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- GESAMP -

REPORTS AND STUDIES

No. 47 1991

REDUCING ENVIRONMENTAL IMPACTS OF COASTAL AQUACULTURE

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

REPORTS AND STUDIES No.47

IMO/FAO/Unesco/WMO/WHO/IAEA/UN/UNEP
Joint Group of Experts on the Scientific Aspects of Marine Pollution
(GESAMP)

REDUCING ENVIRONMENTAL IMPACTS OF COASTAL AQUACULTURE

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1991

NOTES

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DEFINITION OF MARINE POLLUTION BY GESAMP

"Pollution means the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities".

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PREPARATION OF THIS STUDY

This document is based on the work of the GESAMP Working Group on Enironmental Impacts of Coastal Aquaculture. The Working Group met from 7 to 11 January 1991 in Kiel, Germany. The meeting was attended by Margarita Astralaga (UNEP), Brian Austin, Uwe Barg (Technical Secretary), Chua Thia-Eng (Chairman), Richard J. Gowen, Heiner Naeve (FAO), Harald Rosenthal, Heye Rumohr and Philipp Tortell. Written contributions were received from Louise Fallon and Hillel Shuval.

The Working Group was jointly sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Educational, Scientific and Cultural Organization (Unesco), the World Health Organization (WHO) and the United Nations Environment Programme (UNEP). The secretariat was provided by FAO.

EXECUTIVE SUMMARY

1. There have been substantial socio-economic benefits arising from the expansion of coastal aquaculture. However, in some coastal regions, this has caused significant ecological changes.

2. The type and scale of any ecological change associated with coastal aquaculture development will depend on the method of aquaculture, the level of production and the physical, chemical, and biological characteristics of the coastal area. Ecological change has been associated with the large-scale production of bivalves and seaweeds and the release of dissolved and particulate waste from fish, shrimp, and bivalve culture. Destruction of productive wetland habitats has resulted in the disturbance of wildlife and uncontrolled introductions and transfers have altered or impoverished the biodiversity of the receiving ecosystem. Some ecological change, such as the impact of organic waste on the seabed ecosystem, can limit production.

3. The indiscriminate use of bioactive compounds, including pesticides and antibiotics, has caused concern about their release into the aquatic environment. The health implications of the use of chemicals and the consumption of seafood grown in contaminated waters are problems of growing concern, especially in relation to intoxication by phycotoxins and infectious diseases such as typhoid fever, cholera, and hepatitis.

4. Some of the ecological and socio-economic problems encountered are due to the market failure to reflect the true cost of resource depletion and environmental change. The solution to this problem requires policy intervention at national and local level, particularly in regard to the issues of common property rights and economic incentives and deterrents needed to minimize environmental change.

5. Sustainable coastal aquaculture requires adequate consideration of the interactions among the social, economic and ecological changes. This can be achieved through an integrated approach to planning and management of coastal aquaculture within the framework of integrated coastal zone management.

6. Specific actions are essential to effectively utilize the environmental capacity of the coastal ecosystem for food production and generation of income, reducing resource use conflicts, and minimizing health risks to human consumers and adverse ecological impacts. These activities include the formulation of coastal aquaculture development and management plans, application of environmental impact assessment to aquaculture proposals, development of criteria for site selection, determination of the carrying capacity of ecosystems, establishment of guidelines governing the use of mangrove wetland, bioactive compounds, transfers and introductions, improvements in farm operation and management, regulation of farm discharges, and monitoring ecological changes, and application of regulatory measures and economic incentives or deterrents to promote sound environmental management.

Reports and Studies GESAMP

The following reports and studies have been published so far. They are available from any of the organizations sponsoring GESAMP.

1. Report of the seventh session, London, 24-30 April 1975. (1975). Rep.Stud. GESAMP, (1):pag.var. Available also in French, Spanish and Russian

2. Review of harmful substances. (1976). Rep.Stud.GESAMP, (2):80 p.

3. Scientific criteria for the selection of sites for dumping of wastes into the sea. (1975). Rep.Stud.GESAMP, (3):21 p. Available also in French, Spanish and Russian

4. Report of the eighth session, Rome, 21-27 April 1976. (1976). Rep.Stud.GESAMP, (4): pag.var. Available also in French and Russian

5. Principles for developing coastal water quality criteria. (1976). Rep.Stud. GESAMP, (5):23 p.

6. Impact of oil on the marine environment. (1977). Rep.Stud.GESAMP, (6):250 p.

7. Scientific aspects of pollution arising from the exploration and exploitation of the sea-bed. (1977). Rep.Stud.GESAMP, (7):37 p.

