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Recommendations from the Canada/Norway Workshop on Environmental Impacts of Aquaculture

Scientists from Canada and Norway gathered in Bergen, Norway, February 8-10, 1993, under the aegis of the Norway/Canada Science and Technology Agreement to discuss common concerns and interests in relation to the Environmental Impacts of Aquaculture.

It was concluded quite rapidly that both countries faced similar, if not identical, problems, opportunities, and more especially challenges. Two themes dominated the discussions: the first was Pathology (Fish Health) and Chemicals, and the second was Coastal Zone Management: It was also concluded that a permanent bridge was necessary and that to achieve this Arne Ervik (Norway) and James Stewart (Canada) would be the continuing official contacts for communications between the two countries for work and information resulting from the workshop.

Recommendations:

1. As a result of the discussions and work on the Fish Health and Chemicals subject, it was apparent that a number of the same important diseases affect fish growing in Norway and Canada and that a large number of the same chemicals (antibiotics, anti-parasitic agents, etc.) are used to control problems at the farm sites. Matrices of the information characterzing the diseases and chemicals were prepared to understand the dimensions of the issues involved. These were in a very preliminary form and for completion required further work following literature searches and consultation with colleagues. Thus, the recommendations stemming from these topic areas are:

    a) Both parties undertake to complete the matriced and develop a common information base by correspondence.

    b) Both parties undertake to analyze these matrices and determine those areas in which the problems are most outstanding and/or which information sharing should offer some relief immediately.

    c) Norwegian and Canadian scientists will discuss and develop by correspondence and other equivalent means of communication the areas in which cooperation and collaboration could be persued to produce solutions in a shorter period and at less cost than would occur if scientists from both countries persued solutions independently. Examples of common diseases for which cooperative approaches could prove beneficial are Furunculosis, Bacterial Kidney Disease, Vibirosis, Infectious Pancreatic Necrosis, *Saprolegnia*, and the Sea Lice problems. A similar but longer listing of antibiotics and other chemicals is included in the chemical matrix.

2. It was recognized at the outset that in both countries there are many competitors for use of the coastal zone. The interests are diverse and often in conflict with each other. Further, it was recognized that any activity in the coastal zone will have an effect on it and in particular on water quality; thus, there is a need to be aware of this and to determine what are acceptable limits for the departure from the pristine state. The solution of the question of acceptable limits, obviously, entails a political decision.

To make such decisions, it is necessary for those intent on using the coastal zone to divise adequate tools for gauging and predicting the impact their particular activity will contribute to any reduction in the quality of the coastal zone. Thus, the Workshop group concentrated their efforts on discussions as to which are the best tools for predicting and gauging the impact aquaculture would have on the environmental quality of the coastal zone. Again, it was noted that working jointly on these problems should produce progress at a lower cost than work done independently.

a) It was agreed that development of approaches and methods, of which modelling is an important element, is required to predict the concequences fish farm production has on itself (feedback) and on the environmeatal quality generelly which could bring it into conflict with other passive and active users of the coastal zone.

As a consequence, it was recommended that the following issues and projects should be considered in detail for application of the foregoing:

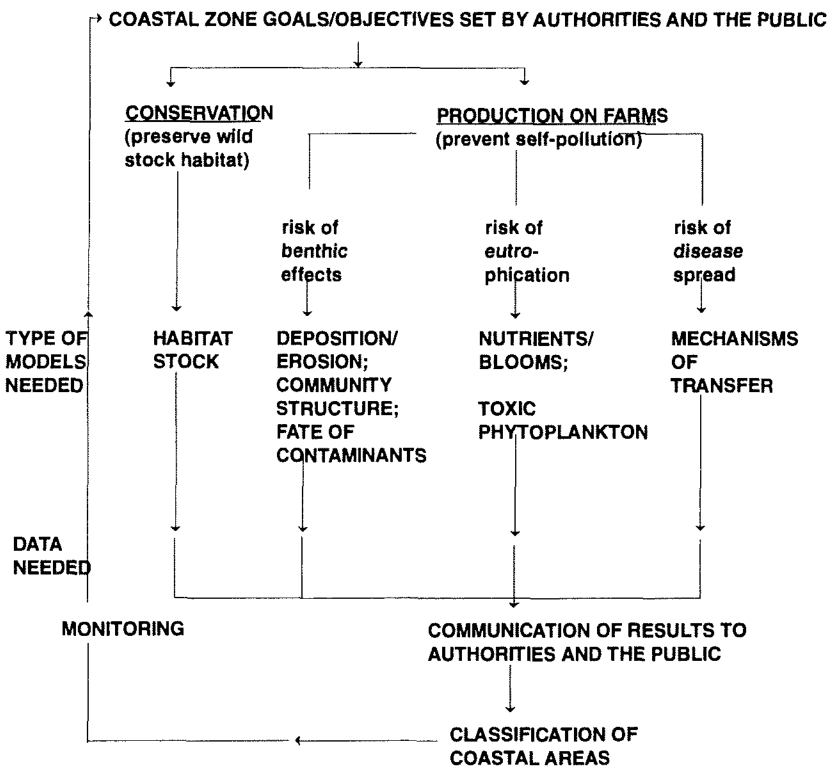
i) Benthic enrichment and ecology;
ii) Phytoplankton enhancement;
iii) Genetic interactions between farmed and wild fish;
iv) Interactions with wild fish, birds, and mammals;
v) Loss and degradation of fish habitat; and
vi) Prediction and monitoring.

b) It was agreed and recommended that relevant project lists should be prepared for both countries (by correspondence) and kept up to date for use in sharing information.

c) It was agreed and recommended that on the basis of these project lists, matrices, and shared information, collaboration and cooperation for individual ventures would be determined and arranged when feasible.

d) It was agreed that the accompanying diagram (Fig. 1) of the coastal zone issues reflected accurately the dimensions of the overall issues, and it was recommended that it is adopted as the framework and guide for future considerations and discussions.

Figure 1



Aquaculture in Atlantic Canada and the Research Requirements Related to Environmental Interactions with Finfish Culture

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Abstract

Currently, salmonids, Blue mussels, and the American oyster comprise the bulk of mariculture production in Atlantic Canada. Salmonids, mainly Atlantic salmon, equal about 70% of the tonnage and about 95% of the value of the 1991 to 1993 mariculture crops. Because of the rather low temperatures imposed by the Labrador Current, success in rearing salmonids is dependent, in Atlantic Canada, on finding those areas which remain above -0.7°C, the lethal lower temperature limit for salmonids. With current technology, southern New Brunswick and parts of Nova Scotia subjected to large tidal ranges of around 6 m have proven adequate. As the suitable areas are quite limited, it is essential that care be taken to ensure that environmental impacts generated in finfish culture by crowding at sites, surplus food, faecal accumulation, and chemotherapeutants do not exceed the assimilative capacities of these locations. These problems have been discussed in the context of salmonid cage culture and the apparent research needs are listed.

Introduction

Beginning in 1970, with a nominal annual production of approximately 1,000 tonnes of farmed salmonids, Norway developed a sophisticated mariculture industry which, in 1990, produced more than 150,000 tonnes of fish, mainly Atlantic salmon. The marine side of the industry now consists of approximately 800 farms employing around 5,000 people and is valued at over $1 billion (US) per year. It is anticipated that international market pressures being exerted now will result in an industry of 120,000 tonnes of salmonids per year for the next few years. One projection suggests as original markets mature and new ones develop, Norwegian production may peak at approximately 200,000 tonnes of salmonids per year. For expansion of mariculture enterprises beyond this, Norway is looking at other species such as cod, halibut, wolffish, turbot, and Arctic charr.

By contrast, the Canadian experience has been much more diverse, covering a wider range of species. Most ventures are at the initial stages of commercial production or in the early phase of what may prove to be exponential growth, somewhat akin to the Norwegian salmonid experience. One example is the production of Atlantic salmon in southern New Brunswick; in the fall of 1982, the production was approximately 38 tonnes. Since 1984, the annual production approximately doubled each year up to 1991, where it has remained stable at around 9,000 tonnes. The Southern New Brunswick production now accounts for approximately 95% of the East Coast production of Atlantic salmon (*Salmo salar*). The diversity of the total Canadian mariculture industry is illustrated in Table 1 (Anon., Fisheries and Oceans Canada, 1992-1994), showing production figures for the main species cultured in 1991, 1992, and 1993. In addition, studies and trials are in progress to examine the feasibility of initiating or scaling up to commercial size culture operations based rather widely in Atlantic Canada on Halibut, Arctic Charr, Atlantic Cod and haddock, and Sea Scallops. As noted earlier and shown in Table 1, the overall production of marine aquaculture currently

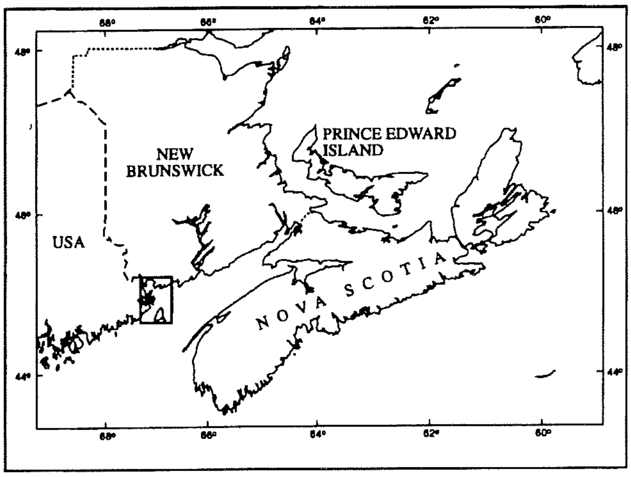

Fig. 1a. Map of Canadian Maritime Provinces with inset.

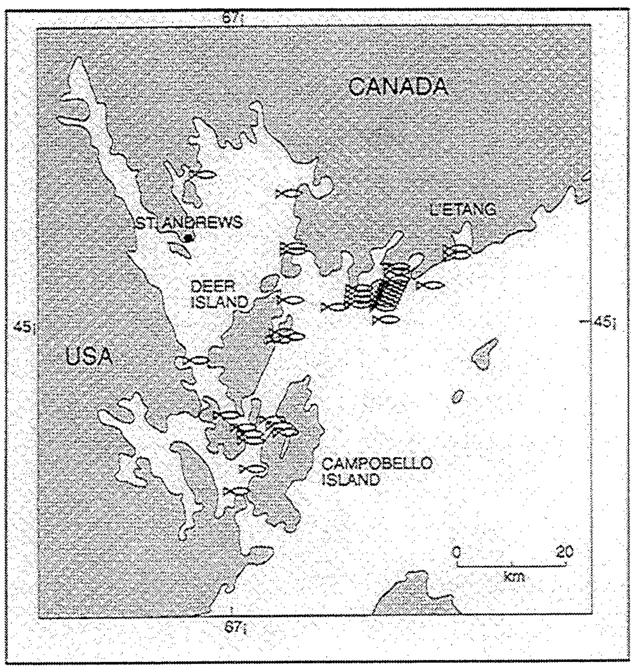

Fig. 1b. Inset showing locations of salmonid netpen farms in southern New Brunswick. Each symbol denotes a separate farm.

Table 1a. Canada: Marine Production Estimates for the year 1991 (Anon., Fisheries and Oceans Canada, 1992-1994).

ATLANTIC COAST	PRODUCTION (METRIC TONNES)	VALUE (CDN $000'S)
NEWFOUNDLAND AND LABRADOR		
Blue Mussels	135.0	Not Available
Atlantic Salmon	31.0	268.2
Rainbow Trout	70.0	174.6
Arctic Charr	0.1	5.2
Cod	17.6	5.2
Sea Scallops	4.4	8.0
Subtotal	**258.1**	**461.2**
NOVA SCOTIA		
Atlantic Salmon	284.1	2,457.4
Steelhead Trout	366.3	2,000.5
Trout	66.5	301.5
Blue Mussels	348.3	501.5
American Oyster	121.6	154.5
European Oyster	5.5	5.9
Bay Scallops	5.9	8.3
Subtotal	**1,198.2**	**5,432.7**
PRINCE EDWARD ISLAND		
Blue Mussels	3,404.0	3,754.0
Oysters	1,310.0	1,689.0
Rainbow Trout	37.0	394.7
Subtotal	**4,751.0**	**6,008.7**
NEW BRUNSWICK		
Atlantic Salmon	8,509.0	84.240.0
Rainbow Trout	272.0	1,700.0
Oysters	19.0	50.0
Blue Mussel	41.0	45.1
Subtotal	**8,841.0**	**86,035.1**
QUEBEC		
Blue Mussels	79.5	166.5
Atlantic Salmon	130.0	836.9
Subtotal	**209.5**	**1,003.4**
ATLANTIC COAST SUBTOTAL	**15,249.8**	**98,941.1**
PACIFIC COAST		
Marine Salmonids	16,500.0	100,000.0
Pacific Oysters	4,500.0	3,500.0
Subtotal	**21,600.0**	**103,500.0**
TOTAL ESTIMATED CANADIAN MARICULTURE PRODUCTION (1991)	**36,849.8**	**202,441.1**

Table 1b. Canada: Marine Production Estimates for the year 1992 (Anon., Fisheries and Oceans Canada 1992-1994).

ATLANTIC COAST	PRODUCTION (METRIC TONNES)	VALUE (CDN $000'S)
NEWFOUNDLAND AND LABRADOR		
Blue Mussels	147.5	275.0
Sea Scallops	1.0	6.5
Atlantic	24.5	222.0
Salmon	70.0	490.0
Steelhead Trout	15.0	50.0
Rainbow Trout	1.0	7.5
Arctic Charr	2.0	3.2
Cod	**261.0**	**1,054.2**
Subtotal		
NOVA SCOTIA		
Blue Mussels	194.6	319.9
American Oyster	51.5	90.4
European Oysters	6.3	19.8
Atlantic Salmon	625.0	4,812.5
Steelhead Trout	285.0	1,567.5
Rainbow Trout	179.2	1,168.6
Subtotal	**1,341.6**	**7,978.7**
PRINCE EDWARD ISLAND		
Blue Mussels	4,020.0	4,400.0
American Oysters	1,300.0	2,000.0
Arctic Charr	15.0	210.0
Rainbow Trout	16.3	158.0
Speckled Trout	eggs and fry only	32.0
Atlantic Salmon	parr and smolt only	30.0
Subtotal	**5,351.0**	**6,830.0**
NEW BRUNSWICK		
Blue Mussels	125.0	137.5
American Oyster	114.0	300.0
Atlantic Salmon	8,836.0	82,738.0
Rainbow Trout	375.0	2,351.0
Subtotal	**9,450.0**	**85,526.5**
QUEBEC		
Atlantic Salmon	80.0	460.0
Blue Mussels	110.0	225.0
Subtotal	**190.0**	**685.0**
ATLANTIC COAST SUBTOTAL	**16,593.0**	**102,074.4**
PACIFIC COAST		
BRITISH COLUMBIA		
Marine Salmonids (Chinook, Coho, Atlantic Salmon, Steelhead Trout)	22,400.0	110,000.0
Rainbow Trout	125.0	715.0
Pacific Oysters	5,000.0	4,000.0
Manila Clams	200.0	700.0
Subtotal	**27,725.0**	**115,415.0**
TOTAL ESTIMATED CANADIAN MARICULTURE PRODUCTION (1992)	**44,318.6**	**217,489.4**

Table 1c. Canada: Marine Production Estimates for the year 1993 (Anon., Fisheries and Oceans Canada 1992-1994).

ATLANTIC COAST	PRODUCTION (METRIC TONNES)	VALUES (CDN $000'S)
NEWFOUNDLAND AND LABRADOR		
Atlantic Salmon	100.0	713.0
Steelhead Trout	113.0	753.0
Arctic Charr	12.0	35.0
Cod	5.3	6.0
Blue Mussels	209.0	147.0
Scallops	2.5	28.0
Subtotal	**441.8**	**1,682.0**
NOVA SCOTIA		
Atlantic Salmon	850.0	5,800.0
Steelhead Trout	285.0	1,600.0
Arctic Charr	*	-
Blue Mussels	200.0	330.0
American Oyster	80.0	200.0
European Oyster	*	-
Scallops	*	-
Chondrus crispus (Irish Moss)	*	-
Subtotal	**1,415.0**	**7,930.0**
PRINCE EDWARD ISLAND		
Blue Mussels	4,540.0	4,994.0
American Oyster	1,078.0	1,973.0
Rainbow Trout	32.0	207.0
Arctic Charr	14.5	166.0
Atlantic Salmon	-	33.0
Speckled Trout	2.3	33.0
Bay Scallops	0.5	3.0
Subtotal	**5,667.0**	**7,409.0**
NEW BRUNSWICK		
Atlantic Salmon	10,145.0	89,280.0
Rainbow Trout	380.0	2,400.0
Shellfish (Blue Mussels and Oysters)	270.0	600.0
Subtotal	**10,795.0**	**92,280.0**
QUEBEC		
Blue Mussels	20.0 34.0	154.0
Atlantic Salmon	**54.0**	75.0
Subtotal		**229.0**
ATLANTIC COAST SUBTOTAL	**18,372.8**	**109,530.0**
PACIFIC COAST		
Marine Salmonids (Chinook, Coho, Atlantic Salmon, Steelhead Trout)	24,027.0	115,000.0
Rainbow Trout	115.0	715.0
Arctic Charr	4.0	30.0
Pacific Oysters	5,000.0	4,200.0
Manila Clams	200.0	700.0
Scallops	*	*
Subtotal	**29,346.0**	**120,645.0**
TOTAL ESTIMATED CANADIAN MARICULTURE PRODUCTION (1993)	**47,718.8**	**230,175.0**

* *Denotes less than three farms reporting and to maintain producer confidentiality, the production numbers are not included.*

is heavily biased in favour of salmonids. They form approximately 70% of the tonnage produced and about 95% of the value gained from mariculture. In this article the emphasis has been placed mainly on salmonid culture in Atlantic Canada (most of which occurs in southern New Brunswick - see Fig. 1 on page 2) in keeping with the workshop theme and for the sake of brevity. For a more comprehensive picture of mariculture in the Canadian Atlantic area the reader is directed to the publication "Cold Water Aquaculture in Atlantic Canada" edited by Boghen (1989) who is currently editing the second edition.

Terrain

The course which mariculture will follow in Eastern Canada would be expected to be different from that anticipated for either Norway or the Pacific coast since the Norwegian and British Columbian coasts, with their narrow coastal shelves and heavily indented shores giving rise to relatively deep fjords with numerous offshore islands for protection, are quite unlike the Canadian East Coast. The Canadian eastern coastal zone consists of a broad, relatively shallow, shelf area extending as much as 150 miles seaward with a depth of approximately 100 m over much of its area. The coastline is not heavily indented nor protected, in most areas, by offshore islands.

In contrast to the Norwegian and the British Columbian coasts which are warmed by the northward-flowing Norwegian Current and North Pacific Drift respectively, the Canadian East Coast is influenced (chilled) by the southward-flowing Labrador Current bringing waters from the Arctic Ocean along these coasts. This results in relatively low water temperatures over most of the shelf throughout the seasonal cycle. In the north the temperatures range from around -1°C to 6°C and in the more southerly regions between -1°C and 12 to 15°C. Much of the area, especially the bays and inlets, are ice covered for several months of the year. Only in relatively shallow-water areas, e.g. the southern Gulf of St. Lawrence, and others like it, do the temperatures become quite warm, around 20°C and as high as 26°C in certain bays and inlets, for several of the summer months. Some of these areas can be exploited for seasonal growth, through rearing pan-sized trout and the hardier molluscan shellfish such as mussels and oysters. In southern New Brunswick and in southern Nova Scotia, the large tidal ranges (up to 6 m) provide sufficient exchange with deep waters to maintain, in most areas, the winter temperatures above the minimum lethal temperature for salmonids of -0.7°C. Fortunately, marine plants and molluscan shellfish with their euryhaline osmoregulation are proof against the low temperatures as long as the temperatures are high enough for the water to remain liquid.

Thus, although the areas available for the conventional, year-round, cage culture of salmonids and other finfish are much more extensive in Norway and British Columbia than on the Canadian East Coast it does not indicate that mariculture on the Canadian East Coast lacks opportunities. The production figures in Table 1 show clearly that significant quantities of finfish and shellfish can be and already are being grown here. The secret has been and will continue to be to exploit very carefully and intelligently the limited areas and the traits of the species available. Obviously, with the intrusion of Arctic waters the nutrient supply is maintained and molluscan shellfish profit by this and grow quite rapidly in the relatively short growth seasons. In those areas where the lethal temperatures (-0.7 °C) and the sea ice do not interfere it has been possible to grow large quantities of the local strains of Atlantic salmon which appear to grow more quickly at these lower temperatures than other strains do at higher temperatures and are also efficient utilizers of food and for which the problem of sexual maturation prior to attaining the best market sizes, has been largely avoided. If the Canadian East Coast finfish culture industry is to prosper and expand, however, it is essential that the extremely limited areas available for application of current technology be wisely managed and husbanded carefully.

Management and environmental concerns

With a growth rate of considerable magnitude, interest is naturally heightened significantly each year; and considerable pressure is placed on regulatory agencies to grant more permits in areas where space is limited; in turn, these agencies turn to the research organizations to provide the background information to ensure that granting more permits is feasible. The aspects which must be taken into account include:

1) possible conflicts with other fisheries;
2) adequacy of areas for culture operations;
3) impacts of mariculture on the environment;
4) competition with other users of the geographical area, i.e. conservation, transport, navigation, and recreational uses; and
5) disease considerations.

All of these add up to ensuring the best use of the coastal resources or, in other words, Coastal Zone Management - an activity in which mariculture is a legitimate competitor. It is obvious even in this brief treatment that the issues rapidly become complicated and require resource management information and skills of a high order along with shrewdness and discrimination on the part of the regulatory agencies.

What will be the nature of the environmental impacts caused especially by finfish culture?

With current technology the answer is largely pollution and fish diseases; these twin threats will usually have the greatest initial impact on the fish farm projects themselves. To aid in understanding why and how this occurs it is probably of most benefit to provide a brief description of the sequence of events occurring at a typical finfish culture site.

Cage culture

In the usual finfish culture operation 1 to 1½ year old salmon smolts are held and fed for a further 1½ to 2 years in the marine environment in large netpens, most of which will enclose around 500 to 1,000 cubic metres (m^3) of water, exceptionally, some of the largest constructed elsewhere enclose amounts in the order of several hundred thousand m^3 of water. Current flow and tidal exchanges are relied on to supply clean, oxygenated water and to flush out deoxygenated water and soluble waste products. The food is supplied in the form of a complete diet of either dry or moist pellets distributed at regular intervals to the netpen water surface by automated feeders or by hand. Uneaten or surplus food will pass through the nets and sink, in some instances accumulating on the sea floor together with faecal material in significant mounds measuring up to 1-2 m in height. This uneaten or surplus food has been reported for moist feeds to equal between 20 and 35% of that fed; farmers using dry feeds are reported to lose only trivial amounts. In addition, the feeding, growing fish release both solid and soluble wastes. The solid, particulate faecal material which equals around 20% or more of the food eaten will also sink and combine with the organic deposits.

Unfortunately, it is not possible to state with certainty exactly how much of the fish food has been surplus in Atlantic Canada because definitive studies on this point have not been conducted or reported. There are, however, some facts and it is possible to put together estimates or approximations based on industry practice and information. Up to the first half of 1992 approximately 60% of the food used in southern New Brunswick fish farms was moist pellet containing about 36% water. The other 40% was dry pelleted feed (8-10% water); the dry fish food is prepared so that "fines" are negligible and hence should not be a factor adding materially to the waste column. The surplus feed was considered to approach 35% of the moist diet fed and for dry feed to be much less, probably on the order of 3%. These figures are suggested and confirmed by the industry conversion factors (feed/gain) of 2.25 (i.e., gross value derived from total food presented per gain achieved) for moist feed versus a probable actual values of 1.4 (i.e. net value derived from amount of food actually consumed per gain achieved); the industry feed conversion values for the dry feed are now considered to be 1.2 to 1.3 (gross values) versus the probable actual values of 1 to 1.1 (net values). The probable actual conversion factors are based on experimental feeding trials with these particular diets (Lall, personal communication).

The two dry feeds now being used throughout the southern New Brunswick salmonid culture industry are high-energy extruded feeds; one diet contains 46% protein (fish meal) and 30% fat (fish oil) and the other 44% protein and 25% fat. These dry feeds cost about one-third more per tonne than the moist feeds, but since the same production figures can be obtained with around 43% less food using the dry feeds results in a net reduction in food costs of about 28%.

Because the local fish food is highly digestible the faecal output does not exceed 20% of the food consumed. Interestingly, these values are quite consistent with the picture of wastes associated with Norwegian fish farming described in the comprehensive review of emissions and waste management in net pen culture by Bergheim *et al.* (1991). The composite farm sequence using moist feed is illustrated in Fig. 2a, which indicates that for each tonne of wet fish produced 1.08 tonnes of waste (36% water basis) is released to the environment; in contrast for dry feeds, Fig. 2b illustrates that for each tonne of fish produced approximately 0.368 tonnes of waste (36% water basis) is released - a marked reduction over that for moist feed.

