A review of information on potential pollution management for sea-cage aquaculture

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Contents

Figures

Tables

1. Introduction

The principal environmental impact associated with sea-cage aquaculture is from nutrients in fish faeces and uneaten food which can cause water pollution, resulting in unacceptable changes to the surrounding environment.

This document is essentially a literature review of environmental impacts and management recommendations from overseas. Sections 2, 3.2 and 6.1 reflect Environmental Protection Authority policy. However, the other sections while written from an environmental viewpoint, do not reflect policies or requirements endorsed by the Environmental Protection Authority.

This document aims to describe the pollution potential of commercial sea-cage aquaculture operations, typical management/monitoring programmes used overseas and describe options to avoid or reduce the likelihood of unacceptable impacts.

A brief description of the pollution control approach for the marine environment used by the Western Australian Environmental Protection Authority is included as are some brief notes regarding wildlife and predators.

Direct quotes from the literature are shown in italics. A glossary has been provided to explain technical terms used in this review.

1.1 Sea-cage aquaculture in Western Australia

There are currently no commercial sea-cage aquaculture operations in Western Australia, however, there are a number of pilot projects operating or proposed.

Monitoring needs for pilot projects, which are usually at a significantly smaller scale than commercial operations, vary according to the scale of the project and the environment in which the sea-cages are located. Some existing pilot projects do not have significant environmental impacts and little, if any, monitoring is required. However, fish farmers wishing to expand to commercial operations would be wise to consider the international literature on sea-cage aquaculture with a view to ensuring sufficient data is gathered during the pilot phase to demonstrate both that increased production levels would be viable and that the environment would be protected with an expanded operation.

1.2 Sea-cage aquaculture — a description

The farming of marine species in pens or cages is not a new phenomenon however, the major recent developments in cage size and increased stocking densities has had a significant impact on fish farming and the environment.

The main sea-cage systems in use today may be categorised as:

i) without support collar;

ii) with non-decked support collar; or

iii) with decked support collar.

The sea-cage system often comprises of the cage units either single, integral or linked and a mooring or working platform. Each type of sea-cage system has relative merits dependent upon the purpose for which it was designed. Design considerations include site characteristics, predator control, species and economics.

Factors which are likely to influence sea-cage design in Western Australia include the potential of increased fouling rates contributing to operating costs and lack of sheltered positions necessitating structures capable of withstanding extreme wind and wave conditions.

2. Pollution control approaches for the marine environment

The Environmental Protection Authority has adopted an ecosystem-based approach to manage nearshore coastal ecosystems in Western Australia against the threat of pollution.

Marine environments generally are affected (ecologically changed) by the input of waste materials. Some, such as the open ocean, may be able to accept certain amounts and types of wastes without causing unacceptable changes, while the same amount and type of waste discharged to shallow, poorly flushed coastal lagoons and embayments, may result in severe changes to their biological communities. The ability of the environment to accept waste is therefore ecosystem and pollutant specific — a fact that must be recognised for effective environmental management and for the maintenance of acceptable environmental quality in the long-term. The 'assimilative capacity' approach (as recently redefined in EPA, 1989) focusses on determining the relationship between the main threat to long-term environmental 'health' (e.g. nutrient inputs) and the primary environmental effect of this threat (eg loss of seagrasses), so that appropriate management action (e.g. limiting nutrient inputs) may be taken to prevent long-term, widespread unacceptable ecological change.

Marine environments have multiple values and uses. In Western Australia the usage classification of waters is known as 'beneficial use', or 'environmental value', as used in the *Australian water quality guidelines for fresh and marine waters*, published by the Australian and New Zealand Environment and Conservation Council in 1992. An environmental value of the environment is defined as 'a designated use of a specified part of the environment for the overall benefit of the community'. For example a particular part of Cockburn Sound might be designated for direct contact recreation such as swimming or windsurfing. The environmental value of another area might be for industrial purposes. Environmental values can also be applied as a planning tool to partition use and minimise conflict when proposed uses of the receiving environment are incompatible.

Each environmental value has a unique set of environmental quality criteria that must be met in order to preserve that environmental value. The environment quality criteria are largely derived from toxicity tests and public health considerations. For example the water quality criteria for direct contact recreation specifies a very low level of faecal bacteria contamination for human health reasons. That same level would be unnecessary if the waters were for industrial purposes only. However, if more than one environmental value is applied to the same water body, the most stringent criteria must apply.

