Environmental Management Guidelines, No. 19

ENVIRONMENTAL GUIDELINES FOR

Fish Farming

UNEP

UNITED NATIONS ENVIRONMENT

ENVIRONMENTAL GUIDELINES

1. Pesticide Use on Industrial Crops
2. Irrigation in Arid and Semi-Arid Areas
3. Watershed Development
4. Pulp and Paper Industry
5. Hides and Skins Industry
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Fish Farming

United Nations Environment Programme, Nairobi, 1990

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Foreword to the series

It has been our concern, shared by other bodies and agencies within and outside the United Nations family, that development projects and programmes should take account of basic environmental parameters and constraints. It is clear that broad-based sustainable development is not feasible, especially in the long-term, without sound environmental assessment and management.

There are many pitfalls to be avoided in initiating development activities and many opportunities that can be availed of without much additional cost. Experience during the last ten years has shown that remedial measures must be incorporated, if they are to be effective, in the conceptual and design stages of projects. The same applies to planning procedures. Later attempts may prove to be only cosmetic, as ecosystems are fragile and complex and may not recover from the stresses to which they are exposed.

Prepared by UNEP, in close consultation with the United Nations specialized agencies concerned, the first six guidelines were jointly financed by UNEP and UNDP. They were adopted by UNDP and distributed to the UNDP Resident Representatives. The remaining guidelines in the series have been prepared by UNEP to cover important areas of emerging concern.

The remedial or preventative measures outlined are meant to be illustrative rather than exhaustive in nature: there is no substitute for local experience, foresight and prudence. We have only attempted to draw attention to the kind of considerations which must be kept centrally in mind in undertaking development activities.

The objectives for which we strive in these guidelines are numerous and interrelated, requiring a formidable array of diverse technologies and disciplines. Although the guidelines are essentially national in nature and scope, international co-ordination to bring into play the different inputs required, may often be necessary.

I sincerely hope that the guidelines will be acceptable and meet practical needs, particularly in developing countries. Additional sectors will be examined and further guidelines prepared in collaboration with the UN specialized agencies, UNDP and other multilateral and bilateral development financing institutions, as appropriate, taking fully into consideration comments and advice which we expect to receive regarding this series of guidelines.

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Preface to the series

At an informal meeting held in Rome in September 1978, the Designated Officials for Environmental Matters (DOEM) of the United Nations Administrative Committee on Co-ordination recommended, on the basis of a report prepared by a consultant, Mr. O.M. Ashford, that UNEP undertake, in close collaboration with the UN specialized agencies, the preparation of environmental operational guidelines to assess and minimize the possible adverse environmental impacts of development activities. The report of the meeting states "that priority should be given to the preparation of guidelines aimed at improving the consideration of environmental aspects at all stages in the planning and execution of projects". It was recognized that the level of sophistication in such guidelines would depend on the audience for which they were intended. Much of the available material was of a general nature which would mainly be of interest to universities and senior international and national officials. At the other extreme, detailed guidelines based on in-depth studies of specific projects would be very useful for specialists but difficulties were foreseen in obtaining the necessary information for such analyses, which would take a long time to complete. The meeting agreed that the primary need was for guidelines which would be useful at the operational level. For this purpose each of the major categories used in the consultant's report (e.g. agriculture) would have to be broken down into a number of sub-areas (e.g. crop pest control and rangeland management). A first list of sub-areas on which guidelines should be prepared soonest was agreed to be as follows:

1. Pesticide use on industrial crops
2. Irrigation in arid and semi-arid areas
3. Watershed development
4. Pulp and paper industry

5. Hides and skins industry
6. Coastal tourism

At a subsequent meeting the DOEM determined that the operational guidelines should "avoid undue technicalities. They should be clear-cut statements of the environmental concerns, parameters and constraints arising in the area of interest. A distinction should be made between what would be useful for informed laymen, such as UNDP Resident Representatives or officials in the Ministry of Planning or Ministry of Economic Affairs of a developing country, to reach a decision on the need for corrective action and nature of the environmental considerations in a given project at a very early stage of its formulation on the one hand, and the analytical tools required by engineers, economists and other scientific consultants in the form of co-efficients, etc., to implement a project on the other. The latter should not be a part of the operational guidelines but be included in manuals of implementation".

In the event, the guidelines that have been prepared vary in the nature of the material assembled and the technical details analysed. This has been done deliberately.

In order to afford an opportunity to assess the practical utility of different approaches to the preparation of guidelines, it was considered necessary to establish models which could be compared and evaluated in terms of practical utility. UNEP would gratefully receive views on the analytical frameworks and approaches adopted in the different guidelines as well as suggestions for their improvement or amendment.

The environmental guidelines in this series are not intended to be prescriptions for corrective action or constraints on the methods, nature and scope of development activities. They are presented in the belief that dynamics and change induced by development aims are not without environmental hazards and risks. It is necessary to identify such hazards and risks where they arise and take early steps, because later attempts at remedial action may be illusory, more costly than preventive action at the outset, and in some cases, may be so costly as to bring into question the overall economic viability of the project.

We acknowledge with gratitude the contribution received from the UN specialized agencies, particularly the Food and Agriculture Organization (FAO), for preparing the earlier guidelines. Without financial assistance from UNDP, the operational guidelines could not have been completed effectively within the time available. We have also been dependent upon the assessment of the Resident Representatives and the Headquarters staff of UNDP on whether the guidelines meet specific needs in the field.

Within UNEP, a number of colleagues have assisted in the preparation and editing of the operational guidelines. I wish to thank in particular Mr. Nay Htun (for the guidelines on the pulp and paper industry and on the hides and skins industry) and Mr. Mohamed Tangi (for the guidelines on coastal tourism). Ms. Merran Van der Tak, Ms. Shahida Chaudhary and Mr. Mark Aeron-Thomas assisted in the research and editing of the first six guidelines in the series; the latest guidelines have benefited from the sustained efforts of Ms. Sophie Schlingemann and Ms. Gill Mayers.

UNEP's decision, to produce further guidelines, on issues currently on the international agenda for environmental action, has resulted in subsequent guidelines in the series. The first six have been complemented by the following:

7. Formulation of National Soil Policies
8. The Restoration and Rehabilitation of Land and Soils after mining activities
9. Afforestation Projects

10. Agricultural Mechanization
11. Agroforestry
12. Farming Systems Research
13. Environmental Consideration in Rural Roads Projects
14. Domestic Wastewater Management
15. Rural Workcamps
16. Flood Plain Management
17. Coastal Protection Measures

The three latest ones are on:

18. Handling, Treatment and Disposal of Hazardous Wastes
19. Fish Farming
20. Sand and Gravel Extraction Projects

On the basis of reports received, additional guidelines are under editorial consideration.

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Introduction

Scope of the guidelines

These guidelines are intended to build awareness of the nature of the relationship between fish farming and the environment and the factors that determine that relationship. The booklet discusses how the culture system used, the scale and intensity of operations, the choice of species to be cultivated, the selection of sites, and the management system adopted all affect the incidence and severity of environmental impacts. It is stressed that most environmental impacts can be avoided by careful site selection and planning. Management measures aimed at mitigating impacts that may be overlooked or difficult to predict are described.