Obviously, it is important to understand

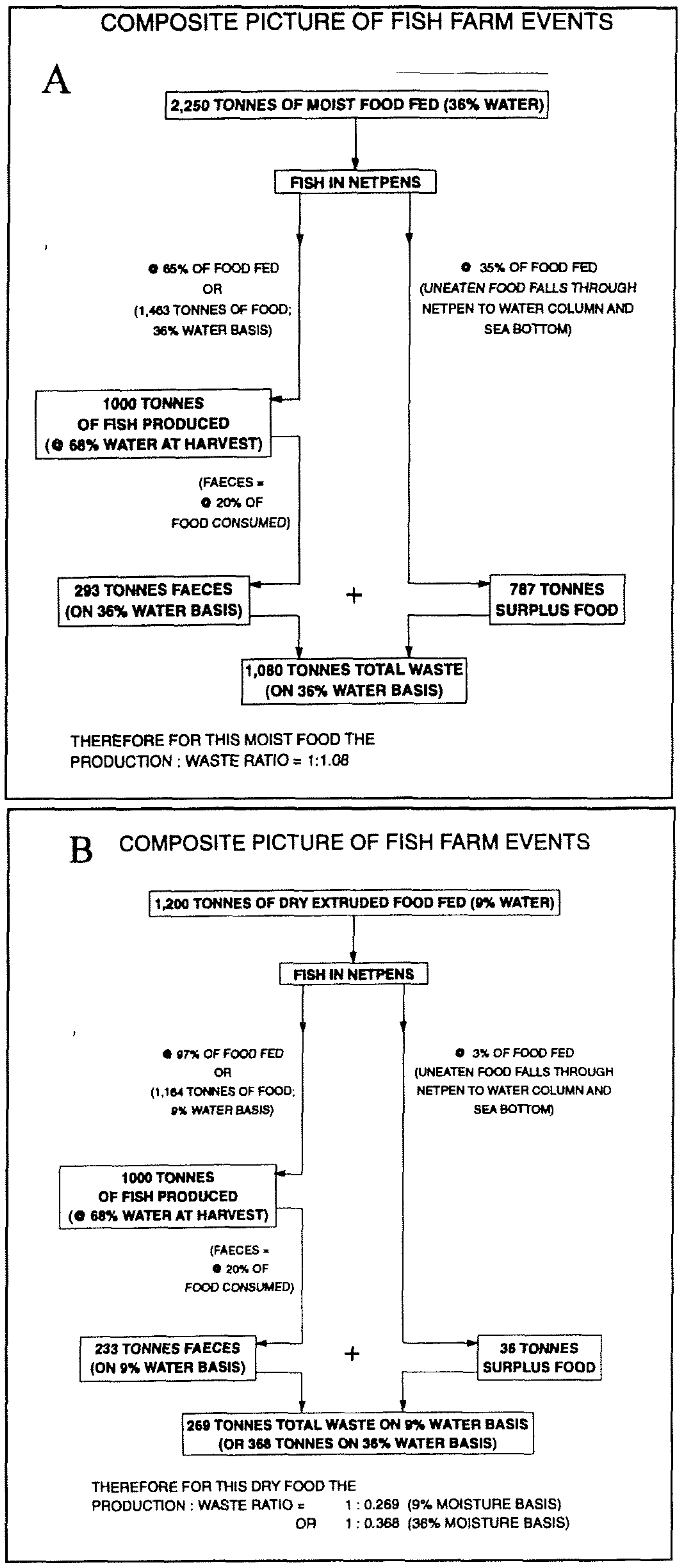

Fig. 2.Sequence of fish farm events using, as examples, in 2A: moist feed (36% moisture) and local conversion factors, and in 2B the events occurring in the recent southern New Brunswick use of dry feed (9% moisture) and local conversion factors.

in detail the fates and consequences of the introduction of these relatively large quantities of organic material to the environment. The initiatives taken over the last year have included improvements to feeding practices and to the physical condition of the feed, resulting in a marked reduction in effluent loading and hence pollution. The advantages inherent in what is essentially demand feeding have been made examined using such devices as the acoustic feeder described by Bergheim *et al.* (1991) or the hydroacoustic feeder currently being investigated in Norway. While on this point, it is of interest to note that the relatively small Australian Atlantic salmon industry (approximately 3,000 tonnes/yr in Tasmania) is developing a similar, essentially demand-feeder, approach to reduce the roughly 20% of food wasted there. They hope to decrease the annual $9 million food bill by at least $2 million by introduction of the computer-controlled AquaSmart Adaptive Fish Feeding System which is reputed to determine when the fish will feed, how much food to give, and by measurement of the surplus when to stop feeding (Australian Science and Technology Newsletter, April 1993, Department of Foreign Affairs and Trade, GPO Box 12, Canberra).

In very deep-water fjords or coastal margins with good flushing the bottom accumulations are less pronounced or non-existent; in these instances the major concern has been for the quality of the water column. Where, as in Atlantic Canada, the sites are taking advantage of shallower water, i.e. less than 20 m depth, material is more likely to be deposited and accumulate dependent on the flushing action of tides and currents in that location.

This overall picture is well understood by the finfish culture industry across Canada including Atlantic Canada where a recent examination of the sea floor around 48 cage sites was carried out. Of the total of 48 situated in southern New Brunswick in around 12 m depth, 8 sites exhibited a high impact on the bottom, 29 had a moderate impact, and the remaining 11 had a low impact (Thonney and Garnier, 1992).

Finfish disease

In intensive rearing, including monoculture in concentrated units, conditions develop which affect adversely the wellbeing of animals. Monoculture, although of major benefit in terms of efficiency of culture operations, also offers almost ideal conditions for the classical enhancement of virulence by serial passage and provides maximum opportunities for rapid transmission of pathogens (Stewart, 1991).

The main diseases affecting Atlantic salmon in Atlantic Canada are Vibriosis, Furunculosis, Bacterial Kidney Disease, Hitra Disease, and the larger parasitic sea lice. A fairly effective vaccine keeps the problems associated with Vibriosis to a relatively low level most of the time. Furunculosis and Bacterial Kidney Disease, however, are notoriously difficult and frequently cause serious problems. Sea lice have been a minor problem in most instances, although the threat is real; one site has been abandoned permanently because of sea lice infestations, and in one year several others were seriously threatened. In addition, and possibly more importantly, recent work has shown that sea lice and marine plankton, obtained from a Norwegian fish farm experiencing a furunculosis outbreak, were carrying the causative agent *Aeromonas salmonicida* in high numbers and hence constitute significant potential vectors for further spread of furunculosis (Nese and Enger, 1993) and possibly are also vectors for Infectious Salmon Anaemia (Nylund et al. 1993, cited in Hodneland et al. 1993).

As a consequence, disease is a constant hazard and when husbandry is inadequate or the host's defenses are overcome and when the limited battery of treatments and disease management techniques fail there is an early resort to antibiotics or other chemotherapeutants. The quantities used can be quite impressive. Initially the amounts of antibiotics supplied (incorporated in the feeds) were very large. As knowledge was gained this usage dropped rapidly to around 400 g antibiotic per tonne of fish produced (Anon., Canadian Government Departments, 1989-1993). Current practice (i.e. over the past couple of years) is estimated to utilize around 200 g antibiotics per tonne of fish produced based on assessment of local practices and comparable general practices in Norway and the excellent Norwegian system of recording therapeutant use (Anon., 1989-1993; ICES, 1992; and Bangen, 1994).

Mineralization and antibiotics

As stated earlier, substantial portions of fish food pass through the net cages uneaten where in certain circumstances it accumulates on the sea floor together with the solid portion of the faeces released by the fish. When diseases occur and the fish are treated with medicated feed (fish food with antibiotics incorporated), the surplus winds up on the bottom; thus, the accumulating sediments will then contain substantial amounts of antibiotics. Certain Norwegian studies have shown that with current practices the levels of antibiotics in the sediments have reached levels between 400 and 500 parts per million (cited in Hansen *et al.*, 1992). The steady accumulation buries the underlying material and ensures anaerobic conditions and thus a slowed rate of biodegradation of the organic deposits and the antibiotics. The antibiotics (through their anti-microbial activities in the sediments) and the anaerobic conditions created by accumulating sediments have a further major negative effect on microbial degradation of the accumulated sediments (mineralization). Other materials such as those used to ward off sea lice, protect structures, or are components incorporated in the diets are all factors in determining and controlling the mineralization rates. As the sediments become anaerobic the consequential incomplete microbial oxidations produce significant quantities of gases (ca. 70% CH_4, 2% H_2S, and 30% CO_2) (Storebakken and Olsen, 1982, cited in Håkanson *et al.*, 1988). As these gases break free of the sediments they scrub (mobilize) materials from the sediments (gas ebullition) including the antibiotics and distribute these in the water column for dispersion or to the surface where the volatile components will enter the atmosphere. Thus these sediments become a significant point source of pollution (Adams *et al.* 1990). The noxious gases traversing the netpen cages will have a negative (feedback) effect on the fish. The antibiotics used in the past in finfish culture included oxolinic acid which, along with all the other 4-quinolones, is now prohibited in Canada for use with fish. Current practice includes erythromycin with the most frequently used antibiotics being oxytetracycline and the potentiated sulfonamides, Tribrissen and Romet 30 (Anon., Canadian Government Departments, 1989-1993). It can be anticipated that this array will change as the inevitable drug resistance develops and new remedies and drugs are needed. Therapeutants and chemical control agents released in mariculture and the admixture of surplus foods and faecal matter are factors of prime and direct environmental significance here and elsewhere (Bergheim *et al.*, 1991; Brown *et al.*, 1992; Gowen and Bradbury, 1987; Braaten *et al.*, 1983; Weston, 1990).

Courses to follow

The directions the industry would like to see taken to overcome these problems were revealed by earlier studies and surveys of the Canadian aquaculture scene which indicated that the key production problems were seen by the industry to be in the fields of:

1) diseases,
2) nutrition and feeding,
3) genetics, and
4) design and array of growth facilities (cages, etc.).

The industry has expressed itself quite clearly on these matters and argues cogently that the main issue in aquaculture is cost reduction or its obverse, maximization of efficiency. They see solutions or advances in the categories listed above as the main avenues to achieving these efficiencies or cost reductions as well as ameliorating the problems of pollution and disease. With the increasing market pressures brought about by burgeoning world supplies of cultured salmon - especially Atlantic salmon - it is clear that efficiency in production, transport, and marketing will be the keys to survival and success. In other words, the entire finfish culture system must be treated as an integrated food production system in which all elements from site selection through to marketing are carefully evaluated and dealt with in terms of their overall contribution; the list necessarily includes environmental activities which can result in significant negative impacts. Obviously, reducing losses from disease through use of more resistant seed stock, development and application of vaccines, and better husbandry will decrease costs for replacement stocks and ease the high costs of treating disease and lessen the need for using large quantities of antibiotics. Good diets carefully tailored to enhance survival and growth, coupled with food and feeding regimes (demand feeding) designed to reduce waste and hence pollution, have already shown benefits in the form of moderated costs. The advances produced by and expected of genetics programs, i.e. more rapid-growing, disease resistant, efficient utilizers of food especially suited to local environmental conditions grown in units designed to maximize production and reduce labour costs should result in further benefits. In addition, good information on a farmer's fish inventory (individual weights and numbers) is critical to good management as at this time the inventory, or what it is estimated to be, is the basis for feeding and medication. If the inventory is wrong, feeding and medication will be wrong proportionately; unfortunately, few fish farmers currently are able to estimate their inventory accurately particularly as the season progresses. The determination of the full significance of the impacts of therapeutants, chemical-control agents, surplus foods, and faecal contributions is essential for any realistic evaluation of environmental impacts. It is necessary to understand what is happening, where the various components of all of these additives go, their ultimate fates, and what effects they have.

The chilling and depressing picture described for prawn rearing in Taiwan by Primavera *et al.* (1993) illustrates what can happen when culture is practiced without background knowledge and too little attention is paid to critical elements.

> " *One of the major factors in the collapse of the 1988 prawn crop in Taiwan was the indiscriminate use of antibiotics which led to temporarily higher prawn survival but long-term resistance in their pathogens (Lin, 1989). The prolonged, repeated or widespread use of an antibiotic leads to the development of resistance in bacterial populations, in the same way that the rotating use of several antibiotics contributes to the occurrence of multiple drug resistance patterns (Aoki et al., 1981, 1987).*"

The authors go on to conclude that the collapse resulted from the combination of high stocking densities, viral and bacterial diseases, accumulation of organic matter, and deterioration of soil and water quality and indiscriminate use of antibiotics and chemicals. As this example makes clear, many of the environmental problems in aquaculture will disappear if and when appropriate solutions are found or advances made on the problems of disease, food and feeding, genetics, and growth facilities.

In addition to the work being done under the headings of disease, food and feeding, genetics, and other topics in Atlantic Canada, there is also a diverse group of scientists looking directly at the environment through the L'Etang Inlet Aquaculture Project (Anon., 1992, L'Etang Project). The L'Etang estuary contains a substantial number of the farms in southern New Brunswick and hence accounts for the bulk of the area production of Atlantic salmon currently. This group examined, at three different spatial scales, the environmental impacts aquaculture could have on coastal habitats:

1) Internal impacts - fish within the cage.
2) Local impacts - those within the immediate vicinity of the cages. Important in siting cages and farms within an inlet.
3) Regional impacts - those which affect an entire coastal inlet. Information at this scale is necessary to decide how many farms or the loading a given coastal inlet can support.

The group working since 1986 concluded that, to be successful, regulation at the regional level must be carried out in the context of a comprehensive Coastal Zone Management Plan. Their work to provide the underpinning for such a plan has included field studies (biological and chemical monitoring), and numerical modelling. For more detail on these activities the reader is referred to the papers by Keizer and Silvert in these Proceedings.

In this context the LENKA Project, initiated by Norway in 1987, has been instructive and influential. The LENKA Project assembled Norwegian coastal data in a form adequate for managers of the coastal zones to gauge the opportunities for finfish culture and to resolve conflicts in the competition for space in the coastal zone, among the users and potential users (Stewart *et al.* 1993). As there is no model or system currently available anywhere to predict or indicate the limits to the assimilative capacity of the various culture locations or the full consequences of exceeding these limits, the attractiveness and advantages of applying the pragmatic but logically based LENKA system are immediately apparent. It allows rational development to proceed in a regulated, albeit, conservative manner while offering flexibility and the opportunity for change as more is learned; there are clear lessons in this for the Canadian scene, especially in Atlantic Canada where suitable finfish sites are at a premium. The lessons learned, from analyzing the LENKA Project and the detailed examination of 15 other case studies describing widely diverse environments and uses worldwide, are extremely valuable and fortunately are now available to guide further work here and elsewhere on Coastal Zone Management (OECD, 1993).

Acquisition of solutions for the problems outlined in this necessarily brief, and somewhat discursive treatment of finfish culture operations concentrated mainly on Atlantic salmon is becoming more urgent with the recent announcements from New Brunswick and Nova Scotia. Although Atlantic Canada production has been relatively static over the past several years, the current plan for southern New Brunswick is to increase Atlantic salmon production to

20,000 tonnes by the end of the decade - an approximate doubling of current production. As well, Nova Scotia has announced plans to expand by investing substantial sums over the next few years to foster and enhance aquaculture production in that province.

Aside from and in addition to the work to overcome the underlying causes of environmental problems or to remove the problems entirely (i.e. diseases, food and feeding, genetic and growth facilities studies, etc.), there is a need to ensure an understanding of the significance of the various factors, the full scope of the issues and to provide criteria for judgement, and reasonable courses to follow. One first and obvious objective should be to keep organic loading from rafts and cages within the capacity of the system to recycle (mineralize) the organic load. This can be accomplished by matching the imposed load to the assimilative capacity of the location or where space or sites are not limited, by adopting the multiple netpen site approach, coupled with fallowing, as practiced widely in Scotland. Other objectives are expressed explicitly and implicitly in the following list:

<u>Determinations required and work needed</u>:

1) Comprehensive listing of materials used in aquaculture and the amounts added to the water column and sediments.
2) Duration and fates of those materials listed in No. 1:
   a) Which are degraded to innocuous products?
   b) What intermediates of consequence are formed?
3) Distribution and partitioning of additives and derivatives over time.
4) Impact of the foregoing No. 2 and 3 on mineralization rates as inputs and temperatures vary.
5) Impacts of materials mobilized from sediments (inputs and derivatives) and in the water column on surrounding organisms with emphasis on benthic cycles.
6) Impact of aquaculture outputs on fish growth rates as temperatures and salinities vary.
7) Development of antibiotic and other drug resistances and their impact on area disease patterns and potential.
8) Modelling of bays and estuaries re loading and general performance of models.
9) Selection of index compounds, parameters, oceanographic features, and relevant model systems to gauge environmental impacts and to be used as environmental sentinels.
10) Influence of farming on enhancement of harmful algae and impacts of toxins on finfish and shellfish especially toxins such as the microcystin-like toxin now reported as the cause of Netpen Liver Disease (Anderson et al., 1993).

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Coastal Zone Management in Norway - Lenka and its Applications

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Abstract

LENKA (Nationwide assessment of the suitability of the Norwegian coastal zone and rivers for aquaculture)* was coastal-zone management programme that started in 1987 and ended in the summer of 1990. The aim of the project was to develop an efficient standardized tool for coastal-zone planning. Consideration was paid to the environment, existing utilization and infrastructure aspects related to Norwegian coastal waters. A method for estimating aquaculture production capacity for aquaculture was presented. The method deals with conditionsrelated to the recipient and the surface area. The coast was divided into three categories of recipients based on topography. Each category was given a production index that quantified the aquaculture production that should be possible without harming the environment. The recipient capacity was compared to the different constraints put on the surface area, and a figure for net capacity was given. The method has been used at county and municipal level to various extent along the coast.

Introduction

During the last ten years the aquaculture industry in Norway has boomed, from a production of about 22,000 tons in 1983 to about 160,000 tons in 1991. The rapidly expanding industry adds to the pressure on the inherently sensitive and often already stressed environment, intensifying competition for coastal space. The rapid expansion of the aquaculture industry has caused local pollution problems and conflicts with open-air recreation, traditional fisheries, marine transport, nature conservation and naval defence. In addition there are problems of disease, spreading of infections, the use of antibacterial agents and environmental threats in the form of possible genetic depletion caused by the mixing of wild and escaped farmed salmon.

* In this paper only the marine part of LENKA will be dealt with.

The organisations involved in licensing of approving aquaculture ventures are under pressure lacking resources regarding the tackling of problems caused by the rapid growth. Most problems can be avoided by reasonable siting of the farms, but no comprehensive plans for siting have existed. The LENKA-project was meant to provide tools for such planning at the county and municipal level, and establish a flexible database thus contributing to a balanced and orderly development of the aquaculture industry in Norway. This paper briefly presents the LENKA project and discusses its possible applications at county and municipal level.

Organization

LENKA was a cooperative project involving the Ministry of Fisheries, the Ministry of Local Government and the Ministry of the Environment. The project was run by a professional secretariat (LENKA-secretariat). The secretariat, together with three expert groups, was responsible for the development of the working methods (marine environment, water courses, and maps and computing). The project started in 1987, and was terminated summer 1990. The budget for the project period was about USD 6.25 million.

Operating procedure

The main operating procedure (LENKA documents, 1989, Kryvi et al. 1991, Ibrekk et al. 1991) is shown in Fig. 1. In order to deal with our 57,000 km long coastline in portions of manageable size the coastal areas were divided into smaller, appropriate geographical units, such as archipelagos, fjords, large sounds or open fjord basins. These major water volumes, called the LENKA-zones, were dealt with separately. The typification process (2) and the capacity assessment process (9) are explained below.

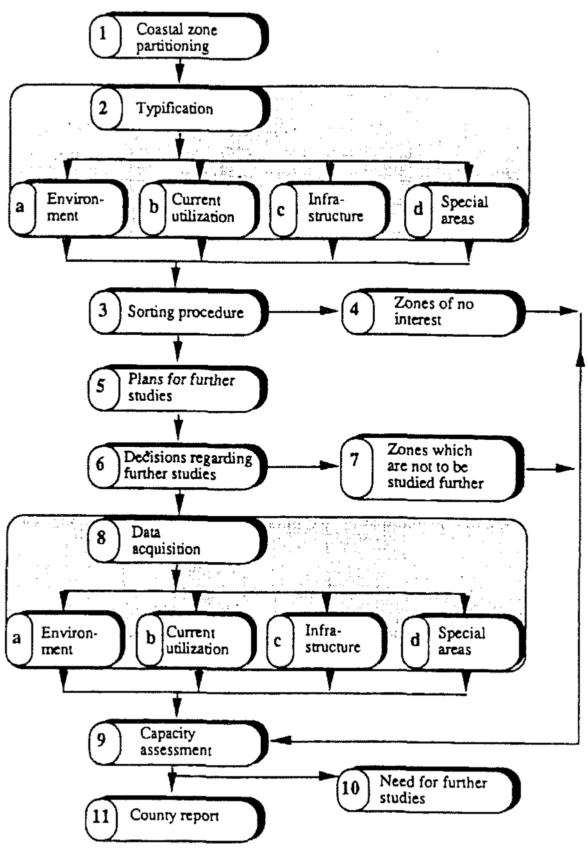

Fig. 1. The main working procedure for the LENKA-project.

Typification of zones was a matter of registration of the environmental properties of the area, and is based on four main groups of parameters: environmental conditions, existing use of the zone, existing infrastructure and special areas within the zone. Under the heading of each of these parameters, data were collected and systemized. The information compiled for each zone was transferred to maps. Environmental factors mapped included pollution, sea temperature, ice cover, exposure (wave height), depth conditions, basins and salinity. Existing use: settlement, recreation, port development, fisheries, shipping traffic, other factors. Infrastructure: road development and electricity, distribution of processed fish, processing facilities, health- and consultation services, offal disposal systems. Special areas: nature reserves, spawning grounds, existing fish farms, protection zones for salmon.

Classification of coastal areas

Each LENKA zone was divided into three holding capacity categories; A, B and C areas, based on the annual water-exchange rate derived from knowledge of the local topography. Designations were made according to the following criteria :

A: Open coastal areas and large fjords (> 10 km, no sills present), more than 50 m deep

B: Open areas and fjords where only one of the following three conditions is met; length < 10 km; depth < 50 m; no presence of sills

C: Small silled fjords and other enclosed areas (archipelagos).

Method for capacity assessments

A procedure for estimating the gross available capacity for aquaculture production in LENKA-zones was developed. This will enable authorities to set up production figures for each zone. A flow diagram of the procedure is shown in Fig.2.

The method for capacity assessments is divided into two parts: 1) evaluation of the conditions in the recipient and 2) evaluation of the surface area availability.

<u>The recipient capacity.</u>

Setting up production figures raised two major concerns:

- organic loadings from the aquaculture production should not degrade the environment
- healthy conditions for the fish in cages should be maintained

Due to the lack of definite environmental quality standards and suitable theoretical models at that time, an empirical approach was chosen. About 150 independent investigations on the effects of fish-farm pollution at different types of site in various parts in Norway were screened. A thorough evaluation of production figures, feeding routines, topography data and the environmental response (hydrography and benthos), was undertaken and correlated to the actual type of water exchange regime (A, B and C areas). On the basis of this sample, which linked production figures to the environmental impact, indices for production in each category were proposed. The following figures of organic loading per year from an average fish farm (mean production of about 300 tons per year) was used: three tons of total phosphorous, 27 tons of total nitrogen and 150 tons of BOD_7.

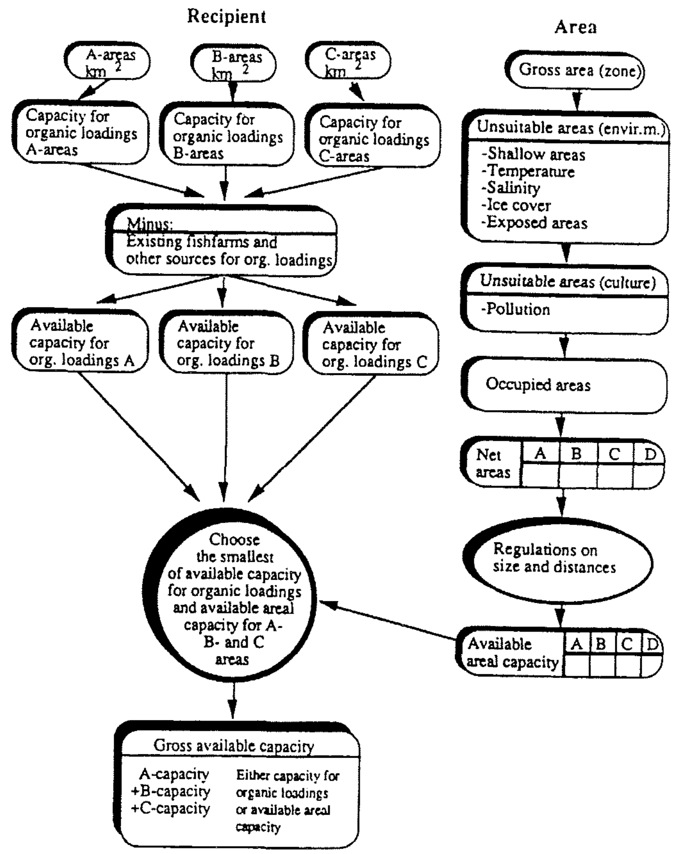

Fig. 2. Protocol for calculating the gross available capacity for LENKA zones.

Indices (numbers in tons produced fish per km²):

Area	A	B	C
Southern Norway	60	30	15
Northern Norway	90	60	30

Because of greater tidal ranges the values of the indices in the northern regions are larger. These figures are highly inaccurate and give merely a rough estimate of production in large areas. More importantly, however, they indicate the need for further investigations, and the calculations are related to a detailed survey programme that includes investigations of hydrography and benthos.

