the resource is not renewable, it is not sustainable. Furthermore, the loading of water with uneaten phytoplankton, organic matter, and nutrients is similar to that of an agricultural farm, except that there is better dilution.

Integrated Fish and Shellfish Aquaculture in the Atlantic Salt Marshes (fish+shellfish+saltwort).

Coastal wetlands are interesting sites for land-based fish farm ponds and tanks, but environmental constraints on effluent discharges are stringent in these areas. In order to limit effluent loading, different techniques have been proposed and are beginning to be put into practice by aquaculturists. On the Atlantic coast of Europe (France, Portugal, and Spain), growout farms for sea bass or turbot are often located in wetlands where salt ponds were previously built. Downstream from the rearing ponds, sedimentation ponds are used to reduce the export of particulate matter. Using fish farm effluents, experiments have been conducted with mass culture of microalgae to convert ammonia and phosphates in diatoms with the systematic addition of required amounts of the limiting nutrient, silicium as sodium silicate or phosphorus as phosphoric acid. Then phytoplankton can be fed to shellfish to lower the organic load of the effluent water. Physical treatments may be added when partial recirculation of the effluent water to the fishponds is employed, using immersed foam fractionators, specifically developed for aquaculture ponds. At the end of the cycle, part of the sea water can be released through saltwort fields. Integrated systems are emergent practices to reduce the effluent charge without additional cost, and even producing a complementary income. A demonstration project (GENESIS) has been launched on these concepts in 2002.

3.2.8 New Research Projects and Applications

Bluefin tuna in the Mediterranean

Spain is the major Mediterranean aquaculture producer of the species, but the bulk of the wild juveniles grown in large sea cages is supplied by French fishermen. They decided to participate in the new technology to increase their profit because of decreasing quotas. Researchers provided information on the following topics: reproduction mastering, feeding improvement, larval rearing and environmental impact (global and site specific).

Models of a Production Basin: the Thau Lagoon

A comprehensive programme was launched to investigate the various physical and biological processes that control the productivity and the sanitary status of shellfish in Thau lagoon. The objective of the programme was to improve through modelling the predictability of environmental events that affect the lagoon and may disrupt oyster farming. The major areas investigated were: sedimentation and resuspension of silt, evaluation and prediction of continental nutrient loading to the lagoon, linkages with oceanic water inflow/outflow, determination of non-native species, inter-comparison with other Mediterranean lagoons, restitution of data collection under a GIS.

Summer mortality of cupped oyster

For 40 years, abnormal mortality has been reported on the Atlantic coast from the interaction of various factors including environmental stress, pathogen prevalence and oyster genetic characteristics. A multidisciplinary four-year programme has been launched in 2000 to investigate this phenomenon aiming at finding tentative explanations and to propose practical solutions for oyster farmers. The major tasks were perfecting the necessary immunology and physiology tools, quantifying and characterising occurring events (*in situ*), and experimental approaches to the environmental effects.

The results from the first year of activity are as follows:

- The nature of the spat (i.e., obtained by artificial crossing) has an effect on the mortality rate. The same families dispatched in various sites responded in the same way;
- The nature of the site also has an effect and mortality rates varied from one site to another. Temperatures above 19° C increased the risk of mortality;
- The reproduction period emphasised the phenomenon, even on one-year-old juveniles;
- Some physiological parameters are correlated to mortality (hyalinocyte counts);
- No epidemic disease could be found.

Berre lagoon

Berre lagoon, near Marseille, is the largest coastal lagoon in France. It has been heavily impacted since the 1960s by industrialisation and as a fresh water supply for a power plant station. As a consequence, significant pollution has occurred and a large halocline is maintained all year long. Under these conditions, fisheries and aquaculture activities have almost disappeared. A restoration programme is proposed to return the salinity concentrations, improve water quality, and to develop resource-linked activities. If managed well, this programme could be a good example of integrated management of a coastal area.

References

Deslous-Paoli, J.M., Dosdat, A., and Peruzzi, S. 2002. Pisciculture et environnement: les bases de physique et de biologie marine en soutien à la législation des ICPE en Méditerranée. IFREMER Report

Dosdat, A., and De La Pomélie, C. 2000. Regulation and monitoring of marine aquaculture in France. J. Applied Ichthyology, 16: 157–162.

Dosdat, A., and Deslous-Paoli, J.M. 2000. National Report for France. WGEIM Report for ICES, 2000.

3.3 Germany

Submitted by: Harald Rosenthal, Institute fur Meereskunde, Kiel, Germany.

Production

Traditionally, Germany has limited coastal and marine aquaculture compared to other European countries, which is expected given the limited coastal area available.

Finfish production in marine and brackish waters remains minimal. There are a few family-operated small-scale cage farms (one in the Kiel fjord, several along the coast of Mecklenburg-Vorpommern) that produce rainbow trout. A farm that had cultured turbot (*Scophthalmus maximus*) is now engaged in a large-scale recirculating production system using turbot and sea bass (*Dicentrarchus labrax*).

Major production originates from extensive shellfish farming in the Wadden Sea of Lower Saxony and Schleswig-Holstein. Trends in the production over the past years are shown in Table 3.3.1.

One oyster farm on the North Sea coast continues to operate a successful rack culture system with imported seed oysters (*Crassostrea gigas*) from an Irish hatchery. It should be noted that in recent years, the Pacific oyster has settled extensively on nearby mussel beds, since the mussels are the only available settling substrate in the Wadden Sea (Reise, 2001).

Table 3.3.1. Shellfish cultivation in Germany. *Mytilus edulis* extensive shellfish beds in the Wadden Sea of lower Saxony and Schleswig-Holstein (T= tonnes; DM= Deutsch Mark).

	1995		**1996**		**1997**		**1998**		**1999**		**2000**		**2001**	
	T	**DM**	**T**	**DM**	**T**	**DM**	**T**	**DM**	**T**	**DM**	**T**	**DM**	**T**	**DM**
Schleswig-Holstein	6.1	3.6	-	-	16.6	16.0	15.5	7.9	21.3	15.8	12.2	13.3	5.0	7.9
Lower Saxony	11.7	6.2	-	-	-	-	-	-	-	-	-	-	-	-
Total	17.9	9.8	32.9	-	16.6	-	15.6	-	-	-	-	-	-	-

New Developments

Macro-algal cultures at sites along the Baltic Coast of Schleswig-Holstein are emerging at a very small scale, mainly producing specific substances for the pharmaceutical industry, while linking seeding activities to rehabilitation programmes for seaweed beds.

Another field of marine culture system development has been the production of marine micro-algae as a potential source for raw materials for industrial use. It is again a small-scale operation targeting at a specific market of small volume with highly valued products.

Test trials for offshore farming systems (seaweed and shellfish) have recently started in conjunction with the development of windparks. A feasibility study was performed in 2001 and the results will be available by 2003. There is considerable interest in developing such systems while there is still a need for co-planning and management with other resource users (such as the power industry and the shipping industry).

Research

A Diploma-thesis performed at the Institute of Marine Science in Kiel dealt with mass balance of nutrient flows between various system components (fish tank, biofilter, settling basin, biochemical treatment unit (e.g., ozonation) and denitrification unit), and defined new approaches to determine the processes involved in denitrification (Wecker, 2002). This preliminary study provided background information to develop a model to simulate pathways and process efficiency under various parameter modifications.

Other research projects presently under way investigate alternative ingredients to replace fishmeal as a protein source, especially for use in recirculation systems (Institute for Marine Science, Kiel). In conjunction with an EU project, the

Institute for Marine Science is participating in research on an integrated recirculation system development with China to determine the flow of matter and energy within the system and to develop modules for effective effluent treatment.

Environmental impact assessment studies are presently under way in partnership with Scottish and Greek institutions and farms within a EU-financed project (MERAMED), to develop models for site-specific holding capacity under non-tidal Mediterranean conditions.

The Federal Ministry of Science and Education is reconsidering support for marine aquaculture development in close cooperation with the coastal "Länder". Presently, programme objectives are being developed and it is anticipated that these will be open for grant proposals later this year.

References

Buck, B.H. 2002. Open Ocean Aquaculture and Offshore Windparks. A feasibility study on multifunctional use of offshore-windparks and offshore mariculture in the North Sea. Berichte zur Polar- und Meeresforschung, (Reports on Polar and Marine Research) 412: 1–252. (ISSN1618–3193).

Rosenthal, J., McGlade, J., and Gollasch, S. 2001. The role of aquaculture in integrated coastal zone management. Bull. Aquaculture Assoc. Canada, 101(1): 5–10.

Wecker, B. 2002. "Anorganische Stoffflüsse in einem experimentellen Seewasserkreislauf mit definiertem Fischbesatz. (Inorganic nutrient flow in an experimental recirculation system with defined fish biomass)". University of Kiel, Institute for Marine Science,

3.4 Ireland

Submitted by: T. McMahon and F. O'Beirn, Marine Institute, Snugboro Road, Abbotstown, Dublin 5, Ireland.

3.4.1 Production statistics for finfish and shellfish in 1999 and 2000

The available statistics for the aquaculture production of finfish and shellfish in Ireland for 1999 and 2000 are given in the table below.

	1999		2000	
Species	**Volume (tonnes)**	**Value (€)**	**Volume (tonnes)**	**Value (€)**
Atlantic Salmon	18,219	55,463,616	17,648	61,445,727
Sea-reared Trout	1,077	3,525,135	1,360	4,831,361
Freshwater Trout	1,098	3,106,335	1,053	2,733,904
Finfish other*	89	236,624	76	428,172
Bottom mussels	9,644	4,115,075	21,615	10,561,888
Rope mussels	6,867	4,525,781	4,045	2,358,178
Pacific oyster	6,555	9,231,120	5,031	6,812,813
Native oyster	696	2,912,4,66	266	1,027,220
Clam	121	426,122	92	360,856
Scallop	33	580,525	61	338,195

*Arctic charr, eel, turbot

Production of finfish was relatively static in the years under review but the production of Atlantic salmon represented an increase of approximately 15 %–20 % relative to the production in 1998 previously reported.

Rope mussel production was also relatively static and the decrease in output recorded in 2000 was mainly the result of prolonged closures of production areas due to the presence of biotoxins. There was a significant increase in the output of bottom-cultured mussels in 2000 relative to previous years.

3.4.2 Fish health (2001)

Finfish

There were no isolations of IHNV or VHSV. IPNV was isolated from one site. All sites were inspected for clinical signs of ISA and samples were taken for virus isolation using SHK1 cells. ISAV was not isolated and clinical signs of the disease were not observed.

Bacterial disease was not found to be a significant problem in 2001. All smolts are vaccinated against Furunculosis (and most against Vibriosis), prior to being put to sea.

For the fourth successive year, gill pathology was described on many marine sites in Ireland during the summer months. Mortality levels due to this problem have been low, however, poor growth rates during the important summer months have been observed.

Shellfish

High mortalities of cultured *C. gigas* were reported during the summer of 2001 in Bannow Bay in Co. Wexford (south coast of Ireland). These mortalities could not be associated with microscopical pathogens or herpes-like viruses.

No mortalities were recorded in any other of the shellfish growing waters.

Ireland has nine exploited native oyster (*O. edulis*) beds and one producer is cultivating native oysters. The health situation in the country has not changed since 1993 with four areas (Clew Bay, Ballinakill Bay, Galway Bay and Cork Harbour) affected by Bonamiasis and none by Marteiliasis. Ireland has a monitoring programme for both diseases

(Decision 93/56/EEC) and an Application for Approved zone status was submitted to the European Commission in October 2001. Final approval from the Standing Veterinary Committee is due.

3.4.3 Shellfish Biotoxins

During 2000 and 2001, some 60 production areas were monitored on a weekly basis throughout the year for the presence of DSP and AZP toxins. In both years, concentrations of both DSP and AZP toxins above the regulatory limit were detected in mussels in production areas along the west coast and closures of production areas of up to 10 months were enforced. In 2001 approximately 8.5 % of mussel samples analysed showed the presence of AZP toxins above the regulatory limit of 16 µg/100 g of whole flesh but only 1.5 % of *C. gigas* showed similar results. DSP and AZP toxins were also detected in the hepatopancreas of wild and cultured scallops. The ASP toxin Domoic acid was also detected in scallops. In 2001 approximately 86 % of samples of scallop hepatopancreas tested had concentrations of Domoic acid above the regulatory limit of 20 µg/g, but only 8 % of gonad samples and 1 % of adductor muscle samples tested showed the presence of Domoic acid above the regulatory limit.

3.4.4 Visual Impact of aquaculture operations

All new applications for aquaculture licences for marine salmon farms in Ireland must be accompanied by an Environmental Impact Statement (EIS). The EIS must include an assessment of the landscape and visual impacts of the proposal. While an EIS is not required for applications for aquaculture licences for shellfish farms, the applicant should address the likely landscape and visual issues when preparing an application.

In August 2000 the Department of the Marine and Natural Resources commissioned a study to develop guidelines for the assessment of the landscape and visual impacts of marine aquaculture operations, including advice on good practice for the siting and design of operations. A report entitled " Guideline for the Landscape and Visual Impact Assessment of Marine Aquaculture" was published in May 2001. In addition, leaflets providing guidance to applicants for both salmon and shellfish aquaculture licences have been published.

3.4.5 National Monitoring Programmes

In May 2000, the Department of Marine and Natural Resources published a series of monitoring protocols relating to finfish farming activities. These protocols related specifically to water and benthos quality adjacent to farming activities, sealice levels on cultured fishes as well as overall fish health (see above). All finfish farming licences issued after 2000 were obliged to carry out these sampling protocols at the cage sites. Details of benthic protocols were previously reported in the WGEIM Report from 2000 and the publication "Regulation and monitoring of marine aquaculture in Ireland" by McMahon, T. 2000. Journal of Applied Icthyology, 16: 177–181. Details of the sealice monitoring protocols were given in the WGEIM Report for 2000.

