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Report of the *ad hoc* Study Group on "Environmental Impact of Mariculture"

by

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Abstract

Following the adopted Resolution CR 1985/2:37 (73rd Statutory Meeting of ICES), CR 1986/2:36 (74th Statutory Meeting) an *ad hoc* Study Group on the "Environmental Impacts of Mariculture" was established in order to: (a) delineate the dimensions of the problem, and (b) recommend a course of action which will lead to a development of criteria and to a standard system of monitoring and reporting." Membership to this ad hoc ICES Study Group was assigned during 1986 with experts nominated from 11 member countries. The Study Group worked by correspondence and met in Hamburg (Federal Republic of Germany) between April 7 and 9, 1987 to prepare the report. The environmental issues addressed include (a) our present understanding of the effects of mariculture on natural microbial communities and on the possible spread of pathogens, (b) the possible changes in the natural populations of marine algae (phytoplankton and macroalgae), (c) the influence of sedimentation on the benthos, (d) the use of chemicals in mariculture, (e) site selection criteria to minimize environmental effects, and (f) the state of the art in developing predictive models of mariculture impacts. Further chapters discuss environmental regulations (as applied to mariculture situations) in various member countries, the need for improved feeds and feeding strategies, and the possible beneficial effects of mariculture. Finally, a number of recommendations are formulated, related to research needs to assess and minimize environmental impacts. Considering the increasing environmental issues that are emerging with the expansion of the mariculture industry, the establishment of an ICES Working Group on "Environmental Impact of Mariculture" is proposed and the terms of references for such a Working Group are presented. Country reports are presented in Appendix 1 and an extended literature list is included in Appendix 3.

Introduction

Aquaculture in marine and brackish waters has shown a recent, rapid expansion in most of the ICES member countries. The introduction of new technologies, the expansion of suitable areas for cultivation, the improvements in feed technology, and the demand for high-quality protein products have opened new opportunities for the mariculturist. In many regions, mariculture has been identified as the only growth sector within fisheries. Several predictive investigations estimate a world aquaculture production of about 25 million tonnes by the end of this century, which requires an annual growth rate of over 12 %. Most of this increase is likely to occur in brackish and marine farming.

Progress in aquaculture development, however, will always be accompanied by problems and constraints that occur with or even through the expansion of the industry. Mariculture systems are structured around the use of natural waters and often of the natural food chain. As such, they are an integral part of the environment, and consideration must be given to their wider environmental impact. Aquaculture effluents from conventional farming systems were, in the past, considered to be "clean" and "natural" and the possibility that aquaculture may affect the environment has largely been overlooked.

Like any other industry, aquaculture has the potential to generate pollutants which are continuously released into the natural environment. Ecological concerns can no longer be ignored and have become a risk factor for the industry itself. The aquaculture industry and natural resource managers are becoming increasingly aware that the heavy demand for new sites, and the expansion of existing operations, may soon require more stringent environmental controls and limitations on the industry. To deal with the rapid growth of the mariculture industry, public administrators who decide not to regulate growth of such an industry must take risks. They must priorize and minimize the amount of time spent evaluating and completing tasks. This includes evaluation of the potential environmental consequences of growth. The development and implementation of environmentally protective site selection criteria are necessary in areas where they do not exist already.

There must be a limit to the number of marine farms (water-based systems) which can be accomodated in a given area, and due allowance must be given for other sectors of the community sharing and competing for the water and coastal resources. This is true for competitive branches of the mariculture industry operating in the same area (e.g. interactions between fish farms and nearby mollusc cultures).

Lack of understanding of the interactions between mariculture and the marine environment can be divided into three major areas which are crucial to the future development of mariculture:

(1) Water quality criteria of the water resource which is potentially suitable for mariculture,

(2) Water quality requirements within farming systems,

(3) The external impact of mariculture on marine ecosystems, including effects which affect the mariculture operation itself.

Improved understanding in these areas could help to determine the most appropriate information that governments could, in the future, expect the mariculture industry to provide in relation to "environmental impact statements". This seems to be of particular importance, because the aquaculture industry itself will be the first to suffer any adverse effects of environmental degradation. It would also be useful if strategies could be developed to minimize waste outputs from aquafarms while at the same time seeking efficient means of utilizing locally enhanced nutrient inputs in a mixture of extensive and intensive culture systems.

For a number of years the "European Inland Fisheries Advisory Commission" (EIFAC) has addressed environmental issues related to freshwater fish-farm effluents and stressed the need to reduce their negative effects. In 1980 an EIFAC Working Party on "Fish Farm Effluents" was established (Recommandation 80/19; FAO Fisheries Report No.248). The most important tasks of this Working Party are: (1) to provide guidelines for the control of suspended solids originating in fish farms, (2) prepare guidelines to reduce inorganic and organic phosphorus loadings, and (3) to review potential problems arising from the use of therapeutic agents in aquaculture. An outline of the present situation in EIFAC countries has been published in a Workshop Report on fish-farm effluents (EIFAC Tech. Paper No. 41, 1984).

Following the adopted ICES Resolutions C.Res. 1985/2:37 (73rd Statutory Meeting) and C.Res. 1986/2:36 (74th Statutory Meeting) an *ad hoc* Study Group on the "Environmental Impacts of Mariculture" was formed in order to (a) delineate the dimensions of the problem, and (b) recommend a course of action which will lead to the development of criteria and to a standard system of monitoring and reporting.

Membership in this *ad hoc* ICES Study Group was assigned during 1986 with experts nominated from a number of ICES countries. An editorial meeting with three Study Group members took place in December 1986 to compile and briefly review the available literature and unpublished data reports and prepare them for detailed considerations at the Study Group meeting. Country reports are provided in Appendix 1. The Study Group met in Hamburg (April 7 to 9, 1987; Appendix 2) and worked also by correspondence. An executive summary is attached as Appendix 3 and an extended literature list is given in Appendix 4.

The Study Group discussed the terms of references and felt that at present it would be difficult to develop a course of action that would lead to a standard system of monitoring and reporting. It was decided, however, to present available information from various member countries on possible approaches to study and evaluate environmental issues of mariculture and practical measures to minimize its impact. The present document does not attempt to provide a comprehensive review of the published information available to the Group but addresses a selected number of issues to outline key areas of concern and to identify research needs.

The Study Group noted inconsistencies in the use of various aquacultural terms and felt the need for proper definitions of terms frequently used by aquaculturists, scientists and administrators. These inconsistencies, if not removed, will lead to continued misinterpretation with the consequent establishment of inadequate regulatory requirements. Although impossible to develop appropriate definitions of terms during the Study Group meeting, it was felt necessary to agree on the rule of common use for several terms for the purpose of this meeting. The following definitions were adopted:

The **carrying capacity** of a defined area refers in ecology to the potential maximum production a species or population can maintain in relation to available food resources within the area. It is necessary to distinguish this from the **holding capacity** of a defined area in which the potential maximum production is limited by a non-trophic resource. An example would be salmonid cage culture in an enclosed bay which is limited by oxygen availability - the holding capacity being the maximum production which can be supported without dissolved oxygen limiting production. **Assimilative capacity** in this example would be the property of the bay to maintain a dissolved oxygen concentration above a defined limiting level. **Hypernutrification:** This term has been defined by ICES (ICES,C.M. 1984 (E:12) as any substantial and measurable increase in the concentration of a dissolved nutrient. **Eutrophication:** Any increase in primary production by phytoplankton as a result of hypernutrification.

In addition, there are a number of other confusing definitions in the aquaculture literature which are mainly related to system performance and water quality criteria. Most of these terms have recently been defined in an EIFAC Report on "Terminology, formats and units of measurements" as they relate to flow-through and recirculation systems (EIFAC Tech. Paper 49:1-100, 1986). Other definitions can be found in the "Glossary on Aquaculture Terminology" (ICES, C.M. 1986/F: 34). Additional clarification of frequently misused terms in aquaculture is required, particularly "Person Equivalent Values" (PEV) and "oxygen availability" (often derived from weight to volume ratios without considering partial pressure).

Important environmental issues relate to the introduction of exotic species through mariculture and to the occurrence of red tides in areas employed in mariculture. The *ad hoc* Study Group decided to touch only briefly on these important issues, because of the extended work done by the respective ICES Working Groups on "Transfer and Introductions of non-indigenous marine organismens " and on "Exceptional Algal Blooms". The reader may be referred to the relevant documents of these Working Groups.

The present document constitutes the report of the *ad hoc* Study Group whose composition was the following: Harald Rosenthal (Chairman, Federal Republic of Germany), Hans Ackefors (Sweden), Jan Aure (Norway), Edward Black (Canada), A.C. Drinkwaard (The Netherlands), L.A. Dushkina (USSR), Arne Ervick (Norway), Richard Gowen (Scotland), Maurice Héral (France), Timo Mäkinen (Finland), M.A. Sampayo (Portugal), Donald Weston (USA), and David Wildish (Canada). Markku Pursiainen (Finland) participated in the Study Group Meeting as observer of the EIFAC-Working Party on "Fish Farm Effluents".

The final report presented here includes numerous comments and suggestions provided by Study Group members and by others. Those who submitted written comments and suggestions but did not belong to the *ad hoc* Study Group were: J. Brown (Dep. Biol. Sci., Simon Fraser Univ., Burnaby, Canada), N. Dankers (Rijksinstituut voor Natuurbeheer, Texel, The Netherlands), L. Håkanson (University of Umeå, Sweden), G.H. Hall (Windermere Laboratory, UK), C. Nielsen (Nykøbing Falster, Denmark), and Ø. Vethe (Institute for Georesources and Pollution Research, Norway). It should be emphasized, however, that the editorial committee (Rosenthal, Black, Gowen, Weston) accept responsibility for the views expressed in the present report.

Environmental Issues

Bacteria

Our understanding of the effect of mariculture on natural microbial communities is extremely limited, despite the fact that several marine microbes are potentially pathogenic to the cultured organisms, the indigenous biota or man. Most microbial work done in connection with mariculture has been directed towards identification of those organisms producing disease in cultured finfish and towards the development of therapeutic methods to prevent their spread. In comparison, much less work has been done in the area of microbial ecology, and specifically, identifying how culture operations modify the environment so as to change the number and type of bacteria.

The majority of bacteria in both freshwater and marine coastal and estuarine waters are heterotrophic, and the number of heterotrophs is largely determined by the concentration of organic matter (Fletcher, 1979). Thus, the input of organic matter associated with mariculture, and particularly the enrichment of bottom sediments, could reasonably be expected to lead to an increased number of bacteria produced in the vicinity of culture sites and to result in selective enhancement of specific bacterial groups.

The effect of culture activities on coliform, and specifically, faecal coliform bacteria is of particular interest because of the importance of this group in water quality monitoring. Finnish authorities have found elevated concentrations of coliform and faecal streptococci bacteria in effluents from freshwater trout ponds (Haavisto, 1974). Subsequent investigations (Niemi and Taipalinen, 1982) found that the fish intestine and the sediments of the mud-bottom ponds can serve as multiplication sites for Enterobacteriaceae (*E. coli, Entero-* and *Citrobacter), Aeromonas* and faecal streptococci which enter the culture systems through the influent water and/or feed. The total number of indicator bacteria in the effluents was low, but detectable in the receiving waters. If oysters were cultivated in the effluent of fish farms they accumulated the enterobacteriacea, faecal streptococci, and also Aeromonas (Coeurdacier et al., 1983). Increased total coliform concentrations have also been reported in receiving waters near several freshwater hatcheries in the western United States (Hinshaw, 1973), although a large freshwater trout farm in Norway caused no change in faecal coliform numbers in receiving water (Bergheim & Selmer-Olsen, 1978). Near-surface waters near marine salmon net-cages in Sechelt Inlet, British Columbia were seen to have a higher total coliform concentration than comparable reference areas. The increase, however, was not statistically significant (E. Black and B.L. Carswell, unpubl.data). We are in need of a clearer differentiation between faecal and total coliform, because the counts obtained with methods usually employed to evaluate sewage effluents and waste waters originating from human activities, may not adequately reflect the species and type composition encountered in fish farm effluents. The development of sound hygienic criteria, specifically adapted to the marine environment is urgently needed.

The most extensive work on microbial dynamics of fish farms is that of Austin and Allen-Austin (Allen,*et al.*, 1983; Austin,1982; 1983; 1985; Austin and Allen-Austin, 1985). Freshwater trout rearing facilities have been shown to have little effect on the bacteria populations of the receiving waters. In most instances bacteria numbers (CFU,=

Colony Forming Units) from the effluent from these facilities are comparable or less than numbers in the influent. After investigation of 6 farms, in only 8 out of 29 comparisons was the number of bacteria in the effluent substantially higher (two-fold or more) than the number in the influent (Allen, *et al.*, 1983; Austin, 1985: Austin and Allen-Austin, 1985). There was also little effect of culture on bacterial composition, with the taxa of the effluent generally typical of unpolluted freshwater. The most significant effect of culture was the selection for antibiotic resistant strains during chemotherapy. The use of oxolinic acid, potentiated sulphonamide and oxytetracycline all increased the proportion of resistant bacteria in the effluent (Austin, 1985). This phenomenon was short-lived, however, for after 9 days or less following cessation of treatment, the proportion of antibiotic-resistant bacteria in the effluent returned to pre-treatment levels.

Austin concluded that unlike freshwater finfish culture, marine culture may result in a net contribution of certain types of bacteria into the receiving water (Austin, 1982; 1983; Austin and Allen-Austin, 1985), although it should be recognized that this conclusion is based on studies at a single farm site and may be more representative of facility management rather than a general pattern. In each of four sampling periods, the number of bacteria in the effluent from a coastal turbot rearing facility was substantially greater than the number in the influent, with the increase ranging from 3 to 50-fold, mainly indicating growth of naturally occurring bactaria. There were also compositional changes in the bacteria including a decrease in the proportion of *Acinetobacter calcoaceticus, Hyphomicrobium, Hyphomonas, Micrococcus, Photobacterium, Pseudomonas, Staphyloccus* and *Vibrio* sp. and a commensurate increase in *Bacillus* spp., coryneforms, Enterobacteriaceae and *Prosthecomicrobium* spp. in the effluent. The Gram-positive bacteria are normally associated with sediments, and the Enterobacteriaceae with faecal pollution.

It is not known whether changes in bacterial composition or numbers in the vicinity of a mariculture pose an increased risk of disease in indigenous biota. Several investigators have raised the possibility of disease transmission from cultured to wild fish, and questioned whether fish pathogens in the effluent from mariculture facilities might infect wild stocks in the vicinity (Austin and Allen-Austin, 1985; Odum, 1974). There are cases of mariculture introducing a disease organism into an area where it had not previously occurred, eventually leading to the infection of wild fish (Rosenthal, 1980). There are, however, no documented cases of mariculture leading to increased incidence of disease in wild fish by a pathogen already present in the environment, but demonstrating no clinical symptoms. Many fish diseases are associated with some form of stress, including vibriosis (Colwell and Grimes, 1984), enteric redmouth (Austin and Allen-Austin, 1985; Bullock and Snieszko, 1975), and fin rot (Minchew & Yarbrough, 1977; Ziskowski & Murchelano, 1975). Deterioration in water quality, poor husbandry or other stresses imposed on fish in the culture environment can increase their susceptibility to diseases caused by opportunistic pathogens (Egidius, 1984; Sindermann, 1984), but appearance of the disease in culture, or even occurrence of the bacterial pathogens in the effluent, does not necessarily pose a risk to healthy, unstressed wild fish.

Studies on bacterial growth and species composition on molluscan culture sites are few. Recently, a Swedish study found no significant differences in bacterial counts and nutrients at sampling point outside and inside a mussel farm, which was located in a well protected inlet with strong tidal currents (up to 10 cm/sec) (Hagström & Larsson, 1985). Since this study was undertaken in April when water temperature is relatively low, the situation may be different during the most productive summer period.

Marine Algae

The Study Group recognizes that mariculture activity could bring about changes in the natural population of marine algae (phytoplankton and macroalgae) in the vicinity of the farm or at a distance where flushing action is vigorous. These effects include stimulation of primary production, changes in the species composition of the phytoplankton, reduction of phytoplankton standing crop, senescence of phytoplankton blooms with subsequent localized areas of low dissolved oxygen, and enhancement of macrophyte growth. These effects have implications for public health, natural populations of marine organisms, and the viability of mariculture industries.

Finfish Culture

By-products of fish metabolism and feed leachates represent a source of nutrients for phytoplankton growth (Gowen & Bradbury, 1987) and could, given suitable hydrographic conditions, stimulate primary production of phytoplankton if nutrients are controlling growth at the time. The input of soluble waste into the water column will alter the natural composition of macro- and micronutrients and it has been suggested that this can bring about changes in the composition of the phytoplankton (Takahashi & Fukazawa, 1982). Organic waste from fish farms might also play a role in stimulating the growth of specific algal species. For example, Nishimura (1982) has shown that, fish farm by-products (fish carcasses and faeces) enhanced the growth of at least one red-tide forming dinoflagellate. Biotin has been implicated in the effects of *Gyrodinium aureolum* (Turner *et al.*, in press) and vitamin B_{12} is a growth requirement for the toxic microflagellate *Prymnesium parvum*. Biotin and vitamin B_{12} are constituents of fish feed but their fate in the marine environment is poorly understood. Recent British studies showed that Vitamin B_{12} in fish feed made farmed fish more susceptible to *Gymnodinium* attack. *Gymnodinium* is as such not toxic to fish but affects mainly the oxygen transfer across gills through sloughing of gill membranes.

There are three mechanisms by which phytoplankton blooms might become a problem for mariculturists : (1) Depletion of dissolved oxygen (DO) in and around culture facilities. During dense blooms, oxygen consumption by algae during the night might reduce the concentration of DO to a level at which cultivated fish are asphyxiated. Reduction in DO during the senescence and anaerobic microbial degradation of large phytoplankon blooms might also have similar effects (Poole *et al*, 1978). (2) Physical damage to sensitive tissues. Blooms of chain-forming species of *Chaetoceros* are known to have caused physical damage to the gills of farmed fish (Bell, 1961). It seems likely, however, that many species of diatoms which have long spines and some of the large armoured dinoflagellates could have similar effects. (3) Formation of algal toxins and subsequent uptake and accumulation by cultured organisms, or direct toxic effects on the cultured organisms. Shellfish toxicity (PSP and DSP) is a serious problem in many ICES member countries. Toxic algal blooms are known to have killed wild fish (A. White, unpublished data) and have been implicated in mass mortalities of farmed fish in European waters (Doyle, *et al.*, in press; Jones *et al.*,1983) and shellfish (Buestel *et al*, 1986). These problems are the subject of an ICES Working Group on Exceptional Algal Blooms and are not discussed in this report.

The formation of anoxic sediments beneath mariculture operations could provide suitable conditions for the accumulation of dinoflagellate cysts by preventing excystment. Dispersal of this sediment, by natural causes or for husbandry reasons, could result in the release of cysts into the water column and, under suitable hydrographic conditions, may result in the development of a bloom. Some coastal regions might be areas of natural cyst accumulation, and mariculture in these areas might be inappropriate.

The possible impact of mariculture on macroalgae is not well understood. The importation of exotic species, particularly shellfish, caused the introduction of new algae which can be considered as pests (e.g. the case of *Sargassum muticum* on the French and British coasts; socalled "Japweed" also has been introduced into British Columbia waters, Canada; see documents of the ICES Working Group on Transfers and Introductions). Their growth tend to replace some native algae. Development of mariculture (fish and shellfish) increases the release of nutrients (such as ammonia and phosphorus) and often provides additional substrate for attachement (e.g. cages, nets, racks, etc.). As a consequence, a large growth of green macroalgae can cause increased fouling on various substrates. The widespread dispersal of their spores can induce "green tides" near the culture installations, particularly in enclosed bays, in marshes and in ponds. These algae act in competition for nutrients with phytoplankton stocks, and this can have implications for the cultivation of molluscs. "Green tides" can also cause large decreases in dissolved oxygen.