Multiplying these indices by the size of each area categorized, gives the overall capacity for organic loading. From this loading potential, contributions of organic matter from other sources such as industry, agriculture, sewage, exisisting fish farms and natural run-off are subtracted. For every area categorized, relevant data are collected and special models for processing the data are used. Total nitrogen has been chosen as an indicator parameter for organic loading, primarily because this parameter is considered to be the growth-limiting factor in the coastal waters of Norway.

A new mathematical model has recently been developed (Aure et al., 1990, and Stigebrandt, 1992), and this has more or less replaced the LENKA approach for calculation of holding capacity (see Aure these proceedings). This model, which is available as a computer program called "Fjordmiljø", has been distributed to the relevant authorities. This model gives the oxygen concentration at certain depths, taking water exchange rates, topography, latitude and organic loading from land sources into account. The model will give a more precise estimate of the amount of organic waste from fish farms that can be tolerated without harming the environment. Together with a monitoring programme that includes benthos investigations this model will provide a more reliable tool for site evaluations and capacity calculation. To make the model operational, the areas categorized areas (A, B and C) will be digitalized. This will simplify the exchange of information tied to these topographic units.

The area capacity

Calculations of area capacity are based on the total marine area of each zone, from which areas unsuitable for aquaculture are subtracted. We have taken into account the fact that some of these areas overlap to a certain extent. The areas subtracted can be regarded as belonging to one of two main groups; areas unsuitable due to natural conditions, and areas already used for other purposes.

The evaluation of the areas defined as unsuitable is based on currently farmed species and currently available technology. Characteristics that make aquaculture impossible or very risky include the following:

- critical exposure, i.e. areas with wave heights over 2 m
- shallow areas, i.e. depths less than 20 m (except current sounds)
- critical temperatures, i.e. areas with sea temperatures below 0°C for long periods, at least once every five years
- freezing, i.e. areas that are iced over at least once every fifth winter
- critical salinity, i.e. areas whose salinity occasionally falls below 10 ppt

- pollution, i.e. areas that are so heavily polluted that aquaculture is regarded as undesirable.

Areas that have been set aside for other purposes, and in which aquaculture cannot therefore be established, have been registered. Important categories of existing use include existing fish farms, temporary protection zones for salmonids, nature conservation areas, defence areas and areas earmarked by local authority planning procedures. The sum of these areas gives the total area set aside for other purposes.

The net area is converted to production potential in terms of tons of fish per year, by estimating that a average farm of 12,000 m^3 produces about 300 tons and requires an area of approximately 2 km^2, i.e. a production capacity of about 150 tons of fish per km^2. The result, called available area capacity, is compared with the available capacity for organic loading for that particular categorized area. The net result gives the gross available capacity. A program to deal with the database and the calculations has been developed.

Final assessment of production capacity

The suitability of each area is further evaluated as to the extent of possible conflicts between aquaculture industry and other interests. These interests are: spawning and fishing grounds, open-air recreation activities, nauyre reserves, naval defence, shipping traffic, protection zones for salmons and so forth. In addition the infrastructure in the area is considered: road development, processing facilities, offal disposal systems, health and consulting services.

The LENKA method thus provides planners and politicians with a rough estimate of the amount of aquaculture production that can be attained in a given area without risking environmental degradation and ensuring healthy conditions for the caged animals. The method also presents a procedure that aims to eliminate conflicts between fish farming and other interests. Together with an infrastructure analysis it is possible to do an overall consideration of the suitability of an area for aquaculture. With LENKA available municipal and county authorities can now use the material in the county reports as a basis for planning and optimizing conditions for aquaculture in the coastal zone and rivers, and for dealing with individual aquaculture projects.

The coastal zone planning situation in Norway

(Based upon a research report by Roger Bennett, Department of Geography, University of Bergen. 1992.)

There is a need for coastal zone planning in Norway and there is a national goal to produce such plans in every coastal municipality. LENKA is intended as an aid to this process. A survey of 257 municipalities (of a total of 286) along the coast as to what extent coastal zone planning has taken place has been undertaken. Some of the findings of the survey follows here:

At county level.

The county administration plays a role in encouraging and initiating municipal planning, and provides professional advice. There are big differences among counties in this respect. Some are very active vis-à-vis the municipalities, while others are not. Counties that were given special support when LENKA was created (among them Hordaland) had a good start.

There has been a tendency during the last years to decline in interest in this kind of area planning at county level. The most prominent worry today on the coast is the lack of economic activity and lack of jobs, rather than a concern about careful use of resources and sustainability. It is therefore more difficult to advise the munucipalities to determine long-term aims, because these might tie them up politically and limit their subsequent freedom of action.

In some counties, part of the drive of the planning work ceased when the LENKA project was terminated. Some of the reasons: the disappearance of state funding, a general scepticism towards part of LENKA meant that a lot of other useful registered data were not used, and the planning authorities (county administration) were not given the responsibility for following up LENKA. The momentum gained from LENKA and the accumulation of expertise were not properly utilized.

In this connection it is worth quoting from the OECD report: "The LENKA Project in relation to coastal zone management in Norway", by James E. Stewart, Stephen Thornton and Edmund C. Penning-Rowsell, 1991, p. 25: "The LENKA project has clearly demonstrated the potential benefits of approaching coastal zone management in an integrated and coordinated way. It is also clear that the primary catalyst for integration has been the project itself. Once LENKA ceases to exist as a formal project the primariy integrating factor will be lost from the institutional framework for coastal zone management. There is a danger that integration will cease along with the project".

At municipal level

Until 1.4.91, 13 % (37) municipalities had plans that were approved, while 35 % (99) were working on plans. One year later 22 % (64) had finished and 30 % (85) were still planning. Thirteen municipalities started the planning that year.

The main reasons for planning were:
- all municipalities: to sort out the uses and conflicts in the coastal zone
- municipalities in eastern and southern Norway : concern for the environment as the second reason
- western and northern Norway: the need for economic development and employment was the second reason.

There is a tendency for more defensive planning in the east and south and a more offensive attitude in the west and north.

Planning has been concentrated on the outer coastal and fjord regions. The municipalities where fish farming is crucial the stresses on the resources are strong have the greatest need for planning and are most active. Of the 65 municipalities that have more than four fish farm permits, 80% are planning. (The south-east region is responsible for less than 2 % of the total fish farm production in Norway.)

The use of LENKA at municipal level

According to the survey 56 municipalities utilize or will utilise LENKA in their planning activities. All of these are north of Jæren in southwestern Norway. A third of the municipalities in the counties of Hordaland, Sogn og Fjordane, Sør-Trøndelag and Troms used the material. Twenty-eight municipalities did not use it: most of these had started before the registered material was available. A further 112 municipalities are uncertain whether they will use it. These lack sufficient knowledge of what is available of geographical data and/or have problems to use it properly.

Final remarks

The LENKA method can be used by the central authorities to analyze the consequences of changing political objectives for aquaculture. Local authorities have been given a planning tool for coastal zone planning in general and aquaculture planning in particular. The "first edition" of the method was inaccurate when it came to assessing production figures for smaller areas and predictions of sites for the individual farms. To a great extent thanks to

LENKA, a new, more suitable model, Fjordmiljø, has been developed (see Aure these proceedings). This process of adjustment is continuing: efforts are being made to improve this approachin order to provide even more accurate estimates of the local impact of aquaculture (see Ervik these proceedings).

That was one of the aims of LENKA: to clear the ground, propose a procedure for planning and start the process of further development of more sophisticated tools for planning sustainable aquaculture in the Norwegian coastal waters.

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Possible Genetic and Ecological Effects of Escaped Salmonids in Aquaculture

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Introduction

During the last twenty years there has been a large increase in the number of aquatic species and biomass cultured by man. This ranges from algae and molluscs to fish and reptiles. In most cases, whether the production is intensive and physically confined or more extensive and open, there is a possibility of gene flow between the cultured populations and their wild counterparts. In several countries this has led to concern about the genetic integrity of wild populations. In the countries boarding the northern Pacific Ocean the discussion has focused on Pacific salmonid species while in Scandinavia the Atlantic salmon (*Salmo salar* L.) has been the species of concern. The basis for this concern can be summed up in three points:

1) species are divided into genetically differentiated populations, which may be adapted to environmental conditions. A wide range of biological mechanisms that serve to restrict gene flow among species and populations, have been identified. Many of the isolation mechanisms are associated with extra costs in terms of energy or time, and it is reasonable, therefore, to assume that they also represent evolutionary advantages and adaptation. The homing of salmonid species is an example of a mechanism that serves to reduce exchange of individuals and genes between populations;

2) cultured populations have been altered genetically through various processes, and therefore they will differ more or less from wild populations; and

3) cultured populations released or escaping may reproduce, either among themselves, with wild individuals or both, and thereby alter the genetic characteristics of wild stocks.

There are several situations in which gene-flow from cultured to wild organisms is to be expected in the future. The following can be immediately identified: 1) escapes from fish farming, 2) ocean ranching and large-scale releases of cultured organisms, and 3) genetically modified organisms for agricultural, industrial or medical purposes. There are a number of similarities in the potential environmental consequences of the various categories of cultured fish, and in the methods that are to be employed to study their interactions with wild populations. Therefore, the experience gained from studies of interactions between escaped farmed fish and wild populations is of relevance for the discussion of transgenic organisms in the environment.

In all three areas expansion is proceeding rapidly. To put the problem into perspective, the following statistics will assist. For example, the Norwegian production of farmed salmon increased from 4,000 tons to 160,000 tons, or 40 times in ten years, and the number of salmon annually escaping from farms now exceeds the number of wild salmon harvested in Norway. The number of juvenile salmonids released in the north Pacific Ocean has doubled every decade for the last four decades, and more than five billion individuals are released annually by Japan, USA, former USSR and Canada. The global harvest of salmon was expected to reach about 1,000,000 tonnes in 1990. It has been estimated that farmed, ranched and wild salmon would contribute 25, 30 and 40% respectively of this total (McNeil, 1991). The production of transgenic fish is said to be growing rapidly, and according to the latest information I have obtained, 22 research laboratoriess in 14 countries are now involved, and at least 14 different species are subject to transgenic research (Kapuscinski and Hallerman 1991).

Studies at the Institute of Marine Research

When it was known that cultured salmon were escaping in growing numbers, it became necessary to find out:

1) How can cultured salmon be identified and distinguished from wild salmon?
2) What are the genetic and ecological consequences of escaped cultured salmon?

It soon became evident that it was not possible to distinguish genetically between cultured and wild salmon at the individual level, neither could the genetic impact of escapement be quantified and scientifically proven directly. It was concluded that the situation had to be studied experimentally by using genetically marked populations. Genetic marking methods are very useful in fundamental research on gene flows among wild populations and introgression between species, but they also offer favourable opportunities to study the migration of alleles from cultured to wild populations. At the Institute of Marine Research we have now experimental populations with genetic markers of three fish species, i.e. brown trout (*Salmo trutta* L.), Atlantic salmon (*Salmo salar* L.) and cod (*Gadus morhua*).

Both brown trout and Atlantic salmon are presently employed in experiments to estimate gene-flow from cultured to wild populations. Here, I will concentrate on the experiments where brown trout is used as a model species to study genetic impact on wild stocks from farmed fish. In the second study, the aim is to quantify the genetic impact on wild populations from ocean ranching. In this case, wild spawners with genetic markers were selectively bred to obtain a genetically marked population. The third study is a model study in which multigeneration cultured salmon with genetic markers are employed to study the fitness of cultured individuals and the gene flow from cultured (transgenic) to wild fish populations. Although our experimental population in not transgenic, transgenic fish will usually be developed from populations that have already existed in culture for one or more generations. Thus, many and possibly most of the environmental implications of transgenic fish can be studied by using multigeneration farmed fish, and therefore we believe that this experiment will add to the knowledge about environmental effects of transgenic fish.

Brown trout as a model

Returning to the initial experiment, the brown trout is an excellent model species to investigate gene flow between populations. First, the brown trout is an opportunistic species; it occupies a great range of different habitats and forms populations with different life-histories. Thus, populations tend to diverge, and genetic distance is built up among populations. Furthermore, the brown trout is regarded as one of the most polymorphic vertebrae species, and biochemical genetic markers are abundant. Also, it has been hypothesized that adverse effects of population mixing should be most pronounced and easy to detect in species where a large portion of the total genetic variability is distributed among populations. There are also other practical advantages with the brown trout compared to Atlantic salmon, as the individuals are smaller, robust and also abundant in smaller streams, well suited for sampling and field experiments.

Gene flow and genetic changes can easily be detected when the populations are genetically marked. In our study, however, we also wanted to know if effects on ecological parameters of the wild trout population could be detected. This was difficult, as we did not know which effects we could expect, and what to look for. Finally, we decided to collect baseline information on several important characteristics of the populations, such as abundance of juveniles, individual growth rates, mortality of juveniles, size and age of smolts, size of eggs etc.

Milestones

This table outlines the key components in a gene flow study in fish together with the time scale. First, we spent some years searching for suitable markers, before a genetically marked brood stock could be developed. Then, when we decided to use the experimental population in a gene flow study, suitable field localities had to be chosen, and genetic and biological baseline information on the local populations had to be recorded. Altogether this mean that a minimum time scale is five years.

The experiment was carried out in River Øyreselv, which drains into the Hardangerfjord on the west coast of Norway. In section A, above a waterfall impassable for ascending anadromous fish, freshwater resident trout is the only fish species found, while section B, located near the sea, is inhabited by anadromous trout and salmon. The lower part of the river is divided in two parallel branches, each about 400 m long. In the first experiment, reared and genetically marked mature individuals were released in both sections of the river. In section A, video observations on the spawning behaviour of reared and wild trout were carried out, and ten reared individuals were kept in an enclosure for this purpose. In locality B, a mark-recapture study on juveniles was carried out to estimate the number and survival of different genotypes in offspring resulting from wild and reared trout, and for a combination of the two, and to assess changes in population parameters. The major effort has therefore been concentrated to locality B.

The experimental set-up in the model study gives an opportunity to concentrate on the activity and success of mature cultured individuals. One of the advantages here, is that we know the exact number of introduced spawners, and it is possible therefore to quantify the magnitude of the manipulation at the time of reproduction. The disadvantages of this set up, is that if the spawning success of introduced fish is low, there will be a correspondingly low number of offspring, and the risk of a sampling problem.

Genetic marker and electrophoresis

In 1986 production of a genetically marked trout strain was initiated. Data on the performance of the different genotypes were recorded. During 1988, genetic information on wild trout populations was sampled to find an adequate locality for the experiment, and electrophoretic studies were conducted. These included the following 12 enzyme systems: aspartate aminotransferase (AAT, 2.6.1.1), alcohol dehydrogenase (ADH, 1.1.1.1), adenylate kinase (AK, 2.7.4.3), creatine kinase (CK, 2.7.3.2), esterase (EST, 3.1.1.-) glycerol-3-phosphate dehydrogenase (G3PDH, 1.1.1.8), isocitrate dehydrogenase (IDHP, 1.1.1.42), lactate dehydrogenase (LDH, 1.1.1.27), malate dehydrogenase (MDH, 1.1.1.37), malic enzyme (MEP, 1.1.1.40), glucose-6-phosphate isomerase (GPI, 5.3.1.9), and phospho glucomutase (PGM 5.4.2.2), encoded putatively by 32 loci.

Two independent types of genetic markers were employed, biochemical-genetic markers, i.e. isoenzymes, and a visible, morphological-genetic marker i.e. a natural variation in spotting pattern to quantify the genetic impact from the reared fish. The visible marker is a variant in spotting pattern on the body that can easily be distinguished from the spotting pattern commonly found in brown trout. Individuals homozygous for this genetic variant have a spotting pattern consisting of tiny black spots, and at the juvenile stage they lack the common parr marks. Heterozygous individuals are intermediate between the fine-spotted and common genotypes in appearance, as they have irregular and broken-up parr marks.

The number of wild spawners in section A was estimated by diving surveys and fish counting, and a sample of adult fish was collected by gillnetting to record the length distribution and weight of spawners. In section B, the number of spawners was estimated by electrofishing and diving surveys. Based on population estimates and the genetic marking, the number in each year-class and the survival of offspring resulting from wild and reared fish were assessed. 0+ parr were sampled by divers and by electrofishing. In section B, the number of 1+ and older was estimated by the mark-recapture method (Peterson).

In the autumn of 1989 genetically marked spawners were released in spawning areas for wild trout in sections A and B. The number of released reared fish in section A was 43, and 104 in section B, which exceeded the number of wild spawners in both sections. Each released spawner was also tagged individually with Floy anchor tags. Diving surveys and video recordings were conducted during the late autumn and winter to estimate the number of released trout still present at the spawning grounds. Samples of the 1990 year-class have been collected in 1990, 1991 and 1992 for genotyping.

Geneflow from cultured to wild populations

The visible marker is rare, and has only been found in three populations in Norway, none of these near the location of the present experiment. Enzyme electrophoresis revealed that the MDH-2*152 allele common in the reared strain, was rare in the population in section A (0.02). We also found that the LDH-5*100 allele, present in high frequency in the marked strain, was present in very low frequency (0.03) in the anadromous trout in section in River Øyreselv and the neighbouring rivers. Therefore one visible marker and one isozyme marker were available in each section.

All samples of wild trout from year-classes hatched before the release experiment confirmed to the expected hardy-Weiberg distribution. Out of 43 0+ parr sampled in section A in October 1990, two individuals homozygous for the visible marker, and seven heterozygous individuals were found, giving a frequency of 0.128 of the visible marker allele. Statistically significant differences were found in genotypic distributions between the 1990 year-class and previous year-classes in both the visible marker ($p<0.0001$) and the MDH-2* marker ($p<0.01$). In contrast with the earlier year-classes, the 1990 year-class deviated significantly from expected distribution in the spot controlling locus as well as in MDH-2*. The genetic contribution from the farmed trout in section A, by September 1990, was calculated as 19.2% based on the isozyme marker MDH-2*, and 12.8% based on the visible marker. The population was also sampled in August 1992, when the frequency was 0.108. No homozygotes for the spotting pattern nor isozyme marker was found.

In section B, the visible marker was only observed in heterozygous form, as no finespotted individuals were found. In October 1990, twenty heterozygotes were recorded in this year-class, giving a frequency of the visible marker of 0.075. The frequency dropped to 0.03 between October 1990 and February 1991. By June 1991 the frequency was found to be 0.027. The frequency for the isozyme marker LDH-5* varied from 0.027 to 0.034 in year-classes between 1986 and 1989, while in the 1990 year-class, this allele was found in 26 out of 134 individuals, giving a frequency of 0.149, significantly higher than in previous year-classes. By June 1991, the frequency of the LDH-5* marker had decreased to 0.106. Observed deviations from expected Hardy-Weiberg equilibrium were significant in both visible marker and in LDH-5*. By June 1992, the frequency of the isozyme marker had dropped further to 0.092.

The genetic contribution from farmed trout was calculated as 16.3% based on the allozyme marker (LDH-5*), and 7.5% based on the visible marker, by September 1990. By June 1991, the genetic contribution from farmed trout in section B had dropped to 10.9% based on the isozyme marker and 2.7% based on the visible marker. Statistically significant differences were found in genotypic distributions between the 1990 year-class and the previous year-classes in both the visible marker and in the isozyme marker (LDH-5*).

In section A there is a fairly close agreement between the change in allelic frequencies estimated by the visible marker and the isozyme marker, LDH-5*, while in section B the observed change in allelic frequency is greater in the isozyme marker. The change observed in the isozyme marker in section B is comparable to the observed changes in section A, while the observed change in the visible marker is somewhat lower.

The relative reproductive success (RRS) of farmed trout compared to wild trout, calculated by 1990 from the frequencies isozyme markers, was 31% in section A and 25% in section B.

The data from section B also indicates that the mortality rate of hybrids was higher than that of offspring from wild spawners, possibly due to differences in size.

As the biotechnological development proceeds, it has become increasingly clear that the term "cultured" is not limited to traditionally bred organisms in aquatic farms and ocean ranching. It is now possible to design new types of organisms by transferring genetic material directly, even across species borders, at a high rate, independent of natural reproduction processes. The combination of DNA technology and industrial mass production of living organisms represent a new dimension in our capability to interfere with other biological species, their ecological interactions and regulations and even with the abiotic environment. Thus, the term cultured will also include transgenic organisms in the near future.

The management, utilization and conservation of biological resources must rest on a thorough knowledge about their function, interaction, regulation and classification. Nevertheless, there is a lot of fundamental information missing on most of the existing species. This is true even for the salmonid species, many of which have been studied for over a hundred years. The challenge from industrial DNA technology must be met with an improved knowledge about natural ecosystems and how they are affected by cultured organisms. A number of people have developed computer programmes which simulate such effects. There seems, however, to be a general lack of empirical information to adjust the models. That knowledge will have to be obtained through planned research.

Conclusions

1) The experiment reflects a situation where a swarm of mature, non-indigenous individuals enter a natural spawning habitat in the beginning of the spawning season of the wild population.

2) The number of 0+ parr originating from wild parents was actually higher in August 1990 than in the two preceding years. Thus, the presence of a high number of non-indigenous spawners seems to have had little influence on the reproductive success of the wild anadromous brown trout.

3) The number of genetically marked 0+ parr present in August 1990 was much lower than expected from the number of genetically marked spawners, and demonstrates a lower reproductive success of the released fish. From the present experiments, we conclude that the relative reproductive success of the hatchery fish compared to the native populations is about 25-30%.

4) Genetic changes were recorded in both of the wild trout populations. Based on population estimates and genetic markers, we recorded a decline in the frequency and absolute number of individuals carrying hatchery alleles during an observation period.

5) The visible marker was less effective than the isozyme marker in discriminating between farmed and wild individuals. The advantage of the visible marker is, however, the possibility to sample and type without killing a part of the population.

6) It has been demonstrated that genetic material originating from a reared strain, and introduced in the two populations in River Øyreselv has been incorporated in the genepools of the wild trout populations.

7) It is important to underline that the genetic impact of cultured fish is dependent on several circumstances, such as the life-stage at which the fish escape. For example, fish that escape at an early stage in life may have more time to acclimatize before spawning, and may therefore perform much better than fish that escape as mature spawners just before the spawning season. Furthermore, there will be differences between species. Therefore, no single experiment will give a complete picture of the actual genetic impact on wild populations from hatchery stocks. It is quite possible to imagine a scenario where cultured individuals compete successfully at the spawning grounds, and mate among themselves as well as with wild individuals. If their offspring then compete successfully survive, the outcome will be a change in the genetic characteristics of the wild populations. On the other hand, if their offspring compete less successfully, with a correspondingly high mortality a whole year-class may be strongly reduced.

8) From the present data we conclude that a single introduction of hatchery fish is not necessarily critical to the native population, as the reproductive success of farmed fish may be low, and the survival rate of their offspring may be reduced. However, when there is a more frequent input of farmed fish, as may often be the case in the real world, the genetic characteristics of the wild stocks will be altered, even when the farmed fish have a reduced reproductive success.

9) There is still little information on the ecological consequences of gene flow from cultured to wild populations. The challenge from the industrial DNA technology must be met with an improved knowledge about natural ecosystems and how they are affected by cultured organisms.

10) A number of people have developed computer programmes that simulate such effects. There is, however, a general lack of empirical information to adjust the models.

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Ecological Aspects of Siting Fish Farms in Coastal Habitats

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Introduction

This paper presents a brief perspective of the importance of knowledge on interacting habitat factors when siting criteria for salmon farms are being developed. In order to optimize the social and economic of fisheries values in the coastal zone, it is becoming increasingly evident that production from both wild and cultured species must be taken into account. Given the fundamental principle that habitat and environmental factors can limit yield of wild and cultured organisms, it is clear that a quantitative assessment of those factors, and their incorporation into siting criteria, would be of great benefit to fisheries managers. Research, ecological monitoring, and economic performance of fish farms can provide information for updating siting criteria. Through iteration, siting criteria for specific regions could be improved (Figure 1). Aquaculture managers could then make recommendations about specific habitats or space that can best accommodate the fish farming industry. At the same time, habitat managers could prevent net loss of productive capacity for wild fish and as well preserve intrinsic values of coastal ecosystems such as biodiversity, in keeping with accepted principles of sustained development and national policies such as no net loss of productive capacity of fish habitat.

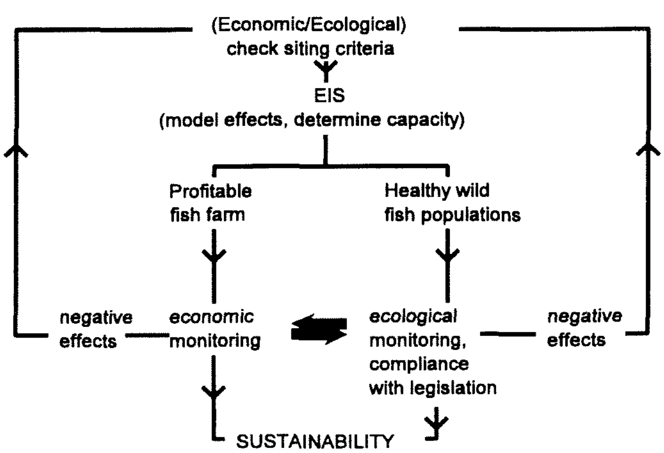

Fig. 1. An iterative scheme using ecological and economic data to improve siting criteria for fish farm siting.

