Environmental Impact of Fish Farming

Review

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THE ENVIRONMENTAL IMPACT OF FISH FARMING - A REVIEW

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SUMMARY

I OBJECTIVES

To determine the potential impact of fish farming activities on surface water quality and native fish stocks and recommend pollution control management guidelines.

II REASONS

Environmental problems associated with fish farming activities are an increasing cause of concern. A better understanding of how specific farming practices affect water quality and native fish stocks is required as the basis for effective pollution control management.

III CONCLUSIONS

The settlement of fish farm waste solids on river beds and the benthos of lakes and coastal waters may cause organic enrichment and deoxygenation of natural sediments, leading to the dominance of pollution-tolerant organisms or even abiotic zones.

Although few incidents of eutrophication have been conclusively linked to waste output from fish farms, such waste does present a serious eutrophication hazard in many UK waters, particularly oligotrophic waters with limited dispersion and/or flushing rate.

River flow depletion due to abstraction by land-based farms is a major concern in many areas of England and Wales. Pollution control authorities in Scotland report no significant flow depletion and believe that control of effluent flow is an effective control on abstraction.

Little is known about the significance of other potential environmental impacts of fish farming, including the interactions between escaped/released farmed fish and wild stocks and the environmental impacts of the various chemicals used on fish farms.

Problems with consenting and compliance monitoring include widely fluctuating effluent quality, and in the case of caged farms, the diffuse nature of the pollutant source.

IV RECOMMENDATIONS

- National guidelines should be developed for the issuing of discharge consents for fish farms.

- Compulsory licensing of all fish farms, including those currently exempt from planning control and abstraction licensing by virtue of their designation as 'agricultural units', is required. Licensing should include planning permission and consent to discharge.

- Environmental impact assessments should be undertaken as part of the site selection process.

- The quantity, environmental fate and toxicity of chemicals used in aquaculture requires further assessment.

- The interactions of farmed fish with wild fish populations require further research. The major areas of concern are disease, competition between escaped farm fish and wild stocks, predation of wild fry by escaped farm fish and genetic erosion of wild stocks by interbreeding with escapees.

- Consideration should be given to controlling feed quality and quantity, especially with respect to caged farms where environmental monitoring is very difficult.

- Detailed guidelines are required for environmentally hazardous operations, such as the introduction of treatment chemicals to infected fish and the siting and construction of fish burial pits.

- Variations in effluent quality caused by farm operations and holding stock (and river-flow for land-based farms) need to be evaluated. Modelling of such variations will assist in pollution monitoring and control.

- Further work is required on the development of cost effective treatment for effluents from land-based farms. Treatment options for recirculating systems should also be investigated, particularly submerged media filters and vegetational filters, and with a view to a more widespread utilisation of water recirculation.

- The installation of effective primary treatment (involving settlement) should be imposed on all major existing and proposed land-based farms. Regular and environmentally safe sludge removal should be monitored by pollution control authority staff.

- Better use should be made of COPA section (34) (4) (d), (e) and (f) in the control of land-based farms, whereby the discharger can be imposed upon to install and maintain flow-gauging equipment, and keep records for regular inspection.

- Serious consideration should be given to prohibiting further caged farm development in fresh or salt-water bodies with low dispersion potential and/or limited flushing.

- Development of water quality models is necessary to predict dispersion and flushing rate, and hence eutrophication risk, in order to assess site suitability for caged farm development.

V RESUME OF CONTENTS

This report reviews the available information on the environmental impact of fish farming, and considers problems associated with water

quality, sediment quality, the ecological implications and how aquaculture may affect other water users. The problems associated with the control of the industry are discussed, paying particular attention to the issuing and monitoring of discharge consents. A region-by-region overview of fish farming in the UK is included, emphasising the major problems faced by pollution control authorities in each area.

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APPENDICES

SECTION 1 - INTRODUCTION

Fish farming has a long history and has existed for many centuries in one form or another. The modern day industry started growing in importance in the UK from around the 1950s, and has been expanding rapidly since then, particularly over the last five years.

There are two methods commonly employed for fish cultivation: land based systems comprising of ponds, tanks and raceways alongside or within rivers, and caged farms where fish are reared within a caged structure, suspended in a body of water.

The two species most commonly produced in the UK are rainbow trout *Salmo gairdneri* Richardson and Atlantic salmon, *Salmo salar* L and it is the production of these species that this report is primarily concerned with. Farming of coarse fish for restocking occurs at relatively low production levels, and there are a small number of farms growing ornamental fish.

In 1986 the total salmonid production in the UK, was 21 250 tonnes (Solbé 1987a). In 1988 this had increased to 35 000 tonnes with Atlantic salmon accounting for 18 000 tonnes. By 1992 levels are predicted to increase to 70 000 tonnes with salmon expected to account for 45 000 tonnes (Anon 1989a).

The industry is expanding rapidly, especially caged farming, and there is concern that insufficient information is available to predict the environmental effects of aquaculture. This information is vital to ensure that appropriate control measures are formulated to limit environmental impact to a degree that is considered acceptable.

This report will address these issues using information from a review of the available literature on the environmental impact of aquaculture and from consultation with pollution control authorities and national experts.

SECTION 2 - POTENTIAL ENVIRONMENTAL IMPACT

Outputs from fish farms can be collectively considered as waste, incorporating excretion products, uneaten food, unassimilated chemicals, dead fish and escaped or released fish. The environmental impact of these factors will be considered in terms of water quality, sediment quality, ecological consequences and detraction from other water uses.

2.1 WATER QUALITY

2.1.1 Hypernutrification

Hypernutrification, the enrichment of a water body by nutrients, can result from the leaching of inorganic nutrients from solid wastes and from soluble nitrogenous fish excretion products.

The principal ecological effect of hypernutrification is the stimulation of primary productivity, which may result in eutrophication of water bodies.

The three major nutrients released from fish farm wastes are carbon, nitrogen and phosphorus. The importance of these elements depends upon whether they are the limiting factor on primary production.

Carbon is usually present in excess of requirements in aquatic systems in the form of carbon dioxide or the bicarbonate ion.

Phosphorus and nitrogen, however, are often in limited supply, and may control primary productivity. Phosphorus is usually considered to be the critical nutrient in freshwater systems, where the nitrogen to phosphorus ratio is greater than 17:1. In marine waters, where this ratio is generally less than 17:1, nitrogen is usually the limiting nutrient (OECD 1982). Other factors may limit primary productivity; water movements can reduce the time algae are in contact with nutrients and water turbidity can impede light penetration.

The presence of a large biomass of algae as a result of eutrophication has a deleterious effect on water quality. Oxygen levels can fluctuate diurnally due to nocturnal respiration and seasonally during oxygen consuming phytoplankton die-offs. Associated with respiratory requirements are changes in carbon dioxide concentration; when dissolved oxygen (DO) is high during the day, carbon dioxide is low and vice versa during the night.

Carbon dioxide and the bicarbonate ion in the water play an important role in controlling the pH of freshwater (the large reservoir of carbon dioxide and bicarbonate in seawater acts as a natural buffer) and a large biomass of algae can cause daily oscillations in pH from below 7 to above 8 (Solbé 1988).

Different pH levels can be directly or indirectly toxic to fish. For example, acidic waters may prove harmful to salmonids or may initiate the release of toxic substances such as aluminium from sediments. The toxicity of ammonia, the major excretion product of fish (see Section 2.1.3), is also linked to pH, with less ammonia being converted into the ionised ammonium ion with increasing pH.

Algal blooms may also prove toxic to fish by releasing toxins during the decomposition of blooms and some algal species may be directly harmful to fish. The Highland River Purification Board (HRPB) implicated diatom blooms as causing marine fish mortalities in 1988 (pers comm HRPB). There is some evidence that fish farm wastes may stimulate the growth of toxic species. Studies in Japan, reviewed by Gowen and McLuskey (1989), have indicated that certain vitamins present in salmon diets could enhance the growth of at least one bloom-forming dinoflagellate. Phillips (1985) has associated the growth of toxic blue/green algae (Cyanobacteria) with nutrient rich waters resulting from fish farm wastes.

2.1.2 Oxygen

The dissolved oxygen concentration in the water column is inextricably linked with water quality. Any reduction in oxygen saturation of the water will impair its overall quality and the organisms it can sustain. Aquaculture can cause reduced oxygen levels directly and indirectly. Direct oxygen depletion is due to the respiration of the farmed fish; the consumption rate will depend on fish size, activity, age, physiological state, feeding and external parameters (NCC 1988). Indirect oxygen depletion can result from: the degradation of organic wastes, which exert a biochemical oxygen demand (BOD) (see Section 2.1.4); the chemical oxygen demand (COD) of ammonia (see Section 2.1.3); and the oxygen demand resulting from eutrophication (see Section 2.1.1).

2.1.3 Ammonia

The chief excretory product of fish is un-ionised ammonia (NH_3) which is excreted primarily from their gills and forms between 80 and 98% of the amino-derived nitrogen. The other major excretory product is urea, which occasionally forms a high proportion of total nitrogenous excretion (Elliot 1979). Un-ionised ammonia is highly toxic to aquatic organisms and Alabaster and Lloyd (1980) recommend that the safe concentration for aquatic organisms is 0.025 mg l^{-1}. In most fresh and marine waters, however, a large proportion is rapidly converted into relatively non-toxic ammonium ions (NH_4^+). The ratio of these different fractions in the total ammonium pool depends on pH, temperature and salinity. The percentage of un-ionised ammonia increases with pH, temperature and salinity.

Ammonia may also affect water quality by increasing the COD (chemical oxygen demand), causing oxygen depletion. The oxygen demand arises from the conversion of ammonia into nitrite (NO_2^-) and subsequently nitrate (NO_3^-).

Ammonia and urea may also serve as a nitrogen source for uptake by phytoplankton and, where nitrogen is the limiting nutrient, may contribute to eutrophication (see Section 2.1.1).

2.1.4 Solid wastes

Solid wastes from fish farms are composed of a suspended fraction in the water column and a sedimented fraction which accumulates on the bottom. The relative proportions will depend upon water movement, current velocities and the density and cohesion of the solid waste particles.

(a) Sedimented solids

Settlement of solids occurs when water currents are slow enough to allow particles to descend through the water column. The accumulation of sediments and extent of the settlement zone is primarily dependent on water movement, depth of the water column and particle density.

If the sedimentation rate exceeds the aerobic biodegradability of the solids, an oxygen demand will be exerted in the zone of sediment accumulation. This may cause an oxygen deficiency in the overlying water, particularly in lakes or coastal areas where thermal stratification restricts the supply of oxygen to the hypolimnion (Phillips 1985). In addition, oxygen depletion can result in highly reducing conditions in the sediments (Elliot 1979). Previously bound up phosphates and ammonium will be released, contributing to nutrification of the water column (see Section 2.2), and various gases such as nitrogen, carbon dioxide, methane and hydrogen sulphide may be released. Hydrogen sulphide is readily soluble in water and has been related to gill damage in fish (Gowen and Bradbury 1987).

(b) Suspended solids

A certain proportion of the solids discharged from a farm may remain suspended in the water column. Suspended solids may affect water quality by increasing turbidity, exerting a BOD as they degrade, and, if nutrients are leached from them, contribute to nutrification of the water column.

2.1.5 Heat

Enhanced effluent temperatures may be a problem from land-based farms, particularly in the north, either from recirculating systems or hatcheries that actively heat their water to improve survival and growth. Hatchery waste water may be 7-8 °C higher than ambient river temperature at certain times (Arabi 1988).

2.1.6 Chemical pollution

Chemical pollution from aquaculture may originate from three sources:

1) Components of fish food required for growth which are not assimilated by the fish.

2) Pharmaceutical or other chemicals used for disease prevention or treatment of the fish.

3) Disinfectants and chemicals used as antifoulants.

(a) Food inputs

The impact of nutrients released and solid loadings from unassimilated fish foods have already been considered in Sections 2.1.1 and 2.1.4. However, no mention has been made of other chemical additives such as vitamins, minerals and pigments contained within the food.

Little is known about the environmental impact of these substances. Some concern has been expressed about the use of canthaxanthin, the pigment used to produce a marketably acceptable coloured flesh in salmon. It is currently banned in the USA because of its possible carcinogenic properties (NCC 1988).

(b) Therapeutics

A wide range of chemicals are used in the treatment and prevention of fish disease (see Appendix A). They may be administered by incorporation in fish food, or by vaccination. Unassimilated chemicals may then enter the environment via uneaten food and excretory products. An alternative treatment method is topical application, where the fish are immersed in a bath or dip and the solution may then be released into the aquatic environment.

Enteral treatments

The group of drugs most commonly administered in fish diets are antibiotics, which are used to treat and prevent a wide variety of diseases, such as Furinculosis Vibrosis, Enteric Redmouth and Bacterial Kidney Disease. The antibiotics used to treat these diseases include trimethoprim, oxolinic acid, oxytetracycline and potentiated sulphonamide. These are generally used in small quantities and once diluted are not considered to directly affect water quality.

There is speculation, however, that some antibiotics are 'sensitisers' and may provoke allergic responses in a small proportion of the human population (Solbé 1987a, NCC 1988). The major concern surrounding the use of antibiotics is their impact on the microbial flora. It is possible that resistant strains of bacteria may develop, affecting species composition (this will be discussed further in Section 2.3.4).

Immersion treatments

Immersion treatments are used primarily to treat ecotoparasites and fungal infection. The treatment solution is usually released to the watercourse after use by discharge of treatment baths. Cage farmers often add the chemical directly to the cage which is usually surrounded by a tarpaulin skirt during treatment; once this is finished the skirt is removed and the chemicals naturally flushed through.

There has been major concern regarding the impact some of these chemicals may have on the environment. Particular attention has been focused on the use of 'Nuvan' 500 EC.

'Nuvan' contains the organophosphorus pesticide dichlorvos and is used in salmon farming to remove salmon sea lice Lepeoptheirus salmonis and Caligus elongatus. The former is the most detrimental and can cause severe damage to fish, resulting in secondary infections and mortalities.

The major detrimental effect of this formulation is the toxicity of its active ingredient, dichlorvos to a wide variety of marine arthropods (this will be discussed in Section 2.3.2 (a)).

The stability of dichlorvos in the marine environment is thought to be low. Samuelsen (1987) found the half life of dichlorvos to be dependent on temperature, pH and aeration rates. With poor aeration at 4.5 °C and pH 8 the half life was found to be 7.4 days, while at increased aeration rates it was 5.1 days. At 13.5 °C the half lives were 6.4 and 3.9 days respectively. This is supported in the NCC report 139h (1988), which reveals that preliminary work undertaken by the Department of Agriculture and Fisheries for Scotland (DAFS) suggests 'Nuvan' rapidly degrades into less toxic substances.

The other therapeutic immersion treatment causing concern is Malachite Green, a very powerful dye. It is used as a fungicide for the treatment of ecotoparasites and, at higher concentrations, for the treatment of Bacterial Kidney Disease. In spite of its widespread use there is little data concerning its toxicity. However, the use of Malachite Green has been banned by several government agencies in the US and it is suspected of having teratological effects on fish and rabbits (Meyer and Jorgenson 1983).

(c) Disinfectants and antifoulants

The most commonly used disinfectants in aquaculture are formaldehyde, quaternary ammonium compounds and iodophors. They are employed to disinfect eggs, all types of surfaces, circulation systems and reduce bacterial numbers in the water. The disinfectants are usually applied in such a way that they are directly flushed into the aquatic environment. The likely impact of these chemicals is largely unknown, although the Scottish Wildlife and Countryside Link (SWCL) report (1988) stated that the environmental effects of these chemicals are currently under investigation.

