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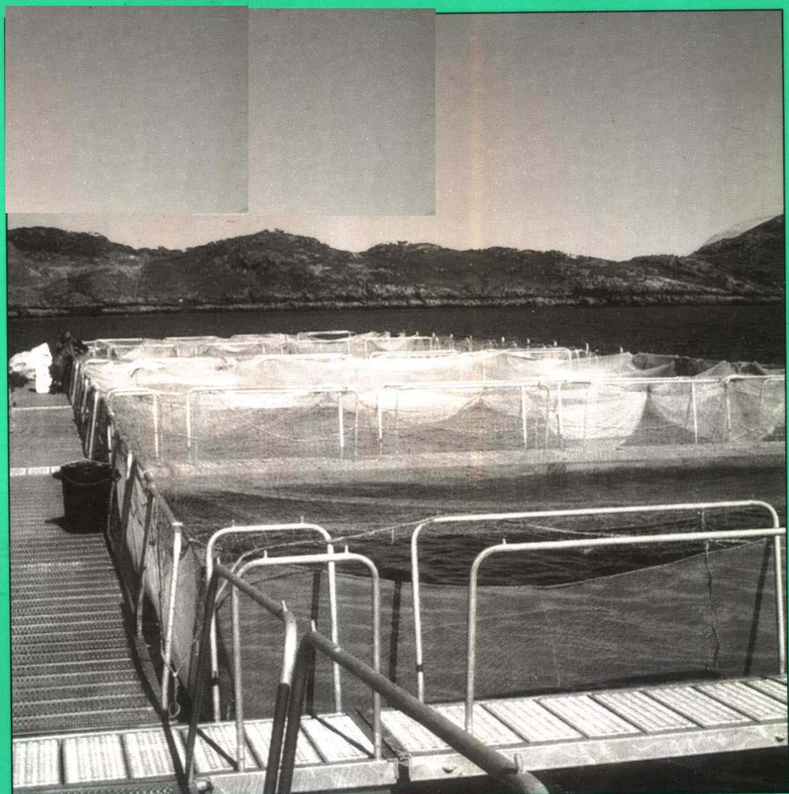
Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP)

Monitoring the ecological effects of coastal aquaculture wastes



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GESAMP

MONITORING THE ECOLOGICAL EFFECTS OF COASTAL AQUACULTURE WASTES

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, 1996

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Courtesy of Dr M.C.M. Beveridge, Institute of Aquaculture, University of Stirling, Stirling, United Kingdom

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PREPARATION OF THIS STUDY

This study has been prepared on the basis of the work of the GESAMP Working Group on Environmental Impacts of Coastal Aquaculture.

The Working Group met in Rome, Italy, 17-21 January 1994 and in Victoria, Canada, 19-23 September 1994. Its report was reviewed by the 25th session of GESAMP, Rome, 24-28 April 1995, and subsequently approved for publication in its present form.

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EXECUTIVE SUMMARY

Soluble inorganic and particulate waste from coastal aquaculture farms can result in organic enrichment of the local aquatic environment. To prevent unacceptable changes to the environment, an environmental management framework should be established as a means of regulating development and evaluating potential impacts before permission to develop is granted. However, any environmental assessment and monitoring effort should be related to the scale of perceived impact of a given aquaculture operation. An Environmental Impact Assessment should be undertaken to predict significant potential impacts, and monitoring carried out (once production has begun) to detect and evaluate the scale of impact. Monitoring is therefore part of the regulatory process which ensures that ecological change associated with aquaculture waste is kept within pre-determined, acceptable levels. Monitoring programmes may provide the information base for decisions to allow for further expansion or development should measured levels prove that observed ecological change is below unacceptable limits. Accordingly, information from monitoring can be essential for deciding whether or not to allow the expansion of existing aquaculture operations.