Benthic Monitoring (2001)

In 2001, 18 sites were subject to benthic monitoring. All sites were required to carry out a Level 1 investigation. A Level 1 survey comprises a visual and photographic dive survey along two (perpendicular) transects through the cage system accompanied by a written report. Final reports were submitted for seven sites before the November 2001 deadline. Draft reports were submitted for four sites. No reports were submitted for seven sites.

One site had exceeded the allowable limits of benthic impact (100 % cover of bacterial mats as shown in photographic images and excessive out-gassing caused by large amounts of pelleted-feed on the sea floor). The operators were refused permission to input smolts at the site until a follow-up survey indicated that the seabed under the cages had recovered. A subsequent survey (February 2002) revealed that the site had recovered and the site was licensed for smolt input. The developer committed to installing feed monitoring cameras on site. All other sites were within the allowable levels of impact outlined in the protocols.

Sea-Lice Monitoring (2000)

It is reported that, of the 442 lice inspections carried out in 2000, there were 11 occasions when ovigerous female lice levels exceeded the allowable levels (McCarney *et al.,* 2001). This triggered a number of responses ranging from harvest of fish to treatment of fish with newly approved in-feed treatments (emamectin). In most cases the levels had fallen below the allowable limits by the next inspection.

References

McCarney, P., Copley, L., Jackson, D., Nulty, C., and Kennedy, S. 2001. National Survey of the sealice (*Lepeopophtheirus salmonis* Kroyer and *Caligus elongatus* Nordmann) on fishfarms in Ireland – 2000. Fishery Leaflet 180, Marine Institute.

3.5 Norway

Submitted by: Arne Ervik, Institute of Marine Research Bergen, Norway.

Regulations

The cultivation of aquatic organisms in Norway requires a licence and a minimum of two approved sites. These sites will operate on a rotating basis in order to separate different generations of fish. Table 3.5.1 presents the number of licences for the individual stages of production of various species in the period 1996 to 2001, while Table 3.5.2 shows the number of on-growing sites for various species.

Table 3.5.1. Number of licences for individual stages of production of various species from 1996 to 2001. Source: Directorate of Fisheries.

	Atlantic Salmon and Rainbow Trout				**Various species**	**Shellfish**
	On-growing fish farms	**Fry Production**		**Brood Stock**		
	No. of licences	No. of licences	Capacity (mill)	No. of licences	No. of licences	No. of licences
2000	854	310	159.8	29	369	869
1999	843	315	150.8	29	390	558
1998	826	313	142.2	29	363	299
1997	820	316	132.8	29	337	243
1996	817	330	132.8	37	340	220

Table 3.5.2. Number of on-growing sites for various species in the period 1998–2000. Source: Directorate of Fisheries.

	Atlantic Salmon and Rainbow Trout	**Shellfish species**	**Other**
2000	1806	950	402
1999	1866	694	438
1998	1847	449	416

Fish production is regulated by the amount of feed that may be used by each licence. In 2001, this was 830 tonnes of dry feed. The Directorate of Fisheries monitors feed consumption closely.

Production

The production of salmonids rose during the 1990s, but due to difficult market access growth has slowed during the past few years (Table 3.5.3). The production of species other than salmonids is shown in Table 3.5.4.

Table 3.5.3. Production and value of cultivated Atlantic salmon and rainbow trout in the period 1993–2000. Source: Directorate of Fisheries.

	Atlantic Salmon		**Rainbow Trout**	
	Production (1000 tonnes)	**Value (mill NOK)**	**Production (1000 tonnes)**	**Value (mill NOK)**
2000	436.74	10,691.91	49.04	1 161.52
1999	425.15	9,110.63	48.69	1 263.20
1998	362.43	7,643.30	48.43	988.85
1997	332.58	6,768.84	33.30	628.96
1996	297.56	5,916.01	22.97	479.60
1995	261.52	6,109.66	14.70	362.51
1994	202.47	5,638.99	14.57	343.78
1993	163.89	4,526.12	8.97	216.09

Table 3.5.4. Production of species other than Atlantic salmon and rainbow trout in the period 1994–2000. A= quantity of finfish and blue mussels in 1000 tonnes, for other shellfish 1000 individuals, V=value in 1000 NOK. Source: Directorate of Fisheries.

	Cod		**Arctic Charr**		**Halibut**		**Other Fishes**		**Scallop**		**Oysters**		**Other shellfish**		**Blue Mussel**	
	A	**V**	**A**	**V**	**A**	**V**	**A**	**V**	**A**	**V**	**A**	**V**	**A**	**V**	**A**	**V**
2000	167	3,377	168	4,982	426	30,566	592	18,385	173	957	184	452	85	1,45	791	5,258
1999	157	2,981	498	16,300	451	28,904	211	9,162	339	2,900	650	3,133	18	2,95	662	5,600
1998	199	3,325	190	7,846	290	19,095	524	6,697	169	1,468	510	1,571	7	184	309	2,835
1997	304	4,355	350	15,237	113	8,680	472	9,108	159	-	147	-	154	-	502	-
1996	191	2,609	221	8,855	138	8,798	259	14,780	92	-	526	-	1	-	184	-
1995	284	3,988	273	10,908	134	8,168	309	16,862	206	-	325	-	37	-	388	-
1994	569	8,394	262	9,641	63	3,360	222	16,595	14	-	1,085	-	302	-	542	-

Production trends

The cultivation of halibut has been hampered by difficulties in fry production, but last year 450,000 fry were produced, 90 % of this in intensive production under controlled conditions (Source: Bergen Aqua). In addition to increasing numbers, the quality of the fry produced in intensive production has improved.

The interest in cod cultivation has grown in response to low stocks of wild cod and high prices. Several companies are engaged in intensive fry production. Within five years, 15 to 17 producers are expected to have a total output of 50 to 60 million fry. Cod farm grow-outs could produce an annual harvest above 100,000 tonnes.

Medicine consumption

As a result of extensive vaccination programmes and hygienic measures, bacterial diseases cause only minor problems, a situation that is reflected in the current low consumption of antibiotics (Table 3.5.5). At present these drugs are used mainly on broodstock fish and usage compared to the total production of on-growing fish is small (Figure 3.5.1).

Table 3.5.5. Quantities of antibiotics used in the Norwegian mariculture industry from 1996 to 2000. Quantities are given as kilograms of active component. Source: Directorate of Fisheries.

	Enrofloxacin	Florfenicol	Flumequin	Oxolinic acid	Oxytetracycline	Others	Total
1996		64.0	97.0	844.0	19.0	19.8	1,043.8
1997		26.5	71.4	445.5	11.8	0.5	555.7
1998		128.6	116.8	421.7	4.2		671.2
1999		65.0	7.0	494.0	25.0		591.0
2000	0.02	146.2	16.8	434.5	2.1		599.6

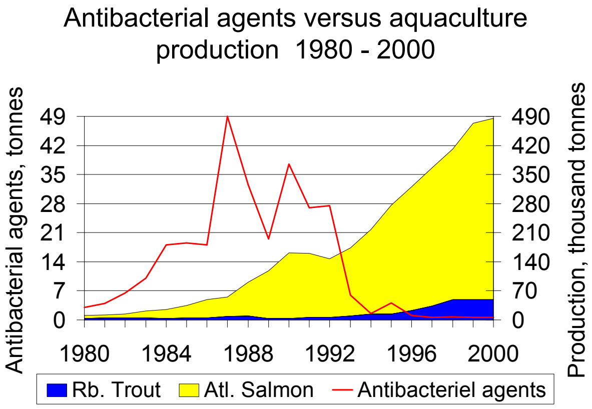


Figure 3.5.1. Antibiotic agent consumption from 1980 to 2000 and production of Atlantic salmon and rainbow trout. Source: Directorate of Fisheries.

Sea lice are the cause of substantial losses in mariculture and lice larvae from fish farms are believed to represent a threat to wild strains of Atlantic salmon in Western Norway. In Mid- and Northern Norway, wild salmon are less exposed to lice larvae from cultured fish due to hydrological conditions. Table 3.5.6 shows a reduction in the quantities of drugs used, due in part to the introduction of the more effective emamectin benzoate.

Table 3.5.6. Usage of ecto- and endoparasite drugs in kg active component from 1996 to 2000. **A**=Bronopol (Pyceze®), **B**=Cypermetrin (Exis®, Betamax®), **C**=Deltamethrin (Alpha Max®), **D**=Diflubenzuron (Lepsidon®**)**, **E**=Emamectin benzoate (Slice®), **F**=Fenbendazol, **G**=Malanchite green oxalate, **H**=Praziquantel, **I**=Teflubenzuron (Ektobann®). Source: Directorate of Fisheries.

	A	B	C	D	E	F	G	H	I	Others	Total
1996	-	-	0.1	103	-	1	12	173	547	968	1804.1
1997	-	0	0	462.1	-	9	3.9	215.7	1429.7	386.4	2506.8
1998	-	8.5	28.4	585.1	0	8.8	3	170	1186.9	128.3	2119
1999	128	19	11	50	3.5	12	24	239	231	14	731.5
2000	421	68.7	17.6	12.4	33.6	39.1	9	100.5	61.5	-	740.8

Research on sealice

Research on sealice has been carried out for more than ten years at the Institute of Marine Research (IMR). The general biology of sealice and impacts on wild Atlantic salmon have been topics of particular interest for the past 3–5 years. Testing testing efficiency of potential drugs for the treatment of salmon lice has also been a high priority. Currently, sealice research at IMR focuses on three main topics: 1) early life stages and behaviour, 2) the spread of sealice and infections in wild Atlantic salmon, and 3) molecular biological studies, with particular reference to digestion in sealice. The first two topics are continuations of earlier projects while the last utilises new technology in Norwegian sealice research. A long-term goal of the molecular biology studies is to identify antigens that could be used in a vaccine against sealice. The use of vaccines has been a major strategy in the Norwegian aquaculture industry, and a vaccine against sealice would provide a new and environmentally friendly way of reducing the problems generated by this parasite. However, experience from vaccine development for other parasites shows that this is complex, time-consuming work with a time frame of at least 5–10 years.

Employment

In spite of major increases in production, automation and efficiency, there has been a drop in the number of persons employed in the mariculture industry (Figure 3.5.2). Nearly 90 % work with salmonids, but more and more are beginning to work with other species (Figure 3.5.3).

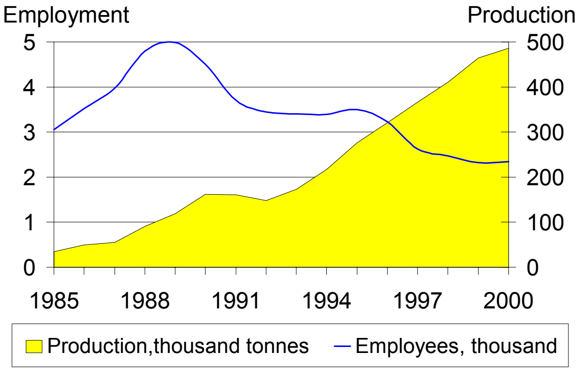


Figure 3.5.2. Number of employees and production of Atlantic salmon and rainbow trout from 1985 to 2000. Source: Directorate of Fisheries.

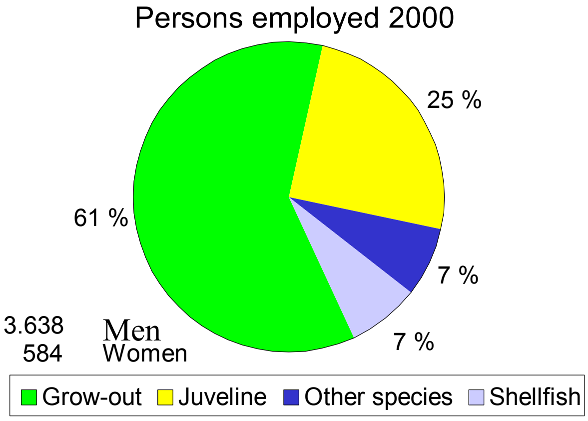


Figure 3.5.3. Number of employees in various sectors of the Norwegian mariculture industry in 2000. Source: Directorate of Fisheries.

Production of feed

The production of Atlantic salmon in Norway is regulated by the amount of feed the fish farmer is permitted to use. The authorities therefore closely monitor feed consumption at the individual farm. The figures presented in Table 3.5.7 give an overview of total sales of feed to the Norwegian mariculture industry and the various sources of fish feed.

Table 3.5.7. Sales of fish feed in tonnes dry feed in Norwegian mariculture and its sources from 1992 until 2000. Source: The Fish Feed Producers Association (FPF).

	FPF	Others	Imported	Total
1992	210,841	-	6,102	216,943
1993	262,946	-	5,812	268,758
1994	332,656	-	9,784	342,440
1995	439,063	-	7,252	446,315
1996	455,264	-	2,896	458,160
1997	522,015	-	1,918	523,933
1998	564,757	10,871	1,626	577,254
1999	589,742	16,000	3,736	609,478
2000	696,180	16,000	3,819	715,999

3.6 Scotland

3.6.1 Annual Survey of fish production 2000

Submitted by: C. E. T. Allan and I. M. Davies, FRS Marine Laboratory, Aberdeen.

Salmon

Production

Production survey information for Scotland was collected from 90 companies actively involved in Atlantic salmon production, farming 346 marine sites, of which 163 sites were actively producing. The total production of Atlantic salmon during 2000 was 128,959 tonnes, an increase of 2273 tonnes (1.8 %) on 1999 production. The small increase also reflects the statements previously made by some companies that they might not be producing salmon in the year 2000 as a result of uncertainty in the industry, with regard both to market conditions and the outbreak of infectious salmon anaemia (ISA).