Fish farming can be environmentally benign if properly planned and managed; however, integrated approaches to fish farming have the potential to bring developmental benefits in an environmentally beneficial way. Integrated fish farming methods and other environmentally beneficial means of tapping the productivity of the environment through the medium of fish farming are discussed.

The Scope of Fish Farming

Fish farming, fish culture and aquaculture are broad terms which refer to the rearing of organisms in fresh, brackish or salt marine waters for part of or all of their life span, so that the resource can be harvested for human consumption or some other use. The main groups of organisms cultured are finfish, including trout, salmon, milkfish, carp, tilapia, mullet, catfish, yellow tail and sea bream; crustaceans, such as fresh water crayfish, shrimp and prawns; molluscs, such as oysters, mussels, cockles, and clams; and seaweeds.

Culture methods are equally varied. For ease of discussion, these can be divided into intensive, semi-intensive and extensive systems. Intensive systems are usually characterized by a high degree of control over production and the environment. Large numbers of high value organisms are raised from artificially produced seed in man-made confining structures and fed with specially formulated feed. Initial costs are high, and there is a strong reliance on modern technology. Production is oriented towards luxury domestic and export markets. By contrast, extensive culture systems exercise a low degree of control over the environment., and tend to use traditional, low-technology cultivation techniques with minimal start-up costs. These low-input, low-output systems utilize wild seed stock and rely mainly on naturally available feed. Extensive systems are frequently developed to satisfy local fish protein needs.

Promotion of Fish Farming

The success in expanding output from agriculture and capture fisheries sectors in part explains the belated development of aquaculture in much of the world. Only China and a small number of other Southeast Asian countries have a tradition of raising fish on any significant scale. However, there is now a more or less global interest in aquaculture as a means of producing food, and the sector is now being heavily promoted.

Intensified fishing effort and improvements in the technology for locating shoals have failed to sustain the increase in fish catches that has characterized the last two decades. It is now thought that, taken as a whole, world fisheries may have surpassed their estimated maximum sustainable yield. In some regions, capture fishery yields have even begun to decline, often with severe economic consequences. There is a general acceptance that the adoption of more effective capture technologies will not reverse the trend, as in many fishing grounds the biomass of commercial species has been reduced to perilously low levels.

Recovery of stocks is often hindered by man-made damage to vital marine habitats. Disposal of industrial and domestic wastewaters, acidification of water bodies from vehicle and power station emissions, dredging, reclamation, sedimentation, alteration of freshwater drainage, and river course modification have degraded and eliminated fish spawning, nursery and feeding areas. Furthermore, global environmental changes, such as the greenhouse effect and ozone layer depletion, may generate effects of a different order of magnitude. For example, it is thought that the increase in ultraviolet radiation expected to accompany ozone depletion will harm the life forms at the base of the marine food chain, and hence negatively affect the biological productivity of the oceans and seas.

The above trends underscore the need for a change of emphasis in fisheries management. The management of individual fisheries through the regulation of catches needs to be complemented by improved environmental management aimed at providing conditions conducive to the recovery of exploited stocks.

Artisanal fishing communities, whose members may depend solely on fishing for their livelihoods, are directly affected by the downward swing in marine capture fishery yields. Governments, too, have become concerned about fluctuations in the availability of this important protein source and the effect reduced catches will have on export earnings. Often they have turned to aquaculture for a solution. The heightened emphasis on culture fisheries development has, however, led many to fear that policy makers will neglect more responsible management of capture fishery resources. This argument notwithstanding, the arguments in favour of fish farming are many and persuasive:

- mitigation against seasonal or longer term shortfalls in capture fishery yields;
- ability to expand production beyond the natural sustainable capture fishery yield of a given water resource;

- circumvention of the common property resource ownership problem which characterizes capture fisheries, and, therefore, prevention of over-exploitation of finite stocks and avoidance of the inefficiency that this entails;
- provision of protein in protein deficit areas;
- simultaneous potential for income and employment generation;
- ability to improve the livelihoods of the rural poor, including the landless;
- energy-efficient production of protein;
- foreign exchange earning potential;
- minimal uptake of land from competing uses; and,
- ability to tap under-used productive capacity of water bodies.

At present, aquaculture's share in fish production is around 5%, however, annual growth of this sector has outstripped that of other food producing sectors. Aquaculture is expected to expand at about 5.5% per annum for the next two decades. Whether predicted growth rates can be realised and sustained rests on a number of considerations; chiefly:

- government and international agency support for the sector;
- availability and development of expertise;
- technological advances in the production of stocking material; availability of ready, stable markets; and,
- environmental constraints, including development and application of the know-how to avoid self-pollution, and availability of suitable pollution-free coastal and inland waters.

Overview of environmental constraints and opportunities for fish farming

Early on in the development of fish farming, the possibility that the industry could have negative impacts on the environment was not widely recognized. Experience has since shown environmental degradation by fish farm enterprises to be a major hindrance to the operation and to the continued expansion and intensification of the industry. Many aquaculture systems make use of natural waters as a source of food, a sink for waste products and as a supplier of seed stock. Pollution by fish farms, therefore, affects the availability and quality of these environmental services. Accidental or deliberate release of farmed stock may lead to the decline of pristine gene pools of wild breeding material valuable for continued improvement of domestic stock. The speed with which new aquaculture innovations have been developed has outpaced improvements in understanding of the biology of different species, their environmental requirements and ecological interactions. As a result, the industry has developed new culture systems such as ocean ranching, the environmental effects of which are unclear.

In addition to these broadly pollution-related effects, the expansion of brackish water pond culture of species such as milkfish and penaeid shrimps has resulted in the destruction of mangroves and other wetlands. The loss of these critical coastal ecosystems has led to a decline in commercial fisheries and localized coastal erosion. In some areas, the introduction of large numbers of cages and other floating fish farm structures has begun to interfere with capture fisheries and other established users.

Governments have increasingly seen the need to regulate the industry both for its own protection and to safeguard the interests of other users of the environment. Environmental impact assessments (EIAS) have, therefore, become mandatory for new ventures in many countries possessing EIA legislation, and standards governing variables such as the distance between enterprises and effluent quality have sometimes been introduced.

Fish farmers need to assess not just the impacts of their activities on the environment, but also the impact of the environment on their activities.

Pollution and habitat modification stemming from other human activities are increasingly affecting resource productivity and limiting the success and possibilities for expansion of the aquaculture industry. Contamination of culture areas with heavy metals, pesticides and radioactive wastes reduces the survival rate of young fish, causes chronic effects in farmed stock and may render the cultured organism unfit for human consumption. Oil slicks cause mortalities in both wild and cultured organisms, and coat fish farm structures. Heavy siltation, caused by runoff from poorly managed upland areas or river and coastal dredging, cannot be tolerated by most cultured species; while increased nutrient loadings from agricultural run-off and livestock, detergents, food processing industries and sewage effluent can stimulate toxic algal blooms, and lead to a drastic decline in the amount of oxygen in the water column. These water quality changes may lead to mass fish kills and contamination with human pathogens and algal-produced toxins.