8. Report of the ninth session, New York, 7-11 March 1977. (1977). Rep.Stud. GESAMP, (8):33 p. Available also in French and Russian

9. Report of the tenth session, Paris, 29 May - 2 June 1978. (1978). Rep.Stud. GESAMP, (9):pag.var. Available also in French, Spanish and Russian

10. Report of the eleventh session, Dubrovnik, 25-29 February 1980. (1980). Rep.Stud.GESAMP, (10):pag.var. Available also in French and Spanish

11. Marine Pollution implications of coastal area development. (1980). Rep.Stud. GESAMP, (11):114 p.

12. Monitoring biological variables related to marine pollution. (1980). Rep.Stud. GESAMP, (12):22 p. Available also in Russian

13. Interchange of pollutants between the atmosphere and the oceans. (1980). Rep.Stud.GESAMP, (13):55 p.

14. Report of the twelfth session, Geneva, 22-29 October 1981. (1981). Rep.Stud. GESAMP, (14):pag.var. Available also in French and Russian

15. The review of the health of the oceans. (1982). Rep.Stud.GESAMP, (15):108 p.

16. Scientific criteria for the selection of waste disposal sites at sea. (1982). Rep.Stud.GESAMP, (16):60 p.

17. The evaluation of the hazards of harmful substances carried by ships. (1982). Rep.Stud. GESAMP, (17):pag.var. (superseded by Rep.Stud.GESAMP, (35))

18. Report of the thirteenth session, Geneva, 28 February - 4 March 1983. (1983). Rep.Stud. GESAMP, (18):50 p. Available also in French and Spanish

19. An oceanographic model for the dispersion of wastes disposed of in the deep sea. (1983). Rep.Stud.GESAMP, (19):182 p.

20. Marine pollution implications of ocean energy development (1984). Rep.Stud. GESAMP, (20):44 p.

21. Report of the fourteenth session, Vienna, 26-30 March 1984. (1984). Rep.Stud. GESAMP, (21):42 p. Available also in Spanish and Russian

22. Review of potentially harmful substances. Cadmium, lead and tin. (1985). Rep.Stud. GESAMP, (22):114 p.

23. Interchange of pollutants between the atmosphere and the oceans (part II). (1985). Rep.Stud. GESAMP, (23):55 p.

24. Thermal discharges in the marine environment. (1984). Rep.Stud.GESAMP, (24):44 p.

25. Report of the fifteenth session, New York, 25-29 March 1985. (1985). Rep.Stud. GESAMP, (25):49 p. Available also in French, Spanish and Russian

26. Atmospheric transport of contaminants into the Mediterranean region. (1985). Rep.Stud.GESAMP, (26):53 p.

27. Report of the sixteenth session, London, 17-21 March 1986. (1986). Rep.Stud. GESAMP, (27):72 p. Available also in French, Spanish and Russian

28. Review of potentially harmful substances. Arsenic, mercury and selenium. (in press). Rep.Stud.GESAMP, (28)

29 Review of potentially harmful substances. Organosilicon compounds (Silanes and Siloxanes). (1986). Printed in limited number only by IMO, but published also as UNEP Reg.Seas Rep.Stud., (78):24 p.

30. Environmental Capacity. An approach to marine pollution prevention. (1986). Rep.Stud.GESAMP, (30):49 p.

31. Report of the seventeenth session, Rome, 30 March - 3 April 1987. (1987). Rep. Stud.GESAMP, (31):36 p. Available also in French and Russian

32. Land-sea boundary flux of contaminants: contributions from rivers. (1987). Rep.Stud.GESAMP, (32):172 p.

33. Report on the eighteenth session, Paris, 11-15 April 1988. (1988). Rep.Stud. GESAMP, (33):56 p. Available also in French, Spanish and Russian

34. Review of potentially harmful substances. Nutrients. (1990). Rep.Stud. GESAMP, (34):40 p.

35. The evaluation of the hazards of harmful substances carried by ships: Revision of GESAMP Reports and Studies No. 17. (1989). Rep.Stud.GESAMP, (35):pag.var.

36. Pollutant modification of atmospheric and oceanic processes and climate: some aspects of the problem. (1989). Rep.Stud.GESAMP, (36):35 p.

