

# Guideline for environmental monitoring in Sudanese marine waters in connection with offshore oil and gas industry activities



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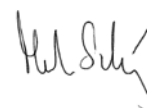
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<p><b>Abstract</b></p> <p>The unique coastal and marine ecosystems of Sudan need protection against anthropogenic influences. Monitoring is required to control that industrial operations in Sudanese marine waters meet environmental quality standards. This report includes a suggestion of guidelines for monitoring in Sudanese Red Sea waters; with a special attention to oil and gas industrial activities. The guidelines provide instructions to how systematic offshore monitoring studies can be performed to collect data required for documenting degrees of compliance with environmental regulatory demands. The report highlights the need for an efficient national legislation targeted to prevent habitat destruction, chemical pollution and other manmade impacts to Red Sea ecosystems. The report also describes the role of monitoring as a key element in assessing the effectiveness of measures adopted for minimising environmental impacts. The present work represents a collaboration between Sudan and Norway and the suggested guidelines were developed as a synthesis of Norwegian monitoring guidelines and monitoring procedures developed for Red Sea environments.</p>
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## **Preface**

*This report is made as part of a bilateral collaboration programme between Sudan and Norway and the work has been funded by the Norwegian Oil for Development (OFD) programme. In the collaboration, the Norwegian Environment Agency (NEA) assists the Sudanese Ministry of Petroleum, General Directorate for Environment and Safety (MoP-GDES), in the development of a good environmental management regime for the Sudanese coastal area. In this connection, NIVA was commissioned to prepare a draft guideline document that describes how offshore environmental monitoring activities of offshore oil and gas activities in Sudanese marine waters can be performed. The involved personnel at NIVA have been Jonny Beyer (PL) and Bente M. Wathne. Focal persons and main contributors from MoP-GDES have been Ms. Rihab Kamal Omer and Dr. Siddig Eissa Ahmed. Contact person for this project at NEA has been Frank Eklo.*

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Oslo, 17.11.2015

*Jonny Beyer*

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## Summary

Sudan's marine waters contain unique ecosystems that call for environmental awareness and urgent protection efforts. Industrial companies that operate in the Sudanese coastal zone must follow the country's environmental legislation. Performance of environmental baseline studies, environmental impact assessment studies and environmental monitoring activities in the company's areas of operations are key elements of this responsibility.

Detailed descriptions of monitoring procedures are provided in guidelines for monitoring. The purpose of environmental monitoring is to provide insight on development trends in environmental status at operation sites seen in relation to the company's activities. The environmental monitoring programme should be suitable for the purpose of (a) supporting a good environmental management practice at the site, (b) assist in meeting regulatory requirements and (c) provide relevant data about the environmental status at the operation sites.

The present guideline provides instructions to oil and gas industrial companies on how to design and perform environmental monitoring activities offshore in the Sudanese Red Sea. Operators are responsible for drawing up programmes for environmental monitoring at sites where they have operations. Environmental monitoring can be based on measurements of ecological community parameters such as species abundance, species diversity and population density as well as chemical parameters such as concentrations of environmental contaminants in the water column or in benthic sediments and in biota from these compartments. A suitable monitoring programme will often need special adaptations to the unique ecological conditions at the monitoring sites and the key aim of this guideline is to assist in this programme development process.

The present guideline is made as a synthesis of monitoring guidelines used by the offshore oil and gas industry operating at the Norwegian shelf and the North Sea and monitoring methods for Red Sea environments described by the regional intergovernmental organisation PERSGA<sup>1</sup>.

The general objective of offshore environmental monitoring is to gather information to support environmentally responsible oil & gas operations. This guideline provides guidance to improve the effectiveness of monitoring activities through discussions of the following topics:

- The rationale and principal structure of environmental monitoring activities.
- Competence requirements for staffs and institutions involved in monitoring activities.
- Evolution of data needs throughout the lifecycle of an offshore project.
- Relevant sampling techniques and measurement variables in monitoring programmes.
- Data management and quality assurance methods to improve confidence in monitoring results.
- Reporting and application of results from monitoring programmes.

Application of the monitoring practices discussed herein could contribute to the protection of the unique and valued ecosystem components that exist in the Sudanese part of the Red Sea.

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<sup>1</sup> The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden. The URL to the PERSGA organisation website is: <http://www.persga.org>

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## Definitions and abbreviations

**Background levels:** Concentrations of selected parameters (hydrocarbons, metals, radioactive substances) at regional stations which are meant to provide levels as close as possible to the natural concentrations in the area.

**Baseline survey:** The first environmental survey of an area or locality to obtain information on its chemical and biological status before a new activity starts.

**Biological impact:** This is indicated in an area if the fauna in a sample is significantly different from that at comparable regional stations. Calculations of biological impact are based on an overall evaluation of all the statistical analyses carried out on the biological material.

**C1-C3 alkyl homologues:** A group of isomers in which the hydrogen atoms in the ring system of aromatic hydrocarbons are substituted with a methyl group (C1), with two methyl groups or one ethyl group (C2), and with three methyl groups or one methyl and one ethyl group or one propyl group (C3).

**Chemical contamination:** Present in areas where the levels of the selected metals, radioactive substances and/or hydrocarbons are significantly higher than the expected background level.

**Concentration field:** A geographical area where the concentration of a contaminant exceeds a specific level.

**Ecologically sensitive area:** A geographically delimited area containing one or more natural resources (species and habitats) or Valued Ecosystem Components (VECs) that are sensitive to a particular pressure and that at best will need a long recovery period to return to a normal state after significant damage.

**Environmental Impact Assessment (EIA):** A study or a formal process used to predict the environmental consequences (positive or negative) of a specified human action prior to the implementation decision.

**Environmental monitoring activities:** Routinely measurements of specified assessment endpoints for a specified VEC over a specified period of time. Hence, environmental monitoring will over a time-period provide empirical documentation on whether the status of the ecosystem component is in a stable, improving or worsening condition.

**Environmental Monitoring Database (MOD):** A database containing data from the environmental monitoring programmes for the Norwegian continental shelf. It can be accessed at:  
<http://projects.dnv.com/MOD/Default.aspx?TOOL=HJEM>.

**Grid:** A grid design is used to determine locations for the sampling stations if the position of the oil/gas field has not yet been established or if obstacles on the seabed make it impossible to use a radial transect design.

