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Sammendrag:

MOM is a system that can be utilised to regulate the environmental impact of aquaculture plants on the basis of the holding capacity of their sites. The system consisits of a standardised monitoring programme with a set of permitted limits for environmental impact (environmental quality standards), a simulation model for estimation of impacts and a procedure that links these components. The report explains the design and method of operation of MOM and includes a user guide for a revised version of the monitoring programme and the environmental quality standards.

Emneord - engelsk:
1. Fish farm
2. Environmental impact
3. Monitoring

Prosjektleder

Seksjonsleder

MOM

(MODELLING -ONGROWING FISH FARMS - MONITORING)

CONCEPT AND REVISED EDITION OF MONITORING PROGRAMME
1997

by

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SUMMARY

This report describes a management system (MOM) which can be used to regulate the environmental effects of marine fish farming, ensure good rearing conditions for the fish and avoid pollution. The latter part of the report contains a manual for the monitoring programme.

MOM is based on a general concept for regulating environmental impact and its main elements are: simulation of impact (model), control of the impact (monitoring programme), and permissible limits for environmental impact (environmental quality standards (EQS)). Two terms link the three elements: the degree of exploitation and the level of monitoring. Through the two terms the monitoring effort is adjusted according to the environmental impact on the site.

MOM is based on agreement that fish farm sites should not deteriorate over time and that the impact must not lead to the extinction of the benthic infauna beneath the farm. The system recognises three degrees of exploitation of a site, each of which is linked to a level of monitoring. If the third degree of exploitation is exceeded the site is being overexploited.

The monitoring programme consists of three types of investigation: A, B and C. The A-investigation is a simple sedimentation measurement beneath the net pens. The B-investigation is a characterisation of the sediment conditions beneath the fish farm, and a set of EQS has been set in MOM. The C-investigation is a sediment fauna study, and general EQS for infauna investigations are used.

MOM distinguishes between three zones of impact around a fish farm: the local, the intermediate and the regional impact zones. The environmental impact is largest in the local impact zone where the larger particles settle. Here both the A-, the B- and the C-investigations are used. In the intermediate impact zone the impact is less and primarily due to the sedimentation of smaller particles. This zone is monitored by the B- and C-investigations. In the regional impact zone the more sensitive areas are monitored by the C-investigation.

The latter part of this report is a manual for the monitoring programme including EQS. It is essential that the persons who perform the B-investigation should have experience of sediment investigations. The C-investigation can only be performed by specialists.

MOM may be part of the scheme for regulating marine fish farming. The system is intended to keep the environmental impact from fish farming within agreed limits and avoid detrimental effects. Improved environmental conditions may increase fish production, and documentation of rearing conditions can be provided.

PREFACE

MOM (Modelling -Ongrowing fish farms - Monitoring) is a system that can be employed to regulate the environmental impact of aquaculture plants on the basis of the holding capacity of the sites. The system has been developed under the terms of a contract for the Ministry of Fisheries and the Norwegian Pollution Control Authority (SFT), and is capable of being utilised as a component of the aquaculture regulatory system.

The Institute of Marine Research, the University of Bergen, Ancylus in Gothenburg and the Norwegian Directorate of Fisheries have taken part in the development of MOM. The Norwegian Institute of Water Research has developed the Group 2 parameters (pH and redox potential (Eh)) for the B-investigation.

The report comprises an introduction to MOM as well as a more comprehensive user's guide to the monitoring programme with its environmental quality standards. It is recommended that the users of the B-investigation have passed a training course.

This report replaces the earlier "MOM. A system for regulating the environmental impact of fish farms": Institute of Marine Research, Report from the Department of Aquaculture, 1993, no. 23, and "User's Guide and Environmental Quality Standards for monitoring environmental impact from fish farms. MOM": Fisken og Havet no. 12, 1995. The report entitled "Model of critical organic loads beneath fish farms. MOM": Fisken og Havet no. 26, 1995, which describes the model for simulating impact on a site, is still valid.

In 1996, the monitoring programme's B-investigation was tested out at thirty-three fish farms in south, mid- and north Norway, and later modified on the basis gained in the course of these trials.

The Norwegian General Standardising Body (NAS) is currently preparing a Norwegian standard on the basis of MOM's monitoring programme and environmental quality standards. NAS has also initiated a standardisation procedure for studies of sediment infauna. The C-investigation will be modified in order to meet this standard when it is published in autumn 1997.

MOM will generate a great deal of data via the monitoring programme. These data will act as a basis for improvements, and we intend to revise the monitoring programme and the environmental quality standards by the end of 1999.

CONTENTS

INTRODUCTION

The basic environmental objectives of the aquaculture industry are to ensure that the fish enjoy good environmental conditions as a basis for good growth and health, and that fish-farms do not unnecessarily affect or damage the environment. Therefore, limits must be set that protect both the fish and the environment, and both frame conditions and specific tools are needed to help us to maintain the effects of fish farming within these limitations.

In Norway the most important problems associated with aquaculture are connected to disease, escapes, chemicals, medicines and organic matter (Environmental objectives for Norwegian aquaculture, 1993; reports of results, 1994 and 1995). However, these problem areas must be considered in relation to each other, and site overloading and accumulations of waste food and faeces may well be an underlying cause of lack of well-being and poor growth of the fish, followed by disease, the spread of disease vectors and high consumption of medicines. Organic matter may thus be of importance for various types of environmental impact.

MOM places most emphasis on the effect of organic matter on the seabed. However, if other types of influence should assume greater importance in the future it will be perfectly possible to integrate these into MOM without altering the concept or the structure of the system.

The threshold values for environmental impact have been determined on the basis of the requirement that long term use of the sites should be ensured and that benthic fauna should be present in the sediment under the farm. In the future it may also be appropriate to set maximum sediment concentrations of chemicals used as antifouling agents or medicines.

The systematically repeated monitoring carried out by MOM provide good knowledge of changes in sedimentary conditions, both close to the fish farm and in the recipient. This makes it possible to follow changes in environmental impact on an ongoing basis and correct any undesirable tendencies.

MOM may be included in a set of frame conditions for the aquaculture industry and may be a useful tool for the coastal planning process. The system offers new opportunities to study the relationships between the environment and health/growth because it will provide information about environmental conditions around all the fish farms. The information can also be used to document the conditions under which fish are produced.

DESCRIPTION OF MOM

In connection with MOM a general-purpose concept for regulating environmental impact has been developed. The system is thus not limited to fish farming, but may be utilised in situations in which there is a direct dose-response relationship. The main elements of the concept are the following:

- **The environmental impact itself is regulated rather than the quantity of emissions.**
- **The main elements of a governance process are integrated into a unit:**
  - *** tool for making prognoses (simulation model)**
  - *** tool for control (monitoring programme)**
  - *** treshold values for environmental impact (environmental quality standards)**
- **The monitoring process is adapted to the severity of the impact involved.**
- **The system consists of a set of modules that can be replaced if new knowledge or new regulations make this desirable.**

The following elements and terms are central to MOM:

- **Holding capacity** - expresses the potential level of fish production per unit area on any given site without the impact exceeding previously determined limits (environmental quality standards).
- **Monitoring programme** - routine measurements of parameters that describe the environmental impact of a fish farm. The monitoring programme comprises of three types of investigation; A, B and C, of which the first is fairly simple, while the last is comprehensive.
- **Threshold values** - a group of maximum or minimum values of parameters in the monitoring programme, which differentiate between different degrees of impact.
- **Simulation model** - a mathematical description of the relationship between emissions from a fish farm and the impact on the site, that can be utilised to estimate (i.e. simulate or model) the severity of the impact.
- **Degree of exploitation** - expresses the severity of the impact compared to the holding capacity of the site. For every degree of exploitation there is a level of monitoring.
- **Level of monitoring** - expresses the comprehensiveness of the monitoring required to ensure that the threshold values are not exceeded.

MOM differentiates between three degrees of exploitation. If a site is placed in the 1. degree of exploitation the impact from the farm is small compared to the holding capacity. The risk of pollution is small and subsequently simple monitoring is sufficient. The 2. degree of exploitation express that there is a certain impact, but still a moderate one, and the monitoring is more comprehensive than for the 1. degree of exploitation. The 3. degree of exploitation expresses a situation where the impact is close to the threshold values and it is necessary to perform thorough monitoring. If the threshold values for the 3. degree of exploitation are exceeded the impact is unacceptable and the site is overexploited.