37. Report of the nineteenth session, Athens, 8-12 May 1989. (1989). Rep.Stud. GESAMP, (37):47 p. Available also in French, Spanish and Russian

38. Atmospheric input of trace species to the world ocean. (1989). Rep.Stud. GESAMP, (38):111 p.

39. The state of the marine environment. (1990). Rep.Stud.GESAMP, (39):111 p. Available also in Spanish as Inf.Estud.Progr.Mar.Reg.PNUMA, (115):87 p.

40. Long-term consequences of low-level marine contamination: An analytical approach. (1989). Rep.Stud.GESAMP, (40):14 p.

41. Report of the twentieth session, Geneva, 7-11 May 1990. (1990). Rep.Stud.GESAMP (41):32 p. Available also in French, Spanish and Russian

42. Review of potentially harmful substances. Choosing priority organochlorines for marine hazard assessment. (1990). Rep.Stud.GESAMP, (42):10 p.

43. Coastal modelling. (in press). Rep.Stud.GESAMP, (43)

44. Report of the twenty-first session, London, 18-22 February 1991. (in press). Rep.Stud.GESAMP, (44). Available also in French, Spanish and Russian

45. Scientific strategies for marine environmental protection. (in press). Rep.Stud. GESAMP, (45)

46. Review of potentially harmful substances. Carcinogens: their significance as marine pollutants. (in press). Rep.Stud.GESAMP, (46)

47. Reducing environmental impacts of coastal aquaculture. (1991). Rep.Stud. GESAMP, (47):35 p.

48. Global changes and the air-sea exchange of chemicals. (in press). Rep.Stud. GESAMP, (48)

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1. INTRODUCTION

Aquaculture is the farming of aquatic organisms, including fish, molluscs crustaceans and aquatic plants (see FA0, 1990). The geographical area covered by the term "coastal" includes the shoreland influenced by the sea, the water column and the seabed extending to the edge of the continental shelf (Sorensen *et al.*, 1984). In this report the term "coastal aquaculture" covers land-based and water-based brackish-water and marine aquaculture practices.

Aquaculture production is rapidly increasing worldwide and at present constitutes approximately 12% of the world's fishery production. FAO (1990a) estimated that 56% of the 14.47 million tonnes of aquaculture production in 1988 came from the brackish and marine environment. Over 90% of molluscs, crustaceans and seaweeds were derived from coastal aquaculture, with 95% of this production being derived from 20 nations. Total world production through aquaculture is expected to attain 22 million tonnes by the turn of the century (FAO, 1989) with a substantial proportion of this derived from coastal aquaculture.

Small-scale coastal aquaculture has been a traditional and sustainable practice in many countries. The levels and patterns of coastal aquaculture practices vary according to the species cultured, sites and methods of farming. There is, however, a trend towards intensification which is usually driven by market forces and competitive use of the resources. This trend is expected to continue for the forseeable future although at present a large proportion of coastal aquaculture is still extensive or semi-intensive. In Asia most brackish-water farms collectively cover a large area, but are individually small and poorly managed. The majority of existing coastal aquaculture is undertaken for profit rather than subsistance farming. It is clear that there has been substantial benefits arising from the expansion of coastal aquaculture.

However, the rapid expansion in some coastal regions has caused ecological impacts such as enrichment and changes in the biodiversity of coastal ecosystems which in turn have had important socio-economic consequences. In general, ecological impact results from a lack of adequate coastal planning, management and consideration of the environmental compatibility of particular sites. Often, mitigating measures have not been considered or have proven to be ineffective and/or prohibitively expensive. In some cases ecological change is irreversible or recovery from an impact slow.

While most of the coastal aquaculture activities are located in Asia, North America and Europe, a substantial number of heavily financed projects are being implemented in Latin America and also, to some extent, in Africa. The potential negative impact due to badly planned and unco-ordinated development in these regions may soon become obvious.

It should be noted that existing aquaculture has been seriously affected by pollution caused by land-based and coastal developments. Furthermore, in some countries, further expansion of coastal aquaculture is limited by the availability of suitable sites.

Some of these problems may be overcome by improvements in technology (such as the development of offshore fish farming), nonetheless, there is an increasing need for coastal zone management to ensure that aquaculture developments are fully integrated into ecological and socio-economic structures of coastal regions. This report analyses the impacts of coastal aquaculture practices and provides guidelines for environmentally sound management of coastal aquaculture.