**Impact monitoring:** Mapping of impact parameters such as ecological alterations, pollutant concentrations or biological effects of pollutants at a study site (often associated to an industrial installation) using collection of data from wild organisms or from transplanted organisms placed in cages near selected installations.

**ISO 14000:** A family of standards that provides practical tools for companies and organizations of all kinds looking to manage their environmental responsibilities.

**JAMP:** Joint Assessment and Monitoring Programme: An international monitoring programme organised by OSPAR, with joint guidelines for planning, implementation, analysis and reporting.

**Kurtosis:** A measure of how peaked or flat the distribution of data is relative to a normal distribution. High kurtosis indicates that the data distribution has a narrower peak than expected for a normal distribution. Used in evaluating grain size distribution.

**Limit of significant contamination (LSC):** A statistically calculated limit for chemical contamination, based on background levels from regional or sub-regional stations.

**Macrofauna:** Organisms larger than 1 mm (i.e. that are retained on a 1 mm sieve).

**Megafauna:** Organisms larger than 20 cm.

**Meiofauna:** Organisms in the size range of 0.063–1 mm. Generally refers to specific groups of organisms (foraminifera, nematodes, harpacticoid copepods, etc.).

**Monitoring:** Repeated assessment of conditions in a specified environmental location, most often relating to a specific action.

**Monitoring of benthic habitats:** Physical, chemical and biological monitoring investigations of the seabed.



**Monitoring survey:** A routine investigation of environmental conditions in a field or area conducted after production drilling has started.

**MoP-GDES:** Sudanese Ministry of Petroleum, General Directorate for Environment and Safety.

**Multivariate analyses:** Statistical analyses that handle more than one variable in the same analysis and look for trends across several dimensions at once.

**NEA:** The Norwegian Environment Agency.

**NPD:** The sum of naphthalene, phenanthrene, dibenzothiophene and their C1-, C2- and C3 alkyl homologues.

**NS:** Norwegian Standard.

**OFD or OfU:** The Norwegian Oil for Development programme.

**OSPAR:** The OSPAR Convention for the Protection of the marine Environment of the North-East Atlantic adopted in 1992.

**PAHs:** Polycyclic aromatic hydrocarbons: all hydrocarbons in which the molecule contains three or more aromatic rings. Hydrocarbons with only two aromatic rings (naphthalenes) are often included as well.

**PERSGA:** The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden.

**Plankton:** Organisms that spend all or part of their life cycle floating or drifting in the water and that have little or no independent mobility.

**Radioactive substance:** A substance that emits alpha, beta or gamma radiation.

**Radial transect:** A radial transect design consists of two axes placed perpendicular to one another with the installation at the origin and the main axis in the prevailing direction of current flow.

**Region:** A delimited area of the continental shelf defined by geographical coordinates. The boundary towards the shore follows the coastal baseline.

**ROV:** Remotely operated underwater vehicle carrying a video camera, which can often be equipped with extra equipment such as sonar, sensors, a manipulator and sampling equipment.

**RSGA:** Red Sea and Gulf of Aden.

**THC:** Total hydrocarbon content: content of all hydrocarbons in the material within a particular range of carbon chain lengths (n-C12 – n-C35), both those formed biologically and those originating from oil and other sources of pollution.

**TOM:** Total organic matter (applies to sediment) – refers to all combustible material containing organic carbon.

**Water column:** The marine environment from the water surface to the surface of the sediment.

**Water column monitoring:** Mapping of pollutants or biological effects of pollutants in or wild-caught organisms or caged/transplanted organisms to describe the degree of impact generated as a result of petroleum industry activities.

## **Scope of the present study**

Through the Norwegian Oil for Development programme, the Norwegian Environment Agency (NEA) assists its Sudanese partner, the Sudanese Ministry of Petroleum, General Directorate for Environment and Safety (MoP-GDES), with capacity development on pollution prevention, environmental conservation and environmental monitoring in Sudanese marine waters.

The key aims of the collaboration are to (A) develop an environmental overview baseline based on existing literature for the Sudanese coastal zone with special attention to vulnerable marine biological resources and regions that may be affected by oil & gas developments (Beyer et al., 2015), (B) to develop an environmental monitoring plan that is specially adapted to the Sudanese Red Sea and the environmental risks which typically are connected to oil & gas industrial operations in coastal and offshore regions (this document), and (C) in the possible continuation of the work, to develop a specially designed capacity development course targeted to training of Sudanese personnel in environmental monitoring activities.

NIVA - the Norwegian Institute for Water Research (Oslo, Norway) was commissioned to this programme and has carried out the work in cooperation with NEA and MoP-GDES. The present report represents the deliverable related to aim B – a draft guideline document that describes how offshore environmental monitoring activities of offshore oil and gas activities in Sudanese marine waters can be performed.

The key objective of the present work has been to develop a guideline for environmental monitoring activities for the Sudanese Red Sea with emphasis on issues relevant to oil and gas exploration and production activities in the coastal zone or off the coast. The purpose of the guidelines is to provide information, instructions and advice about the scope of environmental monitoring activities, the parameters to be analysed, the methods that should be used, necessary accreditation demands, templates for data reports, and how regulation requirements can be met. The design of environmental monitoring programmes at the Sudanese shelf is based on experience from comparable monitoring programmes used in Norway or elsewhere combined with an adaptation to societal and ecological conditions that exist in Sudan and locally in the Red Sea State.

# 1 Introduction

## 1.1 Background and objectives

The Sudanese part of the Red Sea harbours rich and diverse marine ecosystems, see an overview in Beyer et al. (2015). It is a matter of great importance to protect these unique marine ecosystems against the various kinds of anthropogenic stresses that follow the forecasted societal and industrial developments in the coastal zone of Sudan. In particular, a scenario of increased oil and gas industrial developments both at and off the Sudanese coast necessitates development of measures to minimize ecosystem impact. In a collaboration programme between Sudan and Norway, the Norwegian Environment Agency (NEA) assists its Sudanese partner, the Sudanese Ministry of Petroleum, General Directorate for Environment and Safety (MoP-GDES), in strengthening key competences required for sustainable management of ecological resources in the Red Sea waters. The collaboration activities have been funded through the Norwegian oil for development programme (the OfU program). NIVA - the Norwegian Institute for Water Research (Oslo, Norway) was appointed by the OfU programme to carry out parts of the work in cooperation with contacts in NEA and MoP-GDES, namely to develop two deliverables (A) an environmental baseline report for the Sudanese Red Sea based on existing literature (Beyer et al., 2015) and (B) an environmental monitoring guideline for the Sudanese Red Sea targeted especially for issues relevant to hydrocarbon exploration and production activities (present report).