THE MONITORING PROGRAMME

The monitoring programme deals with conditions in the sediment beneath and in the vicinity of fish farms, and should reveal changes that have been caused by increased organic loading. Such changes include alteration of the chemical conditions in the sediment and the type and number of benthic infauna. As mentioned in the previous section, the monitoring efforts required are adapted to the probability of impact.

How frequently the individual investigations ought to be carried out depends on the level of monitoring (Table 1). At the site itself, monitoring consists of the A- and B-investigations, so these are linked and always have the same level of monitoring. However, the degree of exploitation of the site itself may differ from that of the recipient, and the C-investigation may thus have a different level of monitoring from the A- and B-investigations.

Table 1: Relationship between degree of exploitation (DEX), level of monitoring (LOM) and frequency of A-, B-, and C-investigations.

		Type of investigation		
		A	B	C
DEX 1	LOM 1	every 3rd month	every 2nd year	every 8th year
DEX 2	LOM 2	every 2nd month	every year	every 5th year
DEX 3	LOM 3	every month	twice a year (spring & autumn)	every 2nd year

The A-investigation

This consists of a measurement of the rate of sedimentation on the seabed under a fish farm. This investigation is relatively easy to carry out, but its usefulness is limited by a certain degree of uncertainty. With repeated measurements over a period of time, however, it can provide information about the extent of sedimentation under the farm and a certain amount of information about overfeeding. Environmental standards are not used in the A-investigation, but as the fish farmer gains experience, he will be able to compare sedimentation rates, both under different parts of the farm and from year to year.

The B-investigation

This offers a simple description of the sediment condition. The amount of information is much higher than that provided by the A-investigation. At the same time, however, the B-investigation is a rapid means of checking sediment conditions rather than a thorough study or description. The investigation is most sensitive in areas in which the organic loadings are medium to high. In order to gather as much information as possible and obtain the most reliable assessment of the sediment condition, MOM uses three groups of parameters which are explained in more detail below. Separate environmental quality standards have been drawn up for this investigation.

The Group 1 parameter describes the presence or absence of macro-benthos (> 1 mm). If a sediment receives a severe amount of organic matter, the benthic community will be modified and the infauna will finally disappear. By sieving the sediment, we can fairly easily determine whether or not it contains benthic infauna. This investigation merely distinguishes between acceptable and unacceptable conditions. However, we are working on including the identification of some easily recognisable groups of infauna species which will be capable of demonstrating how severely affected the sediment is.

The Group 2 parameters comprise two quantitative chemical parameters, pH and redox potential (Eh). When a sediment is loaded with organic matter, both pH and redox potential change as a function of the processes of decomposition. The redox potential best describes the changes from aerobic to anaerobic decomposition. The alterations in pH are particularly useful when the sediment is severely affected and methane is being formed. Our use of these parameters is based on studies of pH and redox potential in sediments under fish farms (Schaanning 1991, Schaanning and Dragesund 1993), which showed a relationship between the two parameters and that their values lay within a particular range. On the basis of measurements of these parameters, therefore, a sediment may be located within a co-ordinate system and the extent to which it has been affected be determined. In order to enable this system to work with MOM, the range was divided into a number of degrees of impact, each of which was given a certain number of points, so that the degree of impact could be determined.

The Group 3 parameters consist of a number of qualitative variables which change as a sediment becomes more heavily loaded with organic matter. These variables have been included as visual observations in many studies of sediments, and consist of gas bubbles, colour, odour, thickness of sludge, and consistency. Gas bubbles in fish-farm sediment consist primarily of methane and carbon dioxide, and indicate that the impact is severe. The thickness of the sludge (deposits of feed and faeces) can be measured and this provides an indication of the accumulation of organic matter. Soft or loose sediment also indicates a process of accumulation. The colour of the sediment changes with organic loading, and heavily loaded sediments are either black, due to the precipitation of iron sulphide, or brown, because they contain a great deal of organic matter. If a sediments smells, this is either due to hydrogen sulphide, or the sediment has its own "feed smell", which is characteristic of fish farm sediments. The Group 3 parameters provide important information but until now could not be quantified. By using a scale of points MOM has introduced a quantitative element, with the result that the parameters provide an expression of the state of the sediment. These points have been allocated on the basis of previous experience of fish-farm sediments. They are based on the assumption that changes in the parameters can be expressed on a scale, and that they will follow changes in pH and the redox potential of the sediments. All the parameters in Group 3 are evaluated together in order to make the evaluations more robust, so that changes in a single parameter alone will not have a great deal of influence.

The C-investigation

This is a study of the fauna structure in the sediment. The benthic infauna is sensitive to organic loadings and the structure of the benthic community provides a good impression of the load (Pearson and Rosenberg 1978). Studies of the benthos have therefore been the main method used to monitor emissions of organic matter, also close to fish farms. The C-investigation is intended to capture long-term changes around fish farms and in the recipient. The investigation is most sensitive with low to medium organic loadings. A C-investigation is meant to be carried out at new fish-farm sites before the farm starts operating. In the recipients, the general environmental quality standards drawn up for the Norwegian Pollution

Control Body are employed: "Classification of environmental quality in fjords and coastal waters" (Rygg and Thelin 1993). Close to the farms themselves, (local and intermediate impact zones) we employ a separate set of standards specially drawn up for MOM.

THE MODEL

The model developed for use in MOM consists of a number of sub-models. The model has two main applications; estimating the environmental impact of a given fish farm on the site and the recipient, and estimating how a farm can be operated without overexploiting the site and the recipient.

Load sub-model

This is a model for estimating the critical organic load under a fish farm. The model has recently been developed as part of the MOM project and it estimates the maximum fish production compatible with a living benthos under a fish farm on a given site (holding capacity). The estimate is based on two underlying sub-models of dispersal/sedimentation of waste feed and faeces, and oxygen transport to the sediment under the farm (Stigebrandt and Aure, 1995).

The model has been implemented as a program for PC (MS-DOS). The sediment's holding capacity for carbon is calculated as a function of the current and the oxygen content above the sediment. One of the sub-models calculates the dispersal of organic matter from the farm as a function of depth, current, sinking velocity of organic matter and the design of the farm itself. Starting from the feed conversion factor and the above-mentioned simulation of holding capacity the programme makes an "educated guess" about the amount of fish that can be produced annually if the benthic infauna are to survive under the farm. These simulations can be carried out for net-cages placed at different distances from each other and for one to three rows of net-cages. This model is still under development, but it already appears to produce realistic results. Its greatest practical value in its current form will probably be the prospect it offers of calculating the relative changes in holding capacity when sites are being compared, either when specific applications are being dealt with or in the process of drawing up coastal zone plans.

The model is also available in a Windows version. This is a modified and somewhat simplified version of the MS-DOS version. For example, the size of the fish farm is fixed at

12,000 m2 in two rows of net-cages. On the other hand, the program is more user-friendly in that changes resulting from altered input parameters are shown directly on the screen.

The Windows version also includes the following modules:

- Estimates of emissions of phosphorus and nitrogen from fish in fish farms on the basis of feed composition, what is absorbed by the fish and retention values for relevant components of the feed. In addition to emissions the lowest feed conversion factor that is theoretically possible is also calculated. Both the feed conversion factor and emissions of nutrients have been dramatically reduced in the course of the past few years as a result of improvements in fish feeds.
- Growth rates of different sizes of salmon and trout at various temperatures. The model is based on the results of a project carried out by Akvaforsk and Nutreco, in which the number of degree days and environmental and genetic conditions (VF3-factor) are entered as parameters (Holmefjord et al. 1994).
- Wave model. A simple model for calculating wave height at different wind speeds, fetch lengths and widths.

Fjord sub-model

This estimates the holding capacity related to fish farming in fjords and threshold basins, and is based on Aure and Stigebrandt (1989). A number of fjord-related parameters (volume, threshold depth, etc.) and the mass of water involved must be known before the calculations can be made. Both MS-DOS and Windows versions are available, the latter being linked to the Windows version of the model for estimating critical organic loads.

Water-quality sub-model

This is a model for estimating the water quality in fish farms. The model has been further developed by MOM from a model presented by Stigebrandt (1986). The model is expected to be ready for implementation in software in the course of summer 1997.

IMPLEMENTING MOM

Fish farms already in operation can be brought into the MOM regime by the performance of a B-investigation. The results of the investigation are evaluated with respect to the environmental quality standards, and the degree of exploitation and the level of monitoring are decided (Fig. 1). The farm remains at this monitoring level until subsequent investigations possibly move it to another level.