2.1 Control approaches for different pollutant types

Waste generation should be avoided or minimised as far as possible.

The environmental behaviour and fate of the discharged pollutant is central to determining the most appropriate control approach for that pollutant. Some materials can be bio-magnified in the environment, others may simply accumulate, while some may have additive, synergistic or antagonistic effects on each other or with components of the natural environment.

One class of pollutant is synthetic materials. Synthetic materials are defined as those made directly or indirectly by humans and which are not found in nature except as the result of pollution. Specific examples of such synthetic materials are polychlorinated biphenyls (PCBs), organochlorines (e.g. DDT), organotins (e.g. TBT) and certain hormone analogues. Substances such as these may affect marine organisms directly or through bio-accumulation of these materials to toxic levels. In the past, the introduction of synthetic toxic materials such as DDT and TBT into the marine environment has caused widespread deleterious effects (Carson, 1962; IPCS, 1990). Given the lack of scientific knowledge regarding the short and long-term effects of most of these substances, the safest control approach for this class of pollutant is destruction or containment.

Natural pollutants can be subdivided into two broad groups — naturally occurring toxic substances such as heavy metals and hydrocarbons, and biostimulants, primarily the nutrients nitrogen and phosphorus (Table 1).

The extent to which most toxic substances affect marine biota is primarily related to their concentration in water. Therefore their environmental impacts can be managed through the application of water quality criteria based on toxicological studies. Bioaccumulation of toxic substances in filter-feeding organisms and algae, and accumulation in the sediments must also be considered in managing the disposal of these substances.

The use of water quality criteria to protect ecosystems from the effects of biostimulants is, on the other hand, of little use as these materials can be removed rapidly from the water by marine plants. In contrast, the assimilative capacity approach is centred on quantifying the dominant factors controlling the conversion (or assimilation) of biostimulants into organic matter and incorporation into sediments and other internal sinks. It is from this information base, that the ecological consequences of a range of nutrient loadings can be predicted and the upper loading limits determined in relation to an acceptable level of ecological change.

Table 1: Preferred control approaches for different pollutant types.

Class	Type	Effects	Control approach
Natural	Biostimulants (nutrients)	Assimilated	Assimilative Capacity
Natural	Toxic substances (heavy metals)	Concentration related toxicity	Water Quality Criteria
Un-natural	Synthetic compounds (PCBs etc.)	Largely unknown	Containment or destruction

3. Site selection

3.1 Currents, water circulation, water depth and carrying capacity

The currents, water circulation and water depth can have a significant effect on both the environmental impacts of sea-cage aquaculture and the carrying capacity of the site. In this context, the carrying capacity is defined as the maximum level of aquaculture production that a coastal site might be expected to sustain with regard to factors such as oxygen replenishment, the assimilative capacity of the area and environmental values.

In terms of production, good water exchange is essential both for replenishment of oxygen consumed by the fish and dispersion of metabolic wastes and uneaten food. Waste build-up under cages can result in localised oxygen depletion, a build-up of disease organisms, the build up of potentially toxic compounds and generation of noxious gases. The undesirable effects of waste build-up and changes to water quality in the cages are considered in detail in Section 4.2 of this document.

Although not an environmental concern, currents which are too fast (e.g. greater than 0.5 m/s) can cause problems such as stress for the fish, food loss and additional dynamic loadings to the cage (Beveridge, 1987).

It is also important to understand the pattern of water circulation around a sea-cage site. Water circulation can affect the capacity of the area to absorb wastes.

In Western Australia, where off-shore reefs are common, reefs may restrict the flushing of contaminants (including fish wastes) to the ocean. Coastal embayments may also have a low flushing and exchange rate. The flushing and exchange rate of Cockburn Sound for example, is relatively low. In contrast, during winter, water from the Peel-Harvey Estuary at Mandurah has been detected up the coast to Wambro Sound and behind Garden Island. Nutrient rich freshwater flows from Mandurah may affect the carrying capacity and cause small changes in salinity at a sea-cage site in this area.

Tides, offshore currents, bathymetry and meteorological conditions affect water movement and circulation patterns at a site. At a good sea-cage site periods with little or no current flow should be minimal.