The key objective of the present report is to develop a guideline for environmental monitoring activities for the Sudanese Red Sea with emphasis on issues relevant to oil and gas exploration and production activities in the coastal zone or off the coast (Figure 1). The purpose of the guidelines is to provide information, instructions and advice about the scope of environmental monitoring activities, the parameters to be analysed, the methods that should be used, necessary accreditation demands, templates for data reports, and how regulation requirements can be met.

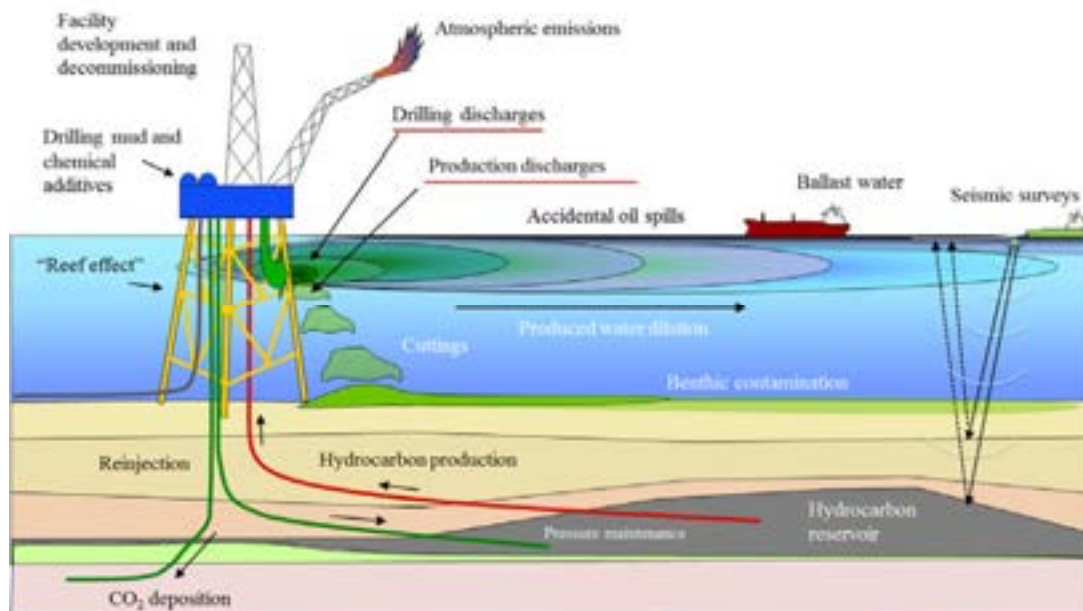


Figure 1: Oil and gas exploration and production activities in coastal areas include multiple issues that represent sources of impacts to local and regional environments.

The design of environmental monitoring programmes at the Sudanese shelf (Figure 2) should be based on experience from comparable monitoring programmes used in Norway or elsewhere combined with an adaptation to societal and ecological conditions that exist in Sudan and locally in the Red Sea State. It is a clear requirement that suggested monitoring procedures are practically feasible for Sudanese monitoring consultants, both with respect to technical equipment and human competences. The monitoring programme must also fit the purpose of providing relevant information on the ecosystem

components which occur at the operation site and with special emphasis on specially prioritised valued ecological components (VECs). Over the programme period, the monitoring data must fit the purpose of showing whether the environmental status of the addressed VECs are stable, deteriorating or improving, as a result of oil and gas industrial activities. The results of the programme should also provide a basis for projections for future developments.

The monitoring results should be pertinent to be used by industry and authorities in Sudan as a source of information and as basis for making further decisions on measures to be implemented for minimalizing environmental impact of petroleum industrial activities.



Figure 2: The Red Sea with the Sudanese Exclusive Economic Zone (EEZ) and the shelf area (less than 200 m depth) indicated in dark blue colour. Map source: Tesfamichael and Ekawad (2012).

## 1.2 Regulatory basis for environmental monitoring in Sudan

The obligation of industrial operators to perform environmental monitoring activities is rooted in the Sudanese governance, regulation, and law and legal enforcement system. The Sudanese government is responsible for establishing regulations (Table 1) to which industrial activities must comply. The regulations also form the legislative basis for governmental institutions at different levels to follow-up the industry in relation to issues of relevance to environmental protection. Environmental law and legislation documents of Sudan are available for downloading from The World Law Guide website (<http://www.lexadin.nl/wlg/legis/nofr/oeur/lxwesud.htm>), or from the FAO Legal Office (FAOLEX) (<http://faolex.fao.org/>), although some of these documents are only available in Arabic language.

Demands for environmental performance and monitoring activities are defined when the official operation licenses are issued by the Sudanese Authorities. In addition, further instructions of required monitoring actions may be given in official guidelines which are made to serve a specific purpose, such as protecting the integrity and stability of a specific VEC in a specific area. The environmental monitoring activities that industrial stakeholders perform should provide data that can be used for

assessing the company's compliance to environmental standards and regulation demands, and this information is forwarded to the authorities in monitoring programme reports.

Table 1: The table shows an overview of national law and regulation documents in Sudan which have relevance for the management of environmental resources and petroleum resources in coastal and marine environments.

Law Ordinance, Regulation	Year (in force)	Government Agency Concerned
Marine Fisheries Ordinance	1937	Marine Fisheries Administration
The Sudanese the Petroleum Regulations	1973	Ministry of Energy and Mining
Amendments to marine fisheries regulation	1975, 1978	Marine Fisheries Administration
Sudan Marine Conservation Committee Regulations	1975, 1995	Ministry of Environment and Tourism
Environment Health Act	1975	Ministry of Health and Local Councils
Sudan Maritime Law	Draft proposal 1996	Maritime Administration
Environmental Policy Act	Draft proposal 1996	HCENR and Attorney General
The Petroleum Resources Act	1998	Ministry of Energy and Mining
Environmental Conservation Act	2001	HCENR and Attorney General