The number and average weight of fish harvested in the year of input were similar to those in 1999. The use of photoperiod and "early" smolts, combined with the rapid rates of growth achieved using high energy feeds and modern husbandry methods, resulted in a further increase in average harvest weight of zero sea winter fish to 3.5 kg. This is only 0.4 kg less than that attained for one sea winter fish and presumably reflects the market-preferred harvest weight.

The numbers of grilse and pre-salmon harvested in 2000 were similar to those in 1999, although the weight increased by about 7 %, reflecting increased individual fish weights at harvest and the emergence of the industry from the effects of compulsory slaughter programmes for the control of ISA, and other factors.

15 companies dominated production in 2000, which between them accounted for 74 % of the overall salmon produced in Scotland.

Survival and Production in Smolt Year Classes

In 1998, the last year-class for which survival can be calculated, the survival rate from smolt input to harvest was 69.1 %. This was a decrease of over 20 % compared to the 1997 year-class, and can be attributed to a variety of causes. These include mortality and culling associated with the ISA outbreak, losses in clinical IPN outbreaks, losses associated with plankton blooms, increases in the numbers of escapes and of losses during sealice control treatments.

Production Methods

Almost all of the production, 128,830 tonnes, was produced in sea water cages, with a further reduction in the proportion from seawater tanks, 0.2 % in 2000. This figure reflects the high installation and running costs incurred in operating seawater tank systems. 48 seawater tank sites are registered in Scotland. Only two were actively producing salmon. Most seawater tank capacity has now been re-deployed to the production of alternative species such as halibut, turbot, cod, etc.

Sea cage capacity increased by over a 800,000 cubic metres in 2000, reflecting the rise in the number of sites in production and a decrease in mean stocking density. Production efficiency in cages, measured as the ratio of fish weight in kilograms produced per cubic metre, increased by 0.4 kg in 2000,

Company Productivity

The west of Scotland, the Western Isles, the Orkney and Shetland Islands, remain the principal locations for the Scottish salmon industry. This is due to the requirements for relatively clean, sheltered areas in which to locate marine fish farms. The salmon industry continued to be a major provider of local employment in these areas. Production per employee can be used as a measure of efficiency, and is related to the scale of production. The greatest productivity (114 tonnes per person) was achieved in those companies having production greater than 2000 tonnes, and the least (5 tonnes per person) in companies producing the smallest quantities.

Fallow Periods

Of the 344 sites recorded as being active in 2000, 184 farms were fallow for a variable period, whilst 75 farms were fallow for the whole year in 2000. The accepted normal production cycle in sea water varies in length between eighteen months and two years, and a fallow period at the end of production can break the cycle of disease or parasitic infections. There were 74 sites that had no fallow period in 2000. These may have been stocked late in 1999 with out of season smolts, or may not have used a fallow period.

FRS recommends that a minimum fallow period of six weeks should be used between on-growing cycles. In May 2000, the Scottish Executive announced that it was going to consider the possibility of mandatory fallow periods at seawater production sites in the future.

Other Species

There is an increased interest in the production of other species, particularly in diversification into emerging marine species. There was a small production of turbot, and some sites were stocked with lemon sole, lumpsucker, and haddock. However, the main current expansion is in cod and halibut, of which 16 and 5 tonnes were produced, respectively. Estimates for 2001 are for 41 and 189 tonnes.

Conclusions

The production tonnage of salmon in sea water increased by 1.8 % in 2000, due mainly to an increased average weight of individual fish produced. The estimated number of smolts put to sea in 2000 was 50.2 million, which would indicate an increased harvest in 2001 and 2002. The estimated harvest forecast for 2001 is 158,479 tonnes, an increase of 23 % on the 2000 total.

3.6.2 Shellfish Production 2000

Submitted by: D. I. Fraser and I. M. Davies, FRS Marine Laboratory, Aberdeen.

Production

The shellfish species cultivated at farms in Scottish waters and for which production returns were received in 2000 were:

Common Name	Scientific Name	Production	Year 2000
Pacific oyster	*Crassostrea gigas*	(000s)	3088
Native oyster	*Ostrea edulis*	(000s)	51
Scallop	*Pecten maximus*	(000s)	323
Queen	*Chlamys opercularis*	(000s)	2084
Common mussel	*Mytilus edulis*	(tonnes)	2003

The number of registered companies and the sites that placed shellfish on the market increased by 25 during 2000, however, the number of active sites decreased by 4 %, reflecting the continued closure of inefficient sites. Many unproductive sites held stock not yet ready for market, others were fallow or were positioned in remote areas where the cost-effective production and marketing of shellfish proved difficult. The number of staff in full-time employment increased by 18 % (to 138), whilst the number in part-time and casual employment increased to 225 during the year. Only the production of scallops increased since 1999, and the number of productive sites fell to 132.

Prices of farmed shellfish fluctuated throughout the year, however, the value at first sale of the species cultivated was estimated. The price of Pacific oysters varied between 15 and 25 pence per shell; native oysters 50 pence per shell; scallops 50–60 pence; queens 5 pence per shell; and mussels £800–£1,300 per tonne. The total value at first sale of all species was around £3,000,000.

The production of all species of shellfish has shown considerable variations from year to year. However, considered over a 10-year period (1991–2000), there has been a steady increase in the production of mussels. The main areas of expansion have been Strathclyde, Shetland, and Highland Region. Production in the Western Isles may now be increasing again, while there is now no production in Orkney.

Over the same period, the production of Pacific oysters has increased from 2.3 to 3 million shells. Strathclyde produces 70 % of the crop, and Highland Region 25 %. Production is small in Orkney and Shetland. Few sites produce native oysters and numbers produced are low.

Production of queen scallops has gradually increased from 0.8 million to 3.7 million shells, almost entirely in Strathclyde region. The production of scallops remains rather low at around 300,000 shells, but the recent developments in Several Orders may increase the production level over the next few years.

Disease and Environmental Issues

Approved Zone status for the notifiable diseases, Bonamiasis and Marteiliasis, was maintained in 2000 (under EC Directive 91/67), following testing to confirm the absence of those diseases in Scottish waters. Samples were taken from ten sites holding native oysters, a species known to be susceptible to these diseases. Approved Zone status continued to offer protection to both wild and farmed native oyster stocks in Scottish waters.

EC Council Directive 95:70 establishes minimum measures for ensuring that controls on certain diseases of bivalve molluscs are in place. Each year, FRS Inspectors visit one third of all shellfish sites under this Directive.

Marine biotoxin monitoring in Scotland continued during 2000. Examination of more than 3675 shellfish flesh, and 646 phytoplankton samples from 38 sites revealed the presence of paralytic shellfish poisons (PSP) and diarrhetic shellfish poisons (DSP) and amnesic shellfish poisons (ASP) in most of the important shellfish growing regions. Voluntary Closure Agreements (VCAs) were agreed where appropriate, and Food and Environment Protection Act 1985 (FEPA) closure orders were imposed in scallop aquaculture and important scallop fishing grounds. The ASP problem continued to the end of the year.

Classification of bivalve mollusc production areas continued during 2000, under The Food Safety (Live Bivalve Molluscs and Other Shellfish) Regulations 1992, and currently 79, 31, 37 and 7 are classified as either A, A/B Seasonal, B, or C, respectively. There are currently some 20 approved depuration systems: 7 small-scale oyster purification plants; 6 bulk bin systems for mussels; and 7 medium-sized plants for the depuration of mussels or oysters. In an attempt to meet the End Product Standard at all times, there is an increasing demand by buyers that all marketed stocks be depurated, including those classified as A (where purification is not essential).

APPENDIX 4

Guidelines for the formation and operation of Area Management Agreements in Scotland (Taken from a report of the Scottish Tri-partite Working Group (TWG), which brings together the aquaculture industry, wild fisheries interests, and Government.)

Area Management Agreement (AMAs)

With the objective of promoting and maintaining the good health of both wild and farmed salmonids, AMAs between fish farming companies and District Salmon Fishery Board (DSFBs)/Fishery Trusts should be formally established at local levels. These AMAs should be formed either through their incorporation into AMAs already existing between farming companies or by the creation of new AMAs where inter-farm agreements do not already exist.

An Area Management Group (AMG) should be established to formulate and manage each AMA. Group members will include representatives of local salmonid farms, the local Fisheries Trust Biologist and/or trustees and a representative of the local DSFB where present. The Group may invite attendance from other relevant parties (e.g., SEPA, SERAD, Area and Community Councils) as appropriate.

Joint AMA Measures

The joint AMAs should aim to incorporate the following measures:

a) Synchronised production: To ensure the breaking of cycles of diseases and parasites, the fish farm production and fallowing cycles should be synchronised within an area. This requires the use of single year classes in the area. It is recognised that farmers with one site will have difficulty in achieving this. Where changes in farm practices would result in significant production losses the AMA will consider supporting the development of new sites or increase in production within the management area.

b) Zero ovigerous sealice objective: Salmon farms in AMAs should have the objective of continuously achieving zero ovigerous salmon lice on stocks. This objective is most critical during the period immediately prior to and during the wild smolt migration periods (February–June inclusive). This can be achieved through:

- strategic timing of fallowing of sites (February–April); or
- rigorous zone control of lice by best currently available treatment methods and synchrony of treatments between farms in the zone.

c) Furunculosis vaccination: To reduce risk to wild fish from furunculosis in farmed stocks, only smolts vaccinated against this disease should be used within the AMA area.

d) Farm escapes: To minimise the risk from escaped farmed salmon, the recommendations of the Escapes Working Group should be taken into account by farms within the AMA area.

e) Relocation: To consider the relocation of some fish farm sites in particularly sensitive areas, if necessary, by encouraging the development of new, more suitable sites, or by increasing the production in less sensitive sites within the general area.

f) Other Codes of Practice: To maintain general high health status of farm stocks, accepted best husbandry practices should be used as recommended by the Scottish Salmon Growers' Association, now Scottish Quality Salmon, Codes of Practice and the recommendations made by the Joint Government/Industry Working Group on Infectious Salmon Anaemia.

Monitoring

Each AMG should submit bi-annual progress reports to the TWG. The reports should, in addition to highlighting successes, highlight any problems arising in the AMA.

ANNEX 4: AN INTELLECTUAL INJUSTICE TO AQUACULTURE DEVELOPMENT: A RESPONSE TO THE REVIEW ARTICLE ON "EFFECT OF AQUACULTURE ON WORLD FISH SUPPLIES"

Not to be cited without prior reference to the authors

International Council for the
Exploration of the Sea

Working Group on Environmental
Interactions of Mariculture
Working Paper 01/09

This is an unpublished working draft of a paper prepared by a group of scientists in response to the paper "Effect of aquaculture on world fish supplies" by Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H., and Troell, M., published in 2000. (Nature 405: 1017–1024.)

An intellectual injustice to aquaculture development: a response to the review article on "Effect of aquaculture on world fish supplies".

By: Eva Roth (1), Hans Ackefors (2), Frank Asche (3) Christian Balnath (4) Edward Black (5), Kenneth Black (6), Andrew Boghen (7), Craig Browdy (8) Peter Burbridge (9) John D. Castell (10), George Chamberlain (11), Konrad Dabrowski (12), Ian Davies (13) Antoine Dosdat (14), Anastasio Eleftheriou (15), Arne Ervik (16), Hillel Gordin (17), Christopher S. Heinig (18), Volker Hilge (19), Ioannis Karakassis (20), Holmer Kuhlmann (21), Thomas Landry (22), Mathias von Lukowicz (23), Jaqueline McGlade (24), Andrew Price (25), Robertt B. Rheault (26), Harald Rosenthal (27), Ulrich Saint-Paul (28), Paul A. Sandifer (29) Marco Saroglia (30), William Silvert (31), Werner Steffens (32), Doris Soto (33), Laszlo Varadi (34), Johan Verreth (35), Marc Verdegem (36), Uwe Waller (37)

(1) Institute of Environmental and Business Economics, University of Southern Denmark, Denmark
(2) Department of Zoology, Stockholm University, Sweden
(3) School of Science and Technology, Stavanger University College, Stavanger, Norway
(4) Institute for Marine Science, University of Kiel, Kiel, Germany
(5) Comox, British Columbia, Canada
(6) Dunstaffnage Marine Laboratory, Oban, Argyll, Scotland, UK
(7) Département de biologie, Université de Moncton, NB, Canada
(8) Marine Resources Research Institute, South Carolina Department of Natural Resources, Charleston, USA
(9) Department of Marine Sciences and Coastal Management, University of Newcastle upon Tyne, UK
(10) Department of Fisheries and Oceans, Biological Station St. Andrews, NB, Canada
(11) Global Aquaculture Alliance, St. Louis, MO, USA
(12) School of Natural Resources, Ohio State University, Columbus, Ohio, USA
(13) Fisheries Research Services, Marine Laboratory, Aberdeen, UK
(14) A.D. Station Experimentale d'Aquaculture, IFREMER, Palavas les Flots, France
(15) Institute of Marine Biology of Crete, Iraklion, Crete, Greece
(16) Institute of Marine Research, Bergen, Norway
(17) Mariculture Div., Dep. Fisheries & Aquaculture, Ministry of Agricult. & Rural Develop., Israel
(18) MER Assessment Corporation, 14 Industrial, Parkway, Brunswick, Maine 04011, USA
(19) Federal Research Board of Fisheries, Institute of Fishery Ecology, Ahrensburg, Germany
(20) Institute of Marine Biology of Crete, Heraklion, Crete, Greece
(21) Federal Research Board of Fisheries, Institute of Fishery Ecology, Ahrensburg, Germany
(22) Science Branch, Gulf Fisheries Centre, Moncton, Canada
(23) Bavarian State Institute for Fisheries, Germany
(24) London University College, England
(25) Ecology and Epidemology Group, Department of Biological Sciences, University of Warwick, UK
(26) Moonstone Oysters, 1121 Mooresfield Rd., Wakefield, RI 02879, USA
(27) Institute for Marine Science, University of Kiel, Kiel, Germany
(28) Center for Tropical Marine Ecology, Bremen, Germany
(29) South Carolina Department of Natural Resources, Columbia, South Carolina, USA
(30) Department of Structural and Functional Biology, University of Insubria, Varese, Italy
(31) Portuguese Institute for Fisheries and Sea Research, Lisbon, Portugal
(32) Deutscher-Fisherei-Verband, Hamburg, Germany
(33) Faculty of Fisheries and Oceanography, University of South Chile, Puerto Montt, Chile
(34) Fish Culture Research Institute, Szarvas, Hungary
(35) Fish Culture and Fisheries Group, Wageningen Institute of Animal Sciences, Wageningen University,the

Netherlands
(36) Fish Culture and Fisheries Group, Wageningen Institute of Animal Sciences, Wageningen University, the Netherlands
(37) Institute for Marine Science, University of Kiel, Kiel, Germany

The publication cited above (Naylor *et al.*, 2000) was interpreted by "NATURE" on its cover page as the "Downside of Aquaculture". We agree with the overall objective of the authors to develop sustainable aquaculture management practices. Unfortunately, the paper contains numerous flaws and misconceptions as well as inaccurate reporting of facts. These shortcomings cannot be fully addressed within this response statement. We therefore focus our comments on a few key issues from the paper.

