OGP

Offshore environmental monitoring for the oil & gas industry

Report No. 457

May 2012

International Association of Oil & Gas Producers

Publications

Global experience

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Our overall aim is to ensure a consistent approach to training, management and best practice throughout the world.

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Many of our guidelines have been recognised and used by international authorities and safety and environmental bodies. Requests come from governments and non-government organisations around the world as well as from non-member companies.

Offshore environmental monitoring for the oil & gas industry

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Revision history

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1	May 2012	First issued

Executive Summary

The oil & gas industry conducts environmental monitoring in offshore areas where exploration, development, production and decommissioning activities take place. The information collected supports environmental management activities, assists in meeting regulatory requirements and provides valuable data on the state of the marine environment. This document provides guidance to exploration and production companies on the design of offshore environmental monitoring studies. Once the decision to undertake a monitoring programme has been adopted and technical objectives have been defined, use of the information in this report should help promote the collection of higher quality data in a cost-effective manner and should lead to enhanced understanding of the possible environmental impacts of offshore oil & gas operations.

Offshore environmental monitoring, in the present context, is the study of the water column and sediment compartments seaward of the intertidal zone. It does not include the monitoring of beach zones or onshore areas, possible impacts from seismic operations, or oil spills and other unplanned incidents. The objective of offshore monitoring is to gather information to support environmentally responsible oil & gas industry operations. This report provides guidance to improve the effectiveness of monitoring activities through discussions of the following topics:

- Evolution of data needs throughout the lifecycle of an offshore project.
- Measurement variables and sampling techniques that may be addressed in monitoring programmes.
- Use of established methods for monitoring.
- Data management and quality assurance methods to improve confidence in monitoring results and ensure the long-term usability of data.
- Use of numerical modelling in the design of monitoring programmes.
- Application of results from monitoring programmes.

Application of the practices discussed here will maximise the value derived from site specific and broader scale offshore monitoring activities.

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1 Introduction

The International Association of Oil & Gas Producers (OGP) has prepared this document to highlight the benefits to be gained from effective marine environmental monitoring programmes. The aim of the report is to promote careful definition of monitoring requirements, generate high quality data and develop a more comprehensive assessment of environmental conditions. This should lead to an enhanced understanding of the interaction between offshore oil & gas operations and the environment.

Monitoring of the environment in offshore areas, where oil & gas exploration and production activities take place, is undertaken to meet a variety of information objectives and regulatory requirements. The purpose of this document is to provide a consistent approach to monitoring of the marine environment. Environmental monitoring can provide support to obtaining access to resource areas and for continued access during the project lifecycle. Monitoring can be used to establish baseline conditions, develop an understanding of potential impacts (which may influence project design), to test hypotheses developed again as part of the Environmental Impact Assessments (EIA) and leads to the identification of possible mitigation measures needed to achieve operational, environmental or regulatory goals and company specific requirements.

For the purpose of this report, the marine environment comprises the water column and sediment compartments seaward of the intertidal zone. Monitoring data are collected for the purpose of environmental management of normal industry operations such as drilling, facility planning, production and decommissioning. Monitoring the predicted effects of operations on beach zones or onshore areas, possible impacts from seismic, as well as oil spills and other unplanned incidents, is outside the scope of this document.

This report discusses how information needs evolve during the lifecycle of a project, the spectrum of available techniques and practices that can be applied for the implementation of monitoring programmes, and the management of monitoring data.

It is important to note that monitoring approaches described in this report are not necessarily appropriate for all assessments. Each project will require evaluation to determine the most appropriate and applicable monitoring to conduct, as well as which endpoints are important considering the project, its potential impacts, sensitivity of local resources, as well as local and company-specific requirements.

2 Environmental monitoring objectives and data needs of an offshore oil & gas project

The environmental monitoring data needs of an offshore oil & gas project are dependent on the local regulatory regime, company specific requirements and the environmental sensitivity of the project, in terms of location and project activities. Environmental monitoring programmes should be "fit for purpose". Oil & gas projects differ in size, complexity and environmental sensitivity and these factors should be taken into account when deciding on a monitoring programme. For instance, a single exploratory well with no evidence of significant surrounding biological communities does not require the same level of assessment as a 20 developmental well programme near sensitive marine habitats and resources. A heterogeneous area will also require a more comprehensive monitoring programme than a homogeneous one.

Environmental monitoring programmes are often conducted as part of a project's environmental impacts assessment (EIA). The EIA evaluates the project from a broad environmental context. It includes a characterisation of the area of interest, including regional and local biodiversity, locations of sensitive habitat and resources, and other users of the resource, e.g. commercial and artisan fishing. Offshore environmental monitoring supports the objectives of the EIA by generating specific environmental information at the site of interest to understand the baseline conditions. Baseline surveys enable an operator to identify sensitive marine communities prior to field development and take action to avoid or minimise impacts. Surveys can also be conducted to monitor any changes to the marine environment during the life cycle of the project. These efforts often require data collection on the physical, chemical and biological properties of the water column and sediments.

Data needs can be better understood by considering the activities during the various phases of the project. Different project phases can be mapped to the OGP e-SHRIMP† framework (OGP, 2007). The e-SHRIMP toolbox was developed by OGP members to assist assessment and management of impacts in all project activities throughout the full field development lifecycle. The process is built on early appraisal and offers the potential to inform the decision-making processes around project approval and sanction. The e-SHRIMP framework is illustrated in Figure 1.

e-SHRIMP provides a convenient system for visualising the more detailed lifecycle phases of an industry project:

- Opportunity Identification
- Project Development
- Project Execution
- Operations
- Retire

† *Environmental, Social and Health Risk Impact Management Process*

2.1 Opportunity Identification

In the O.I. or 'exploration' phase collection of environmental data that support the preparation of EIAs and the detection of seabed physical or biological features are of value. These data may be collected as part of a seismic or rig site survey. Geophysical techniques, such as sidescan and multibeam sonar can provide information on seabed physical characteristics that can influence the selection of well or infrastructure sites as well as aid in the detection of biological communities of special sensitivity.

2.2 Project Development

Monitoring conducted during the 'Exploration and Appraisal Drilling Phases' can provide an indication of possible effects of drilling activities on the seabed environment, and particularly on sensitive sessile organisms that might be impacted by increased sedimentation from the discharges of drill cuttings. Chemical, biological and physical characterisation of the sediment is useful for assessing effects and for verification of the assumptions made in EIAs. Visual documentation is a good tool for documentation of possible impact on sessile organisms. At this early stage of a project, it is important to consider the long term spatial extent of potential impacts and design any baseline assessment with an understanding that areas of interest may expand well beyond the initial drilling sites.

2.3 Project Execution

After the completion of the "Development Drilling Phase", the main portion of any inputs of solids to the seabed would have ceased. Characterisation of the sediment at this point is important as a reference to gauge the future progress towards recovery of seabed conditions, where these are perturbed or where there are possible long-term impacts on sensitive sessile organisms.

2.4 Operations

Monitoring during the 'Production Phase' of the project can provide, through periodic sampling of sediments, information on the seabed conditions as a result of human activity or natural variations. Monitoring of the water column, sediments and tissues of marine organisms can be useful for assessing the potential for exposure to contaminants arising from the operation of the facility.

2.5 Retire

Once the facility reaches the end of its operational life, post-decommissioning monitoring of seabed sediments via chemical, physical, and biological sampling can provide information on the condition of the environment. This enables assessment of the state of the environment or to assess the extent of recovery of sediment conditions. Surveys of the seabed conducted to verify site clearance can also provide a useful record of sea bottom texture that can be compared with future measurements to assess the large scale recovery of sediment conditions.