In Sudan, the demand that the industry must carry out baseline studies and EIA studies in connection with new developments was formally legalized in 2001 when the Environmental Conservation Act was passed (in many sources also called the Environmental Protection Act, EPA 2001). Since the enacting of ECA 2001, a number of baseline studies and EIAs have been carried out in connection with industrial developments in Sudan, see (Beyer et al., 2015) for an overview. But there has been a shortage of necessary by-laws and guidelines giving detailed instructions about the required studies; including the baseline process, monitoring follow-ups, programme duration, timing of EIA reports, as well as protocols for Environmental Impact Statement (EIS) review and auditing procedures. As relevant for the Sudanese petroleum industry, provisions for EIA and monitoring are described in the document "Regulations for Protection of the Environment in the Petroleum Industry, (Amendment 2005)" which in 2005 was approved by the Sudanese Petroleum Affairs Council (2005). According to that regulatory document, industrial operators must develop a baseline study and an EIA in areas where petroleum operations are to be undertaken. The Sudanese Authorities have the privilege to carry out inspection and control of all stages of the environmental monitoring activities, from planning of the monitoring surveys to the use of the results by individual operators to improve their environmental performance. On the institutional side, the real law enforcement capabilities in Sudan have previously been criticised for being too weak and inefficient. Currently, several ongoing activities indicate a process of improvement in this area. Sudanese Authorities have initiated an active collaboration with other countries on the development of sector specific regulations, with the ongoing collaboration between Sudan and Norway on petroleum industry regulation representing a relevant example. Furthermore, the awareness of the value of the unique ecological resources in the Sudanese coastal zone and offshore in the Red Sea is clearly increasing, as also is the determination within the Sudanese Authorities to protect the integrity and stability of these resources.

In Norway, the governmental regulatory regime for petroleum industrial activities at the Norwegian shelf is a product of more than four decades of continuous change, improvement and reform. The established model has served as a template for similar regulatory development processes in other countries, now also including Sudan. The Norwegian system are described in central regulatory documents such as the Framework HSE Regulation document (<http://www.psa.no/framework-hse/category403.html>), and the Activities Regulation document (<http://www.psa.no/activities/category399.html>), both are web-available from the petroleum Safety Authority of Norway (<http://www.psa.no/regulations/category873.html>). The detailed requirements for environmental monitoring on the Norwegian continental shelf have earlier been comprised by the Activities Regulations document, but after 1<sup>st</sup> January 2010 the detailed requirements are incorporated in the official offshore monitoring guidelines (Iversen et al., 2015). The environmental regulation and monitoring system in Norwegian oil and gas industry is dynamically harmonised with the recommendations and demands expressed by significant commissions and advisory boards in Europe, including the OSPAR commissions.

### 1.3 Information sources for this guideline

The performance of field-specific baseline studies as well as follow-up studies within monitoring programmes requires the availability of suitable study manuals, procedure documents, technical guidelines, or Standard Operating Procedures (SOPs). Procedure documents provide instructions for how to carry out specific monitoring activities; such as the performance of a field work, the assessment of the status of a specified Valued Ecosystem Components (VECs), or the performance of a chemical analysis, but also how to interpret data and to report obtained results. In some cases suitable procedures are already available whereas in other cases procedures must be adapted to local circumstances or developed from scratch.

Several information sources have been used in connection with the development of the present monitoring guideline for Sudanese marine waters. The large collection of technical reports published by the regional intergovernmental organisation PERSGA (see PERSGA technical report series: <http://www.persga.org/inner.php?id=145>) has been a particularly important information source. The ecological baseline overview report (Beyer et al., 2015), provides a summary of the different VECs in coastal and marine ecosystems in Sudan largely based on the PERGA report collection.

Three other documents have been extra important as information sources, namely the guidelines for offshore environmental monitoring on the Norwegian continental shelf (Iversen et al., 2015), the guideline for offshore environmental monitoring published by the International Association of Oil & Gas Producers (OGP, 2012) and the PERSGA Technical Series No. 10 – “Standard Survey Methods for Key Habitats and Key Species in the Red Sea and Gulf of Aden” (PERSGA/GEF, 2004). The comprehensive PERSGA survey methods report (PERSGA Technical Series No. 10) include a 320 pages long collection of marine survey methodologies which are adapted to Red Sea conditions and which include description of assessment tools related to:

- RAPID COASTAL ENVIRONMENTAL ASSESSMENT
- INTERTIDAL AND MANGROVE
- CORALS AND CORAL COMMUNITIES
- SEAGRASSES AND SEAWEEDS
- SUBTIDAL HABITATS
- REEF FISH
- MARINE TURTLES
- SEABIRDS
- MARINE MAMMALS

The rapid assessment chapter in the PERSGA survey manual also explains the role of environmental monitoring within a more superior context and multi-step process of coastal management. This is helpful for providing a well-defined structure for when, why and how to perform the key work-packages within coastal management, planning and decision-making processes.

The PERSGA standard survey manual (PERSGA/GEF, 2004) includes detailed descriptions for an array of quality assessment methods for VECs related to the habitats and issues bullet-listed above. Scientists and consultants who are commissioned to perform field surveys and environmental monitoring work in the Sudanese marine waters must make themselves known to the parts of the PERSGA manual that concern the type(s) of habitat being addressed within their work. The comprehensive collection of VEC assessment methods that is provided in the PERSGA survey manual illustrates the organisation’s relevance and importance in marine protection efforts within RSGA.

The Norwegian offshore monitoring guideline was used as an initial model for developing the present guideline and the Sudanese monitoring plan. The environmental regulatory systems which are implemented for the offshore oil & gas operations at the Norwegian shelf are considered to be well developed and well-functioning and this system is one of the key reasons why Norwegian offshore industry has a good standing on environmental issues internationally. The Norwegian environmental monitoring system has been developed over considerable time by the Norwegian Authorities and the official guideline for monitoring was recently revised (Iversen et al., 2015). The Norwegian offshore monitoring guideline can be downloaded for free at the NEA website.

Other important sources of information on environmental monitoring guidelines in the offshore Oil & Gas industry have been the guideline document for offshore environmental monitoring published by the International Association of Oil & Gas Producers (OGP, 2012) as well as the OSPAR Guidelines for Monitoring the Environmental Impact of Offshore Oil and Gas Activities (OSPARCOM, 2004, 2010).

#### 1.4 Offshore environmental monitoring in oil and gas industry

The water column and benthic habitats are the two main ecosystem compartments that are addressed in offshore environmental monitoring studies (Figure 3). Industrial operators in a region where monitoring is planned are responsible for drawing up draft programmes for monitoring of the water column and of the benthic habitats in the region. The operators are required to build their environmental monitoring programmes on the requirements of the regulations and on the instructions to content given in sector specific guidelines which are developed or approved by the Competent Regulatory Authority. In cases when environmental monitoring data indicate that acceptance criteria are not met, the responsible stakeholder will normally be allowed a certain period to get in control of the identified problem, e.g. by modifying its operation towards a more environmental favourable option.