For most types of cage culture the cages should be in sufficient depth to maximise exchange of water, yet keep the bottom well clear of the sea bed to ensure water quality in the cages is satisfactory. Internally generated currents, particularly during feeding can pull water into the cage through the bottom panel (Beveridge, 1987). Overseas, sea-cages are usually about 10m deep and recommendations for separation between the bottom of the cage and the seabed vary from 4 to 5m at low tide to three times the cage depth where the interchange with the current flow is fast and consistent.

The pattern of currents, water circulation and depth should be determined before a decision is made to utilise a site for commercial production.

Several methods have been proposed to calculate the carrying capacity of cage sites based on various parameters such as speed of current, depth, water flow-through and nutrient inputs (See for example Beveridge, 1987; Todd, 1990 and Lumb 1989 referenced in GESAMP, 1991). Figure 1 shows graphs used to determine carrying capacity which appeared in a Draft Code of Practice for Marine Finfish Farming in Tasmania (Tasmanian Department of Sea Fisheries et al, 1989). The graphs are based solely on current speed and water depth. The applicability of methods proposed to calculate carrying capacities should be carefully evaluated with regard to local conditions, type of aquaculture proposed and likely level of accuracy.

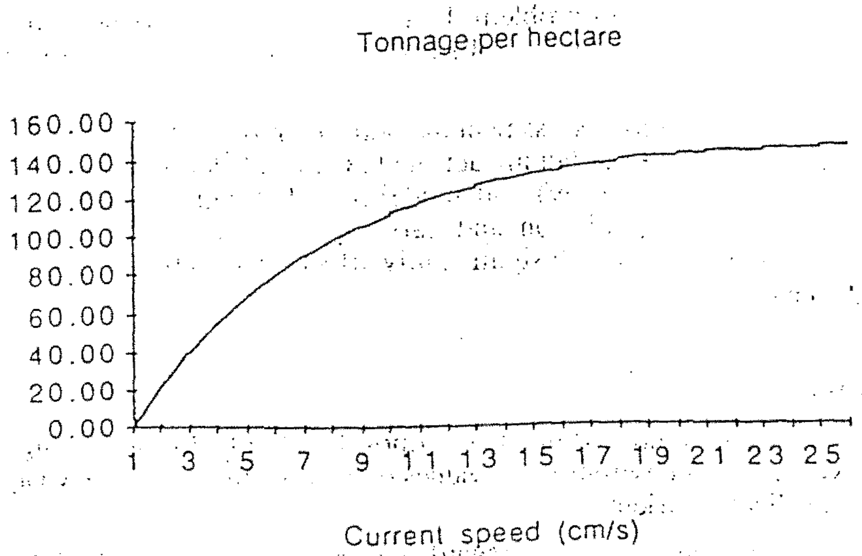
A sound proposal should consider the issues raised above in some detail prior to cage construction and stocking density determination.

3.2 Avoiding important biological communities

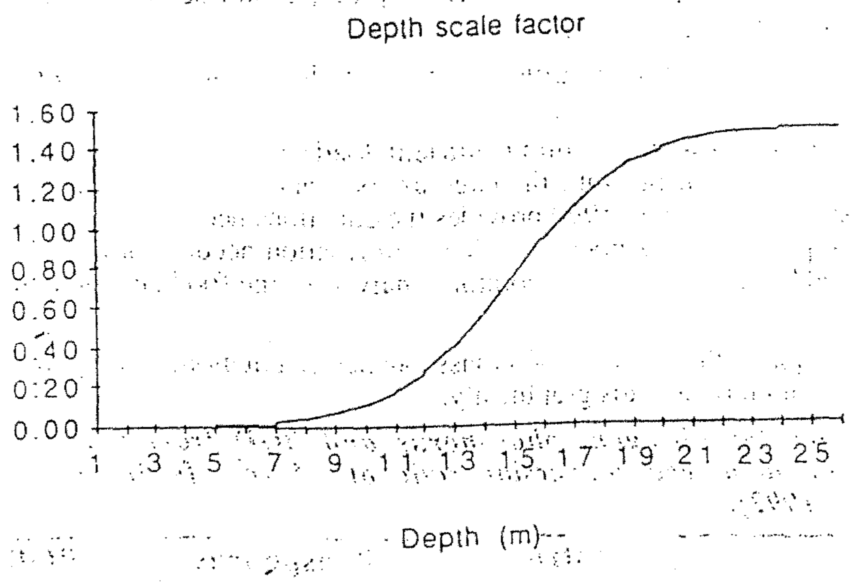
Sea-cages must not be located above or too close to important biological communities and habitats. Seagrass beds, corals and reefs are important biological communities because they are areas of primary productivity (e.g. the base of the food chain where sunlight energy is converted into foods by plants), are often fish nursery areas and play a role in coastal stability.