2.6 Environmental, Social & Health Risk and Impact Management Process (e-SHRIMP)

Figure 1: Initial e-SHRIMP project phases, activities and potential environmental data needs

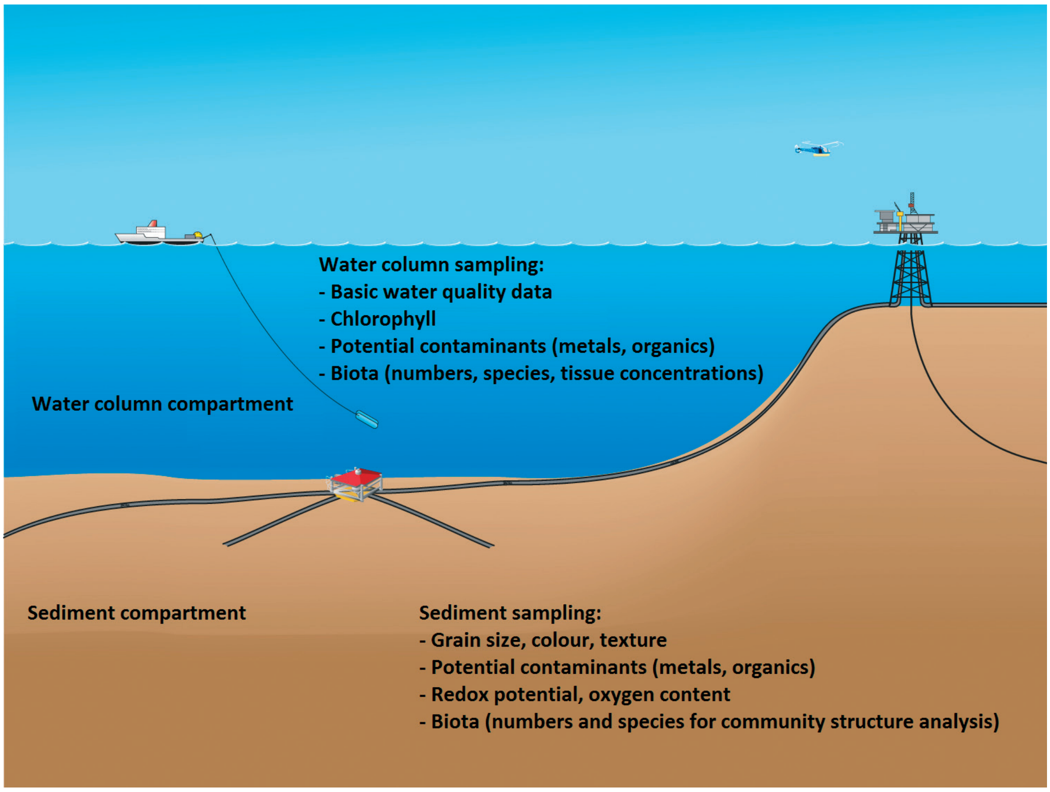
e-SHRIMP project phases	Phase activities	Potential environmental data needs†
Opportunity Identification	• Secure permission to explore • Define type of site needed • Define activities to take place • Define regulatory authorities and restrictions • Define and engage stakeholder community	• *Identification of potentially impacted resources* • *Data on known environmental responses to similar activities in other settings* • *Definition of potential inputs/changes to the environment: wastes, resource use* • *Definition of activities to take place* • *Initial impact predictions through modeling*
Project Development	• Confirm presence of resources • Confirm suitability of infrastructure or needs for improvement • Appraise potential commercial viability • Initial site activites: – Seismic surveys – Exploration/appraisal drilling – Site characterisation surveys • Evaluate options for development: – Type and scale of facilities – Numbers of wells, pipelines, shorebases and structures needed – Development concepts • Identify leading candidate options • Develop environmental management plans/options • Engage regulators and stakeholders to identify preferred alternative	• *Revision and refinement of identification of impacted resources* • *Data on pre-activity environmental status of water column and sediment compartments* • *Measurement of impacts of initial activities and comparison with predictions for water column and sediment compartments* • *Data on water column currents and hydrographic conditions* • *Comparitive assessment of environmental impacts of alternatives*
Project Execution	• Design of preferred concept • Development drilling • Construction of platforms, pipelines and facilities • Implement environmetntal management plan • Commissioning of facilities	• *Preparation* of EIA • *Measurements as needed of impacts on water column and sediment compartments and comparison with predictions* • *Assessment of performance of waste treatment and disposal plans*
Operations	• Facility operations • Stewardship of environmental management plans • Assess environmental performance versus targets • Communication with authorities and stakeholders • Revise operating practices/standards in response to changes in the environment	• *Measurements as needed of impacts on water column and sediment compartments and comparison with predictions* • *Assessment of longer term changes to ecosystems* • *Additional data on oceanographic conditions as needed to support environmental management and emergency response*
Retire	• Plan for and implement cessation of operations of operations • Make facilities ready for removal, reuse and/or disposal as appropriate • Remediate sites as needed for suitability for post-project use • Prepare for and implement in-situ deactivation where appropriate, e.g. pipelines, wellbores, footings • Reach agreement with authorities on acceptability of site conditions	• *Information on environmental status of water column and sediment compartments at cessation of operations* • *Ongoing assessment of site conditions as required by decommissioning plans*

† *Items in italics potentially addressed within the scope of environmental monitoring programmes*

3 Environmental compartments

The interaction of human activities with the environment can be organised as a set of interlinked compartments. In the case of the offshore environment, the focus is often placed on the water column and the sediment compartments. Figure 2 illustrates these two compartments and the parameters that might be considered in a monitoring programme.

Figure 2: Environmental compartments sampled in offshore environmental monitoring surveys.



During production operations, when operational discharges occur, there may be impacts to the water column so monitoring may be appropriate. Monitoring the water column compartment generally focuses of effects from continuous rather than occasional activities because when discharges cease, effluent concentrations in the water column often decrease quickly, subsequently reducing impacts very rapidly.

When assessing ecological impacts in the water column, field assessments generally focus on chemical and physical analyses of the receiving water. In special cases, biota, e.g. free swimming fish or caged organisms, may be sampled to assess potential bioaccumulation. Whole effluents discharged from offshore facilities are also routinely monitored. Oil and grease is the most common analyte measured. Discharges are also often analysed for heavy metals, specific hydrocarbons, salinity and other constituents. In some countries, effluent toxicity of discharges is evaluated using standardised bioassays. With an understanding of the dilution of a discharge, these whole effluent data can be extrapolated to determine whether there is the potential for receiving water impacts.

The following water column properties are of interest in the marine monitoring context (Table 1):

Table 1: Key factors affecting impacts of oil & gas projects to water column

Parameters	Description
Physical	Ocean currents, wind, turbidity, salinity and temperature
Chemical	Suspended solids, organic compounds, and additional substances resulting from inputs from other anthropogenic activities
Biological	Number and distribution of fish and other pelagic organisms, toxicity to or more general health variables of marine organisms

The sediment compartment is a sink for many contaminants in the marine environment. Solids that enter the water column, through either disturbance of seabed sediments or through the discharge of waste solids, may be transported from the site of discharge. Soluble materials that enter the water column may precipitate due to chemical changes or adsorb to natural sediment particles present in the water column. Precipitated materials or sediment particles with adsorbed contaminants then settle on the seabed where they may have direct effects on benthic communities or indirect effects on water column organisms. Although marine processes can redistribute and dilute solids that settle to the seabed, particularly in shallow water, the sediment compartment has a strong tendency to accumulate particles and associated contaminants over time. Potential sediment impacts are often monitored as described in Table 2.

