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PERSPECTIVES ON THE ENVIRONMENTAL EFFECTS OF AQUACULTURE

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Introduction

The presenter of a plenary paper attempts a balanced overview of the subject, aims to stimulate discussion, and is willing to look into the future rather than dwell on history.

Perspectives is in the title because much of the current debate on fish farming arises from viewpoints which are non-scientific in nature but are nevertheless vital to the future of the industry. Such viewpoints include those of the consumer, the major retail outlets, the media and politicians.

The Environmental Effects of Aquaculture is a vast subject. I shall only discuss impacts from on-growing Atlantic salmon in coastal waters. Examples are derived mainly from Scotland but portray circumstances in many countries and will therefore interest a wider audience.

This paper reviews some current concerns, and comments on those most likely to present substantial long term or irreversible environmental hazards. It discusses which future activities and research would illuminate matters or might allow us to avoid unacceptable side-effects.

The main causes of concern are:

- (a) Organic loading on the sea bed.
- (b) The use of anti-foulants (Tri-butyl-tin, copper) on structures and nets.
- (c) The interaction between escaped farmed salmon and wild stocks by genetic contamination.
- (d) The pressure on wild stocks from increased parasitism (sea lice).
- (e) The environmental effects of chemical therapeutants used to control parasites.
- (f) The combined effects of numbers of fish farms in partially enclosed embayments in raising nutrient levels to such an extent that natural biological processes are distorted.
This may lead to blooms of toxic algae, more rapid spread of disease, depletion of dissolved oxygen, unpleasing aesthetic effects, and loss of amenity.

Organic deposition

Early in marine cage fish farming it was recognised that waste organic material, an inevitable by-product of any intensive husbandry, may present an environmental problem. Many investigations of sea bed conditions around fish farms have shown that

organic carbon and nitrogen are increased and that in extreme cases increases in pore-water ammonia, hypoxia in water overlying the sediment, and increased sulphate reduction may threaten the farming enterprise.

The benthic fauna has been shown to change predictably, with a marked reduction in number of species, coupled to increased biomass. Sea-bed growth of bacterial mats (commonly *Beggiatoa* sp) characterises heavy organic loading and is judged by some regulatory authorities to be a reliable indicator of unacceptable environmental pressure.

Environmental concerns focus on whether organic loading of the sea bed is intensive, or extensive, or both. Management has generally aimed at widespread dispersion rather than deep accumulations on small areas. Wide dispersion of organic material is aided by siting cages where water currents are strong or where water is very deep. When problems of organic debris have occurred at well established farms, the practice has developed of fallowing or resting the site for periods long enough to allow the natural fauna to re-establish. Recent work by Nickell throws doubt on the efficacy of site rotation in sediment recovery. Even after many months of resting and apparent recovery, a former site will regress to an unsatisfactory condition much more rapidly than a virgin site. Such findings lead us to question the current strategies for siting and managing fish farms in relation to pollution by organic matter.

In Scotland, current practice is to develop predictive modelling techniques to match the scale of a proposed fish farming development with the capacity of the site to assimilate organic waste without unacceptable departure from the natural regime.

An example is the particle-tracking model DEPOMOD, described later in this conference, which predicts where and to what extent discharged material will deposit on the sea bed.

In fish farming areas bordering the temperate North Atlantic it is unlikely that organic contamination beneath cages results in out-gassing or other phenomena such as have led to spectacular fish kills in warmer climates such as Hong Kong. It is more likely that the site will become 'sour' and that fish will not thrive as they should.

If it is impossible to maintain the sea bed such that the natural fauna is maintained or at least recovers very quickly, then the question arises whether we should contaminate small areas to a considerable depth or much larger areas to a shallower extent. If one considers organic wastes alone and takes a view over an extended time period - say fifty years - then whichever method is most economically convenient may be appropriate.

Experience with dumping sewage sludge at sea in relatively vast quantities shows that recovery of the surface deposits and restoration of natural fauna do eventually happen. That is not to say gross organic contamination should be tolerated but it is arguable that seeking to maintain a natural fauna at all times in the immediate vicinity of cages is not necessarily the best environmental option.

If we account for other contaminants associated with fish farm wastes, for example copper from anti-fouling compounds and organophosphates and pyrethroids from medicines, the argument may move in favour of deposition in small discrete areas so that toxic materials are effectively locked away from the targets of concern and, in the light of developing knowledge, may be recovered if necessary.