Shellfish Culture

Extensive culture of bivalves may affect phytoplankton levels in one of two ways. First, bivalve culture will decrease the density of phytoplankton. Imai (1977) clearly demonstrated that the culture of 50,000 to 90,000 oysters reduced seston biomass (dominated by phytoplankton) by between 76 to 95%. Furthermore there is laboratory evidence that the filtering efficiency of bivalves (mussels) can be so great as to effect the growth of other mussels downstream (Wildish & Kristmanson 1985). Attempt have been made to estimate the seston requirements for growth of mussels (Wildish & Kristmanson, 1979; Incze & Lutz, 1980; Tenore *et al.*, 1982; Rosenberg & Loo, 1983) and Japanese oysters (Héral *et al,* 1983; Sutherland & Roland, 1986).

Secondly, the stimulation of primary production by filter feeding bivalves has also been predicted. Campos and Marino (1982), Kaspar *et al.* (1985), and Tenore and Gonzalez (1975) have suggested that phytoplankton productivity would be stimulated by an increase in the rate of nutrient cycling. A number of investigations have demonstrated that recycled organic and mineral nitrogen excreted by oysters and clams is utilized by several species of phytoplankton (Roberts & Vincendeau,1987; Lannergren, in prep., cited by Rosenberg & Loo,1983). Arakawa (1973) was able to correlate the frequency of phytoplankton blooms in Hiroshima Bay with historical trends in oyster production in those waters. However, field evidence of increased primary production in the vicinity of shellfish culture is lacking (Hagstrom &Larsson,1982)

Sedimentation and Benthos

Mariculture structures can influence sedimentation simply by modification of current velocity and direction. Like any other structure placed in a moving fluid, mariculture structures may alter the flow regime creating zones of both erosion and deposition. In areas of intensive culture, the effects of bathymetry or even coastline topography can be significant. Hanging and stick shellfish culture in the Philippines has increased sedimentation to the point that progradation of coastlines has occurred in some areas (Davis, 1956). Some of the most well-studied examples are the mollusc culture grounds of France (Ottman and Sornin, 1985; Sornin, 1979; Sornin, 1981). Oyster farmers using metal racks in the intertidal zone have been confronted with sediment accumulation beneath and between culture racks. Concurrent with elevation of the sediment surface, erosion around the rack legs has accelerated sinking of the structures. Similar problems have been faced by mussel culturists using the bouchot technique. The numerous poles used to support the mussels reduced current velocity by up to 50%, thus accelerating the deposition of fine sediments. It is estimated that 30% of the oyster and mussel farms of France face problems of active sedimentation, forcing occasional relocation and abandonment of the old beds (Sornin, 1979).

In addition to sedimentation attributable to changes in water flow, all forms of mariculture result in the production of organic-rich particulate wastes. Faeces (and pseudofaeces in the case of bivalves) typically constitute the majority of the particulate wastes. Given the intensity of culture achievable, the amount of particulate material produced can be considerable. A typical oyster raft in Hiroshima Bay, for example, holds 420,000 oysters. Over a nine month culture period such a raft will produce 16 metric tons of faeces and pseudofaeces (Arakawa, et al., 1971). With about 1000 rafts in operation in Hiroshima Bay (Arakawa, et al., 1973) the oyster culture may have a major impact on sediment deposition in the bay. The production of pseudofaeces has also been studied in connection with mussel culture in the Netherlands. For example Misdorp *et al.*, (1984) estimated the rate of sedimentation caused by mussel culture as 10mm $year^{-1}$.

Finfish culture will not only generate faecal waste, but for those operations in which feed is provided, feed which is not ingested by the fish also contributes to the total particulate load. In salmonid culture the amount of unutilized feed can range from 1% to 30% (VKI, 1976; Penczak, *et al.*, 1982; Braaten, *et al.*, 1983; Gowen, *et al.*, 1985;). Faecal production for salmonids is typically between 25 and 30% of the ingested feed (Butz and Vens-Cappell, 1981; 1982). Solid waste from salmonid farms will vary, depending on culture techniques and husbandry practices, but it has been estimated that the production of 1kg of salmon or trout will generate between 0.5 and 0.7kg of particulate waste (Weston,1986a; Gowen and Bradbury 1987). The fate of particulate wastes will depend upon settling velocities and hydrodynamic conditions in the area, but generally a large proportion of the wastes, particularly uneaten food, will be deposited in the immediate vicinity of the culture site (Gowen *et al.*, 1985; Weston, 1986a). In low turbulent environments wastes accumulate typically as a soft, flocculent layer up to 40cm or more in thickness (Ervik *et al.* 1985). The deposition of organic wastes from fin and shellfish culture can result in physical and chemical changes in the substrate including:

-Increases in organic carbon (Dahlback & Gunnarson, 1981; Hall & Holby, 1986);

-Increased sediment oxygen consumption rates (Hall & Holby, 1986; Kaspar, *et al.*, 1985; Pamatmat, *et al.*, 1973);

-Decreased sediment redox potentials (Dahlback & Gunnarson, 1981; Brown *et al.*, 1987);

-Generation of hydrogen sulphide and methane (Cho, *et al.*, 1982; Hall & Holby, 1986; Lieffrig, 1985);

-Increases in organic and inorganic nitrogen content (Kaspar, *et al.*, 1985);

-Increases in phosphorus (Enell & Lof, 1983b);

-Increase in silicon (Hall & Holby, 1986);

-Increase in calcium, copper and zinc (Aulio & Häkkilä, 1986)

The accumulation of organic-rich sediments and consequent physical/chemical changes in the vicinity of the culture site can have significant adverse consequences for the culturist. For example culture of shellfish in shallow embayments in Japan has led to nutrient and organic enrichment of the bottom sediments and consequent declines in culture productivity (Uyeno, *et al.*, 1970; Arakawa, *et al.*, 1971 Takagi, *et al.*, 1980). Clam (*Anadara sp.*) growers in Japan have adopted a strategy of bed rotation. After harvest a period of 1.5 years is required before the beds are reseeded. During this time the area is trawled repeatedly to accelerate remineralization (Terashima, *et al.*, 1972).

Finfish culturists have also been confronted with fish mortality and declines in productivity associated with the accumulation of particulate waste. The accumulation of enriched sediments may be harmful to the fish either because of outgassing of hydrogen sulphide, or the depletion of dissolved oxygen in the overlying waters. Furthermore, deterioration of water quality associated with enriched sediments may increase susceptibility to diseases (Arizono,1979). Some Norwegian salmon farmers have found it necessary to disperse the accumulated sediments with propellors, or rotate cages among several sites, thereby allowing time for recovery of the sediment (Braaten, *et al.*, 1983).

In addition to the effects on the cultured organisms themselves, the accumulation of organic-rich sediments has pronounced effects on the benthic macro-invertebrates. In cases of high organic input the sediment might become azoic but such an effect is usually limited to the sea bed directly beneath the culture structures (Hakleila, 1982, 1984; Junppanen, 1986; Brown *et al.*,1987). At a greater distance, generally less than 30m (Weston, 1986a), the effects are manifested by a proliferation of opportunistic species and a loss of many species intolerant of the physical/chemical consequences of organic enrichment (Kitamori, 1977; Tenore, *et al.*, 1982; Ervik, *et al.*, 1985; Kaspar, *et al.*, 1985; Lopez-Jamar, 1985; Brown *et al.*, 1987). The spatial and temporal effects of mariculture on benthic communities are comparable to those reported from other sources of organic enrichment (Pearson & Rosenberg, 1978; Poole *et al.* 1978).

A good example of the effects of mariculture on the benthos is provided by studies of a Swedish mussel site where the deposition of faeces and pseudofaeces created several centimeters of sediment each year (Mattson & Linden, 1981). Within six months after the start of culture, brittle stars had disappered and species originially dominant in the unimpacted community decreased in number and finally disappeared after 15 months. Opportunistic species became established in the culture area concurrently with the decline of the original fauna. Within six months, large populations of *Capitella capitata* were established, and the species later reached densities as high as 20,000 individuals/m^2. Other opportunistic polychaetes (*Scolelepis fulginosa* and *Microphthalmus sczelkowii*) appeared after one year of culture. Total abundance and biomass decreased initially, but then fluctuated widely depending on densities of the opportunistic polychaetes.

Mattson and Linden (1983) also monitored the recovery of the benthos after removal of a mussel longline that had been in production for three years. Six months after removal the bottom was still covered by 20-40 cm of mussel shells and sulphide-rich sediments. The benthos was numerically dominated by opportunistic species indicative of disturbance. Monitoring continued for a year and a half after mussel removal, during which only very limited macrobenthic recovery was observed. In relation to salmonid culture, Gowen (unpubl. data) found a decline in macrobenthic species richness and biomass three months after initiation of culture. Following removal of the cages, sedimentary conditions showed improvement after three months, but the macrofaunal community showed evidence of substantial alteration relative to reference stations even eight months after cessation of culture.

Chemicals in Aquaculture

A wide variety of chemicals are used in mariculture which, if unrecognized or misused, represent a potential threat to the health of the cultured organism, the indigenous biota or the human consumer. An example of the range of chemicals available to culturists is provided by Schnick, *et al.* (1985) (Table 1). Twenty-four chemicals are registered or approved for use in food fish culture in the United States. The diversity of chemicals available to culturists is far greater in other countries where chemical licensing procedures are less rigorous. Several chemicals which are in use elsewhere have not been registered in the United States and efforts to do so have been terminated because of their potential toxicity, and concerns about human safety. For example furazolidone, nitofurazone, carofur, chloramphenicol and silvex have been dropped from consideration because they are known or suspected carcinogens. In other countries some of these chemicals are widely used. On the other hand, the use of TBT has not yet been banned in the United States while other countries have already restricted its application.

The chemicals in use can generally be divided into three groups, and it is in terms of this grouping that their usage is discussed: (1) Biocides and biostats which are deliberately introduced into the culture system, with the intent of eliminating predators or protecting the health of the cultured organisms (e.g. therapeutics, pesticides); (2) Chemicals which are introduced in the construction materials. They are not used with the intent to affect the health of the cultured organisms, and should there be an effect, it may often go unrecognized. (3) Hormones used to alter reproductive viabiliy, sex or growth rates.

The following discussion of chemical usage in mariculture is intended to illustrate the types and magnitude of chemical usage, and therefore the need to understand the environmental consequences. It should be noted that with the possible exception of Tributyltin (TBT), there is no evidence that the chemicals in general use in mariculture pose a threat to the environment and/or human health. However our understanding of the environmental chemistry and toxicology of these chemicals is too limited to dismiss the issue without further consideration and the need for additional research is clearly apparent.

Biocides and Biostats

There is a long history of chemical usage in mariculture to control predators. For example, in the United States, lime was used as early as the 1930s to control oyster predators (Loosanoff, 1961). Trichloroethylene and dichlorobenzene have also been used to control oyster predators (Loosanoff et al., 1960). The pesticide Sevin is currently used in the northwestern United States to control burrowing shrimp in oyster beds. Copper sulfate has been used by the Japanese to control oyster predators (Koganezawa, 1978), but was discontinued when it was shown to adversely affect oysters.

In areas of intensive culture development the amounts of these chemicals used can be considerable. In the case of antibiotics for example, the 1984 antibiotic consumption by the Norwegian marine salmon culture industry included 6223Kg oxytetracycline, 7820Kg Tribrissen R, 5500Kg Nitrofurazolidone and 9Kg sulphamerizine (Midtlyng, 1985). Considering the total production of salmon in Norway, however, the application of chemicals amounts to only 430g per tonne produced or half of this amount when taking the standing biomass into account. In recent years the use of antibiotics in Norway has been reduced and it should be noted that although there is less information from other countries the use of these chemicals in other countries is probably similar to Norway. The use of chemicals in aquaculture in the United Kingdom is summarized in Table 1a based on a survey of 148 fish farms (Solbe, 1982). Ninety-nine of the farms reported some chemical use with malchite green and formalin being used most extensively. Although the United Kingdom survey was based on freshwater facilities, most of the chemicals could be used in land-based marine culture systems.

The use of biocides and biostats is widespread and intensive despite the fact that little is known about the environmental fate and effects of most of these substances. The work of Egidius and Møstar (1987) has demonstrated that at least some pesticides (i.e., Neguvon® and Nuvon®) as presently employed in salmon net-pen culture are capable of causing mortalities of crustaceans living in the general vicinity of the farm site. Environmental issues associated with use of chemicals have often been raised (Pedersen,1982; Solbé, 1982; Anonymous, 1983; Beveridge, 1984; Midtlyng, 1985), but rarely resolved. To date most attempts to consider potential environmental effects have relied on supposition based on dilution (Beveridge, 1984), persistence (Ackefors & Sodergren, 1985) or water solubility (Weston, 1986a). With few exceptions field data are lacking. Austin (1985) monitored antibiotic resistance of bacteria isolated from trout farm effluents. During treatment with oxytetracycline 90% of the bacteria strains examined showed antibiotic resistance. Within nine days after cessation of treatment, however, all resistance had been lost. Austin (1985) suggested that antibiotic resistance may be a short-term phenomenon. However, since the samples were obtained from effluent from a flow-through system, it is possible that there was a dilution effect rather than loss of resistance in the same bacterial population over time. Antibiotic resistance has been shown to be stimulated by antibiotic use in fish culture (Aoki, *et al.*, 1980) but more work on the subject is urgently needed. The development of antibiotic resistance is obviously of significance to the culturist, but it is only one of the environmental issues for which there are at best limited data. Other issues of equal concern include persistence of antibiotics and other mariculture chemicals, bio-accumulation potential, and toxic effects on indigenous biota.

Chemicals introduced via construction materials

Their presence is either unknown to the culturist (e.g., plastics additives) or they have been intentionally introduced but with the expectation that their use will have no effect on the cultured organisms (e.g., antifoulants). Plastics contain a wide variety of additives including stabilizers (fatty acid salts), pigments (chromates, cadmium sulfate), antioxidants (hindered phenols), UV absorbers (benzophenones), flame retardants (organophosphates), fungicides and disinfectants (Zitko, 1986). Many of these compounds are toxic to aquatic life, although some protection is provided by their low water solubility, slow rate of leaching, and dilution. Nevertheless, mortalities in mariculture have resulted form toxicants leaching from plastic construction material and the environmental effects of these toxicants beyond the confines of the culture facilities remain largely unresolved.

Antifouling compounds provide classic examples of chemicals associated with construction materials which can have profound effects on both the cultured animal and the indigenous biota. For example Tributyltin (TBT) compounds have been the subject of recent intensive study. TBT was first introduced as an antifouling paint in the mid-1960s, and was widely utilized because of many attractive properties (high toxicity to fouling organisms, low toxicity to man, lack of colour thus imposing no restrictions on paint colour, and ability to provide several years protection without retreatment). The first indication of the effects of TBT on non-target organisms were noted in Arcachon Bay, France where 10% of the country's oyster production is carried out in close proximity to a large number of pleasure craft. In the mid-1970s oyster growers began to report poor spat collection, larval abnormalities and shell malformation. Subsequent work implicated TBT as the causative agent (Alzieu, *et al.*, 1980; 1982; Alzieu and Héral, 1984; Alzieu and Portmann, 1984; His and Roberts, 1983).

TBT has since been found in heavily utilized harbours throughout the world, and has repeatedly been shown to cause reproductive failure or growth abnormalities in molluscs, and has a high toxicity to many other forms of marine life (Cardwell and Sheldon, 1986; Cleary and Stebbing, 1985; Grovhoug, *et al.*, 1986; Maguire, 1986; Paul and Davies, 1986a;1986b; Stang and Seligman, 1986; Thain, 1986). TBT has been used extensively as an antifoulant on cages used for salmonid culture, but recent evidence indicates that the compound can cause mortality of the cultured fish and accumulate in the tissues, thus providing a route for human consumption (Short and Thrower, 1986a;1986b;1987). The rapidly accumulating evidence of adverse environmental effects of TBT has led to reductions in its use in mariculture facilities, restrictions on its use in France, United Kingdom, Federal Republic of Germany, Switzerland, and Canada and an ongoing re-evaluation of the compound in the United States.

Hormones

The final group of chemicals in aquaculture are hormones which are used to alter sex, reproductive viability or growth of the cultured organisms. The work of Goudie *et al.* (1986) and Johnstone *et al.* (1983) have reviewed the elimination from fish of a hormon commonly used to control sexual differentiation (Methyltestosterone). Both studies concluded that at those levels of use necessary to control sexual differentiation this hormon posed no potential human health hazard.

Much too little is known on bacterial toxicity and persistance of hormones, biocides, biostats and antibiotics in the marine environment and studies in this field are urgently needed.

Table 1 : Chemicals registered or approved by the U.S. Food and Drug Administration for use in food fish culture[1] (Adapted from Schnick, et al., 1985)

Product	Use
THERAPEUTANTS	
Acetic acid	Parsiticide
Formalin	Parasiticide and fungicide
Romet 30 (sulfadimethoxine and orthomeprim)	Bactericide
Salt	Osmoregulatory enhancer
Sulfamerizine	Bactericide
Oxytetracycline (Terramycin)	Bactericide
ANESTHETICS	
Carbonic acid	Anesthetic
MS 222 (tricaine methane-sulfonate)	Anesthetic and sedative
Sodium bicarbonate	Anesthetic
DISINFECTANTS	
Calcium hypochorite	Disinfectant, algicide and bactericide
WATER TREATMENT	
Fluorescein sodium	Dye
Lime (calcium hydoxide, oxide or carbonate)	Pond sterilant
Potassium permanganate	Oxidizer and detoxifier
Rhodamine B and WT	Dye
Copper sulfate	Algicide and herbicide
Copper, elemental	Algicide and herbicide
2,4-D	Herbicide
Diquat dibromide	Algicide and herbicide
Endothall	Algicide and herbicide
Simazine	Algicide and herbicide
Clean-Flo (aluminum sulfate, calcium sulfate and boric acid)	Algicide and herbicide
Glyphosate	Herbicide
Potassium ricinoleate	Algicide
Xylene	Herbicide

[1]The FDA often registers or approves a compound under a trade name. For example there are eight approved or registered algicides/herbicides containing copper sulfate. A single entry be chemical name has been provided in the table for these cases.

Table 1a : Chemical usage in freshwater fish farms in the United Kingdom (Adapted from Solbé, 1982)

	No. of farms (out of 148 surveyed)	Total amount used per year (sum of all farms)	Average Effluent Concentration (mg/l)
Malachite Green	89	176 kg	0.61
Formalin	56	1230 L	15.2
Hyamine	23	77 L	0.55
Oxytetracycline/Terramycin	16	0.7 kg	
Chloramine T	12	30 kg	
Sodium chloride	12		
Copper sulfate	11		
Tribrissen/Sulphamerizine/Vesadin	10		
Betacide/Marinol/Roccal	9		
Iodophores/Vescodyne/Pevedine/ Vanadine/ Polyvinylpyrrolidone-Iodine complex	9		
Furazolidone/Neftin	8	38 kg	
Buffodine	5		
Methylene Blue	4		
MS 222	4		
Potassium permanganate	3		
Acinitrasole	2		
Acriflavine/Pioflavine-Hemisulphate	2		
Dipterex	2		
Enheptine	2		
Slaked/Quick lime	2		
Sodium hydroxide	1		
Sodium hypochlorite	1		

Water Quality

Information on the effect of marine fish farms on water quality in and around culture facilities is insufficient to allow a detailed evaluation. For freshwater situations, the European Inland Fisheries Advisory Commission (EIFAC) of FAO organized a workshop (Alabaster, 1982) to assess the extent of the problem in freshwater aquaculture in central Europe (Rosenthal, 1983). An analysis of the information gathered through a questionnaire, for which replies were received from 15 member countries (Alabaster, 1982), revealed that fisheries downstream from farms are not adversely affected unless the total flow of recipient waters is less than 5 L per second for each tonne of annual fish production. There was a general tendency for pH to drop slightly when water passed through the farming system (average 0.2 pH units at 1L/sec/t annual production; no change at 4 L/sec/t annual production or higher flow rates). At higher dilutions fresh water farm effluents are still associated with increased eutrophication. Inorganic phosphorus was considered to be the major contributor to the eutrophication effect observed in receiving waters (Sumari, 1982). Oxygen levels in the outlet of farms decreased generally at an average of 1.6 mg/L for an average flow of 12.6 L/sec/tonne annual production. This figure is based exclusively on data obtained from salmonid farms.