Criteria currently in use for siting

In order to provide coastal zone managers with guidance in initial discussions about the location of farm sites, qualitative siting criteria have been developed (Table 1). In most instances the criteria have been selected without systematic investigation or research, and are simply the best judgement of working biologists in particular areas. Ecological factors considered for optimizing cultured production when locations are chosen for salmon farms include the important physical and chemical variables that have been shown to affect salmon physiology and growth (eg temperature, salinity, and dissolved oxygen). Caine et al (1987) rated the importance of these factors for Pacific salmon (*Oncorhynchus* spp) (Table 2), and it is clear from their rankings that temperature, salinity, and dissolved oxygen are key variables. For example, salmon cannot survive at temperatures less than 0.7 C and this has limited locations for salmon farming in the northeast and northwest Atlantic. Temperatures in the upper lethal or sub lethal range can also affect salmon production because fish growing at warmer temperatures are more susceptible to disease (Kent, these Proceedings). Locations where currents moderate temperature are considered optimum, but engineering and wave energy considerations for anchoring pens may limit site locations. During the background studies of the LENKA program (Ibrekk et al, 1991) on the coast of Norway, only 9 % of shorelines were found to be suitable for salmon net pen rearing. Currents are also important for dispersal of waste food and faecal material. If this organic material is not sufficiently diluted, self pollution (ie depressed water quality) can occur which affects growth and survival of cultured fish (Wildish et al, 1993). Thus, flushing rate of the water body where fish are being reared is an important variable that should be considered in the siting of farms (Aure and Stigebrandt, 1990).

Research and monitoring of long term effects of fish farming to refine guidelines

a. Investigations on effects of changed water quality

Only a few published studies have given results of the effects of water quality changes on salmon rearing in net pens. Wildish et al. (1993) showed that the seasonal variation in dissolved oxygen affected growth of Atlantic salmon in an embayment in New Brunswick. Gormican (1989) measured short term changes in dissolved oxygen due to internal tides near a fish farm in a B.C. fjord but effects on fish were not evaluated. When the fish farming industry began in Norway, farms were located in shallow silled fjords characterized by low dissolved oxygen, but most are now in more optimal, deeper sites (Aure pers. comm).

Table 1. Summary of criteria used in eight jurisdictions for siting of salmon net pen operations. nc indicates factor not considered.

Criteria	Site boundary re low tide	Minimum depth	Oceanographic consideration
Maine	n.c.	n.c.	n.c.
New Brunswick	≥45 m	≥2 m[a] ≥8 m	research on dissolved oxygen and nutrients (Wildish et al 1993); farm sites limited by winter temperature.
Ireland	n.c.	n.c.	unsuitable if 80% of current readings <0.1 m/sec over an undefined time span
Washington	n.c.	depends on production	graph relating depth,production, currents
Norway	n.c.	≥20 m	accounted for in LENKA scheme
British Columbia	n.c.	20 m[b]	accounted for in biophysical rating scheme
Iceland	n.c.	n.c.	n.c.

Footnotes

[a] written consent of landowner required

[b] recommended by Department of Fisheries and Oceans, Canada

Table 2. Summary of selected biophysical criteria for salmon net-pen siting in British Columbia (after Caine et al. 1987).

Factor	Rating		
rating	Good	Medium	Poor
Temperature			
Summer	10-15°C	16-21°C	>21°C
Winter	>7°C	5-7°C	<4°C
Short-term (12 h) fluctuations	No 12-h fluctuations	Fluctuations of <5°C	Fluctuations of >5°C
Dissolved oxygen			
Minimum concentration	8.5 mg/l	6.4 mg/l	4.6 mg/l
Minimum saturation	100%	79%	57%
Salinity			
Long-term	24 ppt	15-24 ppt	<15 ppt
Fluctuations	3 ppt	3-5 ppt	>5 ppt
Currents			
At slack water	10-15 cm/s	10-2 cm/s	<2 cm/s
At peak water	10-50 cm/s	50-100 cm/s	100-500 cm/s
Depth at low tide	>50 m	20-49 m	10-19 m
Site physiography	>30° slope; rock, sand, or gravel	15-30° slope; sand and mixed rock	<15° slope; mud or organic ooze
Plankton	No records of harmful blooms	Infrequent harmful blooms	Frequent lethal blooms
Pollution	No nearby sources	Nearby low-level sources	Within areas of high pollution sources
Hydrology	Freshwater lens depth of <1 m	Freshwater lens depth of 1-4 m	Freshwater lens depth of >4 m
Predators	Noe nearby sea lion haulouts; few avian and mammalian predators	Sea lion haulouts nearby; numerous avian and mammalian predators	Nearby sea lions' rookeries and haulouts; bird colonies nearby; major mammal predation
Marine plants and fouling organisms	Low levels of fouling organisms; noe kelp	Moderate levels of fouling organisms; kelp nearby	High levels of fouling organisms; kelp on site
Wind and waves	Sheltered site; wave height <0.6 m	Partially exposed; wave height 0.6-1.2 m	Exposed; wave height >1.2 m

The distance that fish farms are located from critical fish habitat should be one of the general factors that are considered by managers involved in site selection for salmon farms. Critical habitat includes fish migration routes, herring spawning areas, active fishing grounds, shellfish beds, and important fish rearing areas such as eel grass (*Zostera marina*) beds. A review of the guidelines developed by eight different jurisdictions showed that the required "separation distance" between farms and critical fish habitat varied from approximately 90 to 1250 m (Table 3). The rationale for the distance is usually not explicit in the guidelines, but is probably related to dispersion of organic wastes. Consideration is usually also given to depth under the cages since sedimentation of organic material can have an effect on benthic communities. Guidelines for depth under cages vary from 2 to 20 m (Table 1), but Weston (1986) developed a graph which related depth, current speed, and fish production in an attempt to quantify minimum depths. Guidelines for the distance between salmon farms range between 300 m and 8 km, presumably to limit the spread of disease between farms. There are no data to support the guidelines because the mechanisms of transfer between farms and within a region have not been investigated (Kent, these Proceedings). Proximity to salmon-bearing streams has also been considered in a few jurisdictions (Table 3) because of the concern that escaped farmed salmon could ascend streams and possibly interbreed with wild salmon (see below).

Siting criteria often do not take into account rearing and spawning habitat for marine fishes, but some consideration has been given to Pacific herring (*Clupea harengus pallasi*) spawning areas. Research on the effects of fish farm wastes showed no impairment of hatching success for herring eggs even when eggs were suspended within a net pen (Gillis and Hay, in press). However, a 1.8 km separation distance between farms and herring spawn areas is maintained in through unpublished guidelines in British Columbia (Levings 1993). The effects of organic waste from fish farms on benthic habitats have been well studied (Gowen et al. 1991), and underneath the pens, invertebrate productivity is usually reduced to very low levels in the "defaunated area". However the implications of the changes in invertebrate populations for demersal fish production needs to be investigated. Investigations of the predation of farmed fish on wild salmon fry and juvenile herring in British Columbia indicated predation levels were relatively low. Concerns about siting of farms on migration routes for wild salmon fry, which in some instances because of their small size can pass into net pens, were alleviated by these results (Black et al. 1992).

Information on recovery rate of benthic habitats is particularly important when farms are moved temporarily in order to restore water quality at an original location. In constricted water bodies, farm sites may have to be reused after fallowing. Because of the lack of consistent and long term monitoring, few detailed data are available on the temporal aspects of fish farm affects. Only a few studies have examined how fast benthic communities are restored to their original structure after fish farms have been moved. A recent study conducted

Table 3 Summary of guidelines used in jurisdictions for the required distance between fish farms and between fish farms and special habitats

Criteria	Distance between farms	Distance from critical fish habitats	Distance from ecologically sensitive areas	EIS or similar required	Zoning criteria for coastal use
Maine	n.c.	≥402 m	≥402 m	yes	yes; farms prohibited in "pristine areas"
New Brunswick	≥300 m	≥300 m[c]	prohibited within a Federally or Provincially designated ecological or environmentally sensitive area	no	no
Ireland	≥1 km	≥1 km[d]	must be considered	yes, if annual production >100 t	yes; area must be designated for aquaculture
Washington	n.c.	≥91 m	must be considered	yes	yes, shorelines
Norway	n.c.	distance from mouth of salmon rivers controlled	prohibited in certain fjord systems	no	LENKA scheme
Scotland	≥8 km	≥0.5 km[e]	n.c.	yes; in outer lochs, required for farms >6000 m^2; on open coast >12000 m^2	yes; farms prohibited in sensitive areas

Criteria	Distance between farms	Distance from critical fish habitats	Distance from ecologically sensitive areas	EIS or similar required	Zoning criteria for coastal use
British Columbia	≥3 km[f]	125 m[d]; distance from mouth of salmon rivers controlled	must be considered	yes	yes; CRIS scheme
Iceland	≥2 km	distance from mouth of salmon streams controlled; 5 to 15 km[g]	n.c	n.c.	n.c.

Footnotes

[c] herring weirs, lobsters ponds

[d] commercially or recreationally exploited shellfish beds

[e] distance from a specific productive fishing ground

[f] may be relaxed when farms are proposed on the opposite shores of tide-swept channels

[g] if stream producing 100-500 salmon in last 10 y, separation distance 5 km; if stream producing > 500 salmon in last 10 y, separation distance 15 km, but can be shortened to 5 km if local or sterile stocks used

in British Columbia showed that up to 8 months are needed before benthic communities recover, and even then the recovery rate is extremely variable between sites (Anderson 1992). The rate at which the restoration occurs is related to the extent that excess organic material on the bottom has modified the benthic communities which in turn is related to flushing rates.

In countries where production from wild fish is significant, research projects have been conducted to improve siting procedures so that impacts on production are minimized. Much of the emphasis has been on wild salmon, to date. For example in Norway, 9 % of the coastal area cannot be used for salmon farming because of inclusion in salmon protection zones (Ibrekk et al. 1991). The purpose of the salmon protection zones is to avoid possible genetic problems when farmed fish spawn in the same rivers as wild salmon (Hindar 1992). In Iceland, guidelines or zoning regulations have been put in place which determine the minimum distance that salmon farms can be located from the mouth of rivers with wild populations. This distance ranges from 5 to 15 km, depending on size of the wild salmon run in particular rivers (Table 3). Proper siting of farms, in areas protected from storm action, could probably reduce the probability of net pen damage and fish escapement. The issue of escaped salmon is likely to persist as the aquaculture industry grows and concerns for wild fish conservation persist. For example, the number of escaped salmon in British Columbia has increased in recent years. Between 1988 and 1992, approximately 810,000 chinook salmon and 10,000 Atlantic salmon were accidentally released to the environment (DFO, unpublished). Because the industry is much larger in Norway, numbers of escaped salmon are higher. Between December 1988 and January 1989, 1.2 M salmon escaped on the Norwegian coast (Hindar 1992).

b. Synoptic surveys and monitoring

Few studies have attempted to determine the spatial extent of fish farming effects on a coast, but such broad-scale or synoptic studies can be useful to give a perspective on individual siting decisions. Levings and Johannesen (in prep) used data from 56 benthic surveys near salmon farms in Hordaland County (Figure 2), west coast of Norway, to investigate broad-scale effects. The studies were conducted between 1984 and 1989 to determine if environmental conditions were affecting the growth and survival of farmed fish or to get information on oceanographic conditions at a site for a planned fish farm. Using polychaete species as an index taxa, results showed that clusters of samples taken at fish farms could not be separated from those taken at the proposed locations, which represented natural conditions. In addition, results showed that major habitat types such as major fjords could not be separated from embayments. Fish farms were apparently not having a broad scale effect on polychaete communities from the survey locations in Hordaland. However an examination of the species composition of the benthic data showed that at 16 survey locations of operating fish farms the indicator polychaete *Capitella capitata* was dominant among thepolychaete taxa. These data suggest that habitats were enriched by waste organic material from the fish farms. A further 6 fish farm locations were characterized by at least one station where hydrogen sulfide was detected. Together, the data on *C. capitata* and hydrogen sulfide indicate that conditions were not suitable for diverse benthic communities for at least some stations at 46.4 % of the survey locations. A review of similar data from 9 operating fish farms and 1 operating smolt farm in Sogn og Fjordane County showed that only 2 locations (20%) showed evidence of organic enrichment and none were characterized by hydrogen sulfide. In Møre and Romsdal County none of the eight locations reviewed showed evidence of organic enrichment or hydrogen sulfide. The differences along the coast may be attributable to the degree of flushing and tidal energy , which increases to the north and west along the Norwegian coast (Aure and Stigebrandt 1990).

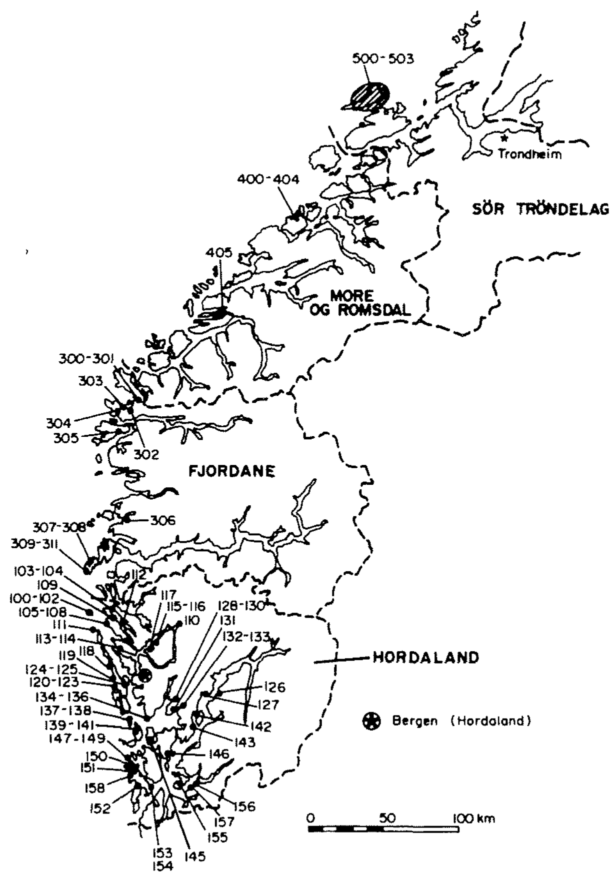

Fig. 2. Map of the west coast of Norway showing fish farms sampled (1984-1989) in four counties for effects on benthic communities (data provided by Per Johannessen, University of Bergen)

Conclusions

Siting criteria are important because they provide prospective fish farmers with a first indication of locations on the coastline that are acceptable to coastal management authorities, before application procedures are begun. Siting criteria currently in use are usually not based on research results, primarily because the topic of aquaculture is a relatively new aspect of coastal zone management. The best way to continually improve siting criteria is through a systematic monitoring of the growth and survival of fish grown by farmers together with the performance of natural ecosystems in the vicinity of the farms. The required monitoring programs require a long term commitment to maintain and review complex data bases and a solid statistical design. However there is no alternative to this approach if sustainable development in the coastal zone is to be placed on a scientific basis.

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Fjordmiljø - A Water Quality Model for Fjords

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Abstract

Fjordmiljø is a diagnostic tool (PC-program) to compute the expected "normal" state of fjords with regard to mean circulation of water above and below the sill depth. Fjordmiljø computes changes in the rate of oxygen consumption and the minimum oxygen level in the basin water as a result of changed organic matter loadings. *Fjordmiljø* estimates changes in the sight (secchi) depth as a result of changed supplies of plant nutrients to the surface layer.
The circulation of water above the sill depth is driven by three mechanisms: estuarine circulation driven by the local supply of freshwater; tidal "pumping" which is the circulation induced by the filling and emptying of the fjord by the surface tide; and intermediary circulation due to the changing density field outside the fjord. The estuarine circulation is computed according to Stigebrandt (1981). The intermediary circulation is computed according to Stigebrandt & Aure (1990), based upon Stigebrandt (1990). The computations of the tidally driven circulation utilizes Stigebrandt's (1980) method.

The circulation below the sill level depends on the rate of vertical mixing (computed according to Stigebrandt & Aure, 1989) and the characteristics of the density fluctuations outside the fjord (from Stigebrandt & Aure, 1990).

The vertical flux of organic matter is computed according to Stigebrandt (1992) which is an extension of the fundamental work in Aure & Stigebrandt (1989).

To run the model for fjords in other parts of the world requires that the characteristics of the density field in the coastal zone are known. This requires considerable density (salinity and temperature) data from a number of suitably spaced verticals. The tidal amplitudes are also required to be known (which are most probably well known), and the natural vertical flux of organic matter.

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An Integrated Approach to Aquaculture Site Selection and Management

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Abstract

The Department of Fisheries and Oceans has a key role to play in the development of marine aquaculture in Canada. It is responsible for both the orderly development of the industry and for the protection of the marine environment. With the decline of the traditional fishery on Canada's east coast there is a great deal of pressure to accelerate the development of coastal areas that are suitable for the culturing of Atlantic salmon. The numerous issues that have to be addressed during the site application review process often make it difficult to properly assess each application. Work has begun on the development of a decision support system based on a geographic information system (GIS) database which will allow managers to access the most current information. The same system will also provide information essential to the proper management of aquaculture sites to minimize environmental impacts.

Introduction

The Scotia-Fundy Region of the Department of Fisheries and Oceans (DFO) is responsible for the management of the fisheries in a large part of the east coast of Canada. Up until the mid-1970's this meant management of the traditional, capture fishery. Since then marine aquaculture has grown steadily. In 1992 the market value of cultured finfish and shellfish was almost 20% of the total value of all fish products from the Region. Cultured Atlantic salmon accounted for most of the value of mariculture products and most of these fish were grown in southwestern New Brunswick.

The area commonly referred to as the Quoddy Region in southwestern New Brunswick has proven to have excellent environmental conditions for the growth of Atlantic salmon. The waters of the Region are neither too warm nor too cold and the large tidal range in the area regularly replenishes the dissolved oxygen used by the salmon. In that area in the late 1970's the socio-economic conditions were also conducive to the development of this industry. Unemployment was chronically high and there were many skilled fishermen looking for work. Also, the Province of New Brunswick took a very positive attitude toward the development of finfish aquaculture and together with other Provincial and Federal agencies provided the technical and financial support that was essential to the initial growth of the industry. There are now approximately 60 farms licensed in this area and last year they produced about 9,000 metric tonnes of Atlantic salmon.

The development of marine aquaculture in Nova Scotia is in marked contrast to the development in New Brunswick. In Nova Scotia the industry is dominated by a large number of mussel growers rather than finfish producers. There are many reasons for this. Environmental conditions along most of the Atlantic coast of Nova Scotia are not suitable for the growth of Atlantic salmon since temperatures below -0.7° C occur regularly in the winter months. In the southwestern and Fundy areas of the province water temperatures are suitable but other factors have delayed the growth of aquaculture. These areas have enjoyed one of the most lucrative traditional fisheries in eastern Canada and therefore there has not been a pressing need for economic diversification. Applications for aquaculture site licences in these areaa have been strongly opposed by traditional fishermen who see this new industry as an invasion of their property and who are wary of potential unknown negative interactions with the wild fish stocks. All attempts in Nova Scotia to date to culture Atlantic salmon have failed either as a result of environmental problems or poor management decisions.

Recently, however the Nova Scotia Department of Fisheries announced an initiative to determine the areas in the Province where there is a potential for finfish culture and to provide the type of technical and financial assistance necessary for the development of this industry. In New Brunswick, there is still a steady stream of requests for either expansion of existing licences or the granting of new ones. It is the responsibility of the federal Department of Fisheries and Oceans to ensure these developments proceed in such a manner that they do not have negative impacts on the traditional fishery or the marine environment.

The process

The Provincial governments have the authority to issue licences for aquaculture sites. There are however a number of other Provincial and Federal agencies that have direct responsibilities in this decision-making process. Once the Province has received the licence application and has conducted a preliminary review, the application is forwarded to all these agencies. After approval by the many agencies involved, an application may then subject to a public review process. At a minimum it can take 6 months for licence approval; it is more likely to take years.

This paper is an overview of the review process within DFO and focuses on the concerns that have to be addressed, the information that is necessary to address those concerns, and how that information can be accessed in the most efficient and timely manner.

The concerns

DFO has the legal responsibility to protect the traditional fishery and fish habitat. It also has made a commitment to delivering initiatives that support the aquaculture industry's long-term sustainable growth (Anonymous, 1990).

During the licence application review process one of the most immediate concerns is the presence of a physical conflict with a traditional fishery. Is there traditional fishing activity in the area, and if so, what is the level of that activity and the value of the landings? Most traditional fishing activities are totally incompatible with the presence of finfish cages. It is impossible to trawl or drag for groundfish or scallops in an area criss-crossed with mooring lines for sea cages. If an aquaculture site licence in an area which supports some type of traditional fishery is approved the fishermen may have to be compensated. This is not a simple task since records of who fishes where and the size and value of catches are usually on a larger spatial scale. It is therefore often difficult to determine who should be compensated and exactly for what loss they should be compensated.

Equally as important as the real physical conflicts are the perceived conflicts which may range from the likely to the highly unlikely. But all concerns have to be dealt with in a responsible manner if aquaculture is to coexist with the many other coastal resource users. Often the questions being asked are very difficult to answer. For example, does the presence of large numbers of salmon in cages prevent herring from entering weirs in that area? Large variations in weir catches make it difficult to assign specific cause and effect relationships. Does the nutrient flow from the salmon farms result an increased abundance of nuisance macroalgal grow on adjacent shorelines? Our present knowledge often does not allow us to answer these types of questions in a manner that is convincing to those who are apprehensive about the environmental impacts of finfish aquaculture.

In 1985 DFO issued the "Policy for the Management of Fish Habitat". By this Policy the Department "recognizes its responsibility to protect and increase fish stocks and their habitats that have either a demonstrated potential themselves to sustain fishing activities, or a demonstrated ecological support function for the fisheries resource" (Anonymous, 1986). The long-term objective of this Policy is the achievement of an overall net gain of fish habitat. While this policy was implemented primarily to control chemical hazards being introduced into marine waters and the management of ocean dumping, shipping and offshore oil exploration activity it also has major implications for the development of aquaculture. It is the Department's responsibility to insure that the development of this industry does not result in a net loss of fish habitat.

The application of the Fish Habitat Management Policy can also be looked upon as one way of insuring the development of a long-term sustainable aquaculture industry. Since the industry is highly dependent upon water quality to insure good growth rates and minimize disease, its operation is generally consistent with the habitat management policy. However it is conceivable that the environment beyond the immediate confines of a fishfarm could be impacted by farm wastes resulting in a loss or degradation of fish habitat. In general the application of this policy is difficult because of our incomplete understanding of the nature and sensitivity of fish habitat. For example, we are not fully aware of what type of refugia are essential for larval or juvenile fish or where the important nursery grounds are for different species of fish.

Information requirements

During the site licence application review process the main time consuming activity is the collection of the necessary information from a variety of sources. Information about the physical and water quality characteristics of a site can often be difficult to obtain. Because of the tremendous length of the coastline and the low population density there are many bays and inlets for which there is very little information. Applications for salmon farming licences are often received for sites where there is no historical data of seasonal temperatures or the magnitude of the currents; information which is basic to making a recommendation for approval or rejection.

The problem of assessing environmental interactions in eastern Canada is magnified by the lack of adequate sites for this growing industry. Once a suitable inlet or embayment has been identified, the industry will attempt to extract the maximum total production by increasing individual farm production and the number of farms in the area. It is no longer sufficient to just assess the impact of individual farms on the environment. The area wide impact and the cumulative impact of all aquaculture sites and other anthropogenic and natural loadings in the embayment have to be considered. In Canada, by law, such wide reaching effects have to be considered. The Canadian Environmental Assessment Act requires that all assessments consider "...any cumulative environmental effects that are likely to result from the project in combination with other projects or activities that have been carried out..."

An integrated approach

During the licence review process basically 2 decisions have to be made;

1. Is the site suitable for the culturing of Atlantic salmon, and
2. Are the potential environmental impacts of the proposed development acceptable?

Suitability of the Site

Assessing the suitability of a site requires information about the physical environment including water depth, current, seasonal water temperatures, identification of any conflicting water resource users, etc. The local fisheries officer is consulted about potential conflicts with the traditional fishery. Information is based on the officer's personnel experience including observations of fishermen setting traps or nets or dragging in the area or anecdotal or second-hand information from local fishermen. At present there is no centralized or formalized record of this type of information. Similarly information on water quality parameters may exist at different agencies in a multitude of formats. It can be very time consuming to make a thorough search for this information and because of time and resource constraints important information may be overlooked.

The provision of access to this type of site specific information is an excellent candidate for a GIS based database management system. As the first step in assessing the feasibility of this type of approach a pilot study is in progress in the Quoddy Region of southwestern New Brunswick. Since the desired data belong to many different people in many different government and private agencies, one of the major undertakings is to facilitate a memorandum of understanding among the data contributors for an effective means of sharing and maintaining the databases. The various types of data, after processing into a suitable format, will then be graphically presented as thematic layers over the base map of the area; e.g. water temperature and depth data. Simple models will be constructed to delineate potential areas for fish culturing operations. The project will then try to identify the minimum information that is essential for site selection in this area.

Prediction of impacts

Prediction of the environmental impacts of a finfish aquaculture operation is not an easy task (Silvert, 1992). A rudimentary assessment is made during the site selection process. Based on the past performance of farms in that area or a similar environment, minimum depth and current criteria can be established (e.g. Washington Department of Ecology, 1986). The inherent assumption in this process is that the environmental impacts at the site are acceptable if there is no negative impact on the growth rates and incidence of disease for the farmed salmon.

As noted earlier, in Canada, by law, potential impacts beyond the immediate site have to be considered. Therefore, in addition to the site specific information, data for all the natural and anthropogenic inputs to the area have to be collected. In order to predict the cummulative impact of all these inputs it is also necessary to know the manner in which they are transported within and out of the area and the time scales for the degradation of these inputs.