Anti-foulants

Encrusting growth on the net restricts the flux of water through the cage, reducing dissolved oxygen supply and restricting removal of metabolites. Early attempts to combat this using tri-butyl-tin coatings eventually resulted in a ban on these compounds once adverse environmental effects were detected. The swim-through weather drying method was then adopted widely and is still used today by those operating small-volume cages. This method kills the encrusting fauna and algae naturally by exposure to sunlight and air. The move to large-volume cages has restored the need for anti-foulant coatings as it is uneconomic to remove such cages from service to permit the swim-through method.

Preparations in wide-spread use rely on copper and zinc as their main active ingredients. Initial investigations indicate that each newly treated net may release around 4 or 5 kg copper to the environment over the first 3 days. Copper is a list II dangerous substance (European Dangerous Substances Directive) and the environmental quality standard in the UK is 5ug/l as an annual average.

There is a significant risk that this may be breached in waters surrounding cages.

Additionally, copper and zinc levels in sediments adjacent to fish farms have been found by Miller to be elevated by factors of 25 and 6 respectively. The washing of anti-fouled nets can result in heavily contaminated effluents (measured concentrations of copper exceed 1,500,000 ug/l) which are unsuitable for direct discharge to the aquatic environment.

The level of biological risk arising from these levels of contaminants is not well understood and may be modified in highly sulphidic and organic sediments.

There is therefore a clear need for further research into the fate of released copper and its polluting effect on planktonic or benthic flora and fauna. Key issues are fate (chemical speciation) and toxic effects of copper in sediments. The continued use of the swim-through method should be recognised as best environmental practice and green accreditation schemes should look carefully at the use of anti-foulant coatings before making awards.

The industry should be aware that deployment of large volume cages requiring the use of anti-foulants carries with it a risk that environmental accreditation may not be attainable and that a complete ban on such anti-fouling for fish cages, as was applied to TBT, may eventually result if further research shows this practice unsustainable.

Genetic contamination

Salmon grown in cages are domesticated as are other intensively bred foods. Favoured genetic traits have been developed, improving the quality and growth rates and providing a uniform product of the preferred size. This process will continue and current major research projects may accelerate it rapidly compared with previous progress. It is precisely these deviations from wild genotypes that raise doubts as to whether escaped caged salmon will breed with wild fish to produce progeny ill-adapted to surviving in the wild.

It is clearly against the interests of salmon farmers to permit escapes but accidents occur and perhaps more could be done to combat the after-effects. Better recording and compulsory reporting of escapes would reveal the scale of the problem.

Large escapes could be countered by a rapid-response involving recapture at sea and increased surveillance of nearby rivers at appropriate times. Further research on cage design, the causes of failures, and other contributory factors such as vessel collisions would also help in reducing the number of future escapes.

Transfer of parasites to wild stocks

The decline in wild stocks of sea trout and salmon is the subject of widespread concern in Scotland, Ireland and Norway. Recent research by Bjorn, Finstad and Kristofersen is persuasive in linking increased wild sea trout mortality from stress, induced by sea lice infection, with proximity to fish farms.

If their results prove generally applicable then Governments may be compelled to protect wild stocks of salmon and particularly sea trout from the pressures imposed by parasites from nearby salmon farms.

Until recently it was believed that the problem for wild stocks would vanish as numbers of lice in salmon farms fell in response to medication. Modern theories suggest that adequate protection for wild stocks would require infestation levels in farmed salmon to reduce to levels (0.05 lice/fish) well below those needed for satisfactory economic husbandry.

If near-elimination of sea lice in salmon farms is not practicable then separation from wild stocks by distance may be the only alternative. It seems likely, in face of emerging evidence, that location or expansion of fish farms near the migratory routes and feeding grounds of wild stocks will soon be severely curtailed if not altogether banned.

Given that stocks of sea trout in some Scottish west coast rivers have shrunk to a mere fraction of what they were a decade or so ago, risk assessments of existing fish farms and programmes of re-location may be needed. Meanwhile, a project to rear smolts from the most threatened river systems merits serious consideration, if smolts from genetically distinct stocks can be reared and released into marine areas where there are better opportunities to avoid infestation the present position may be defended until a longer term strategy is implemented.

Chemical therapeutants

Effective sea louse treatment is seen to be fundamental for the continuing success of salmon farming. A choice of formulations with varying modes of action is also seen as necessary to prevent or reduce the onset of resistance in lice (appendix 1). The strategic control now employed in various parts of the world to treat lice at susceptible life-cycle stages has shown benefits in delaying infestation on smolts and reducing the need for subsequent repetitive treatments.