Most of the water quality criteria examined in the EIFAC study showed an increase in concentrations (Table 2) when comparing inlet and outlet values. However, the effluent quality data available do not provide a consistant figure. BOD load (Biochemical Oxygen Demand) increased only with an increase of suspended solids.

Table 2 : Net increase in constituents of water passing through fish farms (Kg/day/t annual production) according to an analysis of an EIFAC questionnaire. SS= suspended solids; BOD= biological oxygen demand; COD= chemical oxygen demand; NH3-N = unionized ammonia-nitrogen; ND = no data available (modified after Alabaster, 1982).

Country	SS	BOD	COD	NH3-N	oxidized nitrogen	total phosphorus
Cyprus	1.3	1.4	ND	0.4	0	0,16
Denmark	1.4	2.1	1.0	0.2	0.1	0.06
Finland	1.5	1.5	ND	0.1	0.5	0.08
FR Germany	ND	ND	ND	0.5	1.5	0.27
Italy	11.0	1.5	ND	0.4	ND	0.31
Norway	3.5	2.7	31.0	0.3	0.9	0.14
United Kingdom (afterSolbé,1982)	4.1	2.4	ND	0.1	0.5	0.03
United Kingdom (after Purdom,1982)	9.4	ND	ND	0.1	0.1	0.10

Selected water quality aspects

In this report several water quality issues have already been addressed in connection with other environmental considerations. Therefore, only a few aspects are presented and discussed here, placing the main emphasis on oxygen depletion at cage farm sites, the use and misuse of the unit "Person Equivalent" as a means of fish farm waste water evaluations and on the concentration of metabolic nitrogen (such as total ammonia) at water-based farm sites. Table 3 summarizes data from several studies available during the Study Group meeting. They do not provide a comprehensive overview but demonstrate that the net loading for various water quality parameters differs substantially for the same species, and is dependant on site specific conditions, feeding strategy, feed composition and other operational criteria. The dependence of the release of total suspended solids from fish farms on feed conversion efficiency, and on growth rate has clearly been demonstrated in fresh water aquaculture (Knösche, 1971, Table 3). While information on waste output is available for freshwater species and salmonids cultured in marine waters, data are lacking for potential mariculture species such as halibut, turbot, cod and sablefish.

Table 3 : Estimated pollutional load derived from observations at various commercial intensive fish farms using pond and tank system.

System	Species	size	feeding rate (%) bodyweight	feed type	Net loading	Reference
Tanks and ponds	Brown trout (biomass 2,260kg)	2.2g - 100g	17.5 - 1.3%	dry pellets manual + automatic	11.5g COD/kg fish/24h 2.7g BOD_7/kg fish/24h 0.05g Total P/kg fish/24h 0.9g SS/kg fish/24 h	Bergheim et al. (1982)
Tanks and ponds	Brown trout (biomass 7,320 kg)	1.0 g - 25.0 g + brood stock	3-6 %	dry + wet pellets, manual	75.3 gCOD/kg/24 h 83.3 gBOD_7/kg/24h 0.43g Total P/kg/24h 0.24g PO_4-P/kg/24h 1.4-3.8 g Total-N/kg/24h	Bergheim et al. (1982)

Table 3 (continued)

ponds	Brown trout, rainbow trout (biomass 2.690kg)	0.2 - 500 g	0.55- 4.5 %	dry pellets manual	17.0 gCOD/kg/24h 7.1 gSS/kg/24h 0.45 g Total-N/kg/24h 0.08 g Total-P/kg/24h 0.05 g PO_4-P/kg/24h	Bergheim et al. (1982)
tanks and ponds	Brown trout (biomass 5,970kg)	1-550g	0.5 - 16 %	dry, automatic	3.1 g COD/kg/24h 1.6 g BOD_7/kg/24h 1.2 g SS/kg/24 h 0.13 g Total-N/kg/24h 0.05 g Total-P/kg/24h 0.03 g $P0_4$-P/kg/24h	Bergheim et al. (1982)
ponds 12,700m2	rainbow trout	35-150g 500-2000g	?	dry pellets	0.4-0.8 gTotal-N/kg/24h 0.05 g Total-P/kg/24h 1.6-4.6 g BOD7/kg/24h	Bergheim + Selmer-Olsen(1978)
ponds	rainbow trout	2.0 -300g	?	dry pellets, wet feed	0.5-1.4 g Total-N/kg/24 h 0.13-0.18 g Total-P/kg/24h 1.9-5.7 g BOD5/kg/24h	Markham (1978)
Tanks	lobsters	100-200g	?	?	1.43-2.10 g COD/kg/24 h	Tchobanoglous Shlesher (1974)

Table 4: Relationship between suspended solids loading and feed conversion efficiency in intensive carp culture. SS = suspended solids (dry weight), FC = Feed conversion factor, dry to wet weight basis. (modified after Knösche, 1971).

FC	Tonnes SS per tonne weight gain	Suspended solids produced (g SS/kg Fish/day) Feeding rate 2%/day	3%/day
1.0	0,68	13.6	20.4
1.2	0.86	14.3	21.5
1.5	1.13	15.1	22.6
2.0	1.58	15.8	23.7

Oxygen depletion

Oxygen availability at cage farm sites is a problem of immediate concern to the farmer. The best documented example for oxygen depletion in and around net cages is that of the Japanese large-scale yellowtail farming operation in the Usui Bay (Kyushu Island). In Usui Bay, farm operations cover an area of approximately 10 ha, employing about 250 to 350 cages, and annually produce about 750 tonnes of fish. Although tidal currents are relatively strong (3 to4 knots, maximum), oxygen depletion occurred within the cages, especially during slack tide, and in recent years farmers were forced to reduce the number of cages in the inner part of the Bay. Dissolved oxygen concentrations, in the central part of the cage-covered area, decreased by 40-60 ppb during a single pass of the water mass through a single cage (stocking density 6 $kg.m^{-2}$). Between 0.3 and 0.5 mg $0_2 \times L^{-1}$ was consumed when stocking density was as high as 22 kg x m^{-2}. There was also a substantial difference in levels of oxygen depletion between those cages installed close inshore and those further offshore in deeper waters. Figure 1 depicts isolines of oxygen concentrations measured in and around the cage culture facilities (samples taken approximately 1-2 m below water surface) prior to, during, and after feeding. It seems obvious that oxygen depletion and water exchange are largely related to both the shoreline structure and the arrangements of the cage units. Those cages located closer inshore and surrounded by other cage units are likely to be affected first by any oxygen depletion. Oxygen depletion may also be related to seasonal events, especially during the summer and fall. When warm water temperatures support faster growth rates and feeding levels are high, oxygen concentrations in center cages can be reduced to critical levels. The oxygen depleted area extends not only horizontally but also vertically, and this is shown in Figure 1a, which shows the vertical profiles in various farm operations in the same bay and at two different tidal situations. The impact on oxygen levels is largest in the yellowtail farms, followed by the Red Sea Bream cages, and least at the pearl oyster raft site. During several years of studies, the investigators (Kadowaki et al., 1978 a,1978b, 1980) also noted that the situation became gradually worse. This was partially attributed to the substantial amounts of oxygen-consuming substances accumulating at the sea bed under and around the cages. Besides oxygen depletion, gas production in and release from sediments beneath fish cages can occasionally cause fish mortality, probably due to venting of carbon dioxide, hydrogen sulfide and methane.

Person Equivalent values (PE)

Fish farm waste water is not directly comparable to domestic sewage. The use of PE-values, if not specified for individual components, is therefore invalid. Most of the BOD produced in a fish farm is related to the suspended solid fraction which settles quickly. Soluble BOD loads have been estimated to reach 2.56 kg /tonne/day in trout farms , while the settlable solid fraction amounts to 6 kg /tonne/day. Taking the average PE values as 12g N/day, 2.5 g P/d and 75 g Oxygen/day (asBOD_7), land-based fish farms may produce between 21 and 60 PE loads per tonne of fish stocked in the system. Markmann (1982) reports for Danish pond farms a BOD_5 load equal to 19 Person Equivalents, while the loading for N and P would equal 32 PEs. High loadings can be calculated for French trout farms, amounting to 0.2-05 PE per kg fish stocked (Fauré, 1977). These data show, that the comparison with untreated sewage is not valid,mainly because of the totally different C,P,N ratio and the significant difference in settlable and soluble wastes. From a management viewpoint it was felt unrealistic to use PE values as an index of the overall pollutional load in fish farming.

Site selection

In the context of this report site selection for the siting of mariculture operations is confined to a discussion of those criteria which might be used to minimize the environmental effects of an operation and does not include an assessment of site selection criteria to ensure optimal growth of the culture species. Neither does this section discuss site selection for the avoidence of harmful algal blooms, this topic is under review by the ICES Working Group on Exceptional Algal Blooms.

Mariculture operations interact with the water body within which they are located and the benthos over which they are sited. The balance of the impact, that is, which of the two is the main recipient of waste will obviously depend on the operation but it is the intensity

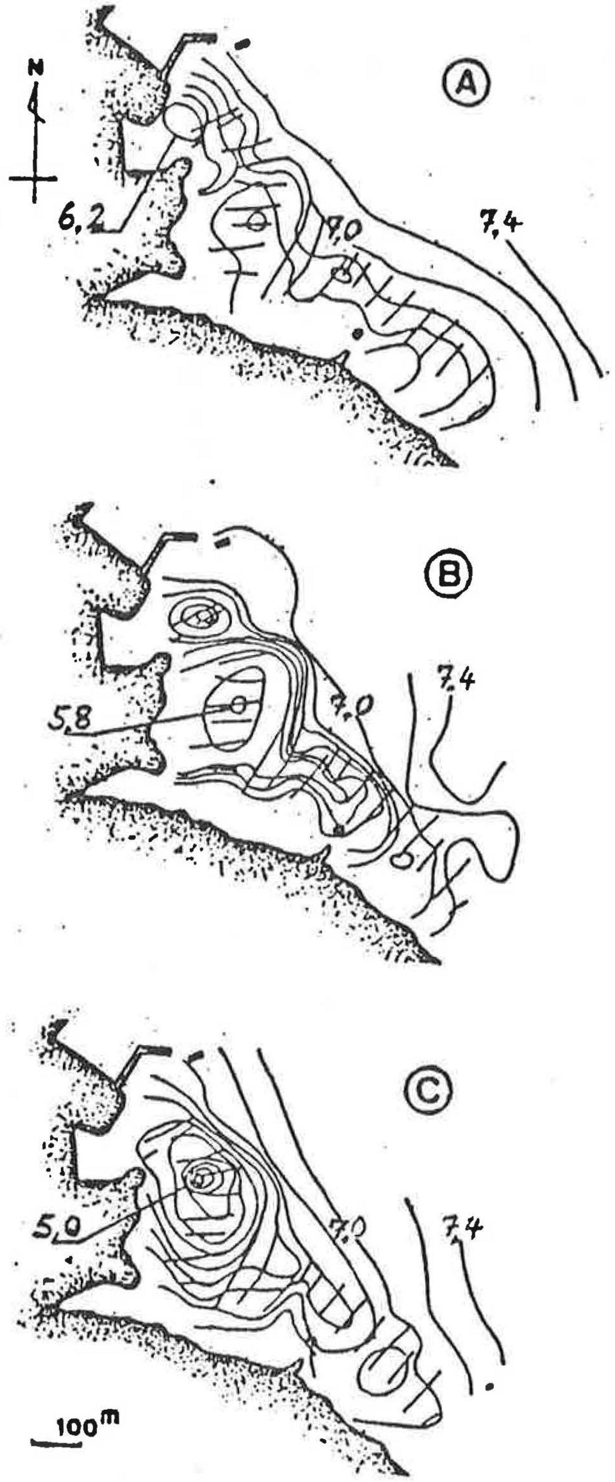


Fig. 1: Examples of the effects of feeding on oxygen depletion in large-scale cage culture facilities for yellowtail (Seriola quinqueradiata) and Red Sea Bream (Pagrus major) in the Usui fish farms: a = pre-feeding; b = during feeding; c = after feeding (by courtesy of Prof. Hirata and Dr. Kadowaki).

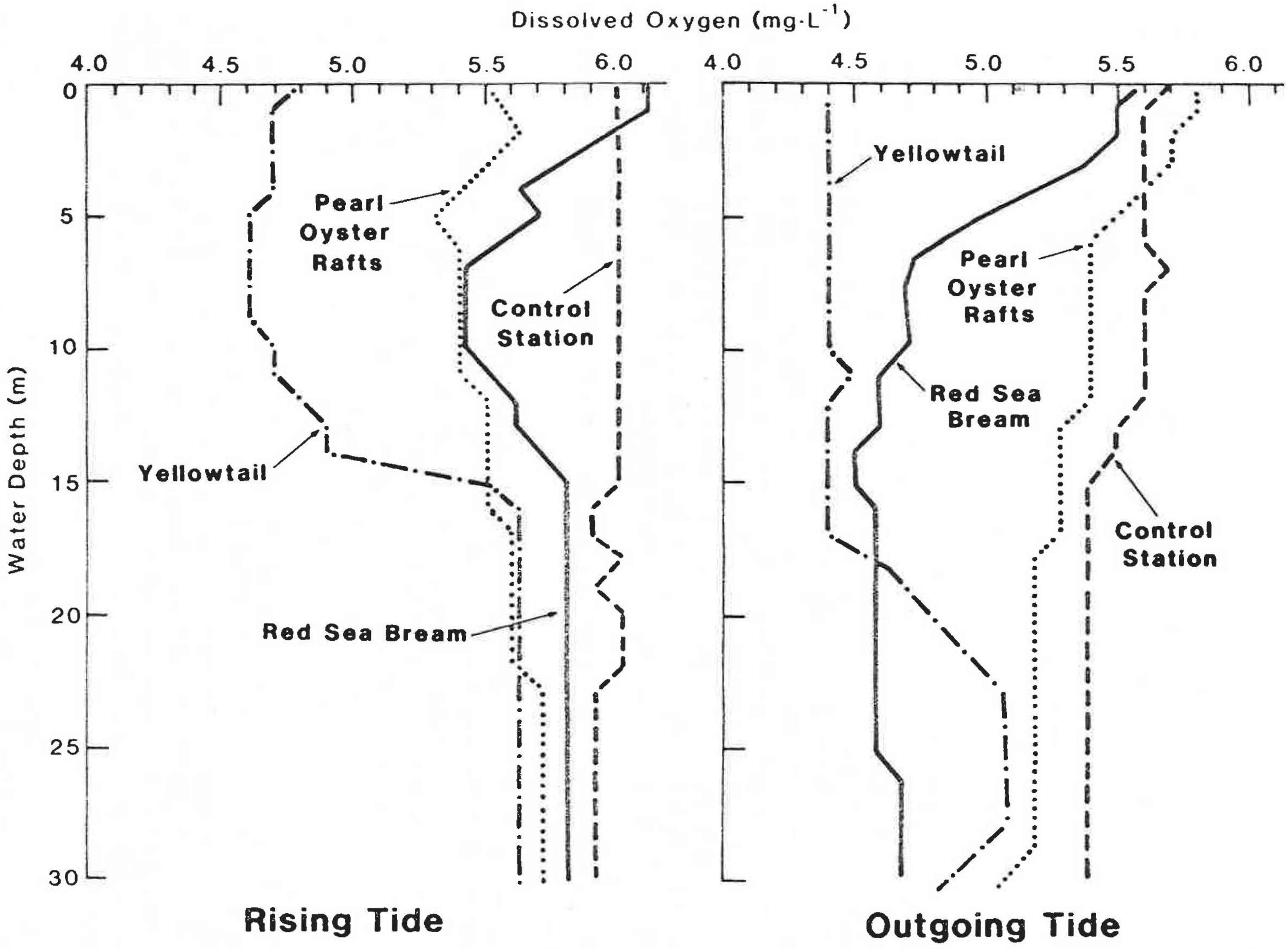


Fig. 1a: Vertical oxygen profiles in various coastal cage farm facilities in relation to the tidal situation (by courtesy of Prof. Hirata and Dr. Kadowaki, Kagoshima University).

and scale of these interactions which will determine many of the broader ecological impacts. The following discussion is confined to those factors which limit the impact of a mariculture operation on the benthos and water quality. Some of these factors might be combined to formulate site selection protocols which would be of use in resource management but the formulation of such protocols needs careful consideration and is beyond the present scope of the Study Group.

Impact on the benthos

For finfish and some forms of shellfish culture (for example raft and longline culture of mussels) the same criteria for site selection can be applied. However, for bottom and near bottom culture of some shellfish, minimizing the impact on the benthos by site selection is more problematic. Careful husbandry practices can minimize the amounts of waste released by finfish farms, however the distribution and loadings of organic waste to the benthos will be dependent on a number of physical processes. In Norway, the possibility of shifting cages to alternative locations has been considered. However, nothing is known on the required recovery time of overexposed sites.

Sediment Type: Sediments can be divided into two broad groups, depositional and erosion. In general the former tends to be composed of fine particles, indicative of regions where fines and organic detritus accumulate. In contrast erosional sediments are generally composed of coarse particles and indicate regions of the sea bed where there is active transport of fine particles. The identification of coastal regions with coarse grained sediments is one criterion for the selection of mariculture sites where the accumulation of organic waste would be reduced. However, grain size is also dependent on the source of the sediment material and a coarse sediment might be a reflection of the fact that there is no local source of fines. In such cases, the sorting characteristics as measured by the sorting coefficient need to be identified (see Holme and McIntyre, 1984: Methods for the study of marine benthos, IBP Handbook 16).

Bottom topography. Regions where sea-bed features promote accumulation of sediment should be avoided.

Water depth: The dispersion of faeces, pseudofaeces and waste feed is partly dependent on the depth beneath the operation. In general the greater the depth the greater the lateral transport of the waste particles. However, this is not always the case. In some areas (for example the deep basins of some fjords) current velocities might be low and result in limited lateral dispersion. Adequate depth under cage systems will also allow hydrogen-sulfide bubbles produced from anoxic sediment to be rendered harmless by the time they pass through the culture facility on the way to the surface (Ervik, pers. comm.).

Current velocity: Current velocities will determine the lateral dispersal of solid waste settling through the water. The higher the current velocity, the greater the lateral displacement of waste particles and hence the accumulation of organic waste will be minimal. Thus in general sites with high current velocities should be selected although it should be borne in mind that high current speeds might have adverse effects on finfish growth. In addition it should be noted that good tidal flow does not automatically lead to good water exchange and the retention time of water around the farm should be considered.

Existing benthic community: Coastal areas where benthic communities provide nursery grounds or natural beds for commercially fished species, and areas of marine conservation interest should be avoided.

Water Quality

Many of the criteria described above will have a bearing on the impact of mariculture operations on water quality. In general factors which promote good water exchange and rapid dilution of soluble waste materials are likely to be useful in site selection protocols.

Water movement : Good water flow through the culture structures will disperse soluble waste materials and reduce the possibility of localized oxygen minima. However, current patterns are also important. Soluble waste could accumulate in regions where there are eddies or gyres despite adequate water flow.

Retention time: The retention time (flushing time or dilution period) of a semi-enclosed water body has an important influence on the dilution of soluble waste. In poorly flushed locations soluble wastes are likely to accumulate and the demands of the mariculture operation on oxygen supply can result in localized minima which could affect the cultured organisms. It is in such poorly flushed locations that the ecological impacts of mariculture operations are likely to be greatest. In some coastal regions water in deep basins can persist for periods of time ranging from several months to years. In these locations the input of wastes(soluble and solid) from mariculture operations could enhance oxygen depletion and nutrient levels within the deep water. Upwelling of nutrient rich water into the euphotic zone could stimulate phytoplankton growth and the upwelling of oxygen depleted water could affect both the cultured organisms and indigenous species.