It is not currently possible to repair damage to some important biological communities, particularly seagrass meadows such as *Posidonia*. The slow rates of lateral spreading of Posidonia meadow suggests that it would not re-grow into damaged areas even after several decades.

Sea-cage sites should not be located in areas which are refuges for protected species (eg. seals). This advice is to protect both the farmer and the protected species. Some protected species, such as seals, are likely to predate fish farms. The potential for disease to be transmitted from the farm to protected species is also a concern.



(a): Maximum tonnage production for a site with a given mean current speed.



(b): Depth scaling factor for a site having a given mean depth.

Figure 1 Graphs used to determine carrying capacity in Tasmania *(not Western Australia).* *To use these graphs, calculate the tonnage per hectare allowed according to the current speed over your site. Next multiply that number by the scale factor given by the average depth of your site, measured around the complete perimeter. the result of this multiplication is the initial stocking limit for the site, expressed in tonnes per hectare (Tasmanian Department of Sea Fisheries 1989).*

4. Assessment of and impacts from uneaten food and faeces

In assessing the pollution potential of effluents from cage farms, comparison with mass flows of pollutants from sewage works treating only domestic wastes has been used by some authors (Pillay, 1992). As sewage has essentially the same pollutants, such comparisons may be useful for a quick assessment of the likelihood of problems based on previous experience with similar sewage discharges in similar environments. However, the level of accuracy of such comparisons is questionable.

A range of aquaculture-specific pollution assessment methods to predict or monitor impacts are outlined in Barg, 1992. The methods to predict impacts include mass balance estimates of waste production (as noted in Section 4.1 below) and modelling of organic enrichment of the sediments, eutrophication, oxygen depletion and carrying capacity. In general, models developed to date have had limitations which significantly affect their usefulness and accuracy with respect to sea-cage aquaculture.

4.1 Nutrient loads

In order to determine whether or not a sea-cage proposal is likely to have a significant environmental impact which affects environmental values or exceeds the assimilative capacity it is necessary to estimate the likely nutrient load.

In the marine environment, nitrogen is generally regarded as being the growth limiting nutrient, particularly for algae. Algal growth stimulated by nitrogen can reduce the amount of light reaching plants to the extent that death of these organisms occurs. Seagrass in particular is sensitive to light levels. It should be noted that increased levels of algal growth sufficient to cause loss of some benthic flora such as seagrass would probably not be noticeable to casual observers so active monitoring is required (See Section 4.3).

Obviously there are major practical difficulties in taking field measurements to determine nutrient loads.

A comparatively easy method of determining nutrient loads is to do a mass balance by calculating the amount of nutrient put into the cage as food and subtracting the amount of nutrient exported as fish. Ackefors et al, 1990 provides the equations needed for a mass balance calculation and this is reproduced as Appendix 1. The information needed for a mass balance calculation can be gained by an appropriate laboratory analysis of the food and the fish species to be grown.

Table 2 provides an example of the outcome of a mass balance calculation, and Figure 2 details information from a study of nutrient loads graphically.

Table 2: Mass balance for nitrogen, phosphorus and BOD from the production of 1 kg of fish (trout) at a feed conversion ratio of 1.5 (dry feed) (Hakanson et al quoted in Pillay, 1992).

	Nitrogen (g N/kg)	Phosphorus (g P/kg)	BOD (g/kg)
Feed (Values given are 1.5 times composition of feed used)	120.0	15.0	2416
Fish	29.6	4.5	848
Faeces	18.0	10.5	444
Excretion (ammonia)	72.4		133
Waste load= Feed - Fish)	90.4	10.5	577