To obtain all of this information for every estuary and inlet would be a formidable task. In Nova Scotia a project to systematically catalogue information about its coastal inlets was recently completed. The shorelines and bathymetry of most of the coastal embayments have been digitized and the information has been published (Gregory et al. 1993) and is also available through a low cost geographic information system, inFOcus/QUIKmap. This system allows the user to define arbitrary cross-sections within an embayment and determine mean tidal currents and flushing times across that section. The next step in this project is to analyze the data and development a system of classification, similar to the LENKA model (Stewart et al., 1990) which will provide at least a general assessment of an embayments ability to flush and/or assimilate wastes.

Another approach to determining these larger scale impacts is to develop a hydrodynamic model, i.e. a model which describes the physical movement of the water, for the area of concern. The development of these types of models is typically very expensive and time consuming and the product is usually not worthy of trust until extensive field validation is completed. In the last few years significant advances have been made in the application of new modelling approaches to these types of problems (e.g. Werner et al. 1992). These new techniques have the potential of providing a more efficient and cost effective means of modelling circulation in coastal areas.

Whatever approach is used to determine localized and wider ranging impacts it is essential that the information be available in a usable format to the manager who is responsible for making decisions. The GIS based information systems are capable of providing information in a timely and manageable manner. However, most managers will have neither the time nor the expertise to run complex models nor are they interested in a detailed 10 year daily record of water temperature or salinity. Through interaction with the managers, the system developers have to determine the optimum manner to package and present the information. The user interface has to be graphical and intuitive and provide a fair degree of flexibility in allowing the manager to apply selected models to the problem at hand. There is a delicate balance that must be achieved between simplicity of use and wide ranging functionality if such a decision support system is to be useful.

To the individual farmer these problems may appear inconsequential compared with his concerns with disease control and a good broodstock program but ultimately a well founded coastal zone management plan is just as important to the long term success of coastal mariculture.

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Modelling Environmental Aspects of Mariculture: Problems of Scale and Communication

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Abstract

A set of models has been developed to calculate the environmental impacts of finfish mariculture, with the ultimate objective of developing tools that can be used by agencies charged with the regulation of mariculture and the issuance of licenses. The modelling work is proceeding well, but it appears certain that because of the variety of space and time scales associated with different environmental effects, several models will have to be used to carry out realistic assessments, and the complexity of these models is such that it is not realistic to expect that they can be adopted as management tools in their present form. Consequently effort is also going into the design and development of a Decision Support System which can be used to enable individuals with minimal technical training and background to use these models and evaluate their output for management purposes.

Introduction

The Habitat Ecology Division at the Bedford Institute of Oceanography has been working for several years to model the environmental impacts of mariculture, particularly finfish mariculture. This project has two principal objectives:

- To be able to calculate the holding capacity of a water body, namely the level of annual production that can be supported without serious environmental degradation.

- To develop tools that will enable regulatory agencies to use this information for the practical evaluation of mariculture license applications.

It might seem at first that these two objectives are redundant, and that once models have been developed they can be turned over to regulatory agencies to be used. This has turned out to be an unrealistic expectation, and the difference between these two objectives will be covered in the paper.

Overview: What needs to be modelled?

Mariculture affects the environment in many different ways, and it is not easy to determine which of these is most likely to lead to serious environmental degradation. Because of this it is necessary to model several factors in order to calculate holding capacity.

Unfortunately it is often necessary to use different models to predict different kinds of effects. One of the principal reasons for this is that the effects can occur on different scales of space and time, requiring very different model structure and dynamics. For example, benthic effects tend to be localized to within 50 or 100 meters of a farm site but may take several years to show severe degradation, while nutrient loadings in a well-mixed estuary may spread throughout a region covering 100 km^2 in a very short period of time and affect bloom dynamics with time scales on the order of days. If the bottom is shallow and depositional the benthic effects may be critical, while in a deeper and more energetic body of water the nutrient loadings may be the factor limiting holding capacity. In a general case one must be prepared to use several models and to accept the lowest holding capacity predicted by any of them.

Structure of multiple models

In order to ensure that several different models could be developed as efficiently as possible while guaranteeing that they would be consistent with each other, a modular approach was adopted. All but one model were written in Fortran using the BSIM software package, which is ideally suited for this sort of model development and is particularly designed to facilitate a modular approach to modelling[1]. The various models and their relationship are shown in Figure 1. Two submodels, FISH and POINT, are common to all of the final models. FISH models the metabolism and nutrient budgets of a single fish as a

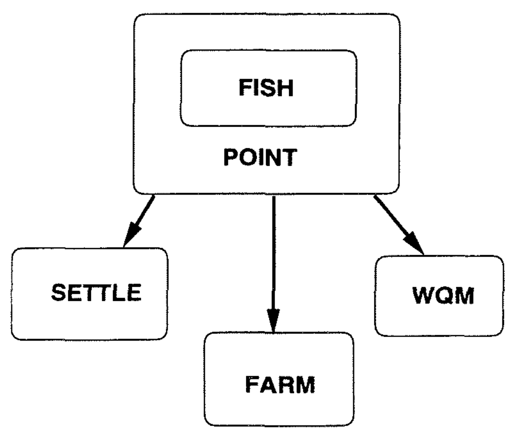

Fig. 1. Relationship between submodels. The **FISH** submodel is called by the **POINT** submodel, which in turn is called by the three models **SETTLE**, **FARM**, and **WQM**.

[1]BSIM is available from the author, and it can also be obtained by anonymous FTP from biome.bio.dfo.ca in the directory /pub/bsim.

function of variables such as size and temperature. We decided not to develop a detailed physiological submodel at this stage, but rather to use a simple allometric model of the form

$$\text{GROWTH} = a \times \text{WEIGHT}^b \times exp(c \times \text{TEMPERATURE})$$

which, as shown in Figures 2 and 3, fits field data on the growth of salmon in S. W. New Brunswick very well (R. Cook, pers. comm.). The most important part of the fit is the summer growth peak shown in Figure 2, since this determines the maximum flux rates.

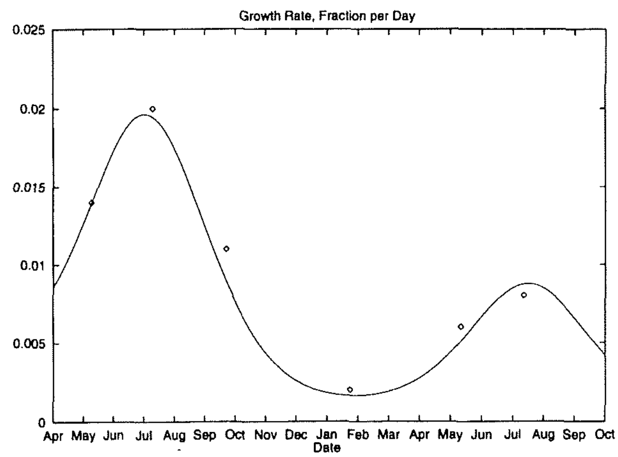

Fig. 2. Simulated growth rate compared with field data for salmon.

The output of the FISH model can be summed over the various cohorts of fish in a farm to assess the total fluxes associated with the farm. On the scale of the environmental effects being considered most farms can be treated as point sources, so this is carried out in a submodel called POINT.

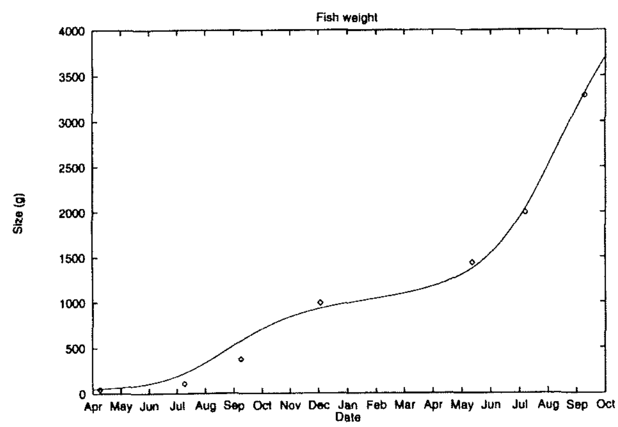

Fig. 3. Size at age compared with field data for salmon.

The FISH and POINT submodels are common components of the three models shown in Figure 1. These three models are more sophisticated versions of three recently described by Silvert (1992, 1993c). The FARM model deals only with oxygen levels, particularly the risk of critically low levels within a farm at low slack tide. As such it is not actually a model of environmental impacts, but it was developed to test the modelling approach for very short space and time scales. The SETTLE model predicts the benthic deposition under and around a farm site, using particulate loads determined by the FISH and POINT models. WQM represents a Water Quality Model with detailed spatial resolution based on multiple point sources described by the POINT model.

Currently a site-specific Water Quality Model has been developed for the L'Etang Inlet in S. W. New Brunswick under contract to the Physical Chemical Sciences Branch at the Bedford Institute of Oceanography, and a study is under way to investigate the water quality in the

Lime Kiln Bay part of L'Etang by using the POINT model to calculate source strengths for each farm based on the annual production figures, combining these with fluxes from other natural and anthropogenic sources, in order to assess the relative importance of aquaculture in determining the water quality in the bay.

Status of the modelling work

It is characteristic of this type of modelling work that the research is never really finished. There are always some unanswered questions, some data that don't quite fit, and some desirable refinements to the models. Consequently one needs to evaluate the work in progress to determine, not whether it has been finished, but whether it is yet ready to be used. In this sense we feel that much of the modelling work could be used for management purposes at the present time, provided that the preliminary nature of some of the calculations was clearly understood and that consequently an adequate margin for error was allowed. There is a need for field validation of some of the nutrient fluxes, and there is probably little value in continuing some parts of the modelling work until these validation studies can be carried out to confirm the correctness of the work that has been done to date.

The most extensive validation work to date has been on a model of benthic loading, and a series of technical reports describing the effects of benthic carbon loading and age of a site on the bottom conditions under fish farms is currently in preparation (Hargrave et al., in preparation). It is premature to conclude that this sort of model provides a reliable prediction of benthic impact, but results to date indicate that this extension of the SETTLE model can be used for preliminary assessment of applications, since it provides a reasonable estimate of the risk of severe environmental impacts.

Turning models into management tools

Even though models may already have the capability of letting us predict the potential environmental impacts of proposed mariculture developments, that falls far short of making them practical tools for fish farm licensing. It is unrealistic to expect that administrators will possess the time or expertise to use several complex models in the evaluation of each new proposal, and unless the processes of collecting the necessary data, running the relevant models, and analyzing the results can be greatly simplified, sophisticated models will contribute little to the routine processing of mariculture license applications.

Fortunately computers are excellent tools for database management, modelling, and report writing, and therefore it is possible to develop computer based packages that greatly simplify the process and bring it into the realm of realistic possibilities. These so-called "Expert Systems" automate much of the work and make it possible for users with little technical training to use large databases and complex models easily and reliably.

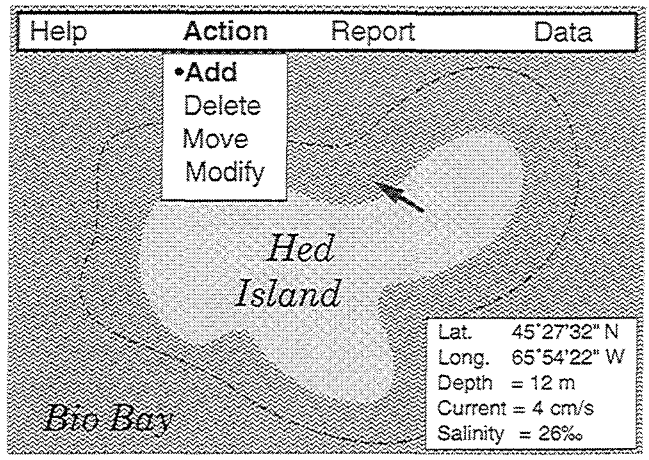

Fig. 4. Prototype graphical user interface for proposed Decision Support System. The user has selected **Action** from the main menu and then has elected to **Add** a site at the position shown by the cursor. As the cursor is moved, the position coordinates and physical characteristics are continuously read from a database and displayed in a box.

A prototype has therefore been developed of an Expert System for the regulation of finfish mariculture. This "Decision Support System" (DSS) is designed to be used by regulatory agencies as part of the decision-making process, and consists of four main components (Silvert, submitted)

- A data-entry interface which is as simple and user-friendly as possible. This uses such standard and familiar features as the use of a mouse to select locations from a nautical chart and dialogue boxes for entry of numerical data. A sample screen from the prototype version of the DSS is shown in Figure 4. The DSS should be fully menu-driven and include detailed context-dependent help at all levels.

- A Geographical Information System (GIS) containing all of the relevant environmental information, including hydrographic and physical data as well as records of competing uses and restricted areas. This would certainly be the most complex and difficult part of the project, since not only would the data have to be available on-line, but the DSS would have to be able to access it automatically. The database would presumably be in a central location and be accessed over a network, although for remote locations it might be better to have a copy of the central database on CD-ROM or other form of mass read-only storage.

- A set of models would be incorporated into the DSS and would run automatically once the data had been obtained from the GIS. This is not actually very difficult, since existing models are computer-based and could easily be automated. This has already been incorporated into the prototype, although only relatively simple models have been used so far (Silvert 1992, 1993a).

- A full reporting capability is required, offering both concise summary recommendations and detailed explanations of all of the factors that went into the analysis. This is not difficult to implement, as similar reporting systems are widely used in computer applications. It would probably be best if this were implemented in a HyperText system so that the user could select a phrase like *benthos* with the mouse and automatically access further information. It would also be possible to present reports in specified formats and to record the analysis in a regulatory database.

The development of such a Decision Support System would be challenging but does not require any fundamentally new technology.

Currently the Department of Fisheries and Oceans is working on the construction of a Geographical Information System for coastal regions of Atlantic Canada that could be the basis for such a DSS (Gregory et al. 1993), and the feasible of developing such an Expert System is currently being reviewed by the Department. A prototype version for MS-DOS computers has been developed and is freely available for examination.[2]

Summary

Modelling the environmental aspects of mariculture is a challenging but manageable task. There are numerous effects which have to be considered, which leads to a multiplicity of models with different space and time scales. Fortunately many of the processes are well understood, and the difficulties encountered in the development of models are primarily incremental in nature; refinement of parameter estimates, field calibration, and so on.

This modelling work requires a modular approach so that the different models can share as much code as possible while still addressing the needs to describe processes on a range of different scales. Currently we have developed two nested submodels, FISH and POINT, which represent an individual fish and a farm considered as a point source respectively, which are embedded in three impact models. These three models are otherwise very different in structure and represent effects on space scales from tens of meters to tens of kilometers, and on time scales from minutes to years.

Turning these models into practical tools that can be used for routine management decisions is at least equally difficult and requires careful attention. One possible solution is to use

[2]The prototype can be obtained by anonymous FTP from biome.bio.dfo.ca in the directory /pub/models/dss. It can also be requested from the author on a floppy disk if anonymous FTP is not available.

Expert Systems technology to design computer programs that can provide communication between the users and the underlying scientific models and data. We have proposed a Decision Support System with a very straightforward and friendly user interface, built-in links to a Geographical Information System containing relevant environmental data, with the ability to run a set of models without technical intervention, and extensive reporting facilities.

Development of scientifically sophisticated and yet practical regulatory tools require that these two phases of the project proceed in tandem. This is the approach currently being followed within our division.

Acknowledgements

This work has been a team effort and has benefitted from the support and participation of many individuals. D. C. Gordon provided inspiration and guidance for this project from the beginning, and P. D. Keizer has played an ongoing key role in coordinating the modelling work with field programs. B. Hargrave has carried out extensive benthic studies in support of this project, and D. Duplisea, a student at Dalhousie University, has been invaluable both in carrying out preliminary literature studies and in support of the field program. The water quality modelling work in L'Etang has been carried out by ASA under the supervision of R. Trites of the Physical Chemical Sciences Branch.

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Modelling and Monitoring Internal Impact from Fish Farms

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Introduction

There are two main reasons for controlling the environmental impact of fish farms. First, there is the general concern for the environment. In many areas the need for environmental protection is so strong, or the total impact on the aquatic or marine areas so heavy, that additional impact must be avoided. Secondly, water quality is an important production factor, and a prosperous fish farming industry can only be achieved if the fish are provided with optimal conditions for existence. Accordingly, control of the impact of fish farms should be accorded high priority both by the regulating authorities and the fish farmers. A method seeking to regulate the environmental impact of aquaculture must aim at controlling both the impact on the surroundings as well as in the net pen.

Effluent and effects

The effluent from fish farms consist of many substances which are released in different forms. Most important are nutrients, organic material, therapeutic and antifouling agents. The quantities vary with farm size and management, and the literature values vary within a wide range (Iwama 1991). A mean of 70 kg nitrogen, 13 kg phosphorous and 700 kg organic material is used per metric tonne fish produced in Norwegian marine fish farms (Norwegian State Pollution Control Agency, Leffertstra pers. com.).
A normally sized fish farm with an annual production of 300 metric tonnes therefore has a large potential for qualitative and quantitative environmental impact. However, the actual impact depends not only on the nature of the effluent (amount, composition and distribution in time and space), but also on the conditions at the given site (water exchange, current velocity, salinity, the oxygen content of the water, depth, topography, substrate and biota). It is crucial to distinguish between the terms load and environmental impact, and a failure to do so will inevitably lead to confusion and misinterpretation (Iwama 1991.).

The environmental impact of aquaculture can be viewed in several ways according to type of effect and the area subjected to impact (Gowen et. al. 1990, Silvert 1992). One should also be aware that a potentially important interaction between aquaculture and the environment is omitted when concentrating on classical marine biological effects such as eutrophification or benthic enrichment. Thus, genetic interactions between farmed and wild populations and the transfer of disease have aroused considerable interest. Such interaction might might turn out to be irreversible, and might be more important than effects on the marine system. At present, the spread of diseases and genetic interaction, rather than the effects caused by effluent, limits the number of sites available for Norwegian fish farms.

Impact on the water column and the benthos

Internal impact is defined as impact within the limits of the farm or in its immediate vicinty, the extension of the influenced zone being at most a few hundred meters (Silvert 1992). When discussing a strategy for modelling and monitoring the internal impact from fish farms, I will discriminate between the water column and the benthos.

The pelagic is influenced by fish metabolism (respiration and excretion), by leakage from feed, faeces and sediments and by physical and biological processes. The pelagic is characterized by decreased oxygen and increased ammonia concentrations (Håkanson et. al. 1988). Due to mixing processes, the values decrease to back ground levels at the boundaries of the internal zone (Aure et. al. 1988).

With normal Norwegian current velocities of 3 to 10 cms^{-1} sea water has a retention time of 1 to 3 hours in the internal zone. This is a short period compared to the generation time of pelagic bacteria and algae of 1 to 3 days respectivily. The organisms have, therefore, little opportunity to utilize the elevated concentrations of nutrients or organic material in the internal zone. This is in accordance with investigations showing no increase of algal biomass or bacteria number inside fish farms (Muller-Haechel 1986, Enger et. al. 1991). The environmental impact on the pelagic part of the internal zone is therefore mainly chemical, and the influence on the organisms are minor. An exception to this is pelagic fish which increase in concentration around the farms (Carss 1990; Samuelsen et. al. 1992 a).

Other important features of water column impact are rapid fluctuations and large amplitudes of parameters such as oxygen and ammonia. The concentrations are in a dynamic equilibrium with supply and removal, and any change in farm operations or current will immediately alter the water quality. The time scale of such changes might even be minutes.

The benthic system is mainly influenced by waste feed and faeces. The sedimentation rates may be very high under the cages, but it is discontinuous and decreases rapidly outside the farm area (Aure et. al. 1988). Organic material often accumulates on the sediments (Braaten et. al. 1983). Sedimentation rates in the internal zone vary with the annual production cycle of the fish farm (Aure et. al. 1988, Gowen et. al. 1988). These variations are reflected in the benthic impact with increased decomposition rates in late summer and autumn (Hansen et. al. 1991, Klovning et. al. in prep). The time scale of these fluctuations is months.

The accumulation of organic material has profound effects on both the chemistry and the biology of the benthic system. Reduced conditions and anoxic decomposition processes prevail (Holmer & Christensen 1992), and the benthic infauna is absent or dominated by opportunistic species. Following medication, the sea bed may contain substantial amounts of drugs, and use of antibacterial agents results in increased frequency of resistant bacteria (Samuelsen et. al. 1992 b, Hansen et. al. 1993). The sediments may also act as refuges where bacteria pathogenic to fish may live for years (Husevåg et. al. 1991).

Consequences of internal impact

Internal impact may cause problems for both industry and the regulating authorities. It is documented that poor water quality in the fish pens leads to poor fish appetite and growth, vulnerability to disease, and increased mortality (Braaten et. al. 1983). In addition to these production losses and environmentally induced health problems, pollution may also harm the status of the industry. Focus on these aspects of aquaculture have in many cases resulted in conflicts with the local people, fishermen and environmentalists. In addition to the operational problems such perspectives may in the long run be detrimental to the marketing of farmed fish.

Regulation of internal impact

The holding capacity of an area is defined as the potential maximum production which is not limited by a non-trophic recourse (Rosenthal et. al. 1987). For fish farms, this means that the internal impact should not exceed the fish requirements for good water quality or the environmental standards set by the authorities.

The task of regulating internal impact has been approached differently by various countries. There are, however, difficulties in deciding which environmental effects are essential and should be emphasized, and only semi-quantitative methods are applied to access holding capacity (Rosenthal et.al. 1993).

In Norway the size of the fish farms are regulated by restricting the joint volume of the fish pens above 5 depth to a mximum of 12 000m^3, and also by limiting the maximum density of fish to 25 kg pr m^3. This results in a maximum surface area of the pen of 2 400 m^2, and a maximum biomass of 300 metric tonnes.

From an environmental point of view this regulation is unsatisfactory. The restriction on volume may lead to overstocking, which has often been the case. It is also difficult to estimate the amount of fish in a pen, both for control and farm management purposes. Furthermore, the regulations are inadequate for adjusting the impact to the holding capacity of the site. Density defined as fish weight per volume has little relevance for controlling internal impact.

A system for regulating internal impact

The following describes the first version of a system designed to regulate the internal impact of marine fish farms. The system comprises a model for simulating impact and a monitoring program. The system has two objectives: to predict the impact of a given farm on a given site, and to ensure that the environmental standards are maintained. Preferably, regulation of the internal impact should include all types of impact, but as a first approach it seems to be most realistic to concentrate on what is considered to be the major impact. This is partly because the system must be simple in use and cost efficient in order to ensure that it will be used by the regulating authorities as well as by the fish farmers.

Chosing between measuring the impact on the benthos versus the impact on the water column, the former express the internal impact best and is well suited for use in the regulating system. The reason is that the benthic impact includes both chemical and biological processes and is less dynamic than pelagic impact. Many methods and parameters can thus be applied in measuring the impact and makes it relatively easy to monitor. The holding capacity of a site is defined as a given benthic enrichment. However, as the the simulation model includes parameters such as fish biomass and metabolism as well as current velocity, the pelagic impact can be included in the system at a later stage.

The system consists of the a simulation model and a monitoring program.

The simulation model has two aims:
a. to simulate internal impact given site and farm
b. to simulate farm output given site and an environmental quality standard

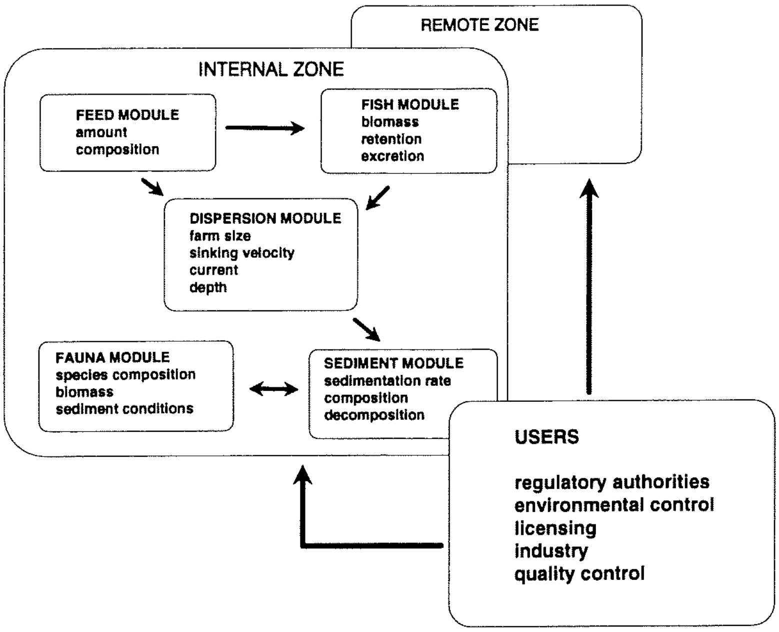

Fig. 1. A flow diagram of the simulation model for benthic impact in the internal zone.

The simulation model is presented in figure 1. The *feed module* gives the composition of feed, pellet size and leakage from the pellets. The *fish module* calculates assimilation, fish retention of different substances and dissolved and particulate effluent. In this simulation the size distribution of the fish and the water temperature are used as calculating-factors. The *dispersion module* simulates sedimentation and the dispersion of waste feed and faeces. The driving forces in these processes are current regime, water depth, sinking velocity of the different particles and the area, form and orientation of the cages. The *sediment module* simulate the decomposition and accumulation of waste feed and faeces, consumption of oxygen and leakage of nutrients and the out-gassing. Finally, the *fauna module* calculates the composition and biomass of the infauna and its influence on decomposition of organic matter.