Water column stability: The stability of the water column can influence the volume of water into which soluble wastes are dispersed. For example in the case of mariculture operations dependent on floating structures the presence of a strong pycnocline immediately beneath the structures could result in limited dispersion of wastes. The effect of water column stability will depend on the duration of the stratification, and the magnitude of such density discontinuities.

Natural levels of nutrients: It has been suggested that the release of soluble nutrients from mariculture operations could influence the ecology of phytoplankton populations within a water body, but only if nutrients are limiting phytoplankton growth at the time. The identification of coastal regions were phytoplankton growth is nutrient limited, particularly during the summer months, might be a means of reducing the impact of soluble nutrients and possibly reducing the risk of mariculture operations stimulating the formation and persistence of harmful algal blooms.

Predictive Models of Mariculture Impacts

The Study Group recognized the importance of models for research into the interactions between mariculture and the marine environment and as tools for resource management. However to date the development and application of models in mariculture has been limited. Models can be divided into two broad groups, those dealing with sedimentation and those dealing with water quality.

Sedimentation Models

In attempting to gain an understanding of the effects of the deposition of organic waste from mariculture activities there have been two approaches. First models for site selection, for example Hakanson *et al.* (1986), examine physical and geomorphological features of coastlines to identify areas of sediment deposition and erosion. Secondly, sedimentation models may predict the accumulation of sediment beneath a particular mariculture operation and thus allow an environmental impact assessment to be made. In the simplest models solid waste is assumed to settle as single independent particles with only a simple lateral component derived from water movement (Hagino, 1977). In relation to sedimentation beneath salmonid cage farms Gowen (unpubl.data) has taken this a stage further by distinguishing between faecal waste and uneaten feed pellets and relating deposition to variations in current speed and direction. However in both of these models the effects of upwelling, resuspension, the hydrodynamic effects of the maricultures structures themselves and the transport characteristics of flocs has been ignored. It may be possible to adapt models which have been developed to determine the distribution of pollutants from other industries (for example pulp mill effluent Parker and Sibert (1973) and Sibert and Parker (1973)).

Water Quality Models

In relation to water quality it is necessary to distinguish between those models aimed at estimating the carrrying capacity of a water body and models for assessing the holding capacity of a water body. In the case of shellfish culture mass balance conceptional models have been developed to quantify the flux of phosphorus and nitrogen between the water column, cultivated oysters and the sediment (Sornin *et. al*, 1986; Feuillet, unpubl.data) Models have also been developed to estimate the carrying capacity of a water body to optimize shellfish production (Roland, unpubl. data) or predict what environmental changes may occur (Smeal *et al.* 1986). These models also give an estimate of the impact of the culture operation on the seston and hence the possible effects on natural populations.

Holding capacity models have been developed with the aim of minimizing adverse interactions between finfish culture operations and the water body within which they are located. Such models are generally based on estimating dilution of specific parameters (for example dissolved oxygen (Inoue *et. al*, 1966;1970; Sakamoto, 1977; Kils, 1979; Pedersen, 1982). In their simplest form dilution models assume that the modelled parameter is diluted evenly in the water passing through a culture facility (Inoue *et.al*, 1966 ,1970; Incze & Lutz,1980; Beveridge, 1984). However these models are likely to find only limited application in coastal waters and those models which attempt to assess the impact on semi-enclosed water bodies and more open coastal waters are likely to be of more use. For example Beyer and Madsen (1974) used a box model approach to model the transport of phytoplankton, dissolved oxygen, phosphorus and nitrogen in a Danish fjord. Black (unpubl. data) has attempted to model the effect of salmonid farms on dissolved oxygen levels in a semi-enclosed water body. Existing models to predict the impact of pollutants from other industries might be of use in assessing some of the environmental impacts arising from mariculture operations (see Weston, 1986a and references cited therein).

Two types of models can be developed for simulating the carrying capacity of a bay for mollusc production. The first one provides a global approach based upon the evaluation of the dynamics of the cultivated species: biomass, production, growth rate (Héral et al., 1986). The second model is an analytical model which can be sensitive to the variability of the environment. This model incorporates the flux of available food calculated with physical numerical models and the consumption, respiration, and assimilation of the molluscs is developed to predict bivalve production (Bucher and Héral, unpubl. data).

Environmental Regulations

The available information on environmental regulations as applied to mariculture situations in ICES member countries is incomplete. The Study Group decided to compile the material available at the meeting under two aspects: (a) country specific information, and (b) environmental criteria.

Regulations in various countries

Canada

In Canada both the Federal and Provincial Agencies regulate mariculture industries- The Federal Department of Fisheries and Oceans and Environment Canada regulate under the Fisheries Act and its requirement to protect the habitat necessary to maintain the wild fisheries and natural populations of fish and shellfish. The Provincial agencies are responsible for the actual allocation of water leases for culture purposes and also have a role in habitat protection. At both levels of government there are, however, regional differences in the interpretation of what is required to accomplish these tasks.

On the West coast, constraints on each application for a mariculture license are principally determined on the basis of site specific information. Regulating agencies require bivalve culture, principally of Pacific oysters, to locate where it will not conflict with traditional harvesting of wild bivalve populations and not within 125 meters of a wharf or finfish culture. The substratum under proposed finfish culture sites must be inspected to ensure no important fish habitat is being affected. As an indicator of whether an area is likely to accumulate faeces and excess feed the local substrate type (fine muds, gravel, bedrock, etc.), is considered prior to permitting culture activities to proceed. It is also required that fish culture activities locate at a distance greater than 1 km from the mouth of salmon bearing streams and that fish culture leases be no closer together than 3 km.

The approach on the East coast is different. Production per farm has been limited to that amount which can be produced from 30,000 seed fish annually maintained on a lease of no more than 2 ha in size. This is expected to yield 75 to 100 tonnes of marketable fish per farm per year. Federal regulations on this coast require that weirs be sited no less than 305 meters from each other. The same separation distance is suggested for application to the siting of fish cage culture adjacent to herring weirs and is required as separation between fish farms. In 1986, as a result of pressure from the industry, the number of seed fish limit (30,000) was scrapped and now they can produce as much as they like on a 2 ha site (number of cages also no longer limited) but separation distance is still maintained at 305 m. The maximum site area of 2 ha is also currently under review.

France

Licences for private coastal aquaculture operations are issued by the State authorities. For oysters, mussels, and clams the licence is governed by a management plan. The plan describes the culture operation's stocking density, orientation of structures and the prevailing currents. The plan also describes those permits required for temporary and/or permanent installation of the structures. The density of the culture can be reviewed on a yearly basis, and depending on productivity new stocking densities may be imposed.

There are at present no regulations specifically for marine fish production, except that combined finfish and molluscan culture is not permitted.

Finland

In Finland there is no general guideline on site selection for net cage farms. At present, the access to a particular coastal area is the most important factor that determines site selection by interested parties. Licences are required for establishing farms over a certain size (which in practice covers all of the present operations), and these are granted by the water courts (Salonen 1986). Authorities (National Board of Waters) generally limit the yearly production of a farm to a level of 30 to 50 tonnes (Turun Vesipiirin Vesitoimisto, 1984).

The Netherlands

Licences for mariculture are issued by the Ministry of Agriculture and Fisheries. The oyster and mussel farmers are free to decide how to use their leased plots. The stocking density of seed, of medium size and marketable size specimens can be adjusted in accordance with local circumstances.

Mariculture of salmonids in net cages is still in an experimental phase; no regulations for licences exists at the present time. For the Eastern Scheldt the possible sites are inventoried by the Porject Group MARIOS (Verreth and Davidse, 1984). Even an explosive growth of salmonid cage farming (up to 1,500 tonnes annually) is expected to have a negligible environmental impact on the whole Eastern Scheldt basin.

Water quality is controlled by the Mariculture Department. The monitoring programme has been set to assess the effect of the environment on the fish farm results.
Norway

Norwegian salmon cage farms are currently limited to a maximum cage volume of 8,000 m^3 per facility. There is no upper limit to the stocking density per unit volume of cage.

The increasing production rate over the last few years, together with the unutilized production potential in existing farms, have resulted in a preliminary moratorium in the granting of new licenses.

The regulations set by the veterinarian authorities ask for a 1 km separation between fish farms in order to minimize the potential for the transfer of diseases or parasites between sites. This regulation has been developed by arbitrary administrative decisions and is not based on any scientific data.

In recent years there has been a growing concern about possible of transfer of diseases and parasites from fish farms to wild salmonid stocks. There exists also a potential of genetic implications on local native salmon strains caused by intermingling of escaped farmed fish. The environmental authority has therefore established restricted areas for fish farming in fjord areas with natural salmon runs.

For new mariculture species (e.g., cod and halibut) there are currently no regulations as to the number of marine fish farms and on the minimum distance between individual farms. In the last year there has been an increase in the number of applications for marine fish farms licenses. Each license must be sanctioned by the appropriate authorities.

Portugal

Licenses for private coastal aquaculture operations are issued by the State Authorities after hearing a commission in which several Departments are presented.

Sweden

There are 3 to 4 acts which regulate aquaculture in Sweden. The County Administration examines applications with the provisions of the Environmental Protection Act and the Nature Conservation Act. The Swedish National Board of Fisheries examines applications in accordance with the provisions of the Fisheries Act. The latter act is concerned with the dissemination of diseases and the ecological consequences for the indigenous fauna if new species or foreign populations are introduced (Ackefors, 1983; Anonymous, 1983; Ackefors & Grip, 1985).

With regard to aquaculture, the basic concept in the Environmental Protection Act is to evaluate the optimal or most suitable site and to restrict environmental impact when considering available technology. Considerations should also be given to economical facts for the farmer.

To establish a farming operations, applications for licensing are divided into two categories :

(1) Farmers who intend to keep more than 10 tonnes of fish in their operations must send in their applications to the authorities. The application must first pass the Environmental Protection Act before a licence can be considered.

(2) Farmers who intend to operate at a size between 0.5 and 10.0 tonnes of fish are only obliged to inform the authorities about the planned operations.

The application from the farmers must also be evaluated in accordance with the Nature Conservancy Act. This Act regulates the protection of the seashore. In principle, areas at a distance of up to 100 m offshore and a land area of the same width from the shoreline are protected against commercial use or settlement.

The mussel operations are also divided into two categories. A plant which covers an area of at least 20,000 m^2 (including space for moorings) must be examined according to the Environmental Protection Act. Farmers who intend to utilize an area between 5,000 and 20,000 m^2 are only obliged to inform the authorities about the planned operation.

Processing plants are also covered by the Environmental Protection Act if more than 200 tonnes of fish and shellfish are processed per year.

Applications for aquaculture can also be made through the Water Rights Act. Under specific circumstances, this Act is applicable to landbased operations, in case the use of ground water or surface water is intended.

The application for aquaculture licences must be sent to both the County Administration and the Regional Fishery Office. These authorities send the application in referal to several authorities for detailed evaluation. Applications for big production units are usually handled through the Environmental Protection Board. This agency can appeal against decisions already made by the County Administration.

The aquaculture operations are included in the Environmental Protection Act because of their possible adverse effects on water quality. Discharging organic matter may also cause oxygen depletion in the water. The nutrient load in the coastal waters of the Baltic Sea, mainly from inputs other than mariculture, is already causing algal blooms. The ultimate effect of these is the depletion of oxygen in bottom waters.

The Swedish philosophy for regulating the aquaculture industry is based on the concept that the phosphorus and nitrogen load should be minimized to a level, which does not change the nutrient status of the receiving water. In freshwater the phosphorus content is checked against the Vollenweider diagramme to estimate the possible allowable amount of aquaculture production that can be accepted with regard to the water volume and the water flow. Although the Vollenweider model cannot be applied in coastal waters, the concept presently employed is almost identical. A nutrient budget is normally made in order to evaluate the extra loading of nutrients through fish farming: However, we are still in need of more detailed knowledge on the hydrodynamics within the water bodies of concern, the amount of nutrient discharged into coastal waters as well as the transformation of nutrients into different parts of the ecosystem.

Water quality in farming areas is controlled by the Swedish Food Administration and in principle, the same rules are applied as for bathing waters with regard to the number of coliform bacteria. The farming is not permitted in " blacklisted waters". Aquaculture is prohibited in waters where wild fish contain high concentrations of environmental pollutants such as mercury (or other heavy metals) and chlorinated hydrocarbons. However, it is obvious from the present experience in such waters that cultured fish which do not depend on natural food but grow on a properly fed diet accumulate little of these contaminants.

The Swedish Food Administration has introduced rules concerning withdrawal time, when antibiotics and other therapeutics are used in aquaculture. The slaughter of fish is not permitted for a certain period of time after treatment. The time limit depends also on water temperature and on the specific properties of the antibiotic.

United Kingdom

At the present time there are no regulations which require fish farms (existing and potential) to assess or monitor the ecological effects of their oporation. The Crown Estate Commissioners who administer the sea-bed for the Crown are responsible for the issuing of leases to potential fish farmers. The Commissioners have a consultative procedure before a lease is granted. This procedure involves obtaining statements conserning potential sites from a number of agencies including the British Nature Conservancy Council, but at present this consultative procedure does not include any assessment of the potential ecological impact.

Regulations regarding various environmental criteria

Sedimentation

In most types of mariculture, there are no regulations intended to prevent the accumulation of faeces, pseudofaeces or fine sediments in the area of the culture site. It is generally the growers´ responsibility to rotate sites, to till the sediment, or take whatever other steps may be necessary to maintain the suitability of the culture grounds. Finfish net-pen culture is the only form of mariculture in which governmental regulations exist to mitigate sediment accumulation.

French authorities have enforced regulations that determine the orientation of raft and tray structures for oyster culture in relation to the prevailing currents. The intent is to minimize sedimentation underneath and in between structures. The duration and time when structures have to be removed is also regulated, especially to utilize the strong winter currents to carry away accumulated sediment.

The potential for feed and faeces accumulation is generally an issue of concern in review of applications, although this review is typically qualitative without defined criteria. In countries where criteria do exist, they generally take the form of a required water depth for pen siting and a lateral separation from other habitats or resources of special concern, which are especially susceptible to sedimentation impacts. British Columbia (Canada) requires that net-pens be located in water depths of at least 10 m, be no closer than 125 m from a shellfish bed, and may not be located near eelgrass beds, herring spawning areas or other habitats of special significance. New Zealand requires that the cages be sited in water depths of at least 12 m, and that the bottom of the cages be at least 4 m from the seafloor. In the United States, the state of Washington utilizes a sliding depth scale which takes into account current velocity and facility production (see Figure 2). A distance of 6 to 18 m is required beneath the cages, with the greates distance being required for large operations in areas of weak currents. Although not formally adopted as law in Washington, applications for salmon net-pen culture are evaluated with respect to these guidelines. The State has also adopted monitoring requirements for assessment of sediment accumulation and its impacts (Table 4).

Water quality

Land-based mariculture operations in which effluent is conveyed through a pipe or similar confining structure are subject to the most intensive environmental regulation. Discharge limits may be imposed for such parameters as Biological Oxygen Demand (BOD)

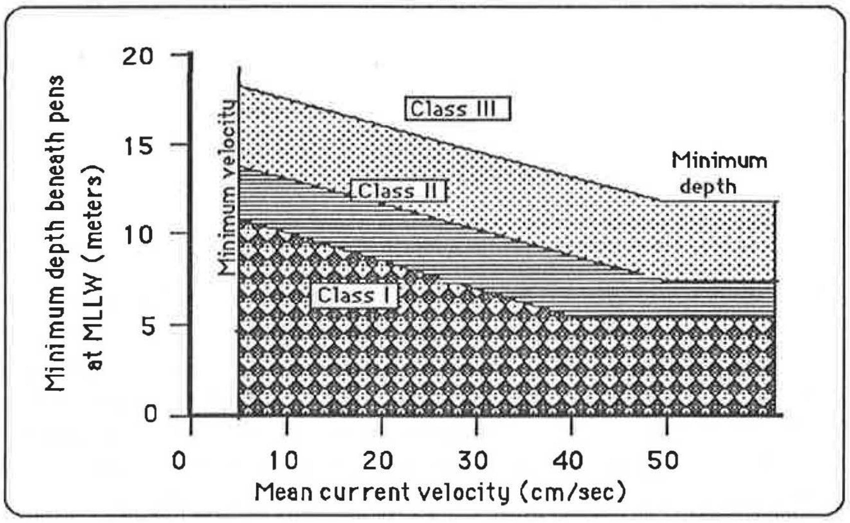


Figure 2 : Minimum depth and current guidelines for salmon net-pen siting in Washington State: Class I= production ≤ 9 t/yr; Class II = 9-45 t/yr; Class III = > 45 t/yr. (From Weston 1986b)

or total settlable solids, and the operator may be required to install settling basins or other devices to meet these limits. Most mariculture operations, however, are in open water where discharges of nutrients or BOD are less easily measured or regulated. Regulations, if any, take the form of density controls (e.g., number of operations within a given area, stocking density limits, or distance between operations) rather than pollutant removal. In Japan, standards are established by the individual prefectures to control the intensity of culture so as to prevent deterioration of the culture grounds. In Kagoshima Prefecture, for example, the hamachi culture grounds have been divided into several subareas determined by the minimum annual dissolved oxygen concentration. In Zone A, where oxygen concentrations outside the cages reach as low as 5.5 $mg \cdot l^{-1}$, stocking densities can not exceed 11 $kg \cdot m^{-3}$ and culture intensity can not exceed 40 $tonnes \cdot hectare^{-1}$. In areas with lower dissolved oxygen concentrations, stocking densities must be reduced to 7 $kg \cdot m^{-3}$ or less and culture intensity can not exceed 20 $tonnes \cdot hectare^{-1}$ (K. Fukusho, National Aquaculture Research Institute, pers. comm.).

Farm size restrictions

The Maritime Provinces of Canada have originally limited the density of salmon cage culture to no more than 24 cages and a maximum of 2 hectares per lease, however, the restriction one cage numbers has been removed while this report was under preparation and the site area of 2 ha is currently under review. In the United States, the state of Washington has placed a limit of 1 million pounds annual production per square nautical mile on salmon cage culture in Puget Sound. Furthermore, the State has established recommended limits for the maximum amount of production in specific embayments. These limits are determined by calculation of the natural flux of nitrogen in the embayment with each tidal cycle, and allowing no more than a 1 % increase in this flux attributable to cage culture.

Disease transmission

A required separation between culture operations is commonly employed both to reduce water quality impacts and to minimize the potential for disease transmission between culture facilities or between cultured and wild animals. The required separation of salmon net-pen culture facilities ranges from 500 m to 1,000 m in Norway to 1,000m in several Canadian provinces. British Columbia and Norway also have regulations requiring a minimum distance between net-pen facilities and major salmon spawning streams. The distance has been established at 1 km in British Columbia and Norway.

No regulation exists in any of the member countries that controls the separation of net cage fish culture and shellfish culture units, except in British Columbia where a separation of 125 m is required.

Transplantations and Importation

The importation of an exotic species or disease organism poses the greatest environmental risk in mariculture, for unlike other environmental effects, the consequences may be widespread and irreversible. Therefore, the importation of live animals or their reproductive products is subject to a greater degree of regulatory scrutiny than any other aspects of mariculture. Before an exotic species is approved for importation, most countries require an evaluation of the potential environmental effects of the introduction. This will include an assessment of the potential for interbreeding or competition with native species, the likelihood of the imported species establishing a self-sustaining reproducing population, and the potential for accidental introduction of pests or pathogens. If introduction of the species is approved, each individual shipment will generally require a permit from the responsible government agency. The permit will carry with it certain conditions which may include restrictions on the country of origin, visual and/or

Table 5: Environmental survey requirements for salmon cage culture in Washington state (From Weston, 1986b)

	Site Characterization Survey	Baseline Survey	Annual Monitoring
Class I Facilities (<9 t/yr)	• Recommended consultation with state and local authorities • Bathymetric survey • Hydrographic survey -current velocity and direction • Diver survey	• None	•None
Class II Facilities (9- 45 t/yr)	• Recommended consultation with state and local authorities • Bathymetric survey • Hydrographic survey -Current velocity and direction • Diver Survey	• None	• Benthic survey - Diver survey
Class III Facilities (>45 t/yr)	• Recommended consultation with state and local authorities • Bathymetric survey • Hydrographic survey -Current velocity and direction -Droque tracking -Vertical hydrographic profiling • Diver survey	• Sediment chemistry sampling • Benthic infauna sampling	• Benthic survey - Diver survey - Sediment chem. - Benthic infauna • Water quality sampling • Current velocity and direction

pathological inspections, periods of quarantine, or disinfection requirements. The number and type of permit restrictions vary widely from country to country. Among the most restrictive regulations are those of New Zealand. The government allows no importation of live, fresh or frozen fish because of concern over the introduction of disease. Only processed seafoods (e.g., canned goods) are allowed into the country. While there are regulatory pathways through which one may apply for special exemptions, the stringent requirements (e.g., two years holding time in a quarantined facility) generally render the importation of live animals for culture impractical.