Successful monitoring will depend on a baseline survey being carried out in conjunction with an Environmental Impact Assessment. The purpose of the baseline survey is to obtain data which can assist in designing an appropriate monitoring programme, and to provide reference data against which changes caused by farm waste can be measured. To optimise resources, the level of monitoring (number of variables and frequency of monitoring) should be related to the size of the operation and the sensitivity of the receiving water body. Additional elements of monitoring programmes which need to be given careful consideration include: selection of reference stations; standardisation of sampling and analytical procedures; analysis and interpretation of data. Given that a particular monitoring programme should be matched to the size, type and location of a coastal aquaculture installation, it is not appropriate to recommend standard monitoring programmes. However, a range of variables commonly used in monitoring are discussed together with an evaluation of their value in interpreting changes resulting from release of waste from farms. To illustrate how particular monitoring programmes might be developed, five example scenarios are presented.

ABSTRACT

GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. Monitoring the ecological effects of coastal aquaculture wastes. *Reports and Studies, GESAMP.* No. 57. Rome, FAO. 1996. 38 p.

Unacceptable ecological change associated with wastes from coastal aquaculture farms can be minimised by good management practices. Any environmental assessment and monitoring effort should be related to the scale of perceived impact of a given aquaculture operation. An environmental management framework should include an environmental impact assessment (involving the use of predictive models) to quantify significant potential impacts and design a monitoring programme. Flexibility of monitoring undertaken for regulatory purposes is necessary, so that monitoring effort is related to the scale of development and sensitivity of the receiving water body. The choice of which variables to monitor must be based on the nature of the impact and the interpretative value of particular variables. Additional elements of monitoring programmes include: selection of reference stations; standardisation of sampling and analytical procedures; analysis and interpretation of data; feed back mechanisms. Five hypothetical scenarios are presented to show how monitoring programmes might be designed.

Key words: Coastal aquatic pollution, aquaculture waste, environmental impact assessment, monitoring

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CONTENTS

1. INTRODUCTION

This report discusses scientific aspects of the monitoring required to assess and manage the ecological effects of coastal aquaculture wastes from the perspective of environmental protection. Other ecological issues relating to coastal aquaculture are discussed by Rosenthal *et al.* (1988), Gowen *et al.* (1990) and Weston (1991). In addition to ecological issues, Chua *et al.* (1989), Chua, (1992 and 1993), GESAMP (1991a), Barg (1992) and Pullin *et al.* (1993) discuss the social and economic consequences of coastal aquaculture development. The scope of this report is restricted to particulate and soluble waste and does not include consideration of the chemicals used in aquaculture (Alderman *et al.*, 1994; Honculada Primavera *et al.*, 1993; Baticados and Paclibare, 1992; OIE, 1992; Smith *et al.*, 1994; Weston, 1996).

Production of fish and crustacea generates particulate organic waste (faecal material and uneaten food) and soluble, inorganic excretory waste. Of the different types of coastal aquaculture, intensive production (which relies entirely on provision of external feed inputs) has the greatest potential to generate waste. It has been estimated for example, that production of one tonne of Atlantic salmon in Scandinavian countries generates ≈ 80 kg of soluble nitrogen (ammonium), ≈ 7.5 kg soluble phosphorus and ≈ 1300 kg particulate carbon (see Ackefors and Enell, 1994, and references cited therein). Certain types of intensive shrimp cultivation can generate ≈ 1500 kg total nitrogen and 400 kg total phosphorus per hectare of pond per year (Phillips, 1995; see also Briggs and Funge-Smith, 1994). Bivalve culture generates faecal and pseudofaecal material (biodeposits) and large scale culture can generate considerable quantities of organic particulate material. Grentz *et al.* (1991) have estimated that approximately 600 kg of particulate biodeposits (faeces and pseudofaeces) are generated for each tonne of production (measured as wet weight).

The waste from coastal aquaculture operations has the potential to enrich aquatic ecosystems, particularly when farms are located in semi-enclosed coastal basins which have restricted exchange with more open coastal waters. Particulate waste settles to the sea-bed and has been shown to bring about changes in the community structure of the benthic macrofauna (Brown *et al.*, 1987; Ritz *et al.*, 1990; Weston, 1990) as well as physical and chemical changes in the sediment, (Brown *et al.*, 1987; Dahlback and Gunnarson, 1981) which, in extreme cases, can result in the sediment becoming completely anoxic (Brown *et al.*, 1987) and oxygen depletion of bottom water (Tsutsumi and Kikuchi, 1983). Soluble excretory waste (ammonium and phosphorus) can result in nutrient enrichment (Gowen and Ezzi, 1992) which in a few cases has been reported to have resulted in eutrophication (enhanced phytoplankton production) in coastal waters (Persson, 1991).