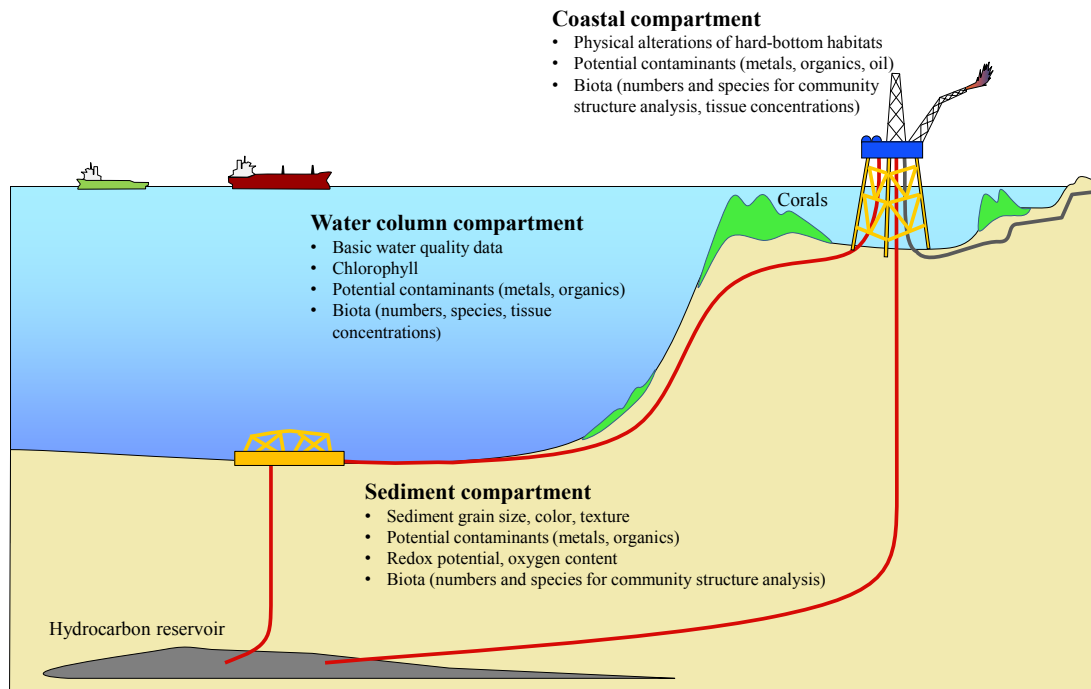


Figure 3: The water column and bottom sediments are normally the main ecosystem compartments that are addressed in offshore monitoring studies, but the common presence of coral reefs at the Sudanese coastline highlights the importance of including these ecosystem compartments in EIAs and monitoring activities in connection with oil and gas industrial developments in Sudanese coastal waters.

In Norway, central tools in the offshore monitoring have been assessments of alterations in the sediment-living fauna and the concentrations of anthropogenic chemical contaminants in sediments. The main methods used for analysing benthic community structure include three general avenues of univariate, graphical/distributional and multivariate statistical tools, as summarised by Trannum et al. (2003). Qualitative assessment methods are based on abundance data of indicator species and/or functional organism groups and results are reported by the number of species/number of individuals, diversity index (Shannon-Wiener,  $H'$ ); the evenness index (Pielou's measure,  $J$ ), expected number of species per 100 individuals ( $ES_{100}$ ), species-area curves, ten most dominant species at each station ("Top 10"), clustering analysis and multidimensional scaling. Other analyses such as canonical correspondence analysis (CCA) and Bio-ENV are also frequently used (Trannum et al., 2003). Of sediment contaminants, it is required to measure total hydrocarbons (THC), selected hydrocarbons

(NPD, PAH and decalines), olefins, ethers, esters and the metals barium, cadmium, copper, lead, mercury, chromium and zinc. Other chemical contaminants may also be analysed depending on the drilling history at the site and the type of drilling fluid used. Characterisation of grain size in obtained sediment samples is done on each station as a supportive parameter. For THC and metals there will always be a natural background level in the sediments and this has to be taken into account when evaluating the concentrations data. On the basis of the contaminant data from regional/sub-regional stations a statistically calculated limit for chemical contamination, the so-called LSC value (Limits of Significant Contamination), is estimated. These LSC values are used as threshold values to decide whether the monitoring area close to the offshore installation is significantly contaminated. Further, based on LSC information from all the sediment stations within the monitoring program, the size of the contaminated area can be estimated. The formula for calculation of LSC based on sediment contamination data from regional/sub-regional sediment stations is given in the appendix III and a more detailed description is provided by Iversen et al. (2015).

## **1.5 Training for monitoring competence**

Environmental monitoring programmes in Sudanese marine waters should be organised and carried out by Sudanese institutions, although contributions from collaborating expert groups and analytical laboratories from abroad will most possibly be required. Conduction of high-quality environmental monitoring programmes depend on a range of factors: the most important being proper backing from authorities and legislative framework, the availability of trained manpower, appropriate infrastructure and equipment for surveys and sample collection, and suitable laboratory facilities for analyses of collected samples. There are already established education programmes in environmental and marine sciences at the Khartoum University and the Red Sea University in Port Sudan. These study programmes should be further developed to include the required competences that currently are missing. Recent baseline and EIA studies that are performed in Red Sea environments by Sudanese research groups show that the current emphasis of studies is put on ecological parameters (e.g. assessments of species abundance and biodiversity) whereas the use of chemical markers of anthropogenic stress is less developed. Biological markers of ecotoxic stress (biomarkers) (van der Oost et al., 2003) have been used to a very limited degree in marine environmental and ecotoxicological studies in Sudan. Laboratory facilities and equipment and instruments for analyses of samples are available in Khartoum and Port Sudan but additional capacities on sample processing, sample analyses, data treatment and quality assurance systems will most certainly be required. The Khartoum University and the Red Sea University should further strengthen their international collaboration on education and training of new students and candidates, as well as on research activities within the study fields of marine environmental sciences.

