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Strengthening and supporting further development of aquaculture in the Kingdom of Saudi Arabia
PROJECT UTF/SAU/048/SAU

Guidelines
on Environmental Monitoring
for Cage Aquaculture
within the Kingdom of Saudi Arabia

Cover photograph:

Aerial view of the floating cage farm of Tharawat Sea Company, Medina Province, Kingdom of Saudi Arabia.

(courtesy Nikos Keferakis)

Guidelines on environmental monitoring for cage aquaculture within the Kingdom of Saudi Arabia

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the Ministry of Environment, Water and Agriculture in the Kingdom of Saudi Arabia
and the Food and Agriculture Organization of the United Nations**

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Preparation of this document

These guidelines are a practical document on the implementation of monitoring surveys for marine cage culture operations within the Kingdom of Saudi Arabia prepared by the consultant Richard Anthony Corner (Environmental Expert) who was commissioned by FAO in the framework of the Project UTF/SAU/048/SAU *"Strengthening and supporting further development of aquaculture in the Kingdom of Saudi Arabia".*

The consultant's terms of reference (TORs) for this was to draft guidelines in the development of a practical Environmental Management Practice or EMP, related specifically to monitoring programmes that will be required after a cage fish farm has been approved through the Licence and Application Procedure and the applicant granted an Operational Licence. It should be noted, however, that the methods developed here are suitable for conducting baseline surveys and necessary data collection for the application process itself, and parts of this document are thus more generally applicable to the Licence and Application Procedure requirements too, including Environmental Assessment. Where specific approaches are not suitable, this is pointed out in the document.

The TORs required that due consideration be given to the timing of surveys, parameters to be collected, collection of data, processing of data, analysis of data collected and what to do with the data. This document has been prepared on this basis, based on sound scientific principles and international approaches to monitoring cage aquaculture facilities.

There is, however, currently insufficient information available on the current speeds and likely deposition of waste particulate material on to the seabed within the Red Sea to be able to determine the most appropriate locations at which monitoring should take place, especially for benthic surveys. Thus, a standardised approach has been proposed here based on the size of the farm, and is subject to change in due course, as further information becomes available and more specific monitoring for each site can be determined.

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Richard Anthony Corner

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1. General Introduction

Aquaculture currently supplies approximately 50 percent of the world's global fish market and within this overall sector, marine aquaculture and the growing of fish in cages at sea is a growing industry. Aquaculture will continue to grow with an anticipated global increase in production of 30 million tonnes required by 2050 to provide fish products and protein to a growing global population. FAO indicates that marine aquaculture will be the major sub-sector of this industry to expand in to the future. The marine environment offers an available resource and provides space for expansion, even recognising competing needs and the potential for environmental impacts.

The Kingdom of Saudi Arabia (KSA) has two coastlines, in the west the Red Sea and in the East the Arabian Sea. The KSA is expected to expand mariculture primarily in the Red Sea and it is on this premise that these guidelines have been developed. Much of the detail, however, is generally applicable and may equally apply to both KSA coasts.

The expansion and long-term sustainability of aquaculture in the Red Sea will depend on the development and adoption of best management practices throughout the whole cycle of production; from site selection, to construction and operation, to fish husbandry and culture practices through to audit and monitoring of activities and impacts. Separate documents are available on Site Selection and on the Application and Licensing Procedure. This document provides guidance on monitoring requirements.

Monitoring involves designing an appropriate survey, then collecting, analyzing and reporting the data, and establishing a link to improve impact management, to help achieve a better understanding of cause and effect relationships between the cage farm and water and sediment quality; and to improve EIA impact prediction and mitigation methods.

Monitoring is used to evaluate changes to the ecosystem and in this context monitoring can be used to evaluate the changes against a measured pre-development state. An example is the assessment of the sediment characteristic before an aquaculture facility is located and again after it has been in operation for some pre-determined time. Monitoring of aquaculture is also used to assess state against some pre-determined minimum quality standards that are regarded as needing to be maintained. Monitoring is used to:

- Establish baseline conditions (as a critical reference point for future assessment);
- Measure the impacts that occur during project construction and operation;
- Check compliance with agreed conditions and standards;
- In the wider context of Environmental Impact Assessment (EIA) to verify the accuracy of impact predictions and determine the effectiveness of mitigation measures.

In this context it is important that each site authorised for the production of fish in cages undertakes a monitoring programme and that this requirement is placed into the Licence issued to the fish farmer.

Some elements listed within this document are only really required once (e.g. Hydrography), but the majority of the monitoring activity will be assessed and reported annually. Further requirements may be needed in the event that multiple farms are present within the same area, in order to monitor cumulative effects, although methods to do this are not listed in the document.

Attempts have been made to ensure that these guidelines comply with the regulations in force within KSA. The aquaculture regulations issued through the Department of Aquaculture at the Ministry of Agriculture (ADMA) and environmental and other Environmental laws and Regulation issued through and administered by the Presidency Meteorology and Environment (PME) should take precedence when any errors or inconsistencies are identified.

In general this is a guide to help support good monitoring practice, with details on what to monitor, parameters to be collected, how data is collected, appropriate ways to process the data and what to do with it once the survey is complete and results available. Such monitoring activity will ensure that cage farms use practices that minimize environmental impacts for the long term sustainability of cage aquaculture within the Kingdom of Saudi Arabia. In this sense the document is for fish farmers and their consultants to ensure a unified process of monitoring using standardised procedures, but is more generally applicable for all stakeholders.

2. Document structure

This document is structured to provide guidance on how to conduct site surveys for the monitoring of specific parameters such as hydrography, sediment impacts and water quality impacts.

The first part of the document outlines some of the possible impacts from cage culture for which monitoring is necessary in order to be certain that farm activities are not having an undue effect on the environment.

Thereafter a detailed monitoring strategy is proposed giving timings of monitoring work covering the range of requirements, followed by methodology for the individual monitoring procedures, the latter including outline methods on data collection, data processing, report writing and delivery of the reports to ADMA for evaluation.

The appendices contain suggested formats for reporting of data. Other specific resources mentioned in the document, such as Excel spreadsheets for the analysis of hydrographic data and particle size analysis are available separately.

Cross-referencing is used in this document and clicking (Ctrl + click) on underlined words will take you to the relevant section. All figures and tables are also cross-referenced, but not underlined.

3. Impacts from Cage Aquaculture for which monitoring can be carried out.

Introduction

The potential for cage aquaculture to impact the environment is significant, but can be mitigated against by undertaking a number of good practices. A non-exhaustive list would include:

- Selecting sites with good water depth and having sufficient currents to allow good flushing of dissolved and particulate wastes;
- Selecting sites for which an Environmental Assessment has been made to ensure the local environment has the capacity to assimilate wastes;
- Selecting species that are appropriate to the local environment;
- Using high quality materials in the development of cage infrastructure;
- Using high quality feeds and efficient feeding practices that produce a healthy stock of fish, with good feed conversion ratios and low feed waste;
- Implementing good management and culture practices using standardized operating procedures that all staff are able to follow;
- Having well trained and competent staff.

These are interrelated activities and working well in only one or a few areas will not minimise impacts from cage culture. Management of impacts and minimising the level of impact is therefore a whole business operation rather than one of managing individual components.

There are, however, a number of outputs from cage farms that are known to occur, and as a consequence it is inevitable that a certain level of impact will occur at all cage sites. Implementing the non-exhaustive list above will go some way to reducing impacts but there are nonetheless specific outputs from cage operations, such as waste feed and faeces, the impacts from which will need to be monitored on a regular basis. Monitoring involves designing an appropriate on-site survey to collect samples for analysis, analyzing the samples and reporting the results, and establishing a link to improve impact management.

This chapter will describe the potential impacts of certain farm operations on the environment. It particularly focuses on the source and effects of solid nutrients, dissolved nutrients and anti-fouling materials released into the environment, and on their potential impacts on water and sediment quality.

Other impacts from cage culture can include the input of other chemicals such as cleaning products, diesel and petrol from boat engines and generators used at the site. Impacts from minor spills is not detrimental to the environment and no further analysis or monitoring is proposed. However, major spills must be recorded with the date, time and location of the spill and the quantities involved, so that if it occurs then further action can be undertaken to monitor effects.

At present there is no requirement to use chemical treatments, against disease for example, and no information on the analysis of such chemicals is included in this document. However, as the aquaculture sector grows and such chemicals are used then further monitoring requirements will be introduced.

Solid Organic Wastes

Fish produced in cages are all fed species and require the addition of a suitable feed to sustain growth, health and quality. When feed is added to open cages it is unlikely that all feed will be consumed by fish and some will be wasted directly. Feed that is consumed is processed through the digestive tract and waste discarded as faeces. Both feed and faeces are high in organic material that will add nutrients into the otherwise nutrient-poor environment of the Red Sea and Gulf coasts. Some of this solid waste may be consumed by wild fish or be dispersed in the water column on dissolution. However, the majority of solid organic wastes will deposit on to the sediment beneath cages where it will accumulate. Once settled it will be consumed by benthic fauna and/or slowly decomposed by sediment dwelling bacteria.

Readily soluble components of the solid organic waste will continue to be lost to the water column after settlement, particularly during microbial breakdown and macrofaunal processing. Perhaps the most important component of settling organic waste, however, is the high levels of organic carbon deposited that will provide a substrate for bacteria in the sediment. If waste accumulation is high, bacterial activity will increase accordingly, leading to increased oxygen consumption in the deeper parts of the water column. In severe cases this can lead to oxygen depletion in the water above the sediment and to very poor sediment conditions that may then have a direct impact on cage operations. In fine sediments, where pore-water flushing and oxygen exchange with the overlying water column is low, or where sediment loading is severe, oxygen consumption can exceed replenishment rate, leading to sediment anoxia. This can give rise to the emergence of sulphur-reducing bacteria, such as *Beggiotoa* sp., which live at the interface between anaerobic and aerobic sediment conditions. Even where the sediment porosity and sediment oxygen loading is high, such as in sandy sediments, the accumulation of finer particles of feed and faecal material can still lead to oxygen depletion and anoxic sediments.

The most efficient microbial breakdown of organic wastes occurs in well oxygenated sediments under aerobic conditions with breakdown processes leading to the production of carbon dioxide and water. Once all the available oxygen has been consumed, less efficient anaerobic decomposition activity occurs, producing compounds such as nitrate, sulphate and carbon dioxide. These compounds are reduced by bacterial respiration to ammonia, sulphide and methane. Since anaerobic decomposition is less efficient than aerobic activity, waste being added from above tends to be higher than breakdown processes and waste levels tend to build up, thus enhancing the problem. In addition, some of the by-products of anaerobic activity, notably methane and sulphide, are highly toxic to fish and may lead to health problems for stocks in the overlying cages, especially in shallow waters where there is only a small distance between the cage bottom and the seabed.

Marine sediments tend to have an aerobic surface layer, where oxygen exchanges readily with the overlying water column, above anaerobic sediment where oxygen is depleted. The depth of the aerobic surface layer influences the types of fauna that colonise the sediment. The depth of this layer can be measured using a redox probe inserted to various depths in a sediment core sample. Organic sediment enrichment changes the sediment characteristics and reduces the depth of the anaerobic layer by moving it towards the sediment surface. This process favours certain opportunistic species that are tolerant of low oxygen and high nutrient conditions. The effects of organic inputs from fish farms have been shown to have similar effects on sediments to other sources of nutrient enrichment, such as waste outfalls.

Sediment Loading

The quantity of particulates that deposit on the seabed is referred to as "sediment loading". The quantity and spatial extent of deposition is a complex issue, affected by:

- Fish physiology – The ability of fish to convert feed into biomass and the quantity of faeces generated by each fish species;
- Feed – The quantity of feed added, and an estimate of the amount that remains uneaten;
- Current speed – which distributes wastes horizontally in the water column;
- Settling velocity – The rate at which the particulates sink which is affected by particle size and density relative to seawater and by salinity and seawater density;
- Water depth – where deeper water increases the time required for settlement and allows a larger horizontal distribution of wastes. Shallower water means the seabed may be affected by wind and waves which can re-suspend settled materials that can be further transported based on the current speed; and
- Wild fish - and the extent to which waste materials are consumed before hitting the seabed

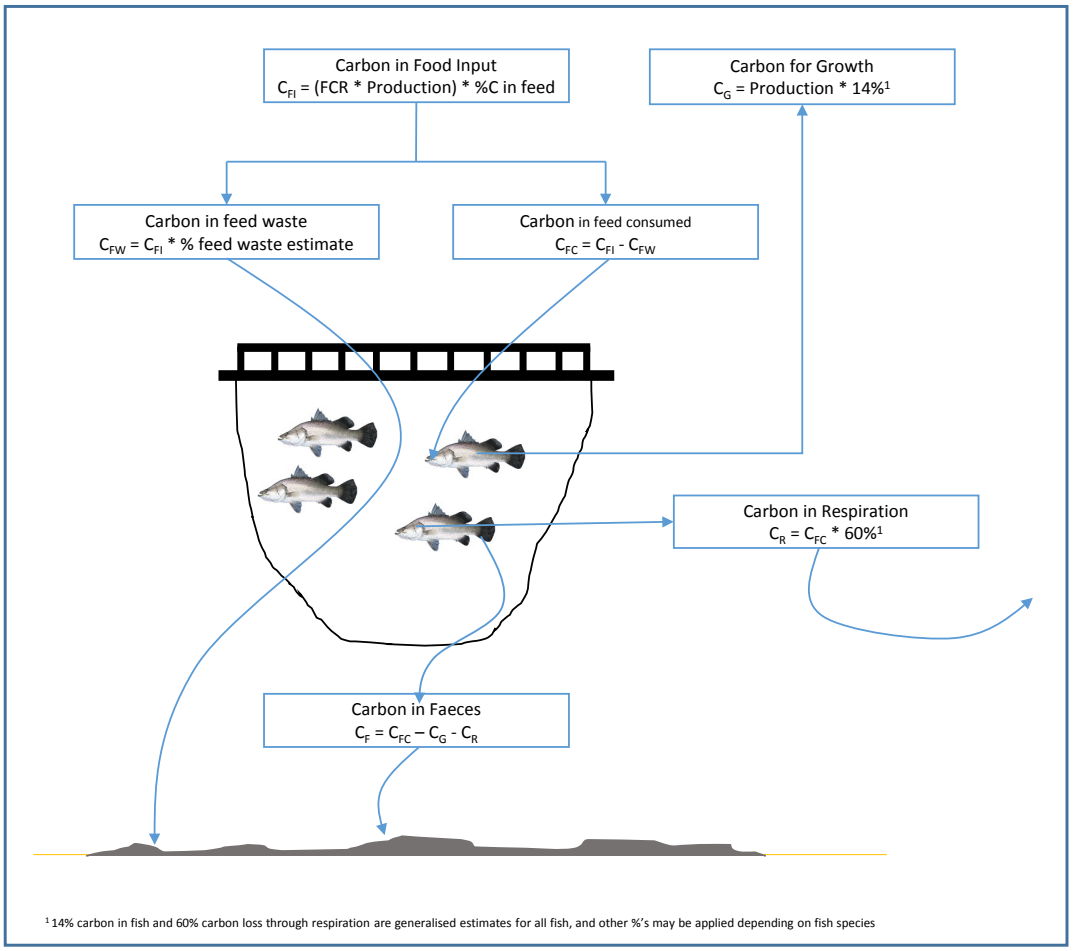

Figure 1: Example mass balance calculations for carbon for a cage aquaculture site.

The potential quantity of wastes can be estimated through a mass-balance approach, in which estimates of fish biomass and Feed Conversion Ratio (FCR) are used to estimate total feed input; whilst outputs in terms of waste feed, faeces, respiratory and excretory waste and output in fish growth are estimated (Figure 1); where all terms must balance. Calculations are generally made on nutrient components, such as carbon (e.g. Box 1), nitrogen and phosphorus.

:BOX 1: **EXAMPLE ESTIMATE OF CARBON WASTE FROM A CAGE FARM THROUGH MASS BALANCE CALCULATIONS**

Mass balance calculations account for input and outputs from a system and balancing the elements so that they match (no gains or losses), in this case based around carbon added to and lost from a fish farm, to explain where the carbon added goes and how much goes there. The principle is ex-
.plained in Figure 1 and with simplified values

Carbon in Feed input = (FCR x Production) × % carbon in feed

Carbon in Feed waste = Carbon in feed input × % Feed uneaten

Carbon in Feed consumed = Carbon in Feed input - Carbon in Feed Waste

Carbon in Growth = Production × % Carbon in Fish

Carbon respired and excreted = Carbon in feed consumed × % Carbon respired and excreted

Carbon in Faeces = Carbon in Feed Consumed – Carbon in Growth – Carbon respired and excreted

:Worked example

Production = 1000 t

FCR = 2

feed uneaten = 10% %

Carbon in Fish = 14% %

carbon in feed = 50% %

Carbon respires and excreted = 60% %

:Thus

Carbon in Feed input = (2 x 1000) x 50% = 1000 t

Carbon in Feed waste = 1000 t × 10% = <u>100 t</u>

Carbon in Feed consumed = 1000 t – 100 t = 900 t

Carbon in Growth = 1000 × 14% = 140 t

Carbon respired and excreted = 1000 t × 60% = 600 t

Carbon in Faeces = 900 t – 140 t – 600 t = <u>160 t</u>

In the above example the values used would need to be estimated or calculated for the specific fish species being grown, and are estimates only for a “general fish”. The two key values above are underlined and represent 260 t of carbon being added to the environment per 1000T of fish produced. These values are significant and will deposit on the seabed, increasing seabed nutrient concentrations. In addition some 600 t of carbon will enter the environment as dissolved waste, mostly in the form of carbon dioxide. Although large in value this is insignificant in terms of dissolved carbon and
.is never monitored

The loading area of sediment around a fish pen is an important factor in determining the impacts of waste accumulation, and is dependent on the quantity of waste released, water depth, current velocity and direction and the settling rate of waste particles. Where wastes are readily dispersed (i.e. through higher current speeds) and low levels of

loading occur over a wide area, or where inputs do not exceed the assimilative capacity of the sediment, adverse effects will be low. In some cases, low levels of extra nutrients can be favourable, providing additional food for sediment macrofauna, leading to increased abundance and diversity and higher rates of bioturbation. However, if high loading occurs in a small area then impacts are likely to be significant leading to very high abundance of very few species (i.e. low diversity), which is a negative impact.

Distribution of particulate wastes in the environment can be evaluated (Figure 2) to give an overall estimate of the spatial extent to which waste feed and faeces will settle on the seabed. The larger mass of faeces deposited (see Box 2) will travel further due to its slower sinking velocity (smaller mass and density) than feed pellets. Overall a generalized picture of the likely settlement pattern can be established (Figure 3) relatively simply.

However, it should be noted that water depth can be variable across a site; water does not move in one direction and changes at different states of the tide (or due to wind); current speed and direction can change with depth; and faecal waste in particular is variable in size and structure and has variable sinking rates.

More complicated assessment of waste dispersion, and accounting for a variable number of cages at any one site, must be carried out using computer-based models which are able to handle variability in time and space.

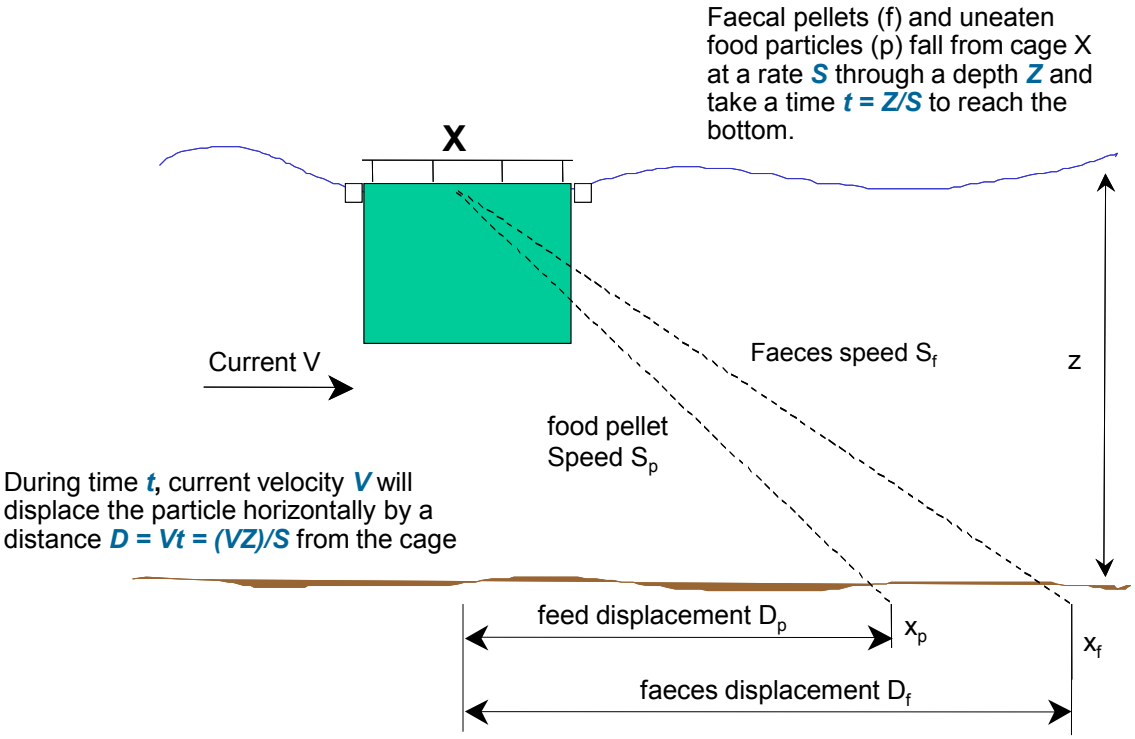

Figure 2: Dispersion of waste feed pellets and faecal pellets from a fish cage.

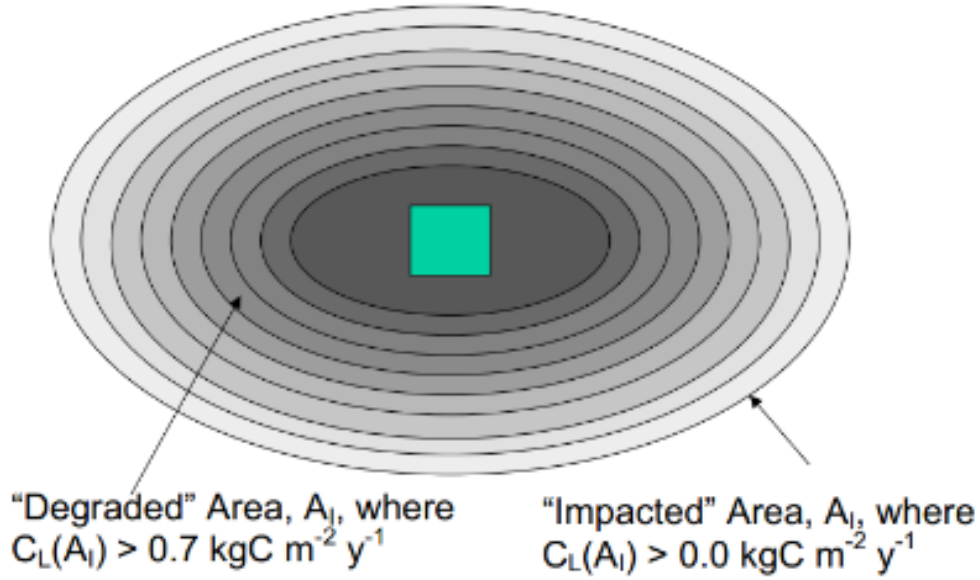

Figure 3: Schematic diagram[1] showing settlement of waste feed and faeces on the seabed under a fish farm (in green), resulting from variable particle settling velocities. Labels identify estimates of area of degradation based on deposition of 0.7 kgc/m^2/yr, with higher impact near to the cages and lesser impact further away. Values for the Kingdom of Saudi Arabia (KSA) would have to be tested and verified.

In monitoring terms, the extent of the distribution of solid organic waste is a specific issue for the KSA, because fish farms are liable to be located in relatively close proximity to coral reef systems. It will be important to ensure that corals are not covered by wastes being deposited from fish farms. Prior to a site being granted, and as part of the Environmental Assessment required under the Application and Licensing Procedure, it is important that current speed and direction are measured at the site and water depth recorded so that some estimate of the likely horizontal displacement of feed and faecal waste can be made. Once the distribution of wastes are estimated farmers can position cages so they are far enough away from the reef system. Box 2 gives an example to show how to estimate the maximal displacement distance.

BOX 2: ESTIMATING DISPERSION DISTANCE OF SEA BREAM FAECAL WASTE FROM A CAGE CULTURE OPERATION

Sinking velocity of sea bream faecal pellets[1] is thought to range between 0.05 and 3.94 cm.s^{-1} with an .average of 0.48 cm.s^{-1}

At a water depth of 30 m (Z in Figure 2) and the average settling velocity identified above (0.48 cm.s^{-1}; .S_f in Figure 2) particles could take as much as 100 minutes to reach the seabed

At an average current speed of (for example) 10 cm.s^{-1} (V in Figure 2) sea bream faecal matter could be .dispersed horizontally over a distance of approximately 600 m

In reality faecal particle size is variable, and smaller particles would deposit further away whilst heavier particles of faeces, and feed pellets, would settle within this distance. Current speeds and water depths around the site will also be variable in time (change of tide, winds) so an accurate picture can only be .established through more sophisticated modelling techniques

Distribution of waste is important for environmental sustainability because damage can be done to the seabed if deposition below the cages is high. Deposited particulate matter changes the sediment chemistry through increased

1 Source : Gillibrand et al 2002, available from http://www.scotland.gov.uk/Uploads/Documents/Report63.pdf
2 Magill et al 2006, available at http://www.sciencedirect.com/science/article/pii/S0044848605003893

bacterial oxygen demand to process the particulate matter, and in high deposition areas sulphide reduction and methanogenesis can occur leading to production of hydrogen sulphide and methane respectively, both of which are toxic to aquatic life. It must be stressed that this happens in extreme cases and if it does occur then it means the site is not really suitable for aquaculture. Good site selection and controlling waste through careful feeding, for example, reduces the likelihood of such extreme conditions occurring.

Deposition of nutrient rich material also changes benthic biology. Under standard conditions, species living in and on sediments live in equilibrium with the environment responding to competition for space and resources, sediment chemistry, to grain sizes present and so on. When excess nutrients are added to the system there is a tendency to reduce species diversity in high depositional areas, increase diversity in transitional areas where deposition is moderate to low, before returning to "normal" at some distance from the cages. The types of species and their response will vary with sediment type (mud, sand, rock). It is therefore important that some form of survey is carried to establish what the typical conditions are prior to the fish farm being operational, and to monitor the site for changes that occur during the years of operation.

Dissolved nutrients

The intensive cage culture of fish tends to produce a large amount of dissolved nutrient waste in the form of urine and respiratory products; and organic compounds are leached from faecal and feed pellets. These can be dispersed by water current flow reducing the impacts, but may have negative impacts during periods of quiescent water or where multiple farms exist within a limited space, leading to nutrient "hot-spots".

Dissolved nutrients consist of nitrogen-based products such as ammonia, nitrate and nitrite; and phosphorus. The impacts of dissolved nutrients depend on the ability of the surrounding ecosystem to assimilate these wastes and the ability of current flows to dilute and dissipate the nutrient products.

Where current flow is slow and water exchange is limited in comparison to the amount of waste loading, then hyper nutrification and oxygen depletion can occur. These impacts may affect not only the surrounding ecosystem but the farm operation itself. When water moves slowly through the cages then ammonia and its breakdown products (notably nitrite) can build up and as these are known to be toxic to fish in high concentrations it could affect the health of the caged stocks, for example.

It is recognised that release of nutrients into the water column, either directly from input of dissolved ammonia or urea or indirectly from decomposition of solid waste in sediments, may have an impact on the water column. One of the potential problems is enhanced growth of phytoplankton. Potential relationships between plankton production and aquaculture activity have sparked current research interest, but there is limited data on a direct linkage.

Various nutrients and light levels are required for phytoplankton growth, depending on the species. In marine systems, dissolved inorganic nitrogen (DIN) is usually the most important limiting nutrient, so when DIN is increased in concentrations through anthropogenic sources such as cage fish farming, this may lead to increases in phytoplankton productivity.

Large increases in phytoplankton abundance can lead to the formation of algal blooms that may be directly harmful to fish through the release of toxins or through gill irritation which reduces the ability of caged fish to uptake necessary oxygen. Indirect problems can also occur following a rapid increase in phytoplankton abundance. Standard nutrient levels may decrease or environmental conditions can become altered (e.g. pH). When the algal population dies this can lead to the production of large amounts of dead organic matter in the water column. This organic matter is broken down by microbial action that consumes oxygen that may cause severe oxygen depletion in the water column. Oxygen depletion in the waters surrounding cage sites can lead to increased stress levels in fish, making them more prone to infections and diseases. A lack of oxygen in the water column will also affect the exchange with sediment pore water that can increase the production of harmful substances, such as hydrogen sulphide in sediments.

An additional issue for the Red Sea is that increased dissolved nutrients in the water column may lead to increases in macroalgal growth that may settle on coral reef systems, or may increase the naturally occurring growth, that may alter the balance between corals and algae within localised reef systems.

Anti-fouling materials

In addition to organic materials there are a number of inorganic materials that can emanate from cage farms. The most obvious of these is from the use of anti-fouling paints on nets. In many contexts anti-foulants are needed to limit the amount of settlement that occurs on fixed structures, including cage farms.

The production of aquaculture anti-foulant products can encompass a variety of solvents and binders but in all cases the active ingredient is toxic Copper Oxide. Most products contain between 10 and 30% Copper Oxide within an emulsion that slowly leaches into the seawater with time and prevents the attachment of fouling organisms. Toxic activity is generally limited to a few centimetres and copper in the seawater is highly diluted and has been shown to have few direct environmental impacts. Copper chemistry in seawater is complex and copper exists in many chemical forms, many of which are non-toxic or not directly bio-available. There is a tendency, however, for copper to form complexes with organic material and to settle to the sediment, where it can accumulate. It is a waste that therefore needs to be assessed through monitoring to ensure that the build-up in sediments is not excessive.

4. Monitoring survey requirements – Summary

The following monitoring requirements will be needed, which should be conducted via a Qualified Expert, also defined in this section.

Hydrographic survey

The measurement of current speed and direction is not strictly speaking a monitoring activity but is nonetheless necessary to characterise the local water flow field. It is important to measure current as water current speed and direction have a direct influence on the distribution of wastes around fish cages. The tidal exchange within the Red Sea is very low and the main currents are wind driven so concurrent wind data are required. Other important information includes the local topography and accurate position fixing of the cages and current meters.

This requirement is needed during the site application phase as part of the Environmental Assessment process. Data recorded at that time will remain valid unless it is specifically requested to conduct another assessment. However, as winds vary within the Red Sea, there is a need to differentiate between coastal sites located to the North of Jeddah, which generally have persistent North-Westerly winds, and coastal areas south of Jeddah which are characterized by alternating wind patterns which see South-Easterly winds during winter and North-Westerly winds during summer.

As a consequence sites north of Jeddah are required to collect hydrographic data once during the year, whilst those south of Jeddah will collect data during two periods (summer and winter) to reflect the changing wind patterns.

Data will be presented in an Excel™ spreadsheet of raw data, within which analysis of the data can be made and graphical representation of the data presented. This spreadsheet will be accompanied by a written report which summarizes the data in graphical and table formats, to be submitted to the Competent Authority for evaluation.

Hydrography is included here as the approaches and methods for data collection and presentation are included in this document.

Sediment survey

The environmental effects of marine cage fish farming on the seabed are most prevalent in relatively close proximity to the cages. The impact on benthic habitats may be long lived at sites where water flow is very low (i.e. in quiescent waters) and conversely may be relatively short-lived at more dynamic sites. Consequently, much of the research activity into these impacts has concentrated on the immediate local environment. Monitoring strategies to assess the 'health' of the benthos surrounding proposed and existing fish farms have been designed to examine and then monitor this risk to the local environment.

Although there is considerable effort and research into the detailed biology and chemistry of changes within the sediment, various easily measured parameters may be used to determine the degree and extent of impacts and risk of impacts. These are based on well documented consequences of organic impacts from fish farms and other discharges. The most appropriate method for assessing the benthic impacts of marine cage farms is to examine a number of specific parameters, which describe the biological and physico-chemical status of the seabed.

A sediment survey is required annually, at approximately the same time each year, although it must coincide with peak biomass which is the period when the highest level of biomass is held at the site and the largest deposition of waste particulate material is occurring due to the heavier feed use. Typically this will be just prior to harvest.

Sediment surveys will consist of:

- A visual evaluation of sediment condition;
- Collection of sediment samples for the analysis of macrofaunal composition or a videography/photographic survey, depending on the scale of production.
- Measurement of sediment redox conditions;
- Measurement of sediment grain size;
- Measurement of sediment carbon and nitrogen content;
- Measurement of sediment copper concentration; where anti-fouling products are used on nets.

Results will be presented in an annual report that will be submitted to the Competent Authority for evaluation. The report must include a comparison against the conditions present when the baseline survey was conducted during the Licence Application and also a comparison against the previous year, both of which will give an overall indication of the level of impact against normal conditions and an evaluation of changes over time respectively.

The spread of waste particulate material can be evaluated through models, as outlined in Section 3, Impacts from Cage Aquaculture for which monitoring can be carried out. More detailed models are available which account for water depth and hydrographic conditions. Such models are new to Saudi Arabia and are not currently included in this guidance document.

Water Quality Survey

The Red Sea is an oligotrophic water system with a low level of primary productivity, so dissolved and solid nutrients being added by fish farms are liable to have more significant impacts within the Red Sea than in other systems.

Water quality needs to be measured daily for water temperature and dissolved oxygen concentration and records kept of the readings taken. It is in the interest of farmers to evaluate these two components on a daily basis, to monitor general water conditions and to ensure the correct feed quantity is used; and conversely to inform the farmer when conditions are unsuitable for feeding, such as during low oxygen periods.

In addition the following parameters are required to be measured monthly:

- Ammonia (as ammonium);
- Nitrate;
- Nitrite;
- Phosphorus;
- Chlorophyll-*a* concentration.

These data are to be combined into a single annual report on water quality status which will be submitted to the Competent Authority for evaluation. The report should include raw data and an analysis of each parameter, and be combined in the calculation of the Trophic Status Index (TRIX index), an index designed to give an overall assessment of the eutrophication condition of the local water column.

Qualified Expert

The Competent Authority requires that the biological and chemical surveys and tests outlined in this document must be carried out by a 'Qualified Expert' in order to ensure the highest possible quality of the outputs.

A "Qualified Expert" means a person or persons having the knowledge and training necessary to undertake monitoring surveys on behalf of the Licence Holder as set out in this document.

Evidence of such knowledge or training will be required by the Competent Authority. Evidence shall take the form of CVs, or similar statements of experience for all staff directly involved in surveys and analytical tests (and for other sub-contractors used for these purposes). The appropriate knowledge or training for "Qualified Experts" must be submitted to the Competent Authority prior to, or in tandem with, the first survey report submitted.

After an initial period the Competent Authority will approve and retain a list of suitably qualified persons and companies, which investors and fish farmers within the KSA are able to use for such services. In the meantime each aquaculture company must satisfy itself that the person or persons employed to complete the monitoring activity is competent and qualified to do so.

5. Survey Type and Timing

At present there is insufficient information available on the current speeds and likely deposition of waste particulate material on to the seabed within the Red Sea to be able to determine site-specific survey requirements and locations at which monitoring should take place. Thus, a standardised approach has been proposed here and is subject to change in due course, as further information becomes available and more specific monitoring for each site can be determined.

All marine cage aquaculture facilities will carry out a monitoring survey in accordance with the protocols set out below. The specific monitoring requirements depend on the level of biomass either proposed for or being produced at the site under Licence (Table 1). The exception is for hydrographic surveys which are required for all sites using a standardised procedure.

Table 1: Survey requirements matrix, depending on site production tonnage

Tonnage	Survey type	Timing of survey	What data are collected
All sites	Hydrographic survey	Once, as part of Application and Licensing procedure	• Current speed and direction • Water pressure • Wind speed and direction
250>	Videographic or photographic benthic monitoring survey	Annual on same date ± 1 month	• Video or photographs of seabed, • Redox measurements, • Samples for particle size analysis, • Samples CN analysis, • Samples for copper analysis (if anti-fouling used on nets
1000 - 250	Simple Benthic Monitoring Survey	Annual on same date ± 2 months[2]	• Sediment samples for faunal analysis, • Redox measurements, • Samples for particle size analysis, • Samples CN analysis, • Samples for copper analysis (if anti-fouling used on nets
1000<	Extended Benthic Monitoring Survey Increased number of) (sample stations	Annual on same date ± 2 months[2]	• Sediment samples for faunal analysis, • Redox measurements, • Samples for particle size analysis, • Samples CN analysis, • Samples for copper analysis (if anti-fouling used on nets
All sites	Baseline benthic survey	Once, as part of Application and Licensing procedure	• Sediment samples for faunal analysis, • Redox measurements, • Samples for particle size analysis, • Samples CN analysis, • Samples for copper analysis (if anti-fouling used on nets

All sites	Water Quality Survey	Data collected monthly[1], except Temperature and Dissolved Oxygen, collected daily for farm .management purposes	• Temperature • Dissolved Oxygen • Ammonia (as ammonium); • Nitrate; • Nitrite; • Phosphorus; • Chlorophyll-a concentration

[1] Collected at approximately the same date each month.