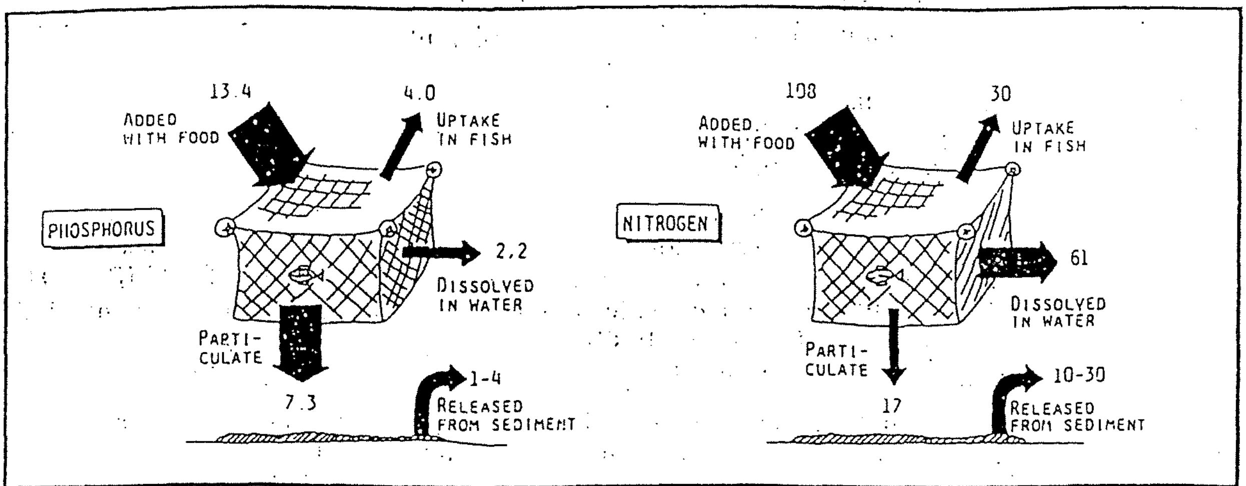


Figure 2: Phosphorus (P) and nitrogen (N) load from cage fish farming, expressed in kg per ton of fish produced per season. The desorption from the sediment is considered to be 50% of the sedimented P and N from the cage fish farm (Copied from Ackefors, 1990)

Protein is the major source of phosphorus and nitrogen pollution from fish farms (Seymour, 1991). There are significant differences in nutrient content of various foods and in the requirements of various species of fish.

The nutrient loads for different farms can vary greatly since the phosphorus and nitrogen load from cage aquaculture depends on the food conversion ratio, the phosphorus and nitrogen content of the feed and the phosphorus and nitrogen needs of the fish (Ackefors, 1990). This is explained in some detail by Beveridge, 1987 with respect to phosphorus for trout, tilapia and carp.

Estimates of nutrient loads (from four studies) vary from 52-100 kg nitrogen and 9 to 23 kg phosphorus per tonne of fish produced.

One factor in the food conversion ratio is the amount of food which is wasted or uneaten prior to passing through the bottom of the cage. Wasted food contributes directly to the nutrient load. Estimates of wasted or uneaten food vary from 20 to 33% for cage aquaculture (Pillay, 1992 & Seymour, 1991).

As noted in Table 1 and in Section 3.1 (which considers currents, water circulation, water depth and carrying capacity), levels of dissolved oxygen are important both in terms of the fish farm and the environment. Information regarding Biochemical Oxygen Demand can be valuable in determining likely effects on dissolved oxygen levels.

4.2 On-site effects of waste and sediment accumulation under cages

The deposition of organic fish farm waste has been shown to cause nutrient enrichment of the benthic ecosystem in the vicinity of aquaculture operations and in some cases affect water quality in the cages to such an extent that cage fish health has significantly deteriorated or mortality has occurred.

The changes which take place include:

- the formation of anoxic sediments, with in some cases the release of carbon dioxide, methane and hydrogen sulphide;
- increased oxygen consumption by the sediment and efflux of dissolved nutrients; and
- changes in the community structure of the benthic macrofauna (GESAMP, 1991).

Where the rate of waste accumulation is high, the amount of oxygen supplied by currents may be insufficient to meet the respiratory requirements of the benthos. Hence the sediments become anoxic, the benthic community changes to low oxygen tolerant and anaerobic species, and the end result of biological and chemical activity is reduced inorganic and organic compounds such as lactate, ammonia, methane, hydrogen sulphide and reduced metal complexes (Pillay, 1992). Effects of such changes on the benthos range from a reduction in diversity and increase in pollution tolerant species to the complete absence of macrofauna (GESAMP, 1991).