The main issue raised by Naylor *et al.* (2000) is that while aquaculture provides a partial solution to the collapse of commercial fisheries stocks world-wide, it also contributes to that collapse. The authors argue that, because of the need for fishmeal and fish oil for pelleted fish diets, the growth in farmed fish harvests from 10 to 29 Mt over the past decade helps to explain current patterns of oceanic fish capture. We counter this argument from three viewpoints.

First, the major increase in aquaculture production originates from herbivorous and not from carnivorous species (Figure A4.1) and, therefore, this development is to date independent of the worldwide capture of wild fish. The greatest increases in production are found in developing countries (FAO, 2000), such as China, where fish farming is building on traditional practices that have been in existence for centuries (Zhiwen, 1999), mainly using carps and other omnivorous species and, therefore have seen an increase in production of species thriving at lower trophic levels. The remaining portion of cultured fish species in Asia and other parts of the world are carnivorous which presently are partially in need of fishmeal as a protein source.

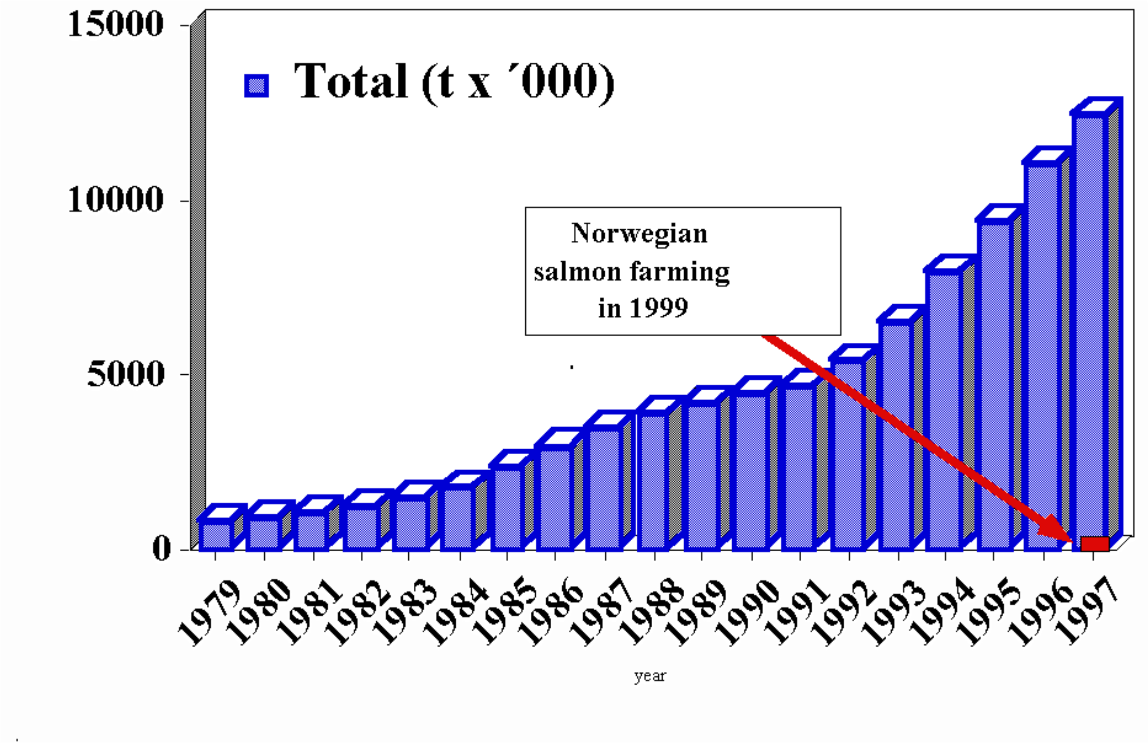
Second, the balance between carnivorous and non-carnivorous species in aquaculture production is heavily skewed towards the latter (Figure A4.1). Farming of non-carnivorous species does not rely heavily on fishmeal-based feeds (perhaps 10–15 %, if it is used at all, for some of the more omnivorous species (Tacon, 2000)). Therefore, the argument that aquaculture based on carnivorous species is driving up the capture of small pelagics is difficult to support. This argument would imply that the demand for dietary protein by aquaculture would increase the world market price for fishmeal. Fishmeal constitutes only 4 % of the total oil meal market demand (Asche and Tveterås, 2000), and estimates of the share of fishmeal for use in aquaculture varies between 17–20 % (Pike, 1999; Gérin, 1999) and 35 % (Chamberlain and Barlow, 2000). Hence, terrestrial livestock production is the most influential factor with respect to the demand for fishmeal. This, together with the fluctuation in fish stock sizes caused, for example, by the environmental effects of El Niño, largely determines the changes in market price for fishmeal as depicted in Figure A4.2. From this figure it can also be deduced from the price structure, that available substitutes (e.g., soya meal) follows the same pattern, indicating that soya is a close substitute for fishmeal. With this market structure, increased demand for fishmeal from aquaculture cannot have any significant effect on fishmeal prices, and it does not follow that it will lead to increase fishing pressure (Asche and Tveterås, 2000).

Other market and environmental scenarios may place severe pressures on the fishmeal market and by far outweigh the importance of aquaculture as a factor in increased fishing pressures as contended by Naylor *et al.* (2000). For example, to limit the spread of the bovine spongiform encephalopathy, BSE, the European Commission recently installed a total ban on the use of warm-blooded animal meals in feeds for livestock animals. In this ban fishmeal and fish oil were not included. As a consequence, the demand for fishmeal as a substitute for meat and bone meal in livestock diets may increase strongly.

A much more important issue than using fishmeal for feeding aquaculture species high or low in the food chain is the fact that many of the fishmeal/fish oil resources today are contaminated by substances such as dioxins to the extent that they can no longer be used for any food production for human consumption (Lundebye *et al.,* 2000; European Commission, Scientific Committee on Animal Nutrition, 2000a, 2000b) unless costly clean-up procedures are effectively developed and employed. This was totally neglected by Naylor *et al.* (2000). This automatically implies that fishmeal and fish oil originating from areas with dioxin pollution will face higher production costs and this will limit their use.

Carnivorous fish culture in the future will not necessarily have to use fishmeal as a protein source. Moreover, less fishmeal is used for each kilogram of farmed fish produced because of improved feed conversion efficiency (Asche *et al.,* 1999). Protein and energy conversion is generally higher in fish than in warm-blooded terrestrial animals (Steffens, 1989; Åsgård and Austreng, 1995). Additionally, there is ample evidence that carnivorous fish can utilize plant proteins in their diets more efficiently than omnivorous fish. Diet formulations for salmonids can, in principle, be made completely fishmeal free without a detrimental effect on growth and with significantly reduced waste outputs (Kaushik *et al.*, 1995; Dabrowski *et al.,* 2000); however, to date it is unclear whether this is desirable. In any event, such shift in protein resource use in carnivorous fish culture would change their "trophic value" in relation to perceived ecological consequences (e.g., "farming up the food web").

Figure A4.1 Trends in Chinese carp production (species low in the food chain) over the past 20 years (after Zhiwen, 1999) in comparison with the 1999 salmon production level in Norway (data from various sources). It should be noted, that the Zhiwen (1999) data might be an overestimate. (Rosenthal, personal communication).

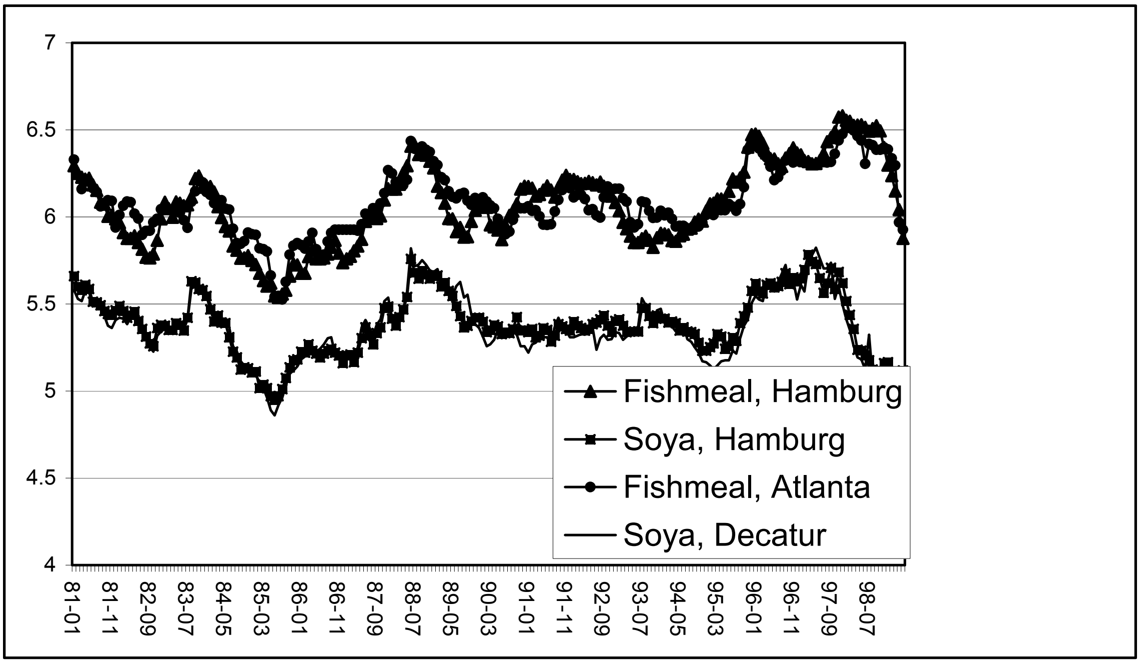


Thirdly, Naylor *et al.* (2000) conclude that culture of non-carnivorous species has a lower ecological impact. This is not necessarily the case. The culture of non-carnivorous species can also have an ecologically damaging effect if not managed properly, depending on the scale and type of operation. For example, it is now recognized that conventional pond farming of fish and inappropriate combinations of species in modern integrated farming systems (e.g., fish, pigs, and birds) in Asia can foster human disease vectors which may subsequently affect human health (e.g., influenza pandemic) (Din *et al.*, 1988).

The argument is not which species are cultured, but rather which species combinations are used, as well as the degree to which production processes are suited to prevailing environmental conditions. Shrimp culture, for example, has caused significant problems in some areas (Primavera, 1997; DeGraaf and Xuan, 1998; Paez-Osuna *et al.*, 1998; Thanh *et al.,* 1999; FAO, 1999) where it has been allowed to operate in an uncontrolled manner (Boyd and Masset, 1997). However, experts agree that shrimp and fish farming can be practiced in an environmentally friendly manner (Hopkins *et al.,* 1995; Sandifer and Hopkins, 1996; Macintosh, 1998; Karakassis *et al.,* 2000). These best practices should be promoted (Boyd, 1999). National laws in shrimp-producing countries now prohibit mangrove alienation. Mangrove conservation and mangrove exploitation are being integrated into farm management practices (Lassen, 1997). Past errors in modern finfish farming which have led to environmental deterioration have also been documented. However, environmental concerns expressed by aquaculturists and scientists have led to substantial improvements in aquaculture systems in past years (ICES, 1995, 1999). For a number of aquaculture systems, integrated culture involving species of various trophic levels could greatly enhance production while minimizing environmental costs and converting wastes into useful products (Soto and Mena, 1999; Shpigel *et al.,* 1993; Neori *et al.,* 1996, 1998). One major constraint in enforcing good practice is the probity of administrations and their determination to support best practice in the face of competing pressures, an important issue often neglected.

Given that there is an increasing demand for freshwater resources and space in the coastal zone, it is critical that there should now be a balanced debate about the extent of aquaculture, as well as the volume and type of species to be produced. Some arguments presented by Naylor *et al.* (2000) derive from rhetoric rather than fact and do little to help the real debate about how we should address food security in tandem with environmental protection.

Figure A4.2. Fluctuations of monthly fishmeal and soybean meal prices (US$ per tonne) at three different markets during the period of January 1981 and April 1999 (after Asche and Tveterås, 2000).



References

Asche, F., and Tveterås, S. 2000. On the relationship between aquaculture and reduction fisheries. IIFET 2000 (International Institute of Fisheries Economics and Trade), Oregon State University, 10–14, July 2000, Corvallis, Oregon, USA, 28 pp.

Asche, F., Guttormsen, A.G., and Tveterås, R. 1999. Environmental problems, productivity and innovations in Norwegian Salmon Aquaculture. Aquaculture Economics and Management, 3: 19–30.