Permanent or seasonal closure of coastal areas bordering industrial, urban or agricultural areas for the purposes of fish farming has inevitably occurred. The routine purging of contaminants from shellfish ("depuration") prior to marketing has also become common practice in pollution-prone areas; and early warning networks monitoring the development of toxic algal blooms have become a costly necessity. Man-made river channel modifications, such as the construction of dams, have led to the irradication of spawning runs of commercially important species, e.g. salmon, and hastened their disappearance from much of their natural range.

There is also considerable scope for the use of aquaculture organisms in environmental improvement projects. Fish can profitably convert potentially polluting waste products into fish protein, and hence contribute to improved nutrition levels. Fish wastes contain potentially polluting nutrients which, in their turn, can be recycled on crop land, reducing expenditure on fertilizers and circumventing another potential pollution problem. Low cost weed clearance in clogged irrigation systems, more efficient treatment of sewage, and control of malaria and schistosomiasis-carrying organisms are further examples of the ways in which well-managed fish stocking can lead to improvements in environmental quality.

The growing pressure on the aquatic environment from a number of source points to the need for active involvement of fishery authorities in the planning and authorizing of all developments. Inter-agency co-ordination and dialogue is vital for the successful multiple use of resources, and to ensure that other agencies are made aware of the needs of culture and capture fisheries so that they can anticipate and take steps to avoid likely adverse impacts of their planned developments. The transboundary nature of most pollution effects should not be neglected and a regional frame of reference adopted in any consideration of environmental impacts. Such co-ordination of planning and resource management is necessary to ensure that resources are put to the best possible use.

Site Selection for Fish Farming Projects

Experience has shown that many of the adverse environmental impacts produced by and impinging on aquaculture enterprises can be avoided, or at least minimised, if sufficient care and attention are given to site selection. The development and implementation of country - or region - specific site selection protocols to aid the selection of suitable sites should be considered. In addition, existing regulations and standards should be adhered to when considering alternative sites for fish farming developments. These may relate to factors such as the distance between fish farming enterprises and natural spawning runs, the introduction of exotic fish species, the concentrations of human pathogens in the culture medium, the distance between fish farms, etc. Elements of a country-wide or regional site-selection survey may be as follows:

- the undertaking of a baseline environmental survey;
- more detailed on-site evaluation of potentially suitable areas.

Baseline Environmental Survey

Information on the distribution of swamps, mangroves, mud flats, intertidal areas, bays, lakes and rivers can help identify sites with potential, as these habitats are likely to provide the best locations for fish farming. The survey will also need to determine whether pristine, highly-valued ecosystems, such as coral reefs, sea grass meadows and shellfish beds, which may warrant protection or particular safeguards, are present. Where existing charts and maps do not give sufficient coverage of aquatic habitats, they can be supported by aerial photographs, satellite imagery, nautical charts, soil maps and other relevant sources of information.

The choice of additional parameters will depend to a large extent on the type of aquaculture envisaged. For cage farming, for example, the baseline environmental survey should pick out sheltered bays with sufficient water depth. Land form and dominant wave direction can be inferred from aerial photographs. Unsuitable areas for pond shrimp farming are likely to be those subject to seasonal inundation, this can be seen clearly on sequential satellite images. A high incidence of severe meteorological events such as tsunamis may cancel out the advantages of a site, as may the occurrence of frequent toxic algal blooms. Records of these events should be readily available. Lakes and reservoirs with high primary productivity may provide ideal sites for cage fish culture of herbivorous species. The spectral signatures of different lakes can be observed from satellite images, and those with highly productive areas can be selected for further investigation.

A survey for suitable sites for fish farming should, in addition, identify all existing and planned uses of the catchment and determine the degree to which they would interfere with fish farming. Where incompatible uses occur which are not amenable to amelioration, the area is clearly unsuitable for fish farming and need not be considered further. Incompatible uses such as river bed sand extraction, harbours (as potential sources of molluscicidal anti-fouling agents and other pollutants), sewage outfalls, oil platforms, shipping lanes, and processing industries such as tanneries, sugar refineries, distilleries, palm oil processing plants may preclude the possibility of any kind of fish culture sharing the water body. National parks, world heritage areas and mangrove conservation areas may preclude aquaculture or may restrict only certain (e.g. exotic) farmed species, and potentially polluting, intensive culture techniques, such as intensive cage culture of finfish, or systems requiring substantial habitat conversion such as shrimp culture in earthen ponds. Less intensive, small scale culture systems, e.g. subsistence culture of molluscs on stakes, may not be at odds with the management requirements of protected areas.

Satellite imagery and aerial photographs are useful sources of information concerning current land uses. Point sources of pollution, such as sewage outfalls, can often be detected. The seasonality of an area affected by point source discharges can be measured from sequential images. Other land uses, such as high input dry or irrigated agriculture, can be similarly mapped and inferences made as to the likely effects of these activities on inland and coastal water resources.

Once the broad areas capable of supporting fish farming have been identified, an on-site evaluation can pin-point the most suitable locations.

Detailed On-Site Evaluation of Potentially Suitable Sites

The method of culture envisaged will help determine the factors investigated in an on-site evaluation. Available dilution, nutrient loading, the presence of basins of accumulated rotting vegetation, and the efficiency of tidal flushing or the presence of eddies and currents, all affect the assimilative capacity of the waters and, therefore, the likelihood that a fish farm development will give rise to pollution problems. An examination of these and other factors can enable estimates to be made of the carrying capacity of the site.

Estimations of wild stock will be necessary for culture systems which rely on wild fry or spawners. The scale of the project or programme may need revision if there is a risk that it may adversely affect the status of wild seed stock. An assessment of predator populations should be undertaken so that the need for and feasibility of ameliorative measures may be weighed up in advance of site selection decisions.

The detailed on-site survey will help confirm the suitability of the site for the culture system envisaged. At this stage it is prudent to reevaluate the choice of culture organism, and the method and scale of operation, bearing in mind the socio-economic, cultural and technical as well as environmental needs, constraints and opportunities.

Management of Fish Farming Projects: Environmental Aspects

If potential environmental problems are overlooked or ignored at the site selection stage of project development, a variety of impacts may become apparent once the fish farm becomes operational. The adverse impacts may be minimized through the introduction of appropriate management measures. The major categories of impacts include changes in water quality, complete removal of parts of ecosystems, impacts on the wild gene pool through escapements and introductions, and threats to public health. These and other possible environmental impacts, and opportunities for their mitigation are now discussed with reference to the various culture systems.

Finfish Culture in Cages and Pens: Environmental Opportunities, Impacts and Mitigation Measures

Finfish species such as salmon, rainbow trout, yellow tail, catfish and milkfish are raised from wild-caught or hatchery-reared fry in cages and pens until they reach a marketable size. These structures, which may be constructed from a variety of materials, are suspended or supported in rivers, lakes, lagoons, estuaries, or near-shore marine areas.

Extensive cage and pen culture generally utilizes herbivorous species of finfish. Stocking densities are usually kept low so that naturally available nourishment suffices and little or no supplementary feeding is necessary to achieve high growth rates. This system of rearing fish normally entails few environmental impacts. On the contrary it may benefit the environment by keeping down the levels of nutrients in the water body. The flexibility of pens and cage enclosures means that these culture systems can capitalize on localised, often intermittent, areas of high primary biological productivity, such as storm drains and rivers with seasonal flow patterns. Cages and pens are stocked with young fish which use the nutrients in these often highly polluted, eutrophic water bodies, helping to reduce pollution levels. Large numbers of enclosures may, however, interfere with other uses and, in addition, reduce the amount of habitat available for wild fish, with impacts for commercial exploitation.