When assessing ecological impacts on the seafloor, field assessments generally focus on the populations of sediment dwelling fauna. Sediment dwelling organisms can be reliable and sensitive indicators of habitat quality. This is because they live in bottom sediments where exposure to contaminants and oxygen stress are most frequent. They are also effective indicators of local conditions because they have limited mobility and cannot migrate to avoid stressful situations.

Table 2: Factors affecting impacts of oil & gas projects on sediments

Parameters	Description
Physical	Particle size distribution
Chemical	Sediment concentrations of metals and hydrocarbons
Biological	Number and distribution of benthic organisms

4 Sampling

4.1 Introduction

Selection of methods used to collect water column or sediment samples for environmental monitoring should be guided by the project phase and the type of survey to be carried out, for example, a baseline study, a trend study or compliance monitoring, and the objectives of each individual study. This report discusses sampling methodologies in general terms, which should help the reader appreciate the range of available techniques. Video and photographic monitoring techniques can also be used and are discussed in Chapter 5.3. The Census of Marine Life (2008) has published a report on the various methods available for water column and sediment sampling.

4.2 Site sampling plan

One of the first steps in conducting an offshore environmental sampling study is to develop a site sampling plan. The plan identifies location and number of stations, sampling methodologies and analytes to be measured.

The location and number of stations should also be related to the project objective, the activity and size of the development. When available, bathymetry and metocean data should be used to define sampling locations. Dispersion modelling may also be useful in selecting sampling sites by predicting the deposition of constituents (see Chapter 5 for more information). Attention should be given to understanding previous and current activities in and around the study area, and how these activities may influence the results that are obtained.

A typical sampling programme should include at least one reference station, measurement stations that reflect presumed gradients and stations that reflect potential nearfield and farfield impacts. This type of programme should allow comparison between affected and unaffected sites, and to discern between project-related impacts and natural variation. When possible, the sampling design should be adequately robust to allow for statistical analysis of the data.

4.3 Water column sampling

Measurements of bulk water column variables such as temperature, turbidity, conductivity/ salinity and dissolved oxygen may be carried out on discreet samples but can also be measured using multiparameter probes. Sensor technology has advanced so many parameters can now be continuously measured by specialised instruments deployed at the seafloor. Measurement of concentrations of substances of presumed concern, for example trace metals, frequently pose significant analytical challenges due to their occurrence at trace levels. However, sensitive analytical methods have been established that allow for accurate detection of these substances both in sediments and the water column. In some environmental research projects, semi permeable membrane devices (SPMDs) or baskets containing live bivalves have been deployed around offshore facilities to assess the presence of polyaromatic hydrocarbons in the receiving water. SPMDs and bivalves accumulate (concentrate) the lipophillic hydrocarbons, which allow for chemical analysis below conventional analytical detection limits.

The suite of analytes to be measured is determined by the objectives of the monitoring programme (and which may include national regulatory requirements). Examples of monitoring parameters are included in Appendix 1. Water should be collected and sampled as specified by the applicable analytical protocol.

4.4 Biological water column sampling

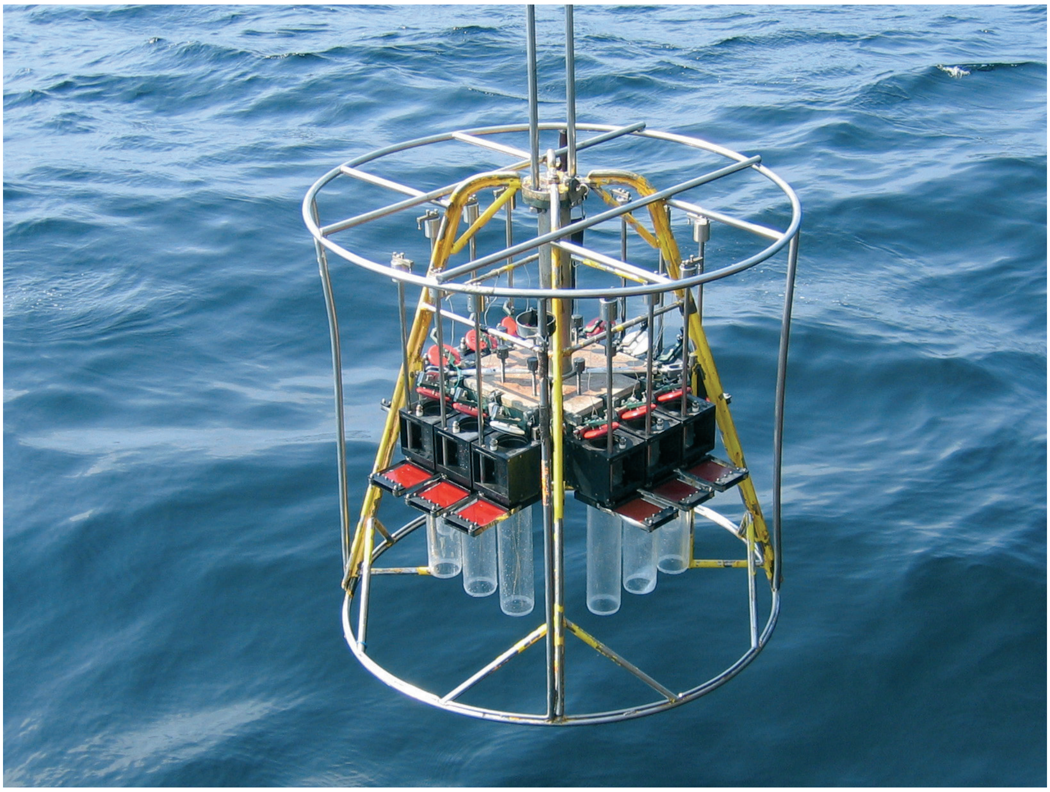
Depending on the purpose of the survey, marine organisms may be sampled to assess possible adverse effects to their health. These organisms can either be feral or caged. Sampling can also be performed to measure the fitness of marine products for human consumption (US. EPA, 2000).

4.5 Sediment sampling

The choice of methods for sediment sampling is influenced by the sediment characteristics (where known), the type of measurement(s) to be made on the sample, the water depth (size of macrofauna relative to water depth may affect sieve size), and the amount of sediment needed for the analyses of interest.

Surface deployed equipment for collecting sediment samplings includes various grab-type, box or multicore samplers. The multicorer can be used to take undisrupted sediment samples from the seabed.

Figure 3: Multicorer



Note: Care should be taken in deep water or when strong currents are present, to ensure that the required location is achieved. Transponders or similar devices can be used to assist.

Sediment cores can also be obtained using remotely operated vehicles (ROV). This approach provides the advantage that the location to be sampled can be selected with precision, e.g. pre- and post-drill sampling.

The required amount of sediments varies according to the type of measurement being made. Physiochemical analyses require approximately 0.1m^2 of sediment (to a depth of 10cm) per sample whereas analyses of the community structure of macrofauna require a larger sample, e.g. 0.3-0.5m^2 to a depth of 10cm, in order to ensure that sufficient biomass of organisms is collected to provide the basis for a representative count.

Samples taken for characterisation of benthic biological community structure are usually processed by washing in a sieve with seawater to remove sediment particles and isolate the biota. The sieve mesh size should be determined by the type of organisms and ecosystems of interest. Benthic macrofauna are the usual focus of these assessments. Organisms<0.5mm are classed as benthic meiofauna and are not usually evaluated in offshore surveys.