2. ECOLOGICAL IMPACTS OF COASTAL AQUACULTURE DEVELOPMENTS

The type and scale of any ecological change associated with coastal aquaculture development will depend on the method of aquaculture, the level of production and the biological, chemical and physical characteristics of the coastal area.

Some impacts such as enrichment of benthic ecosystems have been studied in detail, others for example, the genetic interaction between farmed and wild salmonids and the ecotoxicology of the many chemical compounds used in aquaculture are either poorly understood or perceived as potential impacts. Reviews by Austin and Austin, 1987; Rosenthal *et al.*, 1988; Gomez *et al.,* 1989; Sen Gupta *et al.*, 1989; Gowen *et al.,* 1990 and Gowen *et al.,* 1990a provide general discussions of many of these impacts.

2.1 Enrichment

The release of soluble inorganic nutrients (nitrogen and phosphorus) from intensive fish and shrimp farming has the potential to cause nutrient enrichment and eutrophication (increase in primary production) of a water body. It has also been suggested that the release of dissolved organic compounds together with other components of the diet such as vitamins could influence the growth or toxicity of particular species of phytoplankton (Gowen and Bradbury, 1987, and references cited therein). There are examples of eutrophication of lacustrine waters as a result of fish farming, but few examples from coastal waters. At the present level of coastal fish farming, nutrient enrichment and eutrophication of open coastal waters is unlikely, but could occur in semi-enclosed coastal embayments (fjords, inlets and lagoons) which have restricted exchange of water with more open coastal waters. One example of an increase in phytoplankton biomass attributed to nutrient enrichment by fish farming is from a sheltered archipelago in Finland (Isotalo *et al.*, 1985). Increasing eutrophication can lead to ecologically undesirable consequences and there is the possibility that waste released from fish farms could stimulate the growth of species harmful to farm stock (Nishimura, 1982). During the last decade, there have been many instances of mass mortality of farmed fish caused by the occurrence of harmful algae (see for example Tangen, 1977; Jones *et al.,* 1982). There, is however, no evidence that the occurrence of these harmful events was due to the release of waste-compounds from the fish farms.

The equilibrium increase in dissolved nutrients can be estimated using a simple mass balance approach and relating the output of nutrients to the volume and flushing time (dilution rate) of the water body (Gowen *et al.*,1989). Such estimates must be regarded as approximate because the method assumes complete dispersal (which is often not the case in large embayments) and also fails to account for incomplete exchange for example, Gowen *et al.*, 1983 estimated that approximately 50% of the water leaving a small sea-loch on the ebb tide returned on the flood.

The deposition of organic fish farm and bivalve waste has been shown to cause enrichment of the benthic ecosystem in the vicinity of the aquaculture operation. The changes which take place include: the formation of anoxic sediments (Brown *et al.*, 1987) with, in extreme cases, the release of carbon dioxide, methane and hydrogen sulphide; increased oxygen consumption by the sediment (Kaspar *et al.*, 1985) and efflux of dissolved nutrients (Enell and Löf, 1983; Blackburn *et al.*, 1988); and changes in the community structure of the benthic macrofauna (Brown *et al.*, 1987; Ritz *et al.*, 1989; Weston, 1990). With respect to changes in the macrofauna the effects range from a reduction in diversity and increase in opportunistic, pollution tolerant species (Weston, 1990) to the complete absence of macrofauna (Brown *et al.*, 1987). The release of hydrogen sulphide gas, together with hydrogen sulphide dissolved in the water has been held responsible for a deterioration in the health of farmed fish (increased stress, reduced growth, gill damage and even mortality) and loss of production (Braaten *et al.*, 1983). A high level of enrichment leading to what has been termed souring of sites has been reported from a number of fish farms in several countries. For example, it has been estimated that 30% of oyster and mussel farms in France are periodically abandoned or relocated because of the accumulation of biodeposits (Sornin, 1979). These are clear examples of how production can exceed the capacity of the site to assimilate the amount of waste generated and how ecological change can limit the long-term viability of a site.

Lumb (1989) provides guidelines on the siting of fish farms which can be used to gain a qualitative assessment of the impact of organic fish farm waste on the benthos. However, Hagino (1977) and Gowen *et al.* (1989) present predictive models which have been specifically formulated to predict the dispersal and input to the benthos of organic waste from cage fish farms. In a more general context GESAMP (1986) provide a discussion of the pathway for assessing the impact resulting from the discharge of sediment.