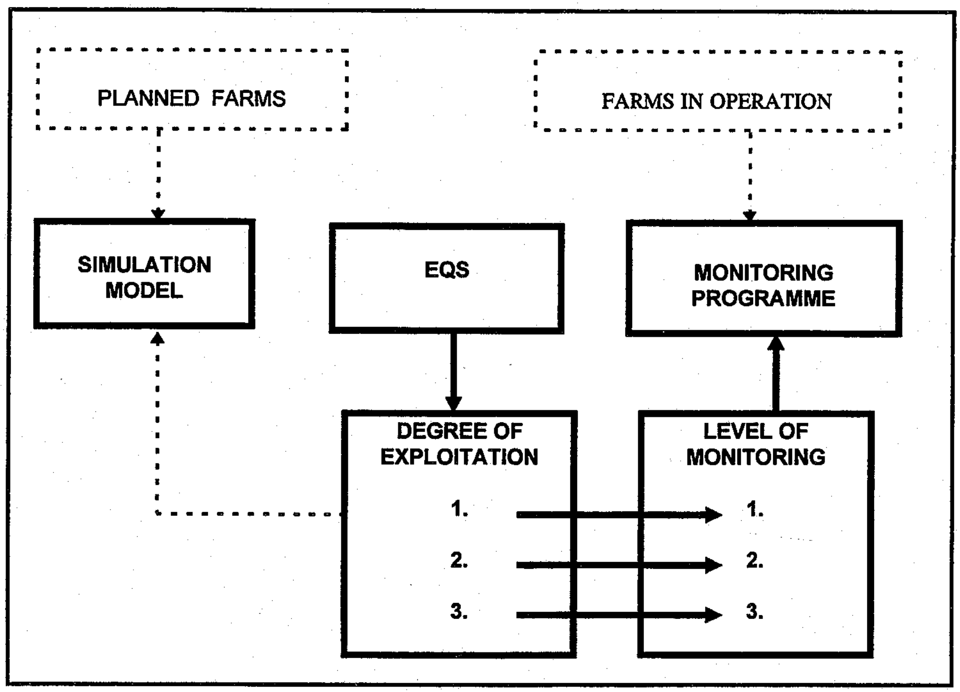

Fig. 1 Implementing MOM. The degree of exploitation is determined first on the basis of benchmark investigations or simulations, and is later modified on the basis of the results of the monitoring. EQS: environmental quality standards.

The continuous process of alternating between investigation, evaluation and determination of further investigation is the backbone of MOM, and this process is identified in Fig. 1 by a heavier line. If the fish farmer finds it necessary to move to another level of monitoring or to alter his operating scheme or his production, he can use the model to simulate the environmental impact of such changes.

For new farms, the impact is simulated, and the degree of exploitation and the level of monitoring for the first investigations are determined. The level of monitoring is subsequently evaluated continuously on the basis of previous B- and C-investigations as explained above.

ZONATION

Emissions from fish farms consist of large particles (waste feed and intact faecal pellets) suspended particles (feed dust and crushed faeces) and dissolved compounds (nutrients, organic compounds, etc.) These emissions have different potentials for spreading, and they affect the water column and the seabed at various distances from the farm. Around a fish farm, zones that suffer different degrees of impact are created (Table 2). The table shows the dominant source and type of impact, the types of investigation that are included in the monitoring programme and the environmental quality standards that are employed.

TRIALS OF THE B-INVESTIGATION

In 1996 the B-investigation was tested out at 31 fish farms in the counties of Vest-Agder, Hordaland, Nord-Trøndelag and Nordland. Two persons fro the Regional Director of Fisheries and the County Department of Environmental Affairs in each region took a course in how to perform the investigation and later carried out the tests. The tests had three objectives: to compare the results of the three groups of parameters studied in the investigation, to test out equipment and procedures in the field, and to determine whether a short course was sufficient to teach people how to carry out the B-investigation. The modifications that were made as a result of the tests have been incorporated in the current manual for the B-investigation.

The choice of farms was intended to cover a range of different types of site and recipient. They are therefore not necessarily representative of the majority of Norwegian fish farms. Of the 31 farms studied, three were in open fjord entrances, 19 in moderately exposed fjord sites, four in straits or sounds, one lay among small islands, three in threshold areas and one at the head of a fjord. Depths varied from 20 to 120 metres. Current speeds were not measured. The farms included both compact plants and free-lying net-cages. The smallest producer slaughtered 180 tons of fish in 1995, while the largest produced 1330 tons.

The majority of the farms were located above hard seabed or compacted sand, where core samplers could not be used. At 25 farms, all the samples were taken by means of grabs, at five all were taken by core samplers and at one, both grab and core sampler were used. Of the 31 farms investigated, 19 end up in the 1st level of monitoring, seven in the 2nd level of monitoring and none in the 3rd level of monitoring. Conditions were unacceptable at five farms.

Table 2. Zonation in MOM. The table also describes the source and the potential of each type of impact, and the investigations that are included in the monitoring programme and the types of environmental quality standards employed.

	Local Impact Zone	**Intermediate Impact Zone**	**Regional Impact Zone**
Definition	Area beneath and close to the farm, where most of the waste feed sediment. The Local Impact Zone ususally extends from 5 to 15 m from the farm.	Area beyond the Local Impact Zone, in which the sediment loading is primarily caused by suspended particles (finely divided waste feed and faeces) and resuspended matter from the sediment. The extend of the Intermediate Impact Zone varies with depth, current and seabed topography, but will usually not be greater than 100-150 m beyond the Local Impact Zone.	Area beyond the Intermediate Impact Zone.
Source of Impact	Environmental conditions are completely dominated by the fish farm activity.	The fish farm activity is the major source of impact, but other activities may be of importance.	Fish farms among several sources of impact.
Potential Impact	Major chemical (organic content, pH, Eh) and biological (bacteria, fauna) changes in the sediment, reduced oxygen content and elevated ammonia levels in the water.	Minor changes in chemical (pH, Eh) and biological (fauna structure) conditions in the sediment.	Increased primary production and oxygen consumption in deep water. Impact depends on nature of recipient.
Monitoring	A-, B- and C-investigations.	C-investigation.	C-investigation, in addition to general coastal monitoring, including oxygen concentration measurements.
Environmental Quality Standards	A-investigation: none. B-investigation: MOM. C-investigation: modified SFT "Classification of environmental quality in fjords and coastal waters".	SFT "Classification of environmental quality in fjords and coastal waters".	SFT "Classification of environmental quality in fjords and coastal waters".

The three farms that lay in relatively small threshold areas all had unacceptable conditions, as did two farms in fjords. The results did not appear to suggest that there was a strong relationship between impact and type or depth of seabed. Nor was there a clear relationship between impact and production.

The B-investigation was originally designed to analyse samples taken by core sampler, where a relatively undisturbed sediment is recovered. The tests showed that many of the farms lay above bottoms where it was not possible to obtain core samples (sand, stone, rock, etc.) In these cases, samples had to be taken by means of a hand grab, and with a good grab this worked well.

The trials showed that one species of polychaete (*Malacoceros fuliginosus*) could survive even in severely affected sediments. This species probably lives both in and above the sediment, and thus avoids the bad conditions. Thus, it does not live solely down in the sediment, and therefore cannot be taken as an indication that there are fauna present in the sediment.

Investigations of pH and Eh were developed for core samples. The measurement procedures functioned well as long as there was somewhere on or close to the farm where it was possible work, preferably under a roof. When the farm was made up of free-lying net-cages it was more problematic, since it is difficult to set up the equipment and carry out the measurements in small boats. However, it may be possible to simplify the electrode measurements by developing an integrated compact electrode set-up that will allow measurements to made where the samples are taken. We are also working on adapting our pH and Eh measurements to grab samples.
The pH and Eh measurements were more sensitive and often indicated that conditions in the sediment were worse than the Group 3 parameters suggested. We had expected that the Group 3 parameters would be less sensitive to small differences between sediments, because these only divide sediments into rough categories, while the pH/Eh measurements cover a continuous scale. However, comparing pH values and measurements of the Group 3 parameters, both individually and as a group, showed that the scale used for the Group 3 parameters was reasonably suitable for its purpose, although pH is more sensitive under bad conditions. The results of the tests showed that the measured values of pH and redox potential lay within the same range as in the original investigations (Schaanning 1991, Schaanning and Dragesund 1993).

In one area, both B and C-investigations were carried out on the same farms. More detailed comparisons and adaptations of the two type of investigation will be carried out when the C-investigation has been standardised via the efforts initiated by the Norwegian General Standardising Body.