4.6 Sample storage and preservation

Sampling plans should specify the type of container, storage conditions and maximum holding times for each type of analysis. Sample containers should be clean and properly stored to avoid contamination. For the water column monitoring, the tissue samples must be taken and prepared on board the boat immediately after the organisms are brought onboard.

Sediments sub-sampled for chemical analyses are stored in containers appropriate for the type of measurement e.g., glass jars for organic compound analyses and plastic jars for metals analyses. Biota samples should be appropriately preserved and stained to facilitate later analyses. A frequently used approach is to chemically preserve the organisms and stain them with 'Rose Bengal'. Storage and preservation conditions e.g. refrigeration and maximum holding times should be specified based on the target analyte and method.

4.7 Quality assurance and quality control

Quality assurance and quality control (QA/QC) procedures are used in environmental monitoring programs to ensure that the results obtained will meet the project's technical and business objectives. Documentation of the steps taken to ensure that the desired data quality is achieved is necessary to provide initial users with confidence in the reliability of the results. Although programme objectives and resources may sometimes limit the QA/QC procedures applied, adherence to accepted standards of quality and control, including chain of custody documentation, sampling storage requirements and holding times, and to the practice of conducting measurements according to established QA/QC guidance will maximise the long term usability and value of monitoring data (ISO/IEC 17025:2005; and USEPA 2008).

5 Parameters for environmental monitoring

Conducting analyses according to established standards offers the advantages of comparability between the results of different surveys and, when supported by appropriate quality assurance, greater confidence in the validity of the measurements.

5.1 Water column

Monitoring survey objectives should guide the selection of parameters to be measured. Techniques for measuring water-column parameters are defined within published standard methods, developed by national or international organisations (see Appendix 1).

Physical, chemical and biological analyses in water are regularly performed around oil & gas operations. Biological analyses have generally focused on bioassays and bioaccumulation measurements. Biomarkers can also be used in offshore environmental monitoring, however, they are considered experimental for offshore oil & gas industry environmental assessments (see Table 6 in Appendix 1) in many regions of the world.

There are several definitions for biomarkers. The National Research Council has defined biomarkers as "a change induced by a contaminant in the biochemical or cellular components of a process, structure or function that can be measured in a biological system" (NRC, 1989).

5.2 Sediment

Sediment samples are characterised by a general description of their appearance, measurements of their physical-chemical properties, and speciation and enumeration of the biota found in the samples.

The following description of the sediment samples should be made in the field for all types of surveys:

- Visual description of the sediment surface, e.g. degree of disturbance, debris and empty shells, homogeneity, bioturbation, texture, colour, stratification, presence of drill cuttings, black deposits, bacterial mats;
- Presence of large and/or conspicuous fauna;
- Odour (such as H_2S or petroleum).

Physical-chemical characterisation of sediments comprises measurements made to define the grain size distribution in sediments, the basic chemical composition (total carbon, total organic carbon, nutrient chemicals), and defining the metals or organics that might be changed as a result of project activities.

Organisms in sediment are analysed to characterise the benthic macrofaunal community. Measurements on sediments address taxonomic identification of the species present and the numeric density of each species (see Appendix 1, Table 4).

In addition, in situ sediment bioassays have been used to assess spatial and temporal impacts of drilling discharges. Sediment concentrations of metals and hydrocarbons can impact benthic organisms directly through toxic effects or indirectly by altering redox properties and pore-water oxygen concentrations, and increased body burdens of contaminants.

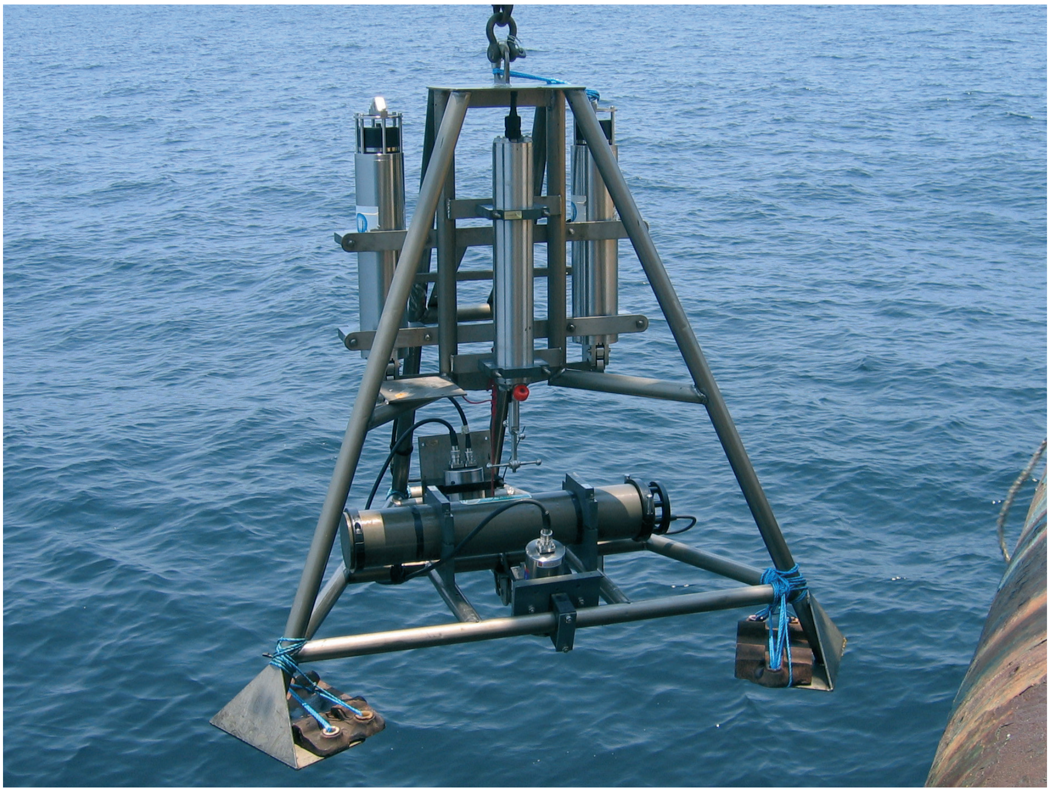
Number and distribution of benthic organisms can be altered by physical disturbance, e.g. sediment burial or smothering, or chemical inputs to sediments. Benthic ecology parameters such as abundance, diversity, evenness and presence of opportunistic species are considered sensitive indicators of disturbance.

5.3 Subsea monitoring technologies

Lander systems (or multi-sensor platforms), such as the one in Figure 4, and remotely operated vehicles (ROVs) are examples of surveillance technologies. They are increasingly being employed by marine scientists and industry to couple traditional environmental data gathering approaches with multi-sensor probes, computing and communication instrumentation. They also often include photographic and video capabilities (see Figure 5).

Landers and ROVs are normally equipped with cameras and bathymetric monitoring equipment. Landers can also carry physical/chemical sensors that measure parameters such as temperature, salinity, turbidity, oxygen and chlorophyll-a. Some ROVs are also capable of taking sediment core samples.