The release of hydrogen sulphide gas, together with hydrogen sulphide dissolved in the water has been held responsible for a deterioration in the health of farmed fish (increased stress, reduced growth, gill damage and even mortality) and loss of production (GESAMP, 1991). Hydrogen sulphide is readily precipitated as ferrous sulphide, giving anoxic sediments their characteristic black colouration (Beveridge, 1987). Accumulated sediments can affect dissolved oxygen levels around and in cages if upwelling of water into the cages occurs.

A study of water quality in trout net pens showed an 8-9 fold increase in total ammonia inside net pens (Seymour, 1991) while another study of a blue mussel farm with significant accumulation of sediments found increases in ammonium nitrogen and phosphate phosphorus concentration in the surrounding water column up to double and quadruple levels respectively (Pillay, 1992). This could lead to local increases in algae concentrations.

It should be noted that the presence of cages in open waters may obstruct current velocity and enhance sedimentation. The current speed inside a cage may be between 35-50% of that outside a cage (Pillay, 1992).

It is not known if leaving cages fallow is sufficient to effect complete recovery of the benthos (Pillay, 1992).

Poor water quality conditions as a result of waste build up at the cage site would most likely have undesirable effects down current of the site, particularly on nearby benthic flora and fauna.

4.2.1 Environmental Index and disease

Ensuring that sediments do not build up may be important both in terms of reducing environmental impacts and for farm management, as illustrated by the following extract from Beveridge, 1987.

> *"In summary the relationship between conditions in the sediments and farm fish mortality has been poorly studied and is very much open to speculation. There is, however, some evidence from Japan of a close link between the two. In a study of yellowtail farms, Arizono and Suizu (1977) demonstrated that major disease outbreaks, where more than 1% of the stock were lost, were related to conditions in the sediments, which they measured as EI (Environmental Index) such that;*
>
> $EI = (TS/DO) \times 100$
>
> *where TS = concentration of sulphides in the mud (mg/g dry mud), and DO = dissolved oxygen concentration of the water immediately above the sediments (ml/l)"*

4.3 Monitoring

The aims of instigating a monitoring programme include (Beveridge, 1987):

- to avoid losses caused by lethal changes in water quality (such as insufficient dissolved oxygen or excessive concentrations of ammonia and nitrite);
- to evaluate siting and configuration of cages within a lake/bay;
- to maintain optimum stocking and feeding rates and avoid over-stressing fish; and
- to gain information on long-term water quality at a site (to evaluate proposed changes to production and environmental impacts).

4.3.1 On-site monitoring

On-site monitoring is necessary to ensure that fish remain healthy and determine the immediate environmental impacts at the site. The following extract from Beveridge 1992 indicates the type of monitoring which is recommended overseas.

> *"The most valuable data that should be collected is on dissolved oxygen and temperature. Ideally measurements should be made daily, preferably at those times when they are likely to be highest and lowest (e.g. at dawn and midday and at slack tide), and readings both inside and outside the cages and at cage surface and cage bottom should be made. However, such a routine would be considered too time consuming and so it is suggested that farmers take periodic measurements throughout the year but that they increase the frequency of observation during warm spells."*
>
> *"Data on nitrogen (ammonia, nitrate, nitrite) and dissolved phosphorus levels, pH, Secchi disc and chlorophyll levels are also of importance in that they give the farmer a more complete picture of what is happening in the farm environment and in particular help alert him or her to dangerous levels of toxins (ammonia, nitrite) and the effect of farming operations on algal populations (chlorophyll levels, Secchi disc)."*

Other information that could be gathered to analyse on-site environmental impacts include photographic records, measurements of waste accumulations beneath cages using marker posts or core samples and analysis of sediments for parameters such as redox potential and/or hydrogen sulphide.

4.3.2 Off-site effects and monitoring

As noted above, sea-cage culture has only been undertaken on a pilot basis in Western Australia. As a consequence, environmental impacts off-site have to be predicted largely on the basis of overseas studies and some intensive work undertaken in Cockburn Sound. It is therefore imperative that off-site monitoring programs are developed as cage aquaculture proposals expand to determine the environmental impacts, ensure potential unacceptable impacts are detected early and assist in predicting of the carrying capacity of the area in which cages are located.