Together with the simulation model, guidelines must be given for registration of the site-specific environmental parameters to be used in the simulations. The intention is to standardize the measurements of parameters like topography, current direction and velocity, substrate type etc.

The monitoring program. In principle the simulation model is a general one. Accordingly one is free to chose any method for expressing the environmental impact, provided the above criteria are fulfilled. At present it is most realistic to concentrate on the accumulation of waste, on the chemical characterization of the sediments, or on the community structure of the benthic fauna. The monitoring program must provide methods, parameters, sampling programs and proposals for environmental standards.

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Benthic Impact of Marine Fish Farming

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Introduction

There are several environmental effects of aquaculture, as discussed by Ervik in the previous contribution, and benthic impact is often a major one. Since sediments integrates impact over time, measurering the changes in the benthic system is a convenient means of surveying a location and preventing overexploitation. Investigations on the benthic impact of organic material from fish farms therefore provide useful information in relation to the future regulation of the aquaculture industry.

Waste sedimentation and sediment response

Organic waste from fish farming, consisting of waste feed and faecal pellets, has a high nitrogen and phosphorus content (Håkanson et al. 1988; Ackefors and Enell 1990) making it a suitable food source for aquatic organisms and easily degradable by microorganisms. The load of organic waste to the surrounding environment primarily depends on the size of the farm, the stocking density and the feeding regime. Dispersion of the waste depends on current regime, depth and the sinking velocity of the particles.
The amount of organic waste sedimenting on the sea floor has been measured by sediment traps and great variations have been found (Ervik et al. 1985.; Merican & Phillips 1985; Gowen et al. 1988; Weston and Gowen 1988, Hansen et al. 1990; Hall et al. 1990; Ye et al. 1991). Some investigators found close correspondence between feed distribution and sedimentation rates under farms (Ervik et al. 1985; Hall et al. 1990 in Holmer 1991), but this can only be expected on sites with low currents where the dispersion of the waste is small. Rates of sedimentation show large annual variations as they mainly follow the feeding strategy with high output in the summer and fall (Ervik et al. 1985; Gowen et al. 1988). With increasing distance from the farms the sedimentation rates decrease rapidly, and background levels can be reached within 10 to 250 m of a farm depending on the time of the year and the current (Aure et al. 1988, Gowen et al. 1988).
The amount of material settling on the sediment under different current regimes can be calculated using dispersion models (Gowen et al. 1989; Silvert 1992). The former model was tested by Weston and Gowen (1988) and was found to predict the magnitude of organic

loading to the sediment within a factor of two. Such models are valuable when adjusting the fish farm production to the natural conditions on a given site.

High sedimentation rates often result in accumulation of organic matter in the sediment under the farms. The amounts that accumulates will depend on currents, sedimentation rates, decomposition rates, the abundance of epi- and infauna and the resuspension of the sediment. Direct measurements of accumulated waste are difficult and indirect methods are often used such as recording layers of loose flocculent material on top of the sediments, *Beggiatoa* mats covering the sediment, and low redox potentials and high sulphide concentrations in the upper sediment (Gowen et al. 1988; Hall et al. 1990; Holmer 1991). Waste accumulation of 18 cm has been found by measuring the sediment depth profiles of carbon and phosphorus (Hall et al. 1990; Holby & Hall 1991). The long term sediment accumulation of carbon came to 18% of the total carbon input to the farm. In other investigations, from one to 40 cm of accumulated waste have been measured by positioning a ruler in the sediment until it hit the hard shellsand bottom (Braaten et al. 1983; Ervik et al. 1985; Hansen et al. 1990).

The accumulation of organic material on the sea bed can induce long-term changes in infauna composition and abundance (Brown et al. 1987; Weston and Gowen 1988; Ritz et al. 1989) and might result in azoic sediments (Brown et al. 1987). Furthermore, the accumulated waste can act as a sink for antibacterial agents (Samuelsen et al. 1992) and copper (Grønnestad pers. com.), as well as a reservoir for fish-pathogenic and antibacterial-resistant bacteria (Husevåg et al. 1991; Samuelsen et al. 1992).

Waste accumulation on the sediment will increase both the aerobic and anaerobic rate of decomposition (Hansen et al. 1990; Holmer & Kristensen 1992). The degradation rate of the organic waste in the sediment will mainly depend on the composition of the waste, the sedimentation rate, temperature, concentration of oxygen in the bottom water and the fauna composition and abundance.
The overall decomposition of the organic material in sediments has been measured either as oxygen consumption or carbon dioxide efflux from the sediment (Blackburn et al. 1988; Hansen et al. 1990; Holmer & Kristensen 1992; Hargrave at al. 1993). The high decomposition rates often encountered in sediments under fish farms may be due to both the amounts involved and the easy degradability of the sedimenting organic material. With increasing decomposition rates the larger part of the degradation is taking place anaerobically, mainly as fermentation and sulphate reduction with concomitant hydrogen sulphide production. This may lead to the anaerobic respiration accounting for the entire decomposition of the organic material (Blackburn et al. 1988; Holmer & Kristensen 1992). Use of antibacterial agents such as oxytetracycline, oxolinic acid and flumequine, however, can partially inhibit the sulphate reduction in sediments for a number of weeks (Hansen et al. 1992).

Annual variations in decomposition rates follow the changes in sedimentation rates and temperature, with the highest rates being measured during summer and fall (Hansen et al. 1990; Holmer & Kristensen 1992; Hargrave at al. 1993). Decomposition rates decrease with increasing distance from the farm and may be 10 to 20 times higher under the farm than in a reference area (Hansen et al. 1990; Holmer & Kristensen 1992).

Reworking of sediment by the infauna is an important mechanism in transporting oxygen and organic material to deeper layers and reduced compounds such as sulphide and ammonia to the sediment surface. This may enhance bacterial decomposition of the organic matter and has been observed in various sediments (Blackburn 1991 and references herein). The effect of bioturbation depend on the abundance, type and activity of the fauna but might also be influenced by the amount of waste feed in the sediment (Hansen et al. in prep.).

Benthic impact and regulation

Substantial waste accumulation on the sediments has several local environmental implications and we consider it unwise to allow this to continue. Some problems, like antibacterial agents in the sediments, can be partly prevented by vaccination of the fish and by generally maintaining a good water quality. The latter might also have a positive effect on the benthic system, during preference of high current locations. In the future, site selection should be determined after careful consideration of the sedimentary conditions of the area and in accordance with the holding capacity of the particular location. A tool capable of predicting the local benthic impact is necessary, together with a monitoring program that ensures that the impact is kept within predefined environmental standards. This may be achieved by employing regulations for the location of fish farms as described by Ervik (these proceedings).

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Macrobenthos: Before, during and after a Fish Farm

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Abstract

We have investigated the effect of a salmon farm on the local benthos and the benthic environment. The site was in use from May 1988 until May 1990, during which time 2417 tonnes of salmon were produced. The bottom fauna was examined before establishment in March 1988, during operation in September 1989 and April 1990, and after closure in March-April 1991. The samples were collected with a van Veen grab from two stations, one at a depth of 76 m near the farm and the other at a depth of 118 m and at distance of 250 m from the farm. The sediment at both stations contained mainly clay and silt. The organic content, measured as weight loss on ignition, varied from 9.1-11.1 % at the proximate station and 14-17.3% at the distant station. There was no increase in the organic content during the sampling period.

The bottom fauna in 1988 was rich and relatively similar at both stations, with the polychaete *Heteromastus filiformis* and the bivalve *Thyasira equalis* among the most abundant species. At the distant station these two species continued to be among the most common throughout the period of investigation. The proximate station experienced a reduction in the number of species from 65 in 1988, to only 11 in 1989. Here, in 1989 and 1990, the polychaetes *Capitella capitata* and *Malacoceros fuliginosa* were most abundant. In 1991, a year after the fish farm was moved the number of species had risen from 9 to 29 with the polychaete *Capitella capitata* and the bivalve *Thyasira sarsii* being the most abundant species.

The fish farm clearly influenced the bottom fauna in the immediate vicinity of the site, but this effect could not be traced at a distance of 250 m. The environmental conditions had improved in 1991 after abandonment of the site, but the fauna had not returned to the status measured before operations began in 1988.

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The Impact of Diseases of Pen-Reared Salmonids on Coastal Marine Environments

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Abstract

With the increase of mariculture, particularly netpen rearing of salmonids, there is a concern about the impact of these operations on the coastal marine environment. Models have been made to assess this impact, but these models have not considered the potential risk of increased disease in wild fishes that mariculture may impose. Diseases of captive fish may pose a threat to wild fish when they are exotic diseases, have the potential to cause an increase in prevalence of an enzootic disease, or if their presence results in the use of drugs that are released into the environment. The transmission and development of disease is a complex process that involves numerous factors that apply to the pathogen, host, and environment. The following paper describes these factors. At this time, most of the information needed to create models that include disease is not available. However, it is recommended that transport regulations should be implemented that minimize the risk of the exposure of exotic pathogens to wild fish.

Introduction

In recent years, the rearing of salmonid fishes in seawater netpens has become a large mariculture industry in several countries (e.g., Canada, Chile, Scotland, and Norway). With the growth of this new industry, there have been concerns about the impact that netpen farms may have on the coastal environment. As with most forms of intensive agriculture, infectious diseases are often a problem in these netpen farms. Therefore, in addition to concerns that these diseases pose to the industry, there is a concern about the potential impact that these diseases may have on coastal marine environments, especially on wild fishes. Models have been developed to assess the impact of aquaculture on coastal marine environments (Ibrekk et al. 1991; Silvert 1992). However, these models havenot considered the potential impact of diseases. Diseases of pen-reared fish pose a threat when 1) they are exotic diseases, 2) they represent an increase in the prevalence of enzootic diseases, and 3) their presence result in the release into the environment of drugs. The following paper addresses the potential threat of infectious diseases from salmonid seawater netpen operations to wild fish. Concerns about the use of antibiotics to control these diseases are dealt with by Samuelsen and Zitko (these proceedings).

Most cases of increased disease in wild fish populations related to aquaculture activities have occurred following deliberate release of hatchery-reared fish into new watersheds. For example, *Gyrodactylus salaris* has been introduced to Norway with the introduction of salmon from Baltic watersheds (Johnsen and Jensen 1991; Bakke et al. 1992). Heavy infections by the parasite have caused high mortality in Atlantic salmon smolts in drainages where the parasite has been introduced. There are also at least two cases that suggest introductions of a disease into wild fish from a fish farm or hatchery. Yoder (1972) concluded that the source of infections by the parasite *Myxobolus cerebralis*, the causative agent of whirling disease, in wild salmonids was a hatchery on the same river. Munro et al. (1976) reported increased prevalence of infectious pancreatic necrosis (IPN) virus in fish near a fish farm in Scotland.

Before farmed fish can be incriminated as the cause of disease in wild fish, the previous geographic distribution of the pathogen and prevalence of the disease in the wild population must be known. In the past, most research on salmonid diseases has been directed towards those occurring in the fresh water. With the rapid growth of mariculture, many apparently new diseases have been reported. Diseases that are thought to be unique to netpen farms may instead reflect diseases that occur in relatively low prevalence in wild fishes in the ocean. For example, netpen liver disease and plasmacytoid leukemia were first described in pen-reared fish, but we have recently found these diseases in ocean-caught salmon (Stephen et al. 1993).

Although it is difficult to determine if diseases of farmed fish have been transferred to wild fish, it is clear that pathogens from wild fish (both salmonids and non-salmonids) have had serious impacts on pen-reared fish. For example, wild salmonids are reservoirs of infection for the salmon louse, *Lepeophtheirus salmonis*, which is a serious problem in pen-reared Atlantic salmon (Pike 1989). Examples of non-salmonid reservoirs for netpen diseases in the marine environment include sea lice (*Caligus* spp.) from a variety of fishes (Margolis et al. 1975), and spiny dogfish *Squalus acanthus* for the eye tapeworm *Gilquinia squali* (Kent et al. 1991). Wild salmon also act as a reservoir for bacterial diseases. Bacterial kidney disease (BKD), caused by *Renibacterium salmoninarum*, is the most serious disease of pen-reared Pacific salmon in British Columbia. In the mid-1980's wild brood stock were used as the source of eggs for the industry, and undoubtably introduced the bacterium, which is vertically transmitted through eggs (Evelyn 1993).

Factors affecting the transmission of disease in sea water

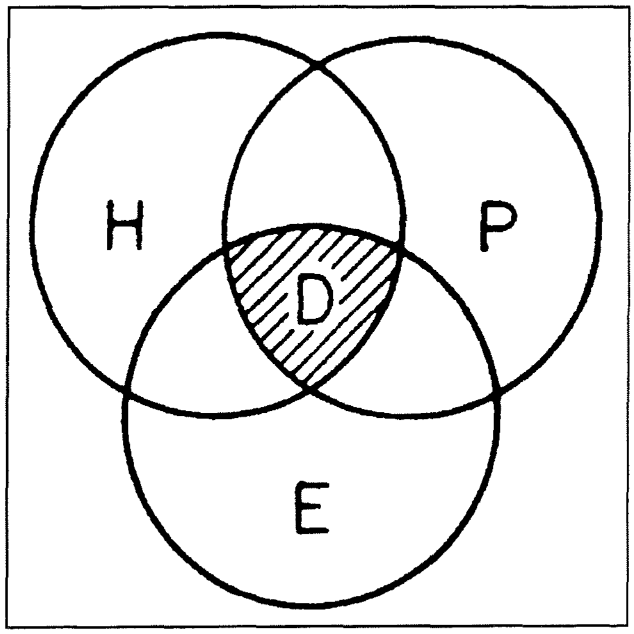

Fig. 1 Snieszko's three intersecting spheres illustrating the complex interaction between pathogen (P), environment (E) and host (H). Conditions in all three affect the occurrence and severity of disease (D).

To assess the potential increased impact that a farm disease may have on the wild population, the following factors should be considered. Factors that affect the development of disease can be viewed in three major interactive categories: the pathogen, the host, and the environment - exemplified by Snieszko's (1973) three intersecting circles (Fig. 1). In other words, the occurrence and severity of infectious disease is dependent on the status of the pathogen, host, and the environment. The latter is particularly important to fish because, being poikilothermic, the physiological state of fish is closely tied to water temperature. The ability of a pathogen to cause morbidity or morality should not be the only concern. Certain relatively non-pathogenic parasites, such as *Kudoa* spp. (Myxosporea) are of concern because they may cause poor flesh quality and undesirable aesthetic changes (Whitaker and Kent 1991). In addition, some fish pathogens may infect humans or domestic animals. Lastly, the presence of certain pathogens in a fish population may impose restrictions on their sale or transport due to governmental regulations, even if the fish are not diseased.

The pathogen

Several characteristics of pathogens from farmed fish are of importance for assessing the risk of increased disease to wild fish. Survival of the pathogen in sea water, ability of the pathogen to multiply in sea water, number of pathogens released from farmed fish, number of pathogens required to initiate an infection, virulence of the pathogen, and route of transmission are all important factors that effect the ability of the pathogen to cause disease in wild fish. Furthermore, to determine if a pathogen from a farmed fish causes increase in disease in a population of wild fish, a reasonable estimate of the previous geographic distribution and prevalence of the infection in the wild population should be available.

The ability of the pathogen to survive in sea water is a major component for assessing seawater transmission. This ability varies greatly between pathogens. Although considered freshwater viruses, IPN virus and the infectious hematopoietic necrosis (IHN) virus are capable of seawater survival (Toranzo and Hetrick 1982). In fact, the latter is capable of surviving much longer in sea water than fresh water (Winton et al. 1991). However, determination of the survival of pathogens in sea water is not a simple task because various environmental factors such as temperature, and organic load may affect survival (see Environment below).

Marine opportunistic pathogens are usually the most capable of being transmitted from farmed fish to wild fish because they are able to multiply in the marine environment outside of the fish host. However, caution must be exercised when implicating these pathogens as a threat to the wild populations. These pathogens may not be responsible for increase disease because they may already be prevalent in the wild fish (Håstein and Lindstad 1991), and only cause disease in the relatively crowded conditions of netpens. However, ubiquitous pathogens, such as *Vibrio anguillarum*, can cause disease in wild fish under the appropriate conditions. Therefore, these pathogens may still pose a threat to wild fish when farming activities result in a significant increases in the numbers of the pathogen in a given body of water.

The numbers of pathogens released from infected fish into the marine environment must also be considered. Certain bacteria and viruses are released into the water in high numbers from diseased fish, whereas others, such as histozoic parasites, may be released only after the fish has died and decomposed.

The route of transmission of a pathogen is another factor that should be considered. Some agents are transmitted directly through the water (e.g., most bacteria), whereas others utilize vectors or require intermediate hosts, such as tapeworms (Cestoda) and flukes (Digenea). For the latter, the numbers of potential intermediate hosts in the environment must also be considered.

The environment

Physical oceanographic conditions play an important role in the transmissibility of the pathogen and the susceptibility of the host. The distance between wild fish and farmed fish, the density of wild fish, and the direction and velocity of water currents all greatly influence the likelihood of a viable pathogen coming in contact and infecting a wild fish.

In addition, water conditions affect the seawater survival of pathogens. Many fish pathogens a have relatively narrow temperature regime in which they can survive, multiply, and cause disease. The amount of dissolved organic material may also be very important. For example, in controlled laboratory conditions, *Renibacterium salmoninarum* survived much longer in sea water when a small amount of peptone was added (Paclibare et al. 1993). Biotic factors also influence the survival and transmission of pathogens. As already mentioned, invertebrates that act as vectors or intermediate hosts may be essential for transmission of heteroxenous pathogens. Conversely, invertebrates may consume pathogens, and thus reduce the possibility of transmission. Paclibare et al. (1993) demonstrated that mussels (*Mytilus edulis*) effectively removed *R. salmoninarum* from sea water, thus their presence on netpens may reduce transmission of the bacterium. Bacterial and viral antagonism influences the survival of pathogens, and Austin and Rayment (1985) found that the *R. salmoninarum* could survive much longer in sterile water than unsterile water.

Wild fishes, both salmonids and no salmonids, should also be considered as biotic factors for disease transmission because they can also act as vectors, intermediate hosts or reservoir hosts. As already mentioned, wild salmonids are important reservoir hosts for a number of pathogens that are important to both wild and farmed fish. An example of an infection in which a fish is an intermediate host is with *Gilquinia squali*, in which teleosts such as whiting are normally the second intermediate host for the parasites (MacKenzie 1975; Kent et al. 1991).

The host

The host's innate resistance, and physiological and immunological status play an important role in determining if an infection will be established and if disease will ensue. The following factors should be considered when assessing the threat posed by a pathogen for a population of wild fish: species susceptibility, strain susceptibility, age of the host, nutritional status, husbandry conditions and water conditions (see above), trauma (e.g., open lesions or abrasions that may facilitate entry of pathogens), sexual maturation, smoltification, preexisting infections and other co-factors, exposure to chemical agents (drugs used in treatment of diseases or anthropogenic contaminants), previous exposure and acquired immunity to the specific pathogen. In addition, unexplained "natural" variations in susceptibility between apparently identical individuals is an important factor.

It is well recognized that there is a wide difference in susceptibility to diseases between species of fish. Many important diseases of fishes have only been reported from salmonids. In addition, there is a great variability in the susceptibility to these diseases between species within the family Salmonidae. For example, Pacific salmon (*Oncorhynchus* spp.) are generally more susceptible to BKD than Atlantic salmon, whereas Atlantic salmon are more susceptible to furunculosis than Pacific salmon. This difference in susceptibility also occurs at the strain level. One of the best examples of differences in strain susceptibility is with *Ceratomyxa shasta*. Chinook salmon from enzootic waters are much more resistant than strains from watersheds where the parasite is absent (Zinn et al. 1977).

Age plays an important role in the susceptibility to disease. Many fish viral diseases, such as IHN and IPN, cause high mortality in fry. Older fish are generally more refractory, even if they have not been previously exposed.

The physiological state of fish during smoltification and sexual maturation may greatly increase the susceptibility to disease in general because these fish exhibit extremely elevated plasma cortisol levels, which is an indication of immunosuppression (Donaldson and Fagerlund 1968; Redding et al. 1984).

Nutrition may also control the severity of disease. Lall et al. (1985) reported that an increase in dietary iodine and fluorine was correlated with reduced prevalence of BKD.

Husbandry conditions (e.g., crowding) play a very important role in the transmission of infectious agents and development of disease. Crowded conditions may cause immunosuppression (Strange et al. 1978). In addition, the close proximity of the fish will enhance water-borne transmission of pathogens. Increased dissolved and suspended organics are often associated with crowded conditions, and can enhance the survival of pathogens in water. Crowded conditions may also increase the likelihood of skin abrasions and other surface lesions by fin nipping or scraping on tank/nets. Such abrasions could provide sites of invasion for pathogens (see Trauma below).

In addition to crowding, suboptimal husbandry conditions, such as too much light, excessive handling, improper water temperature or pH may all induce immunosuppression, and thus increase the likelihood of disease. Temperature may have a profound effect on the fish's immune system. At higher temperatures within a physiologically tolerated range, the onset of the immune response is usually faster and its magnitude is usually greater (Ellis 1982). This is particularly the case with the primary immune response (Avtalion at al. 1976). However, these higher temperature may also promote the proliferation of the pathogen in the water and in the fish.

Trauma resulting in skin abrasions or other surface lesions may enhance disease by providing a portal of entry for the pathogen. *Cytophaga* and *Flexibacter* spp. bacteria infect the surface of marine and freshwater fishes, and infections are often initiated at the site where the skin or fins have been damaged (Kent et al. 1988). In fresh water, the opportunistic fungi, such as *Saprolegnia* and related genera, commonly infect open lesions and necrotic tissue following trauma in freshwater fishes (Pickering and Willoughby 1982).

Infections can cause immunosuppression (Pickering and Christie 1981). There are many examples in which infection by one organism may provide a foot-hold for the establishment of another, at times more virulent, pathogen. For example, in coho salmon held in fresh water, infections by the erythrocytic inclusion body virus probably predisposes fish to infection by *Cytophaga psychrophila* (the cause of coldwater disease). The latter causes skin lesions that allow for *Saprolegnia* infections. Thus, it is common to find coho salmon in freshwater hatcheries infected with all three pathogens (Piacentini et al. 1989). Plasmacytoid leukemia of chinook salmon is probably caused by a retrovirus (Eaton and Kent 1992). However, BKD and a microsporidium *Enterocytozoon salmonis* often are found in fish with the leukemia and may be important co-factors that enhance the occurrence or severity of the leukemia disease (Kent et al. 1990; Kent and Dawe 1993).

Drug treatments and exposure to anthropogenic contamination may exacerbate infectious diseases. Rødsaether et al. (1977) reported that copper, which is often used as an external parasiticide in marine fish, exacerbated vibriosis in eels (*Anguilla anguilla*). Several pollutants, such as heavy metals and aromatic hydrocarbons, have been associated with increase in infectious disease problems in fish (Sinderman 1990; Kent and Fournie 1992; Overstreet 1992).

Lastly, in addition to all of these known factors, there is variation in susceptibility of fish within a population that is unexplained. This results in a phenomenon frequently observed in in vivo laboratory studies, called "the tank effect". In studies involving experimental infection, great differences in the prevalence of disease often occur between tanks in which conditions are apparently identical. This is exemplified in vaccine studies by Nikl et al. (1993). Two tanks holding the same number of apparently identical fish were exposed to the same inoculum of *Aeromonas salmonicida,* and one tank exhibited twice the mortality of the other.

Conclusion

In conclusion, assessing the risk of increased disease in wild fish due to aquaculture activities with any significant precision would be a very complicated task and would require much more information than is currently available. However, the potential introduction of an exotic pathogens that are virulent is probably the greatest risk that aquaculture poses to wild fish. Transport regulations should, therefore, be implemented to prevent the introduction of exotic pathogens into wild fish. To accomplish this specific task, many of factors outline above, such as host susceptibility, virulence, geographic distribution, survivability in sea water, and mode of transmission of the pathogen, should be understood to make rational regulatory decisions. In addition, the disease history of the fish to be transferred should be known and taken into account so that exotic diseases are not introduced with the fish.

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Chemicals in Aquaculture (An Overview)

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The use of chemicals in aquaculture is in part intentional, in part unintentional and is categorized in Table 1. The classification is somewhat arbitrary, particularly for 'Medication' and 'Treatment'. A report (GESAMP 1991) included 'pesticides' and 'antibiotics' under 'bioactive compounds', also called 'inhibitory compounds' and suggested a code of practice for their use in aquaculture.

Table 1. Uses of chemicals in aquaculture

Use				
Intentional			Unintentional	
Nutritional	Medication	Treatment	Contruction	Additives
Lipids Antioxidants Carotenoids	Antimicrobials (Tetracyclines Sulfonamides Quinolones)	Anaesthetics Disinfectants Pesticides Antifoulants	Plastic Wood Metal	'Inert' Unanticipated

Intentional use

<u>Nutritional</u>

Lipids

The fish oils (mainly herring oil) may contain undesirably high concentration of PCB and possibly of other organochlorine compounds. Since many countries, for example Holland and Germany regulate PCB in food on an individual PCB congener basis, feed-formulators may be inclined to use vegetable oils instead of fish oils. Vegetable oils have as a rule much lower concentration of PCB, but they also contain lipids poorer in n-3 fatty acids. Consequently, cultured fish may have a lower n-3 to n-6 ratio than wild fish. This may detract from their nutritional (coronary heart disease) value (van Vliet, Katan 1990). High lipid content of feed tends to change the lipid profile of local fish populations as well (personal observation).