The Study Group also refers to the ICES/EIFAC "Code of Pracitce on the Introduction and Transfer of non-indigenous species" and strongly recommends the strict application of the Code in member countries. It is alarming to see that despite the efforts to minimize transfers the spread of disease agents has rapidly increased.

Bacteria

There are generally no regulatory restrictions controlling the release of bacteria from mariculture facilities, other than those discussed above pertaining to the importation of bacterial pathogens. There are, however, regulations intended to protect mariculture operations from bacteria originating from other sources. Regulations of this nature are most prevalent in shellfish culture. Contamination of shellfish grounds by human bacterial and viral pathogens of faecal origin is a major concern and a common problem throughout the world. Most shellfish producing countries have adopted systems of monitoring and certification of shellfish culture grounds. Since detection and identification of all potential pathogens is difficult, standards are based upon the abundance of faecal coliform bacteria. In those culture grounds which exceed faecal coliform standards, harvest may be prohibited or the grower may be required to hold the shellfish elsewhere for depuration.

Needs for improved feeds and feeding strategies

The reduction of loading by any mechanical treatment method seems to be insufficient in mariculture. The limiting factor for primary production in the sea in general is nitrogen, and only in certain circumstances phosphorus. The nitrogen not retained in fish is mostly in soluble form and not in the settleable solids. This means that the use of sludge collecting devices in net cage farming is not practical. This was also observed in practical experiments (Leminen et al. 1986; Kehitysaluerahasto,1987).

The conclusion is that the only reasonable way to reduce the loading without restricting the production amounts or relocation is the developing of feeds and feeding techniques.

In this context the development of feeds would require lowering of the non-utilizable nitrogen content in relation to metabolizable energy. The aim is to make the protein efficiency ratio as high as possible.This is an important new viewpoint which needs to be taken into account in research on fish nutrition.

Better nutritional knowledge means better feed quality and thus also better feed conversion efficiency. The other option for improved feed conversion coefficients and reduced pollutional loads is to avoid overfeeding (see e.g. Åsgård et al., 1986). The optimization of feeding is one useful way to reduce not only nitrogen loading but also the accumulation of sludge underneath farms. The most important technical problem relates to the inaccuracy of determining the actual biomass in a fish cage. Most farmers estimate the standing stock on the basis of very unreliable figures. The development of more exact techniques to identify growth rates and total biomass without excessive disturbance of the fish too much, are urgently needed. One example on the possibilities for reducing feed losses through the development of feeding technique has recently been experimentally introduced by Norway, employing a floating pellet that is released near the bottom of the net cage.

The development of adequate feeds that allow not only for a high conversion efficiency but also lower the amount of feed wasted is also an important economic issue for the industry.

Beneficial effects of mariculture

Mariculture activities can have beneficial environmental effects. Fisheries can also profit from mariculture through enhanced production. One particular contribution to natural production is known as sea ranching. In the Baltic Sea for example, more than four million salmon smolts and about one million sea trout smolts are released annually, mostly by Finnish and Swedish hatcheries. This has lead to a remarkable development in commercial salmon and recreational sea trout fisheries in the Baltic Sea area where most salmonid spawning runs have been destroyed by various human activities. A significant salmon or sea trout fishery could not exist without the support of an extensive ranching programme. It also is noted that many fish stocks, especially salmonids would have completely disappeared from their natural area without regular stocking from hatchery produced fish. Recent development in the Pacific region (Canada and Japan) and also around Iceland indicate that appropriate ongrowing and release strategies (so-called time-size release window) will improve the efficiency of this type of fishery supportive mariculture (Bilton et al., 1984). Attention has to be paid, however, to the problems of increased fishing pressure on natural populations fished together with the enhanced stocks.

In areas of dense bivalve culture, the development of a polyculture system, which provides nutrients to extensive shellfish farming, could be considered as a possible benificial side effect in a properly managed system combining intensive and extensive operations.

Recommendations

The *ad hoc* Study Group on the Environmental Impact of Mariculture makes the following recommandations on Research and Development.

Work should be encouraged on:

- a critical evaluation of the wider use of chemicals (e.g., disinfectants, antibiotics, algicides, antifoulants) in the developing mariculture industry. An inventory should be established to include information on the types and quantities of chemicals used, the amounts used per unit of fish and shellfish produced, and national regulations controlling their usage.

- chemicals used in mariculture to determine their effects on marine organisms, persistence in the marine environment, degradation processes and products, bio-accumulation potential, stimulation of antibiotic resistance, and public health risks.

- reducing environmental nutrient loadings through the development of feeds having better conversion efficiency, protein efficiency ratios (PER-value), and physical consistencies. Studies should also be undertaken to assess the effects of husbandry practices on feed wastage.

- the effect of mariculture on bacteria including stimulatory effects on indogenous forms (e.g. *Vibrio)* and the introduction of bacteria (e.g. *Staphylococcus)* via the feed. The potential for shellfish to serve as vectors for the transmission of diseases or as reservoirs for pathogens must be evaluated. Bacterial monitoring for public health protection needs refinement to differentiate between the various sources and types of bacteria.

- sources and levels of loadings affecting critical water quality parameters, with the aim of evaluating the effects of aquaculture on spatial and temporal variation in the availablility of oxygen, hypernutrification, toxicity of ammonia and hydrogen sulphide, and particle loadings of the water column.

- waste production from emerging mariculture industries utilizing species such as halibut, turbot, cod, and sablefish.

- the effects of soluble inorganic and organic waste from mariculture on primary production and the formation of harmful algal blooms.

- the potential for enriched sediments beneath mariculture operations to serve as reservoirs for cysts of harmful algae.

-the effects of organic enrichment on the benthos, with particular emphasis on quantifying the relationship between carbon flux and consequent biological and chemical effects.

- to identify criteria for site selection to minimize alteration of benthic communities.

- to determine the "recovery time" of deteriorated cage farm sites which had been left fallow and to develop methods to shorten this period.

-methods to deal with accumulated organic sediment including procedures for deciding when the removal of sediments is necessary, appropriate removal procedures, and environmentally-sound methods of disposal.

- effects of mariculture on indigenous fauna. This work should include: (1) effects of culture activities on species composition and abundance; (2) site selection criteria to minimize impact on critical habitats such as nursery grounds or spawning areas; and (3) potential for alteration of the native gene pool by release/escape of cultured organisms.

- effect of mariculture-related structures (e.g., cages, pens, breakwaters, artificial sills) on the hydrographic regime in coastal embayments. This work should include studies to identify the effects of different configurations and sizes of culture units on the hydrodynamics, sedimentation, and water chemistry of tidal and non-tidal areas.

- development and testing of sedimentation models which predict the fate of solid wastes from mariculture facilities, and water quality models which can be used for the determination on carrying capacity for shellfish growing and the holding capacity for fish cage culture in natural water bodies. These models would be useful to resource managers.

- sediment-water column exchange of oxygen and nutrients for input to models of nutrient and oxygen balances.

Appendix 1: Country Reports

Information on the overall trends in mariculture development and on environmental issues related to aquaculture were available only from those ICES member countries who participated in the Ad-hoc Study Group meeting. Additional information was received by correspondence from The Netherlands and Denmark. The information presented provides a brief overview and is certainly in need of expansion, especially from ICES member countries not mentioned in this report. Aquaculture regulations existing in various ICES member countries are summarized in a separate chapter in the body of the report (see pp. 21-28).

Canada

Mariculture has only begun to develop into a successful industry in Canada during the last 15 years. Physiographic and hydrographic conditions vary widely from area to area. This provides unique culture conditions for different species in different areas of the country. Rapidly developing sectors of the mariculture industry are the British Columbia (B.C.) and New Brunswick (N.B.) salmonid industries, and the Prince Edward Island (P.E.I.)/Nova Scotia (N.S.) blue mussel industries (Table 6). The rapid growth of each industry is illustrated in tables 6 to 8. Environmental problems associated with the developing Canadian industry have had little investigation. Some research is underway.

Table 6: Number of mariculture sites and tonnes(brackets) produced in Canada in 1986

Species	B.C.	Quebec	Newfoundland	P.E.I.	N.B.	N.S.
Salmonids*	82 (397)	1(10)	3(19)	12(9)	27(679)	26 (79)
Oysters	336 (3700)** 3 (<1)***	8(50)	0	0	0	0
Mussels	2 (6)	4(50)	2(14)	50 (1250)	2(3)	65(545)

* *Salmo salar, S. gairdneri* in Atlantic Canada; in British Columbia mainly species of the genus *Oncorhynchus* . ** *Crassostrea gigas;* *** *Ostrea edulis;* mussels = *Mytilis edulis.*

Atlantic Canada

Growth of mariculture in the Atlantic provinces has been dramatic (Table 7). While many types of culture have shown growth at least one has disappeared. Bluefin tuna culture has failed due to lack of available seed stock.

Table 7: Growth of Mariculture Production (tonnes) in Atlantic Canada

	1980	1981	1982	1983	1984	1985	1986
Salmonids	123	114	153	274	272	284	796
Mussels	36	82	174	432	876	886	1859

On the Atlantic coast the most dramatic increase in production has been in the extensive culture of mussels. The intensive culture of salmon is perceived as having the greatest potential for environmental impacts. New Brunswick produces the largest portion of Atlantic cultured salmonids, 679of a total of 679 tonnes in 1986.

A five year production plan has been developed for salmonid mariculture (Anonymous, Department of Fisheries and Oceans, M.S., November 1985) and guidelines have been created for the physical separation of fish farms in order to minimize the potential for the spread of pathogens and pollution from the farm sites.

The potential for increased environmental impacts from salmon farming in this area is limited by its potential for growth. Competition for suitable sites in the Bay of Fundy limits the growth of the Atlantic salmonid industry to areas where the water gets no colder than -0.7°C. Further competition with the traditional herring weir fishery and a shortfall in smolt production also constrain the industry.

The impacts due to mussel culture however can be expected to grow. In this industry seed supply appears adaquate and sites are available. It appears that only market forces will determine the limits for this industry and market surpluses are not projected, even at the present rate of growth, until 1990.

Pacific Canada

- Oysters *(Crassostrea gigas)*

In 1986 the British Columbia oyster industry produced about 1,050 tonnes from 336 active sites operated by 209 growers. The 1986 values are part of a general trend and represent a 7% growth in the number of farmers and an 11% increase in the hectares cultivated relative to 1985.

In the context of obtaining the maximum benefit from the utilization of their natural resources and in order to set a fair value on the rent for usage of crown foreshore, British Columbia has developed a "Habitat Suitability Index" (HSI). Though still requiring some improvement the present HSI is usefull in evaluating the suitability of coastal areas for the culture of *Crassostrea gigas.* The model is an adaption of a methodology utilized by the U.S. Fish and Wildlife Service to document the habitat requirements for a particular species. The model was constructed from information available in the literature. Using biophysical data the model rated the aquaculture potential of a coastal area on a relative scale. The model was subsequently tested at 10 locations over a 14 month period. The output of the model was found to be highly correlated with the growth of oysters in the field; however, density dependent effects are not part of the model's considerations.

- Salmonids

The very rapid growth of the salmon farming industry in British Columbia can be seen in the increase in the total number of applications processed, the number of leases assigned and the number of eggs taken each year to support the new industry. Because the industry is in a period of rapid expansion the growth evident in both the number of active farm sites and in the number of eggs supplied to the industry has not yet been fully expressed as biomass on the farm site or as tonnage of marketed product. As most of these mariculture products require several years of growth before they are marketed it will be several years before we see the full environmental costs or financial benifit derived from the industry's development to date.

Table 7: Growth of the Salmon Farming Industry and Interest in Farm Sites in British Columbia, Canada

Year	1983	1984	1985	1986
Total number of applications	3*	23	124	501
Number of active Farm Sites	8-10	10	35	82
Tonnes Produced	128	107	120	397**
Supply of Eggs (in millions)	2.8	9.6	25	40

*Applications for marine fish farms were not recorded prior to 1984.
**estimated.

Constraints to future development of this portion of the Canadian industry do not appear to be egg supply, or site availability. Feed, financing and expertises are the more likely bottlenecks in the industry's development.

Concerns over potential environmental impacts of mariculture, particularly of cage culture of salmon, are topical. There have been numerous public meetings and articles in the popular literature where these have been discussed. In response to these and other concerns in October of 1986 the provincial government created a one man commission of inquiry to investigate salmon farming in B.C. Among the recommendations of the commission were the strong recommendations for more monitoring of and research into the effects of cage culture on the environment. There has been quick response on the part of government agencies. New environmental monitoring and siting requirements are now being implemented and financing for research is expected to increase. Inventory maps of prime finfish culture areas are also being created for sections of the British Columbia coast. As many of the criteria for the siting requirements and for identification of good areas forsalmonid culture are dependent on good water flushing, the use of this information by the industry will help to minimize environmental impacts of finfish farming in coastal waters.

Research (Atlantic)

- There is regular annual monitoring of benthic conditions in the L`Etang Inlet Bay of Fundy where twenty salmonid sites are located(Wildish *et al.* 1986).

- A physical oceanographic study of L`Etang is planned.

- There has been initiation of a seasonal study of phytoplankton species diversity and density in areas with mariculture.

- A benthic study of the impacts of salmon mariculture in Dark Harbour has been completed.

Research (Pacific)

- Studies are underway on the rate of uptake of tributyltin by oysters near marine net cages treated with tin antifoulant paints, on methods of removing tributyltin paints from netting and on depuration from the flesh of Pacific salmon.

- A field study of possible transmission of sulphamerizine from salmon feed to nearby oysters is in progress.

- A computer model of the water quality response of a fjord to salmon farming is being developed.

- There is an ongoing monitoring of water quality in Sechelt Inlet, an area of rapid mariculture development in a fjord with limited water exchange over a shallow sill.

- Monitoring of bivalve feed availability in a fjord with extensive oyster culture is under way.

- A system to warn mariculturists of the occurence of potentially harmful phyto-plankton blooms is being developed.

- Monitoring of water quality (bacterial and PSP) for growth of oysters is routinely carried out.

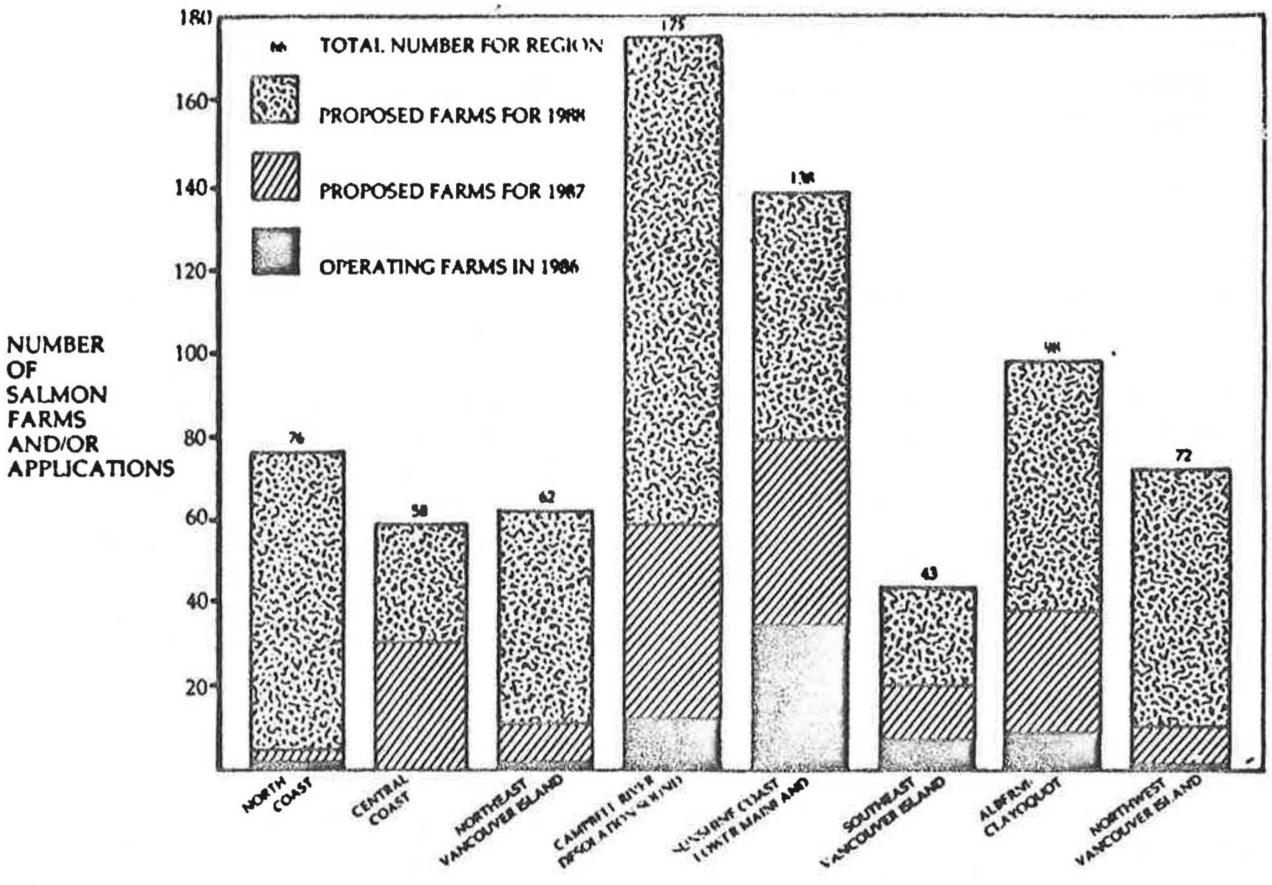


Figure 3: Number of salmon farms and/or applications and proposals in British Columbia for the years 1986 to 1988 (by regions).

Denmark (K.Nielsen)

Production trends

Mariculture in Denmark is dominated by trout production. Shellfish (blue mussels and oysters) are of minor importance. Trout are raised in cages and in land-based flow-through systems. In 1985 the number of cage farms and plants on land were 20 and 7, respectively (Hoffman, 1986). Cage farming of trout was introduced in Danish coastal waters during the late 1970s, the increase in mariculture production has been due mainly to the expansion of these few farms. The total trout production in marine and brackish waters increased from 100 t in 1978 to over 3,800 t in 1986 (Figure 4). The annual aquaculture production in freshwater amounted to about 22,000 to 22,400 tonnes in 1986 (Anonymous, 1986; Henrik Leth, pers. comm.).

Large trout of 0.5 to 1.0 kg wet weight are placed in net cages in early spring. During the summer and autumn most of the fish reach a weight between 3.0 and 5.0 kg. A few cage farms are located in relatively open sea situations, while most of the farm sites are placed in bays and fjords, which offer relative good protection against wind and wave action. The production of trout in both marine and fresh waters is limited by the environmental authorithies and, in 1987, there is a one year freeze on all new applications, and permits will not be granted before 1988.

The production of blue mussel on hanging long line systems was 700 to 1,000 tonnes in 1985 and 1986, but only about 25 tonnes of this production were harvested during the same time period. Experiments with extensive cultures of blue mussels have been carried out, but there is yet no industrial use of this system. In 1985 about 60,000 to 70,000 tonnes of "wild" mussels were harvested. The Pacific oyster *(Crassostrea gigas)* is grown on long lines and in cages. In 1985 and 1986 oyster production reached about 20 tonnes. This production was mainly achieved by one farm at one site (Hoffmann, 1986; Per Sand Christensen, pers. Comm.).