The potential for realizing economies of scale, particularly in the cultivation of high value carnivorous finfish, has pushed up the stocking intensity of cage culture, the need for external inputs - especially prepared feeds - and consequently, the likelihood of adverse environmental impacts. Environmental deterioration due to the build-up of fish wastes in established cage farming areas in northern Europe and Japan has raised fears about the viability of enterprises.

Due to the requirement for pure, unpolluted water, intensive finfish farming has proliferated in pristine environments. In these locations, conflicts with other users and deterioration of environmental quality due to the poor planning and management of operations has been met with strong public resentment. Inevitably, these developments have prompted regulation of the industry.

The impacts discussed in this section relate mainly to Japanese and European experiences with intensive cage culture of carnivorous marine fish. Owing to lower stocking densities and the smaller size of farms, many of the impacts discussed have yet to be observed on any scale in most other countries where cage culture is practiced. Nevertheless, as the drive for greater production efficiency and economies of scale accelerates, these impacts are likely to occur in time if appropriate safeguards are not taken.

The Accumulation of Sediments Beneath Cages

Decomposition of accumulated fish farm residues (mainly fish feed and faeces) under fish cages affects water quality, the ecology of the area, and the health of the farmed fish.

As sediments accumulate on the lake or sea bottom, bottom-dwelling flora and fauna are smothered and replaced by a few opportunistic species. If the cages are removed, rehabilitation of the site is usually rapid.

Of greater concern to the fish farmer is the potential for oxygen depletion and large scale anoxic (without oxygen) events, which are deadly to fish. Decomposition of the accumulated bottom mud creates a high oxygen demand. The oxygen available to the fish may decline to dangerously low levels, particularly if other sources of pollution with a high biochemical oxygen demand, such as sewage, are present, or if the sea or lake bed contains basins of rotting vegetation. Hydrogen sulphide gas and ammonia generated in the sediments are also detrimental to the health of captive fish.

The following management measures may help reduce the extent of sedimentation and the severity of its effects:

- development and introduction of more efficient feeding regimes,involving correct feeding frequency, and the use of non-disintegrating food pellets;
- relocation of cages to areas with swift currents, sufficient water

depth and an absence of natural sinks for organic debris;
- rotation of culture grounds to allow sufficient time for the bottom sediments to recover and water quality to be restored; and
- the cultivation of macrophytic algae on fish cages to absorb excess nutrients and to generate oxygen.

Accumulated fish feed under cages provides fertile feeding grounds for wild fish, which may grow prodigiously. The harvesting of this resource can be seen as a bonus of intensive cage fish farming.

Nutrient Enrichment and the Effects of Algal Blooms

In marine areas, the availability of nitrogen limits the productivity of the waters. In fresh water environments, phosphorous is the limiting factor to algal production. The addition of both nutrients via uneaten fish food and fish faeces, therefore, stimulates the growth of algae and other aquatic plants. So-called "algal blooms" may occur in nutrient enriched culture grounds. This effect is more pronounced in the warm summer months and in tropical countries. The dying and settling of algal blooms depletes the oxygen in the water column, posing a danger to marine life including farmed fish. Areas with sufficient flushing and dilution are not normally prone to algal blooms. Moving cages to these areas may remove the problem. Alternatively, cage numbers and/or stocking density can be reduced in line with the carrying capacity of the water body and formulated fish feeds modified to reduce nutrient wastage.

Certain species of phytoplankton produce toxins. Blooms of these toxic species, or "Red Tides", are being observed with increasing frequency world-wide, and have spread to countries with no prior experience of the phenomenon.

The toxic algal blooms cause mass mortalities or behavioural changes in both wild and cultured organisms through direct toxicity, physical damage to the fish, or oxygen depletion of the water column. Human consumption of contaminated shellfish has resulted in poisoning, paralysis and sometimes death. Respiratory difficulties and skin irritation may occur when winds blow the toxic cells inland to populated areas. The blooms are responsible for economic losses in the capture and culture fisheries sectors and in the tourism industry.

Evidence of an increasing incidence of toxic algal blooms in areas subject to high nutrient inputs, e.g. locations supporting intensive fish farming enterprises or sewage outfalls, has led many to argue that high nutrient loadings are responsible for altering the species dominance of algae in favour of harmful species. In the absence of a treatment for toxic blooms, there is a need to consider more stringent regulation of activities discharging nutrient-laden wastes. The economic cost of fish mortalities and slump in demand for products caused by red tide, the costs of establishing and operating a monitoring network, and the cost of defensive expenditures undertaken by fish farmers can add weight to an economic analysis of sewage or industrial waste treatment facilities. There is, however, no conclusive proof of a causal relationship between anthropogenic nutrient loadings and the occurrence of toxic blooms.

A two-pronged monitoring operation is necessary in areas of planned and on-going aquaculture and in shellfish collecting areas prone to toxic algal blooms. This should consist of regular monitoring of key locations to collect plankton samples for analysis. When high numbers of toxic algae are detected fish farmers are given warning of the impending bloom so that they can take action to save their stock. A range of measures may be taken: Firstly, the cage farmer can evacuate his stock from the toxic bloom. Cages should be designed to be released quickly from their moorings, and to move easily through the water at an adequate speed without unduly stressing the fish. Secondly, stock can be kept free of toxic algae by pumping uninfected water into the cage area from deeper layers, or by lowering the cage. This option requires a knowledge of the water quality of deeper layers. Thirdly, the fish farmer may cut his losses by preemptive harvesting of the caged fish. This may be the most cost-effective method if losses are expected to be severe and other measures are not feasible.

In the interests of public health, monitoring for the occurrence of harmful species should be supported by product toxicity testing. When potentially dangerous levels of toxins are found in shellfish at monitoring stations the harvesting of marine organisms, especially shellfish, should be suspended until samples consistently show that toxin levels have fallen below government-stipulated quarantine limits. Sampling protocols exist and may be adopted in the interests of intra-regional standardization.

Co-ordination of monitoring for toxic algae with monitoring for pollution from human activities could be feasible and may cut costs. The cost of setting up and operating monitoring stations for toxic algal blooms in remote locations may, however, be too high to justify the extension of *aquaculture into these areas.

The development of a register of coastal waters free from or prone to toxic algal blooms would greatly assist those responsible for the selection of new aquaculture sites.

Genetic Impacts on Wild Fish Populations

Cultured fish are the product of years of selective breeding. They are, therefore, genetically different from wild stocks. Breeders depend to a large extent on wild stocks as a source of genetic material for further improvements in farmed stock. The maintenance of a viable wild gene pool is, therefore, highly desirable. Fish farm escapees could, in theory, degrade the wild gene pool and reduce both the numbers and the performance of wild fish. The various options available to help conserve native stocks of farmed species include:

- development of gene banks for storage of fish reproductive material;
- use of improved cage security measures to prevent escape;
- exclusion of fish farms from areas supporting pure, wild populations of the farmed species; and,
- use of local genetic material for stock development.