The build-up of fouling organisms on nets used in caged fish farming needs to be controlled, as they can cause oxygen depletion by impeding water exchange and by their respiratory requirements.

Traditional methods involve painting the net with a slowly released toxic compound. Tributyl tin was the most commonly used agent, but since its ban in 1987 has been replaced with copper-based compounds. These have proved largely unsatisfactory to the farmer, being both less effective as biocides and reducing net flexibility. Tributyltin itself, however, was responsible for adverse pathological effects in caged fish (Bruno and Ellis 1988).

Alternatives to antifouling agents include: net laundries, using net cleaning drums; hosing with high pressure waterjets; and towing nets at high speed through the water. The first of these methods may cause environmental damage from the release of toxic cleaning chemicals discharged at higher concentrations than would have occurred from leaching. Towing nets at high speed may increase site disturbance (see Section 2.4.2).

2.2 SEDIMENT QUALITY

The quality of the sediment fundamentally influences the diversity of species that can be supported on and within it. The sediments also directly affect the quality of the overlying water (see Section 2.1.4 (a)).

The impact of aquaculture on the sediment will depend on the quantity of solid organic waste discharged from the farm which settles. The build up of organic matter will depend upon the settlement rate of the solids, which in turn depends upon particle density and local hydrography. The primary effect of organic waste accumulation is an increased consumption of oxygen by heterotrophic organisms within the sediment. Gowen and

Bradbury (1987) reported oxygen consumption rates of between 45 and 55 mg O_2 m^{-2} $hour^{-1}$ for the sediment beneath a freshwater cage compared to 16 mg O_2 m^{-2} $hour^{-1}$ for undisturbed sediment. If the demand for oxygen exceeds the supply, the sediment will become anoxic and reducing. The extent of this will depend on the oxygen deficit and can be measured in terms of the redox potential of the sediment.

Studies in a fjordic sea loch by Brown et al (1987) showed that within a zone extending from underneath the salmon cages to 3 m distance the sediments were highly reducing, with negative redox values. Between 3 and 11 m from the cages the sediment redox potentials were depressed, becoming very negative in the summer; but 15 m from the cages the redox potentials were positive and comparable with undisturbed sediments.

Settled fish farm waste also acts as a reservoir for phosphorus, as this nutrient is closely linked to the particulate phase. Zuridah and Phillips (1985) estimate that 65.9% of feed phosphorus is lost as solid waste, whilst Enell and Lof (1983) found 80.2% and 71.3% of dietary phosphorus was lost in the particulate phase from two separate farms. Although some of the sediment-bound phosphorus quickly leaches out into solution, the majority remains after sedimentation and is released slowly to the overlying water (this is called the internal loading (OECD 1982)). The rate of release is greatly increased under anoxic conditions; indeed, at redox potentials below +200 mV phosphorus release is dramaticaly enhanced (Marsden 1989) (a fully oxygenated sediment would have a redox potential of around +500 mV). Furthermore, if the external phosphorus loading (from the fish farm) is relieved and the dissolved phosphorus concentration decreases, internal loading is likely to increase due to shifts in sorption equilibria (Marsden 1989). In freshwater systems, therefore, where phosphorus is usually the limiting nutrient, accumulation of settled fish farm waste is likely to present a serious eutrophication risk, even after the cages have been removed.

2.3 ECOLOGICAL IMPACT

Modifications to the aquatic environment by aquaculture may have significant repercussions for the fauna and flora it supports. The impact of aquaculture on plant, invertebrate, fish, mammal and bird populations will now be discussed.

2.3.1 Plant species

(a) Anchored vegetation

Aquatic plants anchored in the river, either to rocks or the river bed, are likely to benefit from nutrient enrichment caused by land-based fish farm effluents. Under such conditions fast-growing species will tend to dominate and shade out less competitive species. This will result in a reduction in species diversity both in submerged and emergent vegetation. Epilithic algal slime may also be stimulated by increased nutrient supply. Studies by Yorkshire Water on a chalk stream, the West Beck, (Chalk 1982, 1986) found a marked increase in the percentage cover and biomass of filamentons algae (notably *Vaucheria*) downstream of some farms, particularly at low river flows. Growth of *Ranunculus* is reduced downstream of farms at low river flows but is stimulated at high flows (pers comm, E Chalk).

(b) Phytoplankton

Hypernutrification of the water column stimulates the growth of algal populations and there is some evidence that phytoplankton species composition may be altered. Nutrient rich waters, resulting from fish farms, have been associated with the growth of toxic blue/green algae or Cyanobacteria (Phillips 1985, OECD 1982). Japanese studies reviewed by Gowen and McLusky (1989) report that nutrients present in fish diet could influence the succession of species and enhance the growth of at least one bloom-forming dinoflagellate.

2.3.2 Invertebrate community

The impact of aquaculture on invertebrate populations will be discussed in relation to the toxicity of chemical pollutants, the impact of fish farms on the benthic community and changes in zooplankton populations.

(a) Chemical pollutants

The toxicity of some chemicals used in aquaculture to invertebrates has caused major concern. Most attention has been focused on 'Nuvan'.

Experiments by DAFS and the Department of the Marine in Eire (O'Brien 1989) have revealed that many marine organisms are affected by concentrations at and below levels used during treatment in fish cages. These organisms include lobster, crabs, native oysters, periwinkles and limpets.

Research reviewed in the NCC report 139 h (1988) and Ross and Horsman (1988) found lobster (Homarus gammarus) to be more susceptible to dichlorvos than either crabs (Cancer parurus and Carcinus maenas) or mussels (Mytilus edulis). At working concentrations of 'Nuvan', lobsters died within 30 minutes, and within several hours at concentrations reduced by a factor of 10.

In Norway, one mass lobster mortality and the decline in numbers of crabs have been attributed to the use of 'Neguvon'; this contains trichlorfon, which degrades to dichlorvos (Ross and Horsman 1988).

It is likely that the larval stages of crustacea are more susceptible than the adults and DAFS are currently undertaking toxicity tests with lobster larvae (pers comm DAFS). It is also possible other components of the zooplankton may be affected, although there is little data available on this.

(b) Benthic community

The benthic community consists of organisms which live on (epifauna) and within (infauna) the sediment.

Discharges from land-based farms may affect the benthic fauna of river beds. Suspended solids in the effluent settle out after discharge in the slower moving reaches of the receiving river. These can infill interstices in coarser sediments and smother the benthos generally, possibly causing deoxygenation due to the high BOD. Salmonid redds are under threat of asphyxiation under such conditions (Crisp, 1989), as is the benthic invertebrate community as a whole. A study of four fish farms on the Hampshire Avon showed changes in the benthic community towards pollution tolerant organisms, persisting 0.5 - 1 km downstream of the discharge point (Wessex Water 1984). A UK survey of fish farms by Solbé (1982) revealed that every farm investigated caused some benthic deterioration, but this was generally restricted to areas just downstream of the outlet.

A survey by Yorkshire Water (Chalk 1986) found a general increase in the abundance of organic tolerant taxa (Oligochaetes, Chironomidae, and the leech Helobdella stagnalis) below fish farms with a decrease in the abundance of taxa sensitive to organic pollution (particularly larvae of the caddisfly Agapetus).

As well as possible toxic effects from treatment chemicals, ammonia may affect the benthic community by its direct toxicity. Low DO levels in the water column may also have a deleterious effect on benthic fauna.

The temperature of effluent from land-based farms may affect the benthic community, as well as plant-dwelling invertebrates. Many insect larvae use temperature-controlled diapauses (resting stages) which inhibit growth at either low or high temperatures (usually the former) (Hynes 1970). A heated effluent in winter may either cause premature emergence of airborne adults into unfavourable environmental conditions or inhibition of growth at a time when growth rate should be at a peak.

Various macrobenthic surveys have been performed in the vicinity of caged farms, to assess the extent of the impact. Brown et al (1987) found the benthic fauna showed four distinct zones of species composition, faunal abundance and biomass. Directly beneath the cage was an azoic zone, devoid of macrobenthic organisms. Further out was a highly enriched zone, typified by low species density and dominated by opportunistic species such as Capitella capitata and Scolelepis fulignosa. In the third zone the species diversity, faunal abundance and biomass were all elevated, indicating increased organic enrichment, but not at a level resulting in anoxic sediments. At 25 m out from the cage was the fourth zone where conditions were comparable with control sites.

A review of other benthic surveys in the NCC report 139h (1988) shows them to be in general agreement with the findings of Brown et al (1987). However, the spatial extent of the affected area was found to vary up to 100 m from the farm.

(c) Zooplankton

Few studies have been undertaken to investigate the relationship between aquaculture and zooplankton. It is likely that enhanced phytoplankton growths, due to hypernutrification (see Section 2.1.1) would stimulate the productivity of zooplankton. Increased secondary productivity at freshwater cage sites has also been reported (NCC 1988).

2.3.3 Indigenous fish populations

The impact of fish farming on wild fish populations will be considered in terms of water quality, interactions with escaped farmed fish, disease risks and changes in habitat and diet.

(a) Water quality

There is evidence to suggest that changes in water quality associated with fish farms could have an impact on natural fish populations. Eutrophication has been linked with increased fish productivity, and generally results in economically valuable species being replaced by less valuable species (OECD, 1982). Salmonid fish are known to be particularly sensitive to the effects of eutrophication (Phillips, 1985) and Penczak et al (1982) linked the decline of species of Coregonidae in a lake with aquaculture.

Many pollution intolerant fish species such as salmonids, are very vulnerable to low or fluctuating oxygen levels. Any wastes from fish farms causing oxygen depletion may place indigenous fish at risk.

Wastes from fish farms may also be directly harmful to fish. Un-ionised ammonia, the chief excretory product from fish, is toxic at very low concentrations. Chemical inputs from fish farms may also prove toxic to fish. During treatment with 'Nuvan', farmed fish displayed sinuous body fluxing and convulsive seizures (NCC, 1988), and 'Nuvan' has been implicated in causing blindness in stocks of wild salmon (Phillips et al 1985).

(b) Escape of farmed fish

The escape or intentional release of farmed fish poses a potential threat to wild fish populations. Areas of concern include competition, genetic contamination and disease transfer.

Competition

The escape of farmed fish has caused some concern that they may compete with indigenous stocks for food and breeding sites.

The biggest threat is likely to occur from competition between different species. Phillips et al (1985) studied the impact that escaped rainbow trout had on natural brown trout (*Salmo trutta*) populations. He found no evidence to suggest a decline of the brown trout, but concluded that the feeding niches of the two species were so similar, that unless additional compensatory food was available, the overall productivity of the brown trout would be reduced. However, the long term impact of rainbow trout would be limited because of their poor breeding success in British waters. Phillips et al (1985) reported that in over 500 UK waters only five contained self-sustaining populations of rainbow trout. However, it may be argued that where there is a steady supply of rainbow trout from restocking and escapes from farms, such populations do not need to sustain themselves to produce a long term impact. Indeed, at a (freshwater) loch cage site in Scotland where there was an estimated annual loss of 2000 live rainbow trout, escapees have become the main fishery catch. Gill netting has shown a ratio of rainbow to brown trout of 4.5:1 (NCC 1989a).

At the Institute of Fisheries Management (IFM) conference at Stirling, April 1989, representatives from the Scottish Anglers National Association voiced concern that where rainbow trout are stocked in important salmon waters they may feed on salmon fry.

Intraspecific competition is considered to be less likely, with hatchery reared fish exhibiting poorer survival rates and competitive ability when compared to wild stocks (NCC 1988, Hesthagen and Johnsen 1989). On-going research in Norway aimed at breeding out territorality in farmed fish will reduce competition even further (Sattaur 1989), although it also brings a genetic risk (see below).

Genetic contamination

The interbreeding of escaped or released farmed fish with wild stock could potentially alter the genetic composition of wild populations. Particular concern has been focused on wild salmon stocks. Electrophoretic techniques have revealed that there are demonstrable genetic differences not only between Atlantic stocks (Davidson et al 1989) but also that there may be several genetically distinct reproductive units within major river systems (Sattaur 1989). Work reviewed in the NCC report 139 h (1988) identified a minimum of 74 genetically distinct salmon stocks in the British Isles. These differences are thought to be the result of natural selection and may be important adaptations for survival in particular locations. Subtle differences in life-history strategies such as in smolting and grisling times may enhance survival during chance events. Stahl (1983) found that hatchery reared salmon showed decreased genetic variability despite the stocks originating from two or more genetically distinct natural populations.

Breeding programmes currently being undertaken in Norway (Sattaur 1989), to produce the ideal domesticated salmon, may have serious consequences if these fish are allowed to interact with wild populations. The optimum traits for farmed salmon are fast growing, late maturity and less aggressive fish. All these characteristics may reduce its fitness and ability to survive in the wild. Therefore, interbreeding between farmed and wild stocks could result in the introduction of a genotype into indigenous stocks which is less able to survive in the wild. Specific genotypes which allow adaptation of sub-populations to local conditions could be placed at risk and the overall genetic diversity of salmon populations reduced. This may make them more vulnerable to diseases and harmful environmental changes.

Allendorf and Phelps (1980) detected a loss of genetic diversity in farmed salmonids. Comparing a hatchery stock of cutthroat trout Salmo clarkii to the wild stock from which they were derived 14 years earlier, these workers found a 57% reduction in the number of polymorphic loci, a 29% reduction in the average number of alleles per locus, a 21% reduction in the average heterozygosity per individual, and significant changes in allelic frequency between age classes. They attributed the loss to both the limited number of founders of the hatchery stock and the effects of genetic drift in the maintenance of the hatchery stock.

Supported by research on the genetic impact of farmed Atlantic slamon on wild populations (NCC 1989a) the NCC have the view that wild and domestic fish should be kept separate and where wild stocks are brought into farms they should be assumed to be domestic after two generations, after crossing with any other stock or even after being kept together with a different stock (NCC 1989a, 1989b). These and other suggestions are included as Appendix B.

Salmon farmers in Scotland have shown preference for fish smolting in their first year (S1 smolts) as these tend to mature later. S2 smolts, fish smolting in their second year, are less desirable economically and genetically as they require holding in freshwater units for a further year and tend to mature earlier. The industry tends to overproduce young to ensure no shortfalls in supply and is keen to dispose of excesses, particularly of S2 smolts which often go to managers of wild salmon stock (NCC 1989a). Stockings of such fish should be carefully considered. Water authorities have had a similar dilemma as to how to dispose of excess brown trout from their hatcheries.

The success of escaped fish compared to wild populations is generally considered to be low (NCC 1988, Sattaur 1989), and escapee salmon often become 'homeless' and may enter rivers at random to spawn. Therefore, there is some controversy concerning the risk of genetic contamination from farmed fish (Needham 1984). However, it is undoubtedly a real concern where escaped fish constitute a large proportion of the total stock in a river.

Fears of genetic contamination in Norway have led the Norwegian Ministry of the Envirionment to ban salmon farming in sea areas near rivers holding significant salmon stocks (Mehli 1988 in NCC 1989a).

Similar genetic heterogeneity exists in the brown trout, with extensive small-scale genetic differences being evident in populations only a few kilometres apart (Ryman 1981). Taggart and Ferguson (1986) genetically tagged farmed brown trout used for stocking and found evidence of extensive introgression between these fish and native Lough Erne/Macnean (N Ireland) brown trout. Owing to the uniqueness of this native trout gene pool, the authors proposed the use of sterile trout in future restocking programmes.