To satisfactorily manage the scale of enrichment and ensure that ecological change does not exceed pre-determined and acceptable levels, a management framework should be adopted prior to development. Such a framework should include the establishment of Environmental Quality Objectives (EQOs) and Standards (EQSs) and must include scope for an Environmental Impact Assessment (EIA) and a monitoring programme. The latter is undertaken to detect ecological change associated with waste production when the farm has commenced production. For the purposes of this report, a working definition of this type of monitoring is given as:

> *"the regular collection, generally under regulatory mandate, of biological, chemical or physical data from pre-determined locations such that ecological changes attributable to aquaculture wastes can be quantified and evaluated."*

It is recognised however, that monitoring may be undertaken for other reasons as outlined in Table I. Section 2 of this report discusses monitoring in the context of an environmental management framework and Section 3 reviews models which have been used to predict the effects of coastal aquaculture waste. The basic principles which should be considered during the design of monitoring programmes are discussed in Section 4 and the variables most commonly measured in monitoring programmes together with an assessment of their interpretative value are presented in Section 5. Given the broad range of coastal aquaculture practices and the need to structure a monitoring programme in relation to the anticipated ecological effect(s), it is not possible to recommend the details of individual programmes. In Section 6 therefore, hypothetical scenarios have been used to show how monitoring programmes can be designed to detect changes in the natural environment.

Table I

The purposes for which monitoring at coastal aquaculture operations may be undertaken.

(i)	Regulation (a) compliance with the terms of the licence (b) protection of the natural environment (ecological protection) (c) safeguarding water quality for aquaculture (e.g. monitoring dissolved oxygen in ambient waters)
(ii)	Farm Management (a) optimising husbandry practice (b) control of water quality (e.g. dissolved oxygen, out gassing from sediment to safeguard farm stock) (c) limiting interference from other aquaculture operations
(iii)	Public Health (a) protection of product quality (e.g. bacterial, chemical or natural toxin contamination) (b) control of disease transmission
(iv)	Research (a) identification of unexpected impacts (b) validation of models (c) monitoring methodology

2. MONITORING THE EFFECTS OF AQUACULTURE WASTES IN THE CONTEXT OF A MANAGEMENT FRAMEWORK FOR COASTAL DEVELOPMENT

It is important to view monitoring as a component of a wider management framework for managing and protecting the natural environment, an example of which is shown in Figure 1. With respect to the impact of aquaculture wastes, the key elements of the framework in Figure 1 are:

i) defining goals or use(s) for a water body
ii) establishment of Environmental Quality Objectives (EQO)
iii) establishment of Environmental Quality Standards (EQS)
iv) undertaking Environmental Impact Assessment (EIA)
v) monitoring
vi) review and evaluation (auditing)