There is a lack of consensus on the genetic effects of cage culture. However, the scale of introductions from this form of aquaculture is insignificant when compared to practices such as ocean ranching and lake stocking discussed below. Further research is urgently needed to clarify this issue.

The Human Impact

If unregulated, cage farming may be accompanied by excessive numbers of floating and land-based structures used for fish processing activities and/or for human habitation. Human sewage may be disposed of directly into the culture site, with possible risks of fish contamination by human pathogens, eutrophication, and increased frequency or likelihood of toxic algal blooms. Human waste also poses a potential hazard to other activities in the bay, such as snorkellers, scuba divers and swimmers. Likewise, where refuse disposal facilities are not made available, packing cases, old nets, polystyrene and other waste may be disposed of in the coastal area, where they cause a nuisance to other users and degrade the often high aesthetic quality of the area. Ghost nets, discarded polythene sheeting, packing materials, etc., kill and disable marine mammals. This world-wide problem can only be rectified if the many small-scale polluters act in unison to stop the unnecessary dumping.

The accessibility of potential cage farming areas for waste disposal and the provision of sanitation facilities are significant considerations which need to be considered by the licensing authority. In addition, regulations may be needed to control the number and uses of structures permitted in the vicinity of the culture area.

Use of Chemicals in Cage Farming

Antifouling agents contain toxins. They should, therefore, be used with caution in and around fish farming areas. The potent biocide, tributyl tin (TBT) has been widely used as an agent to counter the build up of algae on fish cages. Its implication in the failure of shellfish operations, as well as its capacity to accumulate in the tissues of cultured fish and so reach humans, has led to the banning of sales of the chemical in several countries. Although the effects of TBT on humans have yet to be established, this example highlights the need to subject chemicals used in and around food fish culture operations to a strict approval scheme.

Antibiotics are administered both to prevent and treat fish disease. There is some concern that disease-causing bacteria will eventually become resistant to medically important antibiotics. To prevent this eventuality, the use of antibiotics should be limited to treatment only.

Disease outbreaks can invariably be correlated with some kind of stress, e.g. over-crowding, oxygen depletion, excessive handling, or insufficient food. Minimizing stress levels in caged fish can reduce the incidence of disease considerably and hence the need for chemical treatments.

Prevention of Predation

The size of predator populations should be assessed at the site selection stage of aquaculture development. Often the possibility of economic losses through predation is overlooked during the planning of fish farming projects. Consequently, preventative measures are not included in cage design, and unnecessary destruction of predators occurs in order to protect the cultured fish. In many regions, the populations of potential predator groups, such as marine mammals and birds of prey, are already under stress from habitat deterioration, hunting, and incidental killing in fishing nets. In many cases, species are protected by law. There may be a need for region-specific guidelines to assist aquaculturists in the selection of sites which are not in or near to favoured breeding and feeding grounds of potential predators. The guidelines should include notes to aid accurate identification of predators, and descriptions of predator status. Advice on the design of predator-proof cages should also be made available.

The Use of "Trash Fish" as fish feed

Trash fish are fish of low economic value which are usually converted into fish oil, fertilizer, or fish meal for the manufacture of animal and fish feeds. Growth in the intensive culture of carnivorous fish has increased the pressure on trash fish stocks. A sudden, unanticipated decline in trash fish yields could jeopardize the viability of cage culture operations with concomitant adverse socio-economic impacts in fish farming areas. The natural predator populations of industrial fish stocks could also decline.

It may be necessary to regulate industrial fish catches and guard against damage to known feeding and breeding grounds. Regulation may also be needed to ensure that fish caught for use as fish feed do not come from areas contaminated with high levels of conservative substances, as these may accumulate in the cultured organism and ultimately affect human consumers.

The possible socio-economic and environmental effects of switching to an alternative protein source, e.g. soya, should also be examined closely before any decision is made.

Mollusc Culture: Environmental Opportunities, Impacts and Mitigation Measures

Molluscs feed directly on algae in marine waters. The low input requirements and ease of cultivation mean that molluscs can provide an important source of cheap protein for rural populations. Where nutrition and rural employment generation are major national policy objectives, mollusc culture has been a favoured form of aquaculture. The most widely cultured molluscs are oysters, mussels, clams and scallops. Off-bottom culture, which takes advantage of the three dimensionality of the growing medium and minimizes losses to bottom-dwelling predators, is the preferred method of cultivation. Floating racks, long lines and bamboo or wooden stakes are used in off-bottom culture. However, in regions where this is not feasible, due to interference with recreation and other commercial uses, the shellfish may be seeded directly onto a suitable bottom substrata.

Shellfish are an estuarine crop, and are, therefore, subject to greater quantities of pollution than most cultured organisms. Because they are filter feeders, they accumulate and concentrate pollutants that occur in their culture grounds. Owing to these characteristics, public health effects are a paramount consideration in mollusc culture.

Pollution of Culture Grounds by Human Pathogens

Molluscs concentrate and accumulate human pathogens in the water body. The practice of consuming shellfish raw or partly cooked means that they can be vectors of human disease. Prevention of contamination at source, by harvesting in clean waters, is most desirable. However, the growing shortage of unpolluted intertidal areas has pushed aquaculture into sewage-contaminated waters. In these circumstances, "depuration" is carried out to render shellfish safe for human consumption: prior to marketing, the contaminated shellfish are placed in tanks of clean, flowing water, or moved into pollution-free coastal waters. With this treatment, accumulated bacterial pathogens are quickly released. Where the high cost of collection makes this method economically unviable, periodic closure of intermittently polluted shellfish growing areas is necessary. Quarantine regulations must be supported by a product monitoring network.

Pollution of Culture Grounds by Toxic Algal Blooms

The increased frequency of toxic algal blooms world-wide has had the effect of permanently closing off some of the worst affected areas to shellfish culture. Ironically, the areas worst affected by toxic algal blooms are often those most favoured by shellfish producers on account of their high primary productivity. Red tides have caused toxic contamination of shellfish stocks and consequent human illness or death. The shellfish themselves do not appear to be affected by the toxins, although changes in water quality brought about by the collapse of a bloom may kill them. The occurrence of a toxic bloom may depress markets for shellfish with severe economic consequences for producers.

Costly, extensive monitoring and warning systems are often adopted to enable prediction of blooms and identification of infected stocks. Depuration is not an effective means of removing algal toxins, so closure and quarantine of contaminated areas is the only available counter measure. Monitoring for toxic algal blooms in remote aquaculture areas may not be justifiable on economic grounds. Expansion in remote areas likely or known to be prone to toxic algal blooms may, therefore, be unwise.

Nutrient Enrichment of Culture Grounds

Moderate nutrient enrichment of culture grounds provides favourable conditions for the growth of algae, and, therefore, for vigorous growth of molluscs. However, eutrophication can bring about physiological disorders, and the high oxygen demand of the large populations of algae present can endanger the culture. Nitrogen and phosphorous from livestock and agricultural run-off, food processing factories and sewage outfalls are augmented by the waste products of the molluscs themselves. In addition to algal blooms, other organisms may proliferate on the mollusc culture substrata, progressively competing with the shellfish for food.