[2] Actual date depends on species being grown and the likely timing of peak biomass. For sea bream with growth cycle of approximately 12 – 14 months, sampling should take place 12 months after stocking, to coincide with peak biomass. For barramundi with a growth cycle of approximately 24 months sampling should take place at 12 months, and be repeated at peak biomass, at approximately 24 months. Flexibility has been added to timing to ensure that the sampling take place approximately annually, and at peak biomass.

6. Methodology – Field Data Collection

Hydrographic survey

Purpose

The purpose of the hydrographic survey is to measure the tidal current speed and direction at three depths over a minimum fifteen [15] day period, to provide information on physical characteristics of the water body over a spring-neap tidal cycle. Collection will also allow, if required, an estimate of dispersion of water borne particulates to be plotted.

Wind speed should also be measured at the same time to gauge effect of wind action on surface water movements. Wind meters should be deployed at the same time.

The deployment procedure will depend on the current meter type used. There are a number of types of current meter available (see below for a fuller description). The most commonly used is an Acoustic Doppler Current Profiler or ADCP, a single unit that allows simultaneous recording of current speed and direction at a number of depth intervals (called "bins") from the seabed to the surface. Other types are referred to as Discrete Measuring Devices and include acoustic current meters, electro-magnetic current meters (ECMs) and impeller-type current meters which record only at the depths at which the meter is deployed. Three Discrete Measuring Devices are therefore required at each deployment.

In all cases the current meter deployed must have a pressure gauge fitted, either attached to or built in to the unit. The pressure gauge will record changes in tidal height above the specific meters at each depth, and is thus a proxy for changes in water depth.

Discrete Current Meters

Discrete Current Meters include mechanical, electro-magnetic and acoustic devices (Figure 4). In all cases, current velocity is determined by relating measurement of current speed to the orientation of the device. The orientation is most often determined by an on-board electro-magnetic compass. All meters should have a pressure sensor built in or attached so that water pressure (as a proxy for changes in tidal height) can be assessed simultaneously.

Mechanical meters typically employ impellers that complete a calibrated number of revolutions during the specified sampling period, in response to water flow. They therefore return an average of the flow speed during the sampling period. The impeller usually has a minimum starting speed below which it will not turn and at speeds lower than this threshold, no current is recorded. To minimise the effect of short-term turbulent fluctuations in the flow, the sampling period should be more than 30 seconds, but less than 2 minutes to reduce biasing by sub-threshold speeds. Impellers can become tangled with floating algae.

Electro-magnetic meters determine current speed by measuring the voltage generated across pairs of orthogonally aligned electrodes when water moves through the magnetic field applied by the device. They are therefore not as susceptible to fouling and have a very low threshold speed, giving valid readings from near zero to their full scale. However, they are sensitive to the conductance of the water in which they are immersed. This is not normally a problem in seawater but can lead to difficulty in low salinity waters. Consequently, care should be taken in using these meters at sites in proximity to river discharges during and just after the rainy season. The data returned are instantaneous and therefore sub-sampling and averaging are required to describe the average flow-field rather than the detailed turbu-

lent fluctuations. The averaging is normally done internally by use of appropriate instrument settings.

Acoustic meters transmit sound pulses at a specific acoustic frequency. They then measure the Doppler shift in the return signal echoing from particles entrained in the water: this frequency shift depends on the speed of the entrained particles. Orthogonal current components are determined by resolving the signals from two or more transducers aligned with specific divergent beam angles. The recorded speed is an average of a large number of estimates of the entrained particles' velocity. The precision of these values reflects the number of estimates and the sampled volume of water; a useful target for configuring such instruments is that speed precision should approximate to 10% of the mean of the dataset.

Figure 4: Example discrete current meters. L to r: electromagnetic current meter (ECM), impeller-type meter, acoustic-type meter.

Procedure for Discrete Current Meters

a. At each deployment 3 Discrete Measuring Devices should be used to record currents at 3 depths.

b. Deployment of a current meter should record water pressure, and current speed and direction at depths of:

- 3m below the water surface,
- At the proposed net depth (e.g. 10m, 12m 15m etc. depending on the depth of net used), and
- 3m above the seabed.

c. Ideally the boat used for deployment should be fitted with a winch/lifting arm capability. Weights are applied to the meters to keep them in position, and when that weight is greater than 80kg then a landing craft winch system is definitely required for the deployment process. Below this weight, or when a landing craft is not available the meters may be deployed by hand from a smaller craft.

d. Current meters should be deployed at the centre of the proposed cage block. Position fixing is carried out using GPS Latitude/Longitude coordinates. GPS position should be recorded (Figure 5). Water depth should be measured and recorded to ensure the correct length of rope is used. Water depth is found using a hand held echo-sounder (e.g. Figure 5). Date and time of deployment (and subsequent recovery) should also be recorded. A deployment record form is shown in Figure 7, to record necessary data.

e. For Discrete Measuring Devices the rope and meters are each suspended from a float buoy (Figure 6), with adequate buoyancy to support the meters in a vertical position, placed 2-3m above each current meter. On the surface a marker buoy is used to identify deployment position. The mooring is anchored to the sea-bed using concrete (or other appropriate) weights in the range 50 – 100kg depending on issues such as perceived current speed, topography and sediment slope. Weight needs to be sufficient to ensure the meters remain fixed in the same position regardless of the weather and current speed. From the weight at the bottom of the current meter a length of chain is attached to a small anchor, and then via approximately 50 m of rope to another weight, riser line and surface marker buoy. Use different coloured surface marker buoys so you know which line contains the meters and which one is the riser, in case of poor water visibility for example.

g. After a minimum 15 days deployment the meters are removed from the water using a suitable boat (see point c above). To recover the meters, using the configuration shown in Figure 6 for example, pull up the rope from the riser buoy end. The concrete (or similar) weight is then brought to the surface first, to minimise the weight and stress on the meters. Record the date and time of recovery.

h. Meters should be returned to the laboratory. In the laboratory data are down loaded into a suitable computer via the port (e.g. serial port, USB, other) connector. The format of the data available is generally Date and Time; Current speed ($m.s^{-1}$) and direction (^{o} mag N). These are downloaded to an Excel™ spreadsheet for analysis.

i. For specific instructions on how to use each current meter type, please refer to the Manufacturer's instructions.

j. Recording periods for monitoring purposes must be averaging of current speed and direction for 1 minute, every 20 minutes throughout a 15 day cycle, so that the minimum number of recordings is 1080 data points.

Figure 5: Hand held GPS (left) and depth gauge echosounder (right). For illustrative purposes only, other types available

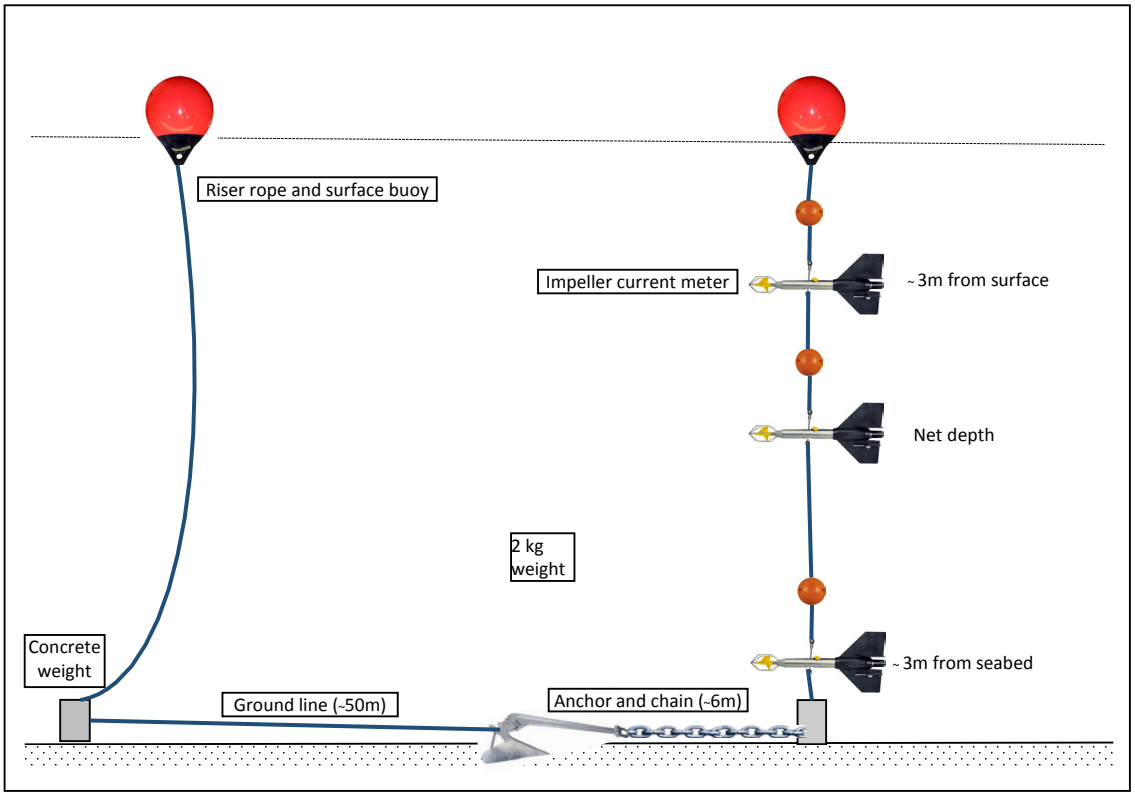

Figure 6: Example mooring system for discrete measuring device-type hydrographic measurement (impeller type current meter shown). All meters on single line at required water depths, and secured with a weight, ground line and riser line and buoy, also secured via a weight. Each meter has float buoy to retain whole line in a vertical orientation.

HYDROGRAPHIC EQUIPMENT DEPLOYMENT RECORD SHEET

Current meter No. _____

Deployment site _____

Deployment position _____ Deployment depth _____

Deployment time _____ Time/height of LW _____

Date deployed _____ Signature _____

Date checked _____ Signature _____

Date retrieved _____ Signature _____

Current meter No. _____

Deployment site _____

Deployment position _____ Deployment depth _____

Deployment time _____ Time/height of LW _____

Date deployed _____ Signature _____

Date checked _____ Signature _____

Date retrieved _____ Signature _____

Current meter No. _____

Deployment site _____

Deployment position _____ Deployment depth _____

Deployment time _____ Time/height of LW _____

Date deployed _____ Signature _____

Date checked _____ Signature _____

Date retrieved _____ Signature _____

Weather Station No. _____

Deployment site _____ Deployment depth _____

Deployment position _____

Date deployed _____ Signature _____

Date checked _____ Signature _____

Date retrieved _____ Signature _____

Figure 7: Hydrographic equipment deployment record sheet.

Procedure for Profiler-type meters

a. At each deployment 1 Profiler Measuring Device should be used to record current speed and direction at multiple depths (called “bins”). A pressure gauge should record pressure readings at the deployment depth, as a proxy for water depth.

b. Deployment of a current meter should record current speed and direction at pre-defined water depths that must include:

- 3m below the water surface,
- At the proposed net depth (e.g. 10m, 12m 15m etc. depending on the depth of net used), and
- 3m above the seabed.

c. Ideally the boat used for deployment should be of the form of a landing craft with winch/lifting arm capability. Depending on type used, the profiler (e.g. ADCP) can be deployed within a steel frame, or otherwise anchored on the seabed according to the manufacturer's instructions, which is dropped to the seabed and marked on the surface with a marker buoy (Figure 8). Note that when the overall weight is greater than 80kg then a landing craft winch system is definitely required for the deployment process. Below this weight, or when a landing craft is not available the meters may be deployed by hand from a smaller craft.

d. Current meters should be deployed at the centre of the proposed cage block. Position fixing is carried out using GPS Latitude/Longitude coordinates. GPS position should be recorded. Water depth should be measured and recorded to ensure the correct length of rope is used. Water depth is found using a hand held echosounder. Date and time of deployment (and recovery) should also be recorded. A deployment record form is shown in Figure 9, to record necessary data.

e. After a minimum 15 days deployment the meters are removed from the water using a suitable boat (see point c above). Record the date and time of recovery.

f. Meters should be returned to the laboratory. In the laboratory data is down loaded into a suitable computer via the port connector (e.g. serial port, USB, other). The format of the data available is generally Date and Time; and Current speed ($m.s^{-1}$) and direction (^{o} mag N). These are downloaded to an Excel™ spreadsheet for analysis (see

g. For specific instructions on how to use and deploy each current meter type, please refer to the Manufacturer's instructions.

h. Recording periods for monitoring purposes must be averaging of current speed and direction for 1 minute, every 20 minutes throughout a 15 day cycle, so that the minimum number of recordings is 1080 data points.

It should be noted that many ADCP-type profiler current meters have integrated software that allows the assessment of wave height. Such information is useful to determine the likely physical impacts from waves into cage infrastructure and along with hydrographic data should be used to evaluate cage design, mooring breaking strengths and anchor requirements. If this facility is available then wave height data should also be recorded.

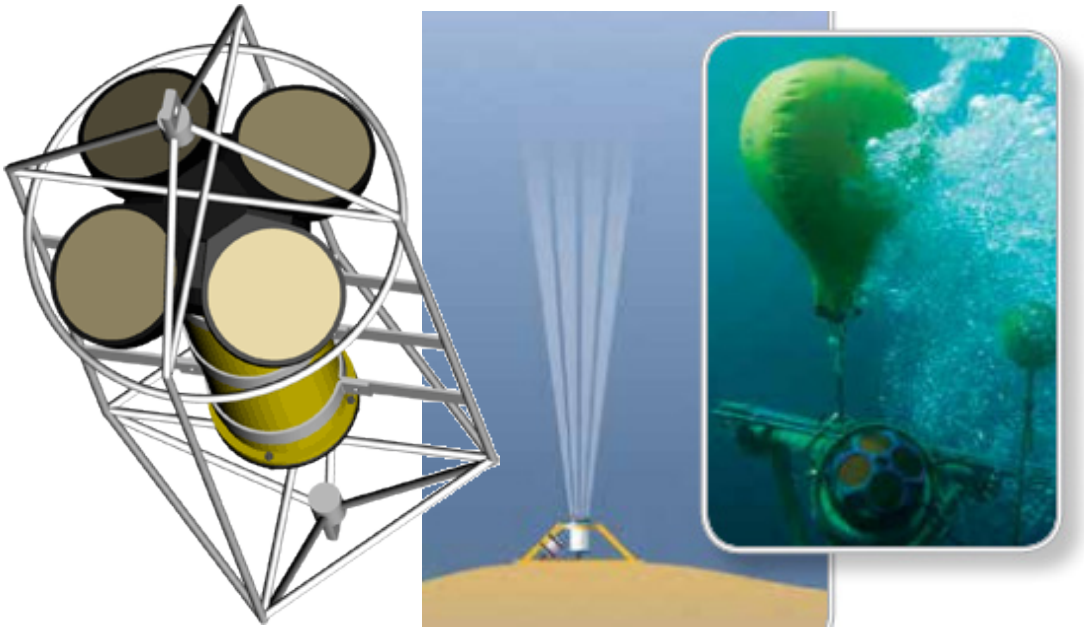

Figure 8: Illustration of ADCP current profiler deployment in frame. Frame can be on seabed or floating above seabed, and recovered manually or through an auto-release system brought to the surface with inflated buoys at the end of deployment.

ADCP HYDROGRAPHIC EQUIPMENT DEPLOYMENT RECORD SHEET

Current meter No. _____

Deployment site _____

Deployment position _____ Deployment depth _____

Deployment time _____ Time/height of LW _____

Date deployed _____ Signature _____

Date checked _____ Signature _____

Date retrieved _____ Signature _____

Weather Station No. _____

Deployment site _____ Deployment depth _____

Deployment position _____

Date deployed _____ Signature _____

Date checked _____ Signature _____

Date retrieved _____ Signature _____

Figure 9: ADCP deployment record sheet.

Wind data

Wind speed and direction are measured using a suitable weather station, which is attached to a fixed location on or as near to the cage facility as possible. Measurements are taken from 2 m above the water surface on three occasions during daylight hours each day of current meter deployment, or averaged over 1 minute every 1 hour if using an automated system (e.g. Figure 10).

Alternatively wind speed data might be obtained by a local existing weather station, such as the local weather authority.

Figure 10: Example recording wind meter, for illustrative purposes only.

Hydrographic and wind data require further processing back in the laboratory. Please refer to Hydrographic data – data processing.

Videographic or photographic benthic monitoring survey

Scope

To conduct a videographic or photographic survey cage aquaculture sites must have a low maximum biomass. This survey type is therefore designed for sites that have less than 250 t of production, such as those associated with small production units, broodstock facilities and research facilities.

As the videographic /photographic surveys are carried out by divers, they may only be conducted if the small site is located in water depths of less than 30 m for diver health and safety reasons. If the site is located in water depths of over 30 m then a Simple Benthic Survey must be completed.

However, if over 30 m depth, a videographic survey could be conducted via underwater Remotely Operated Vehicle (ROV). The company must discuss this with the Competent Authority on a case by case basis.

Video or photographic evidence provides a rough estimate of sediment condition, provides a visual record of the conditions at the time of sampling, including for example any evidence of accumulated fish feed and faeces. It also enables a basic descriptive assessment of sediment types and a basic assessment of observable species presence, rather than a comprehensive assessment of faunal species composition and abundance.

In addition to the video / photo survey, it is important to also measure the physio-chemical nature of the sediments. Sample are collected by a diver using cores and suitable containers to recover sediment that can be brought back to the surface for assessment.

Videographic or photographic surveys are carried out at the same time each year on the anniversary of first stocking ± 1 month.

Procedure for videographic / photographic benthic survey

a. Videographic or photographic surveys are only suitable when the water depth is 30 m or less and a minimum of two [2] divers are used to record the evidence using a suitable underwater video recorder or camera.

b. First the divers must deploy a weighted line on the seabed that has a suitable weight (approx. 10kg) on either end. One end is located on the seabed at the cage edge and the other pulled out along the transect required so that the rope is taught and in a straight line. The line should be marked at 5m intervals with a plastic sign that indicates the distance from the cage edge. Figure 11 shows the layout of the survey, with two transects required, one in-line with the main current direction (Figure 11, Transect A) and one in the cross current direction (Figure 11, Transect B) with the marked distances.

c. When using an underwater video camera the divers follow slowly along the seabed transect, floating approximately 1m above the seabed, recording the sediments. At each “sampling station” (i.e. cage edge, 25 m, 50 m, 75 m and 100 m depending on the transect – see Figure 11) the diver pans around the local environment capturing relevant images indicating species present and other relevant information. The diver must ensure that the station label is clearly visible on arrival at the distance, so that when footage is analysed in the laboratory the distance is known. Repeat for transect B. The diver should record anything of specific interest, such as species present, reefs present and so on.

d. Recorded video should be in digital format and savable as a DVD.

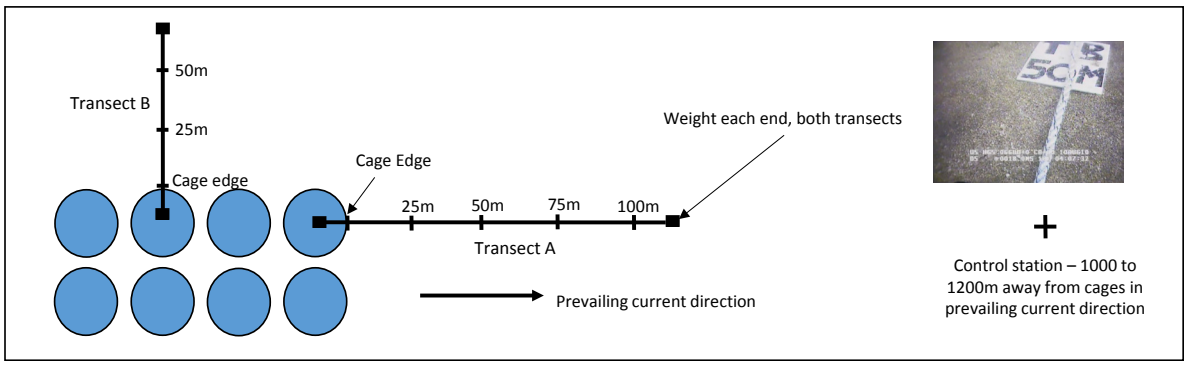

Figure 11: Layout for videographic or photographic benthic survey. Two transect lines (A and B), each line marked with a suitable label (inset) to identify distance from cage edge. Distances shown represent marker points.

e. When making the assessment using a camera (photographic stills), the diver must take a minimum of 5 representative photographs at each station. Photographs should be taken from approximately 1m above the sediment surface and a scale rule placed on the sediment surface for scale reference, which should be captured within the photograph. 1 of the 5 photographs must contain the station number label.

f. Photographs should be in digital format and savable to CD.

Procedure for Physio-chemical parameters as part of videographic/photographic benthic survey

a. After the videographic or photographic survey is completed the diver must return to each station to collect sediment samples for the analysis of physio-chemical parameters.

b. At each station one sediment corer is used to remove sediment samples for additional photographic requirements on the surface and used for particle size analysis. Corers are pushed into the sediment with as little disturbance of the sediment as possible (Figure 12) to a minimum depth of 20 cm (or as deep as possible if less than this). The diver then digs down on the outside of the corer and inserts a rubber stopper into the bottom end of the corer. The corer top is also closed with a rubber stopper (Figure 12, inset), before being pulled out and recovered. Cores should be placed into a suitable wire mesh basket, to support cores in an upright position whilst they are returned to the surface. At the sediment surface photographs are taken of each core, next to a rule for scale (Figure 12, inset).

c. The corer can be a simple Perspex tube of approximately 4 – 5 cm diameter and length of approximately 30cm, with a rubber stopper at either end. All cores should be marked with the transect and station number (e.g. TACE = Transect A cage edge, TB25m = Transect B at 25 m distance) prior to being placed in the water.

d. On the surface, photographs are taken of the cores against an appropriate scale rule. Photographs should present the entire length of the core (see Figure 12, inset). Additional photographs of individual cores can be taken to show a close-up of specific interest and can be included within the report.

e. Using the core samples, redox potential (Eh) is measured directly in the core, using a suitable calibrated com-

bination (redox and temperature) probe and meter. The probe is inserted through the top of the core after removal of the stopper. Eh Readings and temperature are taken and recorded;

- In the water just above the sediment,
- At the sediment surface and
- Then at 1 cm depth intervals to a depth of 7 cm (where possible).

Prior to each measurement the probe is calibrated using a standard solution of Zobells (see safety note below). The meter reading will fluctuate, but should be allowed to stabilise for 15 seconds before the reading is taken. Both the Zobells reading and the sample reading are recorded. The redox probe should be washed in seawater between each new sample.

f. Also at each station, the diver should use a 50 ml Sterilin (or 100/150 ml) universal container (or similar appropriate container) with lid, into which sediment from the top 2 cm can be scooped. New sterile containers are used for each sample. Samples are labelled with transect and station number (see below) and are frozen as soon as possible after collection (usually within 3 hours). Transportation to the laboratory for analysis is in a cold box. No formalin is added to samples.

g. Repeat f. above with 2 further samples, one collected for carbon and nitrogen analysis and one for copper concentration, if anti-fouling is used on nets.

Figure 12: Videographic survey still, showing deployment of corer into the sediment. Corer is a plastic tube of known diameter (approx 4-5cm) pushed into the sediment by hand. Retrieved cores (inset). Courtesy and copyright of marine harvest Ireland.

Simple Benthic Monitoring Survey

Scope

The Simple Benthic survey is required for monitoring at cage aquaculture sites that have a licence to produce between 250 t and 1000 t of fish production, considered small to medium production units.

The purpose of the Simple Benthic survey is to conduct a robust monitoring of impacts at the sites. Quantitative samples are collected and preserved for further analysis. Macrofauna that live on or in the seabed sediment are collected from various stations in order to gauge change in community structure due to cage fish farm impacts. Samples are also collected for the analysis of physico-chemical factors, including redox potential, nutrient concentration (carbon and nitrogen) and particle size to evaluate change in chemical and nutritional state; and copper concentration, if anti-fouling products are used at the site.

Simple benthic surveys are carried out annually on the same date ± 2 months, starting on the first anniversary after first stocking. The survey should, as near as possible coincide with peak biomass at the site, although the timing of this will vary depending on the species being grown. For this reason there is extended flexibility (i.e. ±2 months) in timing of the surveys.

Procedure – Faunal samples – Annual Monitoring

a. Sea-bed sediment samples are collected using a van Veen grab sampler, which are available in various sizes (typically 0.025, 0.045 or 0.1 m^2 - Figure 13). The size of each sample is dependent on the "bite" of the grab and is measured in m^2. The size of grab used influences the number of replicates required at each station as follows:

- 0.025 m^2 5 replicates per station;
- 0.045 m^2 3 replicates per station;
- 0.1 m^2 2 replicates per station.

b. Under the "Simple" benthic survey, samples are taken from a standard set of 5 stations of known position in relation to fish cages along two transect A and B, as defined in Figure 14. The positions are;

- Transect A - Cage edge,
- Transect A – 50 m in the main current direction,
- Transect A – 100 m in the main current direction,
- Transect B – 50 m from the cages in the cross-current direction, plus
- A control station located 1000 – 1200 m from the cages in the main current direction. The control station must be in a similar water depth and have similar hydrodynamic condition to the cage site.

Samples are taken from a suitable boat which is fixed into position by:

- Anchor (to the seabed), or
- Mooring (to the cages or fixed mooring), or
- By tying a rope of defined length or marked at defined lengths (i.e. at 50 m, 100 m and 200 m) to the fish cage and the boat and backing off until the rope is taught, or
- Kept on station using powered means (i.e. outboard/inboard motors).

c. On arrival at each station record water depth (in meters) using a handheld acoustic depth meter (e.g. echo-sounder device), and positional information (longitude and latitude; and number of satellites) using a hand-held GPS device (Figure 5).

d. The grab is set at open using a gravity trigger and this will remain open as long as there is tension on the attached rope. For most sediments the weight of the grab is sufficient to allow penetration into the sediment. For coarse or compacted sediments additional weight may be added to increase penetration depth.

The grab is then lowered slowly to the seabed by hand (generally if less than 40 m deep and only when smaller sized grabs are used) or via a suitable winch (deeper water and/or larger sized grabs) on a rope. On reaching the sediment surface the grab penetrates the sediment and tension is released which allows the gravity trigger to fall. The grab is slowly retrieved from the sea-bed and this lifting action facilitates the jaws to shut thus collecting a sample of sediment. The grab is slowly brought to the surface by hand or winch.

e. Grabs for macrobenthic fauna analysis must be at least “half full” to ensure adequate sample size. Use the top-opening to check the quantity of sediment collected. Grabs less than half full should be rejected and a new sample taken.

If an adequate amount is collected, the sediment is transferred to a strong polythene bag or suitable plastic container with sealable lid (when using a 0.025 m^2 grab size) by opening the jaws of the grab within the mouth of the bag/container. Care is taken to ensure there is no loss of sediment. If sediment is lost the sample is rejected. When using the smaller sized grab it is feasible to take the entire sample back to the laboratory. For larger sized grab samples, these will need to be sieved on site.

For larger sized grab samples, the contents are transferred to a sieving table, examples of which are shown in Figure 15. The sample is washed using seawater pumped into the sieving table and through a 1mm sieve. The sample is washed through until most or all of the unwanted sediment is removed. Remaining sample is transferred to a bag or a suitable sealable container, as described above.

Where the sample is too large for the sieving table then the sample may be placed into a fish box or similar (without any holes so retaining water), before being placed through the sieve in batches. Ensure the whole sample is washed from the box.

Ensure the grab and the sieve (if sieving table is used) are cleaned thoroughly before each use.

f. The sample is preserved by addition of 10% formalin (37% buffered formaldyhyde) in seawater to achieve a 3-4% formo-saline solution (ratio 3:1 seawater) in enough quantity to cover the sediment. The bag/container is gently agitated to ensure even distribution of preservative. If a bag is used the bag is then placed in another polythene bag and sealed by tying a separate knot or sealable lid added to the container.

FIGURE 13: VAN VEEN GRAB SAMPLER, FOR SEDIMENT COLLECTION IN DEPLOYMENT MODE (A) AND IN CLOSE-UP TO SHOW TOP OPENINGS FOR PHYSIO-CHEMICAL SAMPLE COLLECTION (B). ILLUSTRATIVE PURPOSES ONLY AND OTHER TYPES ARE AVAILABLE. SIZES USED GENERALLY 0.025 M^2, 0.045 M^2 OR 0.1 M^2.

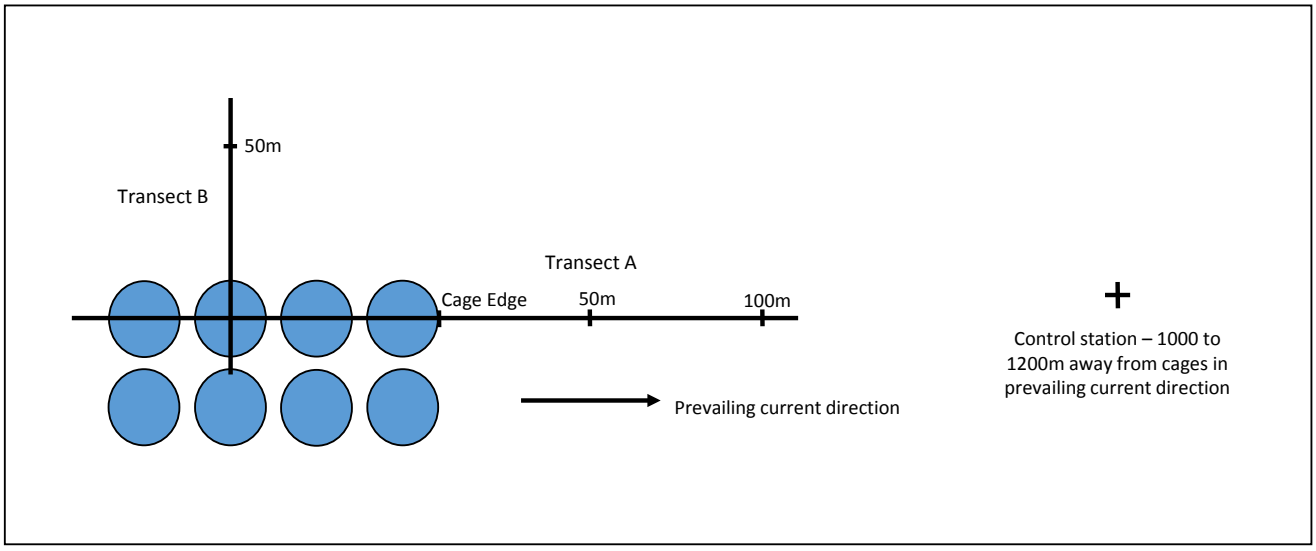

FIGURE 14: MONITORING STATIONS FOR BENTHIC SAMPLING AND PHYSIO-CHEMICAL ANALYSIS FOR FISH FARMS LESS THAN 1000 T PRODUCTION. DIAGRAM NOT TO SCALE.

g. The bag/container must be labelled both inside and outside. Use an appropriate waterproof paper or label and write in pencil. Two labels are used; the first on waterproof paper is placed between the inner and outer bags or inside the container; the second secured around the neck of the outer bag or on the outside of the container. The information contained on the labels is given in “Records” section below.

h. Samples are transported to the laboratory where possible in sealed plastic boxes or in an external trailer. Formaldehyde fumes in a sealed vehicle may be toxic to the driver and passengers. You must not transport samples containing formaldehyde inside a vehicle.

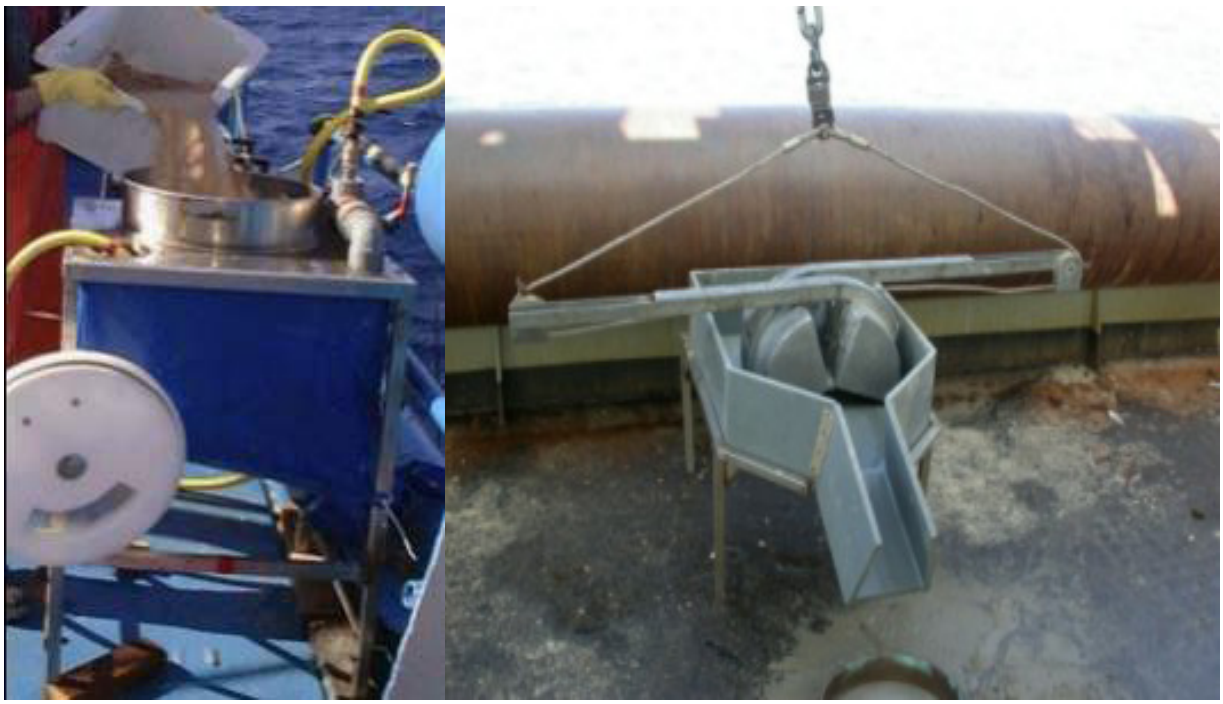

Figure 15: Example sieving tables for illustrative purposes.

Procedure – physio-chemical samples – Annual monitoring

h. Van Veen grab samples are collected as described for faunal samples, above.

i. Samples collected for physio-chemical analysis should not be used for any other purpose, i.e. they should not then be used for faunal analysis. Separate samples are collected for chemical, nutrient and particle size analysis (see below), though redox can be measured from one of these samples.

j. Samples used for physico-chemical analysis are taken from the open hatch in the top of the grab. The jaws remain shut. Such assessment includes Redox potential and collection for chemical and nutrient analysis and particle grain size.

k. Redox potential (Eh) is measured through the hatch using a suitable calibrated Redox and temperature probe and meter device. Readings of Eh and temperature taken in the water just above the sediment, at the sediment surface and then at 1cm depth intervals to a depth of 5cm (where possible) should be recorded. Prior to each measurement the probe is calibrated using a standard solution of Zobells (note safety note below). The meter reading will fluctuate, but should be allowed to stabilise for 15 seconds before the reading is taken. Both the Zobells reading and the sample reading are recorded. The redox probe should be washed in seawater between each new sample.

l. Sub-samples are collected for chemical analysis (e.g. copper concentration) through the hatch in the top of the grab using open ended 50 ml syringes. The end of the syringe is cut off, and a rubber stopper used to prevent loss of sample once collected. New syringes are used for each sample to prevent cross contamination. The sample is transferred to plastic sealable Nalgene jars or similar, labelled (see below) and deep frozen as soon as possible (usually within 3 hours) in an electric freezer. Transportation to the laboratory is in a cold box. No formalin is added to samples.

m. Sub-samples are taken for analysis of grain size using a 50 ml Sterilin (or 100/150 ml) universal container (or similar) into which the sediment can be scooped from the sediment surface (top 3 cm only). New sterile containers are used for each sample. Samples are labelled (see below) and are frozen as soon as possible after collection (usually within 3 hours). Transportation to the laboratory for analysis is in a cold box. No formalin is added to samples.

n. Sub-samples are taken for analysis of sediment carbon and nitrogen using a Sterilised 50 ml Sterilin (or 100/150 ml) universal container (or similar) into which the sediment can be scooped from the sediment surface. New sterile containers are used for each sample. Samples are labelled (see below) and are frozen as soon as possible after collection (usually within 3 hours). Transportation to the laboratory for analysis is in a cold box. No formalin is added to samples.