While chemical analysis may be appropriate to measure on-site effects, it does not provide all the information required to determine pollution effects off-site. Also, it is not the concentration of contaminants per se which are of concern but rather the effects of these concentrations on the environment.

While a range of biological studies (e.g. studies of particular species) or methods such as remote sensing could be suggested as a means of determining impacts of contaminants from sea-cage farming, it is suggested that the most suitable program for assessing the effects of contaminants (or pollutants) on marine systems is an analysis of the effects on the benthic community. This is because benthic organisms are largely sessile (e.g. do not move around) so they must tolerate the pollution or die, because benthic communities integrate the effects of pollution over time and because benthic communities provide a wide range of taxonomic diversity to detect changes (Gray et al, 1991 and Barg, 1992).

However, in order to undertake a benthic sampling program which determines whether changes to the benthos are due to cage aquaculture, natural variation or some other source of contaminant, sufficient baseline information should be collected and the sampling program should be statistically valid. Baseline information needed to prepare a statistically valid sampling program includes:

- Bathymetric and geomorphological data;
- Sedimentological data (because benthic fauna vary in different substrates);
- Oceanographic data on the distribution of water masses and their movements;
- Any known sources of contaminants etc (e.g. nutrients from rivers and sewage outflows) which could be contained in water masses which move through the cage site; and
- Qualitative data on types of benthic communities and their biota (Gray et al. 1991).

Sedimentological data combined with knowledge on the distinct types of water masses within the investigated area constitutes one of the most important elements in planning a sampling program (Gray et al. 1991).

Readers are referred to Gray et al. 1991 for further information on baseline information required and the design of a benthic sampling program.

A benthic sampling program may need to be undertaken over a number of years.

In describing a range of aquaculture-specific pollution assessment methods to predict or monitor impacts one author has distinguished between 'surveillance' and 'monitoring' as noted below (Barg, 1992);

Surveillance differs from monitoring in that predictions are not tested, but target sites or organisms are surveyed to ascertain whether or not there are detectable differences between the surveyed site and control site .

The type of approach adopted needs to be considered in the context of the objectives and purposes of the monitoring and the potential impact of the proposal on the environment (Barg, 1992).

4.4 Management measures

Table 3 suggests ways to reduce potential environmental impacts of an operating cage with particular reference to nutrients. Varying levels of success have been achieved in different situations with the methods suggested in Table 3.

Some of the methods noted in Table 3 have been tried with considerable success. At one location, feed was changed to an extruded pellet with a slower sinking speed and increased fat content which decreased the amount of solid waste from 450 to 200 kg/tonne of trout and improved the food conversion ratio from about 1.15-1.12 to 1.05 (Seymour, 1991).

Trash fish and moist pellet diets tend to be more polluting than dry pellets and have been outlawed in inland cage fish farms in several northern European countries (Beveridge, 1987).

5. Biocides and disease control chemicals

With regard to biocides and disease control chemicals environmental issues centre on:

- longevity of inhibitory compounds in animal tissues;
- the fate of bioactive compounds in the aquatic environment (e.g. affecting non-target organisms); and
- the development and transfer of resistance in microbial communities (e.g. creating drug resistant strains of disease) (GESAMP, 1991).

Systems which minimise loss of chemicals to the environment should be used. For example chemical loss can be minimised by directing fish into a treatment bag and undertaking this operation when current speeds are at a minimum (Beveridge, 1987).

The joint Group of Experts on the Scientific Aspects of Marine Pollution have developed a Code of Practice for the use of inhibitory compounds in aquaculture and this is reproduced as Appendix 2.

Table 3: Suggested methods of reducing potential environmental impacts from cage culture feeding.

Goal	Method	References
Reduce nutrient loadings	• Match nitrogen and phosphorus needs of the fish to percent content in feed (phosphate requirements for fish vary from 0.29 to 0.9% by weight) • Use of high digestibility diets (reduced faeces) • Collect and dispose of dead fish off-site • Reduce stocking density	Beveridge, 1982 & Seymour, 1991
Reduce feed wastage	• Alter feed type so that it is more stable in water and floats or sinks at an appropriate rate • Use extruded feed which doesn't break up easily • Correct timing of feed (to coincide with appetite development - hand feeding in initial phase) • Monitor feed waste beneath cage at feeding times and stop feeding when waste accumulation begins	Seymour, 1991
	• Adjust feeding to prevailing conditions (e.g. temperature) • Avoid overfeeding (extra food can pass straight through stomach) • Reduce feed dust by better manufacturing or sieving the food • Include scavenging fish which eat wasted food in cage • Improved feeder design • Change cage design to reduce food loss (e.g. net curtains to contain food)	Beveridge, 1982
Removal of surplus nutrients from below cages	• Vacuuming to remove wastes from under cage	Beveridge, 1982
	• Catch and remove wastes using suspended funnel-shaped structures (or bags) from which the waste is removed as soon as possible or during feeding	Beveridge 1982& Pillay, 1992