The problem of eutrophication must be addressed at its often numerous sources. An appreciation of the carrying capacity of the area for shellfish culture can, however, ensure that nutrient loads from the cultured organisms are not excessive.

Sedimentation

Suspended culture of shellfish generates large quantities of waste in the form of faeces and shells. Changes in water quality due to the decomposition of these accumulated sediments reduces the productivity of the culture beds. Retiring culture areas periodically to allow time for the condition of the sea-bed to improve, and/or limiting the size of the operation or the density of organisms, can restore productivity.

Siltation

Stake culture and hanging culture alter the wave energy environment of the near-shore zone, slowing down tidal currents and resulting in the deposition of sediments in the culture area. The gradual accumulation of sand and silt deposits in culture grounds has sometimes led to substantial coastal progradation, and the loss of valuable culture areas. Productivity also suffers and shellfish mortalities may rise when water movement is restricted. Generous spacing of stakes and rafts can reduce the scale of the problem.

Pollution of Culture Grounds by Man-Made Chemicals

The use of biocides such as the anti-fouling compound TBT has been shown to produce growth abnormalities and reproductive failure in cultured and wild molluscs. Some plastic construction materials also produce leachates which harm shellfish.

Such chemicals should not be used in shellfish culture areas. In addition, culture grounds should be located away from marinas and other areas where the compounds are used.

Contamination of shellfish with cadmium, mercury, conservative pesticides, etc., may render them unfit for human consumption. Shellfish should not be grown in or harvested from waters where levels of these contaminants exceed specified safe limits.

Pond Culture of Penaeid Shrimp: Environmental Opportunities, Impacts and Mitigation Measures

The trapping and growing of shrimp in tidal ponds is a traditional practice in many Southeast Asian countries. In recent years the high demand and rising prices for shrimp in industrialized countries has provided an incentive for larger scale, semi-intensive and intensive commercial development. Pond culture of shrimp now has one of the fastest growth rates in the aquaculture sector.

Shrimps are reared almost exclusively in land-extensive earthen ponds usually located in inter-tidal areas as other proven methods of culture have yet to be developed. Many tropical countries with extensive areas of unused boggy, marshy inter-tidal land suitable for shrimp production have begun to develop the resource for shrimp production with a view to foreign exchange earnings, agricultural diversification and employment generation. From an environmental perspective, the surge in land uptake for pond construction is perhaps the most significant development in this form of aquaculture.

Destruction of Mangroves

In many tropical countries: the inter-tidal zone supports large stands of mangrove forests. To the fish farmer, these extensive inter-tidal areas represent ideal sites for pond development. Conversion of a large proportion of mangroves to shrimp ponds may, however, be detrimental to the industry itself, as well as to established users.

Mangroves are a highly productive element of the marine ecosystem as they generate large quantities of detritus, which forms the basis of a complex food web. Coastal mangroves also provide breeding areas, nursery grounds, and refuge as well as food for many commercially exploited fish species, including shrimp. As hatchery systems are not well developed, much of the shrimp culture industry is dependent on the remaining mangrove areas to supply wild shrimp larvae for stocking into ponds. In many regions where extensive areas of mangroves have been cleared for pond culture, the productivity of fisheries has suffered and availability of larval prawns has become erratic, raising the possibility of future collapse of the industry.

It is clearly vital to evaluate the proportion of a country or region's mangrove reserves that can be safely developed for brackish water pond culture. A first step is to determine the current extent and status of mangroves. Satellite imagery and aerial photography can be of assistance.

Tight control should be exercised over the release of mangrove stands for development and the conversion of mangroves to ponds should, in any case, only be permitted where this represents the most productive use of the resource. In addition, a number of conservation measures may be employed to minimize the loss of mangrove habitats associated with shrimp pond development:

- the most productive mangrove stands should be kept intact;
- ponds should be sited towards the landward side of the man grove area so as to leave the more productive seaward area undisturbed;
- the proportion of land used for pond development should be small, relative to the mangrove area in which it is sited, and ponds should be well spaced;
- where cleared inter-tidal land is available, this should be used in preference to intact mangrove areas;
- mangroves can be retained or planted in the middle of ponds or on pond banks; and,
- subject to studies of the capacity of receiving waters, grants should be available to encourage intensification of existing ponds, rather than the creation of new ones.

In Japan, hatchery-reared shrimp are released in large numbers to form sea ranching fisheries (see section on culture-based fisheries). Although the ecological implications of such interventions are not yet understood, this innovative culture method offers the potential to satisfy demand for shrimp without necessitating further destruction of coastal habitats for pond-building.

Socio-economic Impacts

The incidence of social costs and benefits of mangrove conversion should be investigated prior to granting of conversion licenses. Small-scale wood extraction and subsistence shellfish gathering are often important local uses of mangrove areas. Clearance for pond-building may, therefore, create economic hardship for local people not involved in cash-cropping of shrimp.

Over-exploitation of Wild Sources of Stock

The large-scale collection of stocking material in coastal waters for aquaculture purposes may adversely affect the viability of wild stocks.

Fry and spawners are a common property resource and therefore regulation may be needed to prevent over-exploitation and depletion of stocks.

In preference to placing a total ban on the practice of collecting wild stocking material, fishery habitat reserves can be set up in suitable areas to help ensure that wild fish populations are maintained.

Self- Pollution

The higher culture densities and intensive feeding regimes associated with intensive shrimp culture have a correspondingly high waste output. Eutrophication of receiving waters and the pollution of incoming water are possible consequences. As in other intensive culture systems, consideration needs to be given to the capacity of the receiving waters to dilute and assimilate aquaculture wastes.

Artificial Stocking of Reservoirs, Natural Lakes and Rivers: Environmental Opportunities, Impacts and Mitigation Measures

The decline of marine capture fisheries and increased human population pressures have led to an appreciation of the need to utilize the productivity of inland waters for their fisheries potential. At the same time, the capacity of rivers and lakes to sustain natural fish production has declined as more and more have been modified to serve the needs of power supply, irrigated agriculture, flood prevention and aquaculture.

The widespread damming of lakes for hydro-electric power production has created new aquatic environments. Most river species are unable to adapt to the modified conditions and so are doomed to disappear. Dams and other river structures present an impassable physical barrier to migratory fish, whose upstream spawning grounds are, in any case, invariably lost due to inundation. The seasonal draw-down of reservoir waters adversely affects food availability and the breeding success of many other resident species. Dam construction and water abstraction for other uses alters downstream river flow regimes with the result that river fisheries may be all but wiped out.

Management regimes, such as installing fish passes and increasing the volume of water discharged from the reservoir, may have some success at preventing the disappearance of some species. However, attempts to recover the lost productivity of inland waters have begun to adjust their focus from saving original fish communities to repeated or single stockings of water bodies with communities of hatchery-reared commercially valuable endemic or exotic species. Often fish stocking has achieved spectacular yield increases; but there have also been failures. Where failures have occurred, cage and pen culture have sometimes been employed to salvage some use from the water body.

In some countries long-established lakes and reservoirs have not developed a healthy, diverse fish community, as the necessary lake-dwelling species are not found in inland waterways. Introductions of exotic species can take advantage of the vacant ecological niches to develop the capture fisheries potential.