The probability of genetic contamination is probably greater for coarse fish stocks, since transferals and releases have been widespread and indiscriminate for a long period of time. However, there are still likely to be a number of genetically unique populations of coarse fish in the UK, particularly in enclosed water bodies.

Disease

Fish are susceptible to a wide variety of diseases (see Appendix A), ranging from viral infections to metazoan parasites. Farmed fish are particularly vulnerable to infections. This is because the transfer of disease agents is easier with large numbers of fish within a confined space, and the natural defence mechanisms of the fish may be impaired resulting from physiological stress caused by farm conditions.

There is a possibility that disease agents from farmed fish may infect wild populations as they pass in the vicinity of the farms or through infected water. Munro et al (1976) concluded that wild trout populations could become infected with IPN virus escaping from an infected farm.

Infected escapees can also act as carriers to wild populations, and are likely to have a greater range than the waterborne disease. Disease transfer from escaped farm fish to wild populations has been reported for the micro-organisms Hexamita salmonis and Loma salmonae (Poynton 1986).

There has been concern about the spread of new diseases by the movement of infected stock to non-infected areas. This may have catastrophic results if no natural immunity to the disease has evolved. The SWCL report (1988) cites an example of this in Norway, where infestations of an ecto-parasitic fluke (Gyrodactylus salaris) has spread from imported farmed fish parr to wild salmon stocks, resulting in the virtual eradication of native salmon in the affected river systems.

However, most studies indicate that the transfer of disease from wild to farmed fish is the more likely situation. For example, the Institute of Aquaculture, Stirling University, found a positive correlation between salmon louse infestations and the distance of a farm from natural congregation areas for wild salmon (NCC 1988).

Many wild fish are also thought to be vectors of diseases, such as furunculosis, without showing any symptoms. The disease agent can be transferred to the farmed fish which may develop the full symptoms due to increased stress. Any resultant outbreak of the disease will cause an increase in the number of pathogens, which may then increase the disease risk back to the wild fish.

(c) Physical alterations to habitats

Land-based farms may physically alter the habitat of a river by abstracting water from it. A large proportion of the river flow is often abstracted, such that the intervening river between the intake and outlet suffers severely depleted flows, or even dries up. This may then present a barrier for the movement of migratory fish (including coarse fish species) and possibly render the affected river bed unsuitable for spawning. In addition, salmon smolts and other fish fry may be attracted to and become entrained in the flow at the abstraction point.

Floral and faunal communities in general are likely to be affected along such stretches, which may be up to one mile in length but typically of the order of a few hundred metres in the Wessex region (pers comm Martin Booth, NRA Wessex Region), and would certainly be heavily damaged if the river bed dried out completely.

(d) Dietary changes

Uneaten food deposited under cages may provide an additional food source for wild fish. Phillips et al (1985) found brown and rainbow trout in freshwater lakes congregating in the vicinity of cage farms. Fish farms also take natural food away from wild populations; it has been estimated that by 1990 the industry will be removing 184 000 tonnes pa of natural prey, such as sandeels and sprats, for conversion into fishmeal (Mills 1989). This has possible implications for other predators dependent upon such prey species (see Section 2.3.5).

The benthic changes resulting from sedimented fish farm waste may also alter food available to fish. There may be an area devoid of species as well as an area of increased productivity. The abundance and species composition may influence the fish the benthos supports. In addition, the fouling organisms which settle on cage structures may provide supplementary food.

2.3.4 Microbial community

The impact of aquaculture on the microbial community is important as bacteria play a role in nutrient cycling, are a food source for planktonic filter feeders and benthic detritovores, and the occurrence of certain groups, such as coliforms, have important human health implications.

There is conflicting evidence regarding the production of pathogenic bacteria by fish farms. A review of studies in the NCC report 139 h (1988) found evidence of coliform bacteria in water and sediments being produced from land based farms, as well as Enterobacteriaceae, *Aeromonas* and faecal streptococci. These were thought to have probably entered in the feed or influent water and appeared to be growing in pond sediments and in fish digestive tracts.

A study of marine farms in Canada also found higher numbers of coliform bacteria adjacent to a cage farm. In contrast Austin and Allen-Austin (1985) found no significant change in bacterial populations flowing through two salmonid farms. Various authors reviewed in the NCC report 139 h (1988) found no increases in coliform numbers adjacent to cages in freshwater lake sites and no increases were found in the vicinity of a cage site in an Irish sea loch.

It is therefore difficult to generalise about fish farms as a potential source of human disease agents. However, temperature, feed quality, site, management and the farming system used appear to be important factors affecting the potential disease risk from aquaculture.

The general effects of aquaculture on natural microbial populations are increased bacterial numbers, biomass and productivity, particularly in warm water land-based farms (NCC 1988). Austin and Allen-Austin (1985) found that total counts were generally higher in effluent compared to influent water in English freshwater farms, but levels were still within the range normally associated with freshwater.

Benthic sediments enriched by organic fish farm waste can become oxygen depleted and dominated by anaerobic bacteria such as the sulphide oxidising sewage fungus (Beggiatoa) communities, which are often a problem downstream of land-based fish farm discharges.

The species composition may also be affected by the use of antibiotics and antimicrobial compounds in aquaculture. Austin (1985) found that during the use of antimicrobial agents, bacterial numbers and the range of taxa in the effluent were less than the influent, suggesting the use of drugs may exert a selective influence. Austin also found evidence that the bacteria developed resistance to the antibiotics.

The increased level of resistance was found to be short-lived and was reduced soon after cessation of the treatment. However, there is still the possibility that overuse of antibiotics could lead to resistant strains of bacteria, which would not only affect fish farmers, but could also have longer-term environmental implications. The use of antibiotics has become such a concern in Norway that their use has been banned in freshwater (Solbé 1987a).

2.3.5 Mammals and birds

Fish farms may affect mammal and bird populations by disturbance of natural habitats, by the killing or trapping of animals by farmers in an attempt to limit predation, and possibly by removal of their natural diet.

(a) Habitat disturbance

Cage fish farms are often located in remote sites which may be used by birds and mammals as breeding and feeding grounds. Repeated disturbances, such as loud noises, the movement of boats, and activities such as net cleaning (involving boats moving at high speed through the water), may cause animals to leave a particular area. In a presentation at the IFM Conference April 1989, Simon Pepper (Scottish Wildlife and Countryside Link) suggested that many rare birds such as divers, grebes and raptors, that occupy Scottish lochs would be vulnerable to disturbances from fish farming operations.

(b) Predator control

Many predatory mammals such as seals, minks and to a lesser extent otters, and birds including cormorants, shags and herons are attracted to fish farms to feed. They are responsible for not only killing large numbers of fish, but may also cause damage to nets, allowing large numbers of fish to escape. Birds may also act as vectors of pathogenic diseases which may affect fish. Farmers try to minimise predators with a variety of control measures including shooting, trapping, scaring devices such as sonic booms, and antipredator nets which prevent the predators from reaching the fish.

The killing of predators by shooting or entrapment is often illegal and may also be counterproductive. There is evidence that shooting seals can lead to an increase in attacks due to displacement of a territorial animal, allowing others to move in (O'Brien 1989).

Antipredator nets are reasonably successful in controlling predators, but unless care is taken, they may be ineffective and may result in the death of predators by entanglement.

The deterrence of predators by visual or acoustic scaring is considered to have only short-term effects (SWCL 1988). The use of the sonic seal scarer is being encouraged and according to the NCC report 139 h (1988) DAFS are willing to lend any farmer sonic scarers developed by them. The success of these has so far proved to be variable (SWCL 1988).

There is limited information available concerning the impact of these control measures on predator populations, but it is likely that the impact on local populations is large. O'Brien (1989) claims that in Scotland the fish farming industry may be responsible for causing the death of more than 1000 seals, 200 herons and 200 cormorants/shags each year as a result of shooting and drowning of animals in farm nets. Otters and other diving birds are also being killed.

(c) Food source removal

The increased strain on sandeel fisheries around Scotland is largely due to an increased demand for fishmeal from the fish farming industry (see Section 2.3.3(b)). The decline of these fisheries, especially around the Shetland Isles, is likely to be due to this increased fishing pressure, and has led to the total breeding failure of Arctic Tern, Kittiwake and Puffin colonies due to prey shortage (Avery and Green, 1989).

2.4 EFFECTS ON OTHER WATER USERS

Fish farming activities may interfere with other uses of a water-resource. The main impacts considered here are changes in water quality and physical intrusion.

2.4.1 Water quality

EC Directives specify certain water quality criteria, which are required for designated uses. These include environmental quality standards for potable supplies, designated bathing beaches, designated freshwaters, for the protection of fisheries and for the quality required of shell fish waters. (These will be considered further in Section 3).

The treatment costs of poor quality water are higher. Solbé (1987a) estimated that eutrophicated water could triple or quadruple treatment costs, compared to oligotrophic water, due to clogged filters. Algal blooms can also exude tainting or toxic substances.

Eutrophication is generally considered to reduce the value of a water resource to other users (OECD, 1982). It can result in increased water turbidity, algal slimes, excessive shallow aquatic plant growths and an increase in biting and non-biting midges, thereby significantly detracting from the aesthetic quality of a water body and rendering it less suitable for other recreational activities, such as swimming, sailing and bankside walking.

Angling may be especially affected by eutrophication. In addition to suffering from the reduced visual appeal of the water body, angling success is reputed to be reduced in turbid waters (Phillips et al 1985) despite the observation that eutrophication may lead to increased fish productivity, especially in the vicinity of cages (see Section 2.3.3 (d)). This may be associated with a decline in more economically valuable fish.

2.4.2 Physical intrusion

The visual intrusion of both land-based and caged farms can have a considerable effect on the scenic appeal of an area.

The location of fish farm buildings on the banks of scenic rivers may detract from the natural beauty of a site. The appearance of dead fish downstream of land-based farms (pers comm G Dolby, Severn-Trent) is unsightly and poses a public health risk.

In Scotland, where the majority of caged farms are sited in scenically very attractive and undeveloped locations, visual intrusion is an important consideration. The detraction to these areas may extend deeper than visual impact, as their beauty is often connected with their associated wilderness. This is a complex intangible quality, which is lost with anthropogenic intrusions, such as noise, boats and litter. It may reduce tourist activity in an area, as well as possibly degrading the quality of life for local residents.

Cage structures may also hinder sailing and other waterborne activities. In sea lochs, cages may not only prove a navigational hazard, but may occupy some of the prime anchorage sites. Land-based farms may hinder navigation by greatly reducing flow between intake and discharge.

2.4.3 Conservation interest

The impacts of water quality and physical intrusion are both likely to reduce the conservation interest of a site. This can be brought about by a lowering of species diversity towards species tolerant of organic enrichment or other pollution, and by mobile species such as birds and mammals moving to other areas with less physical disturbance. Either impact may also result in the loss of national rarities from a particular site.

SECTION 3 - CONTROL OF THE FISH FARMING INDUSTRY

The effective control and regulation of the fish farming industry is of paramount importance in minimising its environmental impact. This section considers the control measures available in terms of legislation and enforcement, the inadequacies of these measures and technology available to reduce the harmful effects of fish farm wastes.

3.1 CONTROL OF FISH FARM EFFLUENTS

3.1.1 Legislation

Under Part II, Section 34, of the Control of Pollution Act 1974 (COPA), the Water Authorities (WAs) and the River Purification Boards (RPBs) have powers to control the discharge of trade effluents into inland surface waters, and coastal waters up to 3 miles offshore. This legislation will be superseded by Chapter I, Part III of the Water Act (1989), which transfers the power of enforcement to the new regulatory body, the National Rivers Authority; however, the legal framework for the control of water pollution laid down by COPA II will be transferred to the Water Act (1989) with very few changes. The Department of the Environment Northern Ireland has similar powers bestowed upon it by the Water Act (NI). For the purposes of this report the term 'pollution control authorities' refers collectively to the WAs, RPBs and DoE (NI).

3.1.2 Consenting of discharges

Before consents can be applied to a discharge, the overall quality objectives for the receiving water must be established. These will be primarily concerned with the protection of current and future identified water uses and, at the minimum, the maintenance of the water body within its existing National Water Council (NWC) water classification category. Although potential uses are included in the NWC classification scheme, the classes are defined by class-limiting criteria, for DO, BOD and NH_3 and standards for toxic substances defined by the European Inland Fisheries Commission (EIFAC) (HMSO 1985a). In Scotland, the old NWC classification (used in England and Wales in 1980) is still used; this quantifies BOD standards but is otherwise qualitative (HMSO 1985b).

The main uses of fresh and saline water which need to be considered have been discussed by Gardiner and Mance (1984a,b). These include the provision of potable water or foods derived from the water (such as fish, shellfish, aquatic plants, etc) for human consumption, and the maintenance of suitable conditions to allow bathing and to support fish, shellfish and other aquatic life and dependent non-aquatic life. The water may also need to be suitable for industrial abstraction, irrigation and livestock watering. Where no particular need can be identified the water quality objective may be simply 'avoidance of a nuisance'.

Having established qualitative environmental quality objectives (EQOs), it is necessary to define environmental quality standards (EQSs) for particular determinands to achieve the required EQO.

Once the EQOs and EQSs have been defined for a particular water body, trade effluents can be consented to ensure compliance with the appropriate EQOs and EC Directives. For discharge consents to be effective in meeting the appropriate EQSs the relationship between the EQO and the EQS must first be established and secondly the relationship between the effluent and the EQS must be known.

For land-based farms where water is supplied from a borehole, water quality consent values for the effluent can be set in absolute terms. However, where the flow to the fish farm is taken directly from the river it is often considered unfair to stipulate absolute water quality conditions for the discharge, as intake water quality is likely to vary greatly depending upon other land uses, leading to the possibility of a farmer having to discharge water of a higher quality than he abstracted. It is therefore deemed more appropriate by many pollution control authorities to consent acceptable changes in water quality between the abstracted and discharged water (incremental, or differential, standards) for some parameters (usually BOD, suspended solids, NH_3 and pH), with the aim of preventing any significant deterioration in the quality of the river and complying with any appropriate EC directives/NWC classification. Wessex Water, in conjunction with the Water Authorities Association, have produced standard consent forms for land-based farms (1984) which have broadly been accepted by many pollution control authorities.

The five major determinands (or groups of determinands) of water quality arising from fish farm effluents will now be discussed in turn.

(a) Nutrients

The addition of nutrients to a water body can increase the trophic status of the water (see Section 2.1.1). This could result in its downgrading to a different water classification class, rendering it less suitable for different water uses.

Nutrification from fish farm wastes in rivers is not generally considered to be a problem in many areas of the UK (pers comms J Chandler, UK EIFAC representative), since most of the UK rivers which are susceptible to eutrophication (ie slow moving rivers) are usually already enriched with plant nutrients and additional inputs from land-based farms are negligible. However, changes in epilithic algal growth and speciation have been observed in eutrophic rivers as far as 5-8 km from the point of fish farm discharge (pers comm A Frake, NRA Wessex Region); this is thought to be due to the presence of micronutrients (vitamins) in the fish feed (see Section 2.1.1).

Pollution control authorities in areas with oligotrophic rivers are expressing concern about enhanced growth of anchored vegetation downstream of fish farm discharges; orthophosphate is sometimes consented in such areas (usually incrementally), since phosphate is usually the limiting nutrient in freshwaters (see Section 2.1.1).