6. Other important issues

6.1 Wildlife and predators

As noted in Section 2.2 cages should not be sited near important biological communities. Predators can transmit disease to the fish (e.g. where the predator is an intermediary host to a fish parasite - See Beveridge, 1987 pg 248), kill or stress fish and damage equipment. A population increase of successful predators or animals which feed of spilled, wasted or accessible fish food is environmentally undesirable.

Shooting of wildlife is generally not permitted as it is usually not successful in deterring or reducing predator numbers and is not seen favourably by the public.

It is essential that sea-cages are designed to deny access by predators, both birds (which can take fish from above or below the cage) and marine mammals. Anti-predator devices that cause death of predators, such as incorrectly sized nets are unacceptable. Some suggestions regarding cage design to deter predators can be found in Beveridge, 1987.

6.2 Escape of fish

There are two principle issues associated with the escape of fish, namely the potential impacts on genetic characteristics which enable local fish to survive and the potential of escaped fish to survive outside of the cage and affect the ecological balance in an area. Changes to the ecological balance of an area may affect existing industries (GESAMP, 1991).

Overseas studies indicate that escape of fish from salmon cage aquaculture is common (Gudjonsson, 1991).

Management measures to prevent fish escape include replacement of materials which deteriorate at appropriate intervals, frequent monitoring of nets for damage with rapid repairs being undertaken, appropriate mesh size and preventing of fish removal by predators such as birds.

6.3 Other users

When selecting a site other users of both the cage site and the surrounding environment should be taken into account. For example existing recreational use, aesthetic impacts and boat traffic routes should be considered.

In Scotland demands were made for a moratorium on fish farm developments on the grounds of scenic detriment, nearness of farms to ancient monuments and adverse effects on tourism (Pillay, 1992).

7. Glossary

Please note that the definitions in the glossary have been refined so that they are consistent with the context of this literature review and therefore the words may have broader meanings when used elsewhere.

Aerobic	Of organisms - living or active only in the presence of free oxygen. In this paper is used to describe an environment where there is sufficient oxygen.
Anaerobic	Living in the absence of free oxygen (gaseous or dissolved). In this paper is used to describe an environment where there is no oxygen.
Anoxic	A deficiency of oxygen in tissues or a body of water. Used to describe an oxygen deficient environment.
Bathymetry	The science of sounding seas and lake. In this paper it means a description of the shape and depth of the sea bed (as it would appear on a contour map).
Benthic/benthos	Those animals and plants living on the bottom of sea or lake (crawling or burrowing there or may be attached e.g. seaweeds and sessile animals). Includes microscopic (e.g. small) animals.
Faeces	Indigestible residue of food, together with residue of secretions, bacteria etc expelled from alimentary canal through the anus.

Geomorphology	The branch of geology which is concerned with the structure, origin and development of topographical features of the earth's crust. In the context of this paper geomorphological data provides additional information to the bathymetric data in describing likely changes to the sea-bed bathymetry from processes such as sediment movement. These processes can affect the distribution of benthic fauna.
Macrofauna	Usually used to describe benthos which is larger than will fit through a 1.0mm sieve.
Nutrient	In this paper it refers to the phosphorus and nitrogen present in fish food and fish faeces.
Oceanography	The scientific description of the ocean. In this paper the term is used with particular reference to water movement and circulation in an area and the effects of that circulation on water quality.
Sedimentology	In this paper refers to an analysis of sediments with particular reference to particle size and nature of the sea bed (e.g. soft or compacted). This has a significant influence on the distribution and species of benthic fauna present.
Substrate	Ground or other solid object (including muds) on which animals walk or to which they are attached or material on which a micro-organisim is growing or placed to grow.

8. References

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Further information

Further information can be obtained from the Environmental Protection Authority by telephoning (09) 222 7000.