USER'S GUIDE TO THE MONITORING PROGRAMME AND ENVIRONMENTAL QUALITY STANDARDS

Maps and charts

The following maps and charts must be available before the monitoring programme starts:

- Chart (1:50,000) showing the site and the position of the fish farm. A fire sheet covering the farm and the surrounding areas should also be at hand.

- Chart of the seabed topography of the farming area. This chart is used to determine where samples should be taken. The chart is produced on the basis of depth measurements taken in connection with the first B-investigation. It should cover the seabed under the fish farm itself and at least 10 m around it (Fig. 2). If the farm consists of free-lying net-cages, the whole area where there are net-cages must be covered.

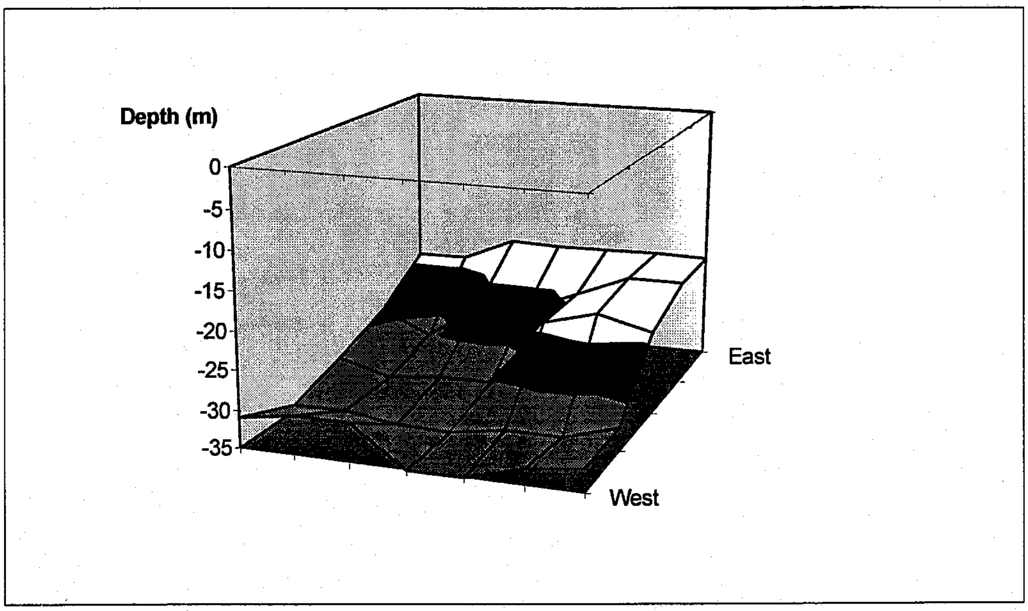

Fig. 2. Example of chart of seabed topography under a fish firm.

- Map of fish farm showing the design and size (length, width, number and diameter of net-cages, distance between individual net-cages) of the farm. This map is used to mark sampling locations and will be obtained from the fish farmer. The map must cover an area extending at least 10 m beyond the farm itself.

Disinfection

The movement of equipment and personnel between fish farms carries with it the risk of spreading disease. Equipment and working clothes must therefore be disinfected, and any samples taken must be destroyed or buried. Iodophores are recommended as disinfectants, but these must be tested on the equipment before use. In cases of doubt, a veterinarian should be contacted.

Persons who are about to carry out MOM investigations should consult the district veterinarian in order to find out whether special precautions are necessary on the fish farms that are to be investigated. Particular care should be taken to find out whether farms are under quarantine, or whether there is any suspicion of infectious disease.

THE A-INVESTIGATION

This investigation measures the quantity of particles that sediment beneath the farm. The measurements are made using two sediment traps that are placed above the sediment.

Objective:

To provide the fish farmer with information regarding the load beneath his farm. Taken in conjunction with the results of the B-investigation, and knowledge of which net-cages contain most fish and are thus given most feed, this will enable the farmer to spread the load and avoid overloading.

Personnel:

The A-investigation is carried out by the fish farmer himself, and forms part of his internal control routines.

Equipment:

Two sediment traps for collecting waste feed and faeces (Fig. 3). The diameter of the traps must be at least 10 cm and their height must be six times the diameter. The traps may be made of PVC. The distance between the trap and the underwater buoy must be at least 5 m, and the top of the trap should lie 2 m over the seabed.

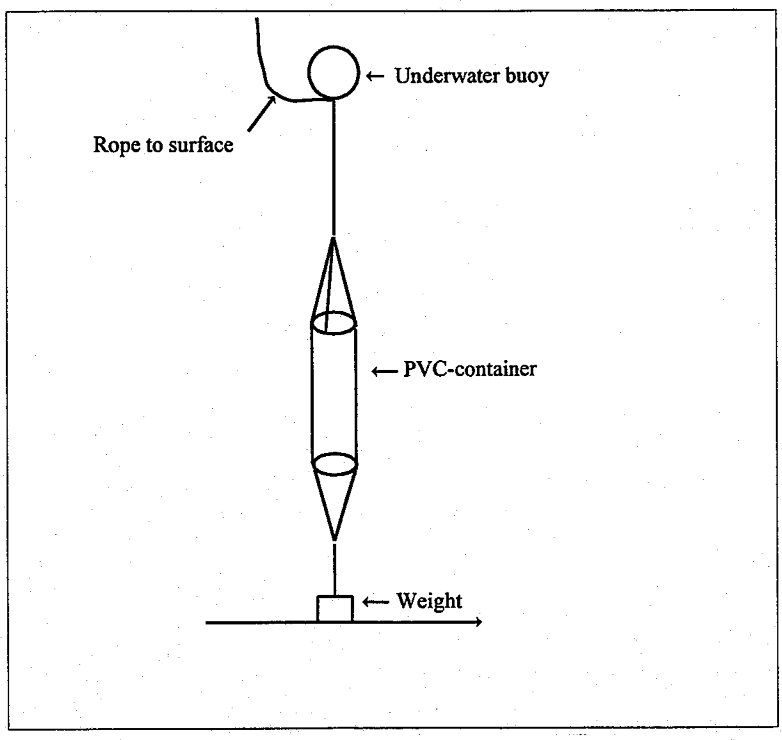

Fig. 3. Sediment trap with attachment rig

Sampling site:

One sediment trap is hung from the edge of the sea-cage that contains most fish or which receives most feed, the other from the edge of a sea-cage with an average number of fish. In compact fish farms, traps are hung from the central gangway.

Sampling:

The quantity of waste collected by the traps in 14 days is measured. The water at the top of the trap is carefully poured off and the waste with the remaining water is poured over into a measuring cylinder, where the quantity of waste can be read off once it has settled. The results are logged. The size of the measuring cylinder is determined by the size of the trap and on the basis of experience of how much waste is collected. The waste can be harmful to the fish and should be deposited on land.

THE B-INVESTIGATION

This investigation is a simple survey of the condition of the sediment beneath the fish farm. It comprises three groups of sediment parameters and has its own set of environmental quality standards. Sampling is carried out using a light equipment and the samples are taken by means of a core sampler or grab.

Objective

The objective of the B-investigation is to perform simple, cost-effective monitoring of the sediment near the fish farm. Because it is inexpensive and its frequency is determined by the degree of impact, the B-investigation can be carried out often to provide an ongoing check of development. This enables measures to be put into effect to head off undesirable trends or prevent undesirable occurrences.

Personnel

The investigation is carried out by personnel who have passed the B-investigation training course.

Parameters - core samples:

- Fauna: Quantitative investigation which demonstrates the presence or absence of fauna after the sediment has been passed through a 1 mm sieve. The polychaete (*Malacoceros fuliginosus*) can survive on the surface of sediments with high organic load, and is not included.
- pH and redox potential (Eh): quantitative investigation in which the values are measured by means of electrodes in core samples.
- Odour, colour and consistency: qualitative investigation in which the parameters are evaluated on a scale ranging from 0 to 4.
- Gas bubbles: investigation in which the presence or absence of bubbles in the sediment is noted.
- Thickness of sludge: quantitative investigation in which thickness of accumulated material is measured and values allocated according to a scale ranging from 0 - 4.

Parameters - grab samples:

- Fauna: Quantitative investigation which demonstrates the presence or absence of fauna after the sediment has been passed through a 1 mm sieve. The polychaete (*Malacoceros fuliginosus*) can survive on the surface of sediments with high organic load, and is not included.