In lentic freshwaters, the following classification system is often used (Phillips 1985): total dissolved phosphorus concentrations of 0-10 $\mu g\ l^{-1}$ would be considered as an oligotrophic system, 10-20 $\mu g\ l^{-1}$ a mesotrophic system and greater than 20 $\mu g\ l^{-1}$ would be classified as eutrophic water. For saline waters where nitrogen is the limiting nutrient such a relationship is not clear. A literature review and examination of coastal waters by the Highland RPB, suggested that at concentrations up to 300 $\mu g\ l^{-1}$ of total nitrogen, no excessive primary productivity would occur (pers comm Highland RPB).

Predictions of the result of nutrient loadings from caged farms on nutrient elevation in the water column will depend on knowledge of the hydrodynamic properties of the receiving water body. If these are determined, the production output can be regulated to achieve the desired nutrient concentration.

Models have been developed by Dillon and Riegler, and Vollenweider, which can be used to estimate the response of lakes to phosphorus loadings in relation to fish output. These are reviewed by Phillips (1985) who found the Dillon and Riegler model gave the best approximation to his own field measurements. Phillips (1985) recommends the phosphate loading approximation to be used in these models should be 8.3 kg $tonne^{-1}$ of fish produced. However, as Table 1 shows, estimates of phosphate loadings are extremely variable. The most commonly accepted value is 10 kg phosphate $tonne^{-1}$ of fish produced. This has been adopted by the Highland RPB. In a paper presented by Phillips at the IFM conference, Stirling (1989), he stated that this value was probably too conservative. His own field measurements of phosphate concentrations in the water column indicated long term loadings of only 4.3 kg $tonne^{-1}$ fish production.

The Scottish Salmon Growers Association (SSGA) and the National Farmers Union (NFU) expressed concern at the Caged Fish Farming Workshop, hosted by Clyde RPB March 1989, that the 10 kg phosphate per tonne of fish

Table 1 - Production of waste nutrients from salmonid farms (kg $tonne^{-1}$ fish produced $annum^{-1}$)

	Total phosphorus	phosphate	Total nitrogen	Total dissolved nitrogen	Total ammonia	Total carbon solids	Total solids	Reference
Rainbow trout land-based	11		83		45		550	Warrer-Hansen (1982)*
Salmonids land-based	22-110			0-548 (Nitrate & Nitrite)	37-80		474-4015	Alabaster (1982)*
				12.0 (Nitrate & Nitrite)	55.5		1350	Solbé (1988)
Rainbow trout cages	13.5	1.9	87	71.4				Enell and Lof (1983)*
	27	8.3 (theoretical)	104	63.9 (theoretical)		95 (theor.)	289	Phillips (1985)
		4.3 (direct measurement)		92.4 (direct measurement)				
	23		97					Penczak _et al_ (1982)

* Reviewed in the NCC report 139 h (NCC 1988)

coefficient was outdated due to improvements in husbandry and lower phosphate diets. A more appropriate consent condition might be to restrict production in terms of nutrient input from the feed. This would then encourage farmers to use higher quality diets and employ less wasteful feeding régimes, resulting in less solid and nutrient waste being produced. However, quality control of feed is reputed to be poor and large variations between batches may occur (pers comm Highland RPB).

In addition, the NFU and SSGA felt it was unjust that fish farm production was being restricted to maintain phosphate levels within an EQS, while the inputs from other industries, notably phosphate run-off from forestry developments, were uncontrolled. The NFU and SSGA suggested that a change in legislation was warranted to ensure they would not be penalised and their production restricted due to phosphate inputs from other sources.

The Vollenweider and Dillon/Riegler models have also been criticised as being too simplistic, since they rely on steady state conditions which in reality do not exist, and incomplete mixing in low energy environments will lead to higher local phosphate concentrations than expected. Phillips (pers comm) is currently developing a new model which will take more account of other phosphorus loadings into the water body. Kamp-Nielson (1985) has considered dynamic eutrophication models as an alternative to steady state models, but the extensive data required limits their use.

Setting discharge consents for marine farms is more difficult. The relationship between nitrogen concentration and phytoplankton community dynamics in sea water is not well understood. The Highland RPB have, however, set limits of 300 $\mu g\ l^{-1}$ for dissolved nitrogen for marine cages, based on the information available (HRPB 1987).

Predicting the changes in nitrogen concentrations due to inputs from farms is also more difficult, as the boundaries of the affected area are more difficult to define. However, there are two models currently available to estimate the water exchange rates; the Tidal Exchange Method, and the Salinity and River Flow Method (see NCC report 139 h

(1988) for details). Gowen, at the Scottish Marine Biological Association at Oban, is currently trying to develop a model to predict both the phytoplankton response to elevated nitrogen concentrations and the consequence of nitrogen loadings on nutrient concentrations in the sea water. This work is due to be completed next year (pers comm, Highland RPB).

There is little data on the nitrogen loadings from fish farming. The Highland RPB use a factor of 123 kg nitrogen tonne^{-1} of fish output, based on research undertaken by Stirling University (HRPB 1987).

(b) Solid waste

Sediments deposited from fish farm waste may affect the benthic fauna and flora (see Section 2.3.2 (b)). Both the total solids and the solid organic carbon (the primary controller of benthic production) are important (see Table 1).

The discharge consents for land-based farms are usually set in terms of an allowable increase in suspended solids between intake and discharge. If the receiving water is used for potable abstraction receiving only simple physical treatment and disinfection, or is a designated river for the protection of fisheries, then to comply with the appropriate EC Directives the effluent must not cause suspended solids in the receiving water to exceed 25 mg l^{-1}. EIFAC also suggest that wild salmon fisheries are more likely to occur if suspended solids are less than 25 mg l^{-1} (Solbé 1988). As suspended solids levels are closely linked to BOD, many pollution control authorities set BOD consent values based on the downstream EQS or NWC classification standard, then set a suspended solids consent value to achieve this BOD.

It is currently considered impractical in the UK to prevent sedimentation beneath cage sites, although the technology is available (Section 3.4.2). To control the degree of sedimentation a mixing zone approach to setting discharge consents may be appropriate. That is, provided that the deterioration in the benthos does not extend beyond a defined area beneath the cage it could be considered to be acceptable.

Highland RPB (Gowen et al 1988) have stated that the affected area should be "insignificant in relation to the total bed area", and have recently set a limit on organic enrichment of three metres beyond the perimeter of the cage (pers comm J Hunter, HRPB) (see Section 4.11). Gowen et al (1988) have developed a sedimentation model to predict the probable distribution of organic waste from fish farms, together with the loadings of this waste to the sediment. The model takes into account the surface area of the cages, the monthly food input and food conversion ratio (the unit amount of food, dry weight, required to produce a unit amount of fish, wet weight), the depth of water at the site, details of the current speed and direction and the settling rate of uneaten food and faecal particles. Gowen et al (1988) unsuccessfully tried to relate the level of organic enrichment to the benthic species composition. However, they were able to estimate that at organic carbon loadings of 8 g cm^{-2} outgassing of methane and hydrogen sulphide (methanogenesis) was likely to occur.

The model is a useful tool in assessing the short- and long- term suitability of a site, as well as indicating the area likely to be affected by sedimentation.

To provide a means of controlling the impact of sedimentation on the benthos, discharge consents might include provisions that a benthic survey be undertaken prior to development with regular post-development monitoring. This option is currently being considered by Clyde RBP (pers comm Hugh Smith, CRPB).

Monitoring of benthic quality is very expensive and may only be warranted or practical for production over certain levels. To avoid serious deterioration of the sediment below the cage, rotation of the cages or single point mooring systems might be considered. This will, however, lead to a total greater area being affected.

The range of solids produced per tonne of fish are quite variable (see Table 1). Highland River Purification board use the figure 6.4 kg $tonne^{-1}$ of fish production day^{-1}, or 32% of the food intake to derive effluent standards (Gowen et al 1988). In contrast, Wessex Water do not use such estimates on the basis that they can be very misleading, often depending upon which feed supplier is used (pers comm M Booth, Wessex Water).

(c) Deoxygenation

The main causes of deoxygenation are fish respiration and oxygen consumption resulting from the degradation of organic solids (see Section 2.1.2).

The requirements of salmonids for high levels of DO (Solbé, 1988) provides a self limiting control on most aquaculture; freshwater farms will try to keep within the EC Freshwater Fish Directive (78/659/EEC) for the protection of salmonid fish, for the health of their own stock. The standards set for compliance with this Directive are that DO concentrations should exceed 9 mg l^{-1} for 50% of the time and guidance values of 3 mg l^{-1} are set for BOD. Adherence to both these standards would also keep the water within the 'Surface Water Abstraction' Directive (75/440/EEC), for water receiving minimum treatment.

Water quality within land-based farms may deteriorate more than around caged units because the wastes are discharged into a confined volume of water. A survey undertaken by Solbé (1987a) found on average there was a decrease in DO of 1.6 mg l^{-1} and an increase in BOD of 1.5 mg l^{-1} as the water moved through the farm. These were found to cause a decrease of 0.3 mg l^{-1} DO and increase the BOD by 0.7 mg l^{-1} in the receiving river. Measurements of fish farm effluents by Wessex Water (Jones 1989) approximately concur with these BOD levels, however, decreases in DO concentrations commonly exceeded 1.6 mg l^{-1}.

For DO and BOD concentrations to be controlled from fish farm effluents the respiratory requirements of salmonids and BOD from salmonid farm wastes need to be known. The HRPB use the following criteria for the purpose of fixing effluent standards; 5500 mg BOD produced kg $fish^{-1}$ day^{-1}, and 6000 mg DO consumed kg $fish^{-1}$ day^{-1}. Increases in BOD of between 2-5 mg l^{-1} relative to the influent water are typically set for land-based farms, while absolute values of between 50-80% are set for dissolved oxygen saturation (Saunders-Davies 1989), dependent upon effluent flow (in relation to total river flow) and intake water quality.

In marine waters, oxygen saturation levels are lower and DO concentrations of between 5 and 6 mg l^{-1} are considered to be the minimum acceptable to marine animals in the NCC report 139 h (1988).

Measurements of DO concentrations in and adjacent to cage farms vary. Several studies have shown undetectable or small decreases compared to ambient levels: Müller-Haeckel (1986) found oxygen concentrations in marine cages to be close to saturation for most of the year and always in excess of 8 mg l^{-1}. Phillips et al (1985) found a slight decrease of 1.0 mg l^{-1} to 9.7 mg l^{-1} compared to control sites.

However, studies in Japan, reviewed in the NCC report 139 h (1988), cite instances where DO concentrations near marine cages were 0.2-2.5 mg l^{-1} less than ambient levels, necessitating a decrease in stocking density. Edwards and Edelston (1976) have developed an oxygen budget model for cages, to determine maximum safe stocking levels. Providing these are not exceeded and eutrophication is kept under control it is not likely that cage farms will cause surface oxygen depletion problems (although deep water deoxygenation may occur, see Section 2.1.4 (a)).

(d) Chemicals

A wide variety of chemical agents are used in aquaculture (see Section 2.1.5). The behaviour of these chemicals in the environment and their toxicity to humans and other organisms is largely unknown. Little information is available on the frequency of applications and quantities used, although the ICES working group on the environmental impact of fish culture are compiling a directory of aquaculture chemicals and usage (EIFAC 1988). The chemicals used in aquaculture are currently considered to be drugs (and not pesticides) and therefore are not covered by the EC Drinking Water Directive (80/778/EEC) which sets limits of 0.1 µg l^{-1} for individual pesticides. The use of drugs used in fish treatment comes under the Medicines Acts 1968 and 1971. This legislation requires all veterinary medicines to have a product licence obtained from the Ministry of Agriculture, Fisheries and Foods (MAFF), covering the sale, supply and manufacture of the drug. It will only be granted if it meets the required standards on safety, quality and efficacy, and is shown not to be harmful to the treated animals, handlers of the drug, consumers of treated animals and the environment generally (Ross and Horsman 1988). However, a provision in the Acts permits the use of any medicine under veterinary prescription. This allows unlicensed products to be used with no official knowledge of their impact on the environment.

The State Veterinary Service, in conjunction with MAFF, are releasing guidelines which will help veterinary surgeons to decide on which scenarios merit the prescription of certain treatment chemicals; for instance, malachite green should not be prescribed for the ova of rainbow trout. These guidelines will hopefully reduce unnecessary usage. At present no statutory screening procedure for existing or new treatment chemicals is likely; each new chemical will be looked at on its own merits and with (voluntary) consultation with relevant environmental research bodies (pers comm, A Gray, Central Veterinary Laboratory).

Most concern is centred around the use of antibiotics, Malachite Green, Formaldehyde and 'Nuvan' (now known as 'Aquagard').

Antibiotics

The major antibiotics used in fish treatment include oxolinic acid, potentiated sulphonamide, trimethoprim and oxytetracycline. Currently, only 6 antibiotics have a formal product licence (Anon 1989b).

The presence of antibiotics is often acknowledged in discharge consents (see Section 4); however, currently no standards have been recommended. Most pollution control authorites cannot monitor for these substances.

The Water Research Centre (WRc) is currently reviewing the ecotoxicology of these substances. However, no recommended limits for potable supplies have been formulated (pers comm, Toxicology Section, WRc). WRc (Crathorne et al 1986) have developed methods for the analysis of these substances. Concentrations downstream of fish farms applying antibiotics were found to be low. At one site, where oxolonic acid was used to treat Enteric Redmouth, concentrations in the effluent were 1200 ng l^{-1}. This decreased to 51 ng l^{-1} in the river water 22.4 km downstream.

There is still concern that the antibiotics may act as sensitisers to a small proportion of the population, or could cause antibiotic resistant strains of bacteria which could act as a source of infection.

Malachite Green

Malachite Green is used mainly as an antimicrobial agent (see Section 2.1.5). There is very limited data regarding its mammalian toxicity and some doubts have been raised regarding the validity of some of the information available (pers comm, Toxicology section WRc). On the basis of this data, however, the WRc have formulated "suggested no adverse response levels" (SNARLs) for the potable concentration of Malachite Green. For a 24 hour period the SNARL, allowing all the proposed admissible daily intake from water, is 50 µg l^{-1}; a 7 day SNARL, allowing 50% of the proposed admissible daily intake from water, is 25 µg l^{-1} (currently a concentration of 0.1 mg l^{-1} is often consented for fish farm effluents, although many pollution control authorities do not and cannot currently monitor levels). It is recognised that these levels may be difficult to measure and that concentrations immediately downstream of fish farm effluents may exceed these limits. However, the affinity of Malachite Green with organic material suggests that it might be readily removed by conventional treatment (see Section 3.4.2(a)).

Formaldehyde

Formaldehyde is used as a general disinfectant in fish farms and concern has been expressed about its carcinogenic properties.

The WRc has recommended 24 hour SNARLs of 250 µg l^{-1} for formaldehyde in potable water, with a 7 day SNARL of 125 µg l^{-1} (1.0 mg l^{-1} is currently being consented for fish farm discharges by some pollution control authorities).

'Nuvan 500 EC' ('Aquagard')

'Nuvan' is the only available treatment for the eradication of sea lice. It has recently been issued a temporary product licence by MAFF (Anon 1989c) under the new name 'Aquagard'. The active ingredient in 'Nuvan 500 EC' is the organophosphorus pesticide dichlorvos, which is a potential List I substance under the EC Discharge of Dangerous Substances Directive (76/464/EEC). It is also a "Red List" substance, that is a chemical identified as being dangerous. At the second International Conference on the Protection of the North Sea, in London 1987, the Government declared it would reduce the input of Red List substances into the aquatic environment by 50% between 1985 and 1995.

There is limited data available on the degradability and ecotoxicology of 'Nuvan'. However, WRc is currently preparing provisional environmental quality standards for dichlorvos in water for the DoE.