2.2 Interaction with the food web

The large scale, extensive cultivation of bivalves can interact with the marine food web in two ways. Firstly, by the removal of phytoplankton and organic detritus and, secondly, by competing with other planktonic herbivores.

Imai (1971), for example demonstrated that the culture of 50,000 - 60,000 oysters reduced the amount of seston (predominantly phytoplankton) by between 76 and 95%. It is therefore possible that the siting of bivalve farms in coastal embayments could reduce the natural productivity of the embayment.

Bivalve grown by suspended culture methods will compete with other planktonic herbivores. For example, Tenore *et al.* (1985) found that in the Ria de Arosa of Spain mussels have replaced copepods as the main pelagic grazing organisms. In addition, the culture structures provided a substrate for the crab *Pisidia longicornis*, the larvae of which also competed with copepods as a planktonic herbivore.

The carrying capacity of a natural ecosystem is the maximum production of a species which can be maintained by naturally available food resources (Rosenthal *et al.*, 1988). This particularly applies to the production of bivalves. Carrying capacity can be assessed by evaluating historical records of bivalve culture (Héral, 1988), measuring the availability of phytoplankton biomass or undertaking more sophisticated studies of carbon flux through the food web (Rodhouse *et al.*, 1985). Furthermore, models have been formulated to predict the carrying capacity of some coastal areas (see for example Héral *et al.*, 1989), the general principles of which hold true for any coastal area.

2.3 Oxygen consumption

Aquacuture production can be limited by the availability of oxygen (Rosenthal *et al.*, 1988). An assessment of this limit for an embayment can be obtained by establishing a mass balance. That is, comparing the oxygen demand of the stock to the pool of available oxygen and the rate of supply. With respect to oxygen, there have been some attemps to model the production potential in relation to aquaculture development (Black and Carswell, 1989; Aure and Stigebrandt, 1989).

In addition to the oxygen demand by the cultured species, wastes and biodeposits released by a farm have a high biochemical oxygen demand. Deposition of organic waste increases the consumption of oxygen by the sediment and can result in oxygen depletion of the bottom water (Tsutsumi and Kikuchi, 1983). A reduction in the concentration of dissolved oxygen in water passing through cage farms has also been reported (Rosenthal, 1983). In general, however, large-scale depletion of oxygen in coastal waters is unlikely. While the small, short term reduction in the concentration of oxygen in water passing through cage farms is important to the farmer, it is probably not ecologically significant.

One possible exception to the above is in low energy coastal environments such as the deep basins of some fjords and inlets. In such locations the retention of deep water within the basin for a period of time (months to several years) results in a natural depletion of oxygen (Gade and Edwards, 1980). The deposition of waste would increase the oxygen deficit. This potential problem has been recognised in several countries. In Norway for example, only a low level of aquaculture production is allowed in fjords with deep isolated basins and this is restricted to the shallow, relatively well flushed near shore areas.

2.4 Disturbance of wildlife and habitat destruction

All forms of aquaculture have the potential to affect wildlife. Human activity can be disruptive in the vicinity of important breeding colonies and feeding grounds, while the aquaculture facility itself can attract predatory species. For example, in Germany cormorant populations have increased as a result of pond farming. However, there have been few detailed studies of the ecological effects of aquaculture operations on wildlife.

The impact of some forms of aquaculture on wildlife habitat is better documented (Paw and Chua, in press). For example 200,000 hectares of mangrove have been destroyed in the Philippines (Gomez *et al.*, 1989) and in Thailand an estimated 25% of the mangrove resource has been lost as a result of aquaculture development.

Coastal wetlands are amongst the most productive ecosystems and are important in sustaining the ecological integrity and productivity of adjacent coastal waters. Mangrove areas, for example, are important nursery grounds for many commercial fish and shrimp species (Linden, 1990, and references cited therein).

2.5 Interaction between escaped farmed stock and wild species

The rapid development of marine cage farming of salmonids in Europe has raised concerns about the impact of escaped fish on natural populations. It has been suggested that farmed fish have been selected for traits which make them suitable for farming (for example, rapid growth and placid behaviour) but less well adapted to the natural ecosystem. Thus, escaped fish could initially outcompete native stocks, but then decline, or the progeny resulting from interbreeding could be poorly adapted to the ecosystem.