Labelling and records

The following records are kept during the field survey on a record form shown in Figure 16:

a. Each day - time of start, time of finish, general weather conditions and any other relevant information.

b. At each sampling station - sample station positions are identified through GPS (using a hand-held GPS). Accuracy in GPS position is improved when the number of satellites is high. Note the number of satellites identified to record GPS position.

c. Problems occurring during sampling, such as inability to collect sample at location and any deviations from the accepted protocol are noted.

d. On recovery of each sample - sample identifier (e.g. station number and position), replicate number, time of recovery of each sample, comments on sample size (full, half full, other), and sediment characteristics (colour, smell, grain size, appearance) is noted.

e. Sample labels contain the following information – site name, sample identification (replicate number and position), date and time of sampling, operator.

Safety

When preservation procedures are undertaken using formaldehyde in the open air, gloves and goggles should be used. If undertaken in confined or semi-enclosed spaces use a formalin mask, gloves and goggles to protect against inhalation and splashes. Avoid contact with skin and eyes. If contact is made with skin wash immediately in plenty of cold water. If splashed into eyes, seek medical attention. Any ill effects from inhalation or contact should be reported to a medical practitioner for treatment.

Zobells is a dilute solution containing cyanide and should be handled with extreme care. The bottle containing zobells solution should be marked according to international standards to highlight its potential toxicity. Always wear appropriate gloves and safety glasses and avoid contact with skin and eyes when using Zobells. If contact is made with skin wash immediately in plenty of cold water and seek medical attention is necessary. If splashed into eyes, seek medical attention. Any ill effects from contact should be reported to a medical practitioner for treatment. It goes without saying, but do not drink the solution.

DAILY LOG **Site name** _____ **Sheet** ____ **of** ____

Date _____

Start time _____ Finish time _____

Weather (general)

_____

_____

Comments (general)

_____

_____

Sample No.	Rep[1]	Time[2]	Depth (m)	Position[3]	Sample observations/comments[4]	Initials

[1] replicate number [2] time of sampling [3] Full lat/long and No of satellites [4] description of sediment colour, grain size, smell

Figure 16: Recording data sheet, field survey benthic sampling

Scope

Larger fish farms are liable to have more significant impacts than smaller farms at the same location, due to the larger scale and additional nutrients added to the environment. There is therefore a need to increase the number of sampling stations, compared to the Simple Benthic Survey. The reasons for the survey remain the same, to test for impacts of aquaculture activity, as outlined above.

Extended Benthic surveys are carried out annually on the same date ± 2 months, starting on the first anniversary after first stocking. The survey should, as near as possible coincide with peak biomass at the site, although the timing of this will vary depending on the species being grown. This is the reason for the additional flexibility (i.e. ±2 months) in timing of the surveys.

Procedure for Extended Benthic Survey

a. The procedures for field data collection for benthic samples and samples for the analysis of physio-chemical parameters are the same as those outlined above under Simple Benthic Survey.

b. The difference between Simple and Extended Benthic Surveys relates to the number of stations. For Extended Benthic Surveys there are eight [8] stations, 7 along two transects plus the control; the positions as outlined in Figure 17.

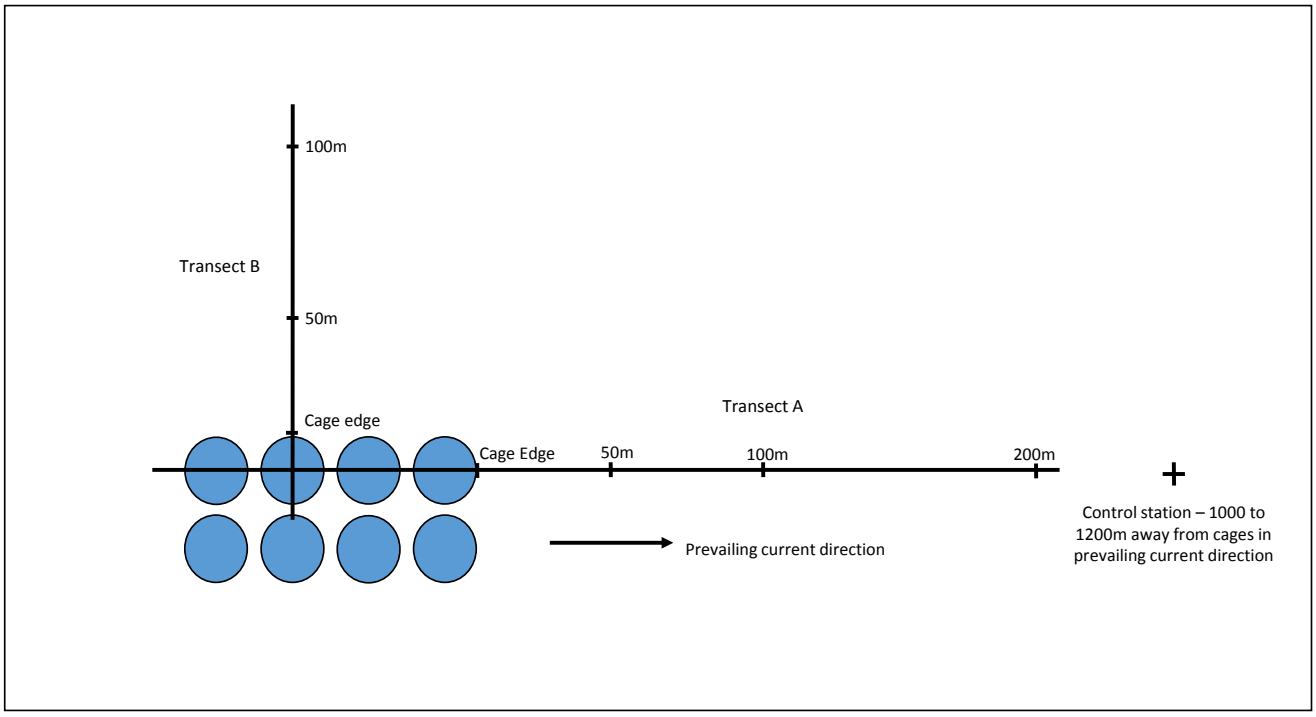

Figure 17: Monitoring stations for extended benthic sampling and physio-chemical analysis for fish farms of more than 1000t production. Diagram not to scale.

Baseline benthic survey

Scope

A baseline benthic survey, is an analysis of the conditions in the sediment at a proposed fish farm site prior to a fish farm being placed there. As such, Baseline Benthic Surveys are undertaken as part of the Environmental Assessment conducted during the Licensing and Application process. Baseline data provide background information on the underlying conditions at the site, against which future monitoring can be evaluated. Baseline surveys must therefore be carried out at all prospective sites.

After a fish farm is granted approval and is in operation, sediment conditions alter as a result of the waste particulate materials being deposited on the seabed, as described in Impacts from Cage Aquaculture for which monitoring can be carried out. Future monitoring will provide information on the state of sediments under production conditions and this is compared against the original baseline state, measured during the baseline survey, the comparison used to evaluate overall impacts. The baseline survey should be a comprehensive evaluation of sediment conditions and as such should be undertaken at significantly more stations than for the monitoring activity described previously.

Procedure for Baseline Benthic Surveys

a. Figure 18 shows the required layout of sampling stations for the baseline survey. Total sampling stations for a baseline survey is fifteen [15], consisting of the same sampling stations as for the Extended Benthic Monitoring Survey described above (i.e. Transects A and B) but in the four main directions from the site (i.e. Transects A and B; and C and D). The larger requirement is to give a broad understanding of the species present within the area where the fish farm will be placed plus the underlying physio-chemical condition of the sediments, in a broad area around where the fish farm is proposed to be located.

Collection along the 4 transects indicated also allows for some flexibility in which 2 transects are then used for the subsequent monitoring programme, although once decided, the same 2 transects should be used for all subsequent monitoring.

b. Baseline Benthic Survey involves the collection of grab samples for analysis of the diversity and abundance of benthic faunal species present at the location, along with sediment redox, carbon and nitrogen analysis, particle size analysis and metal concentrations, especially copper concentration.

c. Sample collection methods for each parameter is as described under Simple Benthic Survey.

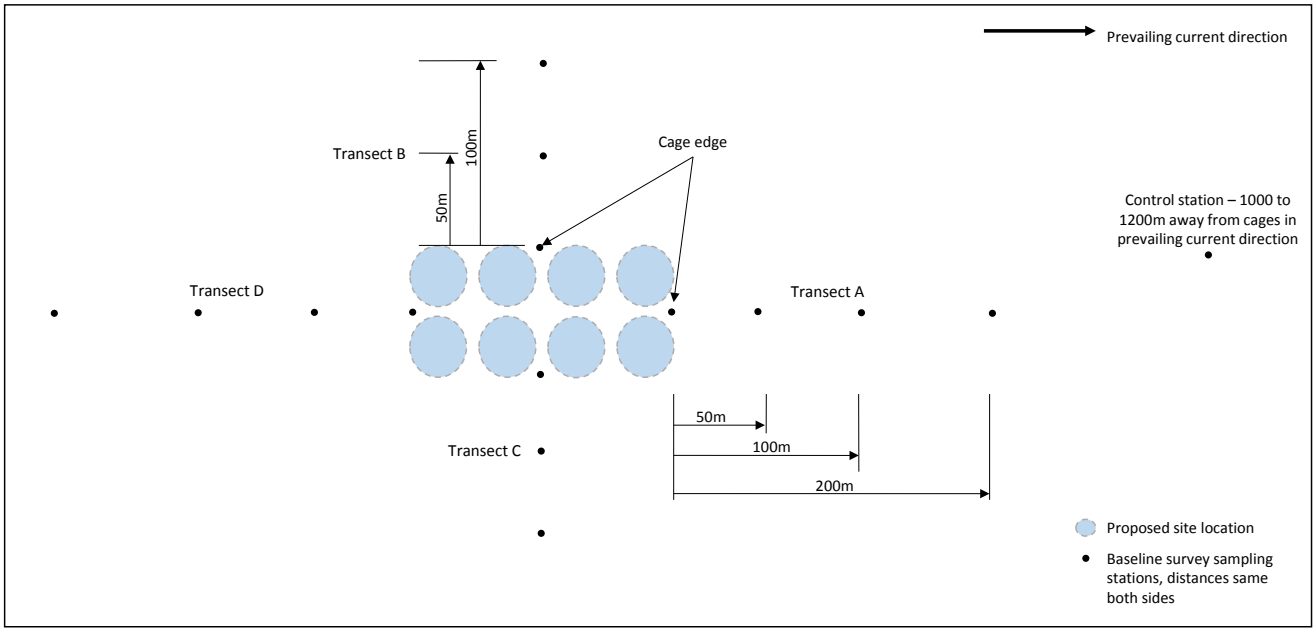

FIGURE 18: BASELINE SURVEY STATION LAYOUT RELATIVE TO PROPOSED CAGE LOCATION. SAMPLES COLLECTED FROM BOTH ENDS OF THE CAGE SITE AND BOTH SIDES, DISTANCES BEING THE SAME ON OPPOSITE SIDES.

Water Quality Survey

Scope

The Red Sea is an oligotrophic water body and excess nutrients from fish farm activity can potentially cause an increase in nutrient concentrations, and in primary productivity through increased phytoplankton growth. There is a body of thought which suggests that not only the quantity of nutrients (e.g. nitrogen) added but the available form of the dissolved nutrients may well be a trigger for the expansion or blooming of certain harmful algal bloom (HAB) species. Certain HAB phytoplankton species are more successful with reduced forms of nitrogen such as ammonium and urea being present and other types of phytoplankton (e.g. most diatom species) doing better with nitrate. All these forms of dissolved nitrogen, along with phosphorus emanate from fish cages.

The purpose of the Water Quality Survey is to evaluate water conditions on a regular basis to ensure the nutrient additions from the fish cages are not excessive and that negative impacts on the environment do not occur. This in turn may have the potential to impact the fish farm itself.

Water Quality surveys are carried out on a monthly basis, starting just prior to initial stocking and continuing on a monthly basis thereafter, at about the same time each month. The exceptions are water temperature and dissolved oxygen concentration which should be measured daily for the reasons outlined previously.

The parameters that need to be measured are:

1) Water Temperature – measured daily for farm management purposes

2) Dissolved Oxygen – measured daily for farm management purposes

3) Ammonia concentration – Monthly

4) Nitrate concentration – Monthly

5) Nitrite concentration – Monthly

6) Total Phosphorus concentration – Monthly

7) Chlorophyll-*a* concentration – Monthly

The design of the Water Quality Survey is somewhat variable depending on the local circumstances, such as whether there are coral reef systems nearby which may increase the number of stations required, but the following summary procedure provide the minimum number of sampling stations needed.

Procedure for Water Quality Survey

The procedure described provides for a non-technological process of water collection for analysis, although it is recognized that certain measures can be taken in the field, whilst others will require further processing in the laboratory.

Automated devices such as sondes, sensors and probes integrated with *in-situ* data loggers are available to automatically record the necessary parameters. This equipment may be used, provided the methods and equipment specifications and sensitivity are detailed in any report. Refer to specific Manufacturer's instructions for use of such technology.

a. **Dissolved Oxygen concentration and Temperature** should be measured on-site. Measurements should be taken a minimum of two times per day (morning and afternoon), at the same time on each occasion (± 2 hours), both inside and outside each cage at the site to provide an overall description of the DO conditions at the cage site. Dissolved Oxygen is critical to fish health and welfare and feeding strategy and should be regularly measured to avoid low oxygen conditions.

Given the regularity required and the level of sampling required an automated system of recording may be more appropriate.

Where an automated system is not possible, then measurements should be taken using an appropriate probe/meter, which measures both temperature (°C), DO concentration (mg.L-1) and dissolved oxygen % saturation to 2 decimal places.

Measures should be taken at a depth of - ½*Net depth – to give a good representation of the conditions which the fish are experiencing. The minimum depth should be 3 m, thus a probe cable will need to be sufficiently long to measure at this depth (e.g. Figure 19).

Alternatively use a water collector (such as a Van Dorn or Niskin sampler – see Figure 20 for examples) lowered in the "open" position on a rope marked at 1 m intervals to the required depth. Drop the "messenger" weight to trigger the closer of the sampler when at the required depth. Recover sampler to surface. Open one end of the sampler and measure dissolved oxygen and temperature immediately.

If decanting the water into a container prior to measurement the approach to decanting should minimize disturbance of the water as much as possible so that air bubbles are not generated during the decanting process, to avoid enhancing the DO readings in the sample compared to the seawater concentrations.

Record the date, time, and cage number and dissolved oxygen concentration on a record sheet. Transfer results to a computer spreadsheet where possible.

b. Water, for the measurement of **Dissolved Oxygen, Temperature and the remaining parameters,** should be collected on a monthly basis at the same time each month (±3 days) from a standard set of stations at the cage farm site.

The stations are detailed in Figure 21 and consist of;

- Cage edge, 100 m and 200 m upstream of the cage block;
- Cage edge, 100 m and 200 m downstream of the cage block; and
- Control station.
- Measurement must be made at 2 water depths, namely:
- ½ * net depth, and
- mid-water depth

c. For Dissolved Oxygen and Temperature, the procedure for sample collection (and measurement) is outlined in section a., above.

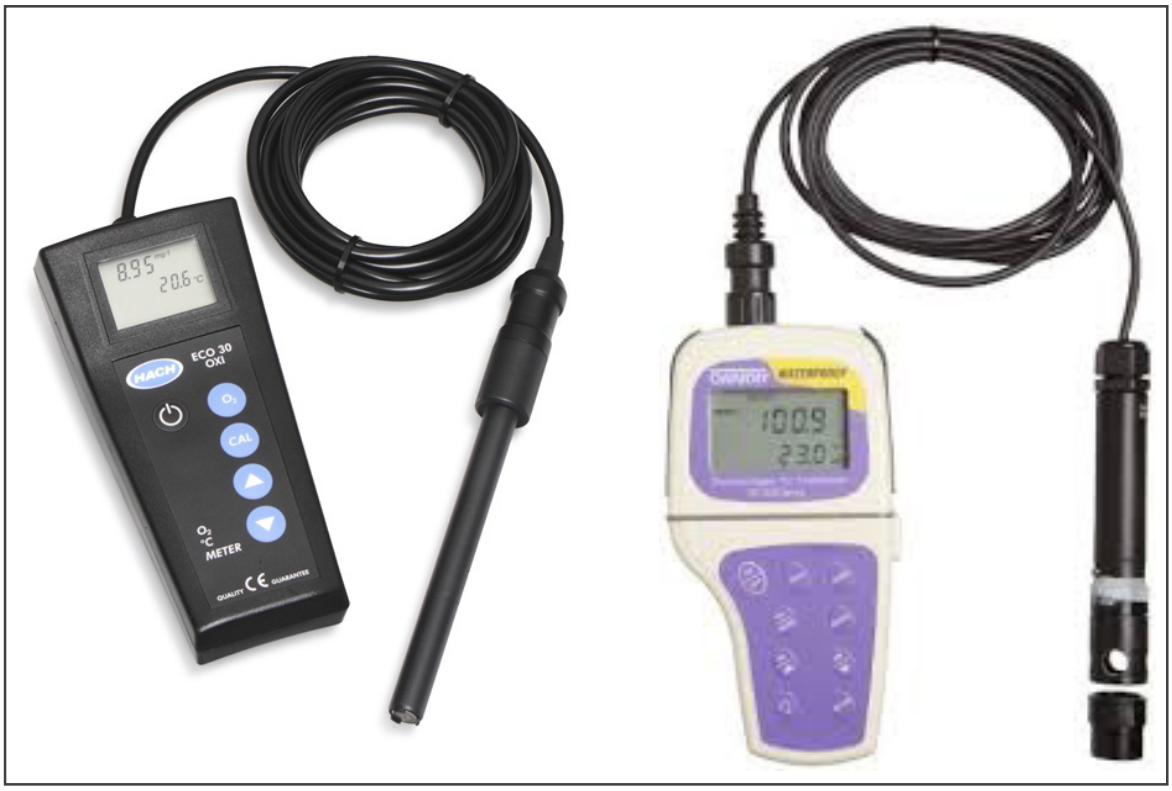

Figure 19: Example dissolved oxygen and temperature probes, for illustrative purposes only.

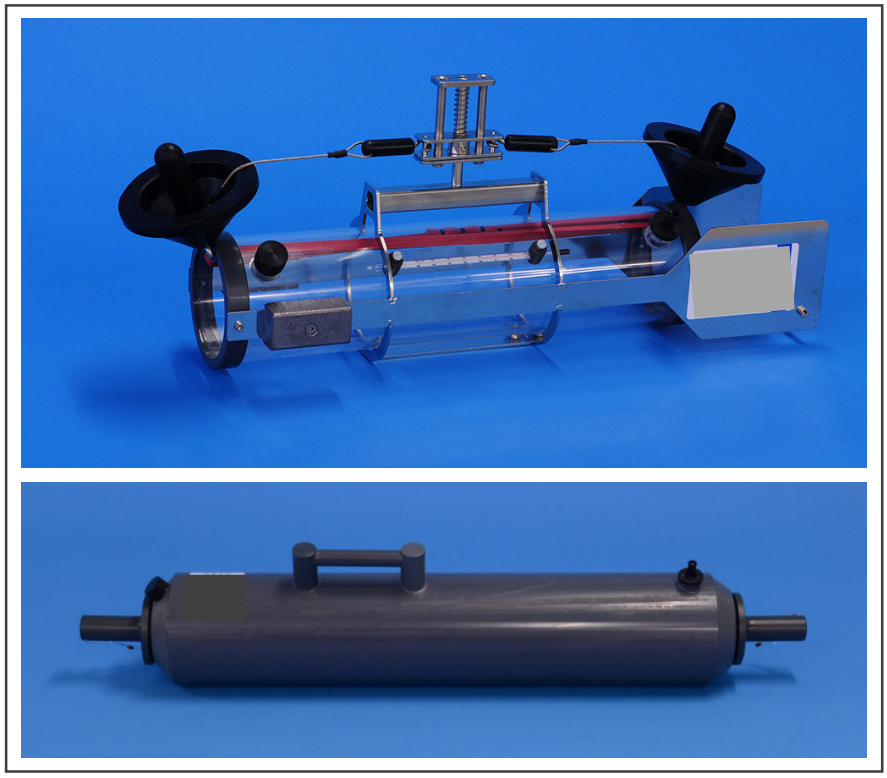

Figure 20: Water samplers, Van Dorn (top) and Niskin (bottom), for illustrative purposes only.

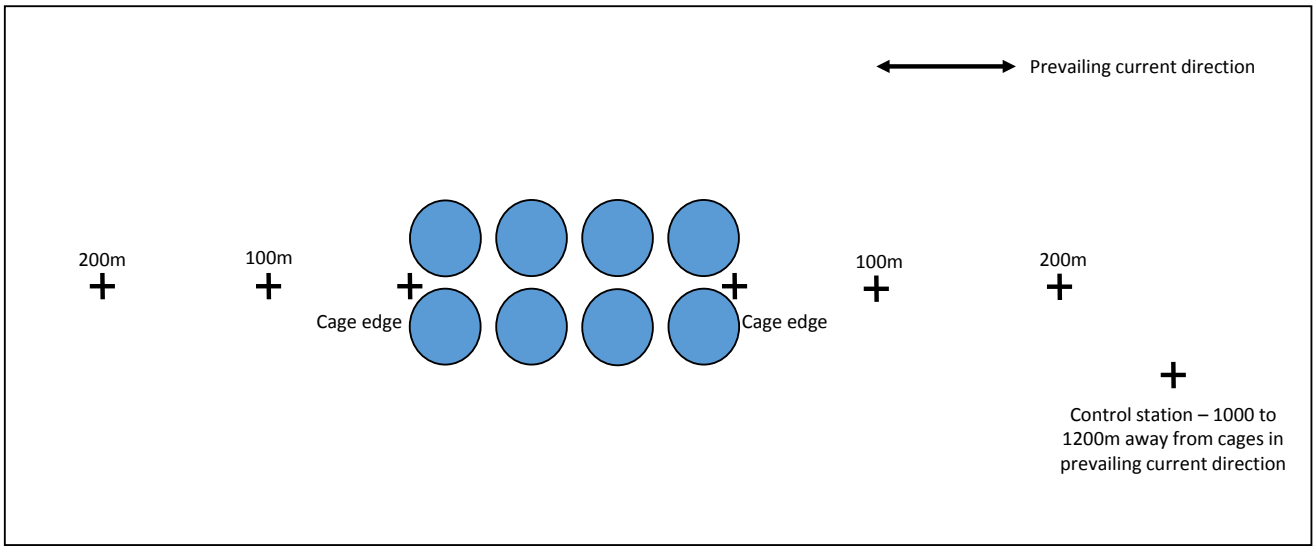

Figure 21: Sampling stations for measurement of ammonia, nitrate, nitrite, chlorophyll-*a* and total phosphorus. Not to scale.

d. For the remaining parameters, namely ammonia, nitrate, nitrite, chlorophyll-*a* and total phosphorus the procedure for water sampling is as follows:

e. Using an appropriate water sampler (e.g. Figure 20) deploy sampler in open position to the required depth using a rope with markings every 1 m.

f. When at required depth send messenger weight down the rope to trigger the closing mechanism and to close the sampler. Recover the sampler to the surface.

g. When at the surface decant a small amount of water into a cleaned* 1000 ml (1L) polyethylene bottle, wash the bottle by swirling around and discard the water. After washing fill the bottle with water until full and cap the bottle. This water will be used for the analysis of ammonia, nitrate, nitrite, and chlorophyll-a.

1. *Bottles should be acid washed with 1:1 HCl and rinsed with deionized water and allowed to dry.

h. Decant a small amount of water into a cleaned 100 ml glass flask and swirl around to wash the flask and discard the water. After washing fill the flask with sample water, cap with a cleaned stopper. This sub-sample will be used for the analysis of total phosphorus

i. Repeat a. – d. for the 2 depths required per station at each sampling station.

j. All water samples should be kept in a cool box, with ice and transported to a laboratory for analysis.

k. For analysis instructions please refer to Water Quality Analysis

7. Protocols – Laboratory work and data processing

Hydrographic data – data processing

Scope

This section briefly describes how to process the current meter readings after collection.

Procedure

Hydrographic and wind data are processed in the laboratory through a spreadsheet specifically designed for that purpose. Please refer to spreadsheet to determine how to process the data.

Processed data should be incorporated into a report which summarises the hydrographic survey results.

Reporting

Both the report and the relevant spreadsheet should be sent to the Competent Authority for evaluation. For reporting suggestions see Appendix 1: Hydrography report.

Benthic species composition – laboratory work and data processing

Scope

The purpose of this section is to describe the methods used to extract macrofauna from sediment samples in a consistent and accurate manner, to identify the faunal specimens in a consistent manner to ensure repeatable precision in identification, to carry out quality assurance on picking/sorting, identification and records, and to report the data gathered.

Procedure

1. Samples are brought from the field in double wrapped polythene bags or plastic sealed buckets, labelled inside and out to identify site, date, and station and replicate number. Larger grab sizes (0.1 m^2 and possibly 0.045 m^2) may have been sieved on site before delivery to the laboratory, and will contain samples and residual sediments. Smaller grab size (0.025 m^2) will generally contain entire grab contents. The samples are stored in a locked area in the open air for a minimum of one week, to allow the specimens to fix sufficiently and to be manipulated without damage.

2. The contents of the bag/container, which represents a single replicate sample, are transferred to a large sieve on a wash stand with 1000 μm (1 mm) mesh size. The sediment is gently washed through the sieve with tap water from a hose. This procedure should be undertaken in an area provided with fume extraction or possibly in the open air, as the samples will contain formo-saline (formaldehyde) solution. Protective glasses and gloves are used. The sieve is washed in-between each sample to avoid cross-contamination between samples.

3. After washing the material retained on the sieve is transferred to a white tray and covered with tap water. The macrofauna collected are removed from the remaining sediment/debris using forceps, in a procedure called "picking". With samples collected using a 1 mm sieve the specimens are normally sufficiently large so that this is normally carried out by eye in a well-lit and ventilated area. After the initial selection a further assessment of the tray is made, if necessary using a strong lamp and magnifying glass to extract smaller organisms. To aid the picking process Rose Bengal stain may be used at the operator's discretion to stain the samples so that they are easier to see. It must be noted, however, that Rose Bengal may have carcinogenic properties and it is recommended that you read the manufacturer's handling instructions before use.

4. All extracted fauna from a single sample are transferred to sterile plastic screw-topped pots of suitable size containing 70% alcohol, for storage. If specimens are too big they may be placed in larger vessels. Each pot is labelled with date of collection, site name, station, and date picked.

5. Any debris or other material remaining in the tray is disposed of, unless required for later inspection (internal QA) or is requested by the regulator for later external inspection (external QA).

6. Identification of the macrofauna is a specialist skill and is undertaken by trained experts (at least degree level biologists) using appropriate, up-to-date literature. Identification is based on distinct anatomical features of the organism being identified which indicate its genera and species. Identification is initially conducted using a suitable stereo microscope with 4 to 45 x magnification and lighting unit to allow identification of the features. If more detailed inspection is required a suitable compound microscope is used (40 to 1000x magnification, with phase contrast capability) so that specific anatomical structures can be observed in detail.

7. Identification is normally achieved to the lowest taxonomic level possible from the condition of the specimen, normally to species level. As the identification is made, for each new species the species name is added to the record sheet, and for each listed species the abundance is counted, typically by making a mark against the species for each one identified. These marks are then added up to give the overall abundance of each species.

8. It is probable that some specimens may have been damaged during collection and processing so that only part of the fauna is present. If only part of an animal is present it is standard practice to count the heads only in determining total abundance.

9. After identification and enumeration all specimens for a single sample are replaced in the plastic screw topped container in 70% alcohol (or separate if too large). The containers are labelled as in para. ii) 2. The containers are stored in fire proof facilities as an archive for a period agreed by the regulatory body, typically two years, that allows for external quality assurance if required. Stored samples are curated allowing samples to be found easily for re-inspection.

10. It may be appropriate for all laboratories who will analyse benthic samples on a regular basis to set up and retain a Reference Collection. A Reference Collection is a set of individual or a few organisms of each species encountered that is set aside for future reference and against which any future samples can be compared. The Reference Collection must contain specimens that have been positively identified by an expert as the species named. The reference collection of new taxa, stored in 70% alcohol in screw topped bottles and labelled with species name, should then be constantly updated. This also allows identifications to be validated by independent experts if required.

11. Species identification and abundance data is entered into a recording sheet as it is identified (Figure 22).

12. Record sheets should be kept on date surveyed, date sorted and date identified as per the record sheet in Figure 23. Record sheets should be retained by the company undertaking the work for external quality assurance inspection, if the Competent Authority deems this necessary.

13. On sorting and again after identification / enumeration the specimens from each sample are placed in labelled screw topped bottles containing the following information: Study name and number, sample number and position, replicate number, date of sampling, date of sorting, sample collector and sorter.

14. Labels are attached to the outside of the container and on printed labels within the container. Samples are retained for a period of 2 years, in case of re-assessment or external evaluation.

MACROFAUNA IDENTIFICATION RECORD SHEET **No _____ of _____**

Study _____ Study No. _____ Survey Date _____

Sample area _____ Signature of identifier _____

Sampling station				
Replicate		Tot		Tot
Taxa				

Figure 22: Macrofauna identification log sheet

MACROFAUNA LABORATORY RECORD SHEET **No _____ of _____**

Survey _____ Survey No. _____

Sample No	Replicate	Date surveyed	Date sorted	Sorter signature	Date checked	Checker signature	Date identified	Identifier signature

Figure 23: Macrofauna laboratory record sheet.

Reporting

Faunal sample data should be presented in a Benthic Report along with other physio-chemical data. See Appendix 3: Benthic report, including fauna results and analysis, and physio-chemical parameter results and analysis.

In the report, as a minimum tables should be included that identify the top 10 species at each station measured (e.g. Table 2), with abundance of each species and cumulative abundance of all species in the top 10, to indicate overall species diversity (i.e. a high cumulative % in the top 10, means the species diversity will be low, or vice versa).

Tables should be accompanied by text that describes the results from the survey and analysis.

Table 2: Example table ranking of species top 10 for a specific station, based on Abundance, and showing cumulative abundance.

RANK	SPECIES	NUMBER	PERCENT	CUM PERC
	Station AG 1 - 25m North from the cage group			
1	*Abra nitida*	544	57.63	57.63
2	*Thyasira flexuosa*	81	8.58	66.21
3	*Oligochaeta* sp.	67	7.1	73.31
4	*Eteone longa*	46	4.87	78.18
5	*Ophryotrocha* sp.	24	2.54	80.72
6	*Maldanidae* sp.	22	2.33	83.05
7	*Jasmineira caudata*	15	1.59	84.64
8	*Capitella* spp.	13	1.38	86.02
9	*Scoloplos armiger*	12	1.27	87.29
10	*Jasmineira elegans*	11	1.17	88.45

Practitioners should use the species diversity and abundance information to calculate a series of univariate indices including Shannon Weiner Index and Peilou's Evenness according to the following equations:

THE SHANNON-WIENER DIVERSITY INDEX (H')

This index is based upon the observed distribution of individuals among species/ taxa and provides a measure relating to dominance in the populations. H' is influenced by both the number of species / taxa and their relative abundance in the sample.

$H = -SUM [(pi) * ln(pi)]$

$E=H/Hmax$

Where,

SUM = Summation

pi= Number of individuals of species i/total number of samples

S = Number of species or species richness

Hmax = Maximum diversity possible

E= Evenness=H/Hmax

PIELOU'S MEASURE OF EVENNESS (J)

J = H'/ln(S) where H' is Shannon Weiner diversity and S is the total number of species in a sample, across all samples in dataset

(Symbols as in the Shannon-Wiener index)

Results can be presented in a Table (e.g. Table 3) with species diversity and total species abundance.

Table 3: Example table of univariate indices summarising benthic species data

	Species Diversity	Species abundance	Shannon's	Pielou's evenness
Control total	28	211	3.389	0.835
Under total	5	283	0.906	0.379
TA 0m total	21	145	2.851	0.772
TA 10m total	19	106	2.734	0.733
TA 20m total	19	145	2.227	0.592
TA 50m total	15	132	2.246	0.662
TA 100m total	18	162	2.436	0.720
TB 0m total	24	287	2.156	0.596
TB 10m total	16	133	2.647	0.729
TB 20m total	15	199	2.294	0.663
TB 50m total	13	136	2.368	0.676
Total	60	1939		

More sophisticated multivariate indices may also be calculated but this requires the use of appropriate statistical packages such as Primer, though others are available. No further information is included in this document on more advanced statistical packages.

Results should be presented in a single report with physio-chemical results, collectively referred to as a Benthic Report see Section 8. Reporting of survey data)

Redox (Eh)

Scope

This section details how to process redox data measured in the field.

The redox potential of sediments is defined as a measure of the ability of organisms to carry out reduction-oxidation reactions, whereby high redox levels predominate oxidative reactions (with oxygen), and low (negative) readings predominate reductive reactions (without oxygen). As such it is to some extent indicative of the level of oxygen available

within the sediment, where oxygen is important for sediment turnover and processing. Under "normal" conditions the level of oxygen in sediment will naturally reduce with depth, depending on the influence of a range of conditions. This is enhanced, that is the depth of the oxygenated layer is reduced towards the surface, by the presence of additional factors, such as adding nutrients to the system from fish farming. Measures of redox potential is a typical method to assess sediment condition, as a surrogate for actual measurement of oxygen flows that are both complex and expensive to carry out.

Redox in marine systems will be influenced by 1) the rate of oxygen diffusion between the water column and sediment; 2) oxygen concentration in the overlying water; 3) the rate of oxygen consumption by chemical and biological processes in the sediment and 4) bioturbation (sediment turnover) that creates burrows and routes for water replenishment. Points 1 and 2 are a function of sediment grain size and hydrodynamic conditions that affect the rate of exchange of water between the sediment and water column. Point 3 is a function of chemical reactions, faunal respiration and microbial activity that utilise oxygen as an electron acceptor in the energetic processes that drive these activities. The latter point (4) is entirely dependent on the species types and to some extent the diversity present in the sediment.

Procedure

When collecting sediment mV readings the probe should have been calibrated using Zobells redox standard solution, which has a potential reading of 430 mV.

To convert the mV reading taken in the field to Eh, the raw field measures need to be corrected to account for the difference between the expected Zobells reference solution value and actual Zobells meter reading in the field and to account for inconsistencies between probes. The difference between the Zobells Reference solution and the field reading is added to the raw data collected at each sediment depth. This is then multiplied by a second correction value that is specific to the combination electrode used. Thus "Eh = (Field measurement + Zobells correction factor) * (probe correction value)" in order to convert the mV values obtained from the samples to Eh. This second correction value varies subtly with temperature; therefore, the temperature of the sediment is measured before readings begin.

Reporting

Data is reported as a table, including calibration measurements, an example of which is shown in Table 4, for illustrative purposes.

Table 4: Example table of redox (Eh), following adjustment of readings by Zobells and probe correction factors.

Sediment depth		Control	TA CE	TA 50m	TA 100m	TA 200m	TB CE	TB 50m	TB 100m
+1		399	397	415	410	404	407	406	452
0		347	360	393	393	360	352	378	415
-1		263	182	170	259	249	209	333	353
-2		219	92	121	181	221	105	233	235
-3		172	76	65	103	176	36	138	179
-4		158	17	-9	63	129	3	105	128
-5		67	-16	-30	26	76	-20	75	111
Zobells field reading		243	239	242	245	250	247	242	239
Reference (mV)	430								
Zobells Correction value		187	191	188	185	180	183	188	191
Probe correction value	0.9486								

Eh = (field measurement + Zobells correction value) * probe correction value

Particle size analysis[2]

Scope

Particle size breakdown can give insight to the physical nature of sediments. For example, coarser well mixed sediments offer increased interstitial spacing and have better drainage and water exchange than finer or poorly mixed ones. Due to these physical characteristics different animal communities tend to occupy different sediment types. When using variation in animal community structure to gauge environmental effects it is therefore essential to have background information on sediment type in order to determine any natural variation in community structure.

This section describes the laboratory procedure and post-processing for a wet-dry sieving method. It should be noted that more sophisticated methods are available to measure grain size, including for example laser granulometry. Detailed methods are not included in this document and qualifies experts are required to present detailed methods in their reports, if alternative methods are used.

Procedure

1. Samples are collected as described above under Simple Benthic Survey. On return to the laboratory samples are stored in a freezer. Before analysis samples are defrosted, placed in an appropriate tin tray and dried in an oven at 95 - 100ºC.

2. Particle sizing is conducted in two phases, wet sieving and dry sieving. The procedure uses an aqueous solution of sodium hexametaphosphate $(NaPO_3)_6$ (at 6.2 g of crystalline $(NaPO_3)_6$ l^{-1}) to prevent clumping and concretion of particles of sediment.