## **1.6 Quality assurance and Quality Control systems**

Quality Assurance (QA) and Quality Control (QC) in connection with environmental monitoring concerns all measures that serve to improve the correctness of the monitoring study. In monitoring of offshore oil industrial operations QA/QC should be anchored with both the oil company and the consultants involved in conducting the monitoring. The involvement of quality documentation systems is essential for the success of the monitoring program. The typical goal of QA/QC system is to ensure that all monitoring-related data are scientifically sound and of known and documented quality. The implementation of QA/QC procedures into monitoring activities concern the collection and storage of sample materials, analysis of samples, validation of measurements as well as interpretation, reporting and storage of data. In order to reach the quality goal, the establishment of standardized procedures, adequate documentation, and appropriate training of personnel is required. The general result of a good QA/QC policy is more trustworthy investigations and data. By this it becomes easier to compare data between studies and to discover real trends of change within the monitoring areas.

The monitoring consultant's QA/QC system should be presented in the tender as well as in the final report of the monitoring program, and the industrial operator must before awarding contracts to environmental monitoring work assess the sufficiency of the described quality system. The quality



system should include verification of sample collection procedures, a plan for using reference samples in connection with analyses, reviewing the quality of analytical methods and results and performing of quality control of the report. Optimally, a standard QA-system should be used, for example ISO 9000 or OSPAR (2002-15). Type and frequency of QA inspections of analyses should be presented as part of the method description in the report. Analyses should be verified against reference samples run in the same test series as the real samples. Presentation of results from the reference samples would be a natural part of result interpretation. The suppliers of services for monitoring programmes (analyses, fieldwork) should preferably be accredited (e.g. ISO 17025 or an equivalent) for the methods they use.

Sudanese Authorities may make exemptions from the above described demands in certain situations. This applies for example to situations when local university institutions are included in method implementations the monitoring activities as a part of a strategic competence development and training programme.

## 1.7 International expert contacts

Depending on monitoring task addressed, scientists who earlier have been expert consultants in ecological assessments or monitoring work in the RSGA area could potentially be commissioned as advisors or active participants in the monitoring work. Such an exploitation of existing expert knowledge is indeed important for ensuring a good quality of new studies in Sudanese marine waters. At the same time, it is essential that key Sudanese institutions and scientists are actively involved in the key activities of the work, as it is a strategic aim to strengthen the national institutions in Sudan on the matters addressed. An overview of some scientific expert who have contributed significantly in connection with ecological assessments and monitoring studies in the RSGA area is shown in Table 2, and similar information is also given by PERSGA/GEF (2004).

Table 2: Overview of international scientists who have been in charge of developing the survey manuals on the different VEC assessment and monitoring issues in the RSGA area

VEC issue	Expert scientist	Address info
Rapid Coastal Environmental Assessment	Professor Andrew R.G. Price (Emeritus)	School of Life Sciences, University of Warwick, Coventry CV4 7LA, England (andrew.price@warwick.ac.uk, +44 (0) 24 76 523532)
Intertidal Biotopes	Dr. David A. Jones,	School of Ocean Sciences, Univ. of Wales, Menai Bridge, Anglesey, Gwynedd, LL59 5EY, Wales, UK
Corals and Coral Communities	Dr. Lyndon M. DeVantier	Australian Institute of Marine Science, Townsville, Queensland, Australia. ( <a href="http://www.researchgate.net/profile/Lyndon_Devantier">http://www.researchgate.net/profile/Lyndon_Devantier</a> )
	Dr. Rebecca Klaus	Seychelles Islands Foundation, IUCN, Biodiversity and Climate Research Centre (BiK-F) Senckenberg Institute, Frankfurt aM, Germany.
Seagrasses and Seaweeds	Dr. F. Leliaert and Prof. Dr. E. Coppejans	Ghent University, Dept of Biology, Research Group Phycology, Krijgslaan 281, S8, 9000 Ghent, Belgium. (Frederik.Leliaert@UGent.be), (+ 09 264 85 76, Eric.Coppejans@UGent.be)
Subtidal Habitats	Dr. Jerry Kemp	Department of Biology, University of York, Heslington, York YO10 5DD, England. (jeremymarkkemp@yahoo.co.uk)
Reef Fish	Prof. William Gladstone	Univ. of Technol, Sydney, Australia ( <a href="http://www.uts.edu.au/staff/william.gladstone">http://www.uts.edu.au/staff/william.gladstone</a> ), (William.Gladstone@newcastle.edu.au)
Marine Turtles	Dr. Nicolas J. Pilcher	Marine Research Foundation, 1-3A-7 The Peak, Lorong Puncak 1, 88400 Kota Kinabalu, Sabah, Malaysia. (npilcher@mrf-asia.org)
Breeding Seabirds	Dr. Stephen F. Newton	BirdWatch Ireland, Rockingham House, Newcastle, Co. Wicklow, Ireland. ( <a href="https://www.researchgate.net/profile/Stephen_Newton">https://www.researchgate.net/profile/Stephen_Newton</a> )
Marine Mammals	Dr. Anthony R. Preen	Oberon, Scott's Plain Road, Rollands Plains, 2441 NSW, Australia

## **2 Water Column Monitoring**

The purpose of the water column monitoring is to describe the degree of impact that can be detected in selected seafood organisms (fish and mussels) in Sudanese marine waters as a result of petroleum industry activities. The monitoring should include oceanographic measurements, analysis of chemical parameters and investigations of both wild caught organisms and potentially also field transplanted organisms placed in cages close to industrial installations. In cases of caging, the use of a suitable filter feeding mussel species is recommended as the selected monitoring species. In connection with caging studies, also passive sampler equipment may be employed as supplement sample collecting methods.

### **2.1 Time frame**

#### **2.1.1 Programme development**

A programme proposal for water column monitoring should be submitted to the Sudanese Authority for comments no later than six months before the field survey is to be conducted. The final programme must be sent to the Sudanese Authority for approval no later than three months before the field survey is to be conducted.

#### **2.1.2 Execution**

Field surveys should be carried out during the winter season, preferably in November-February, when the temperature in the Red Sea State is acceptable for field work. All fieldwork should be conducted around the same period of the year every time so that results are comparable.

#### **2.1.3 Reporting**

A quality assured draft report from the field survey together with associated analysis results shall be submitted to the Sudanese Authority no later than nine months after the survey was conducted, allowing the Authorities minimum three months for evaluation and comments of the draft report. All comments must be answered as a part of the final report which shall be delivered to the Sudanese Authority no later than three months after the comments from the Authorities to the draft report was received. Sudanese Authorities can after application from the operator provide extended deadlines for the reports.

If results obtained during the field surveys or sample processing deviate substantially from the expected status or trend, this must immediately be reported to the Sudanese Authority.