There is insufficient information available to judge whether the interaction discussed above is a serious ecological impact. It is known that farmed fish do escape and that the numbers of escapees can be large. Some countries have initiated studies to address this issue and in recognition of the potential problem Norway prohibits the siting of salmon farms within 30 km of important salmon rivers.

2.6 Introductions and transfers

A number of fish, invertebrate and seaweed species have been transferred or introduced from one region to another for aquaculture purposes. A distinction has been made between the two kinds of movements which differ in their purpose and potential effect (Welcomme, 1988).

Transfers take place within the present geographical range of a species and are intended to support stressed populations, enhance genetic characteristics or re-establish a species that has failed locally.

Introductions are movements beyond the present geographical range of a species and are intended to insert totally new taxa into the flora and fauna.

The problems associated with transfers and introductions have been well studied and recorded (Rosenthal, 1976; Hoffman and Schubert, 1984; Welcomme, 1988a; Munro, 1988; Turner, 1988). These movements can pose risks to human health, the integrity of ecosystems, agriculture, aquaculture and related primary industries. The ICES/EIFAC Codes of Practice and Manual of Procedures for Consideration of Introductions and Transfers of Marine and Freshwater Organisms (Turner, 1988) discusses each of these risks in detail. Transfers and introductions may alter or impoverish the biodiversity of the receiving ecosystem through interbreeding, predation, competition for food and space and habitat destruction (Folke and Kautsky, 1989).

Examples of the type of disease problem which have arisen in the past from such movements are illustrated by the transfer of salmon smolts from Sweden to Norway and Finland, the introduction of infected ova of coho salmon *(Oncorhynchus kisutch)* from the USA and the introduction of Japanese oysters *(Crassostrea gigas)* to France (Munro, 1988).

2.7 Bioactive compounds (including pesticides and antibiotics)

Bioactive compounds should be considered as part of overall disease control strategies. However, it is accepted that many bioactive compounds, including pesticides and antibiotics, are used extensively in coastal aquaculture as the sole means of disease or pest control (see Austin and Austin, 1987). Indeed, the success or failure of aquaculture may in certain circumstances depend on the timely use of such bioactive compounds to combat infectious diseases and parasites. In general, the use of such compounds in aquaculture is haphazard, often reflecting the whims of the aquaculturist or disease adviser. Environmental issues centre on:

- The longevity of inhibitory compounds in animal tissues;
- The fate of bioactive compounds in the aquatic environment;
- The development and transfer of resistance in microbial communities.

2.7.1 Longevity of inhibitory compounds in animal tissues

There is an increasing literature indicating that bioactive compounds linger in animal tissues for greater periods than had hitherto been recognized. For example, McCracken *et al.* (1976) established that the antibiotic trimethoprim remained in rainbow trout muscle for 77 days after the cessation of treatment. After statistical modelling, Salte and Liestøl (1983) recommended that for rainbow trout maintained at a water temperature of > 10°C a withdrawal period of 60 days is necessary when using antibiotics such as oxytetracycline and potentiated sulphonamides. This period is much longer than normally practiced in aquaculture.

2.7.2 Discharge of inhibitory compounds in the aquatic environment

The widespread use of inhibitory compounds in aquaculture has generated fears about the potential release of the bioactive component into the aquatic environment. In the case of antibiotics, this could damage biological filters in recirculating systems. Recent published data suggest that only 20-30% of antibiotics are actually taken up by fish from medicated food; thus, approximately 70-80% reaches the environment (Samuelsen, 1989), notably from uneaten medicated food (Jacobsen and Berglind, 1988). With oxytetracycline in seawater, it has been established that degradation proceeds rapidly (Samuelsen, 1989). However, most oxytetracycline becomes bound to particulates, and is deposited at the bottom of (or beneath) the fish holding facilities in the case of marine cage sites. Within the sediments, oxytetracycline may remain in concentrations capable of causing antibacterial effects for 12 weeks after the cessation of treatment (Jacobsen and Berglind, 1988). Such antibiotic containing sediment affects the fauna. For example, detectable levels of oxytetracycline have been found in blue mussels (*Mytilus edulis*) which were located 80 m from a fish farm using this antibiotic (Møster, 1986).

The problem with pesticides is incompletely understood. Certainly, large quantities of a diverse range of natural and synthetic chemicals, including dichlorvos, malachite green, derris root, and tea seed cake, are used in coastal aquaculture worldwide. To illustrate the extent of the problem, it has been determined that during 1989 3,488 kg of dichlorvos was used in Norwegian fish farms to control infestation by salmon lice. Evidence for some compounds, such as dichlorvos, has shown that some of these chemicals have adverse environmental effects, and, therefore their use in coastal aquaculture must be carefully assessed. The fate of such compounds should be properly addressed.