3. Phase 1 separates the silt/clay (<63 μm) fraction of the sediment from the sand fraction using a wet sieving method and 63 μm mesh sieve. The sieves used should conform to International Standards.

a) Accurately weigh all or a sub-sample of dried sediment. For high mud/silt/fine sand samples a sub-sample of approximately 50 - 75 g would suffice, whereas for coarser sediments, where a sub-sample may not be easily representative, it may be appropriate to weigh the entire sample collected. Dried sample is to be weighed on a four decimal-place (dp) balance (an example is the Mettler AJ100 Mettler-Toledo Ltd, or similar).

b) After weighing place sediment in a beaker with approximately 250 ml of tap water and add 10 ml of aqueous sodium hexametaphosphate $(NaPO_3)_6$ (6.2 $g.L^{-1}$). Sediment should be allowed to soak and break-up, but where this does not occur normally break up the sediment gently with a glass rod. After sediment is broken up stir mechanically for 10 min. Allow to stand for 24 hours and re-stir for 10 min before further processing.

c) Wash the sediment suspension on to the 63 μm sieve placed in a white tray/basin adding water until the sieve surface is submerged. Sieve by puddling the sieve in the basin of water.

d) Transfer the sieve with remaining contents to a drying oven and dry rapidly at 95 -100°C.

e) Gently remove the sieve from the oven. The material retained on the sieve is transferred to a weighing boat over a white tray to catch any spillage, which is also added to the weight boat. This is then weighed on a suitable four dp balance and the weight recorded.

Please note that a wet and dry sieving method is described here. Alternative methods are available including laser granulometry, not outlined in this document. Refer to suppliers' manual for instruction to complete this method.

4. Phase 2 separates the remaining sample into necessary fractions using dry sieving. The fractional division are those according to the Wentworth Phi scale (Table 5).

a) After weighing, the material is transferred to the uppermost (coarsest) of a series of stacked graded sand sieves (size dependant on client requirements but generally 2000 μm, 1000 μm, 500 μm, 250 μm, 180 μm, 125 μm 90 μm and 63 μm), taking care to brush all material from the container. At the bottom a base pan should be used in order to capture any grains below 63 μm that were not removed by wet sieving.

b) The stacked column of sieves and pan is transferred to an automatic sieve shaker (Figure 24 - an example is an Analysette 3 SPARTAN pulverisette 0 automatic shaker or similar) for 10 minutes. After 10 minutes the column of sieves should be rocked and tapped by hand until no further sieving occurs from the top sieve into the sieve below. The column of sieves should be removed in sequence, starting at the uppermost sieve and the process of tapping by hand continued for all sieves in the column.

c) The sediment retained on each sieve is weighed by transferring to a weighing boat with a soft brush and weighing on a four decimal place (dp) balance. The weight can be used to calculate the percentage proportion of each sand fraction to the original total amount.

d) Material retained in the base pan is also weighed. Pan material weight is added to the difference in weight between the original weight (3a above) and the post wet-sieving weight (3e above) to give the total weight of the <63 μm fraction.

5. The sample can be stored in a dry sealable labelled container in case of a need for further analysis. Storage should be for a maximum of 6 months.

Records

1. Records are made on a record sheet, as defined in Figure 25, where date, survey identifier, sample name, survey date, and PSA operator are given for each sample when the sample is logged in before analysis.

2. The actual weight of initial amount of sediment and the weights of the individual fractions are recorded in the same log book. Data records are also stored on a spreadsheet, which is made available to report writers and clients.

Figure 24: Analysette 3 SPARTAN pulverisette 0 automatic shaker, for illustrative purposes only.

PARTICLE SIZE ANALYSIS RECORD SHEET

Study _____

Study No. _____ Survey date _____

Comments _____

_____

RESULTS

Date	Sample	Orginal Weight in Sieve[1] (g)	Weight in Sieve (g)									Operator initials
			Wet <63µm	Dry <63µm	Total <63µm	63µm - 125µm	125µm - 250µm	250µm - 500µm	500µm - 1000µm	1mm - 2mm	2mm - 4mm	4mm - 8mm	

[1] weight of dried sediment to 4 decimal places.

Figure 25: particle size analysis record sheet.

Information on the Particle size analysis record sheet is transferred to an Excel spreadsheet for further analysis. The spreadsheet offers the ability to convert weights to Wentworth phi units under the Wentworth classification of sediment as shown in Table 5 and to provide standard Median sizes, Kurtosis and Skewness measurements, alongside graphical results as shown in summary in Figure 26. Please refer to Spreadsheet for methodology on data input.

Table 5: Relationship between particle size and phi units under the Wentworth classification scheme.

Particle Size Range (mm)	Phi Units	Grade name
> 256	< -8.0	Boulder
256 to 64	-8.0 to -6.0	Cobble
64 to 4	-6.0 to -2.0	Pebble
4 to 2	-2.0 to -1.0	Granule
2 to 1	-1.0 to 0.0	Very course sand
1 to 0.5	0.0 to 1.0	Coarse sand
0.5 to 0.25	1.0 to 2.0	Medium sand
0.25 to 0.125	2.0 to 3.0	Fine sand
0.125 to 0.0625	3.0 to 4.0	Very fine sand
0.0625 to 0.0039	4.0 to 8.0	Silt
< 0.0039	> 8.0	Clay

Reporting

Reports should include the graphical outputs and tables of raw data (Figure 26), presented in a single report with benthic survey results and other physio-chemical results, which are collectively referred to as a Benthic Report, as described in Appendix 3: Benthic report, including fauna results and analysis, and physio-chemical parameter results and analysis.

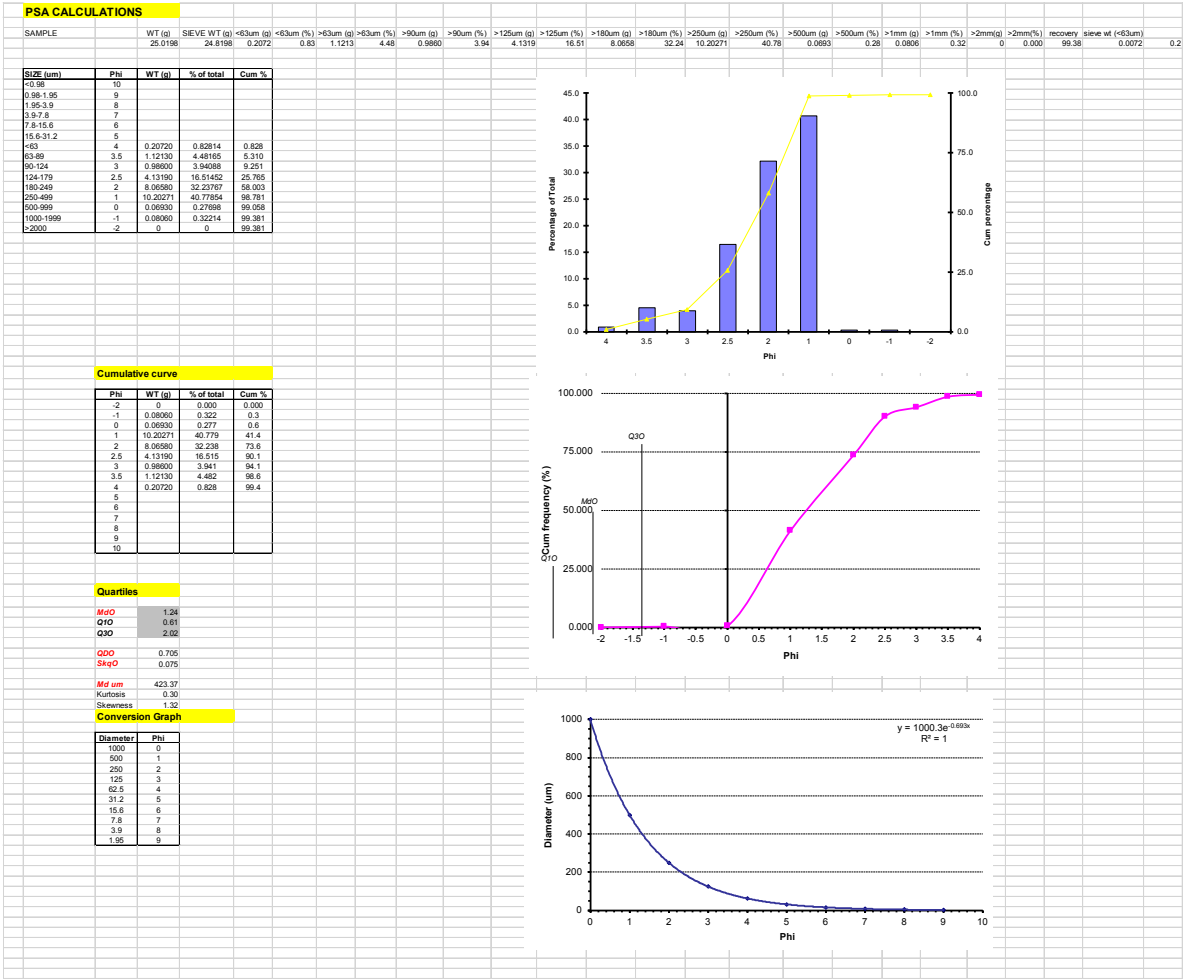

Figure 26: MsExcel spreadsheet showing graphic outputs possible after input of particle size analysis results from measurements taken using wet-dry sieving method.

Carbon and Nitrogen Analysis, Copper Analysis

Scope

Measurement of specific sediment characteristics such as concentrations of carbon, nitrogen and copper require specific analytical equipment, each with specific methods of measurement and appropriate procedures for this. A suitable testing laboratory should be employed to carry out such work. No specific methods are included here.

Procedure

Methods used to sediment measure carbon and nitrogen content and copper concentration, should be identified in any report.

Reporting

Reports should include tables of measured data, presented in a single report with benthic survey results and other physio-chemical results, collectively referred to as a Benthic Report, as described in Appendix 3: Benthic report, including fauna results and analysis, and physio-chemical parameter results and analysis.

Water Quality Analysis

Scope

Measurement of specific water quality parameters such as concentrations of ammonia, nitrate, nitrite, total phosphorus and Chlorophyll-*a* requires specific analytical equipment, each with specific methods of measurement and appropriate procedures for sample preparation and processing. It is therefore appropriate that samples are sent for analysis to an approved laboratory.

Procedure

Methods used to measure ammonia, nitrate, nitrite, total phosphorus and Chlorophyll-*a* in water, should be suitable for measuring low concentrations and be identified in any report. Sensitivity (i.e. minimum detectable concentrations) of the specific method should be identified.

For each component there are a number of different methods available for determination of specific concentrations in seawater. The information listed below is general information for reference only, and not a strict guideline on measurement protocols. Laboratories should report the detailed methodology in any report.

Ammonia

The concentration of ammonia in water is measured as total ammonia (ionised + unionized) and is to be reported in $mg.L^{-1}$. The concentration of unionized ammonia (NH_3) is derived from well-established formulas. There are two typical methods: 1) Ammonia probe: A measuring probe is connected to an electronic ion meter that measures and displays the voltage resulting from ammonia, which is then converted to concentration using a standard curve; and 2) Colorimetric methods in which one or more reagents are added in timed intervals to the sample, such that the intensity

of the colour produced is proportional to the ammonia that reacts with the reagent. This colour absorbance is then measured using a colorimeter or spectrophotometer. Blanks and standards are used to generate a standard curve from which the sample absorbance reading is converted to ammonia concentration.

Nitrate

Nitrate can be measured by a range of methods. Less common is a nitrate electrode, used with a meter of similar function to a dissolved oxygen meter. It consists of a probe with a sensor that measures nitrate activity in the water, by affecting the electric potential of a solution in the probe. This change is then transmitted to the meter, which converts the electric signal to a scale that is read in millivolts. The millivolt values are then converted to $mg.L^{-1}$ of nitrate by plotting them from a standard curve. This is the least sensitive method for marine waters as the probe is affected by high concentrations of chloride or bicarbonate ions in the sample water.

The cadmium reduction method is a colorimetric method that involves contact of the nitrate in the sample with cadmium particles, which cause nitrates to be converted to nitrites. The nitrites then react with another reagent to form a red color whose intensity is proportional to the original amount of nitrate. The red color is then measured either by comparison to a color wheel with a scale in milligrams per liter that increases with the increase in color hue, or by use of an electronic spectrophotometer that measures the amount of light absorbed by the treated sample at a 543 nanometer wavelength. The absorbance value is then converted to the equivalent concentration of nitrate by using a standard curve.

Nitrite

Standard methods for nitrite analysis include colorimetric and ion chromatographic methods. The colorimetric method requires addition of NED dihydrochlorite reagent to a filtered sample to produce a coloured Azo dye that can be measured photometrically. The method can only be used to reliably detect a few micrograms of nitrite, so extensive sample dilution may be required.

Chlorophyll-a

Algal cells are concentrated by filtering a known volume of water through a membrane filter (47 mm, 5.0 µm pore size). The pigments are extracted from the concentrated algal sample in an aqueous solution of acetone. The chlorophyll-*a* concentration is determined spectrophotometrically by measuring the absorbance (i.e. the optical density) of the extract at various wavelengths. The resulting absorbance measurements are then applied to a standard equation to calculate concentration.

Total dissolved Phosphorus

Inorganic phosphorus is available in many forms such as metaphosphates, pyrophosphates and other polyphosphates available in reactive, non-reactive, organic and inorganic forms and the methods for measuring Total dissolved Phosphorus are complex. As a consequence Total Phosphorus (TP) is acceptable.

To determine total phosphorus the sample is reduced to reactive orthophosphate under heat and acidic additions, before analysis is carried out. The TP value can be determined by the molybdenum blue method, by adding a reducing agent. Orthophosphate reacts with ammonium molybdate to a slightly yellow molybdenum phosphoric acid. By adding a reducing agent, the molybdenum blue is formed.

Subsequently the Total Phosphorus concentration can be detected using a spectrophotometer at wavelengths of between 500 - 750 nm against standard curve. This method is particularly suitable for the determination of low concentrations.

Trophic Index (TRIX)

The trophic index TRIX has been applied to many coastal environments and is a means of summarising certain chemical characteristics into a single index which indicates the eutrophication status of the water body.

Eutrophication has a generic definition and is the process of enrichment of waters with plant nutrients, primarily nitrogen and phosphorus, which stimulates aquatic primary productivity and can lead to visible algal blooms, algal scums, and enhanced benthic algal growth of submerged and floating macro-algae. Fish farms can act as a means by which local nitrogen and phosphorus concentrations are increased as a result of dissolved waste outputs from fish digestion and excretion activity.

The TRIX index has values ranging between 0 and 10, with values below 5 generally considered acceptable conditions (See Figure 27).

Calculation of TRIX is as follows:

TRIX = (log10 [Chorophyll-*a* x % O_2 saturation x Dissolved Inorganic Nitrogen x Dissolved Inorganic Phosphorus] + k) / m

Where:

- Chlorophyll-a = concentration of chlorophyll-*a*, in $mg.m^{-3}$;
- % O_2 saturation = absolute value of the percentage of dissolved oxygen saturation, [abs 100 - %0 = $\%O_2$];
- Dissolved Inorganic Nitrogen (DIN) = [nitrate (NO_3) + nitrite (NO_2) + ammonia (NH_4)], in $mg.m^{-3}$;
- Dissolved Inorganic Phosphorus (DIP) = Total dissolved phosphorus, in mg/m^3, and
- The constants k = 1.5 and m = 1.2 are scale values introduced to adjust TRIX scale values with a level of eutrophication.

Values for Chorophyll-*a*, ammonia, nitrate, nitrite and total dissolved phosphorus measured using the techniques outlined above (or some other appropriate method) must be converted to $mg.m^{-3}$ before calculation of the TRIX index.

TRIX values must be calculated for the control station and the cage farm site separately. Control and cage farm data collected from the various stations should be averaged (using both Arithmetic Mean and geometric mean values) before input to the TRIX calculation, where the control site n = 2, and at the cage site n = 12 (see Water Quality Survey).

Geometric mean is used because of interlink between the monthly sampling where the results in any particular month are influenced by the value for the previous month, and is probably the most appropriate for TRIX. Use of the arithmetic mean removes this direct linkage. Both should be calculated and reported.

Reference values for TRIX means, corresponding trophic state and related coastal water quality conditions.

TRIX annual means	Trophic Status	Water quality Conditions
<4	Elevated	• Scarcely productive waters. • Good water transparency. • Absence of anomalous water colours. • Absence of Oxygen undersaturation in the bottom waters.
4-5	Good	• Moderately productive waters. • Occasionally water turbidity. • Occasionally anomalous water colors. • Occasionally bottom waters ipoxia episodes.
5-6	Mediocre	• Very productive waters. • Low water transparency. • Frequently anomalous waters colours. • Ipoxia and occasionally anoxia episodes in the bottom layers. • Suffering of the benthic communities.
>6	Bad	• Strongly productive waters. • High water turbidity. • Diffuse and persistent anomaly in the water colours. • Diffuse and persistent ipoxia/anoxia episodes in the bottom waters. • High mortality rate of benthic organisms. • Alteration of the benthic communities and strong decrease of the biodiversity

Figure 27: Range of value for TRIX trophic index scores. (after Mazziotti, 2013)

Reporting

Reports should include tables of measured data, average concentrations, and calculation of the TRIX values reported in tables, presented in a single report. Text should accompany the data tables that explains the significance of the results obtained.

8. Reporting of survey data

Reporting of data generated through baseline and monitoring surveys should be in the form of comprehensive reports. Attached in the following Appendices are an example of each type, and these are to be used as reference material only, rather than copied literally.

Where the provision of raw data has been requested in the guidance document this must also be submitted with the report to the Competent Authority for evaluation.

Appendix 1: Hydrography report

Appendix 2: Videographic / Photographic survey report, including physio-chemical parameters

Appendix 3: Benthic report, including fauna results and analysis, and physio-chemical parameter results and analysis.

Disclaimer:

The reports presented in these appendices are for reference only to show the type of reporting format that can be applied, the sections needed and the basic approach to describing the methods used for data collection and processing, data analysis, summarising the results of this analysis and drawing conclusions. They are examples, not a prescribed format. The specific layout and content required in reports written about specific sites within the Red Sea will be different and simply cutting and pasting the reports below is inappropriate and should not be done.

These examples, using real data, are based on original reports authored by Dr Richard Corner on behalf of Marine Harvest Ireland, who themselves own the data and copyright. Approval for use, in this edited format, has been sought from Marine Harvest Ireland, and their approval has been given in writing.

Hydrographic report for a potential fish farm site at {site name}.

Report to {Client name}.

2006.

The information and results given in this report constitute an accurate representation of the data collected. Data interpretation and analysis of results have been achieved using the best possible scientific practices.

Author .....

I have assessed this work according to the internal audit practice of the {Company name}

Q.A. .....

Position and address of company who conducted survey inserted here

SITE DESCRIPTION

The hydrographic data described in this report refers to the area of a proposed fish cage site at {site name}. The site will be operated by {Investor/company name}.

SURVEY PROGRAMME

All field deployment, equipment set-up and data collection and analysis were undertaken by {Consultant name}, as outlined in the methods section of this report.

The deployment of the meters, the data recorded and its presentation follow the guidelines stipulated by the Regulator.

METHODS

Data collection

One RDI 600kHz Workhorse Sentinel ADCP current meter was deployed three meters above the seabed for a 15 day period between 6 May and 21 May 2006. The deployment position can be seen in figure 1. The deployment was within 150 metres of the centre of the proposed leased area (see Appendix for position references) in a water depth of approximately 27 metres, 2.49 m above chart datum, during a flood neap tide. The current meter was suspended in a gimballed metal frame 50 cm above the sea bed on a tension mooring (rather than sat on the sea bed), in order to ensure that the meter remained vertical at all times (Figure 2). The gimbal rings were checked in order to ensure that they were functioning correctly both before and after deployment.

Wind data over the deployment period was obtained from a weather station positioned on the shore near the cage site (Figure 1). Hourly averaged wind speed and direction were recorded each hour over the current meter deployment period.

Figure 1: Site location. Current meter deployment position (orange circle) and wind meter deployment position (blue circle) shown.

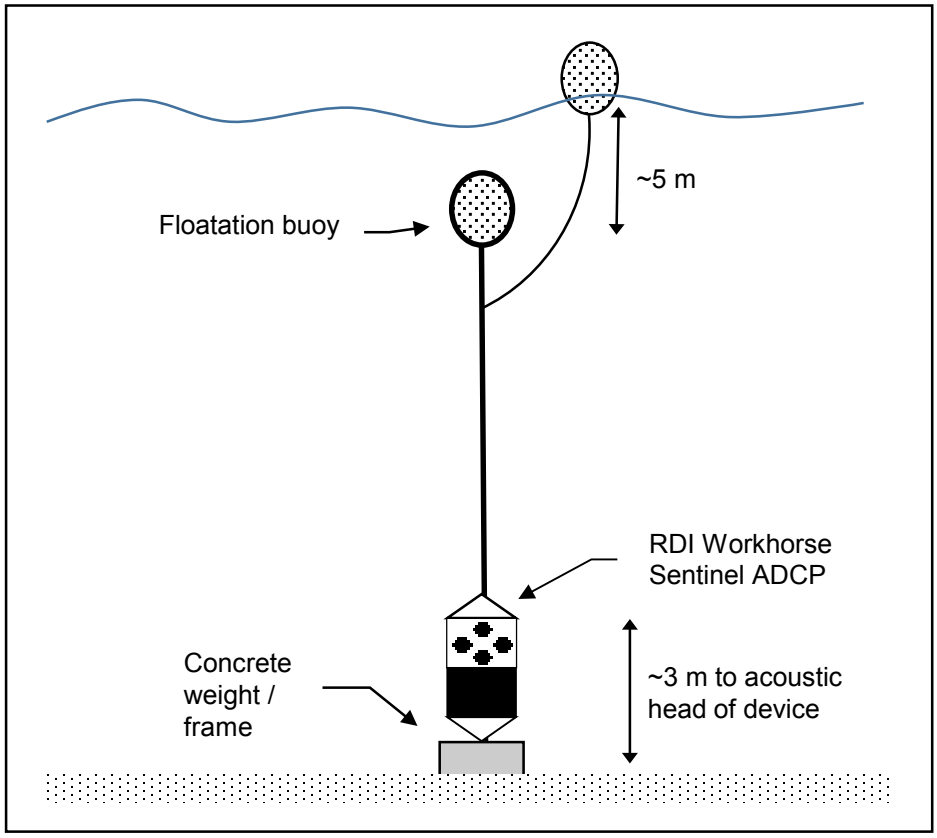

Figure 2:Schematic diagram to show deployment of current meter.

Data presentation

Data from each meter is presented numerically and pictorially, e.g. raw values, mean speed over deployment, scatter plot diagrams, cumulative vector diagrams and time series plots. Frequency and percentile analysis of the current and direction data will be supplied as outlined by SEPA (2005).

Data analysis was undertaken from ASCII files downloaded from the current meter using RD Instruments WinSC Ver 1.29. All graphs were plotted and calculations done using an MS ExcelTM spreadsheet. A compass correction of 4° 30' W 2006 (2° 42' E) was identified and used to convert all bearings from Magnetic to Grid North, using methods given by Ordnance Survey (see www.ordnancesurvey.co.uk). Positions were measured in lat/long (WGS84). Tides are calculated to chart datum using "Tide Plotter" software (Belfield Software, 2006).

SITE SURVEY

The current meter was placed within 150 m of the centre of the proposed cage block area and the position and depth was recorded. The position of a reference station (where the weather station was located) in proximity to this area was also recorded. The data is presented in Tables 1 and 2 below.

Table 1. Survey summary table (date 06/05/06)

Site	Time		Predicted Tidal Height (m)	Depth (m)		sat #	Duration
	BST	GMT		Sounding	(CD)		(min)
Surface Meter	N/A	1204	2.49	7.40	4.91	8	3
Net depth Meter	N/A	1204	2.49	10.40	7.91	8	3
Seabed Meter	N/A	1204	2.49	24.40	21.91	8	3

Table 2: Position of current meter/bathymetry reference station, mooring positions and cage group positions.

Site	Position WGS84	Depth (m) measured	Depth Chart Datum
Current Meter	56° 27.277 N 05° 15.622 W	27.5	25.01
Reference Station / Meteo-*rological Station	56° 26.683 N 05° 12.908 W	-	-

*Reference position at shore base

Table 3: Proposed positions of cage site lease area corners

Position	**(GPS position (Lat/Long**
Corner	56º 27.233' N, 005º 15.500' W
Corner	56º 27.208' N, 005º 15.598' W
Corner	56º 27.339' N, 005º 15.749' W
Corner	56º 27.344' N, 005º 15.717' W

Summary statement

All work described in this document abides by these high standards and has been undertaken impartially and with integrity. This report has been subject to the rigorous internal audit.

The current speeds recorded for the Doppler current meter were shown to follow the spring neap tidal cycle with faster currents occurring during or around the spring tide period. This, along with daily fluctuation, suggests that the meters are recording the currents accurately and there were no technical problems with them. Comparison of the fixed reference site position (and weather station) with the map reading shows no significant positional error. Therefore no correction for the position of the current meter was required.

The currents near the seabed were generally very slow, with a mean of only 0.03 $m.s^{-1}$, which for approximately 66% of the time the bottom water currents did not exceed, however faster peaks were evident during the spring tide period. Whilst at the surface and net depth, the mean current flow reached 0.074 $m.s^{-1}$ and 0.086 $m.s^{-1}$ respectively, with only 18-29% of these flows being less than 0.03 $m.s^{-1}$, again faster flows were detected during the spring tide period.

At the surface and net depth the direction of the current flow was to the north-west, whilst at the seabed the water flow was predominantly to the south-east. We believe the readings are a true reflection of the current speeds, as typically water flow in deep basins within fjordic systems is minimal in calm conditions. For modelling purposed it is presumed that the bulk of the particulate transport from the cages will be due to the surface and net depth flows, with little influence from the bottom currents.

The surface currents presented were measured from a bin at a depth of 4.31 – 6.31 m as the data from shallower bins was rejected as showing evidence of interference (as often seen in Doppler meter data within 4 m of the surface). The depths referred to were actual recorded depths, and not corrected to chart datum. As the tidal range above chart datum at this site was 2.49 m at the time of deployment, this equates to the bin depth range being 1.82-3.82 m to chart datum.

For the majority of the time the wind speeds were fairly slow and varied from 0.2 to 7.3 m.s-1 (approximately 0.4 to 14 knots). Wind direction was predominantly between 40° and 50°, though a large proportion of winds were 260°. It is unlikely that these winds would have significantly affected the water currents during the deployment due to the short fetch or degree of shelter the position of the site provides.

The pressure record (indicating tidal curves over the deployment period) was found to be unusual, and so these were compared with the pressure records from 2 sets of Valeport current meters (1 set of 106s and 1 set of 308s) that were deployed within 50 m of the ADCP current meter, over the same survey period. The pressure records from these other current meters were highly similar, giving confidence that the ADCP pressure records were representative of the conditions of the site during the period of survey.

SUMMARY STATISTICS

Tables 3 and 4 below provide details of the specifications and set-up of the current meters utilised in this survey.

Table 3. Equipment specifications

	Accuracy	Precision	Resolution	Range
Speed	at ±0.3 cm.s^{-1} 0.3%	-	cm.s^{-1} 0.1	(cm.s-1 (default ±5 (cm.s-1 (max ±20
Direction	* °±2	* ±0.5°	0.01°	Max tilt ±15°
Pressure	-	±1.5dB	Depth cell size	80dB
Tilt/Roll	±0.5°	±0.5°	0.01°	±15°
Temperature	-	±0.4°C	0.01°	-5° to 45°C

Table 4. Equipment setup

	(Mean Depth* (m	Resolution (interval in mins)	(Frequency (per hour	No. of Records
Surface	7.5	20	3	1081
Net depth	10.5	20	3	1081
Seabed	24.5	20	3	1081

* The acoustic head of the seabed current meter was positioned 3 m above the seabed.

Table 5. Summary data for the 3 current meters

	Mean speed ((m.s^{-1}	% mean speed	% 0.03≥ m.s^{-1}	Tidal current amplitude m.s^{-1}		Components of current residual m.s^{-1}		Tidal el-*lipse axis	Residual current	
				U	V	U	V		Speed (m.s^{-1})	.Direct (°GdN)
Surface	0.074	58.3	29.0	0.116	0.047	0.029	-0.006	340-160°	0.030	122.4
Mid	0.086	54.1	18.0	0.125	0.041	0.036	-0.011	340-160°	0.038	127.2
Seabed	0.030	66.2	66.0	0.045	0.021	0.006	0.001	160-340°	0.006	278.2

* Estimated from observation of scatter plot

Table 6. Current direction frequency analysis for surface data

Current direction frequency bins (Degrees)	Frequency of readings in bin
000 > to <=010	19
010 > to <=020	20
020 > to <=030	12
030 > to <=040	12
040 > to <=050	5
050 > to <=060	5
060 > to <=070	10
070 > to <=080	5
080 > to <=090	11
090 > to <=100	4
100 > to <=110	9
110 > to <=120	7
120 > to <=130	19
130 > to <=140	35
140 > to <=150	54
150 > to <=160	58
160 > to <=170	40
to <=180 <170	25
180 > to <=190	24
190 > to <=200	17
200 > to <=210	13
210 > to <=220	7
220 > to <=230	9
230 > to <=240	6
240 > to <=250	7
250 > to <=260	7
260 > to <=270	8
270 > to <=280	13
280 > to <=290	16
290 > to <=300	27
300 > to <=310	54
310 > to <=320	99
320 > to <=330	98
330 > to <=340	129
340 > to <=350	94
350 > to <=360	103

Table 7. Current direction frequency analysis for net depth (cage bottom) data

Current direction frequency bins (Degrees)	Frequency of readings in bin
000 > to <=010	24
010 > to <=020	9
020 > to <=030	6
030 > to <=040	6
040 > to <=050	6
050 > to <=060	3
060 > to <=070	2
070 > to <=080	4
080 > to <=090	3
090 > to <=100	2
100 > to <=110	5
110 > to <=120	9
120 > to <=130	9
130 > to <=140	21
140 > to <=150	45
150 > to <=160	81
160 > to <=170	71
170> to <=180	47
180 > to <=190	36
190 > to <=200	13
200 > to <=210	9
210 > to <=220	9
220 > to <=230	5
230 > to <=240	10
240 > to <=250	8
250 > to <=260	10
260 > to <=270	10
270 > to <=280	16
280 > to <=290	18
290 > to <=300	34
300 > to <=310	50
310 > to <=320	90
320 > to <=330	104
330 > to <=340	134
340 > to <=350	105
350 > to <=360	67

Table 8. Current direction frequency analysis for seabed data

Current direction frequency bins (Degrees)	Frequency of readings in bin
000 > to <=010	20
010 > to <=020	24
020 > to <=030	17
030 > to <=040	12
040 > to <=050	8
050 > to <=060	15
060 > to <=070	9
070 > to <=080	5
080 > to <=090	19
090 > to <=100	5
100 > to <=110	23
110 > to <=120	23
120 > to <=130	30
130 > to <=140	48
140 > to <=150	74
150 > to <=160	103
160 > to <=170	82
170> to <=180	68
180 > to <=190	30
190 > to <=200	24
200 > to <=210	23
210 > to <=220	23
220 > to <=230	12
230 > to <=240	21
240 > to <=250	15
250 > to <=260	13
260 > to <=270	20
270 > to <=280	18
280 > to <=290	27
290 > to <=300	28
300 > to <=310	29
310 > to <=320	37
320 > to <=330	37
330 > to <=340	46
340 > to <=350	46
350 > to <=360	47

Table 9. Current speed percentile values

Depth	Percentile										
	0	**1**	**5**	**10**	**25**	**50**	**75**	**90**	**95**	**99**	**100**
Surface	0	0	0	0.01	0.03	0.06	0.1	0.15	0.18	0.24	0.45
Net depth	0	0.01	0.02	0.02	0.05	0.08	0.11	0.16	0.18	0.232	0.29
Seabed	0	0	0.01	0.01	0.02	0.03	0.04	0.06	0.07	0.082	0.11

Hydrographic Data Plots

The data collected by the Doppler current meter can be visualised using graphs and vector plots. The following section provides the data in pictorial form for the surface, net depth and seabed bins respectively.

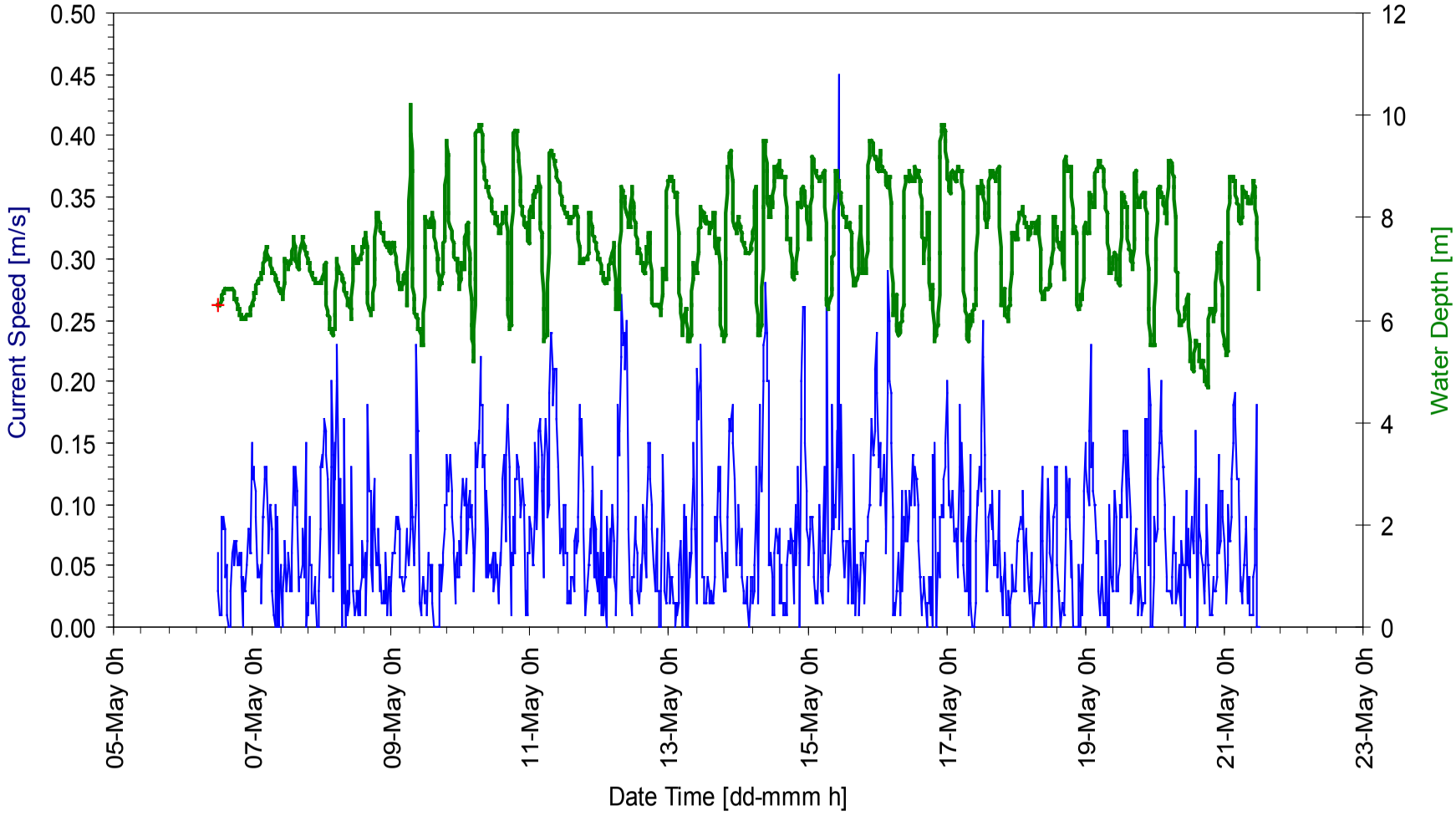

Figure 3. Time-series of current speed and water depth from surface waters, 6 to 21 May 2006.