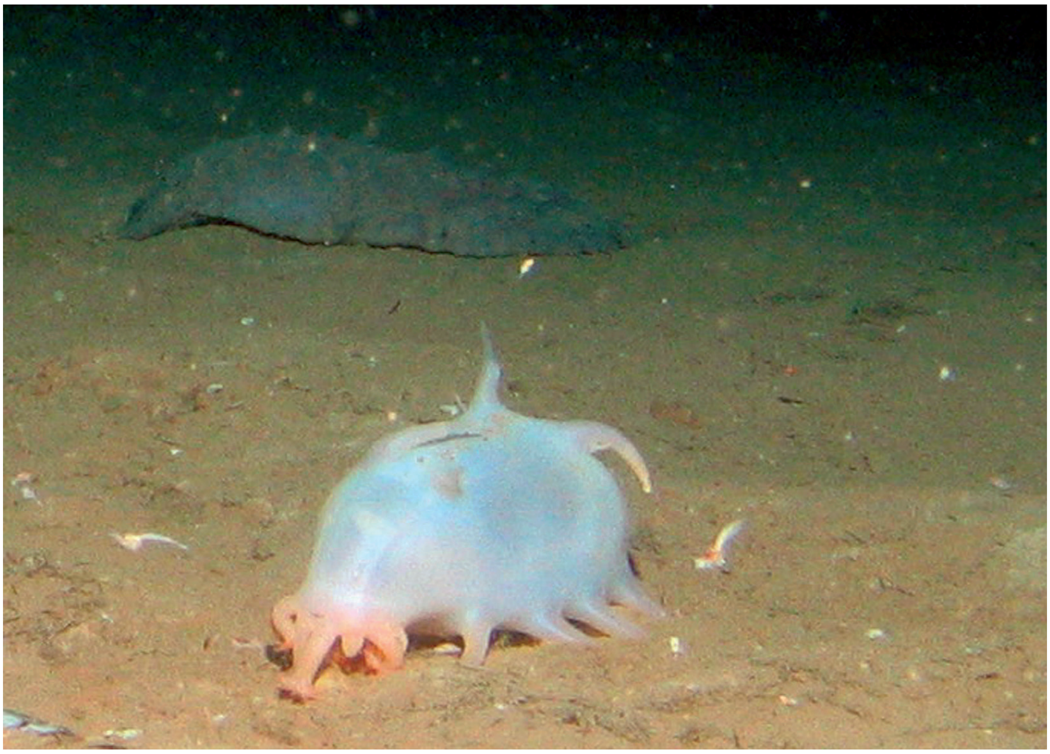
Figure 4: RObust BIOdiversity (ROBIO) Lander



Some of the key advantages of these technologies include:

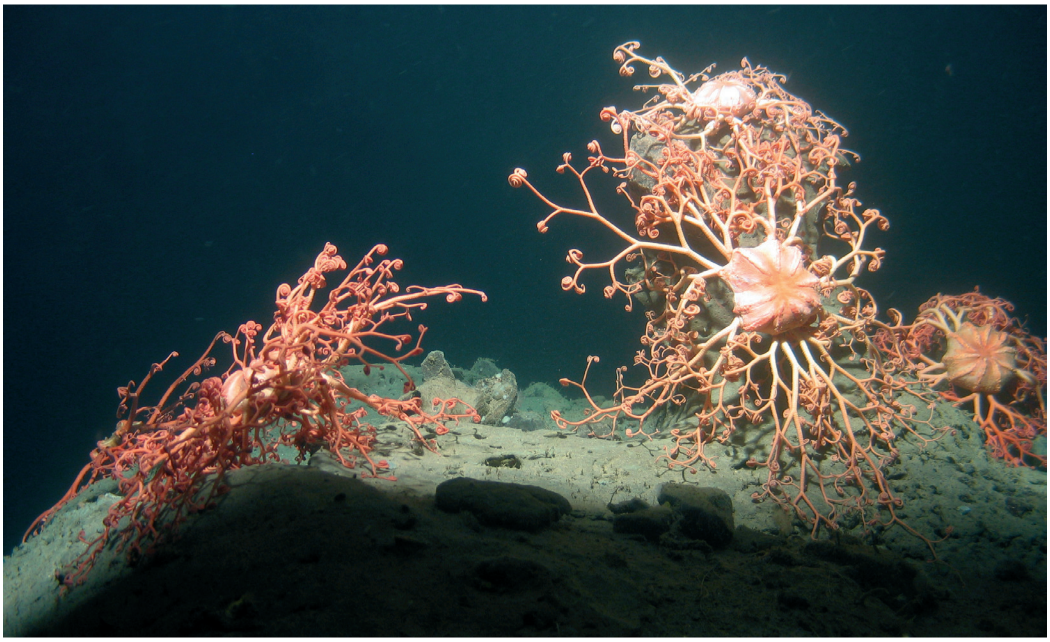
- Allow a large numbers of assessments to be made over a wide temporal and spatial area and are able to track natural seasonal and global changes.
- Possibility for real-time measurements, dependent on the set-up.
- Photographic surveys are non-invasive and provide material that is both useful to scientists and understandable by public audiences.

Figure 5: Photo of Holothurians taken by ROBIO Lander in Angola (photo courtesy of BP)



The SERPENT (Scientific and Environmental ROV Partnership Using Existing Industrial Technology) project (http://www.serpentproject.com), which has been established at the National Oceanographic Centre, Southampton, UK, trains drillship ROV operators to take photos and video footage of marine life. The photos and videos generated from this project, such as the one in Figure 6, have been of immense value to the offshore oil & gas industry and have increased our understanding of biological aspects of the deep water environment.