Research and Monitoring

During the one year ban on all new trout cage farm licences, environmental impact studies have been implemented at existing and proposed farm sites. After completion of these studies it is intended to prepare a national plan for cage farms. Some counties in Denmark have already developed such plans. For example, in the county of Storstrøms amtskommune, such a plan has been developed on the basis of the calculated nutrient loading produced by the farms and released into the environment. The content of total nitrogen and total phosphorus is measured in fish and feeds and a budget is computed assuming a feed conversion coefficient of no more than 2.0. An overall fish production of 100 tonnes of trout would than result in a loss of 12 tonnes of nitrogen and 2 tonnes of phosphorous (Table). On the political level it was decided that the maximum permissible nutrient loading produced by fish farms is to be expressed as a given percentage of the total load a coastal area is receiving from land based sources (Storstrøm amtskommune, 1985).

This simple method with arbitrary limits has been adopted because of the difficulties involved in detecting biological effects in marine ecosystems originating from a single nutrient source at subcritical levels. Mathematical models have not been used due to their great uncertainty of predicting responses in complicated ecological systems. Furthermore, it is felt more relevant to calculate inputs (nutrient loads) from fish farms, when the need arises to control and reduce the total nutrient loading discharged from Danish coasts into the sea.

Cage farms in Denmark are often controlled by measuring the content of N, P and organic matter in the sediment around the farms. Measurements from 7 farms in 1986 located at 5 to 15 m depth show generally no distinct increase in these parameters between May and September. These results can be explained by rapid currents, relatively low nutrient content in deposited material and fast degradation of faecal pellets. In sheltered areas, however, the growth of macroalgae seems to be stimulated and sulphur bacteria cover the sea bed around cage sites (From & Rassmussen, 1984; Storstrøm Amtskommune, in preparation).

In Denmark, the monitoring programme for toxic algae has been expanded in 1987, especially in areas where blue mussels are harvested intensively. Harvesting of mussels has not yet been prohibited as a result of toxic algal blooms in any area and season. The tendency towards hypernutrification may promote conditions for toxic algal blooms along Danish coasts and may, therefore, be considered as a future area of concern to mariculture development.

Table 8. Nutrient load from 100 tons net production assuming 200 tons fodder consumption.

	Fodder (tons)	Fish (tons)	Loss (tons)
Total nitrogen	14,9	2,9	12,0
Total phosphor	2,4	0,4	2,0

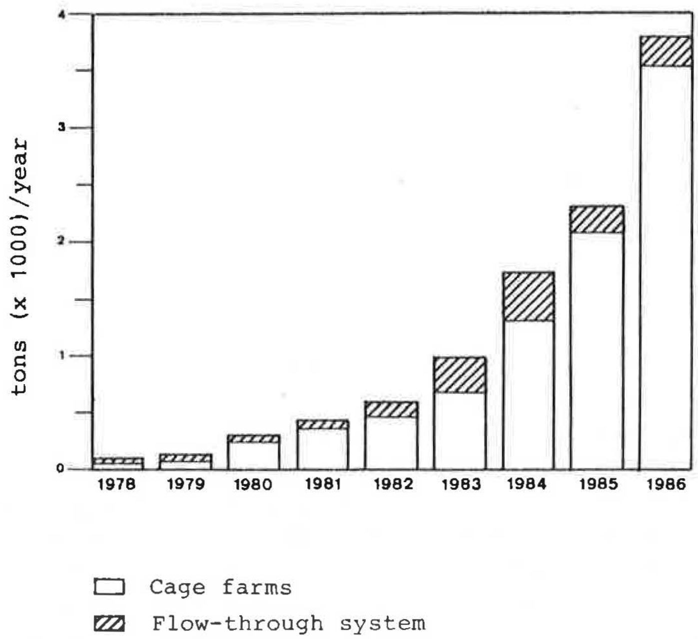


Figure 4. Production of rainbow trout in marine and brackish water.

Federal Republic of Germany (Harald Rosenthal)

Production Trends

Conventional pond farming (trout = 15,000 tonnes, carp = 8,400 tonnes, 1982) contributes the major portion of fish culture products. The number of freshwater farms has drastically increased between 1971 and 1981 (by 58%) while their average size decreased, indicating that more and more farmers share the limited water resources. Marine finfish farming is presently limited to net cage farms in power plant effluents of the Kiel Bight (Baltic coast), land-based hatchery operations for turbot production, brackish-water culture of eels in heated effluents (Emden, North Sea coast) and to a few small-scale oyster farms (total production in 1984 about 2 tonnes, 1985 about 5-6 tonnes, 1986 about 20-25 tonnes). Substantial growth was experienced in extensive mussel farming, although the number of companies operating in the inner German Bight has not changed and will most likely not expand in the near future. In the past, annual yields of blue mussels fluctuated between 11,000 and 17,000 tonnes, and this situation remained constant for more than a decade. A major increase occured in 1982, leading to a harvest of 27,000 tonnes, which increased further to 32,000 tonnes in 1983 and an exceptional level of 51,000 tonnes in 1984. Since then the production figures have levelled off around 30,000 tonnes.

Research

Research activities related to environmental concerns are carried out mainly in freshwater situations. In general, environmental issues in mariculture are restricted to water quality within farming systems, on waste heat utilization and on oxygen budgets and plankton blooms in Baltic coastal waters .

Regulations for mariculture applications are not yet harmonized in various States. Usually, interested applicants apply to the local fisheries authorities. A number of other agencies (transport, water resources, fisheries, environmental protection agencies, Island and coastal protection offices) will be involved in granting a licence. If a licence for mussel farming, for example, is issued, the farmer has to use the lease, otherwise he looses his licence immediately. There are no restrictions as to the size of the operation.

In freshwater, effluent standards have been set for land-based intensive farming systems (flow-through operations), limiting the COD and the suspended solid inputs into the receiving waters.

Finland (Timo Mäkinen, Markku Pursiainen)

Production Trends

Aquaculture has grown rapidly in Finland over the last decade. Figure 5 shows number of farms and total production during the early 1980s. Fish production of brackish water net cage farms has tripled during the 80´s. At present the approximately 7,000 tonnes of rainbow trout constitutes 70 per cent of the total aquaculture yield of the country. In the past it took three growing seasons in freshwater to produce trout of 1.5 to 2.5 kg weight. Because of the utilization of heated effluents to produce fish ready for stocking into cages, this time in freshwater is being shortenend by one year and fish spend only the first spring in the freshwater farm (average weight about 5 g). Most of the production in brackishwater cages is derived from sites in the southwestern archipelago (between Hanko peninsula SE and the city of Pori N, a 200 km long stretch of the coast with 125 fish farms, producing 6,000 tonnes annually). About 30 farms with around 2,000 tonnes annual output are located throughout the county of Åland. Future production increases are not likely to be as rapid (see Mäkinen & Pursiainen, 1987).

Finland also produces salmon fingerlings for stocking into the Baltic. The number of smolts released annually exceeds 2.5 million individuals.

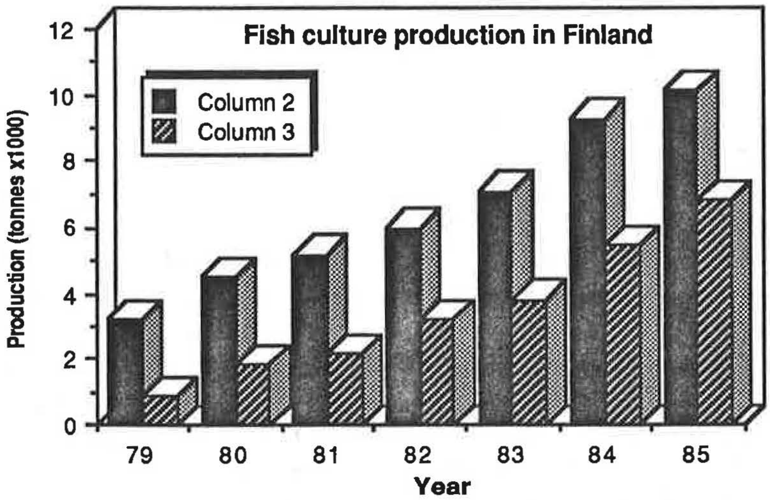


Figure 5: Development of finfish culture in Finland during the early 1980s. Column 1 = total production; column 2 = bracksihwater cage culture

Research and Monitoring Activities

Monitoring aquaculture operations is often requested by the water court, and is done by the farmers themselves. The activity covers the registration of (a) the amount of feed used, (b) the total fish stock on site, and (c) the annual production (Salonen, 1983). Monitoring water quality usually does not show any obvious negative effect in the vicinity of the fish farms (Halonen 1985). In order to gain some understanding on the effect of these farms in oligotrophic fresh and coastal brackish waters several research projects where initiated, studying the immediate - and most important - the long-term biological effects around the net cage farms. Most of the research projects include all trophic levels in their investigation, from primary production to fish community structure (e.g. Jumppanen, 1986; Hallikainen, 1986; Koivisto, 1987).

Research projects aimed at reducing the pollutional load from coastal net cage farms tend to apply methods already tested on land-based fish farms (e.g. Mäkinen & Naukkarinen, 1982; Mäkinen 1984, 1985). On the basis of the Vollenweider-Dillon model on acceptable loading levels decisions are obtained whether measures to reduce the overall load from farms in a particular area have to be implemented. Because feed composition and wastage contribute substantially to the pollution load derived from fish farms, the development of appropriate feeds and efficient feeding technologies are subjects of high priority which can lead to an immediate reduction of the problem. As an example, the phosphorus content of the feed may largely influence the amount of phosphorus released into the environment (Figure 6). To some extent, the removal of sludge accumulated under cage farms has been tested as an option to minimize environmental impact. So far, these studies have provided rather poor results (Leminen *et al.*, 1986; Kehitysaluerahasto, OY., 1987).

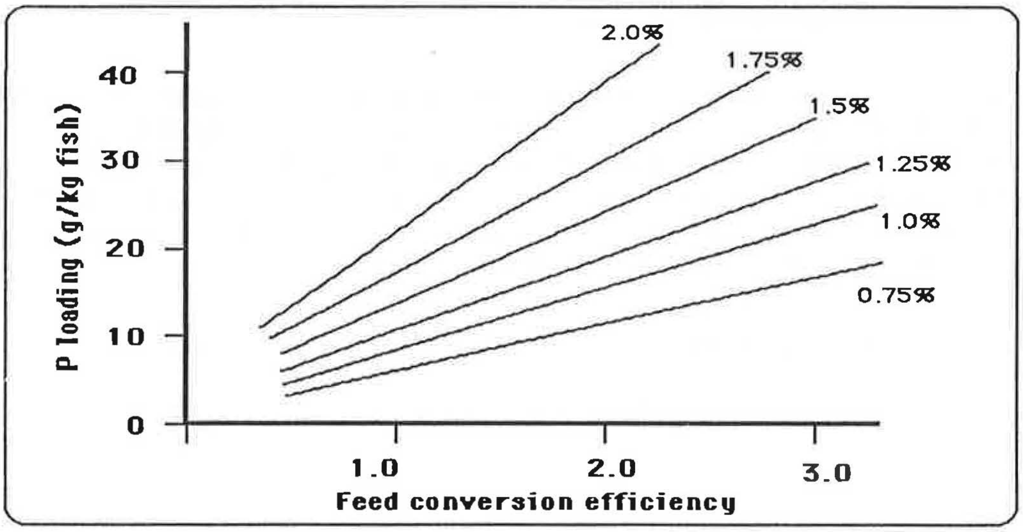


Figure 6 : Estimated phosporus loading per kg fish produced in relation to phosphorus content of feed and feed conversion efficiency (modified after Mäkinen, 1985).

France (Maurice Héral)

Production trends

The primary species utilized in oyster culture in France is the Japanese oyster *(Crassostrea gigas).* The annual production is usually above 100,000 metric tonnes (wet weight), reaching a maximum of 130,000 tonnes. Production of the European flat oyster *(Ostrea edulis)* remains low due to the epizootic disease outbreaks of *Martelia* and *Bonamia*.. The annual production of mussels *(Mytilus edulis,* and *M. galloprovincialis)* has recently reached almost 60,000 tonnes. This has been possible mainly because of the development of long-line culture in new areas. Culture of the Manila-clam *(Ruditapes phillipinium),* is an emerging industry with a yield of 500 tonnes in 1986.

The production of rainbow trout *(Salmo gairdneri)* has reached 27,000 tonnes annually; however, 98% of this figure originates from freshwater production. In 1985, marine cage farming of rainbow trout reached 500 tonnes. Coho salmon *(Oncorhynchus kisutch)* production reached 60 tonnes during the same year. Production is limited principally by the difficulties of cultivating this species in the warm summer water. The cultivation of sea bream *(Sparus aurata)* and sea bass *(Dicentrarchus labrax)* has passed the experimental phase and has recently entered commercial production (100 tonnes). The culture of shrimps *(Penaeus japonicus)* has also recently started on a commercial scale and reached an annual output of 50 tonnes.

Determination of the environmental impact of mariculture has focussed mainly on studies related to molluscan aquaculture (e.g. oysters, mussels, clams). The following aspects have been investigated:

- Development of a dynamic model for oyster carrying capacity based on historical data. The results so far show that the bay studied has a production limit which remains constant even if the total biomass of the stock increases.

- A trophic approach to determine oyster carrying capacity of a restricted area (bay, embayment), combining a physical model of the flux of particulate organic matter to show the distribution of available food. Organic matter is consumed and transferred in the production of the molluscs in accordance with energetic laws. This model will be useful in the future to predict the impact of the various inputs (nutrients, sedimentation, currents) and/or environmental alterations on molluscan culture.

- A model of nitrogen and phosphorus fluxes under oyster and mussel culture units.

- A model of biodeposition from molluscs as a function of seston and particulate organic matter.

No research programmes are in progress as related to environmental issues in marine finfish culture. However, studies on the interaction between molluscan culture and intensive fish farming have shown that bacterial contamination of oysters can occur in the vicinity of fish culture. For example, after the occurence of a furunculosis outbreak in rainbow trout (land-based tank culture), *Aeromonas* spp. have been found in cultivated oysters which were grown in the effluent of the fish farm. The problems of accumulating antibiotics and of the transfer of bacterial resistance to organisms which are pathogenic to human have been discussed.

Tributyltin (TBT), used as an antifoulant on pleasure boats, has been shown to accumulate in fish and can cause difficulties for adjacent oyster culture in the form of TBT accumulation in bivalve tissues, reduced shell growth and increasing spat mortalities

Problems of the carrying capacity of a bay for mollusc culture

Molluscan food is mainly composed of natural phytoplankton and particulate organic material. For that reason the biomass of cultivated molluscs can surpass the carrying capacity of the bay for optimum growth causing not only a significant decrease of growth rate (Figure 7) but also high mortality rates in the stocks. Such events can occur particularly in shallow bays where the residence time of the water body is long so that the quantity of natural food is rapidly depleted through effective filter feeding of the molluscs, limiting their productions. This relationship has been established for the Bay of Marennes-Oleion which is the main European center of oyster production with a mean annual production of 40,000 tonnes (total wet weight). An historical approach has been realised for the cupped oysters, Portuguese and Japanese species. The first sign of overcrowding in an area is decrease in growth rate of the population, which already has occurred for both species.

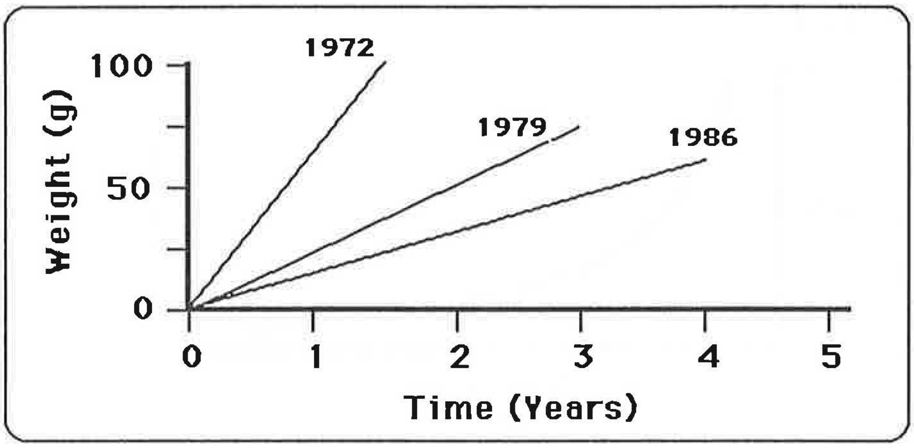


Figure 7: Changes in growth rates of the Japanese oyster *Crassostrea gigas* in the Bay of Mrennes-Oleian, an area of increased aquaculture production, during the period 1972 to 1986.

It has been shown that the changes in growth rates over the years were not caused by internal biological factors, but by overcrowding. The survey also showed that growth depression was more the result of lack of nutrition, which expressed itself in physiological mortalities during the winter and after the spawning period in summer.

The relation between total biomass of the stock (B) and production (P) shows that it follows the Von Bertalanffy function, where P_{∞} corresponds with the limit of the carrying capacity of the bay for this species. It has been demonstrated that climate does not influence this scheme but induces some variability. The evaluation of the annual turnover ratio (P/B) of the stock exhibits a negative exponential curve.

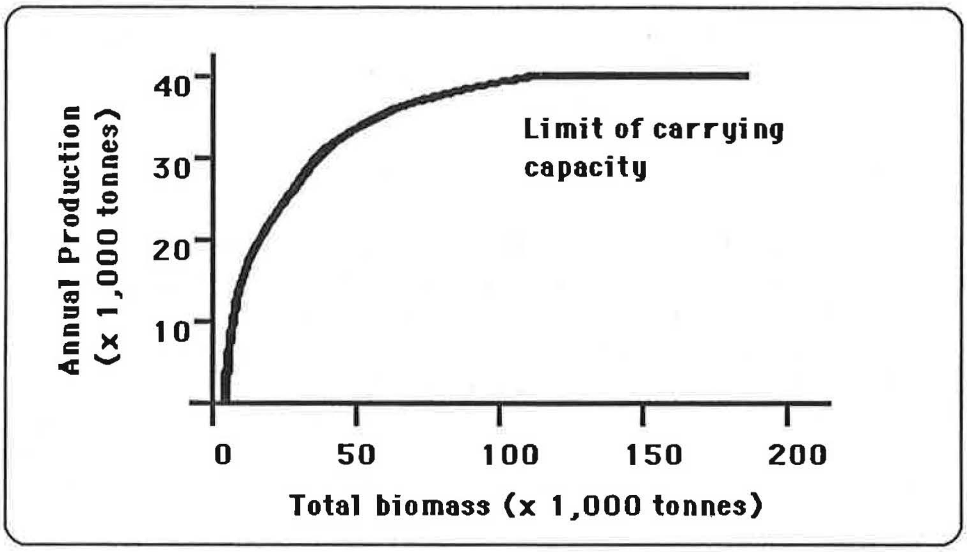


Figure 8: Relationship between oyster production and total stock biomass of the cupped oyster in the Bay of Marennes -Oleion

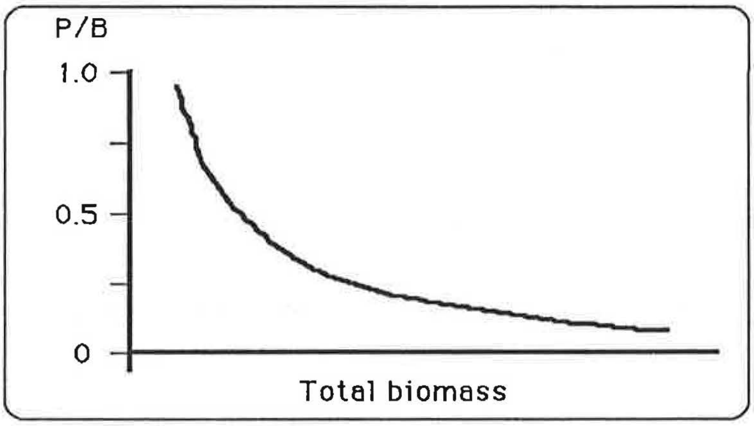


Figure 9: Principle decrease of the oyster production/biomass ratio (P/B) with increasing stocking density (total biomass).