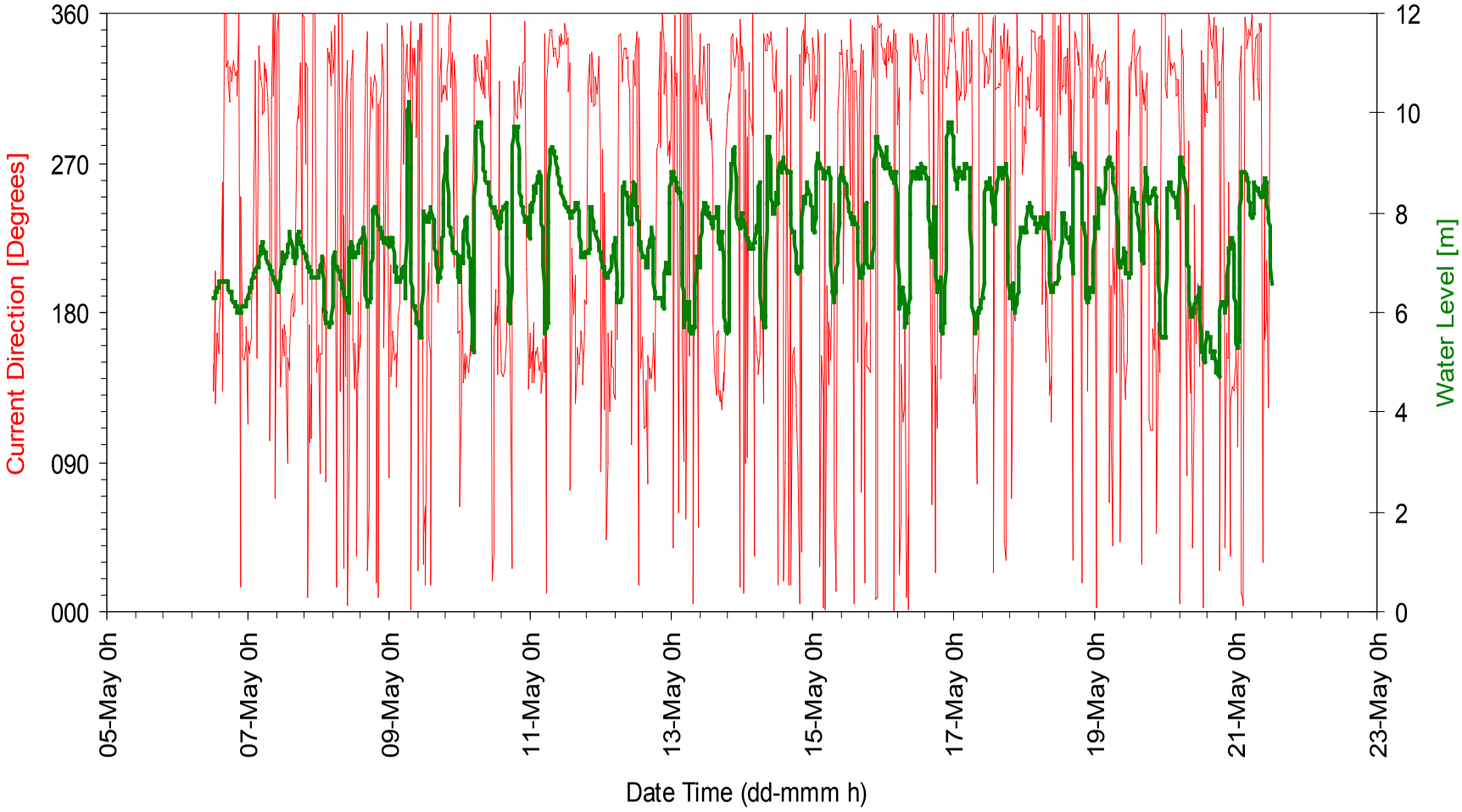

Figure 4. Time-series of direction and depth for the surface waters, 6 to 21 May 2006.

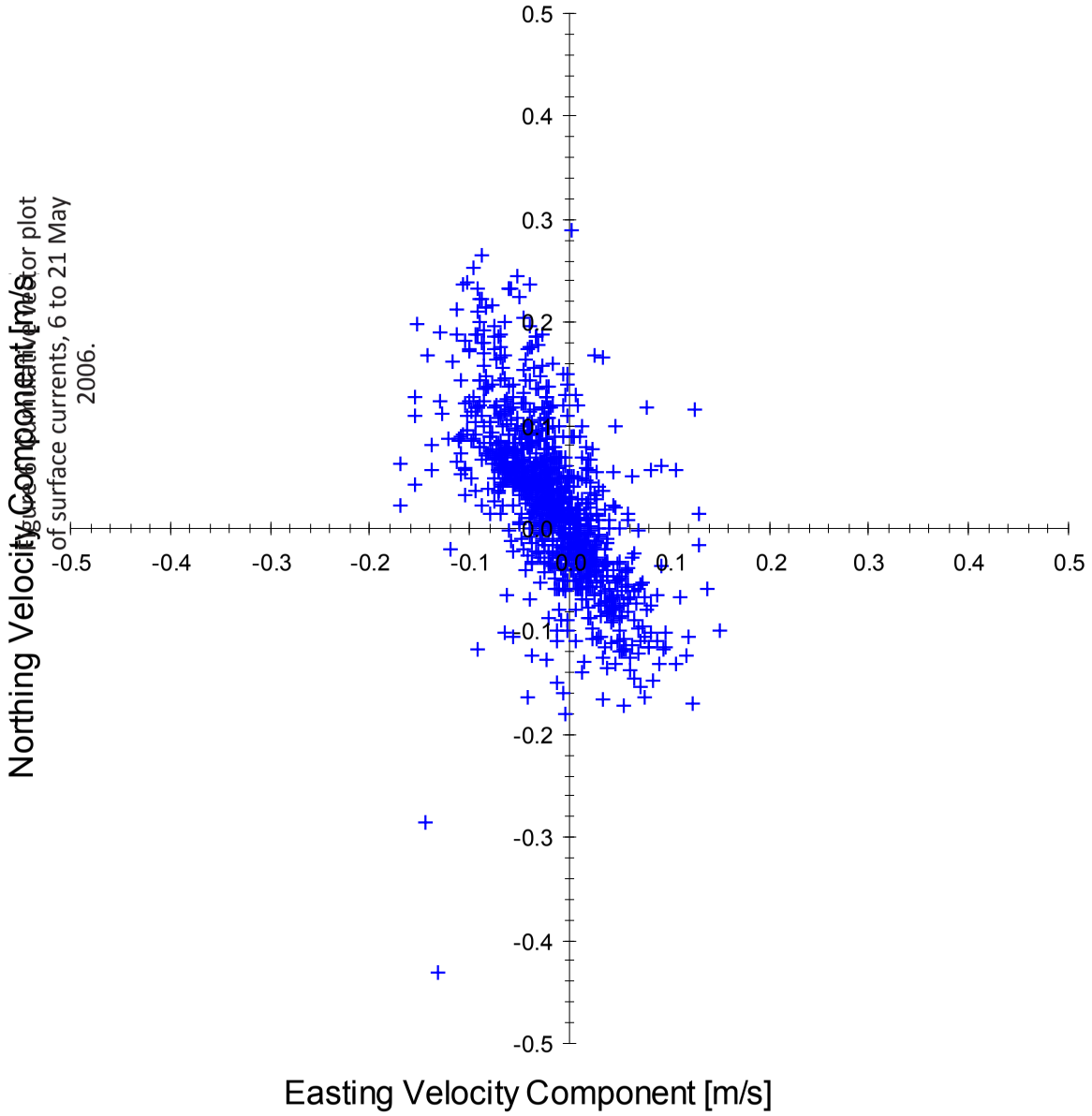

Figure 5. Scatter plot of surface currents, 6 to 21 May 2006.

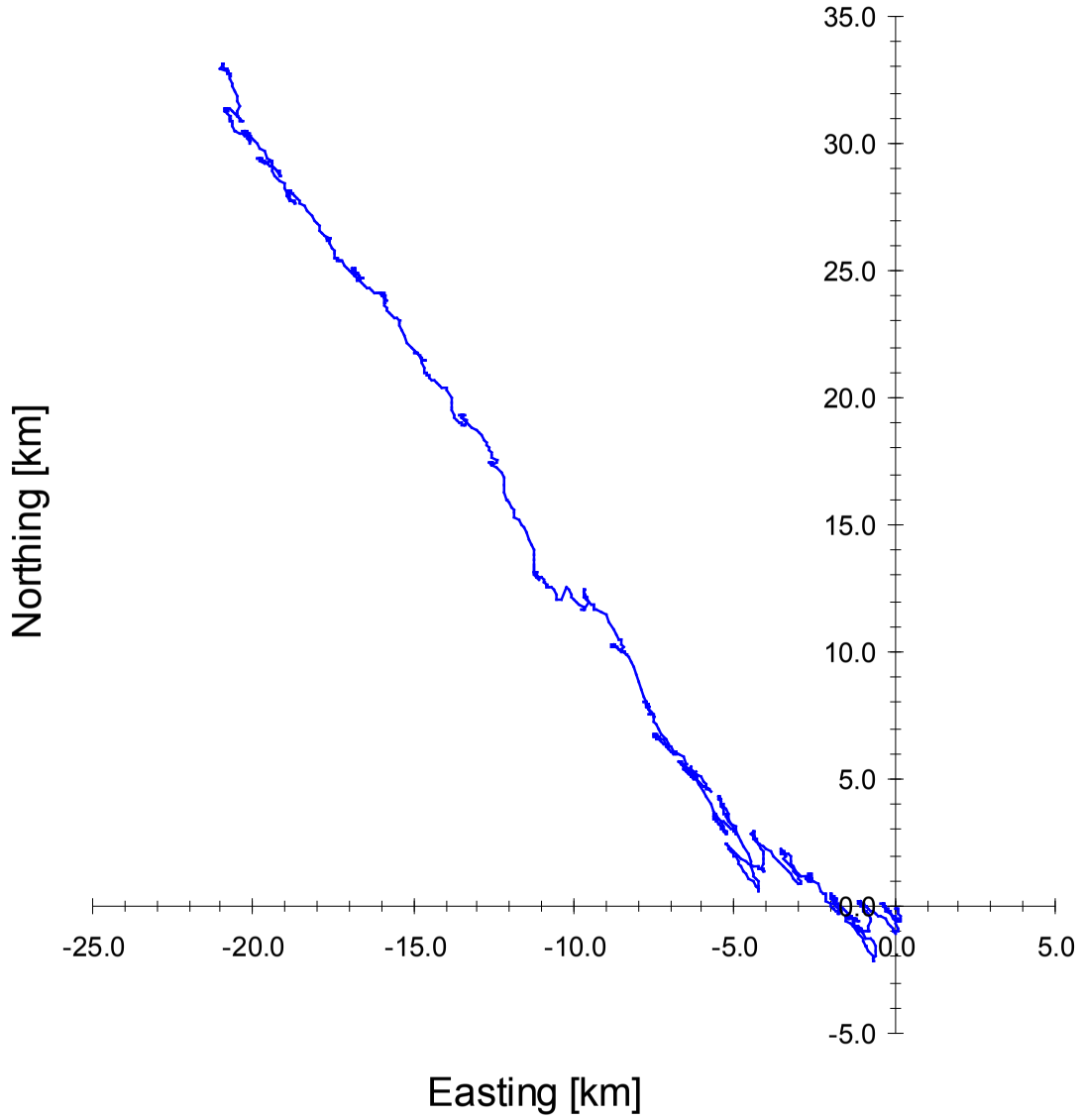

Figure 6. Cumulative vector plot of surface currents, 6 to 21 May 2006.

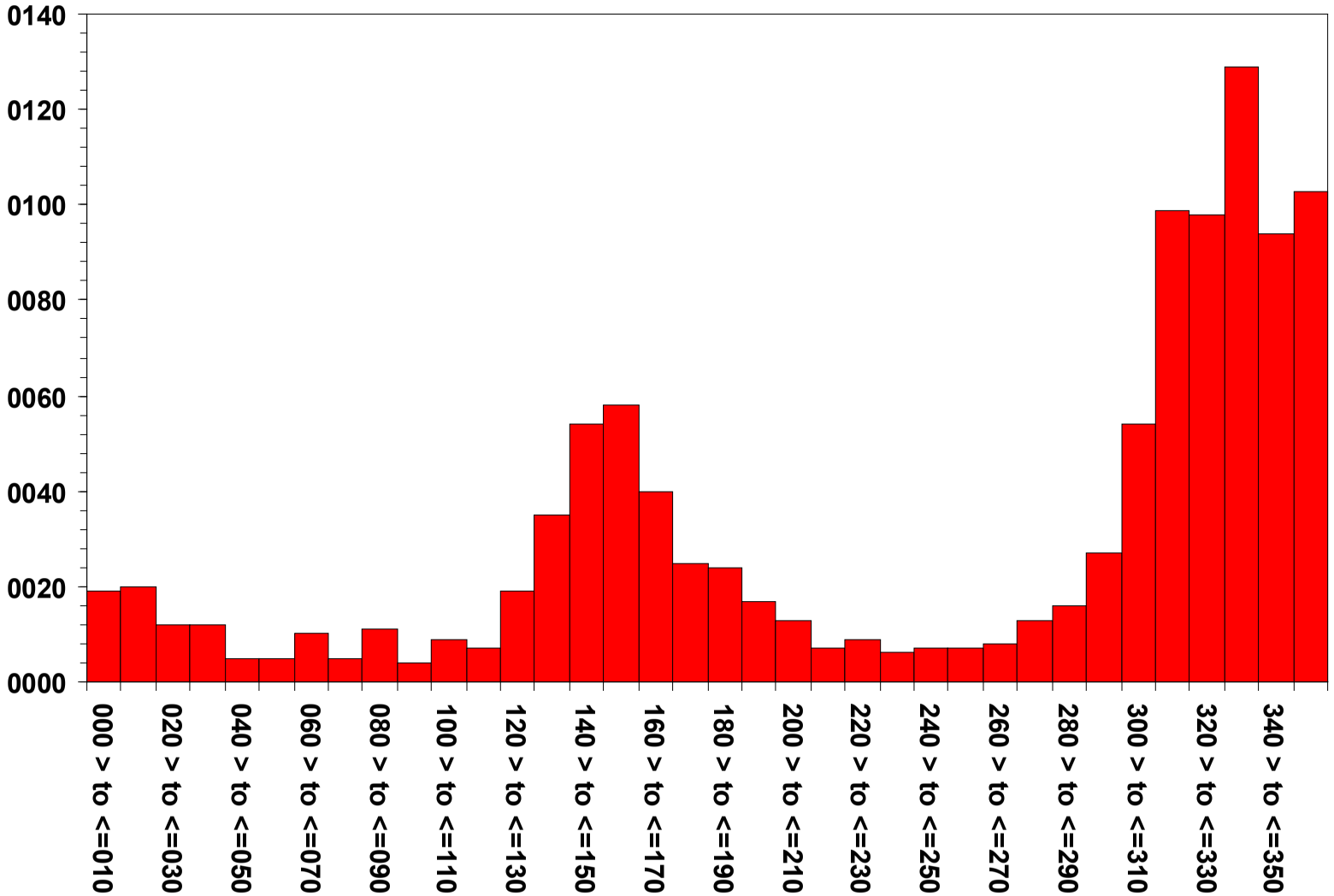

Figure 7. Bar chart of direction-frequency analysis for surface currents, 6 to 21 May 2006.

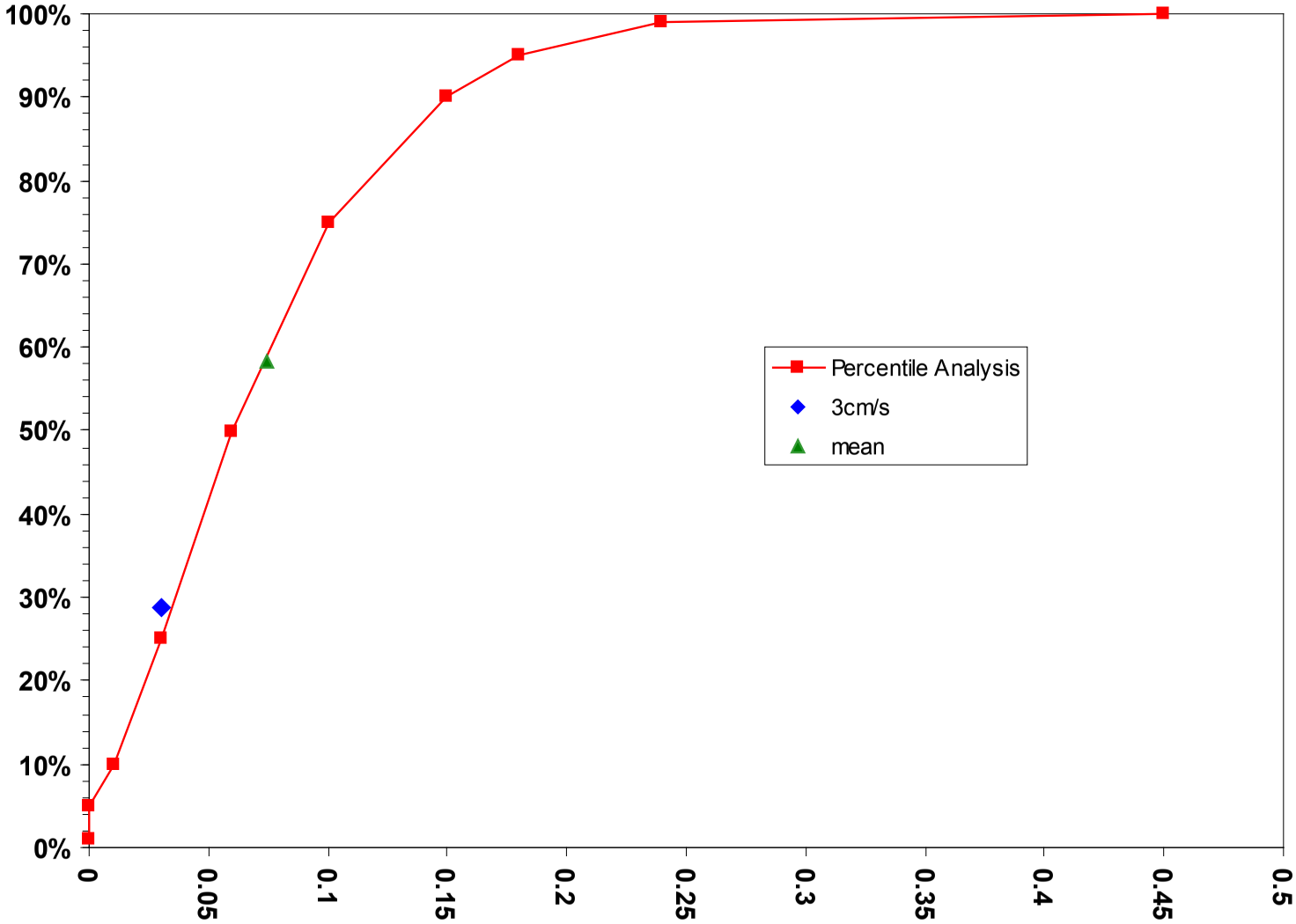

Figure 8. Current speed against percentile for surface currents, 6 to 21 May 2006.

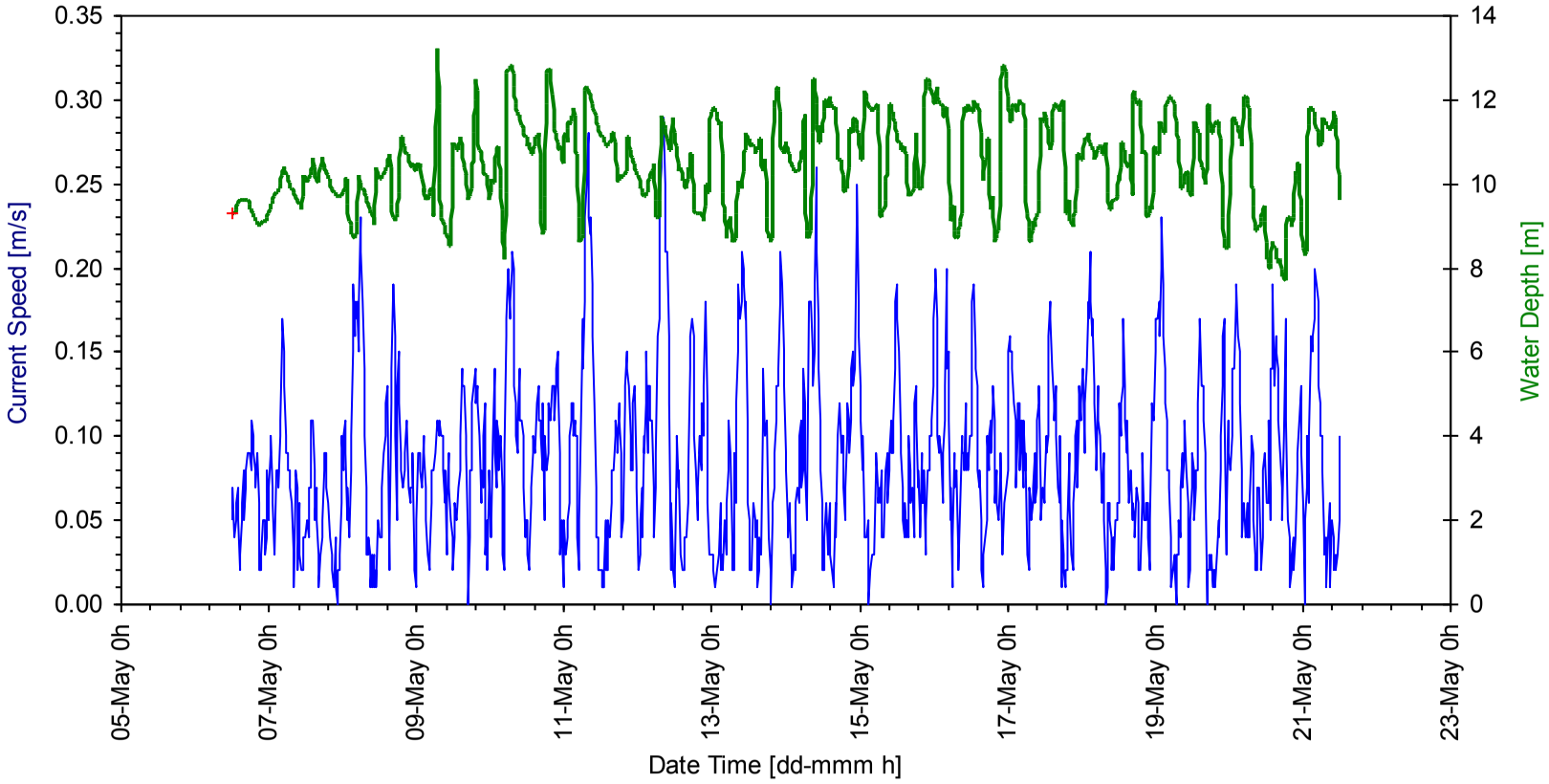

Figure 9. Time-series of current speed and water depth from net depth meter, 6 to 21 May 2006.

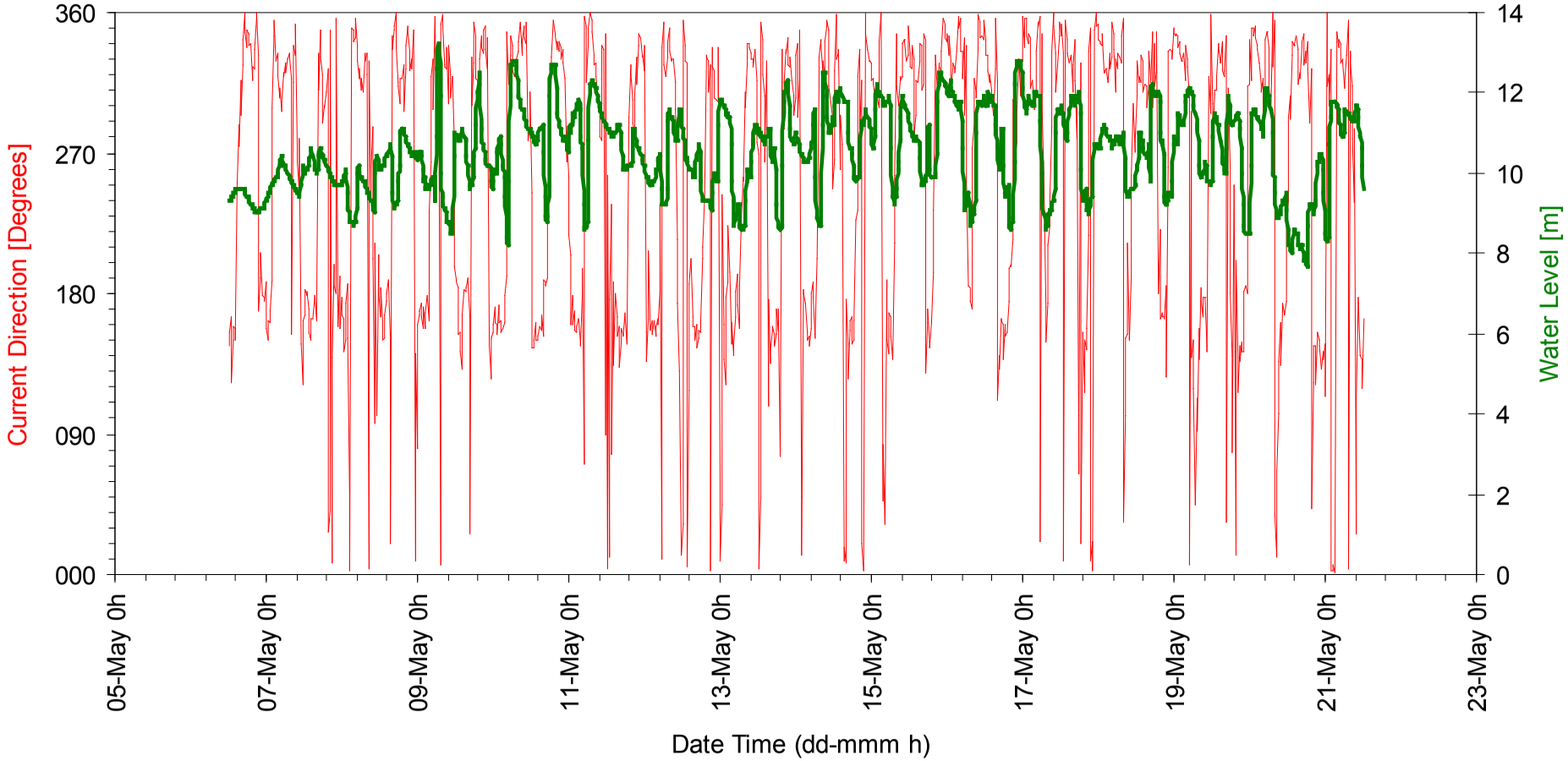

Figure 10. Time-series of direction and water depth from the net depth meter, 6 to 21 May 2006.

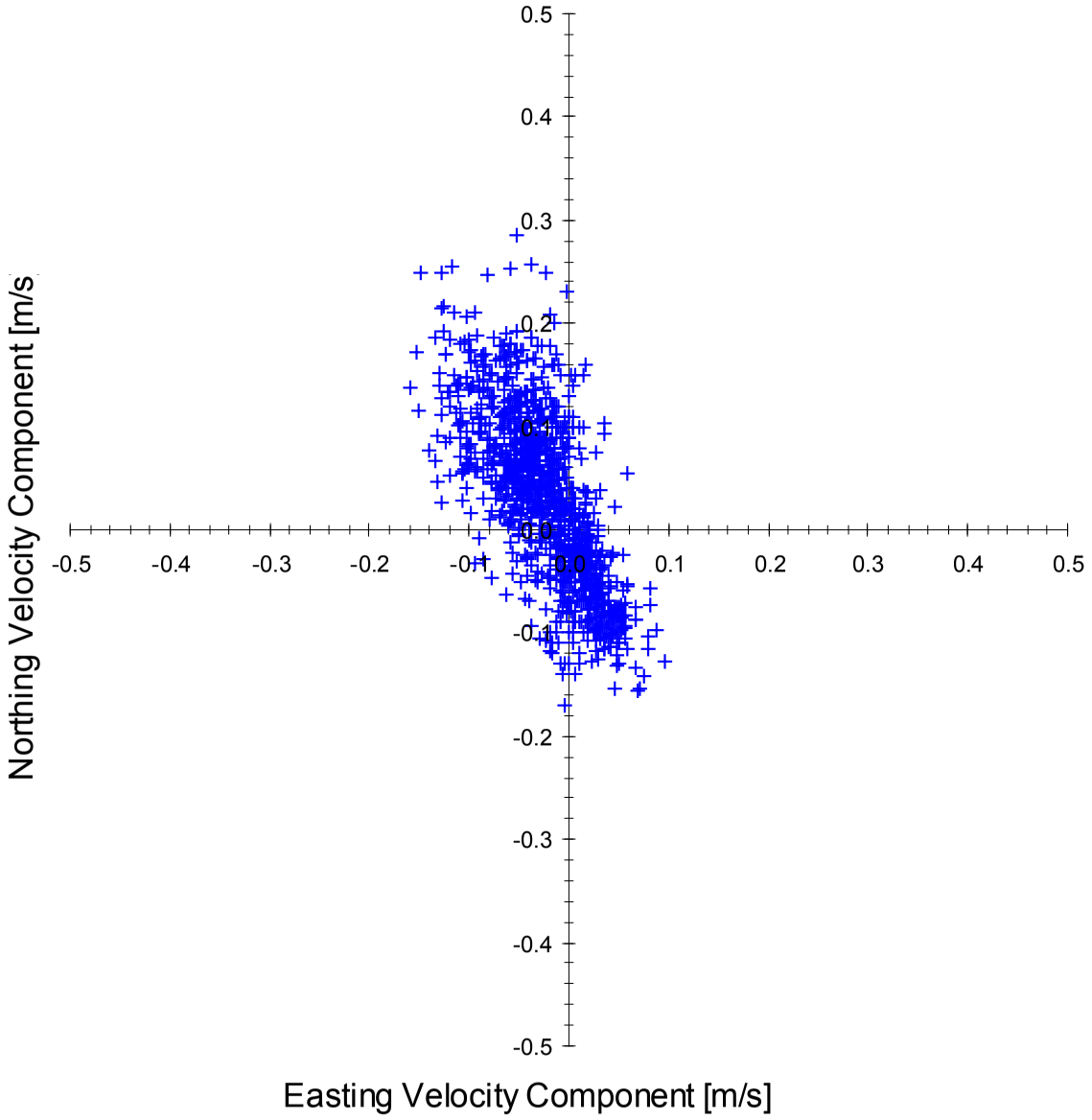

Figure 11. Scatter plot net depth currents, 6 to 21 May 2006.

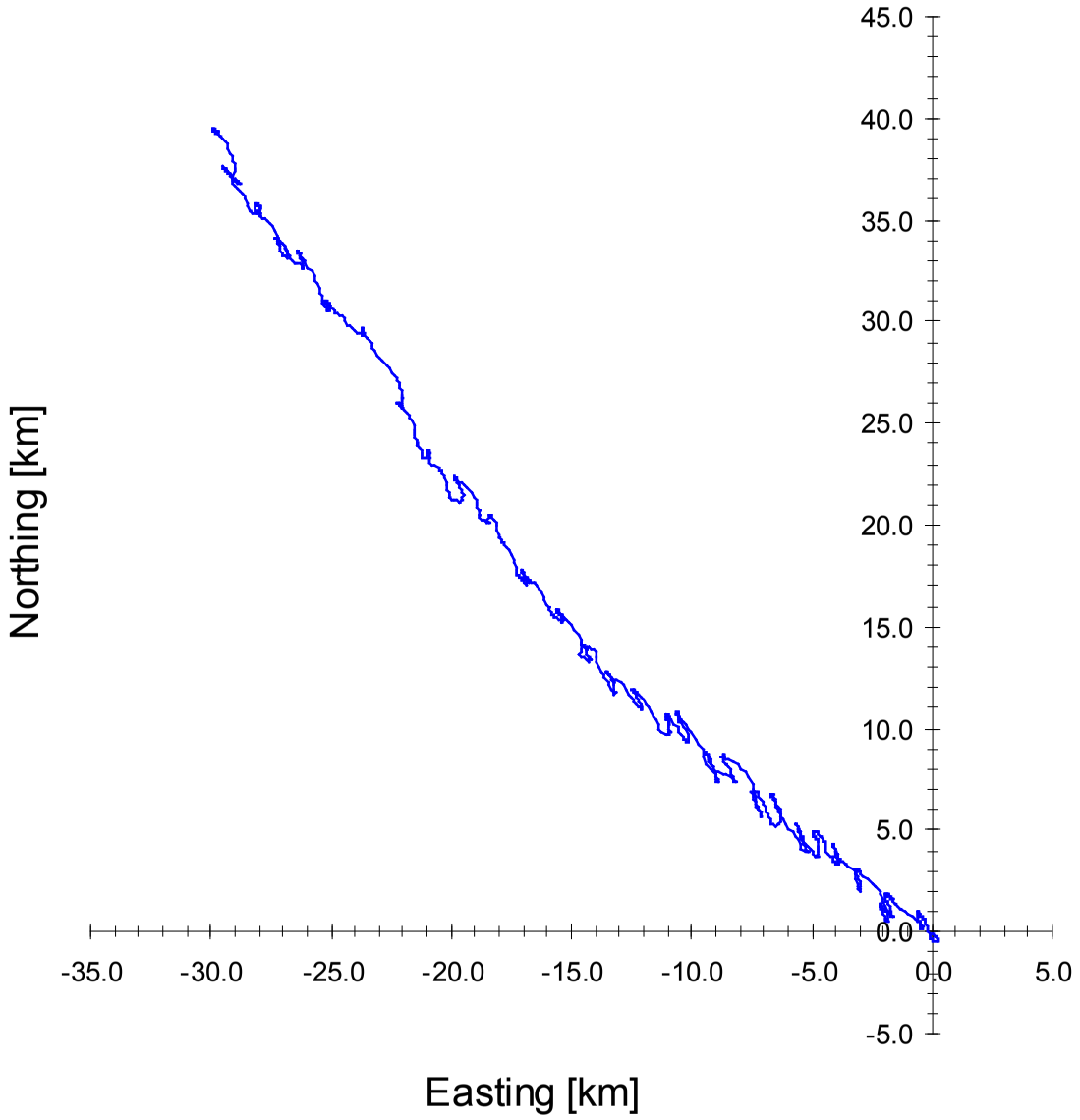

Figure 12. Cumulative vector plot of net depth currents, 6 to 21 May 2006.

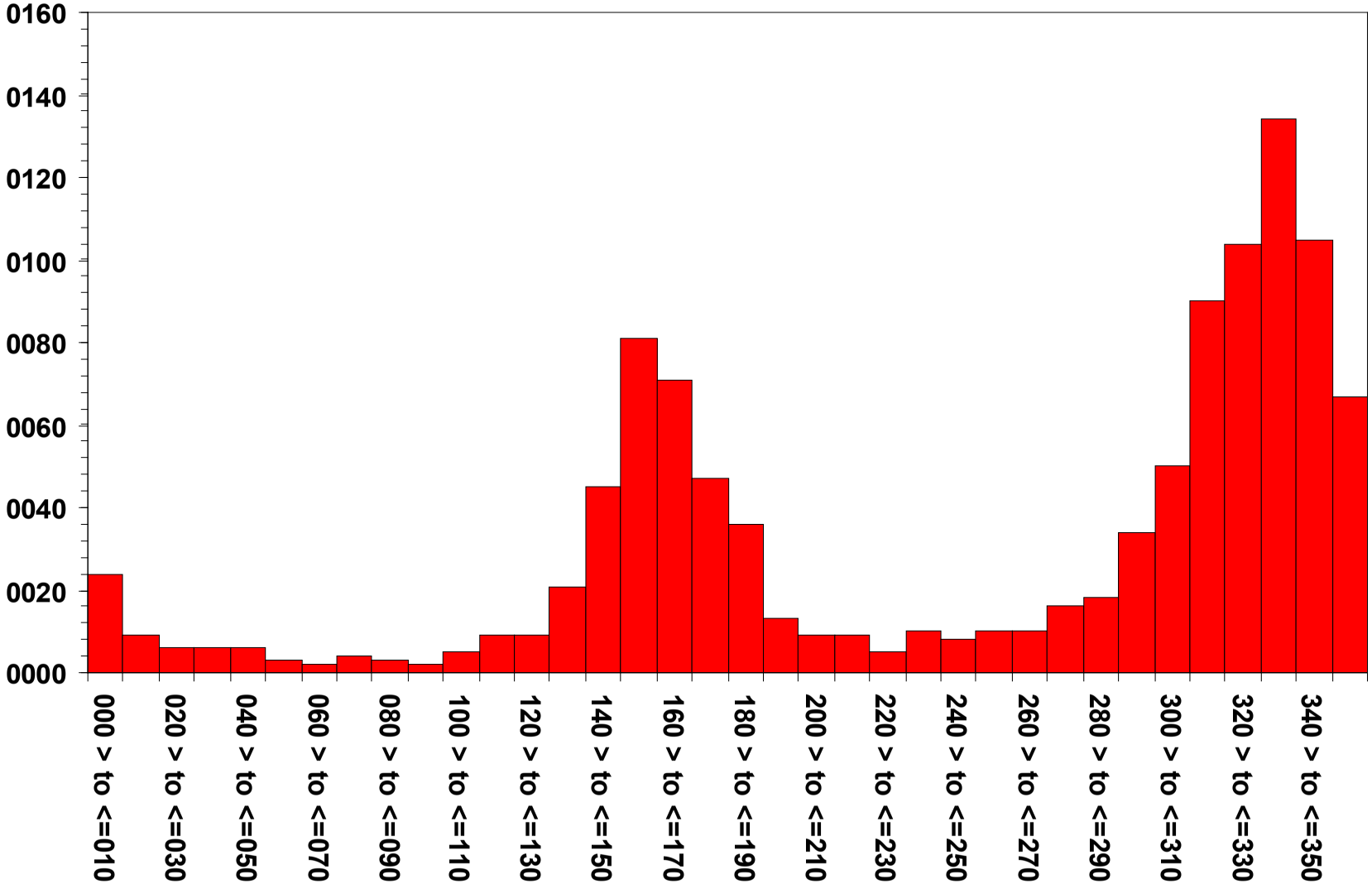

Figure 13. Bar chart of direction-frequency analysis for net depth currents, 6 to 21 May 2006.