(e) Ammonia

Ammonia is a List II substance, under the EC 'Dangerous Substances Directive' (76/464/EEC). EQSs for different water uses have been proposed by the Environmental Strategy, Standards and Legislation Unit of WRc (Seager et al 1988). Surveys of land-based farms have found increased total ammonia concentrations as water passed through the farms. In a survey of UK salmonid farms Solbé (1987a) found increases of 1.6 mg l^{-1} total ammonia in the effluent water, with un-ionised ammonia levels of 0.002 mg l^{-1}. These figures indicate that direct toxicity to aquatic organisms from un-ionised ammonia at usual fish stocking levels would be unlikely to cause compliance problems with EQSs set for un-ionised ammonia.

Discharge consents for ammonia in land based farms allow for between 0.2 and 1.5 mg l^{-1} of total ammonia to be added to the water as it passes through the farm. Various estimates have been made regarding the rate of output of ammonia (see Phillips (1985) for review), and the Highland River Purification Board use the figure 408 mg kg^{-1} fish day^{-1} for deriving effluent standards (HRPB 1987).

Elevated levels of total ammonia have been measured around caged farms (Phillips 1985, Gowen et al 1988). However, these concentrations were much lower than the EQS specified for most water uses, only exceeding the EQS set for potable water receiving class A1 treatment or industrial abstraction for food processing.

It seems unlikely that un-ionised ammonia will present a threat to aquatic organisms, including the farmed fish. Highland RPB have, however, specified in discharge consents for marine cages, that ammoniacal nitrogen concentrations should not exceed 50 µg l^{-1}.

(f) Other water quality determinands

Other parameters may be specified in discharge consents, including pH, turbidity, colour, absence of sewage fungus, no visible oil, fat or grease, and a general provision may be added that no damage is caused to the natural fauna and flora.

3.1.3 Inadequacies of effluent control measures

A number of difficulties are being faced by pollution control authorities at present, which will now be considered in turn.

(a) Land-based farms

Flow

The greatest problem faced by many pollution control authorities in England and Wales is river flow depletion. Current legislation does not adequately control the amount of water abstracted by river-fed farms, which is needed to prevent excessive abstraction from rivers severely depleting flow in, or even drying up, the stretch of river between inflow and outflow (see Section 2.3.3 (c). Abstraction cannot currently be controlled by licensing in most instances, since the majority of farms are considered to be agricultural units (as they produce fish for the table) and are therefore exempt under Section 24 (2)(b) of the Water Resources Act (1963) (covering England and Wales). Moreover, there is no restriction concerning the extent of such abstractions (Section 26 (1)(b) of the same Act), either by volume or proportion of flow. The Water Act (1989) (Schedule 13) will remove the agricultural exemption for all such abstractions in excess of 20 m^3 day^{-1}; this will certainly help to ameliorate environmental problems caused by flow depletion in England and Wales.

However, there are further problems with abstraction control. Many farms claim a 'licence of right' under Section 33 (1) of the Water Resources Act (1963), whereby water can be abstracted according to earlier statutory provisions (including common law rights), or if it can be proven that water was being abstracted at any time within the 5 years previous to the enactment of the 1963 Act. Furthermore, statutory holders of a 'licence of right' are entitled to as much water as they require if previous statutes have not stipulated quantitative restrictions (Section 34(3)). This type of abstraction right can vary greatly, from 50% of total river flow (pers comm R Merriman, NRA Welsh Region), to a set flow figure which may amount to the whole of the DWF of a river (pers comm N Morris, NRA South West Region). 'Licences of right' will not be revoked by the Water Act (1989).

The only possible way of restricting protected abstraction rights is to restrict the effluent flow, which pollution control authorities have done with mixed success.

Failure to control effluent flow has been brought about both by legal complications and monitoring problems. Controllers have been unwilling in the past to infringe the right to abstract with an effluent flow restriction, since this may not be upheld in court. NRA Welsh Region, for instance, consent 50% of total flow since 'licences of right' often entitle farmers to this proportion, and therefore there is no legal contradiction. Similarly, NRA Wessex Region are very uncertain whether their recent decision to restrict effluent flow to 50% of Dry Weather Flow (DWF) is legally enforceable. The Wessex restriction is far more stringent than that of Welsh Region, and fish farmers in Wessex are consequently pressing for a two-stage consent to allow greater effluent flow in winter. Welsh Region would certainly much prefer fixed flow consents than their current consent format, and are currently considering a change in policy to consenting a fixed proportion of DWF (pers comm R Thomas, NRA Welsh Region).

A further legal complication to restricting effluent flow is that farmers utilising river water may use existing channels (such as mill stream channels) to bring water into and out of their farms. Since existing channels merely represent bifurcations of river flow rather than diversions they may well be seen as "inland waters" under COPA, meaning that the effluent flow the farmer discharges is only the difference between outflow and inflow. Clearly, no legally enforceable effluent flow restriction would be possible in such cases. Moreover, if the above applies to the effluent it also applies to the abstraction, meaning that clauses in the Water Act (1989) concerning the licensing of previously exempted fish farm abstractions (Jones 1989) may not apply in a proportion of cases (pers comm M Booth, NRA Wessex Region).

The monitoring of effluent flow has proved a further difficulty to its control. Flow gauges are expensive to install and maintain, and difficult to position (many farms have multiple effluent channels). Owing to these factors gauges have rarely been used on fish farms, such that the only measure of flow comes from infrequent spot readings, and in some areas flow is not monitored at all. Under Section 34 (4) (d), (e) and (f) of COPA, pollution control authorities can force dischargers to install and maintain flow gauges and keep records of results. More use could be made of this piece of legislation.

A possible solution to the problem of flow-monitoring would be an automatic flow-partitioning device which could be set either to allow diversion of all water above a certain stage height into the farm, or to allow diversion of a certain proportion of the total flow (pers comm R Merriman, NRA Welsh Region). The farmer could then take the amount required and divert the remainder directly back into the river.

Incremental standards

A further difficulty with the high flows demanded by fish farms is that there is often little water left in the river to dilute the pollutant load. This means that in order to comply with downstream water quality standards consent values have to be very stringent. For parameters consented incrementally the difference between influent and effluent water quality is therefore small and often on the limit of analytical precision, making many breaches of consent difficult to prove.

Many pollution control authorities try to standardise on an allowable drop in water quality of a proportion of NWC class width but due to the high flow of fish farm effluents such a standard may give rise to consent values below the limit of precision. This is clearly impracticable, and in such a situation the controller may either increase the consent values involved (thus taking a greater proportion of the class width), or refuse the consent (a decision which may well be overturned on appeal). The end result is that one fish farm often uses up the entire pollution "budget" for a stretch of river, making the consenting of other discharges impossible without a drop in NWC classification.

Failing to control flow has allowed a far better chance of complying with consent standards, since consent values are imposed on the discharge and pollutants can therefore be diluted in the effluent to a greater extent than allowed for in the conditions of consent; ie the effuent may comply with consented pollutant concentrations, but if flow is not controlled the pollutant loading may well be higher than allowed for.

Proving breaches of consent using incremental standards set between the intake and discharge has been hampered in the courts by the timelag imposed on water by its diversion through a farm, ie the water sampled at the intake is not the same as that sampled at the discharge unless a suitable time is allowed to elapse; the timelag varies for each farm and is also usually unknown.

The use of instream incremental consents, proposed by NRA South West Region (pers comm N Morris), may at least partly circumvent this timelag problem. Such consents would define an allowable increase in pollutant concentration in the river between a point just above the discharge and a point just below the discharge. Whilst the timelag will be greater for water running through the farm (due to pond residence times) than for water running along the river between intake and discharge, the two samples taken for incremental consent compliance will be considerably closer in terms of time than samples taken under the old incremental system (taken at the intake to the farm and in the discharge). Furthermore, since the amount of water available for dilution of the effluent in river-fed farms depends upon the amount of flow abstracted, assumptions have to be made about available dilution with current incremental consents, which is not the case with the proposed instream consenting. One difficulty with instream consenting would be that any source of contamination discharging into the river between the farm intake and outlet would have to be re-routed downstream of the farm outlet, which will involve some effort. Such re-routing is clearly not possible for diffuse pollutant sources.

Suspended solids

Producing representative suspended solids values has proved difficult due to the high degree of bed load transport, where particles roll along the floor of the effluent channel rather than becoming truly entrained. This leads to underestimates of the solids load entering the river.

Fish farm chemicals

Many consented parameters are not monitored (eg malachite green, formaldehyde, antibiotics) since water quality controllers often cannot analyse for them. Most monitoring is restricted to the sanitary parameters, ie suspended solids, ammonia, BOD and DO (for regional variations see Section 4). NRA South West Region are considering using Section III of the new Water Act, to prohibit the use of certain fish farm chemicals within designated 'water protection zones' (pers comm N Morris).

Multiple discharges

The presence of multiple discharge outlets causes problems with obtaining representative effluent samples, and in many cases the only answer is to separately consent each one due to the layout of the farm. This serves to multiply the monitoring workload. Such situations could be circumvented at the planning stage by better liaison between local authority and pollution control authority (see Section 3.2).

Variability of effluent quality

Fish farm effluent quality varies greatly on a diurnal timescale (feeding regime, fish treatment regime) and a seasonal timescale (river flow, stocking density, total biomass, stock age). Diurnal variations are particularly important as they are very unlikely to be detected or accounted for with low frequency discrete effluent quality sampling.

Pollution incidents

Pollution incidents due to fish farms have generally not been reported as a major problem by pollution control authorities. However, most incidents are unlikely to be discovered using routine discrete water quality monitoring, typically with a fortnightly or monthly frequency for farms with a pollution history and quarterly for others. Incidents may be accidental but may also be deliberate, such as the discharging of settlement pond sediment into the river (often at night) rather than disposing of it to land. Deliberate incidents are even less likely to be discovered by routine monitoring, unless brought to the attention of the water authority through observable effects on the watercourse. The possibility of routine monitoring with laboratory bioassays has been raised, but this suffers from the same discrete sampling problems as current consent-compliance monitoring. Biotic indices based on benthic monitoring are currently the best option for accounting for such pollution incidents, and also for accounting for the general fluctuations in effluent quality discused above.

Safe farm separations

There will be a limit to the number of fish farms any stretch of river can support, in terms of both river ecology and exploitation of water downstream for other (or similar) purposes. With respect to river ecology, if fish farms are spaced too close together effluent impacts will merge into each other, resulting in a long stretch of river with degraded faunal and floral communities.

In terms of exploitation, the correct spacing between farms to ensure water at the downstream farm is not chemically unsuitable for abstraction is rather easier to determine (assuming farms comply with their consents) than the spacing required to keep the risk of disease transmission between farms to a minimum. Since little is known about the waterborne survival time of the diseases involved it is difficult to set safe safe separations; in the case of disease-carrying escapees it is unlikely that there is a safe separation.

It is highly likely that of the two factors under consideration, river ecology would demand a greater separation of farms, since it requires that the length of impacted river is small in relation to total river length; exploitation demands only that a certain standard is achieved before water is required for another use at some point downstream. However, at present there are no legislative biological standards that set acceptable limits of ecological impact to parallel water quality standards set for exploitative purposes. This situation is, however, set to change in the 1990 Water Quality Survey of England and Wales; the NRA are now charged with the organisation of this survey and are planning to introduce a biological classification based on the Freshwater Biological Association's (FBA) 'RIVPACS' system.

In the Wessex Region, the average separation between the discharge of one farm and the intake of another is approximately 5 miles, with the minimum separation being only 200 yards.

Disease control

Some pollution control authorites are concerned about their lack of control over the transportation of fish from farm to farm (under Section 34 of the Salmon Act, 1986). There would appear, however, to be no obstacle to consenting 'an absence of disease organisms' in fish farm effuents under COPA (or the Water Act (1989)).

(b) Caged farms

Until recently caged farming, in both fresh and marine waters, was a problem associated with Scotland only, rather than the rest of the UK. Caged farming is now appearing at various sites in England and Wales, eg the Lake District, Milford Haven, Portland Harbour and now gives wider cause for concern. The experience gained by RPBs could be vital to their control throughout the UK.

There has been some contention by fish farmers in Scotland that caged fish farms are not covered by COPA, as waste from caged farms does not legally constitute a 'trade effluent'; however, amendments have been made to the Scottish provision of COPA (pers comm, Clyde RPB).

Currently in Scotland only Highland RPB has exercised its powers to consent caged farms. However, it seems likely that Clyde and Tay RPB will follow suit in the near future. In Wales, NRA Welsh Region have recently issued a caged discharge consent (pers comm R Merriman) to a farm in Milford Haven.

There are many problems connected with applying discharge consents to caged farms.

Location and frequency of sampling

The diffuse nature of the effluent poses problems of where water quality monitoring should occur and the frequency of sampling. Possible target areas for monitoring include measurements in the vicinity of the cages at various depths of the water column to allow for stratification, at the inlet and, where appropriate, at the outlet of the water body. The timing of monitoring will also be important as many of the parameters measured will be diurnally and seasonally variable (see Section 3.1.3(a)).

Background water quality

Predevelopment background levels of water quality determinands may vary between sites, which could make a blanket approach in setting standards inappropriate and unfair. The general consensus of opinion at the Caged Fish Farming Workshop, held by Clyde RPB on 14 March 1989 was that each site should be considered individually on its own merits, taking into account predevelopment water quality parameters.

Clyde RPB and the Department of the Marine, Southern Ireland (pers comm) advocate environmental impact assessments of sites financed by the farmer, including hydrographic assessments, benthic, sediment and water quality surveys. This would provide baseline information on the suitability of a site and an appropriate monitoring strategy. In addition, Clyde RPB are considering including regular benthic surveys (possibly using stationary underwater cameras), as part of their discharge consents. Highland RPB have expressed concern that these requirements would be prohibitively expensive for farmers.

Monitoring effort

It is generally accepted by the RPBs that they do not have the resources to undertake monitoring of caged farm effluents. In accordance with the 'polluter pays' principle, the farmer should be obliged to undertake routine monitoring which would be audited by the RPBs. NRA Welsh Region is considering the implementation of a formal obligation that cage farmers in Milford Haven should maintain bioaccumulation monitors around their cages, by including a provision in new consents (pers comm R Merriman).

Consent enforcement

It would be very difficult to prove that the failure to meet an EQS was attributable entirely to a fish farm if the parameter breaching the consent is also a pollutant from other local industries/land uses. For example, afforestation can add to phosphate loadings in freshwater lakes due to run off from fertiliser applications. Quantification of the input from such a diffuse source would be very difficult, making prosecutions for non-compliance with an EQS even more problematical.

Lack of feed control

Annual production is perhaps the most easily monitored parameter for caged farms, and a maximum value is always quoted in consents. However, there is no control over the quantity of food fed, and, although it is in the best interests of farmers not to waste food, there is no doubt that overfeeding does occur. Similarly, there is no control over feed quality. Licenses issued to caged farms in Finland specify allowable amounts of feed as well as a maximum allowable annual production (Mäkinen 1988) although it is not clear how feed usage is monitored.

3.2 PLANNING CONTROL

3.2.1 Land-based farms

The planning control for land-based farms is covered by the Town and Country Planning Act 1972. There is controversy as to whether fish farming falls within the definition of "agriculture" (see also Section 3.1.3 (a)); if they are deemed "agricultural units" they are exempt from planning controls under the Act. This has led to the unsatisfactory situation where some farms require planning permission (those producing fish for restocking) and others do not (those producing fish for the table). Furthermore, since the minimum proportion of 'fish for the table' production required for the farm to qualify as an agricultural unit is not specified, there is the possibility that farms planning to use the great majority of their production for restocking can still be exempted.