Åsgård, T., and Austreng, E. 1995. Optimal utilization of marine protein and lipids for human interests. pp 79–87. *In:* Reinertsen, E, Haaland, H. (Eds): Sustainable Fish Farming, Proc. 1st intern. Symp. On sustainable fish farming. Oslo, Norway

Boyd, C.E. 1999. Codes of (ID14) Practice for Responsible Shrimp farming. Global Aquaculture Alliance. St. Louis, MO, USA. 48 pp.

Boyd, C.E., and Massaut, L. 1997. Perspectives for sustainable aquaculture through better environmental management. Proceedings of the IV Congreso Ecuatoriano de Acuacultura, Guayaquil, Ecuador.

Chamberlain, G. W., and Barlow, S.M. 2000. A balanced assessment of aquaculture. Global Aquaculture Advocate, 3 (4): 7.

Dabrowski, K., Rinchard, J., Lee, K.-J., Blom, J.H., Ciereszko, A., and Ottobre, J. 2000. Effects of Diets Containing Gossypol on Reproductive Capacity of Rainbow Trout (*Oncorhynchus mykiss*) Biol. Reprod., 62 (2): 227.

DeGraaf, G.J., and Xuan, T.T. 1998. Extensive shrimp farming, mangrove clearance and marine fisheries in the southern provinces of Vietnam. Mangroves and Salt Marshes 2(3): 159–166.

Din, J.-Y., Guo, X., Fang, X.-Z., Lui, M.-Z., and Zhang, W.-Y. 1988. Preliminary studies on the effect of livestock manure application on bacterial fish disease and human hygiene, Asian-Pacific Research and Training Center for Integrated Fish Farming, Wuxi, People's Rep. China. Network of Aquaculture Centers in Asia, Bangkok, Thailand, 11 pp.

European Commission, Scientific Committee on Animal Nutrition, 2000a. Opinion of the SC on Animal Nutrition on the Dioxin Contamination of Feeding stuffs and their Contribution to the Contamination of Food of Animal Origin, Adopted on 06 November 2000, 105 pp. (European Commission, Health & Consumer Protection Directorate General; Directorate C – Scientific Opinions; C3 – Management of scientific committees II: scientific co-operation and networks).

European Commission, Scientific Committee on Animal Nutrition, 2000b. Opinion of the SCF on the Risk Assessment of Dioxins and dioxin-like PCBs in Food. Adopted on 22 November 2000, SCF/CS/CNTM/Dioxin/8 Final; 141 pp. (European Commission, Health & Consumer Protection Directorate General; Directorate C – Scientific Opinions; C3 – Management of scientific committees II: scientific co-operation and networks).

FAO, 2000. FAO Fisheries Department, Fishery Information, Data and Statistics Unit, FishStat Plus: Universal software for fishery statistical time series, Version 2.3.

Gérin, M. 1999. Feed additives and biotechnologies in aquafeeds: Moving towards sustainable development. Intern. Aqua feed. 1999: 32–40.

Hopkins, J.B., Sandifer, P.A., and Browdy, C.L. 1995. A review of water management regimes which abate the environmental impacts of shrimp farming. pp. 66–75. In: Browdy, C.L., Hopkins, J.S. (Eds.). "Swimming through troubled water". Proceedings of the Special Session on Shrimp Farming" Aquaculture 95. (World Aquaculture Society, Baton Rouge, LA, USA).

ICES. 1995. Report of the ICES Workshop on Principles and Practical Measures for the Interaction of Mariculture and Fisheries in Coastal Area Planning and Management. ICES CM. 1995/F:56, pp. 1–31 (Mariculture Committee).

ICES. 1999. Report of the Working Group on "Environmental Interactions of Mariculture. ICES CM/F:5, pp. 1–120.

Karakassis, I., Tsapakis, M., Hatziyanni, E., Papadopoulus, K.-N., and Plaiti, W. 2000. Impact of cage farming of fish on the seabed in three Mediterranean coastal areas. ICES Journal of Marine Science, 57: 1462–1471.

Kaushik, S., Cravedi, J.P., Lalles, J.P., Sumpter, J., Fauconneau, B., and Laroche, M. 1995. Partial or total replacement of fishmeal by soybean protein on growth, protein utilization, potential estrogenic or antigenic effects, cholesterolemia and flesh quality in rainbow trout, *Oncorhynchus mykiss*. Aquaculture, 133(3–4): 257–274.

Lassen, T. 1997. Environmental extremes versus sustainable policies in aquaculture. World Aquaculture, 28(3): 49–51.

Lundebye, A.-K., Boe, B., and Julsham, K. 2000. Documenting seafood safety: contaminant concentrations in Norwegian fish feeds and mariculture products. ICES CM 2001 P:03.

Macintosh, D.J. 1998. Mangroves and coastal aquaculture sustainability. pp. 242–251. *In:* ADB/NACA 1998. Aquaculture sustainability and the environment. Report on a Regional Study and Workshop on Aquaculture Sustainability and the Environment. Bangkok, Thailand: Asian Development Bank and Network of Aquaculture Centres in Asia-Pacific. XIV, 491 pp.

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

Neori, A., Krom, M.D, Ellner, S.P, Boyd, C.E., Popper, D., Rabinovitch, R., Davidson, P.J., Dvir, O. , Zuber, D., Ucko, M., Angel, D., and Gordin, H. 1996. Seaweed biofilters as regulators of water quality in integrated fish-seaweed culture units. Aquaculture, 141; 183–199.

Neori, A., Shpigel, M., and Ragg, N.C. 1998. The integrated culture of seaweed, abalone, fish and clams in intensive land-based systems: II. Performance and nitrogen partitioning within integrated abalone (*Haliotis tuberculata)* and macroalgae (*Ulva lactuca* and *Gracilaria conferta*) culture system. Aquacultural Engineering, 17:215–239.

Paez-Osuna, F., Guerrero-Galvan, S.R., and Ruiz-Fernandez, A.C. 1998. The environmental impact of shrimp aquaculture and the coastal pollution in Mexico. Marine Pollution Bulletin, 36(1): 65–75.

Pike, I. 1999. The real effect of aquaculture on world fish supplies. Feed International, Sep. 1999: 34–40.

Primavera, J.-H., 1997. Socio-economic impacts of shrimp culture. Aquaculture Research, 28(10): 815–827.

Sandifer, P.A., and Hopkins, J.S. 1996. Conceptual design of a sustainable pond-based culture system. Aquacultural Engineering, 15: 41–52.

Shpigel, M., Neori, A., Popper, D., and Gordin, H. 1993. A proposed model for "environmentally clean" land-based culture of fish, bivalves and seaweeds. Aquaculture, 117: 115–128.

Soto, D., and Mena, G. 1999. Filter feeding by the freshwater mussel, *Diplodon chilensis*, as a biocontrol of salmon farming eutrophication. Aquaculture, 171: 63–81.

Steffens, W. 1989. Principles of fish nutrition. Chichester/New York: Ellis Horwood Ltd. 384 pp.

Tacon A. 2000. Rendered Animal By-Products: A Necessity in Aquafeeds for the new Millennium. Global Aquaculture Advocate, Vol. 3 (4): 18–19.

Thanh, Be., T., Dung, L.C., and Brennan, D. 1999. Environmental costs of shrimp culture in the rice-growing regions of the Mekong Delta. Aquaculture Economics and Management, 3(1): 31–42.

Zhiwen, S. 1999. Rural aquaculture in China. RAP Publication 22,1–71 pp (FAO, Regional Office for Asia and the Pacific, Bangkok, Thailand)

ANNEX 5: AQUACULTURE IN SOUTHERN AMERICA AND ECOLOGICAL INTERACTIONS WITH NOXIOUS PHYTOPLANKTON: INTRODUCTION AND PROJECT SUMMARY

By Geneviève Arzul, Harald Rosenthal and Cornelia Nauen.

Our ability to predict harmful algal events is confounded by our lack of knowledge of the independent processes involved in creating the events we wish to predict. Many harmful algal events (HAE) are known primarily by their symptomology. The events may be described as paralytic shellfish poisoning or as a fish kill, however, the etiology may be independent of algae. There are bacteria that produce the same toxins responsible for algal-based paralytic shellfish poisoning and water quality processes independent of algae that can cause oxygen-mediated fish kills.

Assuming there is solid evidence that the phenomenon to be predicted has an algal etiology (a condition frequently assumed rather than proven), there still exists the problem that at least two independent processes may be involved in the expression of a harmful algal event: algal population growth and toxicity. Some toxic events can occur with undetectable changes in cell abundance in wild populations and, conversely, massive increases in cell abundance can occur without a harmful algal event involving species that are known to produce toxins.

If prediction is to be successful, both cell abundance and cell toxicity must be estimated independently and integrated to predict the occurrence of a harmful algal event. That integration may not involve a linear process because, depending on the species, the conditions that result in cell growth (abundance of growth factors such as inorganic nutrients) may have to be limiting for the production of toxicity by the cells (many cell toxins are produced in response to nutrient limitation).

Within the component processes required for a harmful algal event (HAE), there is also a hierarchy of condition to be met to predict the occurrence of the HAE. There must be a source of seed material either from excystment or from a transported population. The environment must support the algae in question. Flagellated species are favoured by stratification and diatoms tend to occur in water columns where stratification is transitional or unstable. Light penetration in the water column must be adequate to promote population growth, thus diatoms may bloom below the pycnocline when the compensation depth is deeper than the pycnocline. In addition, phenomena that induce lags into the expression of the alga's environment, such as vertical migration and synchronous cell division, must be accounted for in the predictive algorithm.

The consequence is that for any species and area a combination of both laboratory and field studies are essential to successful prediction of HAE. The studies undertaken in the Aquatoxsal programme attempt to create both the laboratory-based information that may be transferable between areas and the local environmental information required to successfully predict HAEs.

Therefore, the overall objective of this project was to provide management tools for the sustainable development of aquaculture in the South of Chile. The rapid exponential growth of the fish-farming industry in Southern Latin America during the last ten years produced important socio-economic benefits. The salmon production during the year 2000 was around 250,000 tonnes, placing Chile second in the world after Norway. This industry is, however, adversely affected by recurring noxious phytoplankton blooms in coastal waters throughout the region. The implications are relevant to human and fish health as well as social and economic effects. The accumulated actual losses due to toxic algal blooms in fishfarming is greater than 12 million US$. The potential losses to the industry due to recurring events are estimated to be greater than 50 million US$, and these figures exclude risks to human health and life.

The specific objectives of the project were to estimate the ecological impact of fish farming on coastal seawater quality, on benthos disturbance, and to determine primarily how these impacts relate to harmful phytoplankton blooms. To achieve these objectives a number of sub-projects were realized:

1) *in situ* measurements to describe the pelagic environment in three different areas, including water quality criteria, as well as benthic conditions used in predictive modelling of carbon deposition under and around farms. (See Chapter A below);
2) *in situ* and laboratory experiments on physiological responses of phytoplankton species to environmental change in order to identify parameters related to aquaculture and involved in algal population imbalances (likely responsible in bloom development). The effects of animal excretion products on phytoplankton growth (e.g., fish excreta, bivalve mucus release and effects of uneaten fish feed on microalgal species performance) were experimentally tested while the effects of aquacultural wastes on phytoplankton community structure were studied *in situ*. Additionally, the potential contribution of atmospheric disturbance (UV) to microalgal physiology and performance was also studied in the Patagonian country (see below);

3) The results of the above studies are brought together to make recommendations for aquaculture management with respect to: the development of impact indices; a predictive dispersion model to be used in the benthic domain while also considering harmful bloom assessment (see below).

Chapter A: Aquaculture impact on the environment

The main ecological effects associated with cage farming (not regarding contaminants through the release of antifoulants, nor the potential effects of antimicrobials and the threats through the establishment of self-sustaining populations of non-native salmonids in the southern hemisphere) are the release of dissolved nutrients and the deposition of particulate organic matter in sensitive habitats. The water column and sediment status in, under and around fish farms was studied in the 10th Region of Chile, the area of presently highest cage farming activity:

1 The water column: dissolved and particulate load

The possible modifications in physico-chemical properties of sea water by intensive fish farming were studied in three hydrodynamic situations representing typical systems used for finfish farming. The study period was during the austral autumn (March 1998). Using specific equipment (Cilas 925 apparatus), particles were measured *in situ*, obtaining real time size characteristics of suspended matter in the water column, and this was determined using laser diffraction techniques. Simultaneously, physical parameters were measured by specific probes, and the water was sampled at discrete depths at site-specific points of the three fish farms under investigation, selecting sampling points which were supposedly expected to be strongly, moderately and not at all affected by the respective farms. Samples were analysed for content in mineral nutrients and dissolved organic substances (probe calibration included).

Description of the study sites

In the Reloncavi Fjord, the fish farm at Cochamo is located in very stratified and deep waters, with salinities ranging between 2 to 20 in the surface layers. The maximum depth in the fjord is around 300 m, the residual current is directed downstream at the surface waters while there is no sill at the head of the fjord. The gross production at the fish farm during the study period was about 481 tonnes of rainbow trout (1998).

In the Seno Reloncavi area, near Puerto Montt, we selected the Huenquillahue fish farm as the study site. This farm location is at a more exposed site in a relatively open bay. This bay receives already some anthropogenic loads from the Puerto Montt city and from surrounding agriculture activity. It presents a medium-stratified water column with salinity ranges between 25 and 32. The annual production at this site is around 2,000 tonnes of Atlantic salmon.

Along the east side of the Chiloe Archipelago, the coast presents itself in numerous islands, channels, bays and small inlets, most of which have already been used for aquaculture, i.e., fish farming and mollusc culture. The Dalcahue channel was selected as the third study site. It is relatively shallow (about 20 m deep), carrying mixed waters due to relatively strong tidal currents and lower freshwater inputs than seen at other sites. During the year of study the annual production of the farm was about 2200 tonnes of Atlantic salmon.