- Odour, colour and consistency: qualitative investigation in which the parameters are evaluated on a scale ranging from 0 to 4.
- Gas bubbles: investigation in which the presence or absence of bubbles in the sediment is noted.
- Grab volume: quantitative investigation in which the sample volume is measured and values allocated according to a scale ranging from 0 - 4.

Equipment:

The following equipment is needed for a full B-investigation.

- Winch: A portable winch can be used to bring core or grab samples to the surface. A winch may not be necessary in shallow water.
- Core sampler: the sampler used during trials of the B-investigation was specially developed by the Institute of Marine Research, but other core samplers can be used,
- Grab: It is important for sampling that the grab should close tightly. It is also an advantage if the grab has openings to enable sub-samples to the taken. During the trials of the B-investigation a 250 cm^3 van Veen grab was used.
- pH measurements: A standard glass combination electrode can be used to measure pH. Such electrodes are highly accurate, but are easily broken, while their glass suffers from wear in sandy sediments and the salt bridge may be blocked by sediment or fine particles. The pH electrode is connected to a standard field pH meter. The trials of the B-investigation utilised the new ISFET (Ion Specific Field Effect Transistor) pH sensor technology (Sentron 1001 transportable pH meter with ISFET pH electrode). This electrode is sufficiently accurate, the sensor is robust, lacks a salt bridge, requires no maintenance and can be stored dry. The equipment functioned well even under sulphide-rich conditions.
- Redox potential measurements: The redox potential is measured by a platinum electrode and a reference electrode or a redox combination electrode. Ag/AgCl (silver/silver chloride) reference electrodes are less temperature-sensitive, and thus more suitable than calomel reference electrodes. The trials of the B-investigation utilised a PHM201 transportable Radiometer pH meter with an M21Pt platinum electrode and an REF210 Ag/AgCl reference electrode.
- Miscellaneous: A 1mm sieve, grab volumeter, disinfectant.

Sampling

- The first time that the farm is visited it is important to obtain an impression of the type of sediment beneath the farm, and how it will be possible to take samples. For this reason, grab samples should be taken at a minimum of ten locations, and the results entered in the

"Sampling Location Form". If these tests indicate that the sediment is soft, samples should be taken using a core sampler. Subsequent investigations should use a core sampler whenever possible; otherwise a grab may be used. With the aid of this type of sediment investigation, plus the topographic map and any available current measurements, the area within which the organic material from the farm is expected to settle can be drawn in (area of influence) on the chart of the area (Fig. 4). It may also be possible to estimate the area of influence with the help of the model.

- During subsequent investigations samples should be taken from at least six locations evenly spread over the farm site, and these locations should be identified on the map of the fish farm. For the sake of comparison, it is important to take the samples at the same locations every time.
- Compact farms: samples can be taken from the gangway as shown in fig. 4. The net-cage at each end of the farm are excluded from the sample area.
- Separate net-cages: The samples are taken as close to the edge of the net-cage as possible, downstream of the main current direction and between the net-cages (Fig. 4). A total of six samples should be taken, if possible from different net-cages. On extremely large sites, more than six samples ought to be taken.

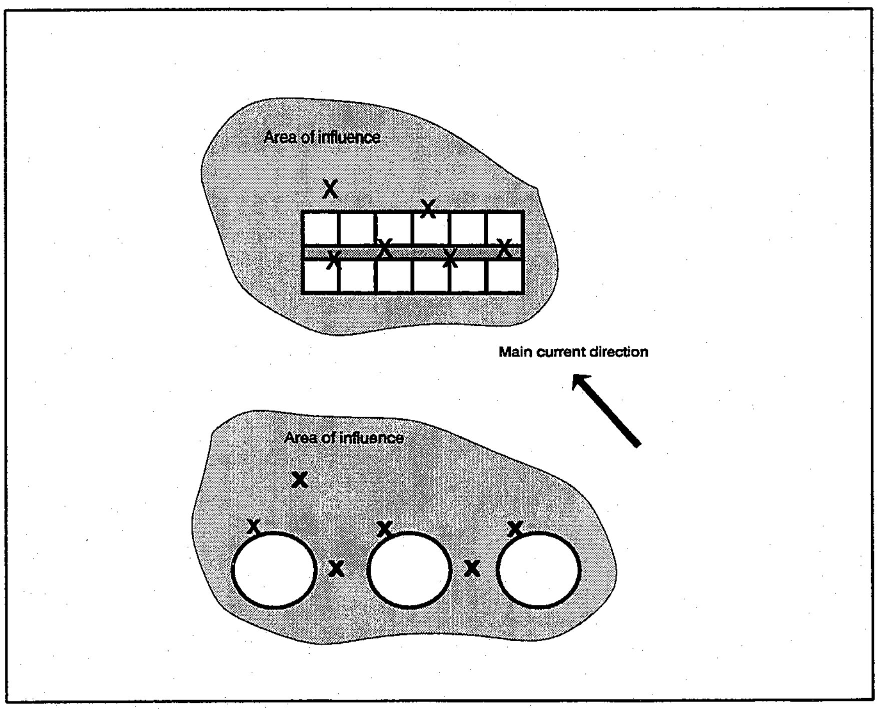

Fig. 4 Areas of influence and sampling sites on compact fish farms and farms with separate net-cages

- Grab samples: two attempts should be made using a grab. If the grab is empty on both occasions, the seabed is presumably rocky without accumulations of organic matter. If the grab contains sediment, this should be evaluated and logged in the "Grab Sample Form".
- Core samples: If the tests indicate a soft bottom, two attempts should be made to obtain a core sample. If such a sample can be brought up, it should be measured and evaluated, and logged in the "Grab Sample Form".
    - Avoid bumps and sudden movements which will stir up the sediment in the cores.
    - Make sure that the samples are tightly stoppered.
    - The cores must be stored dark and cool; avoid heating and direct sunlight.
    - Measurements should be made as soon as possible after sampling.

Investigation of Group 3 Parameter (gas, colour, odour, consistence, sludge thickness, volume of grab sample).

These evaluations do not disturb the sample, and are therefore carried out first. For grab samples, these evaluations may be more easily carried out if the grab has an opening in the top which enables a small core sample to be removed before the sediment is poured into a tray. Points are noted in the "Core Sample Form" or "Grab Sample Form" (Appendix 2). The sum of the points for each core or grab sample is noted under "Sum".

Investigation of Group 2 Parameters (pH/Eh)

Setting up electrodes.

The electrodes must be set up before sampling takes place. They are mounted in an electrode holder, calibrated and left standing in seawater until they are stable.

- The redox electrode is checked by checking its potential in a redox standard solution, in which the deviation from the given value should be no greater than 10 mV.
- The pH electrode is calibrated using buffer solutions with pH 7.0 and 4.0. The buffers must be at the same temperature as the sediment samples. (A 5 °C difference is acceptable; see Appendix 1 "Calibration and measurement of pH").
- After calibration, the electrodes are laced in fresh seawater until they indicate stable pH values (around 30 - 60 min). Stirring may shorten waiting time. Avoid direct sunlight on the pH electrode and the seawater.
- After sampling and before measurements commence, the pH and redox potential of the seawater are noted in the "pH and Eh Measurements Form" (Appendix 2). The pH of seawater usually lies between 7.9 and 8.2, and the Eh between +250 and +450 mV.

Procedure for measuring pH and redox potential

- Avoid breathing in hydrogen sulphide; use a breathing apparatus or ensure that ventilation is sufficient.

- The core with the sediment sample is fixed to a stand. The lower stopper is carefully removed and the core is slid over on the piston. The upper stopper is removed. The piston is used to press the core upwards in the tube until the water has drained away. The electrodes are mounted in such a way that their sensors are at exactly the same level. They are pressed carefully down into the sediment until the sensors are 0.5 - 1.5 cm below the surface.
- The pH is read off when it reaches a stable level and is noted in the "pH and Eh Measurements Form" (Appendix 2).
- The redox potential is read off when drift falls below 0.2 mV/s. If this does not happen within a few minutes, the value is read off anyway (see Appendix 1 "Measuring redox potential"). Note the value in the "pH and Eh Measurements Form" (Appendix 2). Drift can be indicated by means of an arrow pointing up or down just after the figure. The reference electrode's half-cell potential is added to the values that have been read off.
- When readings are being made at different depths, the electrodes are taken out, the core is pressed up in the sectioning cup to the desired level and is sectioned by passing a thin plate in between the test tube and the sectioning cup. The core segment that has been cut off is put aside for subsequent indications of the presence or absence of fauna. The electrodes are rinsed in seawater, water drops removed using absorbent paper and the electrodes are pressed down through the bared surface to the next measurement depth. The core is sectioned at 2 cm intervals and measured down to a depth of 7 cm.
- The lowest pH value and the corresponding Eh value for each core are entered in the "Core Sample Form". The pair of figures is plotted in the "Diagram for Reading Off pH and Eh Points" (Appendix 2) and the points reading is noted in the "Core Sample Form".
- After the end of sampling on the site, the pH of the local seawater is noted and the redox electrode is corrected against a standard solution. Measurements must be corrected for any drift.