Figure 6. Photo of basket starfish colony taken as part of the SERPENT Project

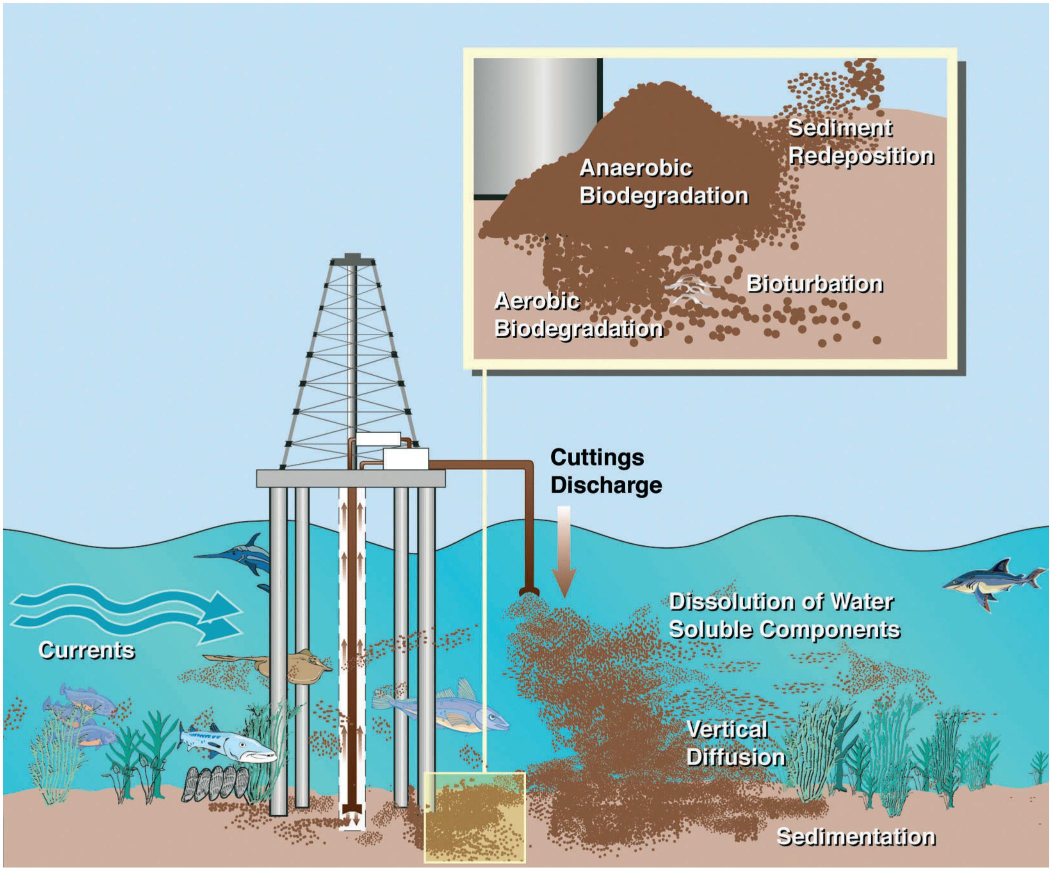


6 Environmental modelling to support monitoring plans

Technology advances in predictive modelling allow better prediction of the fate, effects and risk of offshore discharges and emissions. While models do not substitute for site specific environmental data, they often reduce the amount of field data necessary to make a sound technical assessment. They are also useful to help focus on the most critical aspects of a site specific assessment and thereby pinpoint where environmental data needs to be collected.

Environmental modelling in the offshore has generally focused on produced water and drilled cuttings discharges. Discharge modelling of produced water and drilled cuttings models estimate the vertical and horizontal distribution of the produced water outfall and cutting on the seafloor respectively. Figure 7 presents a conceptual model of the parameters that are routinely considered in this type of model. Though done less frequently, air dispersion models have been used for estimating the concentrations and atmospheric dispersion of air emissions from offshore facilities.

Figure 7: Conceptual model of processes modelled for drilling discharges (OGP, 2003)



Models have generally focused on the relative concentration and exposure of a waste stream or chemical constituents in the marine environment. Particularly in Europe, the Dose-Related Risk and Effect Assessment Model (DREAM) has been integrated with probabilistic risk processes that not only estimate exposure, but also estimate ecological risk (SINTEF, Norway; Johnsen et al., 2000; Reed and Hetland, 2002).

Several models are presently available for evaluating the dispersion of produced water discharges. Among these are the DREAM model (SINTEF, Norway; Johnsen et al., 2000; Reed and Hetland, 2002), the OOC model (Smith et al., 2004), PROTEUS (BMT-Cordah, UK) (Sabeur and Tyler, 2004), MIKE 3 (DHI, 2009) and the CORMIX model (Jirka et al., 1996). All of these models have numerical fate modules which compute the physical dispersion, and biogeochemical transfer of chemical compounds in the marine environment based on physical and chemical characteristics of the compounds and local conditions, such as salinity, currents and winds. Figure 8 shows an example of modelling results from a produced water discharge. As illustrated, constituents in produced water discharges can be diluted over 10,000 fold five hundred metres from the discharge point.

Unlike produced water, drilling muds and cuttings settle on the seafloor and can sometimes persist for extended periods of time. Dispersion modelling is an important tool when trying to estimate the size of the drilling discharge footprint on the seafloor. The models referred to above, except the MIKE model, are all capable of estimating the vertical and horizontal distribution of cuttings on the seafloor. In addition, there is MUDMAP (ASA, US), which was especially developed to predict the transport and dilution of drill fluids. Cuttings dispersion is dependent on drill cuttings volume discharged, cuttings density, water depth and currents. Figure 9 shows the output from the modelling results of drill cuttings discharge. In this particular case, cuttings accumulation on the seafloor is predicted to be no thicker than 1cm beyond 250m of the discharge.

Figure 8: Snapshot of a produced water discharge modelling result

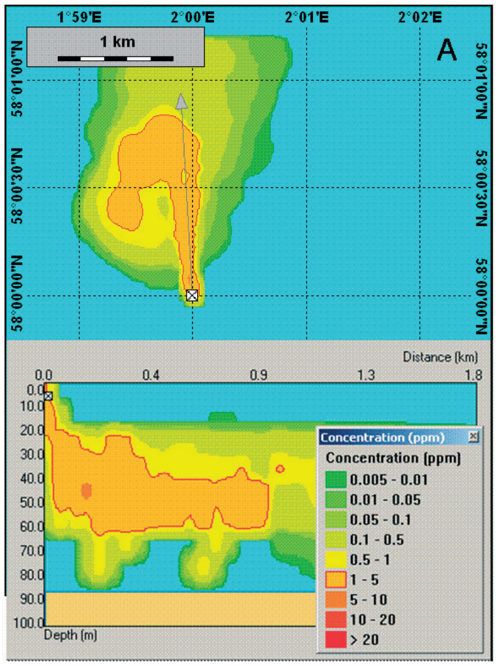
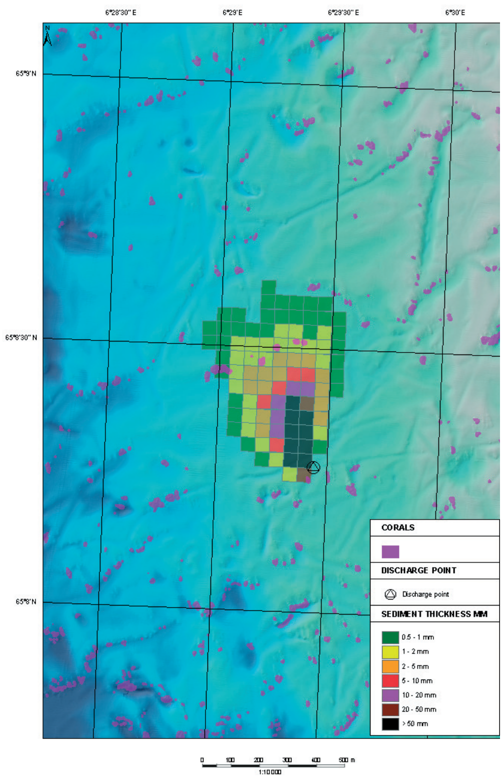


Figure 9: Solids deposition thickness on seabed



7 Summary and application of results

This report provides guidance to offshore operators on when and how to conduct an environmental monitoring programme. Environmental monitoring can be driven by regulatory requirements as well to meet internal environmental requirements and stewardship expectations. Whatever the objective, there is value in applying the consistent, science based methodologies discussed in this report. Some of the key considerations surmised in this document include:

- Use established and consistent methods when conducting assessments to allow comparison in time and space.
- Employ a scientifically sound study design to discern significant changes from environmental variability, account for overlapping inputs from neighbouring wells and facilities and recognise that data needs change through the lifecycle of an offshore project.
- Consider new monitoring technologies such as biomarkers and the use of fixed or mobile subsea sensor platforms such as landers and ROVs.
- Use modelling to better design a sampling plan and optimise the amount of field data necessary to make a sound technical assessment.
- Employ quality assurance and quality control methods to improve confidence in monitoring results and ensure the long-term usability of data.

Environmental monitoring programmes are valuable to offshore operations in making decisions related to facility design, drilling programmes and environmental protection measures. Environmental monitoring can be used to measure and detect changes in environmental conditions through the lifecycle of a project and is useful in the assessment of unplanned incidents such as spills. Applying consistent, well established methods and data management procedures will generate high quality results to meet company environmental stewardship objectives and to be technically credible to stakeholders.