## **2.2 Monitoring frequency and sample design**

### **2.2.1 Monitoring frequency**

As a general rule, field surveys in water column monitoring programme are required at three-year intervals. Any modification in frequency must be justified and approved by the Sudanese Authority.

### **2.2.2 Sampling area and design**

Which areas are to be monitored must be selected in agreement with the Sudanese Authority and relevant operators, and is to be described in the monitoring programme together with the planned station network and sampling design. The study site(s) are chosen based on knowledge regarding the discharges and their dispersal and on the expected risk as a result of these discharges. Monitoring of the water column must look at relevant components in the discharges, including added chemicals.

The monitoring survey must include at least one suitable reference area; both in cases when wild caught organisms are used and in cases when rigs for caged organisms or monitoring instruments (e.g. passive samplers) are used.

In cases when rigs for caged organisms or monitoring instruments (e.g. passive samplers) are used, the positioning of the in a particular area must be decided upon based on knowledge of the physical characteristics of the area and on dispersal models for relevant discharge components, including added chemicals. The basis for the selection of rig positions must be explained in the survey report.

### **2.3 Organisms to be monitored (fin-fish and shellfish)**

The choice of marine species (fin-fish and mussel shellfish) that are suitable for water column monitoring is a key decision and the species selection process should be described in the monitoring program. The selected fish species (one or several species) should fulfil a set of selection criteria, such as:

- It is common along the whole Sudanese coast
- It is commonly caught as seafood by local fishermen
- It has a non-migratory behaviour
- It's typically size is suitable (e.g. 100-400 g for fin-fish, ca. 7-10 cm shell-length for mussels)
- It is quite easy to collect (e.g. for fin-fish by use of baited traps)
- It is reasonably easy to catch in suitable numbers
- It is robust in the sense that it rather easily can be kept alive after catch (e.g. in suitable seawater holding tanks)
- It can tolerate transplant caging (e.g. stay alive in cages)
- It is easy to keep alive in culture and in the lab

With respect to the selection of fin-fish target species, the survey reports of the ongoing fisheries resources mapping surveys conducted by the Red Sea University (RSU) and the Norwegian Institute of Marine Research (NIMR) (Olsen et al., 2013a; Olsen et al., 2013b; Palm et al., 2014) include useful information both for the selection of target fish species as well as for the selection of fishing methods for the wild fish collection. During the second RSU/ NIMR survey in May-June 2013 (Olsen et al., 2013b), a total of 99 different species of fish were caught and the two snappers *Lutjanus bohar* and *Lutjanus gibbus* were most common followed by the emperor *Lethrinus lentjan*. However, there was much heterogeneity in the species composition at different fishing stations. Of the totally 99 species caught, only 17 occurred in 10 or more stations; indicating a large spatial variability in the species structure along the Sudanese coast. A further analysis of the catch data will be reported in the programme report.

The selected fin-fish target species should tolerate to be kept in culture because this will enable the production of reference fish materials by use of controlled exposure studies in laboratory. This is essential for providing quality validation of effect data observed in field monitoring activity and for training of personnel in biological sampling and various kinds of analyses. According to the international Fish Base (<http://www.fishbase.org/search.php>) there are about 350 fish species registered to Sudan marine waters, and more than 250 of these are reef associated. The identification of a short-list of species that are suitable for use in monitoring may be compiled in collaboration with regional fishing experts. It will be a big advantage for the environmental monitoring activity in Sudanese waters if the same fish species are used in different monitoring surveys. In case this is not practically feasible, the selection of fish species that are taxonomically closely related (e.g. same genus) can be used as a second-best alternative.

Shellfish: Filter-feeding mussels have been widely used in connection with marine environmental monitoring in many countries of the world. Most of the considerations described for the fin-fish target species selection are also relevant for shellfish target species. The selected species should be commonly found along the Sudanese coast and it should be robust and tolerant to lab culturing and caging. Filter feeding mussels are in general easier to use for caging in comparison to fin-fish as their filter feeding foraging behaviour enable them to survive transplant caging for long periods (years).

## 2.4 Data collection and analytical parameters

The monitoring programme should specify which analytical parameters are to be included and descriptions of the analytical design, selected methods and reporting format should be given in the programme plan. A suggested set of physical, chemical and biological parameters to be analysed is described below.

### 2.4.1 Hydrographic parameters

The monitoring survey should include as a minimum the following hydrographical parameters:

- Conductivity, temperature and density (CTD) measurements in the water column, with the purpose to establish vertical stratification, should be conducted on a sufficient number of stations in order to provide a satisfactory description of temperature and salinity conditions in the water column in the area.
- Direction and speed of seawater current in the study site measured from at least two stations close (<100 m) to each installation being monitored relevant platform.
- Turbidity data (vertical and horizontal transparency), e.g. measured by means of Secchi disk.

### 2.4.2 Parameters determined in biological materials

The monitoring programme should address a selected set of chemical and biological effect parameters in mussels and fish. The selection of which parameters to include in the monitoring is a key decision and should be based on a judgement of the kind of contamination issue which is targeted by the monitoring programme as well as on practical criteria such as the availability of the necessary analysis infrastructure and analysis competence for the given methods.

In cases when analysis infrastructure and analysis competence is limited, it is strongly recommended that the monitoring-responsible consultant initiate collaboration with international expert laboratories on the performance of analyses and data-interpretation. Collaboration may also include method-training activities to enable the development of method competence in Sudan for future monitoring activities.

The basis/rationale for parameter selection must be described in the monitoring plan. Initial sets of chemical and biological effect parameters to choose from are provided in Table 3 for mussels and Table 4 for fish. In addition to the suggested chemical parameters, one should consider analysing for other chemical components in cases when this can be considered as relevant as based on data from discharge, spreading analyses and risk assessments. Other biological parameters that can be included in monitoring programmes are listed in Iversen et al. (2015).

The chemical analyses of mussels are to be done using four composite samples at each station. All other effect analyses in mussels are to be done on 15 mussel specimens from each station. General procedures for collection and processing of biological samples from mussels are described in the JAMP Guidelines for Monitoring Contaminants in Biota, edition 2010 (OSPARCOM, 2010).

In fin-fish, 30 individual fish from each species and from each area/station are to be analysed, with the exception of DNA-adducts, which are to be analysed on 15 female fish from each species and from each area/station. The most important samples to collect from fish specimens are liver tissue, muscle tissue, bile fluid and gill samples. Procedures for the necropsy and sample collection of individual fish are described in OSPARCOM (2010).