Investigation of Group 1 Parameters (fauna)

The sediment from each core or grab sample is passed through a 1 mm sieve and occurrence of fauna, with the exception of nematodes and *Malacoceros fuliginosus* is noted in the "Core Sample Form" or "Grab Sample Form".

Evaluation of results

If both core and grab samples have been taken from the same fish farm a separate form is filled out for each sampling type (core and grab samples). It remains to fill in the last two columns "Index" and "Condition", by means of which we can determine the condition of the site.

Filling in the "Index" column

- <u>Group 1 Parameters (fauna):</u> The total number of samples containing fauna and the total without fauna are entered in the "Index" column.
- <u>Group 2 Parameters (pH/Eh):</u> The sum of the points for each core is entered in the "Index" column.
- <u>Group 3 Parameters:</u> The sum of the points in the SUM line at the bottom of the form is entered in the "Index" column.

Filing in the "Condition" column

- <u>Group 1 Parameter (fauna):</u> If "Index" indicates that at least half of the core samples contain infauna, the condition is acceptable and an "A" is entered under "Sediment Condition Group 1". If the "Index" indicates that less than half of the core samples contain infauna, the condition is unacceptable and a "U" is entered.
- <u>Group 2 Parameters (pH/Eh):</u> In "Diagram 1" (Appendix 2) the number of cores is plotted against the "Index" and the condition is noted and entered under "Sediment Condition Group 2" on the form.
- <u>Group 3 Parameters:</u> In "Diagram 2" (Appendix 2) the number of core samples or grab samples is plotted against the "Index" and the condition is noted and entered under "Sediment Condition Group 3" on the form.

CONDITION OF THE SITE is determined as follows:

CONDITION OF THE SITE is determined on the basis of the condition of the Group 1, 2 and 3 Parameters. Since each group is given a different weighting, the following procedure should be employed:

- <u>If the Group 1 Parameter (fauna) indicates acceptable conditions (A):</u> If Groups 2 and 3 indicate the same condition, then this condition is CONDITION OF THE SITE. If Groups 2 and 3 indicate different conditions, CONDITION OF THE SITE is set to the Group 2 condition. An exception to this rule is if Group 3 turns out to be unacceptable, CONDITION OF THE SITE must then be set to Unacceptable.
- <u>If the Group 1 Parameter (fauna) indicates unacceptable conditions (U):</u> This may be due either to poor conditions in the sediment or to no infauna having been picked up in the samples. If Groups 2 and 3 indicate condition 3 or unacceptable, CONDITION OF THE SITE is set to unacceptable. If Groups 2 and 3 indicate condition 1 or 2, CONDITION OF THE SITE is set to the same value as that of Group 2.

CONDITION OF THE SITE indicates the final evaluation of the sediment beneath the fish farm. If both core sampler and grab have been used on the same site, we end up with two site conditions. If these are identical the CONDITION OF THE SITE is given. If they differ, both are used. The final evaluation of the CONDITION OF THE SITE (and thus the level of monitoring) will depend on the relative numbers of core and grab samples.

Reporting

When the investigation has been carried out a brief report is written. This should provide such information as is necessary to enable an identical investigation to be carried out at a later date. The report should include a topographical chart of the seabed, a site map showing where all the samples were taken, and all the forms that were filled in as part of the investigation. It should also offer a brief description of conditions beneath the fish farm and a comparison of the results from the various sampling sites. An important part of the report is a comparison of the results with those of previous investigations and the identification of any trends.

THE C-INVESTIGATION

This investigation is a detailed survey of the impact of the fish farm both locally and throughout the recipient. It is carried out by analysing the structure of the benthos community. Sampling is done from a large vessel, using a large grab. Sampling and quantification procedures for marine benthic infauna are currently being revised by the Norwegian General Standardising Body, and a standard will be published in autumn 1997. The C-investigation will then be modified to satisfy the new standard.

Objective

The C-investigation aims to obtain the best possible knowledge of the impact close to the fish farm and in sensitive areas of the recipient. Unlike the B-investigation, this investigation is extremely sensitive, even to changes in areas that are only slightly affected. For this reason, it is suitable for identifying small changes that take place over long periods of time, and as a reference study before an area begins to be affected.

Personnel

This investigation must be carried out by a marine biologist specialised in the classification of benthic fauna and the evaluation of benthic data.

Parameters

- Fauna: Quantitative and qualitative study of macrofauna (>1 mm)
- Loss of ignition: Measurement of the proportion of organic material in the sediment.
- Particle size: Measurement of the proportions of clay, silt, sand and gravel in the sediment.
- Oxygen content: Measurement of the oxygen content of the water column.
- Visual description: Characterisation of the sediment in terms of colour, odour, faeces and feed pellets. This characterisation does not comprise a quantitative evaluation as in the B-investigation, but is utilised merely in support of the evaluation of the infauna investigations.

Equipment

- Grab with 0.1 or 0.2 m^2 opening
- Sieves with round holes (1 mm diameter)
- Neutralised formalin for preserving sieved samples
- Water sampler and equipment for Winkler analyses

Sampling locations

A set of samples is collected downstream of and as close to the fish farm as possible, and another in the deepest part of the area, whether this lies in the local, intermediate or regional impact zone. The first set of samples should be representative of the impact close to the farm, while the other should identify the greatest impact on the recipient, downstream of the farm. If the samples give an impression of unsatisfactory environmental conditions, further samples should be collected from an area between the farm and the deepest part of the whole area. The position and depth of each sampling location should be noted and marked on the chart relative to the position of the farm.

Sampling procedure

Two or three grab samples for infauna studies are taken at each sampling location. From the first grab sample at each location, samples are removed for studies of loss on ignition and particle size distribution. If the sediment is severely affected, with a strong smell of hydrogen sulphide and a lack of animal life, only a single grab sample for loss on ignition and particle size distribution is taken. The volume of the sample is measured and the sediment is washed through a 1 mm sieve. The contents of the sieve are preserved in 4% formaldehyde which has been neutralised with borax.

Sample investigation

- The structure of the fauna community is determined by classifying the animals (preferably to species level) and counting them.
- Loss on ignition is determined by measuring the difference in weight between drying at 105 °C for about 12 hours and combustion at 550 °C for one hour. The loss on ignition is expressed as a percentage.
- Particle size distribution is determined by passing samples dissolved in water through a 0.063 mm mesh sieve. Particles larger than 0.063 mm in diameter are then dried and dry-sieved, while particles below this size are analysed by pipette.

Evaluation of the results:

In the regional impact zone, the results are evaluated according to SFT Guidelines 93: "Classification of environmental quality in fjords and coastal waters" (Rygg and Thelin, 1993). In the intermediate and local impact zones the environmental quality standards described below are used. If the results of similar studies carried out before the establishment of the fish farm are available, multivariate analysis should be used to compare these with the new results. When there are relatively few species with an even distribution of individuals in the samples, as may be the case close to fish farms, diversity indices are not very suitable as measures of environmental conditions. Close to a fish farm, therefore, the evaluation is made as outlined below.

Seabed condition 1

- At least 20 species of macrofauna (> 1 mm) apart from nematodes in a sampling area of 0.2 m^2
- No single species should account for more than 65% of the total number of individuals

Seabed condition 2

- 5 - 19 species of macrofauna (> 1 mm) apart from nematodes in a sampling area of 0.2 m^2
- More than 20 individuals apart from nematodes in a sampling area of 0.2 m^2
- No single species should account for more than 90% of the total number of individuals in the samples

Seabed condition 3

- 1 - 4 species of macrofauna (> 1 mm) apart from nematodes in a sampling area of 0.2 m^2

Unacceptable seabed condition

- If there are no benthic infauna the condition of the seabed is unacceptable.

The oxygen content of the water column is measured during infauna sampling. Since these measurements do not form part of an extended series they cannot be used to estimate oxygen consumption or to measure long-term developments in deep water. If they are evaluated on the basis of season of the year and topographical conditions on the site, however, they provide supplementary information that can be used in the evaluation of the benthic infauna community. The characterisation of the sediment provides important information for the evaluation of the other results. A professional evaluation report containing all the original data should be drawn up.