Dissolved substances

The variations in nitrate, phosphate and silicate concentrations did not show a direct and clear relation to the fish farm locations. The total ammonium concentrations were higher directly at the surface waters of the fish farms in Cochamo and Dalcahue areas (5.3 and 2.55 µM N, respectively), than those observed in samples from other sites. Similarly, the mean ammonium concentrations in the water column presented a negative relationship with sampling distance from the fish farms. One exception to this trend was seen in the Huenquillahue area, where the highest concentrations in ammonium (1.85 µM N at the surface) were observed at the control station. Given the importance of this nutrient component derived from animal excretion as a factor for potential growth enhancement of phytoplankton species in nitrogen-limited systems, we considered an increase in total ammonia concentration as an appropriate indicator of potential *in situ* fish farming impacts in the water column. We also recognized that current speed and distance from the farm at which elevated levels of nutrients do occur will have an important bearing on whether phytoplankton species will be able to take advantage of this enhanced nutrient supply.

Water Column Conditions of a Fjord under Intensive Fish Farming (Clément *et al.*, 2001b)

The Reloncaví Fjord was studied as a natural model system to understand the eventual impact from fish farms on the water column within a semi-enclosed marine system under intensive fish farming. During the study period, no nutrient signal was detected in the surface layer of the mouth of the Reloncavi Fjord that could be related to the fish farm nutrient release. The short-term variability and the magnitude of change within the variables studied in the natural system are already so strongly modified by physical characteristics of the area (such as: tides, density field and wind-induced fluxes) that the potential effects of fish farming were over-ruled within the mass fluxes caused by natural events.

Characteristics of particle populations (Gentien *et al.*, 2001)

The study focused on the particle characteristics in the vicinity of cages and in relation to hydrological features. The seston charge was relatively low compared to other estuarine systems: levels of just about 3.5 mg l^{-1} were observed, however, most of it belonged to the organic fraction, indicating the importance of the biological origin of these particles (40 %). The particle distribution was very dependent on the current regime and the position of the pycnocline, and—in the case of the fjord—most of the material was located in the upper layer (5–6 m). The seston fraction from the fish farm presented an increase in total seston load, and a predominance of large particles (70–400 µm) with a high organic component of its particle composition. Around the fish farm, attenuation of the fluorescence and particle peaks were attributed to the turbulence generated by the structure of the cages and also partly by the swimming activity of the fish. In Dalcahue, the visible impact was limited in the water column to plus or minus 20 metres around the cages. Fish farms contribute to a release of organic particles from the cages but the impact cannot be traced in the water column further downstream than within 50 metres, and this is mainly due to the sedimentation rate of the particles. Sedimentation rates of large particles were relatively slow, probably due to their composition in organic aggregates. Video registration informed on the lateral displacement of flocks on the sea floor (25 $cm.s^{-1}$), in relation to bioturbation and currents.

Fluorescent particles were mainly 10 µm-sized in unimpacted areas, and this relationship was not observed in the vicinity of fish farms. Unlike Cochamo, where fluorescence was not modified near the fish farm, the Dalcahue showed a noticeable decrease in fluorescent particles and this was mainly attributed to physical effects of the overall structure on the phytoplankton cells.

Conclusion

Our results showed that water masses in the immediate vicinity of fish farms are characterized by the relatively high ammonium concentration (>unimpacted sea water), and large particle size (210 µm). The positive relationship between chlorophyll fluorescence and small particle (10 µm) abundance constitutes a good indicator for good quality recovery of the seawater mass, indicating the distance of impact. Considering the sites studied it can be stated that the impact of the aquaculture wastes in the water column was no longer detectable with the methods used beyond a distance about 20 m from the cages.

2 The benthic compartment: physical, biogeochemical and biological aspects

The fish farm chosen as study site at the coast of the Chilenian island Chiloe along the Dalcahue channel was the focus of this study, because this site provided a good example of strong tidal differences in water levels, leading not only to considerable water currents in and along the channel systems between the mainland, the island of Chiloe and the small islands and bights, but also to a water column characterized by less-pronounced stratification.

Bathymetry and Hydrographic conditions

The benthic compartment study was supported by *in situ* measurements and sampling for chemical analyses. A detailed bathymetry was performed using a combination of GPS and an echosounder. Hydrographic and water chemistry conditions in the area of the fish farm have been determined by measuring oxygen, salinity, and temperature as well as identifying the depth profile. Two current meters were moored in a vertical row at 18 and 5 m depth and recorded a set of data every 30 minutes during the better part of a tidal cycle. The current meters had to be recovered during a storm in July 1998. Unfortunately, one current meter (18 m water depth) was severely damaged during the process. The other one, however, recorded an extended set of data (more than 20,000), and these had been used in modelling of the distribution of organic material (Hevia, 1997). The second current meter was flooded during the last period between April and October 1999 and the electronic devices were destroyed together with the data of this measurement period. Therefore, only three measurement periods yielded valuable data.

A total of 166 depth measurements were performed, and their position stored on a GPS system. Using the kriging method for data interpolation, a depth chart of the area around the fish farm was accomplished. Hydrography at the fish farm area showed a well-mixed water column and an oxygen profile influenced by both photosynthesis during summer and by respiration of the caged salmon to different degree at seasons. The current speed ranged between 0.6 and 25 cm s^{-1}. The time series revealed that at low tide the water flows occurred in a SW-direction and in NE-direction during high tide.

Conclusion

The hydrographic situation in the investigated area is favourable for the local management of salmon farming because of the very dynamic water exchange at the site and within a larger water body. The latter might be one reason for the limited signals derived from inorganic nutrient determinations within the fish farm area.

Biogeochemistry and benthos in Dalcahue region (Piker *et al.*, 2001)

The sampling and documentation were designed to allow a comparison of modelled sedimentation patterns and true observations of the *in situ* contents of organic carbon C_{org} as well as other variables at the site. Sediment samples were taken, sensor measurements and underwater video transects were performed during five expeditions at the Dalcahue salmon farm. Redox potential and pH were measured simultaneously in the sediment cores. Oxygen and sulphide concentrations were measured with steel microelectrodes using a micromanipulator. O_2 respiration and SO_4^{2-} reduction rates were calculated using Fick's second law of diffusion. Based on the specific reaction rate, the total oxygen respiration and sulphate reduction per unit area were calculated. The average carbon/nitrogen (C/N) ratio and organic carbon were analysed in the sediment samples. Underwater video recording was performed along several transects during all expeditions in order to document the changes in benthic condition at different distances from the salmon farm.

Physico-chemical properties of the sediment

The sediment directly beneath the fish farm was sandy with a superficial layer of fluffy organic material. It was black and azoic, contained hydrogen sulphide, amine compounds, and dimethysulphide. Sediment from the surroundings of the fish farm (only 5 m distance) showed oxidized sandy sediment in the upper 5 cm. Vertical profiles of pH, redox potential (−290 mV) as well as dissolved oxygen and total sulphide revealed a highly organically enriched situation beneath the studied site. Three zones with different benthic conditions have been clearly identified and documented via underwater video:

1) A heavily polluted area directly underneath the fish farm which appeared almost completely azoic in terms of macrobenthos, with anoxic and sulphidic sediments, important bioturbation;
2) Intermediate transect sampling sites with a large number of small snails (*Nassarius* spp.: 22,400 individuals m^{-2}), indicating that opportunistic organisms took advantage of the enrichment in the vicinity of the site;
3) The "unpolluted" situation which was found at a control station located not too far distant from the farm.

Conclusion

The biogeochemistry was characterised by steep vertical gradients of oxygen, sulphide and redox potential due to the organically enriched sediment. The sediment beneath the fish farm was almost completely anoxic and sulphidic showing that oxygen penetration was restricted to the upper 3 mm of the sediment resulting also in very high sulphide concentrations. Microbiologically mediated reducing processes dominated the biogeochemistry in this part of the sediment, particularly the dissimilatory sulphate reduction, showing high rates of sulphide production. The carbon and nitrogen content was influenced by the fish farm significantly. However, the sediment is only affected down to 10 cm depth and the impact is limited to a very restricted area around the farm, the boundaries of which are almost limited to the area directly under the cages. The results showed that the fish farm's impact on the benthos community is far more prominent than on the water column.

Chapter B: Phytoplankton response to the impacted environment

The response of the phytoplankton to the anthropogenic impact was tested considering two levels: the chemical composition of sea water, and the ultraviolet radiation stress, a nuisance affecting specifically the southern regions of Latin America. A part of the work was realized on natural phytoplankton populations sampled in Chile at different seasons, but some tests were also undertaken in the laboratory using cultivated algae of typical phytoplankton species.

1- Phytoplankton response to the exogenous inputs provided by fish farming

1–1 Response of natural phytoplankton populations (Seguel *et al.*, 2001)

The impact of aquaculture wastes on the phytoplankton is mainly related to the dissolved substances, due to their possible assimilation by the cells. In the case of fish farming, the wastes originate from the animal excretions reared in high densities and limited areas, and from the activity, besides feeding, such as occasional application of disinfectants and antimicrobials (not studied in this project). Natural phytoplankton assemblages were collected during spring, summer and autumn. The results obtained with natural phytoplankton showed that fish farming waste stimulates the biomass production especially the predominant algae. Phytoplanktonic species, certain possibly ichthyotoxic species, beforehand not detected in the monitoring network along Chilean farms, were stimulated in their growth by the exogenic inputs. The supply of inorganic nutrients produces an increase of total biomass and constitutes a possible selective factor for species known as fish killers. The elutriates of uneaten food and faeces provide organic nutrients and exhibited a delayed stimulatory effect on the growth of the phytoplankton species in experimental work. However, under environmental conditions the nutrients dilution rate and turbulence caused by the currents and tides may impair phytoplankton growth and prevent them from taking substantial advantage of the short-term nutrient elevation, thereby not allowing them to form blooms.

1–2 Animal excretions and phytoplankton growth rate (Arzul *et al.*, 2001)

In these studies we focused our work on laboratory experiments based on monospecific microalgal cultures, to detect an eventual preference among the organisms' association. We compared the growth rates of monospecific microalgal cultures in the water enriched by excretions of marine animals. The identification of the compounds playing a dominating role in the modifications of the growth rates was tried starting from a share, extraction of the organic substances and in addition, tests separated on fish mucus, urea and ammonium.

Our results seem to reveal that marine animal excretions may influence the phytoplankton growth rate. Our results present also a general tendency of growth stimulation with shellfish excretions, and growth inhibition by finfish excretions. However, these findings have to be taken with caution in light of several other studies showing either similar or contradictory results. This comes with no surprise as the effects of the different excretion components are extremely complex, their composition variable and our understanding is, therefore, still limited to draw firm conclusions. In all cases the dominant effect was most likely due to the silicagel-extractible dissolved organic substances, and there was no corresponding increase between ammonium concentration and algal growth rate.

1–3 Fish food excess and phytoplankton growth rate (Arzul *et al.*, 2001)

Among the factors contributing to phytoplankton development in fish farming areas, food distributed in excess to the fish may play an important role in algal productivity. Although this effect depends on the reared species and the nutrition mode, we used concentrated granule elutriate diluted in the algal cultures to have 4–40–400 mg/L, e.g., dry granules of different protein amounts. The study was based on the comparison of growth rates of four phytoplankton species in non-axenic conditions. The algal growth rate was unmodified in presence of the lowest concentration (4mg/L). Except for the granules with vegetal protein, concentration 40 mg/L of uneaten fishfood constitutes a stimulator for total algal biomass. Fish feeding excess plays a double role: as stimulator in biomass increase (the stationary phases reached higher values with elutriates addition, in most cases), and selector of the phytoplankton species. Nitrogen, usually considered as a key nutrient for algae in a nitrogen-limited system, probably plays a discriminate role, DON favouring the mixotrophic species. The results point out the risk of over-feeding in fish farms, resulting in environmental degradation in low dynamic areas. The results obtained with fish food elutriates with vegetal protein suggest that partial fishmeal replacement could improve environmental compatibility and the development towards low protein feeds should be encouraged for environment preservation considering microalgal bloom development.

1–4 Influence of organic compounds on the algal lipid composition (Bodennec *et al.*, 2001)

We intended to study the effect of some substances released by fish farming, on the ichthyotoxic potential of some phytoplankton species. The effects of several organic substances were tested both on culture growth rate and on the chemical composition of the algal cell, especially the polyunsaturated fatty acids (PUFAs) known as ichthyotoxin precursors (C18,5).

Biotin, a vitamin added to algal culture and fish food, stimulated the growth of *G. mikimotoi* but we did not observe any modification in lipid composition in the algae. Sea water containing organic substances provided by dead fish maintained and stimulated the growth of *G. mikimotoi* and *Heterosigma akashiwo*. The variations in the percentages of the main PUFAs in *H. akashiwo* cells suggest a possible stimulative action of organic substances provided by the degradation of dead fish, on the ichthyotoxicity of the harmful algae in the vicinity of a fish farm. The response of the algae to aquaculture waste input is not only growth rate modification but also chemical modification in the intracellular composition.

2 – Phytoplankton response to the ultraviolet stress

This activity was planned to assess the effects of UV radiation on organic substances and to study the response of the algae to the stress of ultraviolet irradiation. Moreover, toxic blooms of the dinoflagellate *Alexandrium catenella* (PSP producer) have coincidence with high UVB radiation episodes in the Southern region of Latin America. Among the objectives of the project, the determination of *A. catenella* response to UVB stress constitutes an important step in the understanding of species predominance, and possibly in stimulation of PSP production. Although it is known that *A. catenella* is capable of vertical movement (thereby having the potential to escape stress such as UVB, e.g., movement to compensation depth), we used this species as a model to study the principal processes involved.