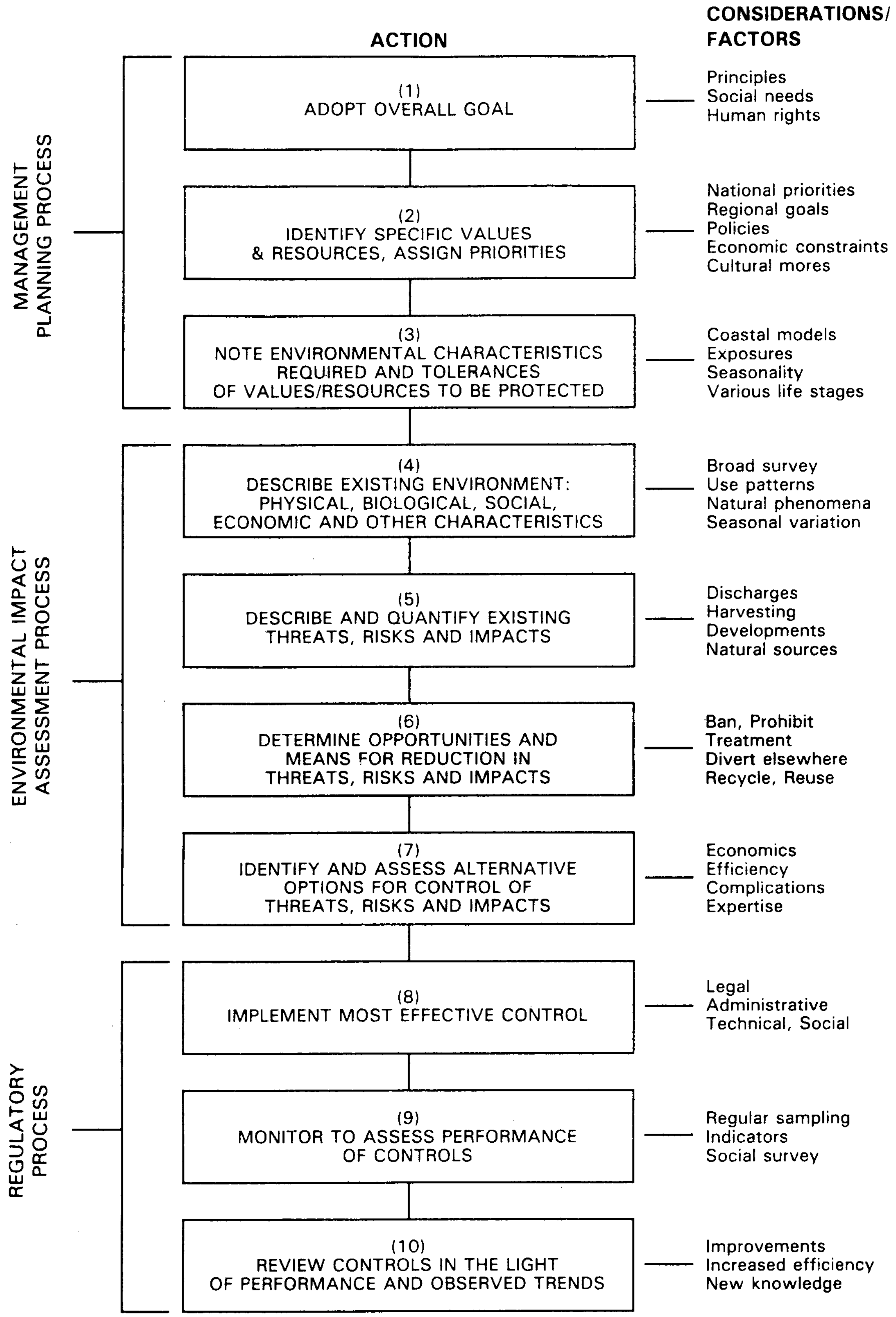

Figure 1. An example of a comprehensive management framework for protection of the marine and other environments. (From GESAMP, 1991b)

Management objectives (based on intended uses) for specific coastal waters might be to maintain the natural environment, or alternatively, to develop activities such as tourism/recreation, aquaculture, fisheries, logging, gravel extraction, etc. Such uses are not necessarily mutually exclusive. The management process should provide for the equitable use of the aquatic resource and safeguard the natural environment by setting Environmental Quality Objectives. These objectives define the conditions to protect a particular use. Environmental Quality Standards are levels of particular variables associated with that use which may be imposed to ensure that the objectives are not compromised. An example of the EQO/EQS approach related to the protection of the natural environment is given in Table II.

Table II

An example of the way in which environmental quality objectives and standards can be developed in relation to a defined use of a water body. In this example the defined use is protection of the general ecosystem. (Modified from MPMMG, 1992)