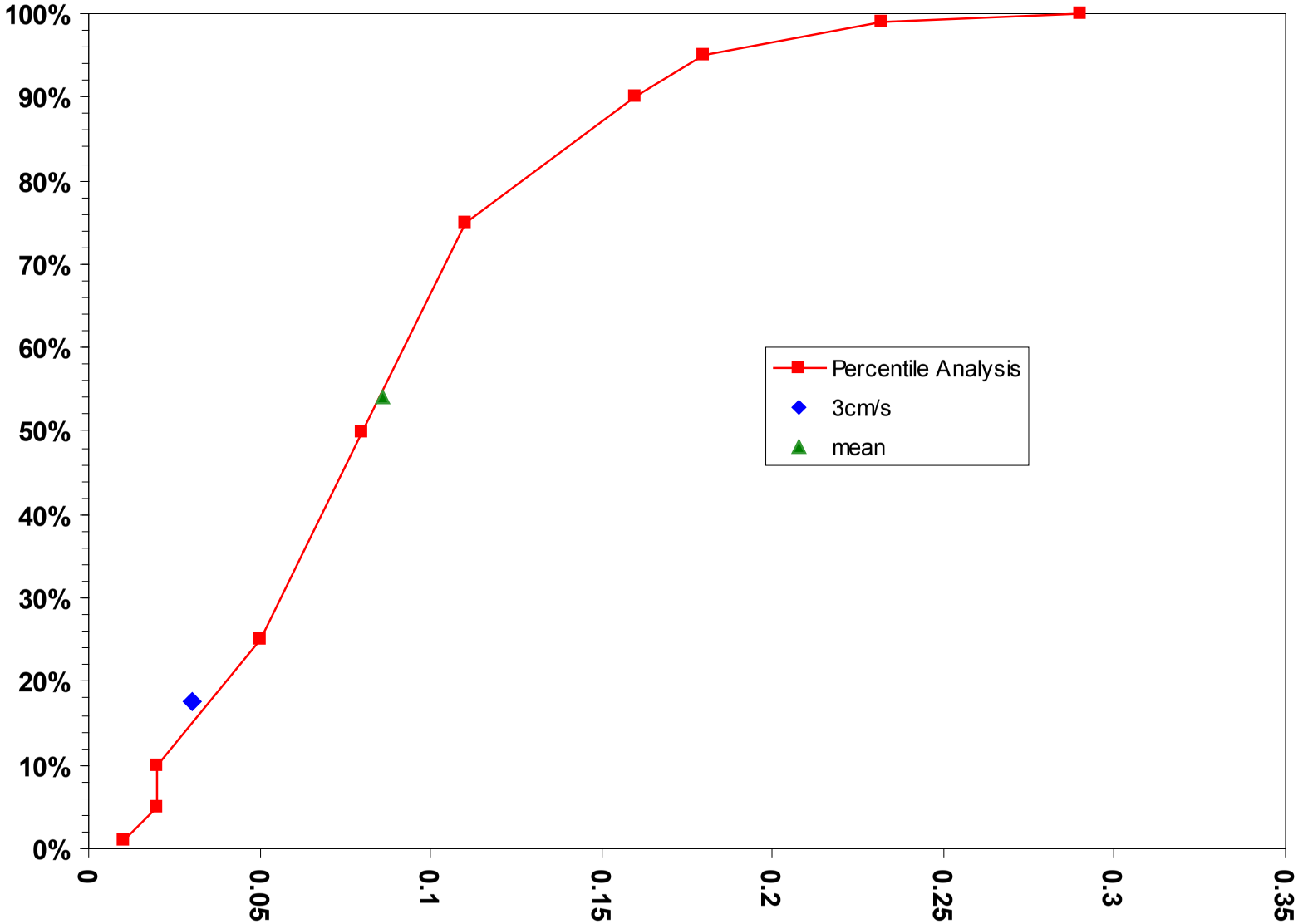

Figure 14. Current speed against percentile for net depth currents, 6 to 21 May 2006.

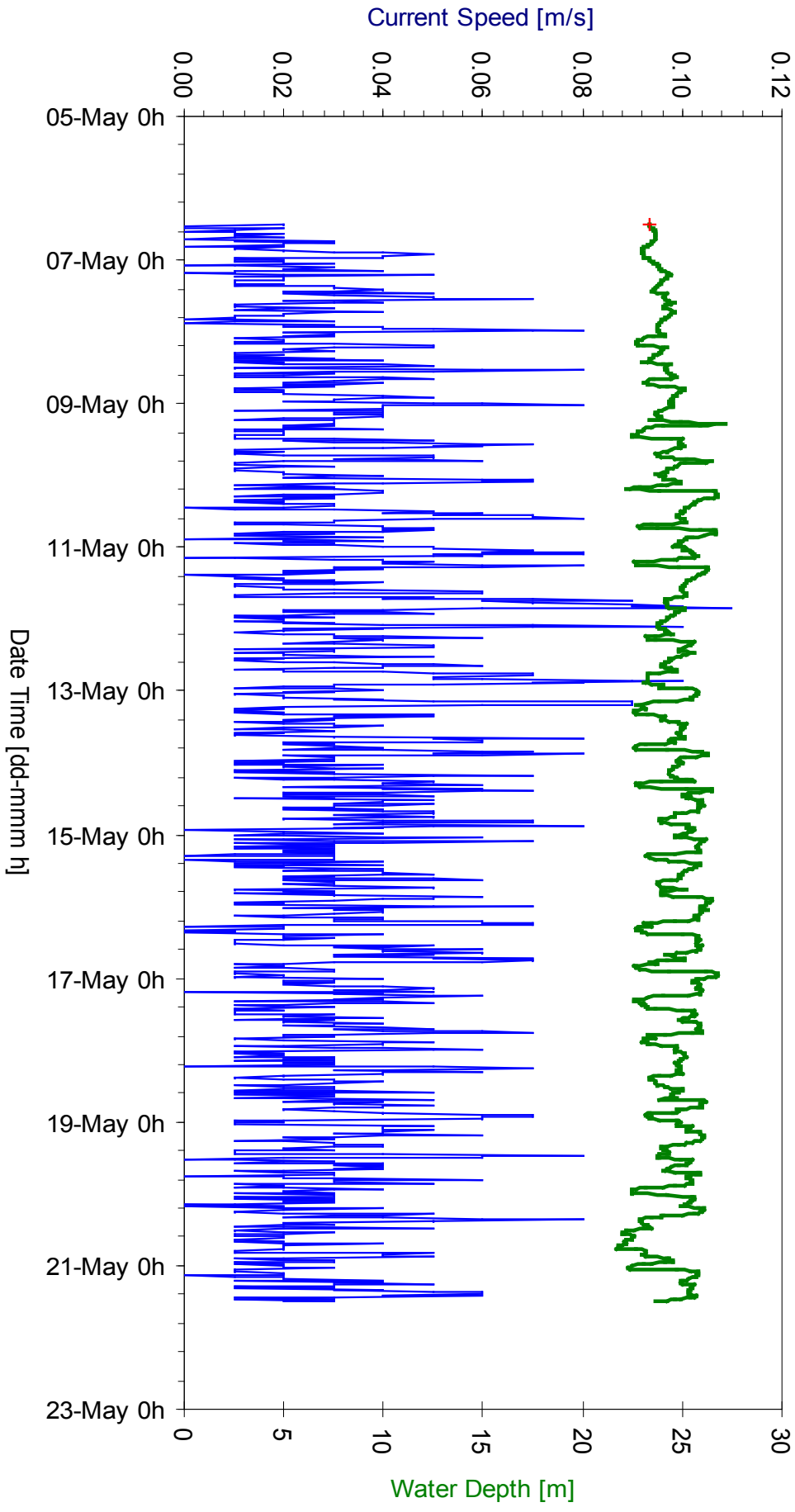

Figure 15. Time-series of speed and water depth at the seabed, 6 to 21 May 2006.

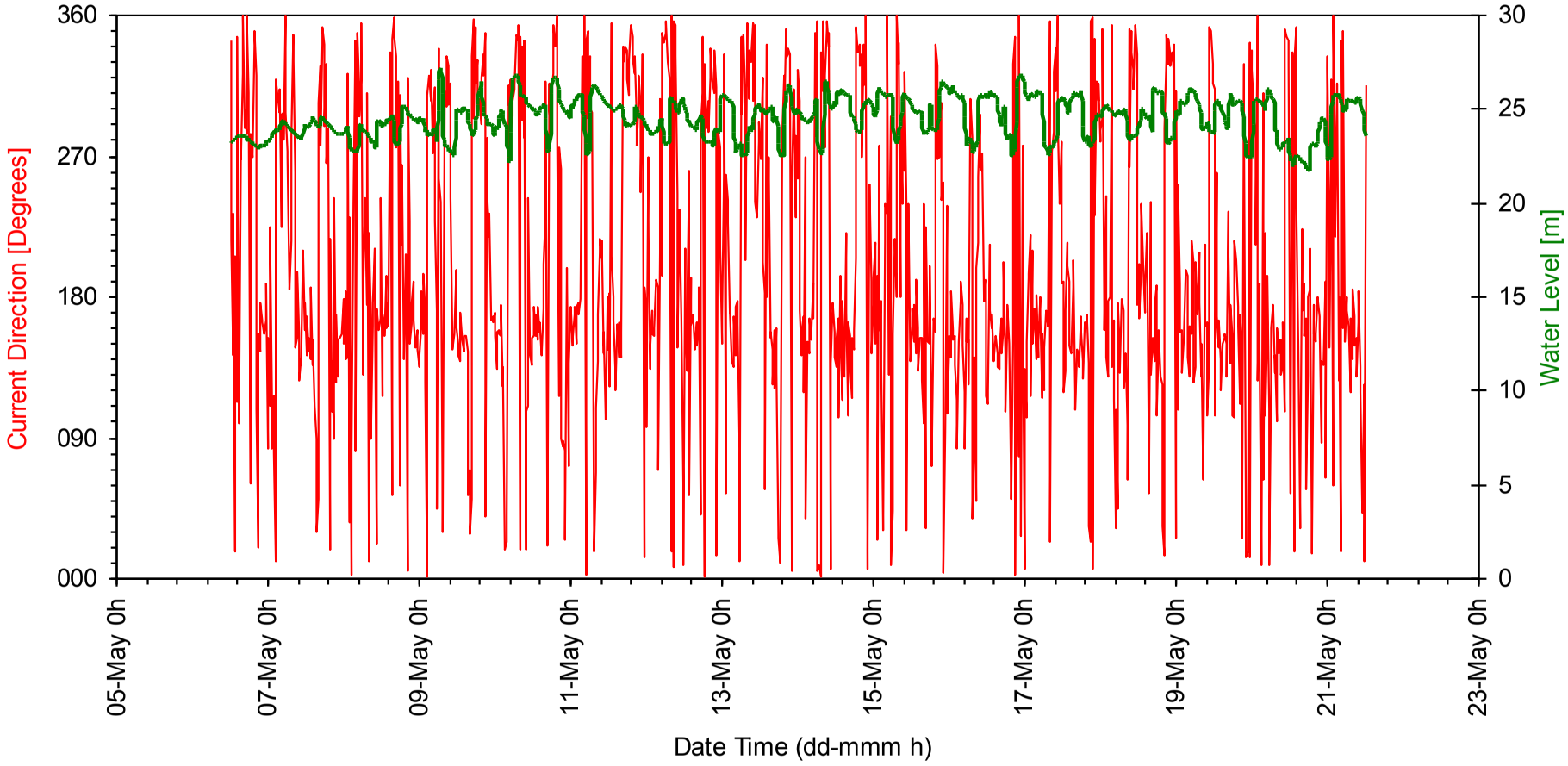

Figure 16. Time-series of direction and depth at the seabed, 6 to 21 May 2006.

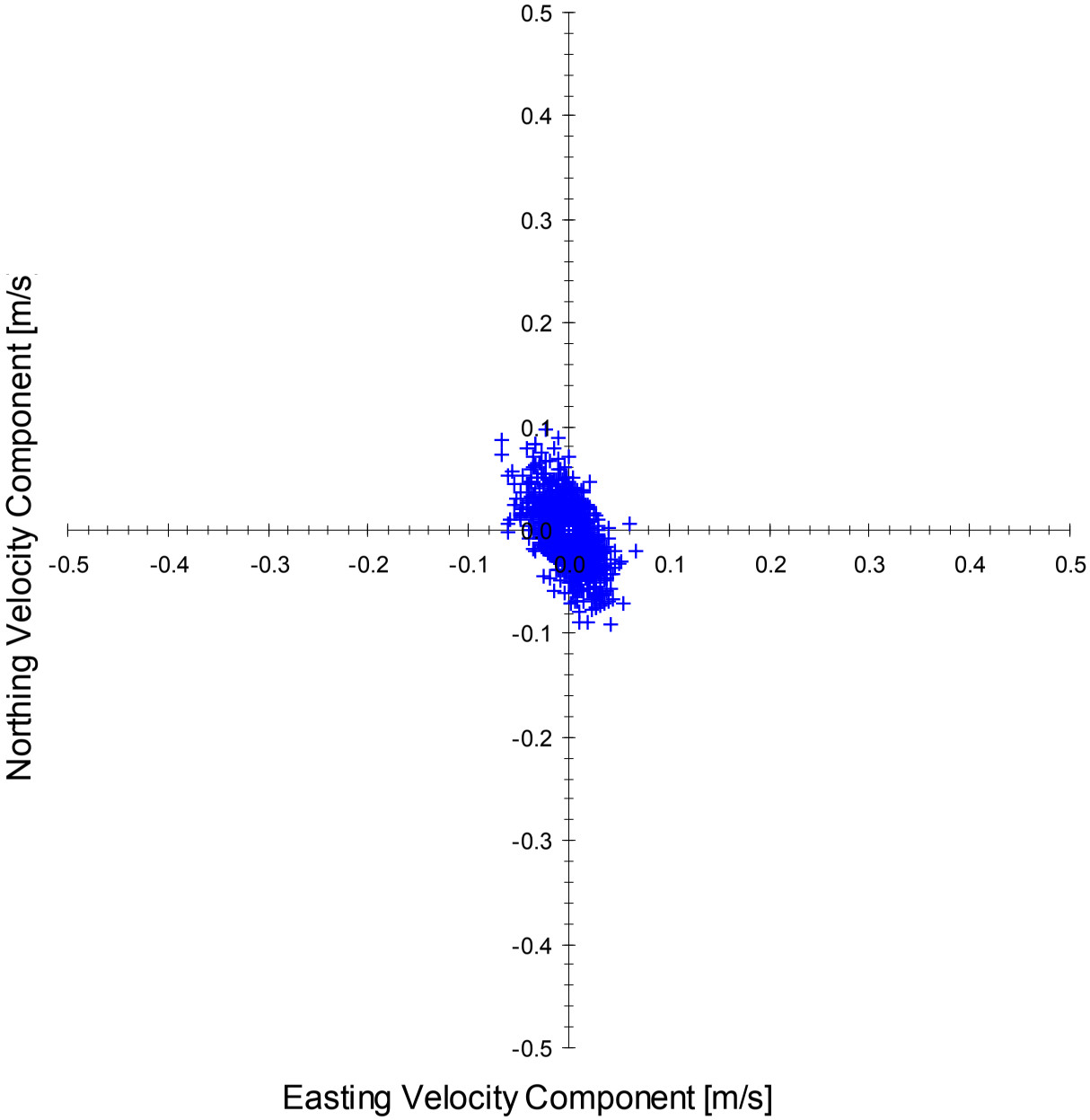

Figure 17. Scatter plot of seabed currents, 6 to 21 May 2006.

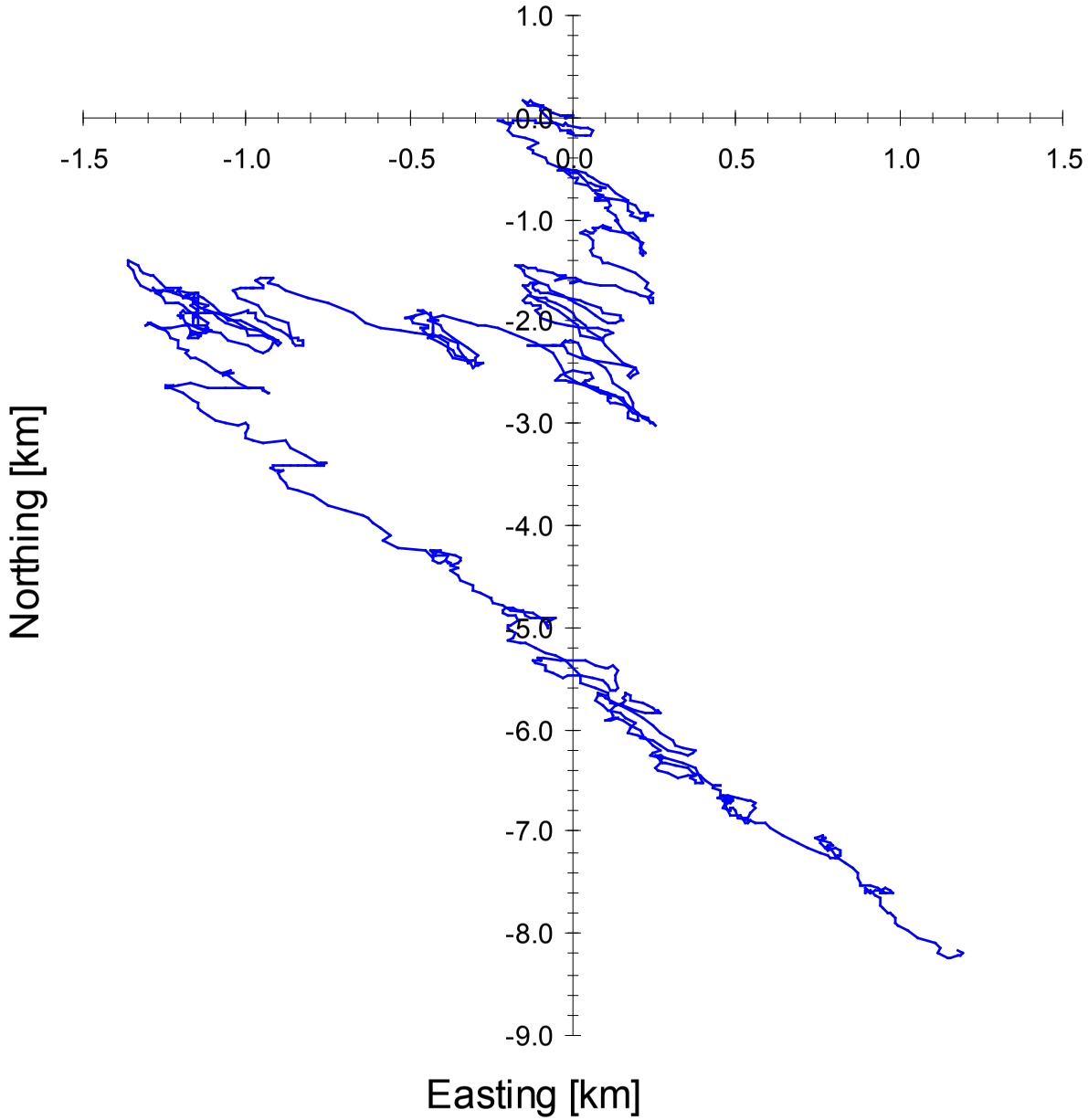

Figure 18. Cumulative vector plot of seabed currents, 6 to 21 May 2006.

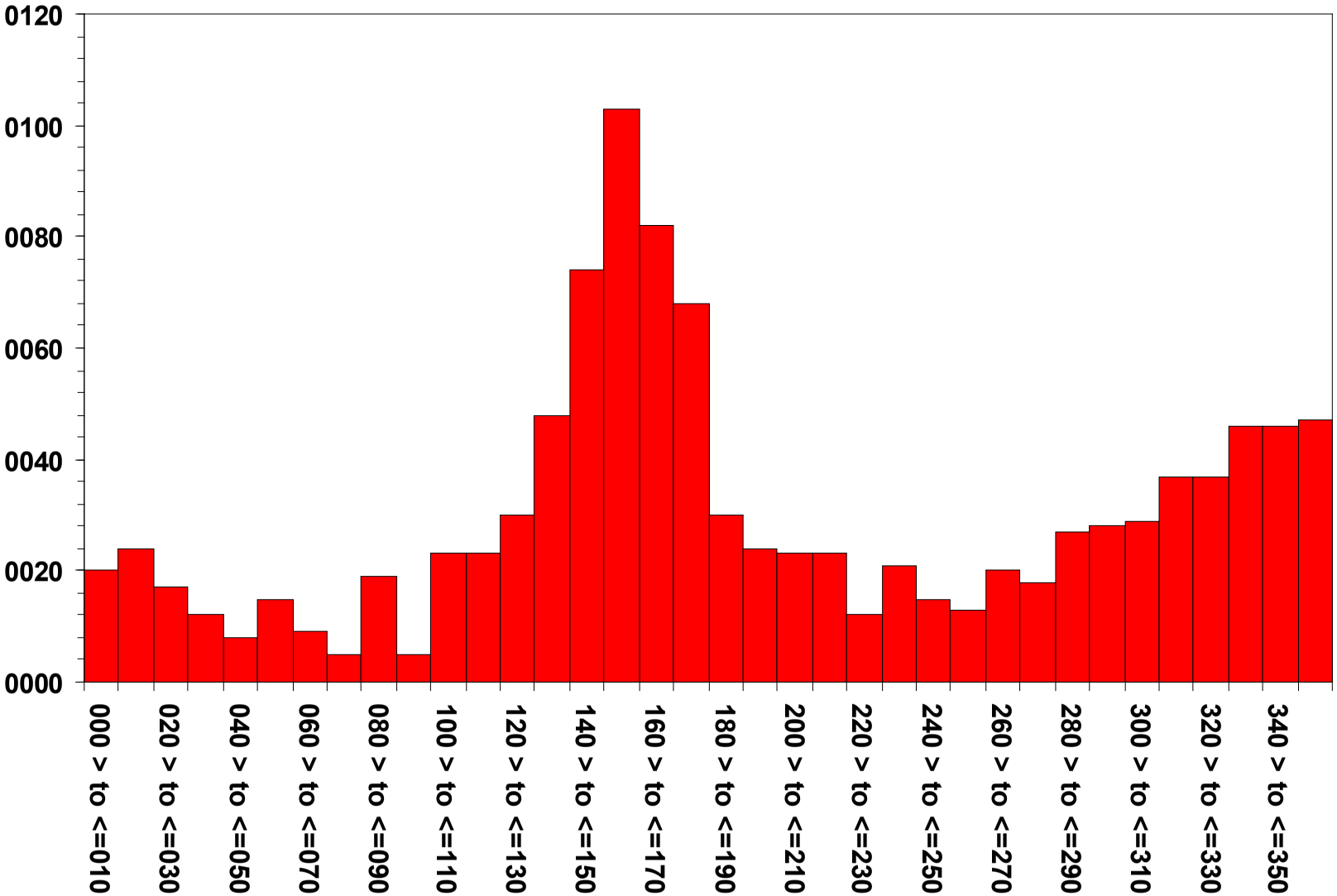

Figure 19. Bar chart of direction-frequency analysis for seabed currents, 6 to 21 May 2006.

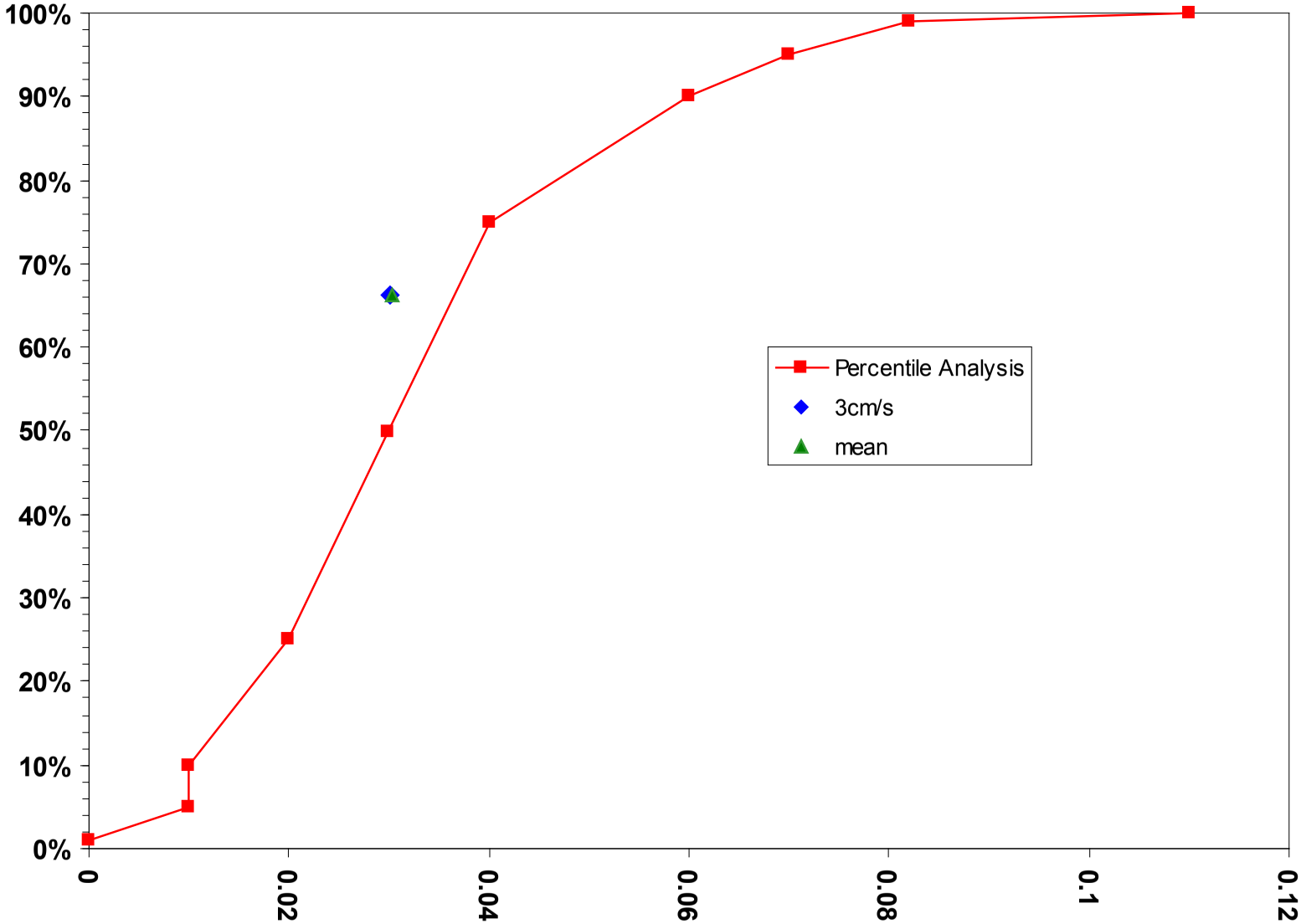

Figure 20. Current speed against percentile at the seabed, 6 to 21 May 2006.

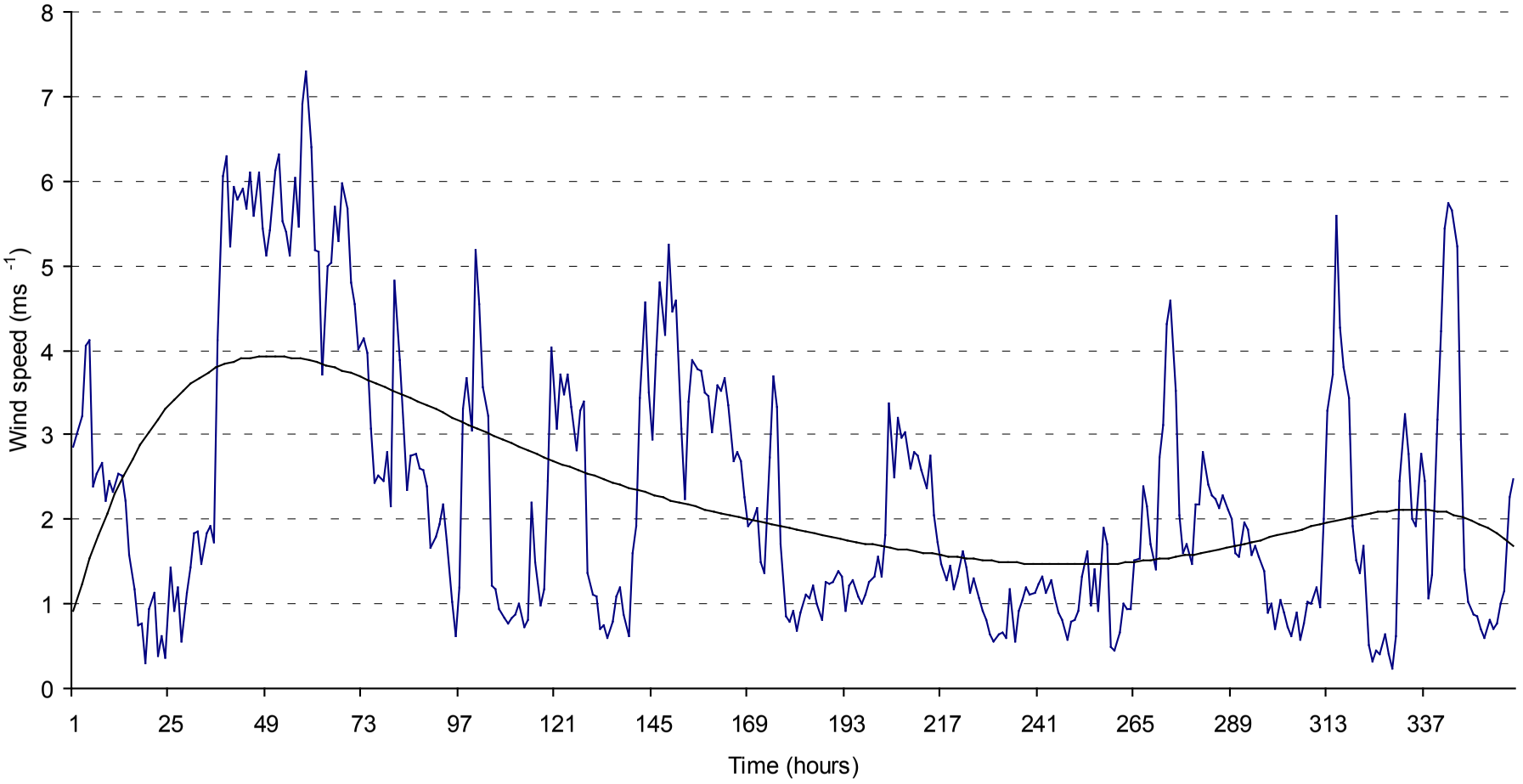

Figure 21. Wind speed ($m.s^{-1}$) over the current meter deployment period (12:00pm on 6th May to 10:00am on 21 May, 2006).

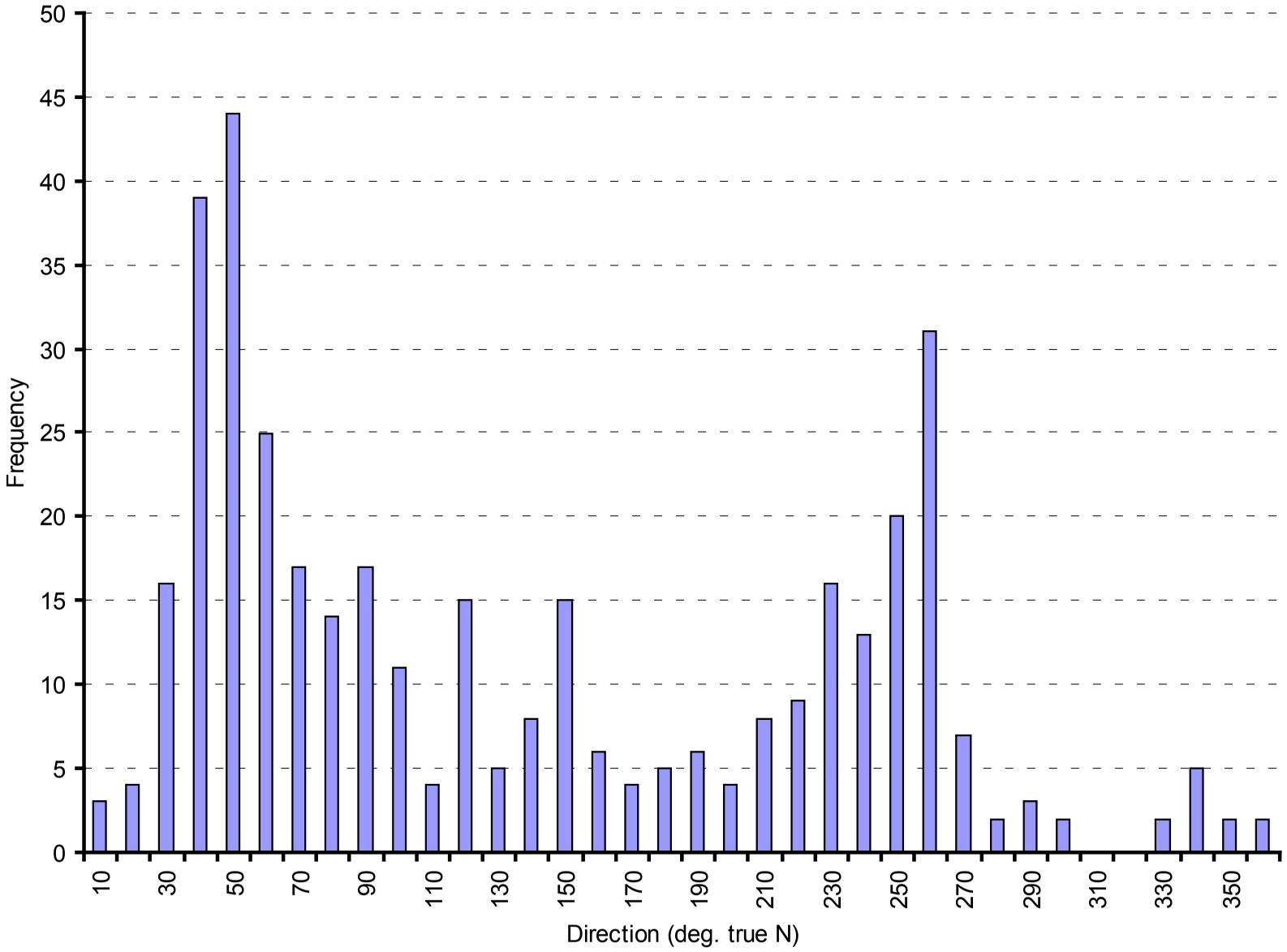

Figure 22. Frequency histogram of wind direction during current meter deployment period, 6 to 21 May 2006.

List any reference material used.

Appendix 2: Videographic / Photographic survey report, including physiochemical parameters

VIDEOGRAPHIC BENTHIC MONITORING REPORT: {SITE NAME} FISH FARM

Issued: {DATE}

By: {AUTHOR}

Position and address of company who conducted survey inserted here

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Introduction

This report presents the results of a level 1 environmental monitoring survey at a fish grow-out sea-cage site at {site name}, the site sits approximately 500 m off the east side of {place}, which provides a reasonable degree of shelter from Atlantic swells. The edge of the Island itself is a Special Protected Area (SPA) under the EU Birds Directive and the area more generally has a number of features listed under Annex 1 of the EU Habitats Directive, though not specifically at the site. The site is approximately 4 – 5 km from the mainland (Figure 1) in both north-east and south-east directions.

The site is licensed to and operated by {Company} for the production of Atlantic salmon (*Salmo salar* L.). In particular the site is used during the first phases of production after fish are transported from fresh water. The site is licensed for biomass up to 500T.

Figure 1: Diagram showing approximate location of {fish farm name}

The monitoring protocols for the survey are those defined by the {the Regulator}. Within this document are defined 2 levels of survey, evaluated through a combination of mean current speed and tonnage (Table 1).

NOTE: This description of levels of survey required is different from the requirement that exists with the Kingdom of Saudi Arabia and is for illustrative purposes only. Read the regulation and accompanying documentation, including this guidance document to understand what is required within KSA.