2.7.3 Development of antibiotic resistant microbial communities

A problem is the development and spread of antibiotic resistance among members of the native aquatic microbial communities. It has been determined that the administration of medicated food has a dramatic effect on the microbial populations within the digestive tract of the aquatic animals (e.g. Austin and Al-Zahrani, 1988).

Plasmids (= extrachromosomal self-replicating elements of DNA), conferring antibiotic resistance properties, abound in fish pathogens and native aquatic bacteria, particularly those in the vicinity of fish holding facilities (Austin and Austin, 1987). Workers have provided evidence of a widespread resistance to antimicrobial compounds (including numerous cases of multiple resistance; see Aoki, 1989) among fish pathogens, notably *Aeromonas hydrophila*, *Pasteurella piscicida*, *Streptococcus* spp. and *Vibrio anguillarum* (Aoki, 1989). It is conceivable that plasmid-mediated antibiotic resistance could be transferred to bacteria of human and veterinary significance. Initial unpublished work has suggested that antibiotic resistance may indeed be transferred between related bacterial groups. Fortunately, cessation of treatment appears to lead to a rapid decline in the levels of antibiotic resistant micro-organisms in the aquatic environment.

2.8 Chemicals introduced via construction materials

Some construction materials release substances into the aquatic environment (e.g. heavy metals, plastic additives). Their presence is unknown to most of the farmers, although awareness is increasing. Frequently preservatives have been intentionally used assuming that they are relatively harmless to the cultured species. These include antifoulants, of which the broad ecological effects of tributyltin (TBT) is a good example (GESAMP, 1989). Plastics contain a wide variety of additives including stabilizers (fatty acid salts), pigments (chromates, cadmium sulphate), antioxidants (e.g. hindered phenols), UV absorbers (benzophenones), flame retardants (organophosphates), fungicides and disinfectants. 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. Mortalities in coastal aquaculture have resulted from toxicant leaching from construction materials, and the environmental effects of these toxicants remain largely unresolved. At the present time there are few standards regulating the composition of materials used in aquaculture facilities.

2.9 Hormones and growth promoters

An increasing number of hormones and growth promoters are used to alter sex, productive viability and growth of culture organisms. Although many studies have been undertaken to describe their physiological effect in the target organism, studies of their wider ecological impact have not been undertaken.

3. IMPLICATIONS FOR HUMAN HEALTH

The implications of aquaculture development for human health assume importance in some geographical areas, but may gain further significance in the future. Many outbreaks of human diseases have been associated with marine fishery products, especially those from wild stocks. Similar problems can result from aquaculture due to poor management.

Much of aquaculture is practised in coastal waters which are subjected to organic pollution. Toxic algal events (blooms) are common in many parts of the world. The consumption of raw or partially cooked fish and shellfish from affected areas is likely to cause diseases due to pathogens or toxins (Shuval, 1986).

3.1 Outbreaks of disease associated with the consumption of shellfish

3.1.1 Typhoid fever

Many epidemics of shellfish-associated typhoid fever occurred in Europe and the USA at the turn of the century. The recognition of shellfish as a vehicle for enteric agents resulted in some modifications of sewage disposal practices, with the lessening of marine pollution. The clear risk of transmission of typhoid fever by bivalves growing in sewage contaminated water was well-established during the early years of this century and served as the basis for the establishment of shellfish sanitation programmes in the UK and in the USA. These programmes were based on approved, clean harvesting areas and shellfish self-purification in clean-water holding tanks, termed "depuration". The subsequent disappearance of epidemics of typhoid fever, transmitted by shellfish, may partially be a result of the success of these programmes (Mosley, 1974).

3.1.2 Infectious hepatitis and other viral diseases

Mosley (1974) reviewed the epidemiological aspects of transmission of infectious hepatitis (IHA) and other virus diseases by shellfish. Epidemics of IHA have occurred in Germany, Sweden and the USA. These outbreaks occurred despite simple sanitary improvements which were sufficient to eliminate shellfish-associated typhoid-fever. The occurrence of shellfish-associated hepatitis is not confined to eating raw molluscs, because steaming as usually practiced fails to raise the internal temperature sufficiently to inactivate the viral agent (Koff and Sears, 1967).