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APPENDIX 1

pH and Redox Potential (Eh) Measurements

Calibration and measurement of pH

Before any measurements are made, pH must be calibrated against two buffers. Follow the instructions supplied with the pH-meter. The usual procedure is to use buffers with pH values of 7.0 and 4.0. The temperatures of the buffers and the actual samples should be as similar as possible. The temperature of the water above the sediment under most Norwegian fish farms is around 5 - 10 °C, so this is the temperature range recommended for calibration and measurement. If the pH meter is capable of temperature compensation, it can compensate for differences between samples and for differences between samples and buffer, but it does not compensate for changes in pH due to changes in sample temperature during storage. Thus, the samples should be measured at their *in situ* temperature.

Once it has been calibrated, the electrode is placed in seawater, which has a much higher salt content than the buffer solutions. This causes a number of problems, one of which is that it takes a long time to produce a stable pH reading. The procedure should therefore be organised in such a way that the electrode can stand in seawater for half an hour to one hour before measurements start. Efficient stirring may cut down this interval somewhat. During the measurement process, the electrode should be stored and cleaned only in seawater or in water to which 30 g of ordinary cooking salt per litre has been added. Long periods of waiting and a great deal of patience will be required if the pH electrode is moved between liquids that differ greatly in salt content.

The pH of seawater is around 8.0, with only slight variations. In the water above the sediment the pH may be slightly lower, but is seldom below 7.6 - 7.7. A pail of seawater can therefore be used as a working buffer throughout the measurement session. If the pH of such a seawater buffer shows a reading of less than 7.9 or more than 8.2, the reason is usually that the electrode has not come into balance with the higher ion concentration, or that an error has occurred during calibration. In such cases, the calibration process should be repeated, or the operator should determine whether there are special conditions such as pollution, algae blooms or inputs of fresh water in the vicinity of the place where the seawater was taken.

It should not be necessary to recalibrate the electrode between measurements. However, the electrode should be checked regularly, e.g. every half hour, in the seawater buffer. If this procedure reveals systematic drift, the results can be corrected at the end of the measurement session. If deviations from the original value exceed 0.2 pH units, recalibration of the electrode should be considered.

Unstable pH readings may be caused by bad batteries, moisture or corroded connections, the salt bridge not being covered by the sample, static electricity or noise from electrical installations in the vicinity. If the source of the fault cannot be identified, and an ISFET electrode is not being employed, the salt bridge has probably become blocked and a spare electrode will have to be used.

Theory of redox potential

Theoretical interpretations of potentials measured using platinum electrodes are usually misleading. The great importance of this parameter is primarily due to the fact that it can be empirically related to an environmental gradient. In the marine environment potentials vary from +400 mV in well aerated surface water to -200 mV in overloaded sediments or water above the sediments in fjords or inlets with low rates of water exchange.

The cell potential E_{cell} is the potential measured using a millvoltmeter connected to a circuit with an indicator electrode and a reference electrode in connection with the sample. It comprises the half-cell potential of the indicator electrode (E_{ind}) and the reference electrode (E_{ref}), such that:

$$E_{cell} = E_{ind} - E_{ref} \qquad (1)$$

If the indicator electrode is made of a chemically inert material such as platinum, gold or graphite, the half-cell potential E_{ind} will be the same as the redox potential Eh. By substituting Eh for E_{ind} and reorganising (1) we get:

$$Eh = E_{cell} + E_{ref}. \qquad (2)$$

The equations shows that the half-cell potential of the reference electrode must be added to the cell potential reading in order to obtain the redox potential. E_{ref} depends on the type of electrode employed and on the type of solutions with which the electrode has been filled. The electrode manufacturer ought to be able to supply information regarding the values of E_{ref} at various temperatures. There are solutions with a well-defined Eh, but we recommend using the given value of E_{ref}.

In other words, the redox electrode should not be calibrated. If there is doubt as to the type of electrode used, or as to whether the instrument or its electrodes are faulty, the set-up can be checked in a standard redox solution. This should always be checked both before and after a series of measurements.

Measuring redox potential

The response time, i.e. the time it takes for the instrument to display a stable value, can be extremely long for this type of electrode. This problem may cause a great deal of frustration and doubt in the personnel who make the measurements. If we assume that a maximum of four to five minutes are available for each individual sample it will be essential to establish routines that provide the most reproducible results within this period of time.

The response time will depend on the electrodes used as well as on the components of the samples. Under normal conditions, 90% of the final value of the reading is obtained in the course of one to two minutes. If a rate of drift of up to 0.2 mV per second is permitted at the instant of reading, in most cases it will be possible to read of a redox potential within +- 50 mV of the true value within four or five minutes. +- 50 mV is equivalent to the absolute uncertainty given by the literature for measurements of the redox potential of natural samples.

In special situations not even such "relaxed" requirements can be met in the course of four to five minutes. This is especially true when measuring sulphide-free samples after a sample that contains sulphide. The platinum electrode can "remember" sulphide for several hours after exposure to a sample that contained sulphide. Readings can be 100 - 200 mV lower after the electrode has been in contact with sulphide. If the measurements are always started with a sample that contains sulphide, or with seawater to which a small crystal of sodium sulphide (Na_2S) has been added, the range of measurement will be reduce somewhat at the upper end of the scale, but better reproducibility will be obtained as a whole. If the Eh is too low, one may try using fresh seawater and cleaning the redox electrode.

APPENDIX 2

Forms and Diagrams

SAMPLING LOCATION FORM

Date:

Company:

Site:

Sampling location (no.)		1	2	3	4	5	6	7	8	9	10
Grab/Core (G/C)											
Depth (m)											
Spontaneous bubbling											
Number of trials											
Bubbling (during sampling)											
Bubbling (in sample)											
Primary sediment	Shellsand										
	Sand/silt										
	Clay										
	Mud										
Rocky seabed											
Stony seabed											
Waste feed/faecal pellets											
Beggiatoa											
MOM 1997											

Feed type:

Feed amount:

Produktion:

Biomass:

CORE SAMPLE FORM

Date:

Company:

Site:

Group	Parameter	Points	Core sample no.						Index	Con-dition
1	Fauna	Yes (1)								
		No (1)								
									Sediment condition Group 1	
2	Lowest pH	From form								
	Corresp. Eh	From form								
	pH/Eh	From diagram								
	Condition of individual sample									
									Sediment condition Group 2	
3	Gas bubbles	No (0)								
		Yes (4)								
	Colour	Light/grey (0)								
		Brown/black (2)								
	Odour	None (0)								
		Some (2)								
		Strong (4)								
	Thickness of sludge	0 - 2 cm (0)								
		2 - 4 cm (1)								
		4 - 6 cm (2)								
		6 - 8 cm (3)								
		>8 cm (4)								
	Consistency	Hard (0)								
		Soft (2)								
		Loose (4)								
		SUM								
	Condition of individual sample									
									Sediment condition Group 3	
MOM 1997									CONDITION OF SITE	

pH AND Eh MEASUREMENTS FORM

Date:

Company:

Site:

Eh* = Eh reading + potential of reference elektrode

CORE no.									
DEPTH(m)	pH	Eh	Eh*	pH	Eh	Eh*	pH	Eh	Eh*
Water									
1									
3									
5									
7									
CORE no.									
DEPTH(m)	pH	Eh	Eh*	pH	Eh	Eh*	pH	Eh	Eh*
Water									
1									
3									
5									
7									

MOM 1997

Potential of refernece electrode:

Buffer temperature:

Seawater temperature:

Seawater pH:

Sediment temperature:

Seawater Eh:

GRAB SAMLPE FORM

Date:

Company:

Site:

<table>
<tr><th rowspan="2">Group</th><th rowspan="2">Parameter</th><th rowspan="2">Points</th><th colspan="6">Grab sample no.</th><th rowspan="2">Index</th><th rowspan="2">Con-dition</th></tr>
<tr><th></th><th></th><th></th><th></th><th></th><th></th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Fauna</td><td>Yes (1)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="2"></td></tr>
<tr><td>No (1)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="10">Sediment condition Group 1</td><td></td></tr>
<tr><td rowspan="18">3</td><td rowspan="2">Gas bubbles</td><td>No (0)</td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="15"></td><td rowspan="17"></td></tr>
<tr><td>Yes (4)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Colour</td><td>Ligth/grey (0)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>rown/black(2)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Odour</td><td>None (0)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Some (2)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Strong (4)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Sample volume</td><td>< 1/4 full (0)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3/4 - 1/4 (2)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3/4 - full (4)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Consistency</td><td>Hard (0)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Soft (2)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Loose (4)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">SUM</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Condition of individual samples</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="9">Sediment condition Group 3</td><td></td></tr>
<tr><td colspan="9">MOM 1997 SITE CONDITION</td><td colspan="2"></td></tr>
</table>

DIAGRAM FOR pH/Eh POINTS.