The economic benefits of oyster culture in the bay can be considered as a function of the curve in Figure 9. All arguments show the necessity to reduce the total biomass of the stock in order to increase the efficiency of aquaculture production on extensive molluscan farming grounds. The relationship is now used practically to regulate stock size and to maximize the production and the overall economic benefits of this operation.

Norway (Jan Aure, Arne Ervik)

Production trends

In Norway salmonid mariculture has developed into a significant industry. Its annual production reached about 50,000 tonnes in 1986, and a substantial further growth is predicted with a possible output of about 80,000 tonnes in 1989 (Table 9).

Table 9: Recent production figures in Norwegian Mariculture and the projected overall production for the year 1989.

Species	Production 1986 (tonnes)	Production 1989 (tonnes, predicted)
Rainbow trout	4 300	6 000
Atlantic Salmon	45 600	74 000
Arctic Char	2	2 - 50
Blue Mussel	200	1 800
Oysters (numbers)	0.1 million	5.0 million

New species are expected to enter production in marine aquaculture in the near future. For the first time cod fry will be produced on a commercial scale in 1987 (2.0 - 3.5 million specimens), and results in experimental halibut culture are sufficiently encouraging to expect soon a commercially feasible operation. Other species of interest include turbot (a production potential of 12,000 to 20,000 tonnes has been estimated), arctic char, wolffish, mussels, scallops and oysters.

Figure 10 shows the number of salmon cage farm licences and their regional distribution in Norway in 1986. The majority of the farms can be found along the western and northern coasts. These regions are sparsely populated and anthropogenic nutrient inputs are insignificant.

Research and Monitoring Activities

Research:

Research on environmental aspects of mariculture has only recently been established. The first projects were partly descriptive and aimed at an overview on water quality variations in cage fish farms and on the effects of these farms on surrounding areas.

The present research activities are more specific, often experimental and aim at specific targets such as:

- **Optimisation of environmental conditions for fish farming.** These investigations include the following two aspects: (a) how does intensive mariculture influence water quality within the farm and in the near vicinity of the farms, and (b) how does the resulting water quality influence the farmed fish? Studies on water exchange rate, the importance of water depth, the effects of stocking density, overfeeding, and feed quality are being conducted. Further, the growth of fish, their health, and the quality of the final product are other factors that are considered. Finally, measures to control environmental factors are studied.

- **Influence of mariculture on the receiving water.** These studies include investigations on the transformation of organic compounds originating from fish farms and their environmental effects. Of central importance are flux rates between sediment and water phases, the pathways by which organic material is transformed, the trophic relations altered by the additional inputs of organics, determination of the holding capacity of an area (e.g. local fjord), and on the development of models for calculating the holding capacity.

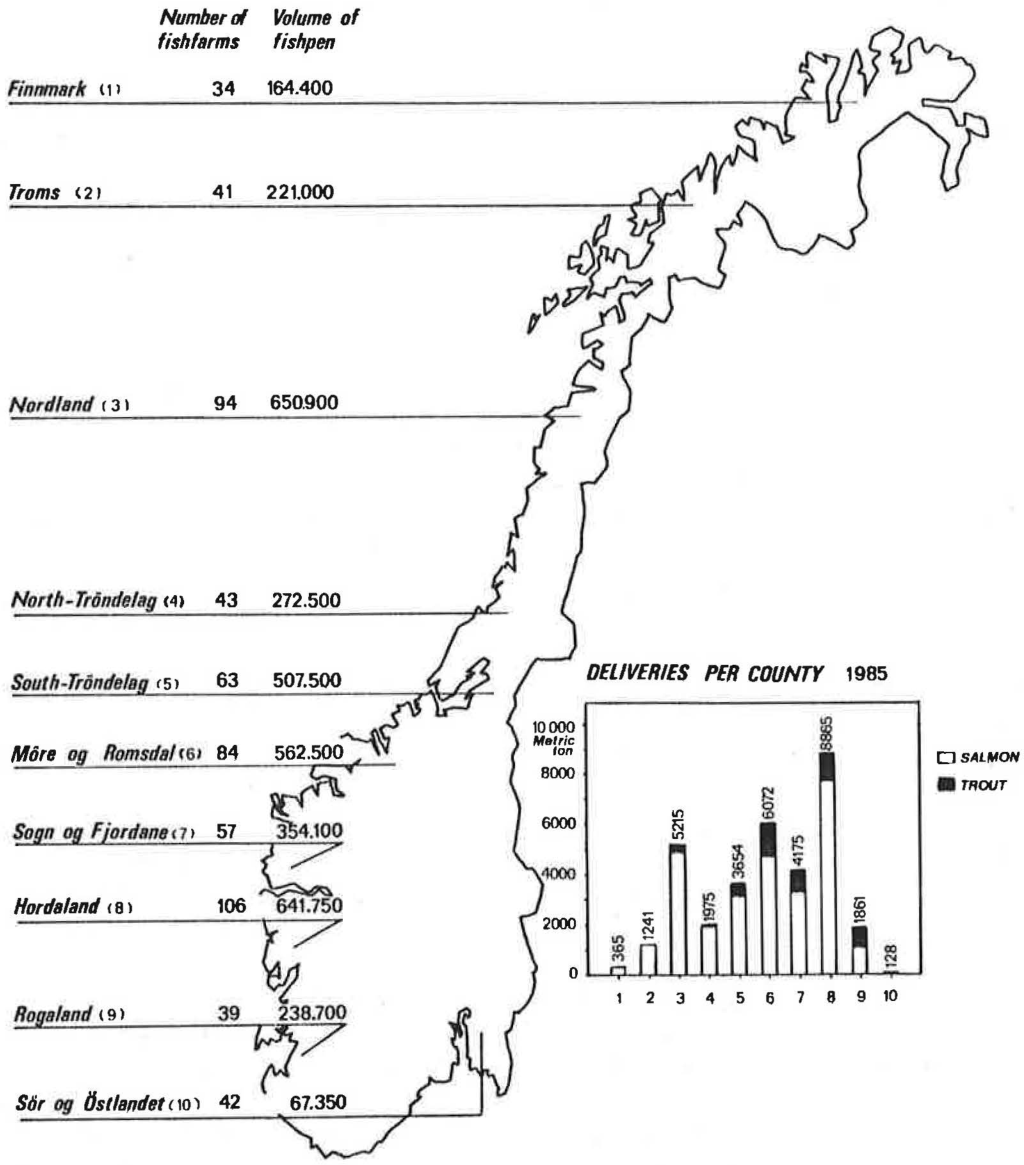
- **Effect of antibiotics on the environment.** Studies concentrate on possible pathways and their alteration, on resistent microorganisms, and on traces of antibiotics in free living consumer organisms.

- **Method for treating maricultural wastes.** Various methods to minimize waste output on farms currently are being evaluated.

Monitoring

Monitoring of water quality is not compulsory and has been imposed on only a few sensitive and contentious areas. Some fish farmers voluntarily monitor their sites with methods available to them. Hydrographic conditions in basins with largely stagnant deep water masses, have been monitored. The studies included water quality, the composition of the sediments, and the macrobenthic community.

Figure 10: Regional distribution of salmon cage farm licences in Norway in 1986.



The Netherlands (A.C. Drinkwaard)

Production trends

The Dutch mariculture industry is based on oyster and mussel culture, particularly in the Zealand streams and Wadden Sea. The Eastern Scheldt is an important storage and distribution area for fresh and processed shellfish, including the Yearseke mussel auction. Annual production capacity is: for the blue mussel 100,000 tonnes (fresh weight); the Zealand flat oyster and the japanese yoster, 20-30 million (pieces); and for the cockle, about 8,000 tonnes (meat).

Some environmental alterations have resulted from the Delta Plan. Some formerly used sea reaches, now cut off from sea, have become brackish. The eastern Scheldt storm-surge barrier has produced a reduction in tidal height, current velocities, and water residence time. Rearrangement of affected mussel plots has followed from an understanding of the modified hydrological conditions (Drinkwaard, 1986).

A former sea reach (Lake Grevelingen) is now used for setting European oyster spat. The 1986 year class may provide 20 million oysters for consumption in 1989-1990. The Yerseke Bank, Eastern Scheldt, again is in use for oyster plots (Drinkwaard, 1984, 1987). Bnoamia ostrea disease has not affected Lake Grevelingen and is now eradicated in the Eastern Scheldt. Production shifts are occurring in the Western Wadden Sea, requiring some adjustments in the leasing of oyster plots. Further potential occurs in the unexploited Eastern Wadden Sea, requiring cooperative development with nature conservancy and environmental protection authorities.

Mussel culture is influenced by a number of abiotic and biotic factors. Current velocity influences removal of faeces pseudofaeces and metabolites, the availability of food and dissolved oxygen. Changes occurring in the biotope as a result of environmental alterations, requires further research attention. In general, expansion of mussel farming in The Netherlands will depend on increased culture efficiency, rather than increased area available for mussel farming. In the Eastern Scheldt, mussel farmers are tending to move to more sheltered, deeper waters. Abiotic limiting conditions result in local structuring of mussel culture, while biotic conditions determine overall possibilities. Wise management must achieve balance where oscillations in production levels occur in regions of differing population density. A number of separate tidal basins are involved. Tidal flushing from the North Sea influences many physical, chemical and biological processes. Som of the basins are estuaries, influenced markedly by freshwater. Knowledge of the influence of mixing and flushing in embayments and for culture is hghly relevant.

From a technical viewpoint, the mariculture target is to increase and stabilize quality and yields considerably above those found naturally. One bottom culture system is to harvest (older) mussel stocks earlier, thereby reducing density and enhancing growth rate in the remaining younger generation. Then , just before the next spawning period, the remaining population is moved, and reseeding of the empty plots can begin.

European oyster *(Ostrea edulis)*

Lake Grevelingen: 500 hm^2 let to 16 oyster growers and a cooperative Society of eel fishers. In 1986, 300 million spat were collected on 5000 m^3 of mussel shells.

Eastern Scheldt: Since the 1981 outbreak of Bonamia ostrea a ban has been in place on planting flat oysters in this area. In recent years, 10-15 million parent stock oysters from Lake Grevelingen were used to supply the commercial market.

The Yereseke Bank, originally assigned 1000hm^2 for oyster farming, has been reduced by exiquencies to 750 hm^2.

Japanese oyster *(Crassostrea gigas)*

Eastern Scheldt:First experiments with this import began in 1964. After 15 years of importation, the naturalized oyster began spawning at the lower prevailing summer temperatures. Wild spat produced a good natural population. Thoughts of its removal, in 1981, were abandoned when a large natural set occurred in 1982. Introduction of the species to the Dutch fauna is now accepted. In 1986, 500 tonnes were marketed, valued at Dfl 2,375,000. The species occupies about 20 growers.

Mussels *(Mytilus edulis)*

Dutch bottom culture depends on transfer of wild seed and young stock from natural beds to private leased plots. Dredging for seed occurs in Man and October. About 75 mussel farmers are in business. Mortality is high (85 to 90% or more) in bottom culture. About 4000 million mussels are marketed annually. Inb recent years, culture efficiency appears to have decreased. One potential cause is a winter population of Eider ducks in the Dutch Wadden Sea; they eat approximately 40 % mussels, 40% cockles, and 20% other foods.

Government mussel culture leases cover 6500 hm^2 in the Wadden Sea and 2500 hm2 in the Eastern Scheldt. Culture areas in the Zealand Streams have been reduced by 1500 hm^2 in recent years. Predation and international shipments currently are below design capacity (Drinkwaard, 1987).

Dutch mussel landings and imports (1986/87) were 64,316 amd 26,587tonnes, respectively. Gross production value (1986/87) was Dfl. 64,754,000 compared with production of 64,487 tonnes valued at Dfl. 32,530,000 for 1984/85. In 1985/86, a normal season, production was 106,399 tonnes with a gross values of Dfl. 54,036,000. During that period, imported mussels were 43,104 tonnes.

Toxic dinoflagellate blooms disrupted harvesting in 1981 and 1986 (Wadden Sea and western part of Eastern Scheldt). Such blooms, and consequent market disruptions, resulted in short supply and high prices.

Cockles *(Cerastoderma edule)*

In earlier years, large year classes adversely affected settlement and growth of younger year classes. It is now recognized that 30-40 cockles per m^2 will leave sufficient spawners to reseed the population. Currently 36 dredgers are licenced, and annual production is about 50,000 tonnes fresh weight. Enhancement of production is now practiced by thinning out dense natural beds, and transfer of the exccess to leased plots for improved growth.

Rainbow trout *(Salmo gairdneri)*

Mariculture of trout has been conducted as a possible means for deversifying production in the Eastern Scheldt. Problems of mortality have occurred during smolting and during summer culture, mainly related to freshwater-seawater transfer and temperatures above 17°C. Some concerns have occurred in relation to contiquous mollusk and fish culture, where mortality has been a problem. Such risks need further examination.

Research and monitoring activities

Environmental aspects of mariculture has been studied since the 1950s. Monitoring simple environmental parameters that determine water and bottom characteristics in relation to the behaviour of the cultured animals, began much earlier. During the last decade ecological research in the Eastern Scheldt has been dominated by studies for predicting the expected biological changes during and after completion of the storm-surge-barrier. Models of hydrographical changes also have been constructed, which are now becoming useful in mussel cultivation. The question of the carrying capacity of the Eastern Scheldt als arose. Reduction of tides, longer residence and renewal time of the water, changing primary production levels, and lower food penetration from the North Sea, possible claims for damage by mussel farmers, all provided a climate for new environmental research utilizing modern techniques. From necessity we obtained a better understanding of the complex processes in the Eastern Scheldt ecosystem, in which extensive mollusc culture occurs. Such research requires much greater financing than normal hydrobiological, fishery and mariculture research institutes can afford, as we have seen until October 1986, when the storm-surge-barrier was completed. It was fortunate that co-operation became possible with the well equipped research body of the Ministry of Transport and Public Works, set up to complete environmental research in the Delta waters. For the period 1987 to 1991 research will continue as an effect study within a evaluation project by the Tidal Water Service, a new group of the same Ministry. This research body is also interested in what happens in the Wadden Sea. Establishment of computational ecological models and monitoring of the parameters needed for such models is a new expedient in managing the use of our natural resources. They can be helpful in determining what can be accepted and what must be rejected of human activities in the Wadden Sea, along the coastland and in the Eastern Scheldt.

Impacts of mariculture on the environment are not yet discussed in The Netherlands. The reason is, as far as it concerns oyster and mussel culture, that these activities are extensive and for a long time have played a dynamic role in the different ecosystems. Research on public health aspects dates back to the beginning of this century, and mariculture has been used as an indicator of sound environments. It is also recognized that the Eastern Scheldt and Wadden Sea ecosystems, supported by strong natural processes, to a certain extent are influenced by several artificial human activities. It may be that this aapproach has been necessary as half of The Netherlands is dependent on human devices to hold back the Sea. Consequently, the water level in the lowlands is adjusted to the ways of land use, including nature and landscape conservation.

For the Eastern Scheldt and Wadden Sea, endorsed priorities are drawn up in a set of aims as directives for the managing institutions. In addition to fishery and mariculture other social sectors have their interests and claims in these waters, including nature conservation, recreation, shipping, freshwater and sewage drainage and explorative drilling for natural gas. Granted, there are local differences in the hierarchy of social functions. Some nature protectionists look with distrust on mussel culture in the Wadden Sea. Yet after the coastline shortening in 1932, this area too is no longer virginal and can not be returned to that state. In any event, this was the reason the Research Institute for Nature Management, also a part of the Ministry of Agriculture and Fishery, obtained the task of helping to make the role clear.

Available mussel culture data obtained since the 1950s, when mussel culture started in the Wadden Sea, have never been used in ecological evaluations, but interest in such work is now increasing. Als studies on the effective role of several other groups of animals and plants have gained attention (variations in macrobenthos composition, throphic levels, flux rates, and nutrient and food evaluations). These studies gain importance when considering carrying- and holding capacity of an area.

The studies concerning the Wadden Sea Ecological Model are based on an integral water system, with no priory limitation to hydraulic, chemical or ecological processes. The western part of the Wadden Sea, with a surface area of 1390 km^2, has been subdivided in to 12 compartments. The ecosystem model contains, other than cockles and mussels, thwenty biological state variables, so-called eco-groups, ranging form benthic and pelagic primary producers to epibenthic carnivores such as worms, shrimps, carbs, fishes and birds. In addition the model also traces detrital pathways by incorporationg 14 detrital state variables. There are important, particularly sensitive parameters that limit the practical use of the models, to which management practice must respond adequately.

We have to aware of the fact that "the public" may be expected to have an opinion about "the environment", "the ecosystem" and perhaps about "the environmental impact of mariculture" or related environmental systems. At the end of the cockle fishera seaoson 1987 we may expect again an "environmentalist campaign", where interest groups voice their concern about "protecting the food of the birds" in "the natural food chain" (which is not natural and would not be as productive if not relayed each year and would , therefore, not naturally support such a large bird population). The quoted terms have become at least popular (if not fashion), although not necessarily involving real knowledge of what really happens in nature.

Extensive shellfish culture, including the defaunating cockle fishery, if well managed, need not create more than a ripple in the total of ecological events with yearly climatological effects of at least the same order of magnitude. Moreover, including discords in practical operation, these ripplings are of a different character than other possible menace to our waters, such as the effects of micro-pollutants aand the input of nutrient loads on a large scale.

Because of climatological effects, physical surveys and models are also important components in the process of assessing and predicting responses of ecosystems. One example is the biotic response to heavy storms and severe winters. Sometimes ice shifting over the flats, and increased current velocities in the channels and gullies below the ice fields interfere, and the whole ecosystem is stressed.

To set up a standard system for monitoring and reporting will be very difficult for mariculture exclusively. However, guidelines for a better understanding in this field can be defined. Mariculture research other than site selection and assessment of the results, concerns more specific aspects to substructure governmental generalship regarding the mariculture branch of fisheries. Support on diseases, entero-bacteria and toxic algae blooms can be given by governmantal specialists. A system of monitoring the occurrence of harmful phytoplankton blooms and the impact on the farmed bivalves has been operational for several years.

Portugal (M. A. Sampayo)

Production trends

Fish and shellfish cultivation in Portugal has a long history and includes mainly extensive culture methods. Marine fishes have been cultivated mainly in connection with salt production at the water entrance ponds serving salinas, in estuarine ponds and in coastal lagoons. Species cultured include *Sparus aurata, Dicentrarchuns labrax, Solea* sp. and *Anguilla anguilla* . Since 1975, however, there are a few additional places that produce marine fish only and this type of aquaculture has recently become a growing industry. Intensive fish culture systems are presently employed only in freshwater aquaculture, using rainbow trout and eel as the prime species.

In shelfish production the species used are *Ruditapes decussata* (clam), *Crassostrea angulata* (oyster) and recently the culture of *Penaeus japonicus* (shrimp) has been introduced.

The 1986 estimates on the overall aquaculture production in Portugal are shown as follows:

Polyculture (Mariculture)	1,000 tonnes
Clams	7,000 tonnes
Other Bivalves	1,000 tonnes
Eels	100 tonnes
Rainbow trout	1,865 tonnes

Research and monitoring activities

Research on environmental aspects of mariculture have, in the past, been sporadic and have focused mainly on water quality variations in fish ponds, shellfish beds and supporting estuaries and coastal lagoons.

Present research activities consider more specific aspects and include often an experimental part and aim at very defined key issues:

- Optimisation of environmental conditions for shrimp farming, including nutrient evaluation, benthos studies and plankton growth.

- Identifying conditions in fish ponds and studying the influence of the intake water on system performance. Consideration is given to water exchange rates and their importance on environmental conditions in the vicinity of farm sites.