When planning permission is required there is often little liaison between planner and pollution control authority, and the hypothetical end-point is that planning permission for a new farm could be given, and the farm could even be built, but its application for a discharge consent refused. The feeling amongst planners seems to be that a discharge consent can always be granted; it merely becomes more stringent if the reach of river to be utilised approaches downstream water quality standards. This attitude puts great pressure on water authorities to consent in some form, since it is difficult to refuse applications if planning permission has been given and the farm is operational.

Whilst planners may liaise sensibly with pollution control authorities in some areas, there is clearly a need for national legislation to formally incorporate the consent to discharge into the permission to develop, ie consenting the discharge becomes a condition of granting planning permission. Wessex Water has campaigned in the past for a licensing arrangement whereby all possible impacts of a development are investigated prior to granting any form of permission.

Expansion of existing farms seems to be more common than new site development at present.

3.2.2 Caged farms

The development of caged farms in freshwater lakes is also covered by the Town and Country Planning Act, and so similar problems to those described above are evident. Indeed, it has been alleged that some local authorities believe freshwater caged farms do not require planning consent (Needham 1988a). In contrast, some EIFAC countries are so concerned about the ecological and aesthetic impact of such farms they are unlikely to permit any new developments (Solbé 1987a); these countries are Austria, Finland, W Germany (in the Bavarian Lakes) and Norway (unless the operation is very small in relation to the size of the water body).

Of all EIFAC countries, only Sweden is as enthusiastic as the UK in its use of freshwater lakes for fish farming. The Vollenweider model (see Section 3.1.2 (a)) is used in the planning process and has apparently worked well.

As with land-based farms in the previous section, a national strategy in the form of a licensing arrangement is required for freshwater caged farms to prevent indicriminate and damaging developments. Such a move would be welcomed by fish farming interests (Needham 1988a).

The provisions of the Town & Country Planning Act do not extend beyond the low water mark of spring tides and as such do not include marine farms, although the Act will cover any associated on-shore developments.

The control of development of the seabed in the UK and much of the foreshore around Scotland is the responsibility of the Crown Estate Commissioners (CEC). The siting of a marine fish farm requires the fish farmer to obtain a lease from the CEC, for which a rent is payable. Before granting a lease, various agencies are consulted voluntarily such as MAFF/DAFS, planning agencies, the Nature Conservancy Council (NCC), the Countryside Commission and the relevant pollution control authority. Consent is required from the Department of Transport under Section 34 of the Coast Protection Act 1949 (NCC 1988). (Other consents are needed in order to undertake fish farming operations but these are not conditional to the granting of a lease).

Criticisms of this system include:

(i) that as landlords and rent collectors, the CEC has a vested interest in granting leases;

(ii) that there is insufficient consultation with the appropriate agencies;

(iii) that there is no public accountability; and

(iv) that each application is considered individually, with no account of forward planning.

The general opinion expressed at the Caged Fish Farming Workshop held at Clyde RPB was that current planning controls for both fresh water and marine farms are inadequate. It was suggested that planning controls should be extended to offshore operations, and that all land-based fish farming, including that on agricultural land, should be subject to planning control.

The SWCL (1988) also calls for strategic national and local planning, which would incorporate important ecological, social and economic priorities in policy guidelines.

Researchers in Norway and Ireland are recommending that sheltered sites with poor exchange should be avoided (Needham 1988b). There is a strong case for discouraging further development within water bodies of low dispersive energy and/or flushing rate, in both the freshwater and marine environment. This would reduce the risk not only of benthic degradation and eutrophication (see Section 2.3) but also of site 'souring', whereby the accumulated sediment underneath a cage pollutes the overlying water (usually by reducing oxygen levels) and causes a deterioration of fish health and growth (Gowen an McClusky 1989). Rotation of the cage site, to prevent souring and allow a fallow period in which the used site can recover, may help the fish farming industry, but environmentally serves to spread their benthic impact further afield. It will probably take several years before fallow sites recover fully in terms of their macrofaunal assemblage (Gowen and McClusky 1989), depending upon local hydrography.

3.3 OTHER CONTROL AGENCIES ASSOCIATED WITH AQUACULTURE

The Ministry of Agriculture Fisheries and Foods (MAFF) and their counterparts in Scotland, Department of Agriculture and Fisheries for Scotland (DAFS) have special statutory responsibilities for aquaculture. These are primarily concerned with disease control. Under the Diseases of Fish Act 1937 and 1983, specified diseases have to be reported to them. They have the power to restrict and control the importation of some species and can control and restrict the movement of fish with notifiable diseases. All fish farms must register with them and provide information on the movement of live fish.

MAFF and DAFS are also responsible for the discretionary issue of licences for the shooting of certain predators.

3.4 WASTE CONTROL TECHNOLOGY

There are many technological innovations which can be used to minimise the environmental impact from aquaculture.

3.4.1 Feed improvements

Improvements in fish diets are an important factor in reducing hypernutrification and solid waste loadings. This can be achieved by improving food conversion ratios (FCRs) (the amount of food required to produce a given output of fish, usually expressed in tonnes) and by reducing the phosphorus composition of diets.

Improved FCRs can be achieved by producing pellets with lower settling velocities, giving the fish more time to consume the food before it settles out as waste from the water column. This is important even for land-based production, as salmonids are reputed not to feed from the bottom of their tanks and ponds. To resolve this, some manufacturers have developed low density 'expanded' pellets (Henderson and Bromage 1987). Other improvements can be made to the digestibility of the food.

A paper submitted by BP Nutrition at the EIFAC conference in Verona, October 1988, reported on the formulation of high energy diets. These use high temperatures during production to improve the carbohydrate digestibility and increase the oil and fat content of the food (pers comm John Chandler, UK EIFAC representative).

Fish food often contains phosphorus in excess of fish requirements. Wiessman et al (1988) found that reductions of phosphorus in feed from 10 g P per kg dry matter did not impair rainbow trout growth rates or food conversion ratios. Commercial diets at the time tended to contain more than 20 g P per kg dry matter. Unmetabolised phosphorus is then excreted, contributing to hypernutrification of the water column. Reductions of phosphorus in the elemental composition of foods would therefore reduce this impact. Feed containing fish meal and fish oil have been found to provide low phosphorus output levels per unit fish weight gain (Crampton 1987). Surveys undertaken by Solbé in 1980 and 1986 (Solbé 1987b) showed a decrease in solid loadings of fish farm waste. This has been attributed to the use of improved feeds, together with improved husbandry techniques. The latest findings from the EIFAC conference in Verona indicate that further improvements have been made. In Denmark FCRs have improved in the last few years from between 1.5:1 and 1.6:1 to 1.2:1, resulting in a 56% reduction of suspended solid loadings, from 200 g of suspended solids kg^{-1} of fish produced to 88 g of suspended solids kg^{-1} fish output. Reduction of the phosphorus content of feed by a third has reduced emissions by 60% (pers comm, John Chandler).

3.4.2 Effluent treatment

(a) Land-based farms

The simplest method employed and the most frequently used in the UK is the settlement pond, which allow solids to settle from the effuent prior to discharge. Since most phosphorous is associated with the particulate phase, settlement ponds may also reduce the risks of hypernutrification. Surface area and cross-sectional area of the pond are critical in relation to effluent flow, in order to allow settlement whilst preventing turbulent resuspension. Design criteria are described by Henderson et al (1989).

Regular removal of accumulated sludge is essential to their proper functioning, since settled solids reduce cross-sectional area (causing resuspension) and also release phosphorus which then enriches the effluent. The need for proper maintenance of settlement ponds is highlighted by the establishment of sewage fungus below a fish farm effluent on the Hampshire Avon, following the installation of a settlement pond. This was probably due to phosphorus release from settled solids in the pond, possibly under anoxic conditions where the rate of release is higher. The Highland River Purification Board (HRPB) have had similar experiences with settlement ponds, with enhanced BOD and nutrient concentrations resulting from their installation. It is believed that more frequent solids removal would not relieve this problem (pers comm J Hunter, HRPB) and hence effluent filtration is now preferred by HRPB.

Although settlement ponds are the most frequently employed treatment in the UK, they are by no means in widespread use. Only 17% of fish farms were found to use them in Solbe's 1980 survey (Solbé 1982). Section 4 gives an indication of the regional variation in the use of settlement ponds.

More sophisticated methods of solids removal have been developed: the swirl concentrator is reputed to remove 60-80% of suspended solids and reduce phosphorous emissions by 30-50%; the triangle filter, recently developed in Sweden, can apparently attain 80-95% solids removal and 70-80% phosphorous removal (Solbé 1987a). Both systems are sensitive to the breakdown of flocs. Triangle filters, costing £3500 at 1984 prices (Solbé 1987a), are an expensive form of treatment which few farmers will volunteer to buy. A substantial number have been bought in Sweden in order to comply with the stringent effluent standards set.

Baffles have been placed in rivers to encourage settlement of effluent solids. Whilst this method may reduce the suspended load there is likely to be a deleterious effect on benthic fauna from the deposition of large amounts of organic particulates and the periodic clearance of accumulated sediment. On-site solids removal is a far better option.

At the EIFAC conference in Verona, it was concluded that the most cost-effective and successful option to date was quiescent settlement zones within production raceways (EIFAC 1988).

The treatment of the dissolved phase of the effluent has received little attention, although dissolved pollutants such as ammonia, BOD, phosphorus, disinfectants and anti-microbial agents can cause problems, especially when a recirculation system is employed. A possible answer for the removal of ammonia and BOD is submerged media filtration, using gravel as a substrate for nitrifying bacteria. Such filters are already used within recirculation systems, but not on their effluent.

Recirculating fish farms usually produce a more concentrated effluent than through-flow farms, but widespread use of recirculation in conjunction with biological filtration of the final effluent would produce not only a cleaner effluent, in both the dissolved and particulate phase, but would also relieve the pressure on rivers in England and Wales caused by excessive water demand. Liao (1974) reports that submerged and trickling filters operating with 90% water recirculation removed 86-89% of the BOD, 79-91% of the suspended solids and 49-69% of the NH_4-N, compared to the pollutant load from a through-flow system.

Damage to the microbial flora of the filter may occur during the periodic use of disinfectants or anti-microbial agents, although Collins et al (1975) indicate that at "normal therapeutic levels" formalin and malachite green have no effect on nitrification. However, for other chemicals, and also to allow for the possibility of misdosing or accidental spillage, a bypass system incorporating physico-chemical filtration would be a sensible safeguard. At such times, filtration through substrates such as activated charcoal, 1 kg of which can remove 150 g of malachite green, may be a useful treatment.

Farms using heated water would reduce the risk of environmental damage, and reduce overheads, by using heat conservation methods. The use of heat exchangers is described by Arabi (1988).

Other methods of treatment that have been investigated include growing crop and field plants, such as lettuce, rye grass and barley, as a method of removing nitrogen and phosphorous from fish farm wastes (Petersen 1987), and using zooplankton and filter-feeding silver carp to control phytoplankton biomass in aquaculture ponds (Smith 1985). Phragmites beds are also likely to be a useful treatment method.

(b) Caged farms

Sediment traps have been developed for the removal of solid wastes from below fish cages. They involve applying gentle suction to the base of the cage using a large funnel, from where the sediment-laden water is passed through a filtration unit and then returned to the water body. Such traps will avoid gross pollution of the benthos under and around cages in both the freshwater and marine environment. Since phosphorus is associated with the particulate phase and is usually the limiting nutrient in freshwater, such traps are also likely to greatly reduce the risk of eutrophication in freshwater systems. However, since the majority of nitrogen is released in the dissolved phase and nitrogen normally limits marine primary production, sediment traps are not likely to reduce the eutrophication hazard caused by marine cages.

Although Sweden has reported satisfactory sludge collection under marine cages, the system became too fouled under freshwater cages (Solbé 1987a). Finland has experimented with sediment traps in the marine environment with variable success (Mäkinen, 1988). Further development will hopefully produce a reliable system in both the freshwater and marine environments; however, the high cost of such traps (EIFAC 1988) may inhibit their widespread use.

The disposal of dead fish has caused complaints in the Highland River Purification Board (HRPB) region, where badly-sited onshore burial pits serving caged farms have allowed leachates access back to the water body (HRPB 1988). Guidance or a code of practice on the siting and building of such pits, together with routine inspection of disposal operations, is the only way of alleviating this problem.

3.4.3 Prevention of genetic contamination

The interbreeding of escaped farm fish with wild fish poses a threat to the genetic integrity of natural populations and thus to the maintenance of their specific adaptations to local conditions (see Section 2.3.3 (b)). The widespread use of triploid fish (Cuellar and Vyeno 1972, Stanley and Sneed 1974), which are sterile, in farms is the only measure likely to prevent this interaction, although the development of effective vandal-proof outlet screens would certainly ameliorate the situation.

3.4.4 Treatments for sea louse

The current method for controlling sea lice is by use of the drug 'Nuvan' as an immersion treatment. The active ingredient is dichlorvos which, as a 'Red List' substance (see Section 2.1.5), may place a question mark over the continued use of this treatment method; however, Nuvan has recently been isued with a temporary (one year) product licence, under the new name 'Aquagard' by MAFF (Anon, 1989c). Some alternatives have been reviewed by Ross and Horsman (1988) and include: the use of 'Nuvan' only in enclosed treatment baths; incorporating it in fish diets; or applying it as a ready mixed medication directly into the water stream, using a pump and fine nozzles.

There are currently no effective substitutes available for 'Nuvan'. However, the University College Galway has been evaluating the effectiveness of 'Ivomectin', a derivative of 'Ivomec' which is currently used in animal treatment. Initial results look promising.

Biological control is being researched in Norway into the possibility of using corkwing wrasse (Crenilabrus melops) as a cleaner fish. The Institute of Aquaculture at Stirling University is currently studying the life-history of the sea-louse to identify how treatment techniques might be optimised.

SECTION 4 - EXTENT OF THE PROBLEM IN THE UK

Information in this section was obtained by questionnaire and follow-up interviews with staff from the NRA regions of England and Wales, and by discussions with staff from various River Purification Boards and DAFS in Scotland. Each region shall now be considered in turn.

4.1 NRA WESSEX REGION

NRA Wessex Region has approximately 50 land-based fish farms, with one marine caged farm having recently been set up in Portland Harbour. Of the land-based farms, roughly 35 are classed as 'fish for the table' and 15 are for 'restocking'; about 10% have settlement ponds and the remainder have no effluent treatment. Fish farming has caused water quality problems, especially in terms of suspended solids, DO and ammonia, but the greatest problem is depleted flows due to farmers with agricultural exemptions or licenses of right. Flow has not been monitored historically, and discrete sampling is performed between 4 and 12 times pa depending upon past history. Although a number of fish farm chemicals are consented, only the sanitaries are monitored. Incremental values are used for suspended solids, BOD, pH, NH_3 and probably for DO in the future. Few pollution incidents have been recorded, but these are unlikely to be picked up under the current monitoring regime (see Section 3.1.3(a)); biotic indices (BMWP, RIVPACS) are used on an ad hoc basis for monitoring problem farms. No work has been performed on disease transmission, competition between farmed and wild fish, or genetic erosion of wild stocks, although all three give Wessex cause for concern. Fish escapes from farms occur regularly in small numbers, with mass escapes being rare. No conclusions have been drawn as to whether greatly depleted flows caused by fish farm abstraction are producing a barrier to migrating salmonids. Effects on coarse fish migrations and entrapment have also been a concern.