Figures in circles indicate the number of points for each hatched area.

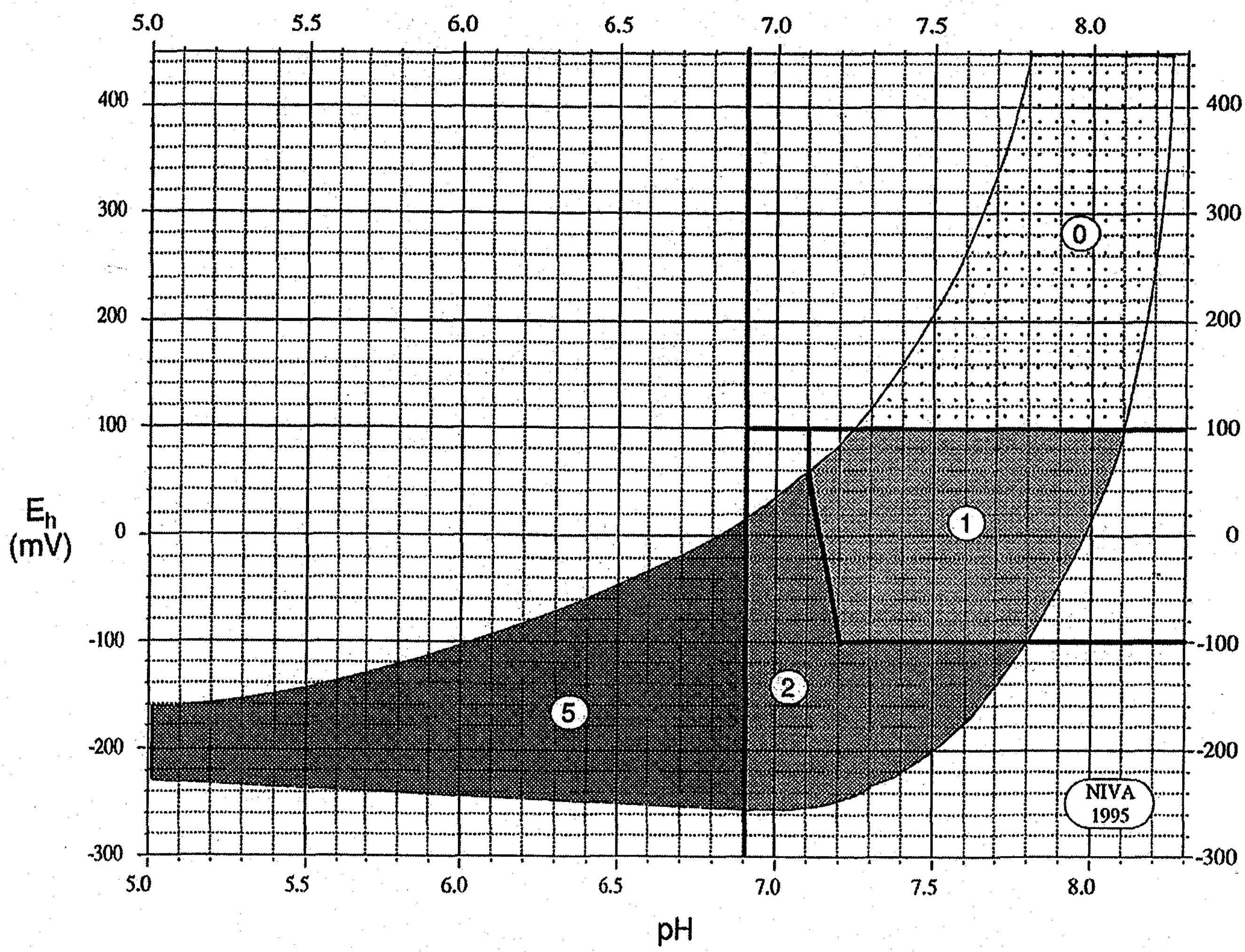

DIAGRAM 1

Diagram for evaluation of sediment condition on basis of measurements of Group 2 parameters (pH og Eh)

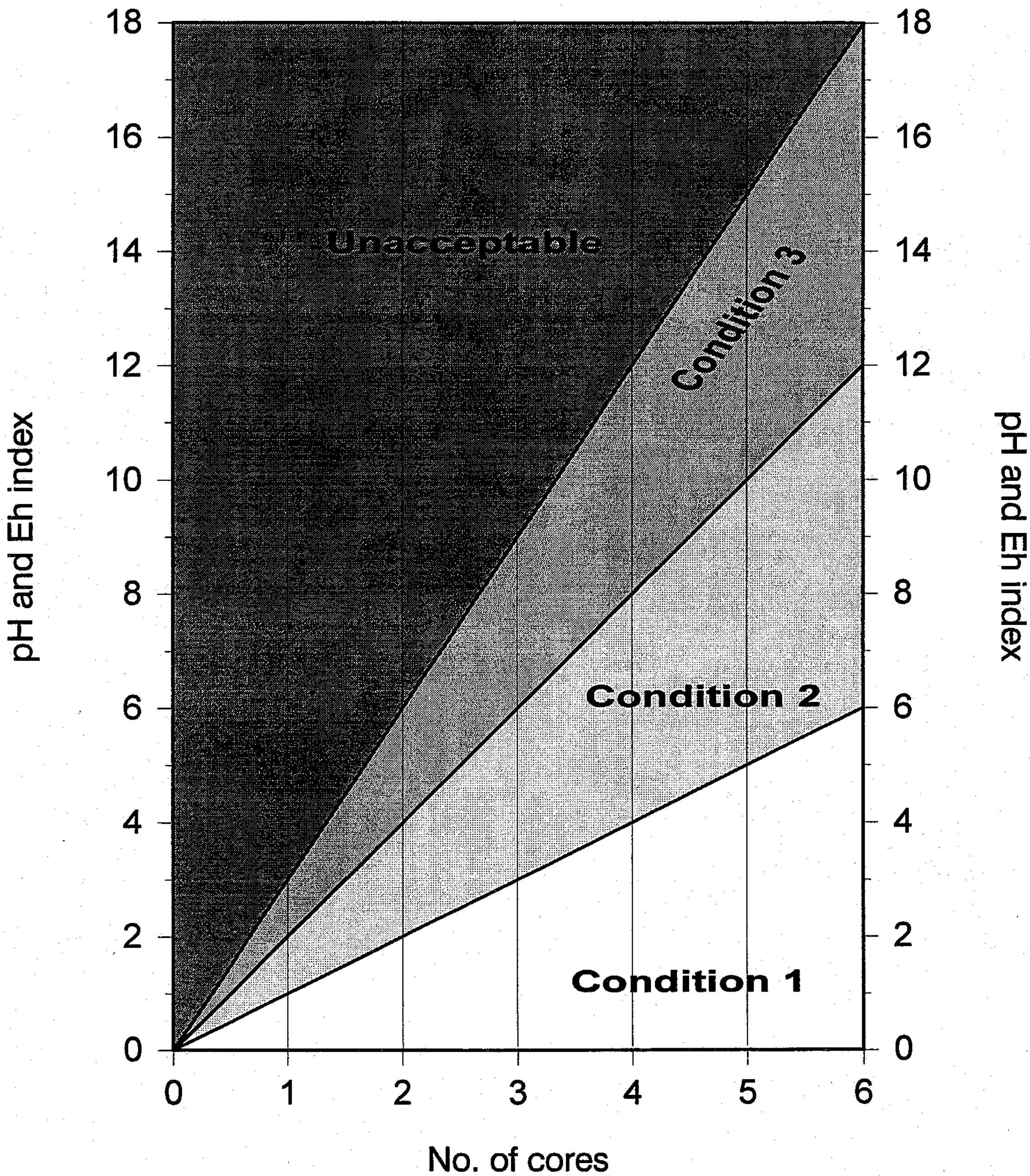

DIAGRAM 2

Diagram for evaluation of sediment condition on basis of Group 3 parameters (gas, smell, odour, consistency, thickness of sludge/grab samle volume)