In over-fished lakes and reservoirs, stocking with the useful species can enable depleted stocks to recover more rapidly. Young fish can also be stocked to compensate for the destruction of fish eggs that inevitably occurs during reservoir draw-down. Heavy stocking with plankton-feeding species in the early post-impoundment phase can take advantage of the abundant algal production stimulated by the decay of flooded vegetation.

Introductions of exotic species may be a one-time event, whereas stocking may occur annually or less frequently to maintain stocks of species which do not spawn naturally. Management is limited to erecting barriers to prevent the escape of stock and harvesting.

The success of introductions and stocking cannot be predicted, and reasons for failure are difficult to establish with any certainty. If the species is able to adapt well to its new environment, its numbers may increase at the expense of native fish. Useful native species may decline or may be irradicated through competition with the newcomers or by predation. The possibility of escape and colonisation of other lakes and rivers is a significant transboundary issue.

Careful screening of all introductions and stockings is clearly vital. Screening procedures need to consider the structure of the resident community, the nature of the lake environment, the ecology and biology of the species under consideration, the risk of introduction of diseases and parasites, and the likely outcome of its interactions with other species. Because of the site-specific nature of introductions and stockings, unified, country-wide stocking strategies and guidelines are inappropriate. However, there is a need to compile and make available a record of positive and negative experiences to date with different species stocked to serve as a guide for future stockings. The experience of other countries in a region is relevant in this context and exchange of information should be encouraged. Legislation controlling introductions of exotic species and stipulating quarantine requirements should be adhered to.

Stocking programmes should be followed up by a regular monitoring programme to collect information on lake environmental parameters, capture fishery landings and the status of fish stocks. The information obtained can help identify the need for and timing of further releases.

Culture-Based Fisheries: Ocean Ranching and Sea Farming: Environmental Opportunities, Impacts and Mitigation Measures

The use of aquaculture technology to produce large numbers of young fish for stocking purposes is not limited to inland waters. The diminishing stocks of commercially valued marine species within 200-mile exclusive economic zones can be similarly enhanced with hatchery-produced young. One of its major advantages over capture fisheries is that reproduction - the most sensitive phase in the life cycle - is controlled, and thus adverse effects of pollution, the proliferation of river obstructions, and other habitat loss are avoided. The method also enables vast numbers of fish to be reared without causing many of the negative impacts now commonly associated with fish farming, such as self-pollution and habitat modification.

Ocean ranching involves the culture of large numbers of salmon fry for release into the ocean. The mature salmon are harvested when they return from their ocean feeding grounds to spawn. Sea farming, as practiced in Japan, entails yearly stocking of billions of sea bream, young scallop and prawn for subsequent harvest by fishing fleets. Provision of supplementary nursery areas such as seaweed beds and fish reefs is an integral part of sea farming.

Although still at an experimental stage, culture-based fisheries have begun to demonstrate their potential to make a substantial contribution to the capture fisheries harvest. The usefulness of this culture method for retaining populations of some species whose spawning grounds have been destroyed is an additional benefit.

However, the potential negative impacts of culture-based fisheries practices may prove substantial. At present, the ecological effects on the ocean ecosystem of these mass stockings can only be guessed at. It is feared that genetically distinct hatchery-reared stock could hybridize with indigenous fish, so reducing their vitality. This eventuality could be circumvented by releasing only fish that are genetically similar to wild populations. Other possible interactions between the released stock and native fish, such as competition for food, also should be investigated before this form of aquaculture can be given a clean bill of environmental health. Research also needs to be focused on the possibility that increased fishery effort associated with the recapture of released fish could intensify the pressure on surviving natural stocks possibly leading to their complete irradication from their natural range.

Semi-Intensive and Intensive Fish Production in Freshwater Ponds and Tanks: Environmental Opportunities, Impacts and Mitigation Measures

Intensive Systems of Pond and Tank Culture

The stocking and feeding regimes of intensive fish culture in ponds has sometimes led to water pollution problems. Pond outflows discharge large volumes of wastewater which may be poorly oxygenated and contain potential pollutants such as suspended solids and nutrients in the form of waste food and fish waste products.

Poor pond siting and management of fish pond effluents has constrained the expansion of pond culture in many countries and necessitated regulation of the industry. Where a programme of intensive pond culture of fish is planned, a cumulative impact assessment of the proposal and other planned and existing resource uses should be undertaken to determine whether the receiving waters contain sufficient assimilative capacity to fully accommodate all likely developments. The volume and nutrient content of discharges must be related to the hydrology, nutrient status and productivity conditions and end uses of the receiving waters.

A wastewater management strategy may also be needed to ensure that the discharge of fish farm effluents does not lead to adverse impacts on the water quality of rivers and lakes downstream. The concentration of potential pollutants in the pond effluents is dependent on the species of fish grown, the feeding regime, and the physical stability of the food presented. Management regimes have, therefore, attempted to manipulate one or more of these variables. Possible waste management strategies may include: modifications to diet and feeding; removal of wastes from ponds for disposal by other means; reduction in the number of ponds; and early harvesting of stock.

- Modification of feeding regimes: output from ponds depends on the content of the feeds. Research is needed to determine the optimum dietary intake of phosphorous and fibre for different species. Phosphorous can enrich receiving waters with detri mental effects on water quality, whereas fibre is a bulky undigestible feed component which is a major contributor to suspended and settleable solids in the ponds. Optimal balancing of nutrients in a non-disintegrating food pellet can reduce loadings of nutrients and solids. Demand feeding machines and hand-feeding give rise to less wastage and, therefore ,cut down on operating costs as well as pollution load.
- Removal of wastes from ponds: settleable solids trapped in ponds can be removed relatively easily from the pond after drainage, or by using sedimentation basins or filtration systems. The sludge can be applied to agricultural land as a fertilizer, provided the level of conservative substances such as

heavy metals is minimal. Other wastes are not removed.

- Reduction in the number of ponds: crude, but effective, this measure does not allow full utilization of water resources.
- Early harvesting of stock, or reduction of summer feeding, reduces waste loads in seasons when less dilution is available in receiving waters.

Integrated Systems of Pond Culture

The culture of aquatic species may be integrated with other human activities. Integrated systems are based on the cycling of waste products with the aim of achieving greater efficiency in the use of resources. Higher output is achieved without the complex, high technology, energy-consuming inputs associated with intensive systems of aquaculture. Integrated systems may involve one simple link between aquaculture and another activity, such as the use of pig wastes as a pond fertilizer. Alternatively, they may be developed into an extended food chain, for example, waste from preparation of fruit is used as pig feed; effluent from pig sties flows into ponds where it fertilizes the water and stimulates algal production; plankton-feeding fish grown in the pond convert the algae into edible fish flesh; other species (a "polyculture") may be grown to make use of all available niches; and accumulated bottom mud is periodically removed from ponds to manure crop land. Chicken and duck production, silk worm culture, palm oil, sugar and rubber processing wastes, and human wastes may also be integrated into fish culture. The continual cycling of nutrients enables relatively high levels of production to be sustained from both land and water resources. Operating costs are lower as the need for manufactured fish feeds and crop fertilizers is much reduced.