Environmental Quality Objective	Criteria and standard or approach to standards	
	Criterion	Standard
Maintenance of environmental quality so as to protect aquatic life and dependent non-aquatic organisms, such that the ecosystem is typical of coastal waters with those physical characteristics and latitude (i.e. biotic characteristics)	Faunal benthic composition	Either (i) faunal composition not to be altered by a set quantifiable change in a suitable biotic index. (Further research is required to define this standard), **OR** (ii) outside of a defined impact zone, faunal composition shall not be significantly different from a control site.
Beyond the immediate farm area, the chemical quality of the receiving environment will be indistinguishable from that of the adjacent marine or brackish water environment	Eh (redox potential) Sediment carbon content	Outside an agreed zone where impact is accepted as inevitable, Eh and sediment carbon content shall not be significantly different from that of selected control sites
	Dissolved oxygen level in water column	Should not fall below 7 mg/l (except in cases where deoxygenation is due to other causes)
	Nutrients	Further work required to define the mechanisms linking nutrients with algal growth

There are a number of definitions of what EIA is and some debate concerning what EIA involves or should involve (see for example, Ahmad and Sammy, 1985; Carpenter and Maragos, 1989; Jernelöv and Marinov, 1990; UN/ESCAP, 1991; Sorensen and West, 1992; Barg, 1992).

It is generally accepted however, that EIA should encompass the evaluation of social, economic and ecological impact of a proposed development as well as the identification of impact mitigation measures and alternative development options (GESAMP, 1991a; Pullin *et al.*, 1993). For the purposes of this report, consideration is only given to that part of the EIA which relates to the evaluation of ecological change associated with aquaculture wastes.

From an ecological perspective, the purpose of an EIA must be to assess or predict the ecological consequences of the planned facility, thereby providing the regulatory authority with the scientific basis to determine the acceptability of the perceived impacts relative to pre-determined standards. EIAs have frequently consisted of collections of largely descriptive data, with little *a priori* consideration of the specific changes to be expected from the proposed development. At best, if comparative data from other operations in similar locations are available, such an approach may provide a semi-quantitative evaluation of potential impact. Often, however, the data obtained serve little more than a basis for a case history, giving little insight into cause and effect in relation to eventual impacts. It is suggested that specific, testable hypotheses be formulated at an early stage in the EIA process. Numerical models have the potential to provide quantitative predictions (Section 3) and are therefore a useful tool in quantifying impacts resulting from aquaculture waste. A combination of field investigation and modelling is recommended since this will introduce scientific rigour into the evaluation process.

Thus, the output from models might be used to develop hypotheses regarding the extent of ecological change which are tested using data collected during the monitoring programme. The use of models may also be cost-effective by reducing the amount of field investigation required, and may help to illustrate impacts in ways which are more readily interpreted. Assessments incorporating modelling and hypothesis testing also facilitate feedback processes which allow results of assessments and monitoring to be used more effectively (see Item 4.8 "Feedback").

Data and model predictions from the EIA are needed to design efficient monitoring programmes. A proposed plan for integrating modelling, monitoring and management of benthic enrichment associated with intensive fish farming in Norway is outlined in Figure 2.

The example in Figure 2 illustrates one way of using predictive models to determine the level of exploitation of a particular site and the scale of monitoring which should be undertaken. As part of an EIA, a dispersion and loading model is used to predict the input of organic carbon waste to the sea-bed. The model prediction is compared to an EQS and the degree of exploitation (maximum size of farm) decided. On the basis of this, one of three levels of monitoring is imposed. The results of the monitoring programme are used to assess the EQS, evaluate the model predictions and ensure that the degree of exploitation does not compromise the EQS.

In most cases, an EIA has not been undertaken prior to development of an aquaculture operation (see for example, Burbridge *et al.*, 1993). In the absence of a management framework with pre-determined standards and an EIA to define the scope of the monitoring programme, many monitoring programmes have failed to fulfil their function. On occasion, monitoring has been imposed as a result of public pressure because of the perceived ecological damage caused by aquaculture wastes. The result has often been: the measurement of a wide range of ecological variables, many of which are inappropriate; the collection of data which are difficult to interpret; failure to analyse and interpret data and implement feedback mechanisms to modify farm practice/ production and the monitoring programme itself. The converse is also true. When socio-economic and political pressures have superseded ecological concerns, only limited monitoring has been undertaken and the resultant ecological change has sometimes had adverse consequences for the sustainable operation of farms. Unfortunately, in many countries there are budgetary, manpower and organisational constraints which often restrict the implementation of monitoring programmes.