2–1 Photodegradation of dissolved organic substances

The experiment was realized on dissolved organic substances released by fish farming: a senescent dense culture of *C. gracilis*, fish feed elutriate and faeces leachate. The three solutions were irradiated under two specific UV lamps (emission at 312 nm and 365 nm). Our results showed that the photodegradation increases significantly the amounts in mineral nutrients, mainly ammonium which constituted more than 80 % of the total inorganic nitrogen after 46 h irradiation. The chlorophyllian material is the most potent and rapid provider of mineral nitrogen, before food and faeces elutriates. The mineral phosphorus production was higher in fish food elutriate, but more rapid in faeces elutriate, and not significant in the vegetal. This information has to be taken into account in the exploitation of oligotrophic media.

2–2 Phytoplankton cultures and experimental UV stress

The five algae species were inoculated monospecifically and non-axeniquely in the oligotrophic media (control) and in media with organic input. Both were submitted to PAR and PAR+UV, during 46 h. PAR was of 60 µmol m^{-2} s^{-1} and UV radiations were produced as above. Cells were counted at the end of the exposure. The deleterious effects of UV radiation towards the phytoplankton are lowered in the presence of dissolved organic substances. The most sensitive species to UVB injury were: *H. akashiwo* and *G. mikimotoi*. *A. minutum, A. catenella* and *C. gracilis* seemed protected, by their theca and frustule, respectively.

2–3 Natural phytoplankton populations and organic substances under UV stress in the Magellan region

Quite similar tests were conducted on natural algal populations in channels of the Magellan region, to validate the above-presented results. In field experiments natural phytoplankton was exposed to UV and PAR by aid of appropriate filters, meanwhile in laboratory UV and PAR emission spectra were obtained by using incubators, suitable lamps and filters (Pizarro *et al.*, 2001). Different irradiation regimes and organic additions were applied. These treatments were also applied, in laboratory conditions, to seawater units deprived of phytoplankton. In this last condition, photochemical effects of UVB radiation increased all dissolved inorganic substances**.** As observed in strictly artificial conditions, the photomineralization by ultraviolet irradiation of the organic input constitutes a nutrient source for phytoplankton in spring, during the thinning of the ozone layer, and also in summer conditions. No significant differences due to treatments in field experiments on phytoplankton controlled variables and in Chlorophyll *a* and nutrient concentrations were detected (Guzman *et al.*, 2001). This could be allotted to the protective role of the added organic substances or to the corresponding inorganic nutrients. However, the response of natural populations to the different wavelength irradiations revealed the general deleterious effect of UVB on the living cells, but also possible tolerant species.

2–4 Physiological disturbance of the irradiated phytoplankton

Standards of mycosporine-like amino acids (MAAs) were obtained from different algae. The isolation, final purification and identification of standards were carried out in the laboratory. In addition to known MAAs, the developed methodology allowed the detection of a series of complex MAAs not previously reported in the literature.

Analysis of pigments and MAAs in samples from Punta Arenas The results obtained in the field in Punta Arenas, (Carreto *et al.,* 1999) were compared to the laboratory results (INIDEP). Phytoplankton growth was never observed in the samples *in situ*, and the photosynthetic pigments were degraded, especially Chlorophyll *a*. Inhibition in algal growth seems not to be due to UVB, as no important differences were observed in the different treatments. The senescent characteristic of the populations was probably a consequence of the low nutrient enrichment. The results confirm the dependence of MAA synthesis with photosynthesis.

Pigment profile of the ichthyotoxic *Gymnodinium* sp The ichthyotoxic *Gymnodinium* sp. which bloomed in Chile in Autumn 1999 showed a complex pigment profile (Carreto *et al.*, 2000). In addition to fucoxanthin and its derivatives, two carotenoids were detected, one of them was not previously characterised. In *Gymnodinium* sp. fucoxanthin is the main carotenoid. The pigment composition of *Gymnodinium* sp. resembled those reported for other ichthyotoxic *Gymnodinium* species and some prymnesiophytes. However, the pigment profile of *Gymnodinium* sp. was more complex, and therefore, these new pigments cannot be considered as pigment markers for ichthyotoxic dinoflagellates. The only exception is gyroxanthin diester, which could be potentially a useful indicator for the detection of this, or eventually other toxic *Gymnodinium* sp. in coastal waters of southern Chile. However, the absorption maxima of this pigment are similar to those of other carotenoids, and its distinction through remote sensing technology is not feasible.

Studies on MAAs, PSP and pigment profiles on different *Alexandrium* species (Carreto *et al.*, 2001)

The three dinoflagellate species *Alexandrium tamarense, A. catenella*, and *A. minutum* are toxic isolates, forming blooms near the surface, and exposed to high light conditions. Nine MAAs were separated and identified. In the three species analysed, palythene and shinorine were the predominant MAAs. Several forms of atypical MAAs, not previously reported in the literature, were also revealed in the three *Alexandrium* species, while their chromatographic profiles showed great differences. The biochemical composition of the cells is highly variable with growth conditions. The toxin contents of *A. tamarense* and *A. catenella* were similar (63.2 and 50.5 fmole cell^{-1}) and several times higher than that of *A. minutum* (1.0 fmole cell^{-1}). The toxin profiles of *A. tamarense* and *A. catenella*, were very different from that of *A. minutum*.

Effects of solar radiation on growth and MAA content in an Antarctic diatom (Hernando *et al.*, 2001)

To investigate the role of MAAs in the short-term (hours) and long-term (days) photo-acclimation to solar ultraviolet radiation (UVR), we used a cultivated Antarctic diatom *Thalassiosira* sp.

The chemical analyses revealed that the synthesis of MAAs is dependent on high irradiance conditions (PAR or PAR+UVA) and that their accumulation presents an inverse correlation with UV photo-inhibition. However, the acclimation to UVB was not total since the growth rate was slightly higher in the cultures exposed to PAR.

Short term effects of ultraviolet radiation on the dinoflagellate *A. catenella* (Carreto *et al.*, 2001)

The short-term effects of ultraviolet radiation on pigment MAA composition were studied on the toxic dinoflagellate *A. catenella* (isolated from Chile) in cultures maintained during several generations at exponential growth under medium PAR irradiance. Aliquots of these cultures were exposed to higher irradiance levels and different spectral compositions. The MAAs composition increased with PAR intensity in a few hours. In the stock cultures, palythene was the principal UV-absorbing compound. Shinorine, porphyra-334 and palythenic acid were also present as major components. Submitted to high irradiance, the transference of *A. catenella* caused a small decrease of most of its light harvesting pigments and a rearrangement in the carotenoid biosynthesis that increased the cell content of photoprotective carotenoids. Although both UVA and UVB enhanced these effects, UVB was more efficient on chlorophyll's photooxidation and diatoxanthin synthesis induction.

Effects of ultraviolet radiation on the toxin composition of the dinoflagellate *A. catenella* (Montoya *et al.*, 2001)

A. catenella was exposed during 12 days to two higher irradiance levels of three different spectral compositions. The extracts were analysed by the post-column derivatization HPLC method. Among the six different experimental conditions, the net toxin production varied over the growth cycle of the cultures. A significant increase in toxin concentration began after the first day of acclimation to the new experimental conditions and continued up to day 2, after which there was a period of toxin synthesis inhibition in all treatments. The strength and persistence of toxin synthesis inhibition was strongly dependent on the intensity and spectral light composition of the exposure. Inhibition of toxin production was higher at the higher light intensities and increased dramatically in the cultures exposed to PAR+UV. Under PAR and PAR+UVA, there was a recovery in the toxin production rate to levels similar to or higher than those initially found, while UVB blocked the toxin production.

Long-term effects of UV radiation on the pigment and MAAs in *A. catenella* (Carignan *et al.*, 2001)

Long-term effects of ultraviolet radiation on the synthesis of pigments and MAAs were studied in adapted cultures of the toxic dinoflagellate *A. catenella* and submitted to that same treatment as above. At the lowest PAR and PAR+UVA, chlorophyll *a* concentration varies in a similar way to that in the control series. In the cultures exposed to UVB, photo-inhibition of chlorophyll *a* synthesis was observed. After two days of exposure, a dramatical increase in the relative amounts of diatoxanthin and diadinoxanthin was observed under all light conditions, positively correlated to the intensity and depending on the spectral composition of the light. This enhancement was reduced by the simultaneous exposure to UVB radiation. After four days, the rate of synthesis of MAAs was lower at high UVB. After this initial period the synthesis of MAAs was inhibited at the higher UVB and the cell MAA content decreased to values lower than that initially found. In contrast, under low UVB the amount of MAAs in the cells was several times higher than that found in all treatments. In the absence of UVB no net accumulation was observed.

Chapter C: Application of the results to aquaculture management

The final objective was to provide information usable by the regulatory bodies and the industry management responsible for the future development of aquaculture, thereby safeguarding the environment and the industry. The overall conclusions specifically addressed in this chapter can be summarized as follows:

- the application of a predictive model of dispersion and of sedimentation of the detrital particles derived from fish farms is possible with satisfactory accuracy. This allows also an assessment of sedimentation of the carbonaceous substances in a long-term forecast to estimate the impact of the aquaculture on the benthos while permitting at the same time to regulate (limit) the input to a level agreed upon by management as to the needed residual bioturbation required for minimized and acceptable limits of impact;
- an analysis of the current knowledge on the frequency of the ichthyotoxic outbreaks and bloom occurrence in the studied area during the years of the project and its short-term possible application;
- general conclusions on phytoplankton and fish farming interaction.

The complexity and the great diversity of the hydrodynamic situations in the area of study did not permit to carry out a generalized modelling approach to dispersion for the dissolved substances. This would have required a great number of time series data according to the tides, the geo-topography of the systems, the seasons and the climatic conditions, periods and level of feeding, biomass gain and capture of the livestock. Because of the distance and because of too expensive transfer costs for extensive equipment, we had to restrict ourselves to the acquisition of source data envisaged initially. However, the extensive exploitation of our available data sets allowed us to derive the following recommendations:

1- Salmon farming, waste input and nutrient load in the medium

We attempted to estimate nitrogen excretion into the environment for salmon and trout fed high energy diets in Chile, according to the example of British Colombia. Our calculations show that hydrosoluble N and P provided by overfeeding constitute more than 30 % of the nutrient input and the solid discharge is 40 % of the produced gross input. The high hydrodynamic status is necessary to attenuate the local input. The case of Reloncavi fjord was considered for the estimation of the waste dilution. The calculated concentrations are much lower than those measured *in situ* at the stations not impacted by the fish farm wastes, and the calculated dilution of food excess following the same pattern is about 100 times lower than the local estimated excess. The same theoretical dilution of the fish farming wastes in Dalcahue channel gives much lower values than the concentrations measured *in situ*.

The turbulence is the main factor regulating the algal population growth. In the cases of our studies, it appeared that at the local scale, the physical forces were the most important features affecting the short-term variability in the nutrient concentrations. This underlines the importance of a good selection of the site for fish farming, considering not only the waste dilution, but also the turbulence, and avoiding proximity of water masses suspected to be vectors of harmful algae.

The contribution of the ultraviolet radiation to the nutrient input by the photomineralisation of the degradable organic substances, and their selective effect on toxic microalgal species, must be seriously taken into account, in the possibility of a project of extension of the aquaculture in the areas of extreme south of Chile. The dissolved excretions of marine animals unbalance the N/P ratio in favour of the nitrogenous nutriments. According to many studies these conditions are favourable to the harmful species of algae, and phosphorus-limiting conditions are often associated with stimulation in toxin production.

2 – Modelling of dispersed organic material (Hevia *et al.,* 2001)

A model of the spatial distribution and loading of organic fish farm waste to the seabed was used and refined in the Dalcahue Channel. The 90 % isoline of the sedimentation model marks the boundary of ecologically influenced sediment compared to *in situ* data, considering (i) carbon content, (ii) macrobenthos, (iii) redox potential, and (iv) metabolic solutes. This indicates a maximum loading capacity of 5 g C m^{-2} d^{-1} for the benthos in the investigated area before an influence on benthos and biogeochemistry is visible or measurable, respectively.

The sedimentation model is a powerful tool to predict organic carbon sedimentation and its distribution over the sea floor, thereby assisting in managing site-specific limits. The sedimentation of organic carbon can spatially be correlated to the impact on the benthos, however, it is a conservative measure and is negligible when considering the overall carbon cycle in a fish farm area.

3 – Mass balance (Piker *et al.*, 2001)

Most associated biogeochemical and ecological effects at the seafloor are triggered by increased sedimentation of organic material. To evaluate these effects we studied the fate of organic carbon and inorganic nitrogen. It was estimated using data from this study and literature data. The results revealed that the organic carbon oxidation by anaerobic processes beneath the fish farm plays an important role in the carbon and energy cycle. Organic carbon accumulation is negligible in the budget. The fate of introduced organic carbon into the ecosystem is also driven by processes not within the sediment but on the sediment (snails: *Nassarius* sp.) or in the water column (fishes).

4 –Aquaculture and harmful phytoplankton blooms (Clement *et al.*, 2001b)

Our experiments did not provide a clear indication to establish the relation between the aquaculture nutrient release and the occurrence of the *Gymnodinium* sp. bloom in autumn 1999, but showed only that water from the cages made it possible for the algae to survive. Available data suggest that meteorological and climatic conditions constitute decisive parameters in algal blooms. However the nutrient input by intensive fish farming constitutes a favourable support for bloom extension and our results brought about more precise insights into the role of nitrogenous detritic components on the predisposition of some algal species in relation to toxin production (Bodennec *et al.*, 2001). Finally, the extension of fish farming into the extreme south of Latin America presents a high potential risk for safeguarding the production, and this potential is concluded from the deleterious effects of ultraviolet radiation shown to occur on organisms under experimental conditions. Additional nutrient input in the oligotrophic water masses, either photodegradable organic wastes or inorganic substances, could contribute to the increase and extension of the problem, in particular when extreme natural events (El Niño, La Niña periods) are superimposed with their own effects.