The use of waste products from industry and agriculture as inputs to semi-intensive integrated aquaculture makes sound economic and practical sense. Conversion of wastes into a food resource is profitable, reduces the need for treatment, and avoids the environmental impacts associated with waste dumping.

The Use of Human Wastes in Aquaculture:

The scope for adoption of different integrated systems rests on cultural as well as socio-economic factors. This is particularly true with regard to the cycling of human wastes, whether by the addition of "dry" wastes to ponds as food and fertilizer, or through the growing of fish in wastewater treatment ponds. The use of human wastes to fertilize ponds is a fully accepted and widespread practice in much of Southeast Asia. It has also been suggested for parts of Africa where other organic fertilizers, such as animal manure, are best reserved for agriculture. However, the innovation has been met with a lack of enthusiasm.

The human wastes - fish culture combination has the potential to reduce disease transmission and pollution of waters, while at the same time converting valuable nutrients into fish. However, domestic wastewater provides pathways for the transmission of disease when used in pond fish culture. Consequently, the practice is only desirable if public health can be effectively safeguarded.

The following groups may be at risk to infection:

- the consumer of contaminated fish: pathogens multiply in the gut and mucus, and if present in the culture environment in sufficiently high concentrations, can penetrate the muscle tissues of fish, with consequent health risks to consumers of the raw or partly cooked product;
- those involved in fish preparation risk accidental ingestion of pathogens; and,
- workers involved in post-harvest pond cleaning may come into contact with pathogenic organisms.

Mitigatory measures include the following:

- Depuration: holding fish in clean water for several days removes pathogens;

- treatment of wastewater: fish may be reared in effluents which have undergone secondary treatment in stabilization ponds to remove pathogens;
- preparation: gutting and thorough cooking of fish;
- lengthening the food chain: fish grown in human effluent may be used for purposes other than human consumption, e.g. fish meal manufacture or crop manuring, if bacterial concentrations exceed safe limits. Alternatively, ponds fertilized by human sewage can be used to grow aquatic plants, trash fish or snails, which are fed to fish grown in sewage-free waters;
- occupational health and hygiene: encouraging high standards of personal hygiene and the wearing of protective footwear and gloves can help minimise direct pathogen contact and thus reduce the potential for disease transmission.

The Use of Thermal Effluent in Aquaculture:

Great potential exists for the rearing of fish in warm waters discharged from the cooling systems of thermal power plants. Dramatically enhanced growth rates can be achieved, and warm water organisms can be grown outside their natural range. Technical difficulties involved in ensuring a continual supply of water free from chemical contaminants and at a steady temperature have contributed to the slow development of this promising form of integrated aquaculture.

Cultivation of Fish in Flooded Rice Fields:

In many tropical countries, fish are grown in rice paddies as a secondary crop. The young fish are trapped in flooded rice fields or stocked intentionally either as a consecutive or simultaneous crop. In this way, protein and carbohydrates can be obtained from the same plot of land and, in the event of a poor rice harvest, a harvest of fish may still be guaranteed. In addition to providing a supplementary food source, fish help improve rice yields by consuming algae and weeds, and fertilizing the water. Their foraging behaviour also improves soil texture.

The application of increasingly potent chemical pesticides to rice paddies has had a severe impact on the fish crop. Rice growers have reported fish kills as well as a suspected reduction in productivity. Pesticide use has also been linked to fish disease epidemics in rice fields and ponds. Yields of river fisheries and fish ponds have also been affected by the chemical-laden run-off of the flooded rice fields. Accumulation of pesticides in fish has, furthermore, raised fears about possible human health impacts.

The screening of pesticides for their toxicity to fish is vital and should be introduced if not already operative and findings widely disseminated. Systematic studies are needed to trace the health effects on pesticide users and those exposed to pesticide residues in food. Pesticides appearing on the UN list of banned products and the WHO classification should not be available for use. Where practicable, integrated pest control strategies, which call for the selective use of certain, less toxic., chemicals only when necessary, should be practiced where fish are cropped in rice-growing areas.

In addition, fish toxicity can be minimized by following a code of practice for pesticide application in fish-cum-rice growing areas (Little and Muir 1987). Measures include:

- avoiding excessive run-off by using granular as opposed to spray pesticide applications;
- draining the paddy field and removing fish or retaining the stock in trenches during application and for several days subsequent to application; and,
- stocking with larger individuals, which have been found to be less sensitive than younger fish.

Growing of Fish in Irrigation Channels:

Aquatic plants clog irrigation systems, slowing down the delivery of water to crops. Herbivorous species of fish such as grass carp can be stocked to reduce weed growth and at the same time provide a source of protein for consumption or sale to offset the cost of stocking. Larger grass carp will also eat the snail carriers of schistosomiasis, and so can contribute to reducing the spread and incidence of the disease.

Fish Culture and Processing Wastes:

Agricultural residues from rice mills, fish processing plants, fruit and vegetable preparation, and industrial wastes from processing industries such as palm oil plants can also be used as inputs to fish culture.

Natural Flood Plain Aquaculture: Environmental Opportunities, Impacts and Mitigation Measures

Natural flood plain fish culture methods enable the natural productivity of river floodplains to be enhanced without the need for high inputs or complex management. For example, river fish may enter specially excavated channels or flood plain depressions with rising flood waters, to be trapped when the river level falls, and harvested after a growing period of variable length. Fish may also be lured into small pools by the shelter afforded by specially planted clumps of vegetation. The crop is harvested from the "refuge traps" using nets. These extensive, minimal input methods are the natural precursors to more intensively managed flood plain culture methods. They provide respectable yields at no environmental cost. On the contrary, the maintenance of standing water bodies through the dry season raises the level of the water table in the vicinity of the flooded depressions, thereby improving grazing pastures.

Environmental Impacts of Fish Processing

The major constituents of processing waste are blood, offal, trimmings, fish heads, and under-sized fish. Improper disposal of these wastes may lead to environmental impacts in receiving waters, such as low dissolved oxygen, eutrophication, and generation of unpleasant odors. Depending on the assimilative capacity of receiving waters, processing wastes which cannot be sold as human food, fish meal, or livestock feed must be treated adequately prior to disposal.

Conclusion

Fish farming has expanded very rapidly. To date, this expansion has been based on a relatively superficial understanding of the farmed species and their interactions with their culture environments. Costly errors have brought fish farmers face to face with the economic realities of self-pollution and public health impacts. Informed site selection and skillful management can help aquaculturists to avoid or mitigate these adverse environmental impacts. These measures alone, however, cannot ensure success of fish farming ventures. Those involved in the culture and capture fisheries industries must increasingly participate in decision-making which affects the development and management of land and water resources. In this way, fishermen and aquaculturists can help to ensure that the quality of their resource base is not further eroded, and that their needs are harmonized with the needs of other users.

Further Information

An indispensable source of further information and advice on the environmental impacts of fish farming is the global information service on the environment, INFOTERRA, UNEP Headquarters, PO Box 30552, Nairobi, Kenya.

Advice on aquaculture developments can be sought from the Food and Agriculture Organisation of the United Nations, Via delle Terme di Caracalla, 00100 Rome, Italy.

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