As most of these compounds fall within the scope of the EC Dangerous Substances Directive, EC member states are required to impose site-specific emission standards to meet stated environmental quality objectives and standards. In Scotland this requirement

is additional to the general assessment carried out by the Veterinary Medicines Directorate when a marketing authorisation for a new product is applied for.

Considering the range of available medicines, one finds that countries have adopted different views on their suitability. The UK has been very slow and careful in authorising the use of chemical therapeutants and requires a detailed assessment at each site before issuing consents which are site specific and limit the quantities which may be used. For certain medicines eg Dichlorvos (appendix 2) a combination of regulatory pressure and increased resistance by the sea-lice has resulted in sharply reduced releases to the environment in recent years. For those bath treatments which expose the fish to specified concentrations of the medicines, the limitations on quantity require the water to be fully contained and reduced in volume by use of flexible tarpaulins.

With very large cages this becomes extremely difficult and, although more chemicals are used and lost to the environment, it is more convenient to partially enclose the whole cage by surrounding it with an impermeable skirt. Some of the chemicals (organophosphates and synthetic pyrethroids) are capable of severe environmental damage, especially to crustacea, on a large scale. The problems of such bath treatments are compounded by the recognition that, within discrete water bodies, sea lice are more effectively controlled by multiple treatments in as short a time as practicable over a wide area.

Unfortunately if the intention was to deliberately eradicate the natural fauna that is the technique that would be adopted.

In-feed treatments (Ivermectin, Amamectin, Teflubenzuron, Difiubenzuron) are targeted more closely at the sea lice on the fish and dosing can be more closely tailored to minimum effective dose, but they too are not without problems. Some of the residues of in-feed treatments are very long lived and may accumulate in sediments close to the cages or further afield, depending on their nature and rate of metabolism. These residues may then endanger non-target species or re-enter the food chain in, for example, shell-fish.

Medicines are subject to comprehensive research and scrutiny before they are authorised for use but the safety margin is such that they must be used strictly in accordance with the instructions and relevant licences. Further research is urgently required on the fate of medicines in the environment and, in particular, on predictive models to provide essential information on eventual distribution, concentration, pathways, and life expectancy.

Contemporary market medicines result from long term research and validation and are carefully designed for purpose, including the components used to carry the active ingredients to the target and then permit rapid breakdown. They are expensive to purchase and it is a matter of deep concern that cheaper alternatives carrying the same active ingredients (cypermethrin, azamethiphos) but produced for entirely different situations may be employed. To make matters worse these alternatives are readily available, at a tenth of the cost of authorised medicines, without prescription or the necessity to record their use.

In these circumstances it is not surprising that some fish farmers may be tempted to act in a highly illegal and irresponsible manner, with great risk to the environment, and to the aquaculture industry if consumers perceive that the product is unwholesome.

Habitat degradation

The fish farming industry has grown rapidly in the last decade. Scotland now has over 400 farms, producing 100,000 tonnes of salmon per year and with the number of farms producing more than 1,000 tonnes increasing year by year. As farms proliferate and increase in size so does concern that their combined impact on the environment, as opposed to their footprints on individual sites, is not being properly addressed by the regulators or scientific community. Concern centres on those areas where a number of farms in close proximity may additively have sufficient impact to change fundamental biological processes in large bodies of water such as major arms of the sea or extended coastal strips.

The kinds of effects being suggested include distortion of eco-systems at the microbe level leading to changes throughout the food chain not easily recognised by current monitoring techniques. The suspected changes may evidence themselves as increased occurrence of toxic algal blooms or reduced zooplankton food sources for valued species.

For each tonne of salmon produced approximately 100kgs of nitrogenous compounds, for example ammonia, are released into the aqueous environment. Since combined nitrogen forms the main limiting factor in the production of marine phytoplankton it is clear that there is potential for enhanced production when more nitrogen than is natural to the area is made available. However that increased production may favour certain species thus distorting the ecological balance and causing undesirable blooms or red- tides.

The Scottish salmon farming industry centered mainly on the west coast and northern islands produces 100,000 tonnes of fish per year so that the approximate discharge of nitrogen to the environment is 10,000 tonnes per year.

This figure may be compared with a nitrogen flux from all Scottish rivers of around 40,000 tonnes per year. On that somewhat rough and ready basis the quantities involved are not insignificant.

The complexity of trophic modelling and the paucity of relevant research make it very difficult to accept, or refute scientifically, such hypotheses. To counter the challenge presented, and for our own peace of mind, we do need more work in this difficult, expensive and time consuming area. One such project recently commenced in Scotland is the PAAP (Post Authorisation Assessment of the Environmental Impact of Sea Lice Treatments Project).