Wessex are currently attempting to restrict effluent flow (and thereby river abstraction) to 50% of dry weather flow, but the legality of this has not yet been tested in court. There is pressure to alter consenting policy to a two-stage flow consent, allowing for greater effluent flow in the winter.

Wessex are now normally consulted when planning permission for a new farm is sought, but some may still go undetected. No policy decision has been made on the consenting of caged farms as yet.

4.2 NRA SOUTH WEST REGION

There are 66 known fish farms in the South West region, 37 being classed as 'fish for the table', and 29 are restocking farms; there are also some freshwater caged farms in the area. All farms have settlement lagoons, but their design and efficiency varies widely. Two or three farms use recirculation, but reconditioning of recirculated water is rudimentary, usually just reoxygenation. Suspended solids output and the growth of sewage fungus cause problems in the area. Flow depletion is causing great concern, with a number of farms drying out their river supplies during this year's drought and producing barriers to the upstream migration of salmonids. No easy solution to flow depletion is foreseen in the region since it is believed that monitoring a prescribed flow in a river must come from abstraction control, not effluent control (pers comm N Morris); changes in legislation are required to keep abstraction by all farms in check. At present, it is believed that the only constraint on flow for some farms is if there is insufficient residual flow to dilute the effluent and allow the river to conform to downstream water quality standards. When consenting, this may be used to reject applications or force a lower production rate (and thus a lower flow rate); however, no such constraint exists if the farm produces an adequately clean effluent.

Most consents are currently expressed in absolute terms, but will soon be changed to 'stream consents' (see Section 3.1.3(a)), which will allow incremental consents to be set without the legal problems caused by timelags in flow through the farm. Although a suite of fish farm chemicals may be consented (excluding antibiotics), only DO, NH_3, BOD and suspended solids are monitored routinely, at a frequency of 6 times pa or less. New policy is now dictating that all farms be monitored 12 times pa. Biological monitoring (BMWP) is undertaken on an *ad hoc* basis, and the effort is set to increase in the future.

Notification of new or expanding developments that require planning control is good, but those farms exempted from planning provision can and do set up without applying for discharge consents.

4.3 NRA WELSH REGION

Of the 20-25 land-based farms of a significant size, the majority are classed as 'fish for the table'. There are also 2 freshwater caged farms and 2 marine caged farms in Milford Haven (with another 3 proposed). The larger land-based farms have settlement ponds, and this summer perhaps 40% of farms turned to recirculation to make up their required flow. Flow is again the main land-based concern, with some farms taking 80-90% of the flow; this has resulted in salmonids being prevented from reaching spawning redds. NH_3 and BOD repeatedly breach consents, but settled solids are generally not a problem since flows are usually high and there is little opportunity for settlement. Phosphate is also not a great concern due to high flows.

Discrete sampling for sanitaries is conducted between 4 and 12 times pa; with the exception of malachite green, fish farm chemicals cannot be monitored. Pollution incidents are infrequent; biotic indices are rarely used, but ecological effects tend to persist for up to 1 km downstream of discharge. Disease transmission, competition and genetic erosion have not been studied, but the steady trickle of escaped farmed fish is causing concern in these areas. Entrapment of smolts in fish farm intakes is common, partly because there is no legal requirement for 'exempt' farms to screen at the abstraction point.

No flow gauges have yet been installed on any farm, but consents are being revised to make farmers responsible for the installation and maintenance of gauges at specified locations. The possibility of an automatic separation of river flow, to ensure a set amount/proportion of water remains in the river after abstraction is being considered. 50% of total river flow is currently being consented for the effluent, but this requires flow-gauging of both effluent and river and also means that smaller incremental consent values have to be set. Welsh Region are now looking to consent effluent flow as a proportion of DWF, and foresee no legal problem in enforcing this.

The environmental impact of the caged farms in the area is not clear. Consents are based on a maximum allowable annual production, with a committment on the discharger to maintain records of fish stock, feed and therapeutic treatments. There is also a committment to maintain cages of bioaccumulating organisms.

Welsh are often not consulted at the planning stage since most farms in the area are exempt from planning control.

4.4 NRA ANGLIAN REGION

There are approximately 45 land-based farms in the Anglian region, at least half of which are restocking farms and therefore require abstraction licences. There are also some caged farms in lakes and gravel pits. Fish farming does not really present many problems in the area, since restocking farms tend to be less intensive, and many land-based farms are fed by borehole rather than from the river which precludes the possibility of depleted river flows. Flow is not normally consented for land-based farms, although it is considered; it is not monitored. Discrete sampling for sanitaries is conducted between 1 and 12 times pa depending upon the size of farm and past history. Other consented parameters, which include some fish farm chemicals but no antibiotics, are occasionally monitored. Borehole-fed farm effluents often improve river quality, rather than degrade it.

Biotic indices (BMWP, ASPT, LQI) are used below larger farms but no significant effects have been observed. Disease transmission is a concern in the area, although there have been no specific problems yet. Escapes from farms are infrequent and involve only small numbers of fish.

The planning procedure appears to work adequately, with Anglian Region being consulted at an early stage. This may be due in part to the smaller proportion of exempted farms. No applications for consent have yet been refused.

4.5 NRA NORTH-WEST REGION

There are about 20 land-based farms in the region, perhaps 75% of which are consented. With the exception of one restocking farm, all farms are either 'fish for the table' or part-table/part-restocking. Very few farms have settlement ponds and no farm uses recirculation. There are also some freshwater caged farms. Fish farms do pose environmental problems, particularly siltation or river beds, BOD and growth of sewage fungus. One farm has probably caused a downgrading (due to BOD) of NWC river class from 1A to 2, on the River Dussop. Nutrients are not consented but their possible effects are causing concern. Effluent flow is consented not to exceed 50% of DWF, but is only monitored where there is a readily observable problem; one farm is drying up the river bed between intake and outlet.

Discrete sampling is conducted approximately 4-6 times pa for sanitary parameters; treatment chemicals are consented but not monitored. Incremental values are not used for any consented parameters. The low sampling frequency causes concern within the authority, since effluent quality varies greatly with feeding regime, stock size and time of day.

Biological monitoring (BMWP, ASPT, Trent) is carried out quite frequently, with effects persisting 100-200 metres downstream. Generally inefficient screening has led to some major escapes of farmed fish, with frequent minor incidents. Although there is no evidence for disease transmission between farmed and wild fish, this is a major area for concern.

The degree of consultation at the planning stage is variable, with some farms becoming operational without any warning to the water authority. A number of applications for discharge consent have been refused, using empirically derived estimates of pollutant output to assess the risk of an NWC class downgrading.

The freshwater caged farms in the area are causing control difficulties and many are operating without consents. Esthwaite Water has changed from oligotrophic to mesotrophic status, but the impact of the caged farm there is confused by contributions of phosphorus from the local sewage treatment works.

4.6 NRA SEVERN TRENT REGION

Of the 50-60 land-based farms in the area, about half are classed as 'fish for the table' and half are restocking farms. Only a few farms have settlement ponds and the rest have no effluent treatment. Although some breaches of consents occur (especially by the larger farms), fish farms only cause localised water quality problems. Incremental consents are used for river-fed farms, but Severn Trent would like to move to absolute values on all parameters. Effluent flow is consented as a proportion of DWF for river-fed farms, but it is not monitored as it generally does not cause a problem. Discrete sampling is conducted at least 4 times pa for all consented parameters, which include malachite green and formaldehyde but no other fish farm chemicals.

Biotic indices are used (BMWP, Trent) on an ad hoc basis. Fish escapes occur occasionally, often due to vandalism of screens. Waterborne diseases are transmitted from wild to farm fish in river-fed farms, but there have been no reports of transmission from farm to wild stocks. The appearance of dead fish downstream of some farms causes aesthetic problems and probably enhances disease risk in wild fish. There have been no reports of genetic erosion or competition between wild and farmed fish.

Severn Trent Region are generally consulted in the early stages of planning, but occasionally farms are discovered after becoming fully operational.

4.7 NRA SOUTHERN REGION

There are approximately 30 land-based farms of a significant size in the area, all being either 'fish for the table' or part-table/

part-restocking. Nearly all farms have settlement ponds and NRA Southern Region are now stipulating two ponds in parallel in new consents. A few farms are testing swirl concentrators, and no farms employ recirculation. Fish farms are considered not to cause significant water quality problems in the region.

Effluent flow is consented as no greater than 50% of available flow for chalk streams, and as a proportion of DWF for other rivers. Where consented and gauged, abstraction volumes are often exceeded. Although depleted river flows have been a problem in the past, this has now been largely overcome. Incremental consent values are used for suspended solids, BOD, NH_3, pH and turbidity. Malachite green is the only consented fish farm chemical. Consent conditions are stringent, with turbidity and suspended solids often failing. Consents are never rejected, but may be made so stringent that they are not economically viable. Discrete sampling for all consented parameters is conducted between 4 and 12 times pa.

Biological monitoring is occasionally performed; a drop in BMWP score up to 200 metres downstream is considered acceptable. Fish escapes from farms with inefficient screens are frequent; anglers frequently complain of rainbow trout escapes into the Upper Itchen, which is a designated brown trout fishery. Entrainment of smolts is a potential problem but intake screen design has improved. No transmission of significant diseases from farmed to wild fish has been proven. Complaints of competition from escaped rainbow trout damaging wild brown trout stocks are as yet unsubstantiated.

Southern Region are generally aware of new developments at the planning stage.

4.8 NRA YORKSHIRE REGION

There are approximately 60 land-based farms in the region, half of which are either 'fish for the table' or part-table/part-restocking farms. About 40 farms have a settlement pond and one has a swirl concentrator. One farm employs partial recirculation. Fish farms cause significant water quality problems in the area, particularly the larger farms, with BOD and suspended solids breaching consent standards most frequently. BOD, suspended solids and NH_3 are consented incrementally and malachite green and antibiotics are also consented. DO is not usually consented, neither is phosphate although significant weed growth has been observed downstream of discharges. Flow is not consented quantitatively, but river-fed farms are obliged to leave sufficient flow in the river to allow passage of salmonid and coarse fish; this is not always adhered to, resulting in large depletions of river flow. Many farms have flow gauges but they are not routinely checked by water authority staff. Discrete sampling is conducted 12 to 24 times pa for sanitary parameters; fish farm chemicals are not monitored.

Biotic indices (BMWP) are beginning to be used downstream of fish farms. Pollution incidents occur occasionally, usually due to cleaning out settlement ponds which results in reduced DO levels and occasional fish kills. Complaints of malachite green discoloration have also been received. Fish escapes occur regularly due to variability in the effectiveness of screens. There is no evidence of competition between escaped farmed fish and wild stocks, but brown trout populations have been declining in the region and such competition could be one of the reasons. There is also no evidence of genetic erosion but again this is a concern. MAFF have studied disease transmission between farmed and wild fish in the region but have found no evidence; this has resulted in the lifting of an IPN disease order, which Yorkshire Region are concerned about.

New developments usually come to the attention of Yorkshire Region before or during the planning stage, but occasionally 'fish for the table' farms are discovered after they become operational. Consents applications have not been rejected but conditions have been made so stringent that farming would be economically unviable.

4.9 NRA NORTHUMBRIAN REGION

There are only two land-based farms in the area, both of which are restocking farms and thus require abstraction licenses. No environmental problems have been reported from either site.

4.10 NRA THAMES REGION

There are 44 fish farms in the area, only six of which are involved in restocking. Approximately half have settlement lagoons, and recirculation is employed by hatcheries during water shortages. Farms in the clean headwaters of catchments cause significant but localised water quality problems, with the main concerns being the growth of sewage fungus and water discoloration by malachite green. Incremental values are used in consents for suspended solids, BOD, NH_3 and DO; treatment chemicals are consented qualitatively as 'noxious compounds', but are not routinely monitored. Diurnal variations in effluent quality are seen as being very important; it is believed that if effluent samples were taken at night they would fail the consent conditions and the standards set for RQO's would also be breached (pers comm J Haines). Effluent flow is consented as a maximum fixed volume, related to DWF, and no flow depletion problems have been apparent. A number of pollution incidents, due to chemical release and the cleaning of settlement ponds, has been attributed to fish farms. Although biotic indices are not generally routinely used, BMWP score is used on a regular basis on farms located in clean headwaters.

Mass escapes of farmed fish have occurred (on the rivers Wey, Loddon and Lyde, and Amprey Brook), but screening of intakes and discharges is generally seen as being adequate. The transmission from farmed to wild fish of Myxosoma cerebralis, Proliferative Kidney Disease (PKD) and Enteric Redmouth (ERM) has been reported, whilst the transfer of Furunculosis has been reported from wild to farmed fish. There is circumstantial evidence of competition between wild and feral/first generation escaped farm fish in Cotswold streams.

The legislation controlling development and planning permission is considered to be adequate for fish farms in the Thames region, but major problems are evident in the interpretation of this legislation and in its policing.

4.11 SCOTLAND

The majority of the expansion in the UK fish farming industry over the past decade has been due to increases in freshwater and marine caged farming in Scotland. At present, the observed environmental impact of such caged farms is localised, although zones of macrobenthic impoverishment have been reported to extend to distances of up to 100 metres. Eutrophication incidents directly attributable to caged farms are rare, but the hazard posed causes great concern. Other major concerns in Scotland, particularly if caged farming continues to grow at its current rate, include: toxic effects of various fish farm chemicals (particularly 'Nuvan', or 'Aquagard'); deep water deoxygenation due to oxygen-consuming settled fish farm waste; interactions between escaped farmed fish and wild stocks; and impoverishment of macrobenthic communities. In the case of benthic degradation, the Highlands River Purification Board (HRPB) allow organic enrichment beneath cages up to a distance of 3 metres, outside which the sediment should be no more organic than natural loch sediments.

The River Purification Boards (RPB's) interviewed (Highland, Clyde, Tay) felt that land-based fish farms do not pose a great environmental hazard when compared to caged farms. Depletion of river flow due to abstraction by fish farms has not been observed. Unlike water authorities in England and Wales, RPBs have no power over abstraction by any fish farm; however, it is felt that restricting effluent flow (at least in Scotland) adequately protects residual river flow. Solids accumulation below fish farm discharges has been reported as a problem; this has resulted in the growth of sewage fungus and areas of river bed inhabited only by oligochaete worms. Settlement ponds were found to reduce solids output considerably, but BOD and nutrient levels were enhanced due to interactions between the settled solids and the effluent (pers comm, J Hunter, HRPB) (see Section 3.4.2(a)).

The RPBs are not responsible for the health of native fish stocks in Scotland. The Department of Agriculture and Fisheries for Scotland (DAFS) are dependent on specimen returns from the District Salmon Fishery Boards to assess the health of native stocks. In recent years, the number of specimen returns has been declining (pers comm A Munro, DAFS); it is not clear whether this is due to a lower rate of disease incidence or a reduced effort by the Salmon Fishery Boards.

4.12 NORTHERN IRELAND

There are approximately 30 land-based farms in the area, two or three freshwater caged farms and one caged salmon farm (off the Antrim coast). There is also one caged shellfish farm in a marine loch. No significant problems have yet been caused by fish farming in the area. Breaches of consent are rare and biological monitoring of land-based farms downstream of the discharge has shown little impact. Incremental standards of 10 mg l^{-1} suspended solids are typically consented, and this does not appear to cause significant downstream sedimentation. Water quality monitoring is undertaken on each farm over a period of 24 hours once a year; this accounts for diurnal variations in effluent quality, but not seasonal variations (see Section 3.1.3). Effluent flow from land-based farms is restricted to 50% of available flow; it is believed that this is legally enforceable in all cases except where a farmer has a protected right to abstract. One farm in the area has an ancient right to abstract all of the flow in the river by virtue of its historical use to drive a water mill (long since demolished); it is thought that these rights would be supported in court against any restriction on effluent flow.