Appendix 1 – Methodologies used for offshore environmental monitoring

The following appendix contains references to analytical methods and standards applicable for use in analyses of samples taken for offshore monitoring. Methods and standards referenced herein are presented as examples and are in no way endorsed or recommended by OGP. Other methods and standards may also be available and suitable for laboratory analysis of samples taken as part of an offshore monitoring program.

The methods described in the tables below range from classical monitoring techniques, such as water column and sediment analyses, to more advanced analyses of biological tissues such as fish muscle, blood and liver bile. While water column and sediment analyses are generally part of an offshore monitoring program, the chemical analysis of tissues and analysis of biomarkers are relatively new techniques that have been applied almost exclusively in Norway.

When conducting biomarker analyses as part of a monitoring program, it is important that they include a suite of complementary methods since a positive response from one method does not necessarily represent a significant biological response. Also, in any biomarker assessment, the general health of the fish should be assessed (e.g. condition, liver somatic index, gonad weight) in addition to contaminant-specific methods.

Table 3: Analytical methods and standards for water analyses

Physical-chemical analysis		
Parameters	**Methods**	**Standards**
Suspended solids	Filtering then weighing Centrifugation	ISO 11923 T 90-105-2 EPA 160
Nitrates, nitrites, orthophosphates	Ionic Chromatography	EN ISO 10304-2 EPA 300 EPA 353 EPA 365
Chlorophyll pigments and phaeopigments	Extraction then spectrophotometry or fluorescence	NF T 90-117 EPA 445
Dissolved Oxygen- pH-Temperature- Salinity- Electrical Conductivity- Turbidity- Visibility	Simple procedures and equipments by using probes	SM 4500
Metals	Metals analysis with nitric acid	OSPAR/ICES 2002 EPA 6010 EPA 6020
Hg	Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence Spectrometry	EPA 1631
Ba, Cd, Cr, Cu, Pb, Ni, Co, Sn, Zn	Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES)	EN ISO 11885 EPA 6010
Hydrocarbons	Three possible approaches 1. Direct sampling – difficult because HC concentrations are very low. Integrating samplers: 2. passive (SPMD) 3. living (caged bivalves)	
Total Hydrocarbon Content (THC) THC can be measured to understand the hydrocarbons in the water column. These can also be used to further understand the composition of aliphatics, aromatics and PAHs in the water sample.	Gas-chromatography (GC)/FID Internal reference standard for quantification	X 31-410 EPA 8015 EPA 8021 ISO 11046
Aliphatic Hydrocarbons (if THC > 0.01 mg/L)	Gas-chromatography (GC)/FID Internal reference standard for quantification	X 31-410 method B EPA 8015 EPA 8021 ISO 11046

Physical-chemical analysis

Parameters	Methods	Standards
Polycyclic Aromatic Hydrocarbons (PAH16*)	Gas-chromatography (GC)/MS	X 31-410 EPA 8270
	High Performance Liquid Chromatography (HPLC)	ISO 11046 EPA 8310
	Internal reference standard for quantification.	EPA 610
Mono Aromatic Hydrocarbons (BTEX)	Gaschromatography (GC)	NF ISO 11423-1 EPA 8015 EPA 8021

Table 4: Analytical methods and standards for sediment analyses

Physical-chemical analysis

Parameter/activity	Procedure principle	Standard
Planning of field work for sediment monitoring	General planning of activity and adjoined QA-QC routines	Norsk Standard NS 9420 EPA 823/R-92-006
Sediment sampling	Sampling by use of grab or box corer. Preferred grab type is long-armed vanVeen	Norsk Standard NS-EN ISO 5667-19:2004 EPA 823/B-01-002
Sample handling, subsampling, storage	Provides guidelines for sampling equipment and sample treatment in the field, sorting and species identification, storage of collected and processed material. Guidelines generally focus on macrofauna retained on a 0.5mm sieve, though deepwater assessments may also include organisms collected on a 0.3mm sieve	Norsk Standard NS-EN ISO 5667-19:2004 (chemical parameters) NS-EN ISO 16665:2005 (fauna) EPA 823/R-92-006
Total organic matter, TOM (also called total organic carbon, TOC)	Analysis as loss on ignition. Maximum ignition temperature 480°C to prevent loss of inorganic carbonate	NS 4764 EPA 415
Sediment grain size distribution	Sifting through different meshes of sieves	Buchanan (1984)
Total hydrocarbons, THC	KOH/methanol saponification, followed by pentane extraction and determination by GC/FID of the C12-C35 molecular interval. Reference oil: HDF 200.	IOC 1982 EPA 8015 EPA 8021
Aromatic HC: NPD	Internal standards. Saponification and extraction as above. Determination by GC/MS	NS 9810 NS 9815 EPA 8270
Aromatic HC: PAH_{16}	Internal standards. Saponification and extraction as above. Determination by GC/MS	NS 9810 NS 9815. EPA 8270
Barium, Cadmium, Chromium, Copper, Lead, Zinc	Freeze dried <0.5mg sample fraction eluted with nitric acid. Determination by ICP-AES	NS-EN ISO 11885 EPA 6010
Mercury	Freeze dried <0.5mg sample fraction treated to the cold vapour technique: Reduction with $SnCl_2$ followed by spectrophotometric quantification	NS-EN 1483:2007 EPA 7471
Biological analysis of sediments: Benthic macrofauna	Sample washed with water in a 1mm sieve to remove formalin, all macrofauna individuals[†] sorted out under a dissecting microscope and preserved in ethanol prior to species identification and enumeration. *N.B. There is a miniaturising effect on macrofauna in deep water thus 0.5mm and 0.3mm sieves may be required.*	NS-EN ISO 16665:2005 EPA 823/R-92-006
Limit of significant contamination	Statistical difference in concentrations relative to reference stations	None applicable. Procedure described in Annex 1

† Taxonomic groups omitted: nematoda, colony forming hydrozoa, bryozoa, porifera, harpacticoida, zooplankton, hyperbenthos, fish

Physical-chemical analysis

Parameter/activity	Procedure principle	Standard
Statistical analysis of biological data: Univariate characteristics of macrobenthos per station	Calculation of number of taxa†, total number of individuals, Shannon-Wiener diversity index, Pielou evenness, expected number of species per 100 individuals, 10 numerically dominant taxa.	Shannon & Weaver 1963, Pielou 1966, Hurlbert 1971, Sanders 1968
Statistical analysis of biological data: Station similarity in macrofauna structure	Cluster analysis and nonparametric MDS ordination analysis based on Bray-Curtis similarity index	Gray et al. 1988

Table 5: Sampling methods and preparation for analysis

Physical-chemical analysis

Parameter/activity	Procedure principle	Standard
Planning of offshore field work	General planning of activity and adjoined QA-QC routines	Norsk Standard NS 9420
Fish Sampling and sample handling	Sampling of selected open sea fish species by standard commercial fishing methods (trawling)	OSPAR 1999 Norsk Standard NS 9420
Field studies using caged fish	Field deployment of mussel and cod fish cages in the Norwegian OCS. N.B. *Cod are used in the North Sea but, for other regions, this method may also be applicable to other fish species*	Hylland et al. 2006
Sampling of fish (cod)	Determination of length, weight, sex and condition. Extraction of subsamples of liver, bile, and blood for analysis	OSPAR 1997 OSPAR 2003
Sampling of mussels	Determination of length. Extraction of subsamples of haemolymph, haemocytes, gills, hepatopancreas, digestive gland, and soft tissues for analysis	OSPAR 1997 OSPAR 2003

Table 6: Methods for the performance of biomarker and PAH analyses in marine organisms