The results of this research will answer commonly asked questions on the ecological significance of the use of medicines for the treatment of sea lice infestations, under realistic treatment regimes, with respect to macrofauna, zooplankton, meiofauna, benthic diatoms, phytoplankton and macroalgae. The study will take at least five years to complete and even then given the complexity of the issues may pose more questions than it will provide answers.

The results of the study should aid the setting of discharge limits based on robust statistics, while identifying key taxonomic components which should be targeted for regulatory monitoring.

The scientific objectives of the study, which has been awarded to a consortium of three major marine research bodies in Scotland are:

(a) To determine the effects of each of several sea lice treatments chemicals on:

- Microfaunal assemblages
- Zooplankton assemblages
- Meiofaunal assemblages
- Benthic diatom assemblages
- Phytoplankton assemblages
- Microbiological and littoral assemblages

(b) To measure the concentrations of each of several sea lice treatment chemicals in the environment post treatment.

(c) To determine the significant correlation between ecosystem responses, time and .therapeutant concentration. (d) To determine the proportion of the observed environmental variance attributable to the treatments against a background of responses due to other parameters such as waste organic materials and nutrients. (e) To model the dispersion and deposition of farm wastes in the marine environment.

Within the range of objectives specified (d) is by far the most challenging but certainly the most rewarding if success can be achieved.

It may be argued that research at this level and on this scale should have been undertaken some time ago and that fish farming should not have been permitted to develop as it has done without the results having been reviewed and validated.

Summary and Conclusions

The marine cage fish farming industry has been very successful in terms of rapid rate of growth coupled with the economic and social benefits which it has brought to remote communities. In the wake of that success it has been difficult to assess all the possible environmental effects within the time scale and to the standards of scientific integrity which some Sectors of the community demand.

It may be that the envisaged continuing rapid growth of the industry including expansion to other species such as halibut will have to be curtailed while we address and provide convincing responses to some of the issues raised. Taking a broad view of the current situation and bearing in mind the huge scale of the oceans which form the sink for at least the soluble components of discharged wastes the following observations are submitted as relevant.

(a) Particulate organic wastes, deposited in the close vicinity of cages have received more attention than any other environmental effect. As relatively natural components of the environment at large their long term importance may well have been over-emphasised.

- (b) The use of biocides to control fouling of structures and nets by attached organisms can, and should be, strictly controlled without unbearable detriment to the industry.
- (c) The genetic modification of wild stocks of salmon through cross breeding with increasingly domesticated farmed fish should be recognised by all concerned as a real and present danger. The long term (100 years) effects of such cross- breeding are not understood. Loss of farmed fish to the natural environment should be restricted by all practical means. When escapes do take place a rapid-response team should take immediate action to recover the lost fish.
- (d) The case that damage to stocks of sea trout and wild salmon by sea lice associated with caged fish farming is very serious in certain circumstances has been made to the point that it should now be accepted as beyond reasonable doubt. The remedy lies with the near elimination of sea-lice within cages or separation by distance of cages from the entry points of smolts to the marine environment, or a combination of both. This particular environmental effect may be at near-crisis level now and immediate comprehensive action is required.
- (e) The range of chemical therapeutants available to treat sea-lice infestations of caged salmon has increased rapidly in recent years, and effective control of these highly damaging parasites is now realistically in sight. Although potentially capable of widespread and acute destruction of natural fauna including species highly valued for food, their use, at least in the UK, has been subject to careful pre-examination, regulation, and scrutiny. The main dangers in the near future lie with misuse of licensed and authorised products or substitution of alternative unauthorised (cheaper) products not designed for this purpose.
- (f) Allegations that wastes from fish farms and in particular nutrients and trace substances can produce major ecological change at the primary production level have begun to attract research funding on a serious scale (PA.APs project). It has been hypothesised that toxic algal blooms are a direct result of increased nutrient loading, if these claims are substantiated or indeed if they are not disproved then these environmental effects pose by far the greatest threat to the growth and prosperity of the industry. Unfortunately it is very difficult, time consuming, and expensive to measure such effects in the field or to design and execute experiments which will test the hypothesis.

Toxic algal blooms have occurred widely in the near-natural environment for many centuries and may to a large extent have gone unnoticed or unrecorded. However prickly this thorn may appear to be - it would seem to be in the best interests of the industry and those who regulate it on behalf of the community - to grasp it firmly and with determination to establish the facts.