- Monitoring shellfish beds from a sanitary viewpoint.

The awarness among scientists that a growing mariculture industry may face environmental problems is increasing, calling for more detailed studies to identify the extent of the problem and to seek solutions. Circumstantial evidence exists that a recent unusual localized plankton bloom (red tide) may have occurred in a succession of repeated releases of nutrient rich waters from nearshore intensive pond culture systems (near Alvor Ria, Lagos Bay, Algarve coast, in 1983) and that this event was favoured at the time by calm weather conditions.

Since most of the present and future intensive fish farms in Portugal will operate as land-based systems, regulations on possible effluent treatment requirements for new farms and/or effluent standards currently being considered.

Sweden (Hans Ackefors)

Production trends

The cultivation of fish and shellfish for the market has been very slow to develop, in part because of strict regulations based primarily on environmental considerations. Rainbow trout, salmon, arctic char, carp, eel and blue mussel are farmed for the commercial market. The 1985 production was as follow:

	Marine Production (tonnes)	Total Production (tonnes)
Rainbow trout	1,772	2,532
Salmon	81	81
Arctic char		5
Carp		1
Eel		47
Blue mussel	415	415
Total	2,268	3,081

The present production of blue mussels is about 3,000 tonnes. However, the harvesting of blue mussel has been banned many times during the two last years due to the high concentration of toxic substances (DSP and PSP) induced by algal blooms. The mussel farmers use the long line method. Vertical polypropylene strips are suspended in the water from horizontal ropes. The normal growing season lasts 18 months.

Present annual production of rainbow trout is in the order of 4,000 tonnes. About 70% of the production originates from brackish or marine waters.

Sweden currently has an extensive hatchery programme for the conservation of its fishery. Between two and three million salmon and sea trout smolts are cultivated annually and stocked in Swedish rivers. This is necessay because the natural spawning areas were destroyed when hydropower plants were built. In addition, a number of other salmonid species are raised in hatcheries to enhance sportfisheries. Most of the marine fish production takes place in net cages and only a minor part is produced on land in flow-through systems. The largest eel plant, with a production capacity of 100 tonnes per year uses a land-based technique. The eel facility employs a brackish water flow-through system and utilizes waste heat water from three sulphuric acid plants (Ackefors et al., 1986). Only one commercial eel plant is using a recirculating system.

Research/monitoring activities

Swedish authorities and scientists have been concerned with the loading of nutrients and organic matter from cage culture. In addition, chemical therapy and antibiotics in feeds have been critical issues.

A topic of primary concern was originally phosphorus input, which can increase primary production, and the input of organic matter which can cause depletion of oxygen. In recent years, research emphasis has shifted to both phosphorus and nitrogen loading, and the effect of these substances in freshwater and marine waters.

Enell (in preparation) has investigated the variation of nitrogen and phophorous in various feed types. He found that the phosphorus content varied from 14 to 20 mg P/g TS, while the nitrogen content varied from 55 to 100 mg N/g TS. The average content of phosphorus in the feed was 1.62 % of the dry matter and the content of nitrogen was 8.45 %. Wide variation in nitrogen and phosphorous was found not only between feeds provided by different manufacturers, but among batches from the same supplier. Enell (in preparation) also investigated the contents of phosphorus and nitrogen in rainbow trout (the harvest). Enell found that the average values were 1.07 % for phosphorus and 8.06 % for nitrogen on a dry weight basis, although there was substantial variation during the year.

The amount of sedimentation under freshwater cage culture operations was investigated over a three year period in eutrophic lake (Byasjön) and an oligotrophic lake (Skärsjön). The annual production of fish at each site was in the order of 20 to 40 tonnes. The amounts of sedimentation per day and m ^{2} were 20-40 g measured as dry substance and 0.4-0.6 g measured as phosphorus. At the reference stations the values were much lower although the sedimentation measured as dry substance was about 1/3 in the eutrophic lake. The redox potential in the sediment was only slightly lower relative to the reference station under the net cage in the eutrophic lake, while in the oligotrophic lake, the sediments had a far lower redox potential relative to the reference stations.

Enell & Löf (1983a; 1983b) investigated phosphorus and nitrogen flow in an open net cage operation of rainbow trout. Ackefors & Södergren (1985) used their values to show a scenario with a nitrogen and phosphorus budget for a production unit of 50 tonnes of rainbow trout. The calculated values were as follows:

A. Phosphorus

1. Production	50,000 kg
2. Feed coefficient (1.6)	
3. Feed amount	80,000 kg
4. Phosphorus in fodder (1.1 %)	880 kg
5. Phosphorus in the harvest (0.4 %)	200 kg (23 %)
6. Phosphorus dissolved in the water	97 kg (11%)
7. Phosporus particulated (sediment)	580 kg (66 %)

B. Nitrogen

1. Production	50,000 kg
2. Feed coefficient (1.6)	
3. Feed amount	80,000 kg
4. Nitrogen in fodder (7.2 %)	5,760 kg
5. Nitrogen in the harvest (2.9 %)	1,450 kg (25 %)
6. Nitrogen dissolved in the water	3,570 kg (62 %)
7. Nitrogen bound to particles	780 kg (13 %)

These figures indicate that most of the phosphorus (66 %) in the feed accumulated in the bottom mud, while only 11 % was dissolved in the water. Only 13 % of the nitrogen accumulated in the bottom while 62 % occurred as dissolved nitrogen in the water.

A device to collect the feed wastes and faeces under the net cages was constructed by a Swedish company (Enell & Löf, 1984). Funnel-shaped PVC-cloth was attached under the net cages and the waste was siphoned to a tank. The initial results were good. However, in practice this procedure has not been a success.

The water quality around a cage fish farm in the Bothnian Sea was investigated by Müller-Haeckel (1986). Criteria studied were dissolved oxygen, nitrate, phospate, particulate organic matter and the annual cycle of planktonic algae abundance. None of the investigated parameters showed significant differences between farm site and reference station.

From marine cage culture, Hall and Holby (1985, 1986) presented the first results from the Swedish west coast (Gullmar Fjord area, Bohuslän), where rainbow trout are raised in cages (15 cages, 25x35 m total area coverage) between April and December/January. The model farm produces a maximum biomass of about 40 tonnes of trout annually and cages are placed in waters of 18 to 21 m depth. Bottom sediments under the farm are always below the halocline (surface water 20-25 % S, bottom water 30-35 % S). The findings on sedimentation rate, benthic fluxes of nutrients, sediment oxygen uptake, gas ebullition and chemical composition of sediments and pore waters indicate that the top 12-15 cm of the sediments under the farm were strongly influenced by the farm, resulting into high sulphide concentrations in pore water and a high flux of sulphate, drastic enrichment of nutrients in the top layer (i.e. phosphate concentration up to 400 μM). Under the farm the organic carbon load was about 10 times the concentration in sediments near the farm, but 20 times higher than from control stations. Similar figures were found for nitrogen.

Studies on sedimentation rates using sediment traps showed that flux values ranged from 50 to 200 TPM (Total particulate matter; g/m^2 /day, dry weight) during the peak growing period (May - October), with an average value of about 115 TPM (control values for the fjord: 4-5 TPM). Phosphate was rapidly released from the sediment, being 400 times higher under the farm than 50 m outside the farm and still 40 times above values for the control station. In this study gas ebullition was measured for the first time under marine cage farms. During late summer and early fall gas ebullition rates averaged 7.9 L/m^2/day in September (Depth 19 m = 23 L/m^2/day at 1 atmosphere pressure). The gas consisted entirely of methane.

It is assumed that further studies in Sweden will provide site specific data on nutrient loads and on biological criteria identifying the areal extent of the impact.

Research has been done to find out the best selection of sites for aquaculture. One approach to this problem in a non-tidal area was taken by Håkansson (1985). This author constructed a model based on two key environmental factors: (1) the water retention time and (2) the bottom dynamic conditions. Together with co-workers (Håkansson et al., 1986a) this method was developed further to predict in a simple way a first approximation on the best location of aquacultural net cage operations.

United Kingdom (Richard Gowen)

Production Trends

The finfish industry in the United Kingdom was relatively small, with a first sale value of approximately £ 44.4 million in 1984. At present this industry is expanding rapidly. Rainbow trout production has grown from 1,000 tonnes to over 12,000 tonnes in the last 10 years. Atlantic salmon output has risen from about 20 tonnes in 1974 to over 4,000 tonnes in 1984. In 1986 the production of salmon was 12,000t. The production of salmon in marine waters takes place almost wholly in Scotland. By 1990 the annual production is expected to exceed 20,000 tonnes.

Other species farmed include eels, turbot, and carp, and with Dover sole on an experimental basis. The past production trends are outlined in Table10. Shellfish production is also listed in Table 10.

Table 10: Production trends for fin fish farming in the United Kingdom.

Tonnes (live weigth)

Year	1974	1980	1981	1982	1984	1986	1987
Atlantic Salmon	20	598	1,133	2,150	4,000	10,000	16,000
Rainbow Trout	1,100	5,707	7,001	6,700	12,500	12,000	12,000
Eels						50	50
Turbot						100	150
Dover Sole						20	20

Shellfish (1986 estimates): mussels= 500t, oysters= 300t, Scallops= 50t.

Current Research in Scotland

At present there are two projects aimed at assessing aspects of the ecological impact of fish farming.

1) Stirling University (Dept. of Biological Science) is conducting a study to assess the effect of fishfarming on the benthos and water column of Scottish fiordic sea lochs. The aim of this work is to develop guidelines or a model which would allow the potential impact of a fish farm (shell or finfish) in any location to be assessed (Gowen, *et al.* 1985; Gowen & Bradbury, 1987; Brown *et al.*, 1987).

2) The Department of Agriculture and Fisheries for Scotland (DAFS) has recently started a study to assess the level of hypernutrification resulting from salmon farming.

DAFS has undertaken studies on the effects of Tributyl tin and are about to undertake toxicity trials to evaluate the toxicity of Nuvan® (used in the treatment of sea-lice infested salmon).

United States (Don Weston)

Production trends

With the exception of extensive bivalve culture, commercial mariculture in the United States has been largely limited to a small number of salmon farms along the northeast and northwest coasts and a few shrimp culture facilities on the Gulf Coast. Production trends are presented in Table 11. Oyster culture comprises the vast majority (~80%) of total United States mariculture production. Culture of Pacific salmon (Oncorhynchus kisutch) began in the mid-1970's and continue to the present time. Culture of Atlantic salmon (Salmo salar) is presently conducted in the States of Maine and Washington, although since significant production did not begin until 1986, the species is not shown on Table 11. The table also does not reflect shrimp culture since the industry is limited to a few farms on the Gulf Coast which are still in the developmental stage and have only recently begun to attain significant yields.

Research and monitoring activities

Little attention has been given to the environmental effects of mariculture. A great deal of work was done in the 1970s on water quality effects of freshwater culture (e.g., Hinshaw, 1973; Liao, 1970; Willoughby, et al., 1972), but comparable work in mariculture has been generally lacking, or confined to the gray literature. Odum (1974) represents one of the first attempts to review available information on the effects of mariculture, but the scope of this review was seriously limited by the lack of data.

Within the past few years, a number of investigators have begun to consider the environmental consequences of continued industry growth. Some examples include:

1) The use of tributyltin has attracted much recent attention in the United States as it has around the world. Staff of the National Marine Fisheries Service have specifically studied the use of the compound as an antifoulant on salmon cages. They have found that the substance can be toxic to salmon and was responsible for the mortality of fish at one mariculture facility (Short and Thrower, 1986a). Residues of TBT were found in the flesh of market cage-reared salmon, thus providing a route of entry into the human diet (Short and Thrower, 1986b).

2) Much work has been done in the United States on diseases of cultured marine organisms (e.g., reviews of Fryer and Rohovec, 1984 and Sinderman, 1984). While most of this work has been directed towards improving the health of the cultured organisms, either by improved disease diagnosis or treatment, there has been some recognition of the environmental consequences of disease in mariculture (Sinderman, 1977).

3) Cage culture of salmon shows potential for rapid growth in the states of Maine and Washington. In Washington in particular, considerable interest has been shown on the environmental effects of cage culture including effects on the sediments and the benthic infauna, water quality, and native salmon stocks. This interest has spawned several studies at individual farms (Milner-Rensel Assoc., 1986; Pease, 1977) and a review of the literature on environmental effects of cage culture and suspended shellfish culture (Weston, 1986a).

4) The work of Stanley Katz and associates at Rutgers University represents one of the few on-going efforts to examine the environmental effects of antibiotic usage in both agriculture and aquaculture. This group has undertaken studies of antibiotic persistence in soils (Gavalchin, 1983) and surface waters (Schomburg-Barrett, 1982), and evaluated the potential for stimulation of antibiotic resistance in bacteria (Katz, unpubl.; Brady, et al., in prep.).

Table 11: Mariculture production in the United States (compiled from data supplied by Merle Broussard, U.S. Department of Agriculture and Dale Ward, Washington Department of Fisheries) All data are given in metric tonnes

Species	1980	1981	1982	1983	1984	1985
Clams	254	no data	293	766	770	720
Oysters	10775	no data	9878	10569	11135	10193
Mussels	no data	no data	165	351	416	421
Pacific Salmon	391	871	678	833	1213	1726

Sovjet Union (L.A. Dushkina)

Production

Besides ocean ranching programmes for salmonids, mariculture production along the coasts of the USSR is relatively small when compared to freshwater production.

Research activities

In order to realize cage rearing of salmonids in the coastal zone of the White Sea, the Polar Research Institute undertook studies to implement this method. Trout for stocking the cages were received from a farm near Imanda Lake, which uses heated water for rearing. The optimum weight of fish for stocking was determined and the effects of various stocking densities were evaluated in relation to various feeds. The results of the studies showed that 1-year-old rainbow trout of 100-140 g weight were the best suited size class to be planted in cages for summer growth in the White Sea. A cultivation period of 120 days during the summer yielded marketable fish weighing between 350 and 400g. Feed conversion efficiency reached a factor of 2.2. The use of automatic feeders decreased the conversion factor to 1.6-1.7. The best stocking density for cages measuring 3 x 4 x 2 m was determined to be 10 kg m^{-2}, resulting a final density at harvest of 30 to 35 kg m^{-2}. The growth rate of trout fed an experimental diet was higher (3.2-3.6 g/day) than that of trout feeding on commercial standard diets (3.0-3.1 g/day).

In 1986, research was also conducted to determine the acceleration of growth of young Atlantic salmon in order to obtain early smolts which can be stocked into sea water. The cultivation of juveniles at 12 to 14^{o} C resulted into a weight increase of the 1-year old fish in the order of 5 to 10 g in comparison to 0.8 to 1.0 g in fish raised in non-heated water. Studies of the chloride cells in the gill epithelium showed that raising in heated water had no negative effect on smoltification but enhanced the process by a factor of 2- 3.

The effectiveness of artificial reefs were further studied in the Baltic, Azov, and Black Seas. Experimental and industrial trials proved that these reefs were effective in providing protection for juvenile fish, for reproduction of some hydrobionts and for elevating the biological productivity in coastal areas. Reef communities were studied in the Azov and Black Sea, especially the development of biocenotic patterns.

The biotechnology of growing mussels in the White and Black Sea was further developed, reaching densities of 50 to 60 tons per ha. The cultivation of mussels to marketable size takes 4 years in the White Sea and 1.5 year in the Black Sea.

The impact of mussels farms on adjacent environments has also been studied. It has been shown that the composition of sediments, bottom species composition and the biomass of the benthos changed in the vicinity of mussel farms.

Appendix 2: Executive Summary

Following the adopted Resolution CR 1985/2:37 (73rd Statutory Meeting of ICES), CR 1986/2:36 (74th Statutory Meeting) an *ad hoc* Study Group on the "Environmental Impacts of Mariculture" was established in order to: (a) delineate the dimensions of the problem, and (b) recommend a course of action which will lead to a development of criteria and to a standard system of monitoring and reporting." Membership of his *ad hoc* ICES Study Group was assigned during 1986 with experts nominated from 11 member countries. The Study Group worked by corresspondance and met in Hamburg (Federal Republic of Germany) between April 7 and 9, 1987 to prepare the report. Country reports on present production figures, anticipated yields and effective regulations were received from Canada, Denmark, Federal Republic of Germany, Finland, France, Norway, Portugal, Sweden, United Kingdom, and the United States. The environmental issues addressed include (a) our present understanding of the effects of mariculture on natural microbial communities and on the possible spread of pathogens, (b) the possible changes in the natural populations of marine algae (phytoplankton and macroalgae), (c) the influence of sedimentation on the benthos, (d) the use of chemicals in mariculture, (e) site selection criteria to minimize environmental effects, and (f) the state of the art in developing predictive models of mariculture impacts. Further chapters discuss environmental regulations (as applied to mariculture situations) in various member countries, the need for improved feeds and feeding strategies, and the possible benificial effects of mariculture. Finally, a number of recommendations were formulated, as they relate to research needs and to the assessment and minimization of environmental impacts:

Recommendations:

Research should be encouraged on:

- the significance of wider use of chemicals (e.g., disinfectants, antibiotics, algicides, antifoulants) in the developing mariculture industry. An inventory should be established to include information on the types and quantities of chemicals used, the amounts used per unit of fish and shellfish produced, and national regulations controlling their usage.

- determining the effects of chemicals used in mariculture on marine organisms, persistence in the marine environment, degradation processes and products, bio-accumulation potential, stimulation of antibiotic resistance, and public health risks.

- reducing environmental nutrient loadings through the development of feeds having better conversion efficiency, protein efficiency ratios (PER-value), and physical consistencies. Studies should also be undertaken to assess the effects of husbandry practices on feed wastage.

- the effect of mariculture on bacteria including stimulatory effects on indigenous forms (e.g. *Vibrio)* and the introduction of bacteria (e.g. *Staphylococcus)* via the feed. The potential for shellfish to serve as vectors for the transmission of diseases or as reservoirs for pathogens must be evaluated. Bacterial monitoring for public health protection needs refinement to differentiate between the various sources and types of bacteria.

- sources and levels of loadings affecting critical water quality parameters, with the aim of evaluating the effects of aquaculture on spatial and temporal variation in the availablility of oxygen, hypernutrification, toxicity of ammonia and hydrogen sulphide, and particle loadings of the water column.

- waste production from emerging mariculture industries utilizing species such as turbot, cod, and sablefish.

- the effects of soluble inorganic and organic waste from mariculture on primary production and the formation of harmful algal blooms.

- the potential for enriched sediments beneath mariculture operations to serve as reservoirs for cysts of harmful algae.

-the effects of organic enrichment on the benthos, with particular emphasis on quantifying the relationship between carbon flux and consequent biological and chemical effects.

- to identify criteria for site selection to minimize alteration of benthic communities.

- to determine the "recovery time" of deteriorated cage farm sites which had been left fallow and to develop methods to shorten this period.

-methods to deal with accumulated organic sediment including procedures for deciding when the removal of sediments is necessary, appropriate removal procedures, and environmentally- sound methods of disposal.

- effects of mariculture on indigenous fauna. This work should include: (1) effects of culture activities on species composition and abundance; (2) site selection criteria to minimize impact on critical habitats such as nursery grounds or spawning areas; and (3) potential for alteration of the native gene pool by release/escape of cultured organisms.

- effect of mariculture-related structures (e.g., cages, pens, breakwaters, artificial sills) on the hydrographic regime in coastal embayments. This work should include studies to identify the effects of different configurations and sizes of culture units on the hydrodynamics, sedimentation, and water chemistry of tidal and non-tidal areas.

- development and testing of sedimentation models which predict the fate of solid wastes from mariculture facilities, and water quality models which can be used for the determination of carrying capacity for shellfish growing and the holding capacity for fish cage culture in natural water bodies. These models would be useful to resource managers.

- sediment-water column exchange of oxygen and nutrients for input to models of nutrient and oxygen balances.

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Indication of spine colours

Reports of the Advisory Committee on Fishery Management	Red
Reports of the Advisory Committee on Marine Pollution	Yellow
Fish Assessment Reports	Grey
Pollution Studies	Green
Others	Black

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