Highly unsaturated fish oils require the addition of antioxidants. The common antioxidant in aquaculture is ethoxyquin (EMQ, 2,2,4-trimethyl-1,2-dihydro-6-ethoxyquinoline) (Jackson et al. 1984, Skaare and Roald 1977). EMQ preparations contain many impurities (Kato, Kanohta 1985, Taimr, Prusikova 1991). This is a potential problem for a re-evaluation of the safety of EMQ. The impurities could be eliminated by using ethoxyquin hydrochloride instead of the free base (Kim 1985). EMQ is metabolised extensively, at least in mammals where five metabolites were identified (Meulen et al. 1980). This may make the safety evaluation even more complex. We detected a relatively high level of EMQ dimer, an EMQ oxidation product in the foam in the vicinity of an aquaculture unit and also in an EMQ preparation used in a vitamin supplement. This preparation also contained a large number of impurities.

Canthaxanthin (beta-carotene-4,4'-dione, synthetic) and astaxanthin (3,3'-dihydroxy canthaxanthin) and its esters are usually added to color salmon flesh pink. The isomeric composition of astaxanthin may depend on its source. The commercial formulations are Carophyll' Red and 'Carophyll' Pink, (5% of canthaxanthin and astaxanthin, respectively). The bulk of these formulations is a starch-gelatin matrix. Antioxidants given on the label are EMQ and ascorbyl palmitate. We found EMQ only in the former. Carotenoids are not likely to cause problems, although there was a regulatory difficulty with salmon containing astaxanthin. At one time the U.S. FDA would refuse entry of all fish containing 'Carophyll' Pink (DFO Fish Inspection). For similar administrative reasons salmon and trout containing canthaxanthin were not allowed in Germany (Nieper 1990). There is some confusion about the subject since yet another report states that canthaxanthin is an EEC annex 2 additive with use monitored and reviewed annually (Nature Conservancy Council 1989).

Medication

Antimicrobials

High concentration of fish in aquaculture operations makes them prone to bacterial diseases. These are treated by assorted antimicrobials. In Canada the main ones at the moment are oxytetracycline, Romet 30 (sulfadimethoxine and ormetoprim 5:1), and Tribrissen (sulphadiazine 20% trimethoprim 80%). The literature on antimicrobials in aquaculture and in fish diseases in general is quite extensive, see for example (Meyer, Schnick 1989, ICES 1992). Data on the uptake, residues, depuration, levels in non-target biota, and environmental fate and effects in general are considerably less abundant. The main reason for this are costly, involved and time-consuming analytical techniques. For a recent review of analytical techniques see (Shepherd 1991).

The details of the aquaculture application, effects, and fate of antimicrobials are beyond the scope of this overview. Just briefly, data are available mostly for oxytetracycline and oxolinic acid. The excretion times are very long, particularly in cold water, and the antimicrobials are quite persistent in the environment and detectable in wild fish in the vicinity of aquaculture sites (Jacobsen, Berglind 1988, Samuelsen 1989, Bjorklund et al. 1990, Steffenak el al. 1991, Samuelsen et al. 1992). Data on sulfonamides appear rather limited. Relatively long excretion periods were reported for sulfamerazine ands trimethoprim, whereas chloramphenicol and chlortetracycline are excreted rapidly (Anhalt 1977).

It is important to have better data on the use, levels, and fate of antimicrobials, in aquaculture. These compounds have a high biological activity, consequently, consumer protection and environmental effects are of concern. Even a perception that fish produced by aquaculture contain 'antibiotics', or that the 'chemicals' are spreading in the environment, could cause considerable harm to the aquaculture industry.

Data on residues of chemotherapeutics in fish are not readily available. Published data from Germany are in Table 2.

Table 2. Therapeutics residues in fish, Germany (Bergner-Lang et al. (1989))

Year	Posit/total	Chemical	Concentration (μg/kg)
1984	36/286	Chloramphenicol	0.5-86
	2/286	Malachite green*	30, 540
1985	17/178	Chloramphenicol	0.4-52
	20/178	Malachite green	2-2400
1986	14/272	Chloramphenicol	0.1-30
	1/272	Sulfamerazine	1400
	71/272	Malachite green	0.8-1300
1987	20/208	Malachite green	1-440
	2/228	Sulfamerazine	80, 120

* fungicide

The stability of antimicrobials in medicated feed and in concentrates may not have received sufficient attention. We have some indication of OTC decomposition in some concentrates.

<u>Treatment</u>

Anaesthetics

The more common anaesthetics used in routine aquaculture operations are listed in Table 3. There do not seem to be any problems associated with their use.

Table 3. Anaesthetics

Chlorobutanol	1,1,1-trichloro-2-methyl-2-propanol
Benzocaine	ethyl p-aminobenzoate
MS-222	ethyl m-aminobenzoate, methane sulfonate salt

Disinfectants

The common disinfectants include chlorine, hypochlorites and chloramine T (N-chloro-p-toluene sulfonamide). Oxidation by hypochlorite is their mode of action. They are very toxic to aquatic biota, consequently they must be used with caution. Some countries have effluent limits for chlorine residuals. In Canada the guideline is 2.0 ug/L for freshwater.

Another important disinfectant is formaldehyde. There are strict guidelines for occupational exposure to formaldehyde and the Province of British Columbia has an effluent limit of 5 mg/L. With a careful use one would expect no problems.

Iodine is also used as a disinfectant. It is formulated as various iodophors, for example Wescodyne, containing iodine in the form of complexes with polyoxyethylene/propylene and with nonylphenoxypoly (ethyleneoxy) ethanol, or ethoxylated nonylphenol (ENP) for short, with a minimum of 1.6% titratatable iodine. The main mode of action is probably oxidation by iodine. Iodine is relatively rapidly reduced to iodide and no problems are expected with the polyoxyethylene/propylene portion of the formulation. On the other hand, depending on the length of the ethoxy chain in ENP, these compounds may be quite toxic to aquatic biota and they are also biodegraded only very slowly. Consequently, formulations like Wescodyne must also be used with caution. They also form a very stable foam. On one occasion we detected an ethoxylated nonylphenol in foam collected from the seawater surface in the vicinity of an aquaculture establishment.

Potassium permanganate also appears to be a disinfectant used occasionally. I do not think it would cause environmental problems.

'Quats' (quaternary ammonium compounds) are widely used commercial disinfectants and there are indications of some limited use in aquaculture. They are as a rule very toxic to aquatic biota, but tend to get adsorbed on particulates. With a careful use I do not expect problems.

Pesticides

This group of chemicals consists of insecticides, fungicides, and herbicides (Table 4).

A major parasite problem of cultured salmon is sea lice. The treatment of salmon against sea lice consists of treating the fish by a solution of either dichlorvos or trichlorfon. Neither one is registered in Canada for this purpose. One commercial formulation of dichlorvos, we had a chance to look at, contained also dibutyl phthalate as a carrier in a fairly high concentration.

Natural pyrethrins are being considered as a treatment for sea lice. A potential problem is their very high toxicity to aquatic fauna, particularly to inverterbrates. No details about the composition of the formulations are available. Ivermectin is another potential candidate. There is little information on its potential effects on the environment.

Hydrogen peroxide seems to be another candidate.

Table 4. Pesticides

Insecticides	
Dichlorvos	2,2-dichlorovinyl dimethyl phosphate
Trichlorfon	2,2,2-trichloro-1-hydroxyethyl phosphonate
Pyrethrins	
Ivermectin	
Fungicides	
Malachite green discontinued, replacement needed Replacements being tested	
Formaldehyde	
Dichlorophene	2,2'-dihydroxy-5,5'-dichlorodiphenylmethane
Trifluralin	2,6-dinitro-N,N-dipropyl-p-toluidine
8-hydroxyquinoline sulfate	
Potassium permanganate	
Sodium chloride	
Algaecides/Herbicides	
Diquat	1,1'-ethylene-2,2'-bipyridilium ion
Paraquat	1,1'-dimethyl-4,4'-bipyridilium ion
Copper sulfate	

A reliable all-purpose fungicide does not seem to be available. Abnormalities developed in several species of fish treated with high levels of malachite green. Malachite green is also potentially hazardous to humans and there are long lasting residues in fish.

Algaecides and herbicides are in general not very toxic to aquatic fauna, with the exception of copper sulfate in fresh water. I do not know how extensively they are used in aquaculture, but do not expect major problems.

Antifoulants

After the ban of TBT, it appears that the only antifoulant used in Canada, and only on a small scale, is Flexbar XI (Table 5). The status of Easy Net is not known.

Flexgard III was in the registration trials. We happened to obtain a sample and by a routine check of the composition detected the presence of TCMTB, which was not declared in the documentation or on the label. TCMTB is an antifoulant in its own right and when we detected it, the company claimed that it is used only as a preservative in the formulation and therefore not subject to registration. Flexgard III was later formulated without TCMTB. It did not seem likely it would get very far on account of chlorothalonil itself, and we have not heard about it lately.

Table 5. Antifoulants

Name	**Composition/status**
TBT	banned
Flexbar XI	Waterbase preservative 26.5 % cuprous oxide
Easy Net	registration not required? 5% Diethylaminoethanol 2% Ethylene glycol monophenyl ether 5% Oleic acid 2% o-Phenylphenol Balance ?
Flexgard III	probably withdrawn from registration 9% Chlorothalonil = tetrachloroisophthalonitrile (1% TCMTB) = 2-(thiocyanomethylthio)-benzothiazole

Unintentional use

<u>Construction</u>

Plastic

Low molecular weight components of plastics (molecular weight < 1000 D) may be a source of contaminants, both of the fish and of the environment. According to function, low molecular weight additives to plastics include plasticizers, stabilizers, lubricants, coloring material, antioxidants, UV absorbers, antistatics, and flame retardants (Zitko 1977, 1985/86, 1988). The user is generally not aware of the presence of many of these materials and the situation may get worse as a result of the recycling of plastics.

For example, a polyvinyl chloride liner contained a fungicide OBPA (10,10'-oxybis-10H-phenoxarsine) which may have caused mortalities of juvenile Atlantic salmon (Zitko et al. 1985).

Floats made of polystyrene 'beads' are another source of low-molecular weight contaminants. In addition, the floats disintegrate into individual beads that may resemble fish eggs. The low molecular weight fraction is present at a concentration of about 2.5 %. The fraction contains the flame retardant HBCD (hexabromocyclododecane), two other related brominated flame retardants, three additional halogenated compounds and a large number of chemicals, as yet unidentified. Many seem to be styrene dimers, trimers and related compounds. We have been noticing some of the components in the hexane-extractable fraction of foam that started appearing in our area more frequently during the last year or so. At one point we also found pieces of plastic tubing filled with poorly cured epoxy resin containing free bisphenol A and probably several oligomers. This material might have originated in the local aquaculture operations.

Recycled plastic may be increasingly used to replace wood. Its toxicity to aquatic biota was compared with that of chromated copper arsenate (CCA) treated wood, with mixed results (Weiss et al. 1992). Obviously, the properties of recycled plastic will depend on its composition and before any extended use, the low molecular weight components must be identified.

Wood

The common wood preservatives, pentachlorophenol and creosote are not suitable for aquaculture construction. Chromated copper arsenate (CCA) may be a better alternative. To be on the safe side, the best choice is dried (aged) lumber. Many low molecular weight wood extractives are toxic to aquatic biota.

Metal

Hazards of heavy metals to aquaculture are toxicity to, and accumulation in, aquatic biota. This is true particularly for cadmium, lead, copper, and zinc. The risks are minimized by proper surface protection by paint or plastic coating. Again, these must be well cured and the low molecular weight components of the plastic coating must be known for an adequate risk assessment. For example, we found that some PVC coatings contain triphenyl phosphate and phosphite. Both these compounds are toxic to, and at least triphenyl phosphate accumulates in aquatic biota.

<u>Additives</u>

'Inert'

Some 'inert' components of formulations are not inert in terms of aquatic biota. Examples are emulsifiers in pesticide formulations and dibutyl phthalate in Nuvan. Emulsifiers are notorious by their relatively high toxicity to aquatic fauna and dibutyl phthalate in on the priority list of environmental protection legislation in many countries.

Accurate risk evaluation cannot be made with the knowledge of all chemicals present in the formulation. A full disclosure should be made by the formulator. It is not cost-effective to spend time analyzing a material of known (to the formulator, hopefully) composition.

Unanticipated

To avoid surprises such as TCMTB in Flexgard III a large number of chemicals in recycled plastics or in polystyrene 'foam', samples of the materials must be obtained from the manufacturer and analyzed.

Conclusions

The need to control the proliferation and indiscriminate use of chemotherapeutics and other chemicals in aquaculture is urgent. Contamination or even a perception of contamination could destroy a young, promising, and very valuable new industry.

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Environmental Impacts of Antibacterial Agents in Norwegian Aquaculture

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Introduction

Problems with diesases are frequently encounted in modern intensive salmon farming. Although vaccination of fish has reduced the occurrence of some diseases, chemotherapy against bacterial infections must frequently be employed. The antibiotic/chemotherapeutic agents are administered in the form of medicated food pellets. Since fish suffering from bacterial diseases usually show reduced appetite, much of the drug intended for therapy passes through the cages and into the environment. Oxytetracycline, a widely used antibiotic in fish farming, has shown to be very poorly absorbed from the intestinal tract of the fish (Cravedi et al. 1987), probably due to complexation with Ca2+ and Mg2+ ions (Lunestad and Goksøyr, 1990). Accordingly, much of the oxytetracycline passes through the fish and enters the environment in an unchanged, active form via faeces. The drug-containing faeces from the farmed fish and the medicated food are either dissolved into the seawater, eaten by the wild fauna or reach the bottom deposit under the farm. Both oxytetracycline and oxolinic acid are known to induce resistance to antibiotics/chemotherapeutics in the marine microflora. The sediment under a fish farm contains large amounts of bacteria, including bacteria pathogenic to fish. If drug is present in the sediment for a prolonged period following medication, the change of bacteria developing resistance to the drug may increase.

The experiments

To study the persistance and metabolism of furazolione, oxytetracycline, flumequine and oxolinic acid in a marine aquaculture sediment, eight circular aquaria, (90 cm i.d. x 100 cm hight) were each supplied with a 10 cm thick layer of shell sand at the bottom and a 10 cm thick sediment layer from a salmon farm on top (Fig. 1). Prior to addition to the aquaria, the sediment was homogenised with one of the drugs to give concentration of 400 µg per ml (oxotetracycline, furazolidone) or 100 µg per ml (oxolinic acid, flumequine). Two portions of the sediment were homogenized without drugs and served as controls. A sea water supply of approximately 10 l per min per aquarium created a stable current. The average temperature of the seawater was 4°C. Sediment samples were collected from the aquaria using a poly-propylene coring tube (1.5 cm i.d., 20.0 cl length).

The tube was forced into the sediment and a rubber stopper was placed on the top of the tube to prevent the sample from falling out on withdrawal from the sediment. Before withdrawal, a large polypropylene tube (2.5 cm i.d., 10 cm length) was forced into the sediment on the outside of the coring tube to prevent the sediment from collapsing when the coring tube was withdrawn. The lower end of the coring tube was sealed with a rubber stopper immediately after withdrawal from the sediment. The larger tube remained in the sediment.

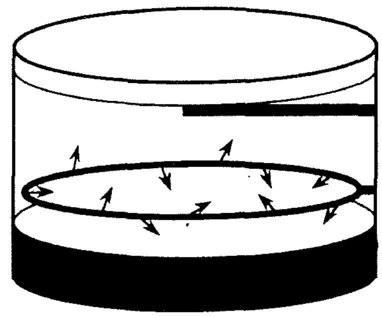

Fig. 1 Experimental set-up.

A salmon farm outside Bergen on the West coast of Norway, with a weak water-flow for waste transport and therefore a rather large sedimentation under the cages, was treated with oxytetracycline for 10 days. The dosage was 75 mg oxytetracycline per kg body weight per day. The sediments under three cages were selected for sampling. The cages contained approximately 1500 kg fish (cage 1 and 2) and 1150 kg (cage 3). The salmon in cage 1 took part in a vaccination program against "vibriose" (*Vibrio anguillarum*) and "cold water vibriose" (*Vibrio salmonicida*) directed by the Institute of Marine Research (Bergen, Norway) and were therefore not given the antibiotic. At day 23, the fish in cage 3 were removed. Therefore, no feeding took place and further sedimentation of excess food pellets and feces under this cage was minimized. At day 51, another 5 days of medication with oxytetracycline took place in cage 2, using the same dosage as described previously. Sediment samples, six cores from under each of the three selected cages, were taken by divers. One meter long white sticks were placed in the sediment as markers and ensured that the sampling was taking place within the same area of the sediment each time.

The large input of antibacterial agents has effects on the wild fauna in the vicinity of the farm. Recent research has shown that during and shortly after medication, wild fish, mussels and crustacean in the vicinity of the farm contain drug residues (Bjørklund et al., 1990, Hektoen et al., 1991, Møster, 1986, Samuelsen et al., 1992a).

Excess drugs also have an effect on the bacteria in the environment. Samuelsen et al. (1992a) found an elevated level of bacteria resistant to oxolinic acid in blue mussels (*Mytilus edulis*) collected on a farm at the day of terminated medication with this drug. The presence of antibacterial agents in the sediment has shown to induce drug resistance in the sediment bacteria (Nygaard et al., 1992, Hansen, et al., 1992, Samuelsen et al., 1992b).

Results from the investigation of wild fish from 5 different fish farms medicating with oxolinic acid is presented. At one farm the occurrence of bacteria resistant to oxolinis acid and oxytetracycline was examined in blue mussels and the gut content of wild fish. Samples were collected on the last day of medication (farm 1, 2) or the first day (farm 3, 4, 5) following terminated medication. Samples of fish intestine, liver and muscle were taken at the farm. Blue mussels were collected from the ropes or the floating devices of the farm both prior to the medication and following terminated medication.

Results

The persistence of the drugs in a marine aquaculture sediment is shown in Figs. 2-4.

Furazolidone remains in the sediment for a very short time ($t½$=18h) and was actively metabolized to 3-(4-cyano-2-oxobutylideneamino)-2-oxazolidone by the microorganisms in the sediment, probably following the metabolic pathway described for *E. coli* (Abraham et al. 1984) and for other organisms (Abraham et al. 1984, Nakabeppu and Tatsumi 1984, Tatsumi et al. 1978, Vroomen et al. 1988). According to Vroomen et al. (1987 b) this metabolite exhibits no mutagenicity and according to our findings, no antibacterial activity (Samuelsen et al. 1991).

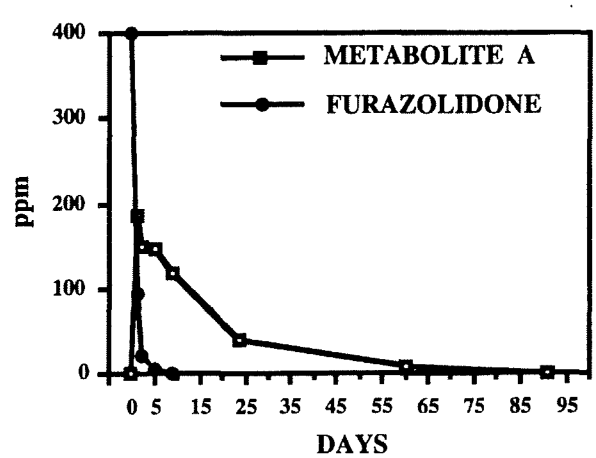

Fig. 2 Metabolism of furazolidone in a marine aquaculture sediment

Figs. 3 and 4 show that oxytetracycline, flumequine and oxolinic acid persist in the sediment for a much longer period than furazolidone. No reports concerning possible microbiological degradation processes of oxytetracycline, flumequine or oxolinic acid in marine sediments have yet been published. It is therefore likely that since they are soluble in sea water, a solvation and diffusion process is the most likely mechanism whereby they escape from the sediment.

In experiements using aquaria, we have shown that the persistence of oxytetracycline in a fish farm sediment was highly dependent on the sedimentation following a medication. Based on measurements for 224 days and with the oxytetracycline containing layer (crushed medicated pellets) placed on top of the 8 cm thick sediment, t½ was found to be 72 days. When the oxytetracycline-containing layer was immediately covered with an additional 4 cm of sediment, the calculated t½ was nearly doubled (135 days) (Samuelsen 1989). Examination of the vertical distribution of oxytetracycline in the sediment from the salmon farm showed that the oxytetracycline first disappeared in the upper layer of the sediment. A gradually increasing cover on the drug-containing layer with additional faeces and food residues will inevitably result in a reduced contact with the overlying sea water and decrease the solvation and diffusion process.

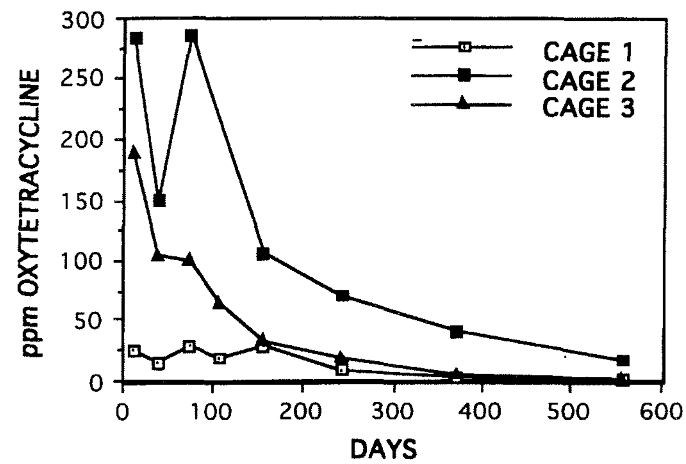

Fig. 3. Persistence of oxytetracycline in the sediment under three cages at a fish farm.

At the salmon farm, further sedimentation after the medication was larger in cage 1 and 2 than in cage 3 due to removal of the fish in cage 3. Therefore, considering the different extent of sedimentation in the cages, t½ calculated for cage 1, 2 and 3 (125, 142 and 89 days respectively) are close to the values calculated in the aquaria experiment using crushed medicated pellets (135 and 74 days). Mixing pure compound into the sediment as was done in the last aquarium experiment (fig 4), did not reduce the persistence of the drugs in the sediment. Both figs. 3 and 4 and other experiments (Samuelsen 1989) show that the drugs disappear quickly from the sediment during the first weeks, but that residual concentrations persist in the sediment

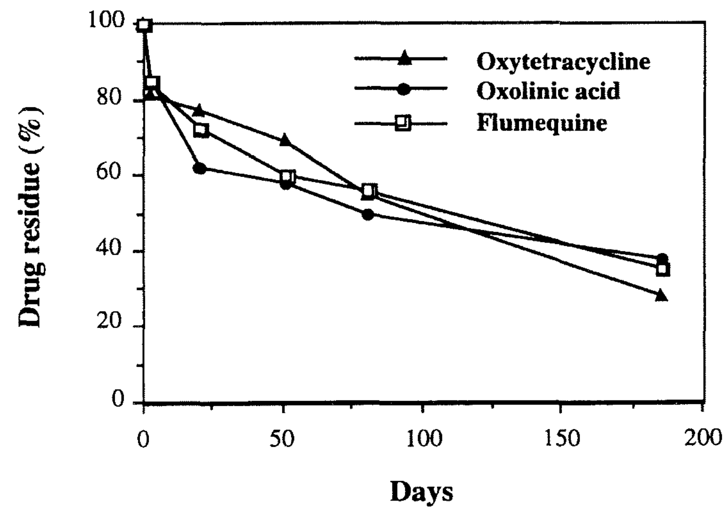

Fig. 4. Persistence of oxolinic acid, flumequine and oxytetracycline in a marine aquaculture sediment

for months following an enrichment or a medication. However, decreased diffusion due to sedimentation may not be the only reason for these drugs to persist for such an extended period in the sediment. Crystalisation (Merck Index 1983), complexation (Lunestad and Goksøyr 1990) and binding to particles may prevent the drug molecules from dissolving in the interstitial water.

In the wild fish investigation a total of 189 fish representing 9 different species were analysed. Of these, 166 individuals contained residues of oxolinic acid. Residues of oxolinic acid were found in both pelagic and dermersal species and the relative frequency of positive samples varied from 74% at farm 4 to 100% at farm 1. The highest concentrations, both maximum and mean, were found in saithe which also was the most abundant species at the farms. For the other species the number of individuals was low but the pattern with relatively high concentrations and frequencies was revealed. The concentrations of oxolinic acid found in the wild fauna exceed by far the concentrations allowed in food for human consumption in Norway. If fish, crustacea and blue mussels are harvested close to a fish farm during and shortly after medication, the risk of the drug reaching consumers is high. Oxolinic acid has also proved to be rather thermostable and no reduction in antibacterial activity was observed when boiling the drug in an aqueous solution for 15 minutes (Samuelsen et al., 1992a). A plot of the total amount of oxolinic acid used during medication and the mean concentration in muscle of seithe is shown in fig. 5.

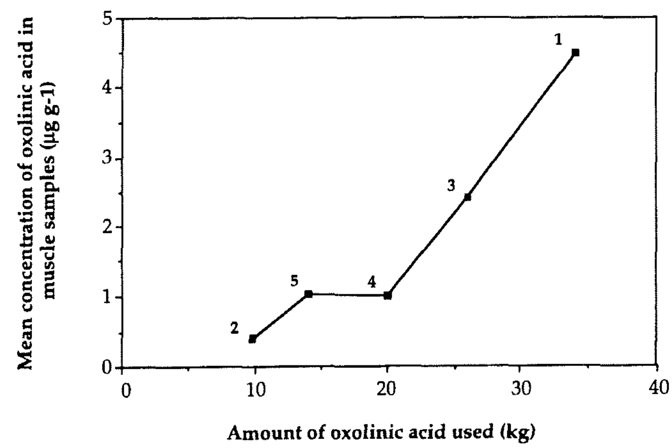

Fig. 5. The amount of oxolinic acid used in the farms (1-5) during medication and the mean muscle concentration in saithe.