5 – Overall Conclusions and Outlook

The project has provided a wealth of scientific data that greatly assist in identifying the potential role of fish farm waste in eutrophication processes. In particular it has been shown that the form of nutrient inputs affecting phytoplankton biomass and population assemblages is of great importance, while factors involved in long-term climate change are also recognized as being critical in interacting with the overall response of phytoplankton communities to natural and man-made changes. The following conclusions can be drawn from the findings:

5–1 The results obtained in Chile are in accordance with the observations made in other regions of the world where salmon farming in coastal cages takes place: they confirm the global change conditions illustrated by red tides intrusion in the inland sea, and selection of resistant phytoplankton species under changed ultraviolet radiation exposure, a consequence of the increased depletion of the ozone layer at times of high productivity.

5–2 For Chile, it becomes urgent to carry out a total assessment of the mass balance contributions of nutrients regulating eutrophication, through flux models. While site-specific impacts can well be regulated, in order to lead to a sound strategy of prevention of the risks, we suggest to take into account the following scientific criteria and integrated management options:

- Salmon/seaweed integrated aquaculture should be seriously considered to improve coastal water quality, by removing (converting on or near site) the nutrient input due to fish farming. This integrated cultivation constitutes an interesting bioremediation by converting nutrients into production and, at the same time, diversification of the fish farming industry.
- While there is quite a good understanding of the immediate, localized impact of fish farming allowing to set site-specific production limits for environmental protection, there is room for developing mitigation measures further

to control unnecessary consequences, through improved husbandry techniques and through appropriate monitoring programmes. However, there is a need to obtain better data for modelling the regional and area-specific conditions that help in estimating the carrying capacity, to safeguard the environment and the industry in its further development. Hydrodynamics and production (primary and secondary in the trophic chain) are not appropriately mirrored in the present work, for the reasons mentioned above.

- The salmon farming industry in the Chilean region does provide a substantial nutrient source that has the potential to influence primary productivity at least locally. The field work, however, does not at the present time provide sufficient evidence to conclude that the increased nutrient load through fish farming in the region is the **major** contributor to productivity and community change. To consider only the theoretical dilution of wastes to assess the fish farm impact in a local area does not bring sufficient information concerning the risk of harmful blooms. We need a better understanding of how the local hydrographic regimes around fish farming centres in southern Chile are interlinked with the larger events along the coastal shelf seas
- For future activities we recommend the study of oceanographic water mass exchanges in order to gain more information that could be used to calculate the regional mass balance of inputs and fluxes. A very good understanding of the dispersive capacity within the area exploited for fish farming along the entire Chilean coast (including areas considered for further development) appears indispensable, in order to assess the potential risk of harmful algal developments associated with their deleterious effect on fish productivity and to environmental disturbance. The results observed under experimental conditions demonstrated that several rare but highly toxic species can potentially be promoted. Some areas are more exposed than others, to promote the development of harmful species: low dynamic areas, proximity to oceanic water masses suspected to likely contribute as a factor for inoculation. Among the consequences of red tides, the remnant of cells constitutes a risk for the future years. Along the same lines of argumentation, the presence of permanent cysts as resting stages, being available in anoxic sediments under and around farms, poses a serious threat when resuspended at the wrong time of the season. Benthic modelling on carbon deposition along with regulations requiring a minimum benthic diversity (bio-turbation) is one way to limit this risk of anoxia. Another factor to be considered in the future for co-management is the risk of transfer of organisms (including parasites, diseases, and resting cysts of toxic algal species) via trade, be it with live transport of fish for stocking, or through the more and more globalized shipping industry, affecting aquaculture. Ballast water of the shipping industry is one case of international importance which constitutes a threat not only to environmental quality but also to the sustainability of coastal aquaculture development.

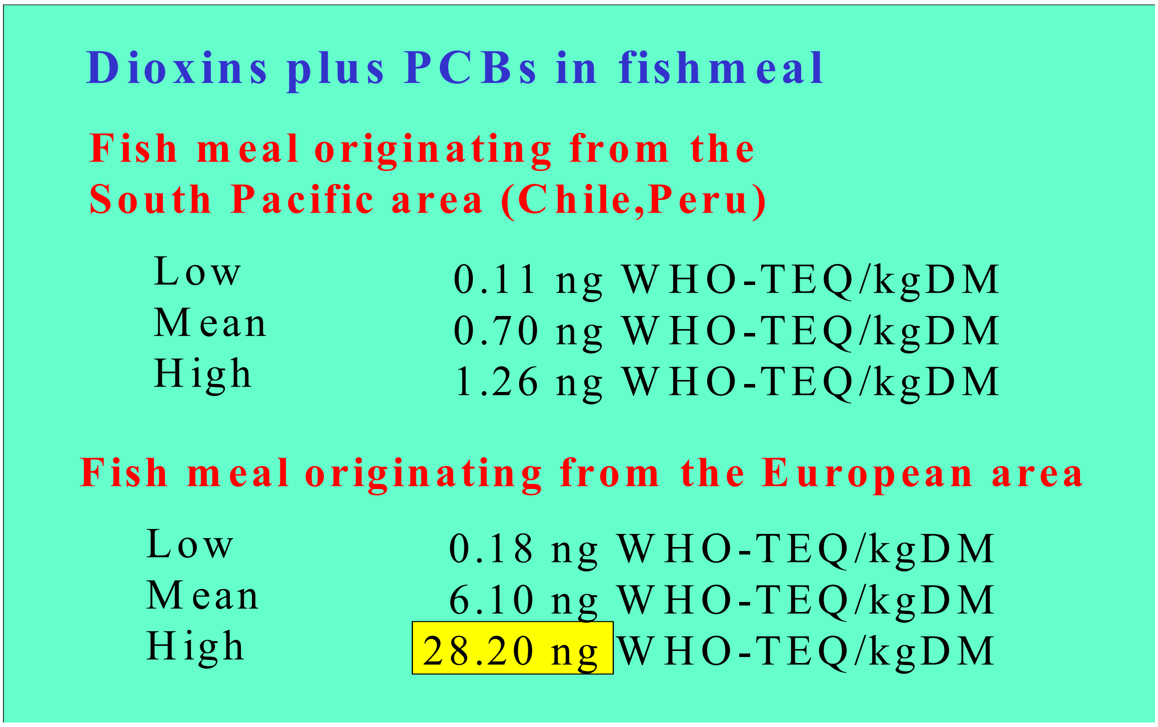
Monitoring the hydrological conditions in view of phytoplankton bloom prediction, using probes and sensors constitutes a promising technology for fish kill prevention within the farming industry. In the context of a short-term prediction, the use of bio-optical methodologies (Lunven and Gentien, 2001) is now operational for application in exploited areas. At the very short-term, several technologies are used by fish farmers (pumps and artificial upwelling), and additional preventive methods are proposed (adaptation in progress). It can be anticipated that in the future, remote sensing techniques will become also an important tool to monitor the areas of early outbreak of blooms, their extent over time as well as their dissipation.

There still seems to be a need in improve the application of appropriate feeding technology thereby reducing unnecessary loss of feed and unnecessary environmental load of organics and nutrients. Improving the feeding technique, feed conversion, working towards higher energy feeds and reducing protein content for various size classes, would greatly help to minimize impacts or at least keep impacts at the same level while increasing overall production in an area. The incentive for such development must come from consumer acceptance and from eco-labelling as the highest quality fish feed resource is readily available in the area and the need for fishmeal replacement is not based on the same economic pressures as in other regions of the world.

During the project it became obvious that improved husbandry and management practices will lead to better environmental compatibility, but require solid and comprehensive education for farm operators to better utilize the options for environmental protection available through modern systems and farm technology. Improving educational skills is necessary. The more effective measure is auto-regulation by the producers and their organisations and through certification. The well-being of the industry and sustained growth can only be maintained through careful and professional management aiming simultaneously at environmental compatibility.

These interacting environmental and economic factors can present an incentive to attempt ecosystem preservation, and should be seriously considered by the producers themselves as well as by the authorities in charge of setting the policies for aquaculture management.

While dealing with a large variety of tasks and disciplines, the team engaged itself also in discussions related to multiple resource use issues. One area of concern not covered by the project directly, but frequently addressed was the potential transmission of disease agents and toxic algal species via other human activities such as shipping, posing new threats to the environment and the fish farming industry. The potential of HAB species transmission in ship ballast water needs urgent attention and studies need to be initiated on how to reduce the risks of transfer of HAB species. In particular, ballast tank sediments carry a lot of cysts and pose potentially a similar high risk to coastal ecosystems by transferring harmful species. Although the present project did not address this question, the problem became obvious during the project phase. For example, the Japanese microalga *Chatonella* sp., first recognized in the southeastern North Sea during 1998, caused a first bloom in early 2001 (February) subsequently being responsible for a massive kill of cultured salmon (about 1000 tonnes) in southern Norway. Ballast water volumes transmitted intercontinentally increase steadily. The intended offshore ballast water exchange strategy presently being promoted by IMO through MARPOL, seems not necessarily to be a satisfactory solution. Chances are that new threats are posed when carrying bloom species to other areas. Studies should be initiated to follow the fate of HAB species after release into new habitats. In particular, survival capabilities of species while in transit between continents should be assessed as well as the risk arising from the release of tank bottom sediments containing dormant cysts and other resting stages of HAB.



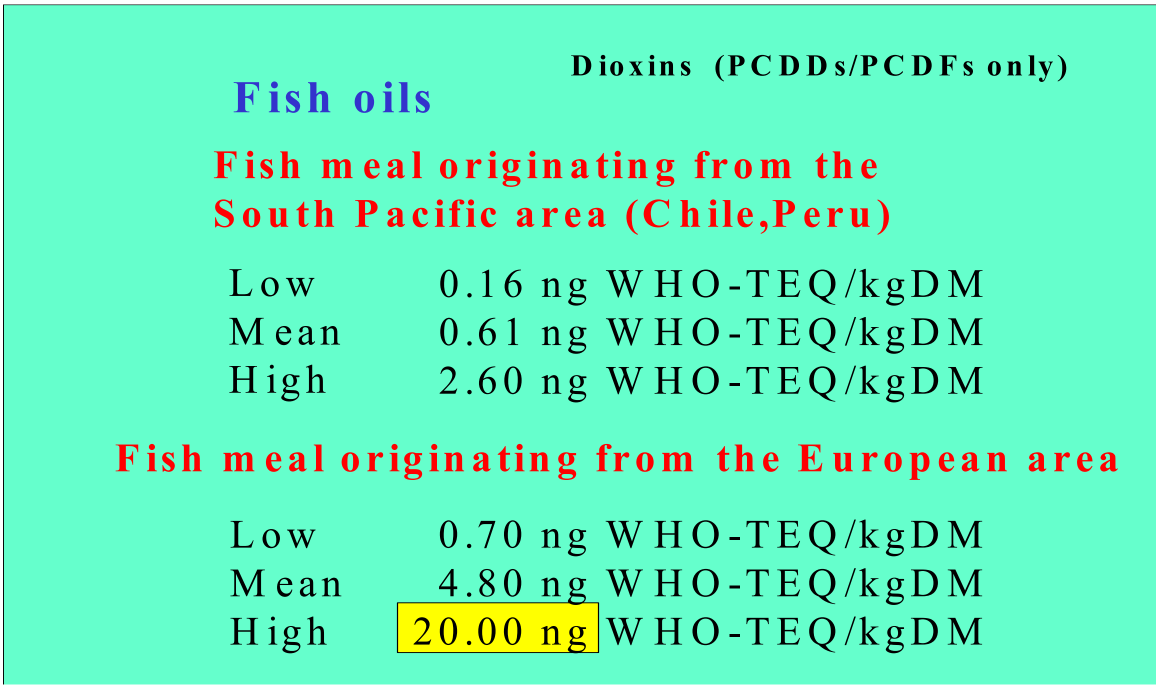
Dioxins plus PCBs in fishmeal

Fish meal originating from the South Pacific area (Chile,Peru)

Low	0.11 ng WHO-TEQ/kgDM
Mean	0.70 ng WHO-TEQ/kgDM
High	1.26 ng WHO-TEQ/kgDM

Fish meal originating from the European area

Low	0.18 ng WHO-TEQ/kgDM
Mean	6.10 ng WHO-TEQ/kgDM
High	28.20 ng WHO-TEQ/kgDM



Dioxins (PCDDs/PCDFs only)

Fish oils

Fish meal originating from the South Pacific area (Chile,Peru)

Low	0.16 ng WHO-TEQ/kgDM
Mean	0.61 ng WHO-TEQ/kgDM
High	2.60 ng WHO-TEQ/kgDM

Fish meal originating from the European area

Low	0.70 ng WHO-TEQ/kgDM
Mean	4.80 ng WHO-TEQ/kgDM
High	20.00 ng WHO-TEQ/kgDM

Dioxins plus PCB TEQ data

Fish oils

Fish meal originating from the South Pacific area (Chile,Peru)

Low	0.80 ng WHO-TEQ/kgDM
Mean	**3.00 ng** WHO-TEQ/kgDM
High	**13.00 ng** WHO-TEQ/kgDM

Fish meal originating from the European area

Low	3.50 ng WHO-TEQ/kgDM
Mean	24.00 ng WHO-TEQ/kgDM
High	100.00 ng WHO-TEQ/kgDM

TEQ- Toxic Equivalents

Dioxins in feed material

	Low	medium	High
Cerials and seeds (Legumes)	0.01	0.10	0.40
Vegetable oil	0.10	0.20	1.50
Fish meal Pacific (Chile, Peru)	0.02	0.14	0.25
Fish meal Europe	0.04	1.20	5.60
	0.16	0.61	2.60
	0.70	4.80	20.00

Contamination in fish meals and fish oils is always higher than in agricultural products

An environmental burden placed by societal on all aquatic aquatic resource users: fishery, aquaculture, hobby fishers