Table 1: Matrix of production tonnage vs. Current speed to determine level of benthic monitoring required (from Monitoring Protocol 1).

	(Mean current speed ($cm.sec^{-1}$		
Tonnage	5>	10> - 5<	10<
499 – 0	Level 1	Level 1	Level 1
999 - 500	Level 2	Level 1	Level 1
1000<	Level 2	Level 2	Level 1

The {fish farm site name} has a capacity less than 500 t and has a mean current speed on the seabed of 0.12 $m.s^{-1}$, which suggests the average speed across the full depth is likely to be something more than 0.1 $m.s^{-1}$. Applying the matrix means [site name] fish farm therefore requires a Level 1 monitoring survey. According to the DAFF Monitoring Protocol (2008) this entails completion of the following:

1) Transects on the seabed be taken in two directions and from the cages, along the main current flow direction (Transect A (=TA)) and perpendicular to it (Transect B (=TB)), and that a suitable control station be selected.

2) That along these transects and at the control station either a video or photographic record of the sediment condition be collected.

3) That at specific sampling stations (under the cages, at the cage edge [=0 m], at 10 m, 20 m, 50 m [and 100 m in the main current flow direction] from the cages and at the control) measures of redox are taken and a sediment sample taken for analysis of organic carbon concentration.

Background

Video or photographic evidence provide a rough estimate of sediment condition, provides a visual record of the conditions at the time of sampling, including evidence for accumulation of fish feed and faeces, and enables basic assessment of observable or evidence of species presence.

The redox potential of sediments is defined as a measure of the ability of organisms to carry out reduction-oxidation reactions, whereby high redox levels predominate oxidative reactions (with oxygen), and low (negative) readings predominate reductive reactions (without oxygen). As such it is to some extent indicative of the level of oxygen available within the system, where oxygen is important for sediment turnover and processing. Under "normal" conditions the level of oxygen in sediment will naturally reduce with depth, depending on influence by a range of conditions. This is enhanced, that is the depth of the oxygenated layer is reduced towards the surface, by the presence of additional factors adding nutrients to the system, such as fish farming. Measures of redox potential is a typical method to assess sediment condition, as a surrogate for actual measurement of oxygen flows that are both complex and expensive to carry out.

Redox in marine systems will be influenced by 1) the rate of oxygen diffusion between the water column and sediment; 2) oxygen concentration in the overlying water; 3) the rate of oxygen consumption by chemical and biological processes in the sediment and 4) bioturbation (sediment turnover) that creates burrows and routes for water replenishment. Points 1 and 2 are a function of sediment grain size and hydrodynamic conditions that affect the rate of exchange of water between the sediment and water column. Point 3 is a function of chemical reactions, faunal respiration and microbial activity that utilise oxygen as an electron acceptor in the energetic processes that drive these activities. The latter point (4) is entirely dependent on the species types and to some extent the diversity present in the sediment.

Changes in organic input leading to variations in chemical properties combined with the physical nature of the sediment can in turn affect the biology characteristics through direct or indirect impacts on benthic fauna. In marine sediments, polychaetes form the dominant fauna and can be used as indicators of change. Increases in opportunistic species such as *Capitella* sp. and *Malacoceros fuliginosus* tend to dominate communities in organically enriched, oxygen depleted sediments (Pearson and Rosenberg, 1978). In areas where highly anoxic conditions exist, benthic infauna can be absent or severely reduced, and sediments can be characterised by the presence of sulphur reducing bacterium, *Beggiotoa*.

A pollution gradient usually occurs with increased distance from a point source of organic waste input along which sediment enrichment decreases. In the sediment around sea cages there may be distinct zones of impact that might be regarded as Gross, Heavy, Moderate and non-impacted (Henderson and Ross, 1995) although these zones can be indistinct in their separation. Such distinctions may or may not be visible through videographic or still photographic assessment, although such methods are routinely employed to evaluate impacts. Obvious impacts, such as the deposition of feed waste, for example, can be determined using observation techniques. They are, however, limited in the ability to quantitatively evaluate the outcomes of such deposition, other than in the broadest terms. The obvious manifestation of this is presence/absence of large invertebrate species, whereas species living within sediments or those that are small cannot necessarily be observed. The important factor with video/photographic methods is the ability to readily check and identify broad-scale impacts and if necessary conduct more quantitative assessment after this.

Broadly speaking the biology, chemistry and the physical nature of sediments, as they are impacted by fish farms, combine to provide an overall description of the benthic habitat. These are readily assessed through monitoring.

METHODS

Survey work was carried out on 11th August 2010 by staff members of the Institute of Aquaculture, Stirling University, in cooperation with Marine Harvest Ireland staff, particularly the diving unit.

It is known that [site name] is a relatively new site for MHI. The biomass held on site at the time of the survey was unknown.

Location of samples collected at sea cage and control sites

Weighted seabed lines were positioned by divers, with surface markers at cage edge (0 m) and at 100 m in the principle (main current) direction and out to 50 m in the cross-current direction.

The main current direction (designated Transect A or TA) was collected between GPS coordinates 53:49.128N 09:57.437W at the cage edge and 53:49.167N and 09:57.490W at 100 m. A video transect was taken along this transect (the full version of which is available in a DVD format) and screen shots used in this report. Along this transect samples were taken using a Van Veen grab for organic carbon content, and cores for redox. Sediment samples were collected using a Van Veen grab for benthic faunal analysis.

In the cross-current direction (designated Transect B or TB) sampling was done between 53:49.147N 09:57.360W at the cage edge and 53:49.124N and 09:57.408W at 50 m distance. The same process and samples as described above were collected.

The location of the control sites was 53:48.827N 09:56.311W.

Each of the site locations was identified on the seabed with the use of markers, identifiable in the video recording (full CD) at (TA0m, TA10m, TA20m TA50m, TA100m in the main current direction; and TB0m, TB10m, TB20m and TB50m in the cross-current direction).

Sediment organic carbon

Samples were collected on the seabed for analysis of organic carbon content using a Van Veen grab (0.025 m^2) from which a sub-sample was taken. CN samples were stored in an airtight container and deep frozen for later analysis. Organic carbon (and nitrogen) content was measured using a Perkin Elmer's 2400 Series ii CHNS/O analyser with an integrated 4AD-minibalance to allow for accurate pre-weighing and immediate downloading of starting dry weights. The CHNS/O analyser is a combustion method, which measures the extent of the gases produced during a complete combustion, to indicate carbon concentration. Samples had previously been dried in an oven at 90°C and stored in air-tight containers until analysis.

Sediment redox analysis

Sediment profile images were taken at each of the stations along each transect and at the control station. A single 70 mm diameter Perspex core was pushed into the sediment and bunged when sufficiently penetrated. These samples were taken at each of the site locations (TA0m, TA10m, TA20m TA50m, TA100m, TB0m, TB10m, TB20m, TB50m and control) and were photographed as a visual record.

On retrieval a visual assessment of the sediment condition was made including colour, smell and texture. Redox potential of water above the sediment was measured when possible and within the sediment itself was measured in each of the individual core samples, at 1 cm intervals, to a sediment depth of 6 cm (where possible). The equipment used was a Russell CEPTR II/300 redox probe attached to a standard Jenway millivolt meter. At the [site name] site the sediment in the main consisted of hard packed very coarse sand, which resulted in less than 6cm depth being achieved. In the majority of cases only 1 cm depth was achieved.

The probe was standardised against a standard Zobell's solution, at ambient temperature on the day of measurement. Measured values are then corrected (added to) for the difference between the reference potential (430 mV) and the measured Zobell's reading in the field just before the samples are assessed. Redox measures are temperature dependent and readings reduce with reduced temperature. Thus a further correction factor was applied assuming a water temperature of 10°C (deemed to be an average seabed water temperature, mid-summer), from a standard table. This resulted in the corrected Zobell's readings being further multiplied by 94.86% (i.e. an adjustment for the temperature). After the two corrections are applied a reading of -100 mV or less are believed to be indicative of severely reduced (= severely impacted) conditions.

Benthic video/photography

Identification of impact was evaluated primarily through a photographic assessment using an underwater camera, collected by the MHI dive team**.**

Upon return to the laboratory each photograph was assessed and a broad evaluation of observable information reported. Within this report, all information is summarised in broad terms, with specific comment on selected photographs only, where possible.

RESULTS

Location of samples collected at sea cage and control sites

Weather conditions during the survey were variable, with light to moderate winds. All necessary samples and information were collected satisfactorily, except where specified.

Sediment organic carbon

Total carbon levels in the sediments ranged between 3.5 and 4.6% across all the stations assessed (Table 2), which was very consistent across the whole area. The slight increase in carbon at TB20m, probably has something to do with the thin spread of what appeared to be seagrass on the seabed at that location (Figure 14), although this started at TB10m (Figure 13). Nitrogen content was very low in all locations.

Table 2: Total carbon and total nitrogen (%) sediments collected at [site name] site in 2010.

SITE	Total C %	Total N %
Control	3.49	-0.01
Under	3.93	-0.01
TA 0m	3.76	-0.01
TA 10m	3.72	-0.02
TA 20m	3.89	-0.01
TA 50m	3.42	-0.03
TA 100m	3.8	-0.01
TB 0m	4.11	-0.02
TB 10m	3.88	0
TB 20m	4.57	0.03
TB 50m	3.5	0.01

Sediment redox and condition

Corrected redox measures taken at stations at the [site name] site are presented in Table 3. Samples were collected to a depth of 3 – 4 cm in the sediment, which was too compact below this to give reasonable readings.

Redox measures remained relatively constant throughout the depths measured in most of the core samples. Under the cages the adjusted redox reduced to 216 mV at 3 cm deep from an adjusted reading of 451 mV at the surface. TA10m had the worst situation reducing to 52 mV at a depth of 3 cm. At all other stations redox readings reduced with depth, but at a fairly constant rate, resulting from reduced water exchange (which replaces oxygen from the water column) at sediment depths of 3-4 cm.

Positive redox values indicate that settlement of particulates from the fish cages was not causing significant

oxidative/reduction reactions in the sediment and none of the samples assessed was in a highly reduced state at any depth.

Table 3: Corrected redox (mV) measurement in sediment at stations along transects (TA & TB) at [site name] fish farm. Data shown are field measures corrected for zobell's solution measurements in the field and for temperature (times 94.86% - see methods in text).

Sediment depth	Control	Under	TA 0m	TA 10m	TA 20m	TA 50m	TA 100m	TB 0m	TB 10m	TB 20m	TB 50m
+1	458	453	458	459	457	456	454	469	461	459	459
0	457	451	456	440	453	454	451	459	459	456	457
-1	452	395	394	395	390	450	445	415	446	445	449
-2	446	314	386	216	378	388	438	356	397	418	446
-3	406	216	287	52	323	172	397	277	325	376	414
-4	305		311		286			226	307	346	276
-5											
-6											
Zobells	235	233	237	235	234	235	234	241	235	235	235

There was, however, a range of sediment conditions in core samples collected, which are identified below.

Under Cages

The core sample from underneath the cages (Figure 2) was a mix of fine and medium sand. The top 2cm of sediment was normal "sand" colour and the sediment was light grey below this depth to the full depth taken (approximately 22cm). There was no evidence on the sediment surface of any waste feed or faeces from the fish farms above, the current speed at the site probably sufficient to dilute the waste over a larger area.

Figure 2: Core sample from [site name] fish farm site, taken from under the cages.

Transect A (left to right, 0 m, 10 m, 20 m, 50 m and 100 m) – Figure 3

Grain size appeared to remain fairly constant in the sample along transect A, and were a mix of fine and medium sand. At TA0m normal sand colour was present in the top 2 cm, and the sediment was light grey below this to the full depth taken (Figure 3). In subsequent samples along the transect the depth of sediment that was light brown sand colour, increased; such that at TA10m the depth was 4 cm, at TA20m 5-6 cm, at TA50m was 20 cm and at TA100m was sand colour over the full depth taken (30 cm).

There was no visible evidence of fish farm derived waste on the seabed along transect A.

Figure 3: Core samples from [site name] fish farm site taken along Transect A at 0 m, 10 m, 20 m and 100 m from cage edge.

Transect B (left to right, 0 m, 10 m, 20 m and 50 m) – Figure 4

The majority of the core samples collected along transect B (Figure 4) were fine and medium sand. The depth of the light brown layer on the sediment surface in sample TB0m was 4-5 cm, compared to 15-20 cm in samples TB10m and TB20m, and to the full depth taken (26 cm) at TB50m.

There was no visible evidence of fish farm derived wastes at any of the stations assessed.

Figure 4: Core samples from [site name] fish farm site taken along Transect B at 0 m, 10 m, 20 m, and 50 m from cage edge.

[site name] Control site

Sediment at the control station (Figure 5) was a mix of fine and medium sand. Colour was consistent over the full depth taken (25 cm).

Figure 5: Core sample from control station approximately 1 km from [site name] fish farm site.

Benthic photographic survey

The following video stills are from a number of locations under and around the fish farm and were taken under the cages and along transects in the main current direction (Transect A or TA) and perpendicular to the main current (transect B or TB).

The specific direction of travel was determined through discussion with the fish farm staff, who had some knowledge of the current flows, based on their daily observations.

On the accompanying CD the video footage names are as follows:

- VTS_1_1 Transect A
- VTS_1_2 Transect B and under the cages

The control station was photographed using a camera.

Overall visibility in the water column on the day of sampling was good. . The number of species that were directly observable on the sediment surface was quite low, but included the echinoderm starfish *Asterias rubens*, brittlestars (either *Ophiura* or *Amphiura* sp.), hermit crab (Family Paguridae), common crab (*Liocarcinus* sp.), polychaete worm *Sabella* sp. (also called feather duster worm) and tube dwelling anemone, probably *Cerianthus* sp.. Across the transects many holes were present and whilst no species could be identified, given their size are likely to be a crustacean species, such as *Corophium* possibly; or may have been the polychaete *Sabella* sp. whilst retracted. The 2009 report for this site indicated these holes/depressions may also identify the locations of heart urchins. As no sediment samples were collected, none of this can be confirmed directly.

Under Cages

Figure 6: Sediment under [site name] fish farm cages. Snapshot from video taken using a mini-ROV.

Figure 6 shows the condition of the sediments beneath the cages at [site name] fish farm.

As has already been observed the sediment was a mix of fine to medium sand. There was no evidence of waste feed or faeces, as was observed in the core samples. Sediment colour at the surface appears slightly darker (greyer) that surrounding sand (see below).

Starfish (*Asterias rubens*) and waste from what was thought to be a *Nethys* sp. (polychaete) are arrowed.

Transect A – TA0m (to 5 m)

Figure 7 shows that the sediment was a mixture of fine to medium rippled sand, which had no evidence of fish farm deposits. Holes are visible on the sediment surface, *Asterias rubens* is visible (bottom left – arrowed) as is a brittlestar (bottom right – arrowed).

Figure 7:Sediment at fish cages along Transect A at 0m from cage edge (Station TA0m) at [site name] fish farm site. Snapshot from video taken using a mini-ROV

Transect A - TA10m (to 15 m)

The surface sediment at TA10m (Figure 8) was similar in colour and texture to previous station. Starfish, brittlestar and example burrow hole all arrowed. The algae (top right) is not attached, species *Laminaria* sp..

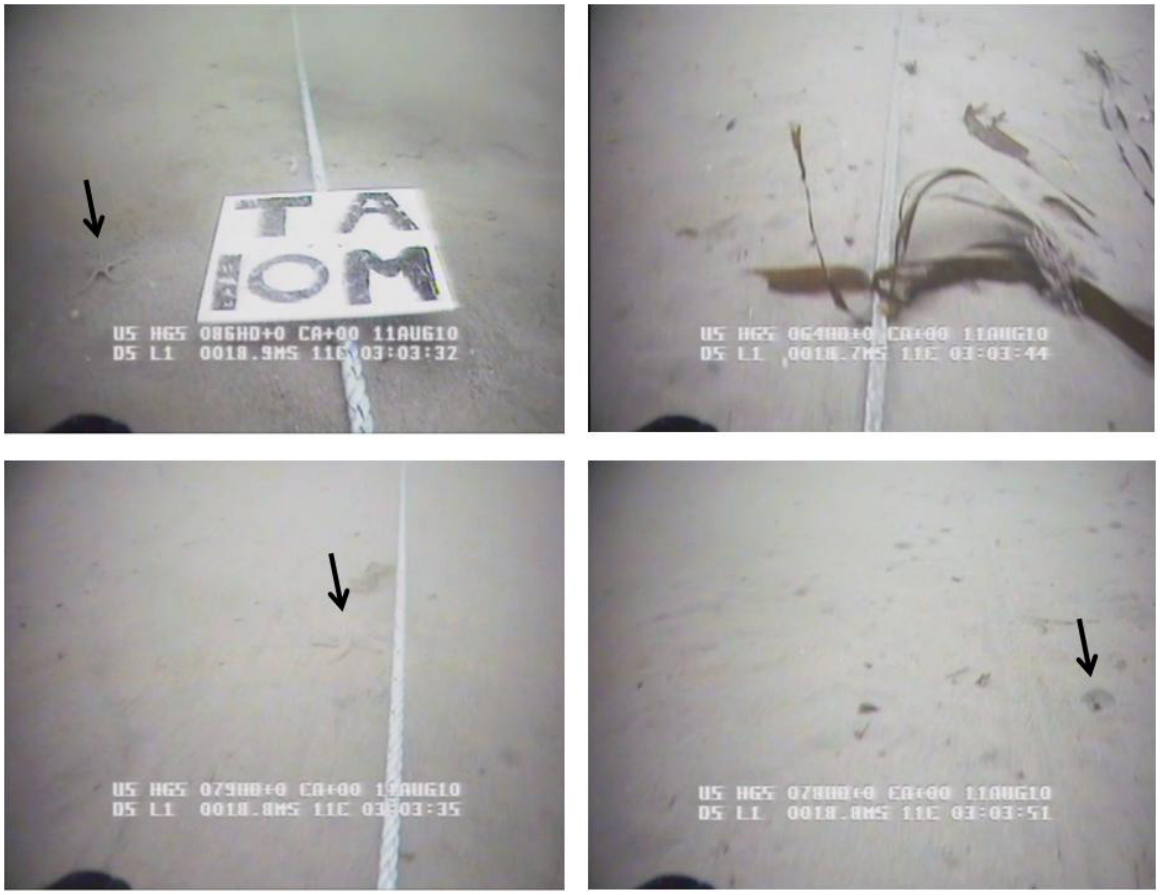

Figure 8:Sediment at fish cages along Transect A at 10 m from cage edge (Station TA10m) at [site name] fish farm site. Snapshot from video taken using a mini-ROV.

Transect A - TA20m (to 25 m)

Surface sediments at TA20m were fine to medium sand. All algae seen was unattached and included fronds and stipe of *Laminaria* sp, plus other red and brown more filamentous algae.

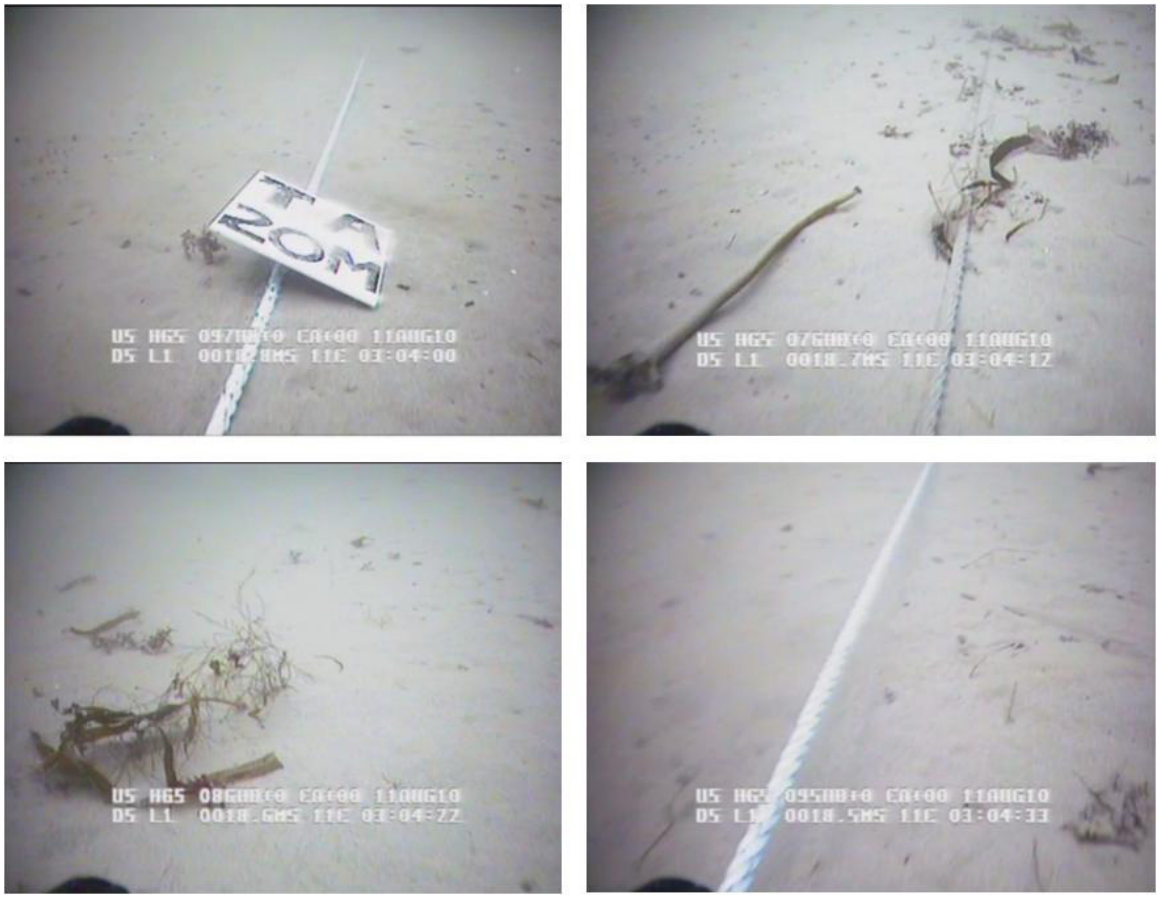

Figure 9: Sediment at fish cages along Transect A at 20 m from cage edge (Station TA20m) at [site name] fish farm site. Snapshot from video taken using a mini-ROV.

Transect A - TA50m (from 45 to 50 m)

The underlying surface at TA50m (Figure 10) was fine to medium sand, though near to this station sediment grain size increased in patches, with larger deposits of shell fragments (bottom left) in some areas. In the top-right image a starfish is arrowed, top left a tube dwelling anemone (probably *Cerianthus* sp.) arrowed, and bottom an example depression with hole is arrowed.

Figure 10: Sediment at fish cages along Transect A at 50 m from cage edge (Station TA50m) at [site name] fish farm site. Snapshot from video taken using a mini-ROV.

Transect A - TA100 m

The top-right image (Figure 11) shows the diver collecting the core sample for redox and CN analysis. The arrows highlight the positions of brittlestars (possibly *Ophiura* sp. or *Amphiura* sp.) which were numerous at this location and a small starfish (*Asterias rubens*). Sediment grain size was uniform with the other sample stations, being fine to medium sand.

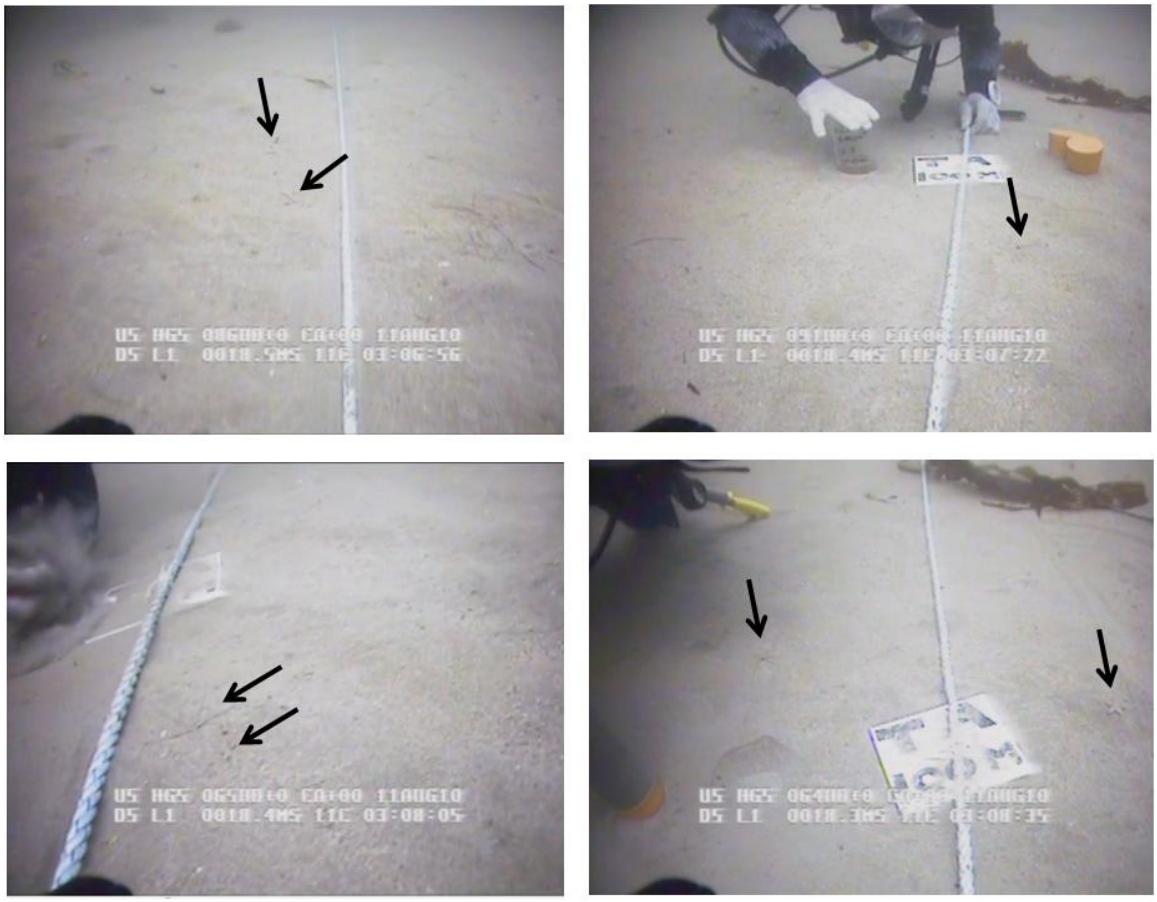

Figure 11: Sediment at fish cages along Transect A at 100 m from cage edge (Station TA100m) at [site name] fish farm site. Snapshot from video taken using a mini-ROV.

Transect B - TB0m

The sediments at the cage edge at the start of transect B (TB0m) at [site name] (Figure 12) light brown in colour, and of fine to medium grain size composition. Brittlestars were present (arrowed) as were e depressions with holes, that may be made by a crustacean, a polychaete or a heart urchin. Floating over the surface were detached fronds of *Laminaria* sp. No feed and faecal pellets were visible on the sediment surface.

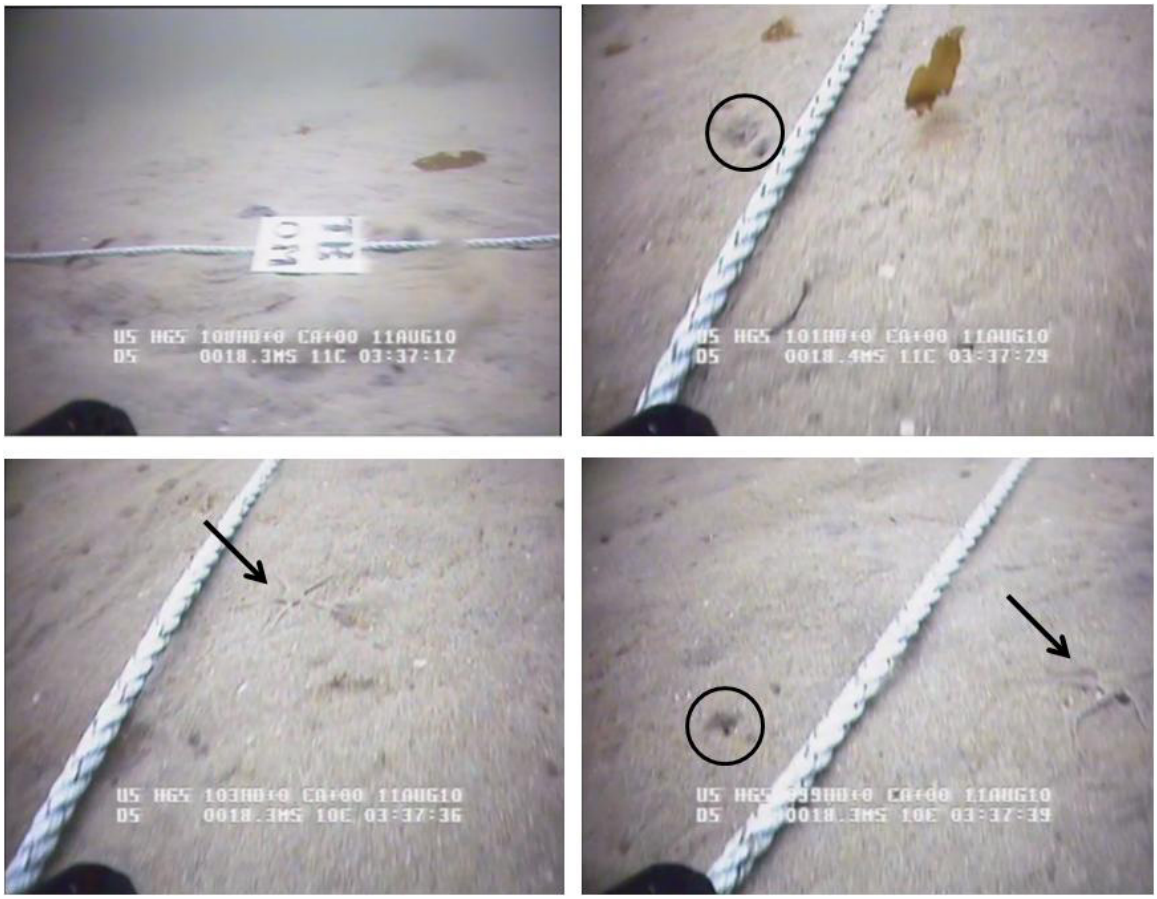

Figure 12: Sediment at fish cages along Transect B at 0 m from cage edge (Station TB0m) at [site name] fish farm site. Snapshot from video taken using a mini-ROV.

Transect B - TB10m

The sediments 10 m from the cage edge (TB10m) (Figure 13) were fine to medium sand and light brown in colour. Depressions were present throughout the area. The arrows point to the start of sparse seagrass. Floating over the surface were detached fronds of *Laminaria* sp.. No feed and faecal material was evident.

Figure 13: Sediment at fish cages along Transect B at 10 m from cage edge (Station TB10m) at [site name] fish farm site. Snapshot from video taken using a mini-ROV.

Transect B - TB20m

Sediment condition at TB20m (Figure 14) was as specified previously. Top-right image shows the sparse sea-grass extended to this station.

Figure 14: Sediment at fish cages along Transect B at 20 m from cage edge (Station TB20m) at [site name] fish farm site. Snapshot from video taken using a mini-ROV.

Transect B - TB50m

Floating over the surface at TB50m (Figure 15) were detached fronds of *Laminaria* sp. including a stipe (right), next to which was a hermit crab (Paguridae family). Sediment was as described previously at other locations.

Figure 15: Sediment at fish cages along Transect B at 50 m from cage edge (Station TB50m) at [site name] fish farm site. Snapshot from video taken using a mini-ROV.

[site name] control

Sediment at the control site (Figure 16) was a mix of fine to medium sand, with some shell fragments. A single tube dwelling polychaete (probably the feather duster worm *Sabella* sp.) was observed (top arrow), as was a brittlestar (also arrowed).

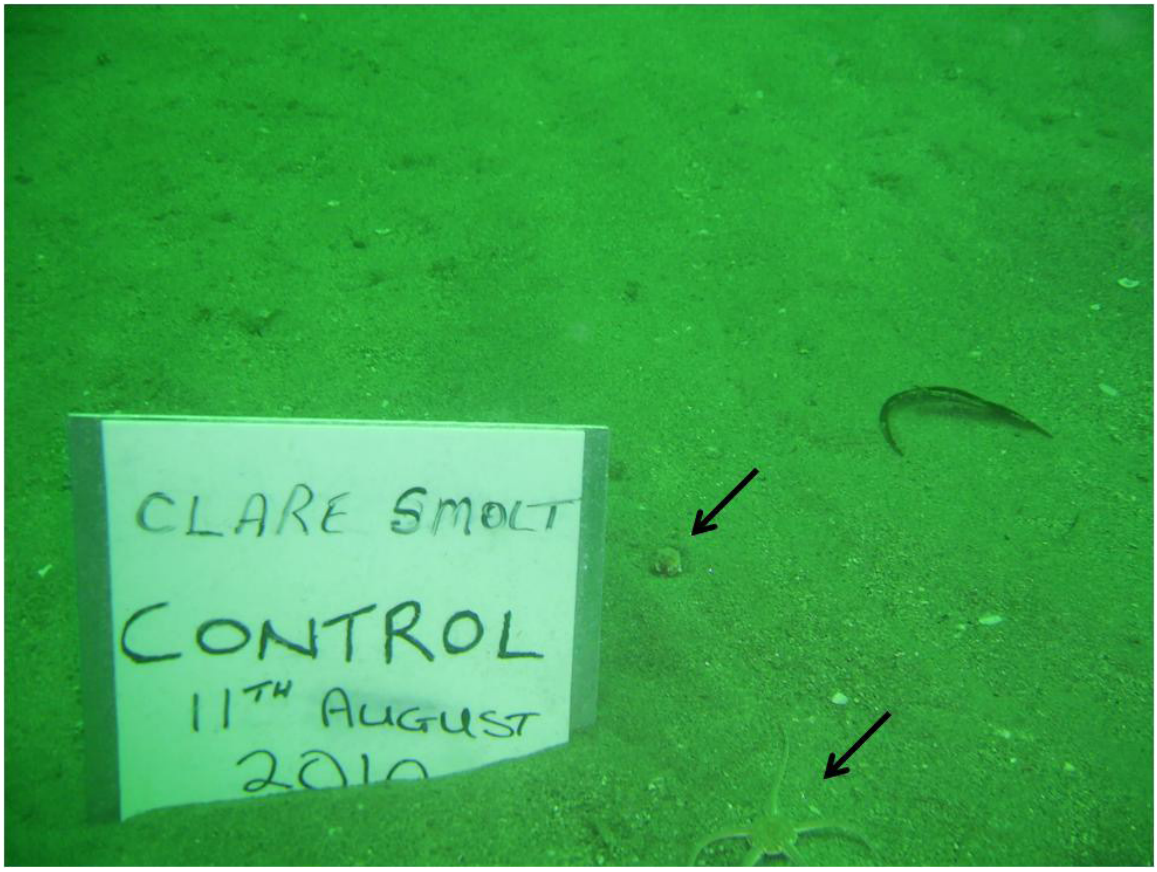

Figure 16: Sediment at [site name] control site. Picture taken using hand-held underwater camera.

General conclusions

This report presents the results of the 2010 survey to assess sediment quality at the [site name] fish farm. A level 1 survey was carried out according to the requirements of the Department of Agriculture, Fisheries and Food (An Roinn Talmhaíochta, Iascaigh agus Bia) Monitoring Protocol No.1 for Offshore Finfish Farms – Benthic Monitoring, revision unknown, dated December 2008.

Monitoring encompassed:

- A visual assessment of the sediment during sample collection,
- Measures of redox readings with accompanying pictures as a visual record of the cores taken,
- Samples taken for analysis of organic carbon content
- A visual assessment using a Seabotix LBV200-4 miniROV (CD available) with snapshot pictures in the report.

Sediment samples collected and photographed were a mixture of fine to medium sand, which was consistent at all stations. The nature of the sediment, and the fact that there was little to no fine material over the sediment surface, suggests that current flows at the site are high, such that fine particulates are unable to settle. Such a current speed is also likely to disperse waste feed and faecal material over a large area. Under the cages the video showed there were no obvious signs of any significant settlement of such wastes, although the core sample from underneath the cages maintained a light brown colour in only the top 2 cm (grey below this), which is indicative of some degree of low impact due to fish farming activity.

Redox measures were positive over the full depth measured, indicating low to no impact from cage culture within the site area up to 100 m away. The greying sediment and change in colour along transect A in particular shows that the farming activity is having some impact, but that this is deemed to be low by virtue of both the lack of wastes, and the positive redox measures to a reasonable depth of sediment. Total carbon concentrations were also low (and consistent) across the site. The pictorial assessment highlighted a few species visible on the sediment surface, including brittlestars and starfish predominantly, which were consistently found at all sample locations. There is uncertainty about which species creates the depressions/holes, which were also consistently found at all locations.