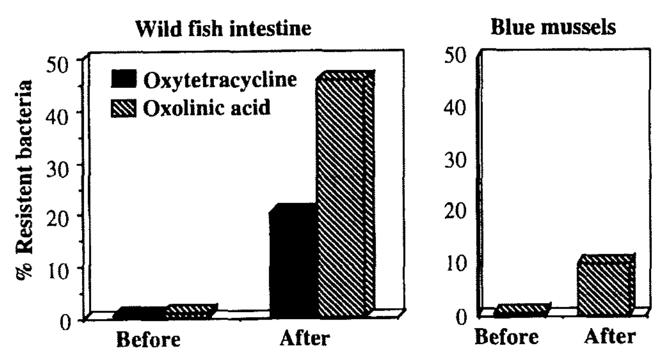

Fig. 6. The % resistance towards oxytetracycline and oxolinic acid in the gut content of wild fish and towards oxolinic acid in blue mussels before and after a 10 days medication with oxolinic acid.

Prior to medication at farm 4, 0.6 and 1.0% of the fecal becteria in wild fish were resistant to oxytetracycline and oxolinic acid respectively while 0.7%

of the bacteria in blue mussels were resistant to oxolinic acid. After terminited medication with oxolinic acid, 46% of the fecal bacteria were resistant to oxolinic acid and 20% to oxytetracycline while 10% of the bacteria in blue mussel were resistant to oxolinic acid (fig. 6).

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Determining the Potential Harm of Marine Phytoplankton to Finfish Aquaculture Resources of the Bay of Fundy

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Abstract

The presence of natural phytoplankton blooms which cause direct lethality to fish is becoming increasingly common throughout the World, although a toxic phytoplankton event of this kind has not occurred in the Bay of Fundy salmonid culture industry. We describe a method to proactively assess the likelihood of a toxic phytoplankton event resulting in cultured salmon mortalities. The three steps of the method are: (1) determining the seasonal patterns of phytoplankton species and their abundances in the local area; and (2) sublethal behavioral and physiological bioassays with salmon smolts in a flume during a control and treatment period. In the treatment period, the flume is dosed with a known concentration of cultured or wild phytoplankton, chosen either because it is dominant locally or because it is a known toxin-producing species. Finally, in (3), lethality tests with salmon smolts are conducted to determine cell densities which result in mortalities.

Introduction

The Bay of Fundy is a large macrotidal estuary with characteristically energetic tidal currents and large tidal ranges, >8 m near the mouth, where the salinities are 30-32 o/oo. Much of the primary productivity of the Bay supports a predominantly pelagic (herring) fishery and production is estimated to be five times greater than demersal fish production (Emerson et al. 1986). Most secondary production in the mouth of the Bay of Fundy is realized within the water column through zooplankton, which is available trophically to support herring growth.

Beginning in 1979, a salmonid grow-out culture industry was started in the Letang/Western Isles region at the mouth of the Bay. The annual production reached 9500 tonnes from 54 farms in 1991. Site depth is shallow: 5 to 27 m, depending on tidal stage, because all of the sites are located close to the shore. The industry is situated at 45°N and experiences a cold temperate climate with marked seasonal changes.

Radical renewable resource use changes, as in the development of mariculture, have occurred recently in many parts of the World. This has revealed previously unrecognized, or resulted in new, environmental problems. One example which has been a particular problem for the salmonid mariculture industry is the lethal effects of some phytoplankton to finfish. Two ways that this can occur are following decay of a bloom which rapidly uses up available dissolved oxygen resulting in asphyxiation of the fish, or following production of a toxin by the phytoplankter. Species of dinoflagellates, flagellates and diatoms are the main toxin producers (Table 1) so far recognized.

Table 1. Toxin-producing phytoplankton which are implicated in finfish mortalities. *C.S. = cultured salmon; W.F. = wild finfish.

Species	Location	Finfish*	Reference
Dinoflagellates			
Alexandrium excavatum	Faroe Islands	C.S.	Mortensen, 1985
A. excavatum	Canada - east coast	Fish larvae	Robineau et al., 1991
A. fundyense	Canada - east coast	W.F.	White, 1980
Gyrodinium aureolum	Norway, Scotland, Ireland	C.S. + W.F.	Dahl & Tangen, 1993
Unnamed toxic species	U.S.A. - east coast	W.F.	Burkholder et al., 1992
Flagellates			
Prymnesium parvum	Finland	W.F.	Lindholm, 1993
Chrysochromulina polylepis	Norway	C.S. + W.F.	Eiknem & Throndsen,
C. leadbeateri	Norway	C.S.	1993
Heterosigma akashiwo	Canada - west coast	C.S.	Black et al., 1991
?*H. akashiwo*	Chile	C.S.	Murphy, 1988
Chatonella marina	Japan	W.F.	Endo et al., 1992
Diatoms			
Chaetoceros convolutus and *C. concavicornis*	U.S.A. - west coast	C.S.	Horner et al., 1993
?*Chaetoceros* sp.	Scotland	C.S.	Bruno et al. 1989

Previously in the Bay of Fundy herring, *Clupea harengus*, mortalities were reported (White 1980) after eating calanoid copepods which had been feeding on the toxic dinoflagellate *Alexandrium fundyense*. The circumstantial evidence suggested that paralytic shellfish toxins vectored by the zooplankton and eaten by the herring were the cause of the herring deaths. To date, no mortalities of cultured salmon have been associated with phytoplankton in the Bay of Fundy. In view of the common occurrence of this problem in other salmon culture areas of the World (Table 1), it is possible for a similar problem to occur in the Bay of Fundy.

The objective of this presentation is to describe a method, currently under development, to assess the possibility that locally dominant phytoplankters might result in cultured salmon mortalities.

Assessing seasonal phytoplankton densities

Sampling was from a 15-m long research vessel equipped with an hydraulic winch and wire and set of Niskin bottles, each with a reversing thermometer. The bottles were of polyvinyl chloride and of 1.8 or 5.0 L capacity. They were used to sample at 10 m depth and 1 m above the bottom with surface seawater being obtained in a bucket. A Seabird CTD was also deployed for measurement of temperature, salinity and conductivity. The number of stations sampled ranged from 4 to 17, and generally were located near the salmon farms. The sampling frequency was weekly in the summer (May-September) when phytoplankton growth was most active, and monthly in the winter when little growth occurred.

Chemical oceanographic variables, inclusive of temperature, salinity, dissolved oxygen and chlorophyll a, were determined for each sample by standard methods (Strickland and Parsons 1968). a seawater sample of 200 mL was taken from bottle or bucket and preserved in 2.5% formalin:acetic acid (1:1) mixture or in 1% Lugols iodine. In the laboratory, a 50-mL subsample was settled in a counting chamber and the cell densities of each species identified with an inverted microscope (number of cells/L). Ten-minute tows with a 0.5 m diameter plankton net (Nitex mesh 20 μm) were also made to obtain living, natural phytoplankton for further physiological or behavioral experiments. The material was transported on ice in a 1-L glass jar and used within 24 h of capture.

Typical results from phytoplankton monitoring are shown in Table 2. In this table, the top 10 species of dominant phytoplankton are arranged in numerical abundance rank. One dominant microalga, the diatom *Nitzschia pseudodelicatissima* is known to produce the toxin, domoic acid (Martin et al. 1990), although it has not been reported to affect finfish.

Table 2. Dominant species found in the Letang/Fundy Isles area, arranged in descending order of density as found at all stations sampled and at all depths (from Wildish et al. 1990).

1987	1988	1989	1990	1991
Nitschia pseudodelicatissima	*Nitzschia pseudodelicatissima*	*Nitzschia pseudodelicatissima*	*Skeletonema costatum*	*Thalassiosira nordenskioeldum*
Chaetoceros sp.	*Thalassiosira gravida*	*Skeletonema costatum*	*Nitzschia pseudodelicatissima*	*Nitzschia pseudodelicatissima*
Thalassoisira gravida	*Chaetoceros debilis*	*Ceratium minutum*	*Leptocylindrus minimus*	*Scrippsiella trochoidea*
Alexandrium fundyense	*Eutreptia* sp.	*Mesodinium rubrum*	*Rhizosolenia delicatula*	*Peridinium* sp.
Mesodinium rubrum	*Mesodinium rubrum*	*Alexandrium fundyense*	*Thalassiosera gravida*	*Rhizosolenia delicatula*
Rhizosolenia delicatula	*Peridinium* sp.	*Leptocylindrus minimus*	*Skeletonema costatum*	*Leptocylindrus minimus*
Chaetoceros debilis	*Chaetoceros* sp.	*Nitzschia closterium*	*Scrippsiella trochoidea*	*Chaetoceros* sp.
Peridinium sp.	*Peridinium triqueta*	*Thalassiosira gravida*	*Mesodinium rubrum*	*Ceratium minutum*
Skeletonema costatum	*Leptocylindrus minimus*	*Distephanus speculum*	*Chaetoceros socialis*	*Mesodinium rubrum*
Nitzschia pungens	*Thalassiosira rotula*	Tintinnids	*Ceratium minutum*	*Leptocylindrus danicus*

Alexandrium fundyense is also a dominant in the Bay of Fundy (Table 2) and produces paralytic shellfish poisons, reported to be toxic to finfish (White 1981). A related species, *A. excavatum* , was lethal to cultured Atlantic salmon in the Faroe Islands, although at very high densities (1 x 10^6 cells/L - Mortensen 1985). Two other species occur in the Bay of Fundy which are known toxin producers affecting finfish: *Chaetoceros convolutus* and *Gyrodinium aureolum* (see Table 1), but have not been dominant and so do not appear in Table 1 because they are present only at low densities (<1 x 10^3 cells/L).

Behavioral and physiological bioassays

Preparation of Phytoplankton

Two methods were used: collection of wild phytoplankton and in vitro culture of unialgal species. Wild phytoplankton collected in the manner described in the previous section was acclimated to the test temperature a few hours before use and then added to the flume at a dilution to give the desired concentration, based on microscopic counts of the density in the original sample. Two difficulties with this method are that the sample contains other microalgae besides the one of interest and that the handling stresses involved in capture, transport and transfer dictate rapid use and may still involve physiological stress to the microalgae.

Batch culture of microalgae was undertaken by generally standard methods (Guillard 1984) in 10-L glass carboys in a controlled environment room. The room was equipped with banks of wall and ceiling fluorescent strip lights, temperature control and clear plastic shelving. Unialgal cultures were grown up from isolates kept in controlled conditions in the laboratory. Aliquots of isolates grown up in 2.5-L Fernback flasks were used to seed the carboys containing autoclaved filtered seawater to which suitable nutrients and a vitamin/mineral supplement had been added. In some cases, the carboys were stirred by means of aeration. When the cultures were in log stationary phase, a microscope count of a well stirred and representative sample was taken to estimate the culture volume required in the flume (Table 3). Unless the higher stationary phase densities were reached, a difficulty with this method is that an unreasonably high proportion of the flume volume would be culture solution. For example, at 1 x 10^7 cells/L and concentration required in the maxiflow tank of 1 x 10^6 - the culture volume required would be 100 L.

Experimental Fish

Salmon smolts, *Salmo salar* L., of 15 to 30 cm fork length and 200 to 400 g wet weight which had been fully acclimated to locally available seawater (S ~30-32 o/oo) were obtained as a batch of 400 fish in the fall 1992 from the Atlantic Salmon Federation. The smolts were held in a single 3 m x 1.5 m deep tank, supplied with ~20 $L^{-1} \bullet min^{-1}$ filtered seawater. Seawater temperatures in the tank varied seasonally, but generally were a few degrees above ambient. Feeding was daily, except weekends, with a commercially available dry food supplied by hand, when mortalities or sick fish were also removed.

Table 3. Estimated culture volumes (L) required in two flumes to provide the phytoplankton concentration required (cells/L).

	Mini-flow tank volume = 200 L		Maxi-flow tank volume = 1000 L	
Stationary culture concentration cells/L	Conc. required cells/L	Culture volume L	Conc. required cells/L	Culture volume L
1×10^9	1×10^6	0.2	1×10^6	1.0
	1×10^5	0.02	1×10^5	0.1
	1×10^4	0.002	1×10^4	0.01
	1×10^3	0.0002	1×10^3	0.001
1×10^8	1×10^6	2.0	1×10^6	10.0
	1×10^5	0.2	1×10^5	1.0
	1×10^4	0.02	1×10^4	0.1
	1×10^3	0.002	1×10^3	0.01
1×10^7	1×10^6	20.0	1×10^6	100.0
	1×10^5	2.0	1×10^5	10.0
	1×10^4	0.2	1×10^4	1.0
	1×10^3	0.02	1×10^3	0.1

Flume

A smaller working version of the flume - the mini-flow tank - was initially built to check that the flow characteristics were adequate. The flume was constructed in three parts of acrylic which were bolted together. the volume required to fill the mini-flow flume was ~200 L. The seawater was recirculated in the flume by an outboard motor propellor driven by compressed air. The compressor motor was located in a building away from the flume laboratory so noises associated with it were isolated. Flow rate, temperature and chlorophyll a could be continuously recorded by sensors immersed in the flume and by pumping seawater through a Turner flow fluorometer. The sensors were connected to a *Diana Chart* data logger and a PC so that they could be displayed against time.

The dimensions of the mini-flow tank (Fig. 1) did not allow much swimming space (23 x 60 x 16 cm) for smolts. However, the hydrodynamic characteristics of the flume (Wildish 1991) proved to be satisfactory with free stream velocities achieved of ~100 cm●s^{-1} without wave formation or aeration. Characteristic of the flow profiles at low velocities (10-20 cm●s^{-1}) showed that boundary layers on wall and flume floor were <2 cm in height, and that the upstream throat worked well in producing a well behaved flow. One finding was that in longer experiments the recirculating, filtered seawater in winter warmed up during the experiment (1-2° per 2 h). This was rectified by the addition of a freon-containing cooling coil in the bottom return duct of the flume which was automatically operated by a temperature-sensitive switch.

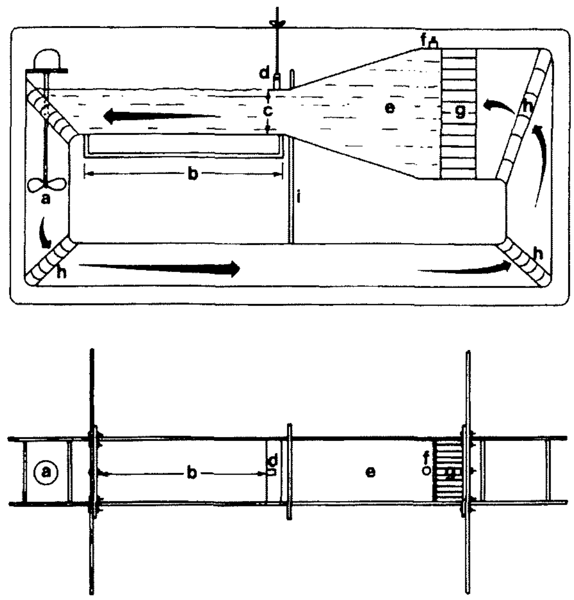

Fig. 1. Mini-flow tank - a. propellor; b. flume working section, distance = 60 cm; c. depth = cm; d. flap; e. throat section; f. air removal hole; g. collimator; h. turning vanes.

Design considerations and the experiences with the small flume suggested that a large flume - the maxi-flow tank - of ~1000 L volume capacity was required. This would allow a flume space of 30 x 90 cm for swimming smolts. A meshed gate would be required at either end to prevent the fish from swimming around the flume and hence reaching the propellor. A cooling coil would also be required to maintain temperatures in the flume. This design is currently under construction.

A side-by-side flume was considered in which two 1000-L flumes connected in the open flume section would allow fish to swim on either side, one of which could be dosed with the test phytoplankton, allowing avoidance to be tested. This design was rejected because flow simulation computer modelling suggested that smolt-sized fish would mix the phytoplankton too rapidly.

Behavioral Tests

Single fish behavioral tests are contemplated in which the tagged smolt is monitored in a 1-h control period, followed by similar monitoring in a 1-h treatment period during which it is exposed to a known sublethal concentration of phytoplankton cells.

It may be possible to automatically record and monitor behavior using a time-lapse video camera and VCR which can subsequently be analyzed on a VCR editing controller linked to a frame grabber board which is PC controlled through custom programmed Optimas software.

Variables which will be analyzed include time spent in A or B halves of the flume, swimming speed, distance travelled, turning angle and rate of turning. Based on small program modifications to the Optimas software and time-lapse frame analysis, the collection of smolt behavioral responses to putative toxin-containing phytoplankters can be partially automated.

Physiological Tests

The use of acoustic methods to obtain electrocardiograms of free-swimming fish unconnected by wires or other physical tethers was introduced by Wardle and Kanwisher (1974) and improved by Rogers et al. (1984). Such methods have been used by Ferno et al. (1988) to record ECGs of salmon in sea cages. There are two reasons why monitoring heart beat rates in fish may be of value in detecting the sublethal presence of toxins produced by phytoplankton. The first is that many of them are neurotoxins which may therefore directly affect heart rate and, secondly, heart rate is a more or less direct indicator of metabolic change through the Fick equation (Butler 1989).

We have successfully operated on live fish anaesthetized with tricaine methane sulfonate (135 mg/L) until no response to pressure on the caudal fin was obtained, and gills were perfused with anaesthetic (60 mg/L) during implantation of a 4 cm x 8 mm acoustic tag (developed and manufactured by Vemco Ltd., R.R. #4, Armdale, Nova Scotia, B3L 4J4). The tag is placed in the visceral body cavity and an electrode just pushed through the pericardial wall into the pericardial space. After suturing the wound, the fish is allowed to recover in clean seawater. Three of five fish tested survived the 3- to 5-min surgical procedure and behaved normally for a period of at least 24 h following it. During this time, the swimming smolts' heart rate could be monitored from impulses from the heart registered as an acoustic sound with the aid of a battery in the tag. The sound is monitored by a hydrophone and relayed to a receiver unit where it is digitized.

Experiments could be run concurrently with behavioral tests in the flume with a control and treatment for each individual smolt tested.

Lethality tests

If the sublethal testing of salmon smolts suggests that a particular species of phytoplankton is toxic, then lethal tests involving unialgal cultures at high concentrations must be set up. To facilitate this (see Table 3), static low volume (≤50 L) test tanks could be used, with precautions to keep the seawater well mixed, oxygenated and at a constant temperature. Since natural exposure involves whole, live phytoplankton cells, the lethal tests should provide these conditions. However, lethality can be tested more economically by interperitoneal injection of a slurry of the phytoplankton (White 1980). With the latter method, the natural barriers posed by availability from the algal cell and uptake rate across the smolts' membranes are ignored and thus this is an unrealistic bioassay in the ecological sense.

Conclusions

We describe a three-step method to determine the potential of native, local phytoplankton to harm finfish such as the Atlantic salmon. Parts of the sublethal bioassays are still being developed and so no results are presented here. It is hoped that data will become available during 1993 after we have taken delivery of the maxi-flow flume.

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Salmon lice - Problems and Solutions

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Introduction

The ectoparasitic salmon lice (*Lepeophteirus salminis* and *Caligus elongatus*) are causing severe problems in intensive cage culture of Atlantic salmon (*Salmo salar*). Lice infections frequently become epidemic and if no anti-lice treatment is given, lice attacks will, very likely lead to high fish mortality. The organophosphate dichlorvos (Neguvon, Nuvan) was found to be an effective and selective treatment against salmon lice (Brandal and Egidius....) and has been used successfully for lice control until recently. However, during recent years these pesticides has been reported to be less effective, either because of possible resistance development in the lice or from more rational, but less favourable ways of administrating the agent. Besides, this chemical treatment has been found to have several negative aspects. It is relatively costly and as multiple treatments normally are needed, labour and chemical costs may contribute significantly to the production cost. To this may also be added production losses due to reduced feeding during increasing lice infestations and starvation periods associated to the treatment. It is difficult to assess the total costs caused by salmon lice, but a conservative estimate indicated that the total costs from lice infestation and lice control in the Norwegian salmon farming industry was about NOK 200 million in 1991 (Ø. Bjerk, pers. comm.).

In addition to the direct economical losses, lice infestations and the chemical treatment has been found to major stressors to the fish (Bjordal et al. 1988, Furevik et al. 1993). Although difficult to prove it is reason to believe that stress and direct skin damage caused by the lice may reduce the health of the fish and thus lead to disease and secondary mortality.

The organophosphates also represent a health risk to farm workers and recommended to use under strict safety precautions. Further, the chemicals are released into the surrounding water after use and might cause mortality in the fauna - particularly in crustacean larvae. Due to the different negative effects of the Dichlorvos treatment, there has been a strong demand for new methods for sea lice control.

New methods for salmon lice control

In a review on methods for salmon lice control, Costello (1993) mentions six main factors that should be considered when choosing methods for sea lice control:

- Efficacy of the treatment in terms of the proportion of lice and life stages removed, with implications for the frequency of treatment required,
- Stress caused by the treatment to the salmon, with implications for feeding, growth, health, conversion efficiency and associated equipment and employees time,
- Possible hazards to farm employees and the environment,
- Marketing implications of the treatment, including both the withdrawal period necessary, the perceived quality of the product ("chemical free"), and perception of how production methods affect the environment.

Possible solutions to the sea lice problem might be classified as vaccines, chemical treatment and biological control. Different alternatives are reviewed and commented by Costello (1992), and I will therefore discuss only the present trends on salmon lice control in Norway. Nuvan is still used, but there seems to be a significant decrease in the use of this criticized method. This is explained by increased use of cleaner-fish, treatment with hydrogen peroxide and coordinated treatments at neighbouring farms.

Coordinated treatments.

This method has been tried in several regions, based on the idea that coordinated treatments do reduce the total stock of sea lice in the area. Thus the recruitment and risk of re-infestation of lice between farms will be reduced. Although it is difficult to prove or quantify the effect of this practice, it is believed that it has an over all positive effect on the sea lice problem.

Biological control: cleaner-fish.

The first successful experimental trials using wrasse (Labridae) as cleaner-fish for lice infested farmed salmon were carried out in 1987 (Bjordal 1988). The method was then applied with good results at a commercial farm in 1988 (Bjordal and Kårdal 1989), and since then the use of wrasse for lice control in salmon farming has been increasing, particularly in Norway, but also in Scotland and to a certain degree in Ireland (Bjordal 1990, 1992, Costello and Bjordal 1990, Smith 1990, Kvenseth 1993). The development on the use of wrasse in Norway is given in table 1. In 1992 close to 300.000 wrasse were used for lice control in 67 salmon farms in Norway, and in 1993 the number of wrasse used for delousing is expected to approach one million. Most of the farms that have used wrasse for lice control report that

Table 1. The use of wrasse in Norwegian fish farms

YEAR	FARMS	CAGES	WRASSE	SALMON	% WRASSE
1988	1	1	600	26000	2,3
1989	20	115	50000	230000	2,2
1990	22	133	53000	310000	1,7
1991	28	220	135000	520000	2,6
1992	67	408	281000	850000	3,3

lice infestations are kept at continuously low levels and that chemical lice treatment normally are avoided.

Wrasse are still mainly used to clean the smallest salmon (first year in sea cages), but the method is also increasingly used on larger salmon. The proportion of wrasse needed for lice control may vary between farms according to the local degree of lice infestation. However, it has become a rule of thumb to stock one wrasse per fifty small salmon (2%), while the proportion of wrasse for lice control with larger salmon has been up to 15%. The wrasse are supplied by local fishermen, with baited pots or fyke nets as the most commonly used fishing gear (Bjordal 1993).

Even though the wrasse method now is widely applied, it is not a total solution to the lice problem - with variations in seasonal and geographical availability as the main restriction. Wrasse are not found locally in northern Norway, and in southern Norway wrasses are abundant, but the catch and use of wrasse is limited to the period when sea temperatures exceed 8 degrees c. This limits the "wrasse season" from May/June to November/December. However, this coincides to a large extent with the period of the serious lice infestation.

Recent experiments have shown that the use of cleaner-fish for parasite control also may be in the rearing of tilapia (Cowell et al. 1993).

Hydrogen peroxide

The use of the organophosphates Neguvon and Nuvan has been heavily criticised by environmental agencies (e.g. Ross and Horsman ...), and the possible use of more environmental chemicals for lice treatment has therefore been investigated. Among these are hydrogen peroxide, which breaks down to harmless products (water and oxygen). During the last two years, experimental work and full scale trials have shown that hydrogen peroxide represents an effective de-lousing agent, and it has been applied with good results at a number of fish farms in Norway and the Faroe islands (Thomassen 1993). Besides being an effective de-lousing agent, the major benefit of hydrogen peroxide is that it is relatively harmless as compared with Nuvan, for example. However, there is also a bath treatment with costs comparable or exceeding those of Nuvan treatment, and there are several comparable negative effects as toxicity, stress of fish and the need for repeated treatments.

Concluding remarks

From a situation where Neguvon and Nuvan treatments were the only solution to the lice problem in salmon farming, there are now different alternatives and more favourable methods for lice control. Use of cleaner fish is steadily increasing and this method fulfills most of the recuirements for optimal lice control.

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