Physical-chemical analysis

Parameter/activity	Procedure principle	Standard
Cytochrome P4501A (CYP1A) in cod liver	Elevation relative to controls maybe indicative of PAH exposure	Goksøyr 1991
Vitellogenin in cod blood	Elevation relative to controls maybe indicative of exposure to endocrine disruptors	Hylland et al. 1998 Biosense Laboratories AS, Kit V01006401
Zona radiata protein (ZRP) in cod blood	Biomarker for exposure to xenoestrogens (hormone disruptors). Exposure increases the levels of ZRP which are important in the formation of eggshell. This prevents polyspermy and provides mechanical protection for the developing embryo.	Arukwe at al. 1997
DNA adducts in cod liver	Elevation relative to controls maybe indicative of PAH exposure.	Ericson and Balk 2000
B(a)P hydroxylase activity in bivalve hepatopancreas	Elevation relative to controls maybe indicative of PAH exposure.	Michel et al. 1994
Immunocompetence in mussel haemolymph	This is generally suppressed by exposure to various contaminants, so this is a biomarker expressing general stress	Pipe and Coles 1995

† Species or higher level groups

Physical-chemical analysis

Parameter/activity	Procedure principle	Standard
Lysosomal membrane stability in mussel haemolymph	Indicator of organism stress	Lowe and Pipe 1994
Micronucleus formation in mussel haemolymph	This is among the most widely used tool in eco-genotoxicology. It reveals a time-integrated response to complex mixtures of pollutants by an increase in number of micronuclei	Burgeot et al. 2006
Aromatic HC: PAH_{16}/NPD 4 in fish liver and muscle	Internal standards added. KOH/methanol saponification of wet sample followed by cyclohexane extraction, extract reduction and determination by GC/MS	NS 9810 NS 9815 EPA 8270
PAH-metabolites and Alkylphenol metabolites (B only) in fish liver bile	A: Methanol:Water diluted bile is directly analysed by fixed fluorescence. B: Internal standards. Extraction with ethyl acetate, conversion to ethers and determination by GC/MS.	A: Aas et al. 2000 OSPAR 2003 B: Krahn et al. 1992, Johnsson et al. 2003 EPA 8270
PAHs in mussels	Internal standards. Extraction of wet sample with n-pentane, cleaning, re-extraction with cyclohexane and determination by GC/MS	NS 9810 NS 9815 EPA 8270

Standards referenced in this appendix

Norsk Standard NS-EN 1483. Vannundersøkelse. Bestemmelse av kvikksølv. Norges Standardiseringsforbund. (Water investigations. Determination of mercury).

Norsk Standard NS 4764. Vannundersøkelse. Tørrstoff og gløderest i vann, slam og sedimenter. Norges Standardiseringsforbund. (Water investigations. Dry weight and loss on ignition of water, sludge and sediments).

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Norsk Standard NS-EN ISO 5667-19:2004. Water quality – sampling – Part 19: Guidance on sampling in marine sediments.

Norsk Standard NS 9810. Opparbeiding av prøvemateriale for bestemmelse av PAH. Norges Standardiseringsforbund. (Preparation of samples for determination of PAH).

Norsk Standard NS 9815. Gasskromatografisk analyse for bestemmelse av PAH. Norges Standardiseringsforbund. (Gas chromatography analysis for determination of PAH).

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Norsk Standard NS-EN ISO 16665. Water Quality – Guidelines for quantitative sampling and sample processing of marine soft-bottom macrofauna. International Organization for Standardization 16665:2005.

SM 4500. Standard Methods for the Examination of Water and Wastewater, Method 4500.

US Environmental Protection Agency Method 160. Residue, Non-Filterable & Total Suspended Solids.

US Environmental Protection Agency Method 300. Determination of Inorganic Anions by Ion Chromatography.

† Naphtalene, phenanthren/anthracen, dibenzothiophene and their C_1-C_3 alkly homologues

US Environmental Protection Agency Method 353. Nitrate-Nitrite (as N) - Colorimetric/ Cadmium.

US Environmental Protection Agency Method 365. Phosphorus, All Forms - Colorimetric/ Automated.

US Environmental Protection Agency Method 415. Organic Carbon, Total - Combustion or Oxidation.

US Environmental Protection Agency Method 445. In Vitro Chlorophyll & Pheophytin by fluorescence.

US Environmental Protection Agency Method 610. Polynuclear Aromatic Hydrocarbons.

US Environmental Protection Agency Method 1631, Revision E: Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence Spectrometry.

US Environmental Protection Agency Method 6010. Inorganics by ICP – AES.

US Environmental Protection Agency Method 6020. Metals by ICP/MS.

US Environmental Protection Agency Method 7471. Mercury in Solid or Semisolid Waste.

US Environmental Protection Agency Method 8015. Nonhalogenated Organics Using GC/FID.

US Environmental Protection Agency Method 8021. Halogenated Volatiles by GC+ Cap Column.

US Environmental Protection Agency Method 8270. Semivolatile Organic Compounds by GC/ MS.

US Environmental Protection Agency Method 8310. Polynuclear Aromatic Hydrocarbons (PAH) – HPLC.

US Environmental Protection Agency Report #823/B-01-002. Field sample sediments & interstitial water.

US Environmental Protection Agency Report #823/R-92-006. Sediment Classification Methods Compendium.

Glossary & acronyms

Bacterial mats

A thin layer or microbial bacteria that may form on sediment.

Benthic

Relating to the marine zone on or near the seabed.

Biomarkers

There are several definitions for biomarkers. The National Research Council has defined biomarkers as "a change induced by a contaminant in the biochemical or cellular components of a process, structure or function that can be measured in a biological system".

Biota

Comprised of all the living organisms in a given location.

Bioturbation

The mixing of sediments caused by benthic organisms.

Deep water

Refers to oil exploration and production in ocean depths of or greater than 1000ft (300m) to the seafloor.

DREAM

Dose Related Effects Assessment Model. A model used for evaluating the dispersion of produced water discharges.

Drill cuttings

Rock pieces dislodged during drilling. Cuttings from offshore wells are often discharged and settle to the seafloor.

Drilling fluid

A mixture of liquids and gases pumped into a borehole during drilling for the purpose of cooling and cleaning the drill bit and carrying out drill cuttings.

Ecosystem

All of the living organisms in an area and the nonliving factors on which they depend.

e-SHRIMP

The OGP Environmental, Social and Health Risk Impact Management Process (e-SHRIMP) is a method developed to assist users in early identification and management of the environmental, social and health impacts associated with oil & gas developments throughout the project lifecycle.

Lander systems

consist of a rigid metal frame hosting autonomous instrumentation, and these are deployed on the ocean floor where they gather scientific data until commanded to return to the surface via telemetry from a ship.

Epifauna

Benthic fauna that live on a surface, such as the sea floor, other organisms, or objects.

Macrofauna

Benthic fauna that are retained on a 0.5mm sieve.

N.B. In deep water assessments 'macrofauna' may also cover organisms retained on a 0.3mm sieve.

Meiofauna

Benthic fauna that are near the size range between macrofauna and microfauna.

Microfauna

Benthic fauna that can pass through a 0.5mm sieve.

Pelagic

Relating to the marine zone not adjacent to the shore or near the seafloor.

Produced water

Water extracted from an oil or gas well due to formation water in the reservoir or injected water used to extract oil.

ROV

Remotely operated vehicles designed for underwater use.

Stratification

Layering of sediments on the seafloor.

Water column

A vertical segment of a water body reaching from the surface to the seafloor useful for analysing the effects of stratification or mixing.

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