Although no significant problems due to agriculture have been observed in Northern Ireland, there is concern that not enough is known about the the potential impacts of the industry.

SECTION 5 - CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

5.1.1 General

The settlement of fish farm waste solids on river beds and the benthos of lakes and coastal waters may cause organic enrichment and deoxygenation of natural sediments, leading to the dominance of pollution-tolerant organisms or even abiotic zones.

Nutrient outputs from fish farms present a eutrophication hazard in many UK waters, particularly oligotrophic waters with limited dispersive energy and/or flushing rate. However, few incidents of eutrophication have been conclusively linked to the waste output from fish farms.

There is a paucity of data concerning the environmental impact and fate of chemicals currently used on fish farms for disease and parasite control.

Little work has been carried out on the effects of escaped or released fish on indigenous fish stocks. The main areas of concern are: competition for ecological niches, predation on indigenous fry, contamination of local gene pools and disease transmission. All four interactions are likely to be significant.

The siting of fish farms and the effects of their activities often reduce the aesthetic value of a location, and may reduce the conservation interest by making the area less favourable for habitation by sensitive fauna and flora.

The planning controls on fish farms are inconsistent, in that not all farms require planning permission. Pollution control authorities are often unaware of the construction of farms exempt from planning control.

Liaison between planning authorities and pollution control authorities prior to planning permission being given is generally poor.

5.1.2 Land-based farms

River-fed fish farms in England and Wales with agricultural exemptions from abstraction licensing, or with "licences of right" to abstract, regularly severely deplete river flows in the summer and some even run their source rivers dry. This has led to the inhibition of upstream migration of salmonids. Flow depletion does not cause a problem in Scotland.

Statutory control of abstraction volume is inadequate, and will not be fully resolved by the implementation of the Water Act (1989).

There is uncertainty within some NRA regions concerning the legal validity of restricting abstraction by river-fed farms through the restriction of effluent volume.

Clarification is required over the legal status of "natural" bifurcations of river flow (see Section 3.1.3(a)) with respect to river abstraction.

Water recirculation in river-fed farms is grossly under-utilised and could provide an answer to flow depletion problems due to excessive abstraction.

Effluent quality varies widely on a diurnal (feeding regime, treatment regime, pond and tank cleaning) and seasonal (stock biomass and age, river flow) basis.

The frequency of discrete effluent quality sampling for consent compliance monitoring is too low to adequately represent the widely fluctuating effluent quality produced by fish farms. It is also highly unlikely to detect pollution incidents.

Biological monitoring is under-utilised in the monitoring and control of fish farms effluents, but is likely to give a far better representation of effluent quality than discrete chemical monitoring.

Bad farming practices in using treatment chemicals and cleaning settlement and holding ponds have led to occasional pollution incidents in many areas. These have rarely led to fish kills.

The effectiveness of screens over fish farm intake and outlet(s) at preventing the incursion of wild fish and the excursion of farmed fish is very variable.

The presence of multiple outlets for fish farm effluents is unnecessary and could be designed out at the planning stage if greater liaison existed between planning and pollution control authorities.

It is yet to be established whether a safe separation between farms exists to minimise the risk of disease transmission between farmed stocks.

5.1.3 Caged farms

Effluent quality varies widely on a diurnal (feeding regime, treatment regime, net cleaning) and seasonal (stock biomass and age) basis.

The diffuse and fluctuating nature of effluents from caged farms causes problems with water quality monitoring of consent compliance. Non-compliance is difficult to prove due to uncertainty about the source of contamination.

Cage rotation to prevent site "souring" extensifies the damage incurred by the benthos, and there is little information available on the rate of benthic recovery. Cage rotation also increases the areal extent of the sedimented phosphorus reservoir, thus increasing the eutrophication hazard in freshwater bodies.

The Crown Estate Commissioner's (CEC) role as development controller and landlord for fish farms in coastal locations is contradictory.

5.2 RECOMMENDED POLLUTION CONTROL MEASURES

5.2.1 General

Compulsory licensing of all fish farms, to include planning permission and consent to discharge, is required. Licencing committees would consist of representatives from planning authority and pollution control authority, with statutory consultation with local and conservation interests. The licensing procedure would include a full environmental impact assessment to gauge site suitability.

A statutory screening programme is required to fully assess the potential impact on the environment and human health of existing and future treatment chemicals used in aquaculture.

Tighter control is required over the release of rainbow trout into important brown trout and salmon fisheries.

5.2.2 Land-based farms

Better use should be made of COPA section 34(4)(d),(e) and (f), whereby the discharger can be imposed upon to install and maintain flow-gauging equipment, and keep records for regular inspection.

An increased effort is required in enforcing effluent flow restrictions on farms that severely deplete river flow. If such restrictions are not found to be enforceable in England and Wales for farms with "licences of right", modifications will be required to the Water Resources Act (1963) to allow relevant authorities to alter such abstraction licences in order to maintain adequate river flows.

Effluent flow restrictions based on Dry Weather Flow (DWF) are recommended over those based on available flow.

The installation of effective primary treatment (involving settlement) should be imposed on all major existing and proposed farms. Tanks or ponds accumulating solid waste must have facilities to allow isolation

Studies are required into the variation in effluent quality caused by farm operations, and variations in holding stock and river flow. Data from such a study could be used to model effluent quality.

The effects of fish farm nutrient output on the anchored vegetation of rivers requires investigation.

5.4.3 Caged farms

Development of hydrodynamic water quality models to predict the dispersion of dissolved and particulate waste from proposed caged farms is necessary in order to assess site suitability. This work should centre on the impact of fish farm nutrient outputs on eutrophication.

Studies on the variation in effluent quality similar to those proposed for land-based farms would also be useful for caged farms, with a view to incorporating findings into dispersion models.

The possibilty that increased demand for sandeels and sprats by the fish farming industry is causing nutritional shortages for wild salmon and seabirds requires investigation.

Farms should be required to keep up-to-date records of feed supplier, feed quality, changes in holding stock, rate of feed use, disease outbreaks and medications used (including dosage and method of application).

Environmental monitoring should include mixing zone and background sample points of both water and sediment. Water samples should be collected over a full tidal cycle, preferably on neap tides. The results from such monitoring may be used to revise the consented annual production.

A standard lower limit on the depth of water required for caged farm development should be adhered to, in conjunction with a standard upper limit on cage depth.

5.3 FURTHER RECOMMENDATIONS

5.3.1 General

Detailed national guidelines are required for the issuing and monitoring of discharge consents.

Caution should be exercised when basing consideration of applications for discharge consents on estimates of pollutant output per unit of production. For phosphate this should not be reduced from 10kg P per tonne of production unless the variability in output is reduced considerably.

Where possible, restocking programmes should involve fish derived from local gene pools.

The viability of using triploid (sterile) fish in farms on a widespread basis to prevent genetic erosion of wild stocks requires investigation.

Detailed guidelines are required to advise farmers on how best to introduce treatment chemicals to infected fish whilst minimising environmental hazard.

Farmers should be encouraged to use buoyant food pellets that reduce wastage and thus solids output by remaining in the feeding zone for longer periods.

Guidelines are required for the appropriate siting and construction of fish burial pits in order that leachate does not find its way back to watercourses.

5.3.2 Land-based farms

When a new farm is constructed, the distance between intake and discharge should be kept to a minimum so that as little riverine habitat as possible is subjected to reduced flows.

Where river abstraction is licenced, thought should be given to an automatic separation of flow which allows the prescribed flow to pass down the river at all times. This could take the form of an overspill set at the correct stage height across the intake.

Where flow depletion is a problem the use of recirculation, with settlement and biological filtration of recycled water, should be encouraged by pollution control authorities.

It is important that farmers are made aware of the importance of desludging settlement ponds at regular intervals. Guidelines concerning the desludging operation and various disposal options are necessary.

5.3.3 Caged farms

Serious consideration should be given to prohibiting further development (either by expansion or site acquisition) in fresh (particularly oligotrophic) or saltwater bodies with low dispersion potential and/or limited flushing. Farmers should be encouraged to develop on more dispersive sites which will not only utilise the assimilating capacity of the sea more effectively, but will reduce the risk of toxic algal blooms, general eutrophication and site "souring".

Where site "souring" occurs dispersal energy is too low; if it is allowed to continue the use of sediment traps is preferred to site rotation. Sediment traps are also recommended at any site where serious benthic deterioration is evident, even if it does not end in site souring.

Benthic deterioration may be consented using a mixing zone approach, where a certain amount of impact is permissable within a confined area; however, gross deterioration, even under the cages, should not be deemed acceptable.

Consideration should be given to methods of controlling feed quality and quantity. Maximum allowable phosphate and nitrogen contents and standards for nutritional quality are required.

5.4 RESEARCH RECOMMENDATIONS

5.4.1 General

Research is required into the nature of disease transmission between farmed and wild stocks. The importance of the following needs to be quantified for each disease causing concern:

a) waterborne survival time, transport and fate;

b) the importance of escaped farmed fish as vectors of disease;

and

c) identification of the environmental triggers causing disease outbreak.

Further development is recommended of research in Norway to breed out territoriality in farm fish (see Section 2.3.3 (b)). This would make obsolete the practice of overfeeding fish in order to minimise aggressive behaviour, which enhances pollutant output levels, and would also reduce the competitiveness of escapees. To avoid genetic erosion of wild stocks, the product of such research would have to be sterile.

Further research is required on the extent and degree of competition between wild and escapee fish, on the predation of wild fry by farm fish, and on the extent and degree of genetic erosion on local wild stocks caused by interbreeding with escapees.

The environmental behaviour and toxicity of chemicals used in aquaculture should be assessed to establish acceptable human ingestion levels, ecotoxicity, reaction with other chemicals (especially during chlorination) and their fate in the environment.

Information should be collated on the quantity of chemicals used on fish farms and their dosage (exposure concentration and duration).

Research should be undertaken to assess whether the long-term use of antimicrobial agents could result in the development of antibiotic-resistant strains of bacteria, and whether their use could evoke allergic responses in the human population.

Further work is required on the potential of vitamins in feed to stimulate plant growth. It may be necessary to develop feeds with lower residual micronutrient levels.

5.4.2 Land-based farms

The effect of the installation of settlement areas within a farm, and the frequency of sludge removal, on nutrient and BOD levels in the effluent requires investigation.

Studies are required into the most cost-effective treatment for effluents from land-based farms. Such studies would include the best treatment options for recirculating systems, looking particularly at submerged media filters and vegetational filters.

Studies are required into the variation in effluent quality caused by farm operations, and variations in holding stock and river flow. Data from such a study could be used to model effluent quality.

The effects of fish farm nutrient output on the anchored vegetation of rivers requires investigation.

5.4.3 Caged farms

Development of hydrodynamic water quality models to predict the dispersion of dissolved and particulate waste from proposed caged farms is necessary in order to assess site suitability. This work should centre on the impact of fish farm nutrient outputs on eutrophication.

Studies on the variation in effluent quality similar to those proposed for land-based farms would also be useful for caged farms, with a view to incorporating findings into dispersion models.

The possibilty that increased demand for sandeels and sprats by the fish farming industry is causing nutritional shortages for wild salmon and seabirds requires investigation.

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APPENDIX A - DISEASE TREATMENTS (GUIDELINES ONLY) TAKEN FROM WATER QUALITY IN SALMON AND TROUT FARMING (SOLBÉ 1988)

Formulation	Disease	Dose	Duration of dose
Chloramine T	Fin Rot, Tail Rot	2-5 mg l^{-1}	1 hour
Erythromycin	Bacterial Kidney Disease	25-100 mg/kg fish/day	7-21 hours
Flumequine	Furunculosis	6 mg/kg fish/day	6 days
Formalin	Costia, Trichodina Gyrodactylus etc	167-250 mg l^{-1}	1 hour
Furanace	Fin rot Bacterial septicaemias	0.5-1 mg l^{-1}	10 mins
Furazolidone	Furunculosis Vibriosis	25-75 mg/kg fish/day	7-21 days
Hyamine 3000	Bacterial Gill Disease	2 mg l^{-1} (soft water) 4 mg l^{-1} (hard water)	1 hour 1 hour
Malachite Green	Saprolegnia fungus Proliferative Kidney Disease	1-5 mg l^{-1}	1 hour
Malachite Green/ Formaline	Ichthyophthirius Ectoparasites	(3.68 g m.green l^{-1}) (25 mg formaline l^{-1})	1 hour
Methylene Blue	Enteric Redmouth Ichthyophthirius	1-3 mg l^{-1}	3-5 days
Nuvan (50% dichlorvos)	Sea louse	2 mg l^{-1}	1 hour
Oxolinic acid	Furunculosis, Vibriosis, Enteric Redmouth	5 mg/kg fish/day	7-14 days
Oxytetracycline	Furunculosis Vibriosis Enteric Redmouth	(50 mg/kg fish/day injection) (50-120 mg/kg fish/day)	7-14 days
Proflavin hemisulphate	Fin Rot, Tail Rot, Lesions	20 mg l^{-1}	30 mins
Roccal	Bacterial Gill Disease	1-2 mg l^{-1}	1 hour
Sodium chloride	External Bacterial Lesions	1.5%	1 hour
Streptomycin	Mycobacteria (Tuberculosis)	50-75 mg/kg fish/day	5-10 days
Sulphamerazine	Fresh water septicaemias	200 mg/kg fish/day	14 days
Tribrissen (potentiated sulphonamide)	Fresh water septicaemias	30 mg/kg fish/day	10 days

APPENDIX B

RECOMMENDATIONS FOR STOCKING AND BREEDING OF FARMED FISH (AFTER NCC 1989a)

1. Always distinguish between 'wild' fish and 'domestic' fish and keep them separate.

2. Where wild stock are brought into the farm, assume that they are domestic after two generations, after crossing with any other stock, or even after keeping different stocks together.

3. Stocks in important salmon rivers should be maintained and protected in each geographic area. The east coast rivers, which accounted for 72% of Scotland's wild salmon catch in 1988, are of particular concern in this respect. In these areas, stocking and hatchery practices should be more strictly controlled and fish farm developments subject to wider consultation and more careful monitoring than is presently the case.

4. Where salmon stocking is proposed, the necessity or purpose of such releases should be carefully examined using appropriate scientific information and expertise.

5. Broodstock for hatcheries involved in supplying fish for stock enhancement should be obtained regularly from the wild, and not kept in captivity for more than one generation. Relatively large numbers of adults should be used as broodstock to maintain genetic diversity. Avoid unconscious selection (for example in connection with fish size, place of capture, season of capture or spawning time) when taking wild broodstock from any stock assumed to be discrete.

6. If stock enhancement is necessary, use local broodstock from the intended area of release, together with local facilities for stripping, hatching and rearing.

7. If local facilities are not available, explore the possibility of obtaining first generation fish from a fish farm which has just taken in wild stock from the river system concerned. Do not use surplus fish from farms for stocking in the wild unless they are of this type.

8. Research should be initiated on genetics of wild salmon and domestic stocks (including sterile fish), and on the effects of introducing fish from either domestic stocks, or from wild stocks, into local salmon populations.

9. The long term value of linking each unique wild stock with an individual fish farm unit should be considered.

10. A register of British Atlantic salmon stocks should be developed in conjunction with a system of stock exchange.