From the evidence collected there does not appear there was a significant impact from the fish farm activity on the seabed.

Appendix 3: Benthic report, including fauna results and analysis, and physico-chemical parameter results and analysis.

Survey of sediment quality at Site X fish cage site, Area Y in 2008.

Report to {Company name}

January 2009.

TABLE OF CONTENTS

1. Introduction

The current report presents the results of an ongoing annual environmental monitoring programme at {company} Atlantic Salmon seacage site at {Site X}, within Area Y (Figure 1). Survey work was carried out by staff of the {Environmental Consultant name}, on 31st July 2008.

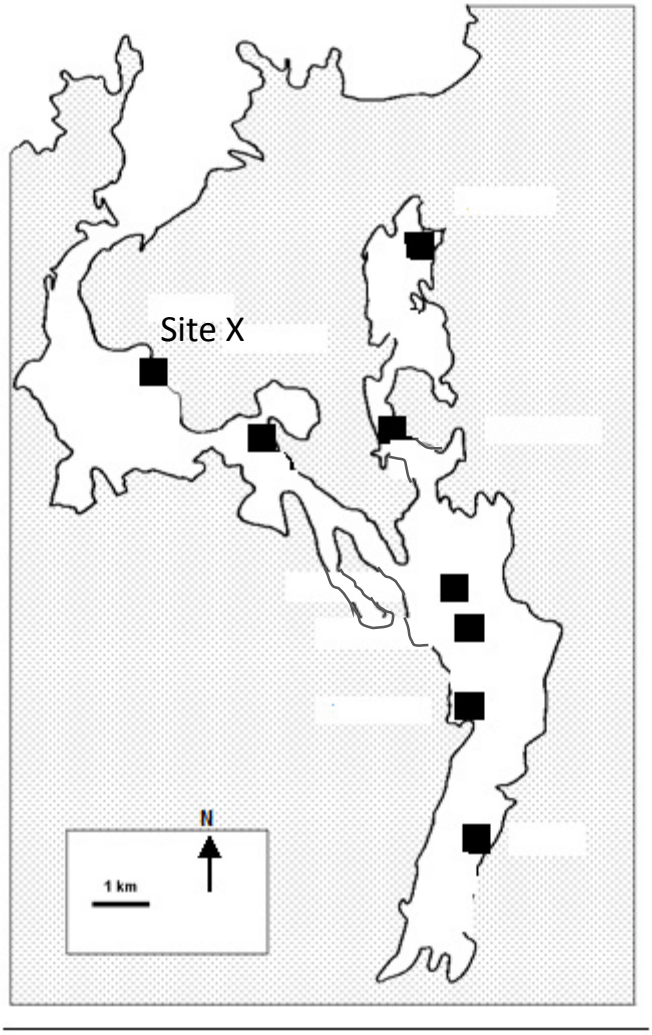

Figure 1: General map of area Y with location of cage sites throughout bay. Report on Site X.

This report presents the results of biological and chemical analyses on sediment samples collected at Site X cage site in Area Y. Measures of redox and a general description of the sediment characteristics has been reported separately (report date 27th August 2008).

Several chemical analyses can be used to determine the quality of sediments, including redox potential and organic fraction (measured as a function of % carbon and nitrogen). Organic inputs to sediments can be measured directly by calculating their carbon content, as nearly all carbon isolated from fish farms is organic carbon. Generally a carbon content of less than 5% indicates little or no organic enrichment, while values of 5-15% suggest a certain amount of enrichment. Values greater than 15% only generally occur in areas of serious organic pollution. As these values do not account for shell matter, which can increase the overall carbon content (%) it is important to make observations of the physical characteristics of sediments to compare with the results of chemical analyses. Organic nitrogen levels may be a more reliable indicator of sediment nutrient input, as nitrogen levels reflect the nutrient status of sediments and

unlike carbon, are not influenced by the presence of shell matter. In addition, the sediment carbon / nitrogen ratio can be used to measure waste dispersion. Values of less than 11 generally indicate poor dispersion of waste food and faeces (Gowen & Bradbury, 1987) although this can again be influenced by shell matter.

The redox potential of solutions is defined as a measure of the ability of organisms to carry out reduction-oxidation reactions, whereby high redox levels predominate oxidative reactions (with oxygen), and low (negative) readings predominate reductive reactions (without oxygen). As such it is to some extent indicative of the level of oxygen available within the system, where oxygen is important for sediment turnover and processing. Redox in marine systems will be influenced by 1) the rate of oxygen diffusion between the water column and sediment; 2) oxygen concentration in the overlying water; 3) the rate of oxygen consumption by chemical and biological processes in the sediment and 4) bioturbation (sediment turnover) that creates burrows and routes for water replenishment. Points 1 and 2 are a function of sediment grain size and hydrodynamic conditions that affect the rate of exchange of water between the sediment and water column. Point 3 is a function of chemical reactions, faunal respiration and microbial activity that utilise oxygen as an electron acceptor in the energetic processes that drive these activities. The latter point (4) is entirely dependent on the species types and to some extent the diversity present in the sediment. Measures of redox potential is a typical method to assess sediment condition, as a surrogate for actual measurement of oxygen flows that are both complex and expensive to carry out.

Changes in organic input leading to variations in chemical properties combined with the physical nature of the sediment can in turn affect the biology characteristics through direct or indirect impacts on benthic fauna. In marine sediments, polychaetes form the dominant fauna and can be used as indicators of change. Increases in opportunistic species such as *Capitella* sp. and *Malacoceros fuliginosus* tend to dominate communities in organically enriched, oxygen depleted sediments (Pearson and Rosenberg, 1978). In areas where highly anoxic conditions exist, benthic fauna can be absent or severely reduced, and sediments can be characterised by the presence of sulphur reducing bacterium, *Beggiotoa*.

A pollution gradient usually occurs with increased distance from a point source of organic waste input along which sediment enrichment decreases (Pearson and Rosenberg, 1978). In the sediment around sea cages there may be distinct zones of impact that might be regarded as Gross, Heavy, Moderate and non-impacted (Henderson and Ross, 1995) although these zones can be indistinct in their separation. The extent of organic enrichment in the marine environment can therefore be assessed using changes in benthic invertebrate community composition.

Biology, chemistry and the physical nature of sediment combine to provide an overall description of the benthic habitat.

2. Methods

Methods used in the collection of sediment samples are outlined below. Weather conditions during the survey were changeable, with moderate winds.

2.1 Location of samples collected at sea cage and control sites

GPS positions of the stations used to obtain grab samples at Site X are given in Table 1. Grab samples were taken from the centre of the cage block (termed 'mid') and at 25 m from each end of the cage block, along a transect that was parallel to the prevailing currents (north - south). Sediment samples were also obtained at a control station, located over 500 m from the cage site in a water depth similar to that at the cages; hence representing undisturbed sediments in Area Y, that can be used as a comparator.

2.2 Sediment carbon and nitrogen

Four grab samples were taken at each sediment sampling station using a 0.025 m^2 van Veen grab, one for carbon and nitrogen (CN) analysis and three for benthic fauna identification. Sediment samples for CN analysis were consequently stored in an airtight container and deep frozen for later analysis. Carbon and nitrogen content was measured using a Perkin Elmer 2400 Series ii CHNS/O analyser on samples dried in an oven at 90°C.

2.3 Sediment character and redox

A visual assessment of the sediment condition, including colour, smell and texture, within each of the core samples was made.

One core sample was taken by diver at each of the sediment sampling stations (Figure 2), using a 70 mm Perspex corer. The redox potential of water and sediment water within each core sample was measured at 1 cm intervals from +1 cm (in water column) to a sediment depth of 4 cm (where possible). The equipment used was a Russell CEPTR II/300 redox probe attached to a standard Jenway millivolt meter.

The probe was calibrated against Zobell's solution at ambient temperature on the day of measurement. Measured values are corrected for the reference potential measured in the field just before the samples are assessed. However, redox measures are temperature dependent and readings reduce with reduced temperature. Thus the true correction factor uses the standard readings identified above interpolated to readings at 10°C (deemed to be an average seabed water temperature, mid-summer), from a standard table. This results in field measured Zobell's readings being multiplied by 94.86% (i.e. an adjustment for the temperature). After the correction factor is applied, readings of -100 mV or less are believed to be indicative of severely reduced (= very poor) conditions.

2.4 Benthic Macrofauna

The faunal analysis samples were sieved on-site using a 1 mm sieve and the material retained was placed in separate labelled double-bags and preserved in 10% formosaline solution. On arrival in Stirling, the samples were further sieved through a 1 mm mesh. The sieve material was placed in a white tray and all fauna was picked by hand and placed in a 70% alcohol solution. Macrofaunal samples were identified using a stereo dissecting microscope with a range of 10 to 40 x magnification and a light source of adequate power to clearly see features for both incident and transmitted light. If further magnification was required (such as observation of the structure of polychaete chaetae) a compound microscope with a range of 100 to 1000 x (using oil immersion) magnification was used. Specimens were identified, using appropriate keys, to the lowest taxonomic level possible (usually species).

Table 1: Positions of sediment sampling stations at Site X, Area Y, 2008.

Station	(Lat / Long (WGS84	NGR	Depth
Control	55º 12'20.1 N 07º 46'93.2 W	13857 E 39610 N	2.6m
25m N	55º 12'10.8 N 07º 46'93.4 W	13916 E 39438 N	8.5m
Mid	55º 12'03.3 N 07º 46'88.7 W	13967 E 39298 N	12.2m
25m S	55º 11'94.8 N 07º 46'77.5 W	14087 E 39141 N	9.2m

2.5 Data analysis

Macrofaunal communities are described numerically using univariate measures including abundance and number of species. This data can also be combined to provide an indication of overall diversity and the evenness of distribution of species (Pielou, 1984). One multivariate technique was used to assess differences in species community structure for stations at each cage block. Cluster Analysis (a classification technique) uses species abundance data to assess similarity between collected samples, forming a matrix in the form of a dendrogram output that clusters similar data together. This can employ a variety of sorting methods. In the current study Bray-Curtis (or Percentage) similarity with Unweighted Pair Group Method using arithmetic Averages (UPGMA), recommended for community level analysis, was used for the analysis. The species data sets used in multivariate analyses were $\log_{10}(x + 1)$ transformed in order to decrease the significance of any dominant species that can often "wash-out" contributions made to community structure by rarer species (Greig-Smith, 1982).

There were insufficient stations to carry out meaningful Detrended Correspondence Analysis (DECORANA), which would typically require a minimum of 6 stations compared to the 4 at this site.

3. Results

3.1 Sample collection

There were no issues of note regarding collection of samples for analysis of CN and macrofauna at Site X. All samples were collected successfully.

3.2 Sediment carbon and nitrogen

Sediment carbon and nitrogen values for Site X are presented in figure 2 and table 2.

Table 2: Sediment carbon, nitrogen and carbon / nitrogen ratios for sediments at Site X cage site, Area Y, 2008.

Station	(%) Carbon	(%) Nitrogen	C/N Ratio
25m N	4.13	0.08	51.625
Mid	5.10	0.04	127.5
25m S	6.47	0.08	80.875
Control	1.70	0.07	24.286

The carbon content (%) of the sediments at Site X ranged from 1.70% at the control station, to 6.47% at the 25m S station. As in 2007, sediment carbon levels at the mid and 25m S stations were slightly above 5%, which indicates a certain amount of enrichment, however levels of carbon enrichment were minimal at 25m N and the control site.

Sediment nitrogen content (%) at Site X ranged from 0.04% at the mid station, to 0.08% at the 25m north and south stations, overall nitrogen levels at all sample sites were low and similar to, or less than those at the control site. Since 2007, nitrogen levels have reduced at all sites, whilst levels of carbon have remained similar, though a slight increase was evident at 25m S, however nutrient levels remain well within acceptable limits.

A review of surveys carried out since 2004 at Site X, shows that although there has been a slight increase in the mean value of % C above that recorded in 2007, the mean value in 2008 was less than those previously recorded from 2004 to 2006. However the overall range has remained similar across the past 5 years (Table 3). Levels of percentage nitrogen from 2004 to 2006 have also remained fairly stable (Table 4), although they increased slightly in 2007, in 2008 the mean nitrogen level was lower than previously recorded. Overall, the range of nitrogen values across the past 5 years have remained low.

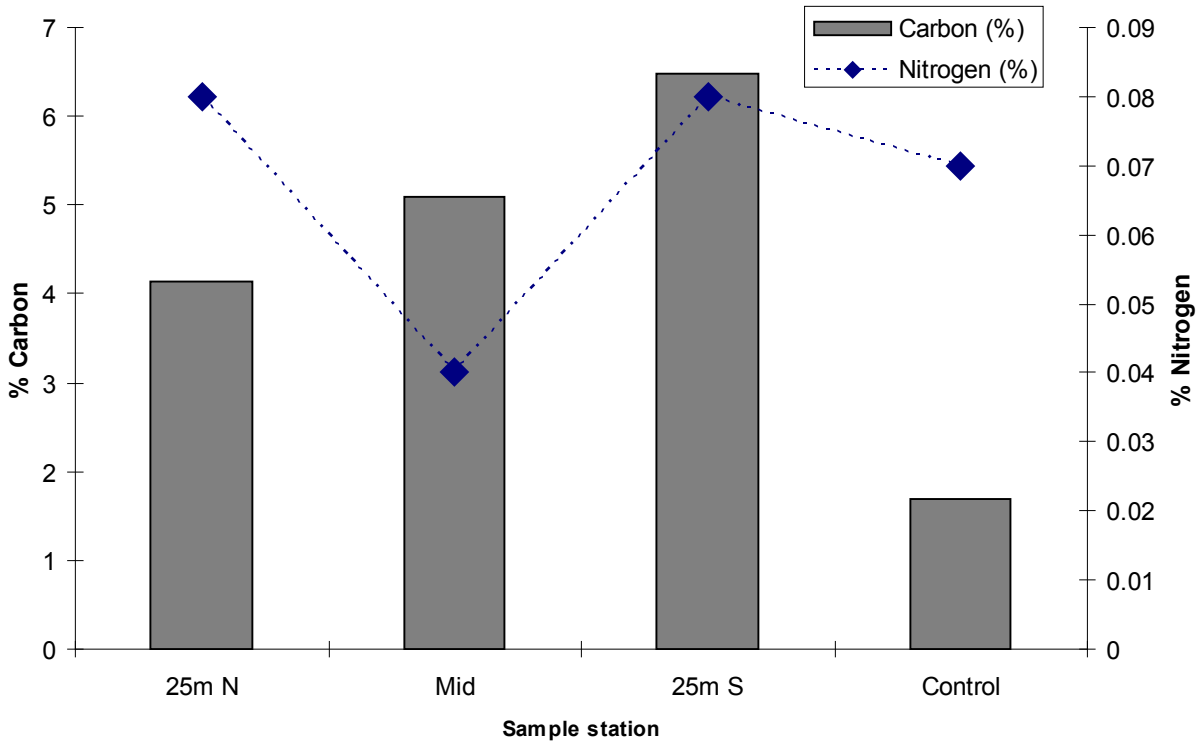

Figure 2: Percentage carbon and nitrogen values in sediments at Site X cage site, Area Y, July 2008.

Table 3. Comparison of percentage carbon in sediments taken from locations at Site X cage site and reference station since 2004.

Year	Mean %	Range %	N stations	Reference %
2004	5.58	3.82 – 7.3	3	8.22
2005	5.94	4.44 – 7.14	3	5.7
2006	5.37	3.3 – 7.6	3	1.79
2007	4.94	3.37 – 5.73	3	1.29
2008	5.23	4.13 – 6.47	3	1.70

Table 4 Comparison of percentage nitrogen in sediments taken from locations at Site X cage site and reference station since 2004.

Year	Mean %	Range %	N stations	Reference %
2004	0.13	0.09 – 0.21	3	0.16
2005	0.18	0.07 – 0.32	3	0.23
2006	0.19	0.11 – 0.27	3	0.08
2007	0.31	0.18 – 0.44	3	0.17
2008	0.067	0.04 – 0.08	3	0.07

3.3 Sediment character and redox

Observations of physical sediment characteristics made from core samples taken at each station are given in Table 5. The sediment predominantly consisted of light to dark grey sand, with dead mearl present at the mid and 25m S stations. The sediment was generally firm and uniform with depth with no waste feed, smell of hydrogen sulphide, out-gassing, or *Beggiotoa* present.

Station	Depth	Sediment type	Sediment consis-tency	Waste feed present	Smell of H_2S	Gassing present	*Beggiotoa* present
25m N	8.5m	Top 1cm grey, rest dark grey fine sand	Firm	No	No	No	No
mid cage	12.2m	Light grey medium sand, dead mearl	Firm	No	No	No	No
25m S	9.2m	Light grey medium sand, dead mearl	Firm	No	No	No	No
Control	2.6m	Fine dark grey mud	Firm	No	No	No	No

Table 5: Sediment characteristic descriptions

Corrected redox potentials for 2008 sampling stations are given in Figure 3, with comparative tables presented in Appendix 1. Measures were taken to a depth of 4 cm or more where practical.

All corrected redox readings from the surface sediments indicated positive oxygen concentrations. However from a depth of 2-5 cm, sediments from the mid, 25m N and 25m S stations showed increasing levels of deoxygenation (Figure 3), with all 3 sample stations exhibiting reduced conditions. It is evident that impacts from fish farming activity are increased at the north end of the cage block, indicating a higher distribution of particulate wastes at that end of the site.

Redox results suggest that, in 2008, there is an increased negative impact of fish culture at Site X on the ability of sediments at and near to the cages to exchange water and therefore increase oxygenation, compared to results in 2007, with an increased level of negative readings below 1cm sediment depth. Generally the impact of farming could be termed moderate at this site, with no redox measures recorded below -100 mV.

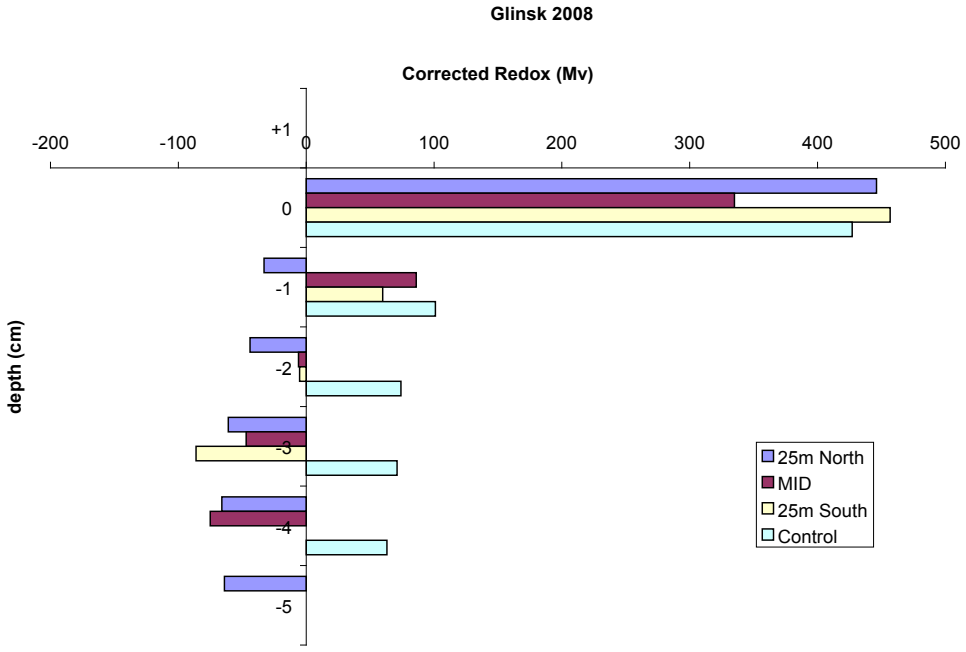

Figure 3: Corrected redox measures (Mv) taken at Site X in 2008, to a depth of 5 cm.

Redox comparison between years

Similarly to 2007, redox potentials were lower at the northern end of the site than at the southern end; however, redox readings at the 25m N and 25m S sites show evidence of a decline in sediment oxygen levels since the previous year. At a depth of 3 cm, both the mid and 25m stations had redox potentials in the region of, or less than -50 mV, which is of lower quality than previously recorded (Appendix 1, b).

3.4 Benthic macrofauna

The top ten ranked abundant species at each sample station at Site X cage site are given in Table 6. (A full species / abundance matrix for Site X can be found in Appendix 1).

In 2008 the macrofaunal community was characterised by the presence of oligochaete and polychaete worms and only low levels of other groups. At the 3 stations close to or at the cages the top 3 species were *Capitella sp, Nematoda, and Tubificoides benedii*, with each dominating to a greater or lesser degree, accounting for 95, 94 and 69% in the 25m North, Mid and 25m South stations respectively. All these species are ITI Group 4 sub-surface deposit feeding species and given their respective dominance account for the low ITI score against each of these stations (Table 7).

However, the ITI scores and the other univariate measures, despite still being low overall (i.e. showing that sediments are severely impacted), continue to improve slightly from the previous year. Although dominating in percentage terms the absolute number of individuals has reduced again in 2008, as it had done in 2007 compared to 2006 data. Also important is the increase in the number of species present at the mid-station in particular, up from 6 species in 2007 to 23 in 2008. This general improvement is also evident from an increased number of species at both 25m stations. That said, the top 10 species account for 99% of all animals present, with the remaining 13 species contributing 1 or 2 individuals only, which clearly indicates the impact of fish farming activity in the immediate vicinity of the cages.

Table 6: Top ten ranked species for sample stations at Site X, Area Y, 2008.

Control				
RANK	SPECIES	NUMBER	PERCENT	CUM PERC
1	*Spio decorata*	44	17.6	17.6
2	*Nematoda*	42	16.8	34.4
3	*Scoloplos armiger*	35	14	48.4
4	*Prionospio fallax*	14	5.6	54.0
5	*Tubificoides benedii*	14	5.6	59.6
6	*Nemertea*	12	4.8	64.4
7	*Microdeutopus anomalus*	12	4.8	69.2
8	*Tubificidae pseudogaster agg.*	10	4	73.2
9	*Capitella sp.*	9	3.6	76.8
10	*Microspio mecznikowianus*	8	3.2	80.0

25m N				
RANK	SPECIES	NUMBER	PERCENT	CUM PERC
1	*Nematoda*	870	68.8	68.8
2	*Tubificoides benedii*	192	15.2	84.0
3	*Capitella sp.*	122	9.7	93.7
4	*Ctenodrilus serratus*	27	2.1	95.8
5	*Scoloplos armiger*	12	0.9	96.8
6	*Nemertea*	11	0.9	97.6
7	*Spio decorata*	8	0.6	98.3
8	*Sphaerosyllis taylori*	4	0.3	98.6
9	*Ophryotrocha spp.*	3	0.2	98.8

10	*Nephtys hombergii*	2	0.2	99.0
Mid RANK	SPECIES	NUMBER	PERCENT	CUM PERC
1	*Capitella sp.*	1347	69.9	69.9
2	*Nematoda*	403	20.9	90.8
3	*Tubificoides benedii*	77	4.0	94.8
4	*Nemertea*	64	3.3	98.1
5	*Tubificidae pseudogaster agg.*	6	0.3	98.4
6	*Anthozoa*	3	0.2	98.5
7	*Anaitides mucosa*	3	0.2	98.7
8	*Platynereis dumerilii*	3	0.2	98.9
9	*Protodorvillea kefersteini*	3	0.2	99.0
10	*Grania spp.*	3	0.2	99.2
25m S RANK	SPECIES	NUMBER	PERCENT	CUM PERC
1	*Nematoda*	548	28.5	28.5
2	*Tubificoides benedii*	530	27.5	56.0
3	*.Capitella sp*	244	12.7	68.7
4	*Tubificoides insularis*	194	10.1	78.8
5	*Scoloplos armiger*	101	5.2	84.0
6	*Nemertea*	87	4.5	88.5
7	*Anaitides mucosa*	40	2.1	90.6
8	*Mediomastus fragilis*	37	1.9	92.5
9	*.Grania spp*	37	1.9	94.4
10	*Protodorvillea kefersteini*	24	1.2	95.7

The Infaunal Trophic Index (ITI) classified all of the cage related sites (25m N, mid and 25m S) as degraded, with ITI scores between 0 and 30 (WRc, 1992), whilst sediments at the control station were classified as modified (scores of 30 – 60) (Table 7). This suggests that benthic faunal communities in the vicinity of the farm are being impacted by the deposition of organic matter, but that the area generally is also impacted in some way not associated with farm activities (i.e. a modified "control" site). Despite of the reductions in absolute numbers of individuals and changes in the number of species referred to above, since 2007 the sediment conditions at the cage related stations remain 'degraded'. There had been a continued improvement in conditions at the control site though it remains as a modified status, probably typical of the area generally.

Table 7: Results of univariate analyses on macrofaunal data from Site X cage site, Area Y, 2008.

STATION	N	S	D	Hb	Hs	P	ITI
Cont	250	32	0.90	2.54	2.73	0.91	44.41
25m N	1264	23	0.49	1.06	1.09	0.49	2.01
Mid	1928	23	0.46	0.93	0.95	0.47	1.95
25m S	1925	40	0.81	2.01	2.05	0.81	6.75

N = Number of individuals	Hs = Shannon-Wiener Index
S = Number of species	P = Pielou Evenness

D = Simpsons Index	ITI = Infaunal Trophic Index
Hb = Brillouins Index	

Results of multivariate analyses on data from Site X are presented in Figure 4. This attempts to purely assess similarity between the different stations by comparing their species composition.

There is a relatively low similarity between the mid- and 25m S stations (Figure 4). They are both degraded, had a similar species in the top 5 (Table 6), and had similar high abundance and low number of species (Table 6) but clearly overall the species present at each site does vary (hence the lower similarity in Figure 3). This is probably due to the variability not only in species composition but also in the absolute abundance of those various species. The 25m N station was the next most similar but differentiated from the other two by the increased number of species present at the 25m N station. In species composition terms the 25m N stations was more similar to the control (40 and 32 species respectively, Table 7), but not closely so and differentiated by virtue of the increased abundances at the 25m N station compared to the control.

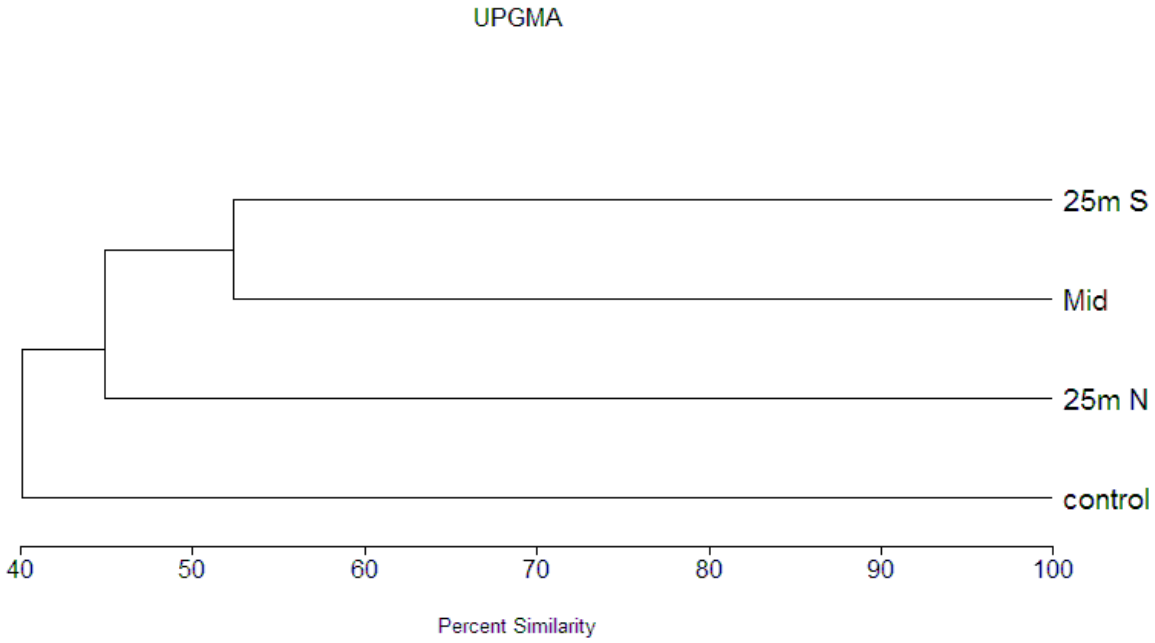

Figure 4:Dendrogram showing results of cluster analysis, using Percentage Similarity for log-transformed data with UPGMA sorting, for Site X, Area Y, July 2008.

4. Conclusions

Sediment quality at Site X cage site in Area Y was assessed using both qualitative and quantitative physico-chemical and biological parameters. This report presents the results of the 2008 survey findings for carbon and nitrogen and faunal composition.

Chemical analysis revealed that the carbon content (%) of the sediments at Site X ranged from 4.13% to 6.47%, compared to a low 1.70% at the control site. Nitrogen settlement remained low at all sample locations and differed very little from control levels. The differences in nutrient level can have knock-on effects, altering the composition of benthic macrofauna communities at the sample site and control locations.

Results from visual assessments of the physical properties of the sediments in 2008 showed that sediment throughout the survey area was generally of a firm sandy consistency. At all stations there was no accumulation of waste material; no out-gassing or hydrogen sulphide was observed. The comparison of site data has shown that in general the sediment quality at Site X has deteriorated since 2007, as indicated by lower corrected redox potential readings. There we, however, no reading below -100 mV and therefore the sediments can be classified as moderately impacted.

At farm locations there were a very high proportion of group 4 sub-surface deposit feeders typical of degraded nutrient rich sediments, including *Capitella sp, Nematoda, and Tubificoides benedii*, accounting for up to 95% of the abundance at some stations. That said, in general terms the species found in 2008 were similar to those identified in 2007 and before, and are typical of species to be found under and around fish farms. There continues to be a decline in the absolute abundance of certain species, particularly those identified above. This is combined with a further increase in species richness over 2007, which has seen, for example, the number of species at the 25m S stations increase to 40, from 28 last year and 18 in 2006. Overall the diversity and evenness scores have remained similar across the site stations, at a degraded quality level, whilst conditions at the control site, although showing an improvement between 2006 and 2007, remain at a 'modified' classification.

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Annex 1 – Data tables

a) Redox measures for Millstone and Site X from 2002 to 2008.

	(years ago (2002 6				(years ago (2005 3				(years ago (2006 2				(Last year (2007				(This year (2008			
	Site X				**Site X**				**Site X**				**Site X**				**Site X**			
	25m N	**Mid**	**25m S**	**Control**	**25m N**	**Mid**	**25m S**	**Control**	**25m N**	**Mid**	**25m S**	**Control**	**25m N**	**Mid**	**25m S**	**Control**	**25m N**	**Mid**	**25m S**	**Control**
+1	256	257	259	28	246	241	242	242	226	235	212	245	211	230	226	231				
0	241	168	189	-67	245	239	240	241	-75	123	77	-44	206	93	218	221	226	114	232	208
-1	-121	56	-30	-167	-111	126	231	37	-229	-190	-71	-44	117	-124	194	50	-253	-135	-165	-118
-2	-224	-46	-140	-193	-208	40	211	-67	-284	-225		-93	-15	-300	138	-36	-264	-227	-230	-145
-3	-239		-162	-202	-265	-107	-101	-226				-84	-63	-297	66	-62	-281	-268	-311	-148
-4	-248			-229		-158		-227				-98	-156		-66	-74	-286	-296		-156
-5	-258			-239									-189		-122		-284			

b) Corrected redox readings for Millstone and Site X from 2002 to 2008.

	(years ago (2002 6				(years ago (2005 3				(years ago (2006 2				(Last year (2007				(This year (2008			
	Site X				**Site X**				**Site X**				**Site X**				**Site X**			
	25m N	**Mid**	**25m S**	**Control**	**25m N**	**Mid**	**25m S**	**Control**	**25m N**	**Mid**	**25m S**	**Control**	**25m N**	**Mid**	**25m S**	**Control**	**25m N**	**Mid**	**25m S**	**Control**
+1	487	488	494	259	474	466	467	466	440	462	429	461	438	451	447	454				
0	472	399	424	164	473	464	465	465	139	350	294	172	433	314	439	444	446	335	457	427
-1	110	287	205	64	117	351	456	261	-15	37	146	172	344	97	415	273	-33	86	60	101
-2	7	185	95	38	20	265	436	157	-70	2		123	212	-79	359	187	-44	-6	-5	74
-3	-8		73	29	-37	118	124	-2				132	164	-76	287	161	-61	-47	-86	71
-4	-17			2		67		-3				118	71		155	149	-66	-75		63
-5	-27			-8									38		99		-64			

Annex 2- species abundance

Table 2A: Species / abundance data for sample stations at Site X cage site, Area Y, 2008.

Species	control	25m N	Mid	25m S
Aoridae spp. (female)	0	0	1	0
Chamelea striatula	0	0	1	0
Demonax sp. indet.	0	0	1	0
Dexamine spinosa	0	0	0	1
Diastylis rugosa	0	1	0	0
Ensis sp. (juvenile)	0	0	0	1
Fabriciola baltica	1	0	0	0
Microdeutopus anomalus	12	0	0	0
Mytilus edulis (juvenile)	0	0	0	2
Platynereis dumerilii	1	0	3	4
Pomatoceros lamarcki	0	0	2	0
Spio decorata	44	8	2	1
Venerupis senegalensis	0	0	0	2
Abra alba	1	0	0	0
Abra nitida	0	1	0	0
Adyte pellucida	0	0	0	1
Amphipholis squamata	0	0	1	0
Aonides oxycephala	0	0	1	4
Caulleriella alata	2	1	0	0
Chaetozone zetlandica	1	0	0	0
Clymenura sp.	1	0	0	0
Corbula gibba	0	1	0	0
Eupolymnia nebulosa	0	0	0	1
Exogone hebes	4	0	0	7
Flabelligera affinis	0	0	0	2
Gibbula cineraria	0	0	0	1
Harpacticoida	0	1	0	0
Leptosynapta inhaerens	0	0	0	1
Leptosynapta sp. (juvenile)	2	0	0	2
Malacoceros tetracerus	0	0	1	1
Microspio mecznikowianus	8	0	0	1
Moerella donacina	0	0	0	1
Mysella bidentata	1	0	0	8
Nicolea zostericola	0	1	0	0
Onoba semicostata	0	0	0	2
Perioculodes longimanus	0	1	0	0
Pherusa plumosa	0	0	0	1
Polyopthalmus pictus	1	0	0	0
Prionospio fallax	14	1	1	1
Pseudocuma longicornis	0	1	0	0
Pseudopolydora pauchibranchiata	7	0	0	0
Pygospio elegans	2	0	0	0
Rissoa interrupta	0	0	0	1
Sphaerosyllis erinaceus	1	0	0	0

Anaitides mucosa	0	0	3	40
Anthozoa	0	0	3	11
Atylus vedlomensis	0	0	0	1
Eteone longa agg.	1	1	0	3
Euclymene oerstedii	8	0	0	0
Glycera sp. Juv.	0	0	1	0
Lucinoma borealis	0	0	2	3
Mediomastus fragilis	6	1	0	37
Nemertea	12	11	64	87
Nephtys hombergii	0	2	0	0
Nephtys kersivalensis	1	0	0	0
Nephtys sp. (juvenile)	0	1	0	0
Nephtys sp.	0	1	0	0
Nereididae juvenile	1	0	0	0
Philine sp.	1	0	0	0
Pholoe baltica	0	0	0	1
Pholoe synophthalmica	0	0	0	1
Scoloplos armiger	35	12	0	101
Sphaerosyllis taylori	4	4	1	0
Syllidia armata	0	0	0	1
Capitella sp.	9	122	1347	244
Ctenodrilus serratus	0	27	0	0
Grania spp.	2	0	3	37
Limnodriloides sp.	0	0	1	16
Nematoda	42	870	403	548
Notomastus sp.	1	0	0	0
Ophryotrocha spp.	0	3	0	0
Protodorvillea kefersteini	0	0	3	24
Tubificoides pseudogaster agg.	10	0	6	0
Tubificoides benedii	14	192	77	530
Tubificoides insularis	0	0	0	194

These guidelines are a practical document on the implementation of monitoring surveys for marine cage culture operations within the Kingdom of Saudi Arabia prepared by the consultant Richard Anthony Corner (Environmental Expert) who was commissioned by FAO in the framework of the Project UTF/SAU/048/SAU "Strengthening and supporting further development of aquaculture in the Kingdom of Saudi Arabia".

In general, this is a guide to help support good monitoring practice, with details on what to monitor, parameters to be collected, how data is collected, appropriate ways to process the data and what to do with it once the survey is complete and results available. Such monitoring activity will ensure that cage farms use practices that minimize environmental impacts for the long term sustainability of cage aquaculture within the Kingdom of Saudi Arabia. In this sense the document is for fish farmers and their consultants to ensure a unified process of monitoring using standardised procedures, but is more generally applicable for all stakeholders.

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