Animals used for preparation of biological effect samples must be kept alive until the biological samples are taken. This is an important point, as the quality of the biological samples rapidly decreases after the study organism dies. The fish and mussels may after the capture, and prior to the sampling, be kept alive by means of suitable seawater holding tanks (sufficiently ventilated with fresh seawater), or by means of holding-nets that are hanging into the water. For the mussels it may be sufficient to keep the animals alive by use of suitable cooling containers with ice (at least for some hours).

All sample processing procedures on board the survey vessel or in laboratory facilities must take place in clean (i.e. uncontaminated) environments. The samples must in general be handled in such a way that the risk of sample contamination is minimised. The sample processing procedures must be

described in the survey report. A standard set of sampling data must be registered in a sampling form; including the species, date, location (geographic co-ordinates), fishing depth and fishing gear used.

Table 3: Suggested inventory of parameters to record/analyse in mussels in water column monitoring.

Parameter	Method	Type of tissue/matrix	Method-relevant references
Size	Total mass and length, soft tissue mass / volume of the mussel	Whole mussel	(OSPARCOM, 2010)
Spawning status	Histological	Gills / gonad	(OSPARCOM, 2010)
General health state	Clearance rate and respiration or «stress on stress»	Whole mussel	(Al-Subiai et al., 2011; Hellou and Law, 2003; Viarengo et al., 1995)
PAH/NPD	GC-MS	Soft tissue	(OSPARCOM, 2010)
Metals (Hg, Pb, Cd, Ba)	ICP	Soft tissue	(OSPARCOM, 2010)
Chromosome damage	Micronucleus formation	Haemocytes	(Venier et al., 1997)
Lysosomal membrane stability (LMS)	Histological	Digestive gland or haemocytes	(Castro et al., 2004; Garmendia et al., 2011; Regoli, 1992)
Acetylcholinesterase inhibition (AChE)	Enzymatic	Gills	(Escartin and Porte, 1997)

Table 4: Suggested inventory of parameters to record/analyse in fish in water column monitoring.

Parameter	Method	Type of tissue /matrix	Method-relevant references
Size and condition index (CI)	Weight (without intestines and gonad)/length	Whole animal	(Lloret et al., 2002)
Liver somatic index (LSI)	Liver mass/body mass (without intestines and gonad)	Liver	(Lloret et al., 2002)
Gender and Gonad somatic index (GSI)	Gonad mass/body mass (without intestines and gonad)	Gonad	(Corsi et al., 2002)
PAH/NPD and metals	GC-MS (for PAH/NPD), ICP (for metals)	Filet	(OSPARCOM, 2010)
Concentration of PAH metabolites	GC-MS/LC-FD	Bile	(Aas et al., 2000; Beyer et al., 2010)
Fish gill ultrastructure and histopathology	Histology	Gill	(Afifi et al., 2014), (Hesni et al., 2011)
Fish skin ultrastructure and histopathology	Histology	Skin	(Afifi et al., 2014)
Tissue changes, including lysosomal changes	Histology	Liver	(Bilbao et al., 2010)
DNA damage	DNA adducts	Liver	(Lyons et al., 2004; Myers et al., 1998)
DNA damage	DNA strand breaks (comet)	Lymphocytes	(Mitchelmore and Chipman, 1998; Nagarani et al., 2012)
Chromosome damage	Micronucleus formation	Red blood cells	(Barsiene et al., 2013; Bombail et al., 2001)

## 2.5 Reporting of Water column monitoring surveys

The purpose of offshore environmental monitoring is to provide an overview of the environmental status and of trends over time, seen in relation to offshore oil and gas activities. It is important therefore that the survey results are assessed taking into account the state of the marine environment as registered in previous investigations as well as the discharge history in the area. With this in mind, one should assess the condition of and potential impacts on the environment as part of the reporting process.

All reports should consist of a concise executive summary and a main report including a detailed scientific description of the survey.

The executive summary should not exceed 20 pages and must be produced in both English and Arabic language. The main target groups for the reports include oil and gas companies, environmental authorities, research institutions and consultancy firms. The survey and results must be presented in such a way that they also make sense for professionals who have not participated in the actual monitoring.

The report must provide a description of the extent to which organisms have accumulated hydrocarbons or any other petroleum-related substances. It should also indicate whether the organisms show signs of exposure and/or stress from discharges released in the area.

All unprocessed data and results should always be available to the Sudanese authorities, preferably in a central database and in appendices to the report. Information of where all the data is stored, and who is the contact person should be stated in the report.

The report should provide an overall interpretation of the monitoring results.

Optimally, the biological responses should be presented not only as a function of distance to the source, but also as a function of the substances' concentration in the analysed tissue, other exposure parameters and time integrated water concentrations (e.g. as estimated from the analyses of passive samplers). The report should also discuss the importance of the biological response at several levels: for the individual, for the population and for the population in time and space.

Each report is to be submitted electronically and in five paper copies in addition (unless other numbers of copies are stated). Final reports from conducted field surveys/monitoring will be published at open access sites once the Sudanese Authority has approved them.

### 2.5.1 Report content

The scientific report should contain a complete documentation of the completed survey, focusing on:

- sampling design / field activities
- analytical parameters
- analytical methods and quality assurance
- results and conclusions of the survey
- main trends in the region or sampling area (if relevant)
- issues to be given priority in future monitoring

#### *Executive summary:*

The summary should not exceed five pages. The target group includes the oil and gas companies, public administration and the general public. It should include the following elements:

- a brief description of the goals;
- a description of the field work;
- presentation (in figures and tables) and discussion of the most important results;
- main trends and comparison with any earlier surveys;
- conclusions and recommendations

### *Introduction*

The following should be described for the region or area sampled:

- discharge history with concentrations of the different components in the discharge and other activities that may have affected chemical and biological conditions at the time of the survey;
- earlier surveys (table);
- goals and priorities for the survey in question.

### *Methods*

The methods section should provide information about the following:

- reasons for the choice of sampling areas and sampling stations
- brief description of the completed field work, including the time frame for conducting the survey, number of stations/instrument rigs, sampling programme at each station or each sampling area and any deviations from the programme, with reasons (complete field log in the appendix);
- map with scale and depth contours showing the position of the stations and installations;
- brief description of the laboratory procedures for physical, chemical and biological analyses, including description of any deviations, with reasons, and an evaluation of whether/how results are affected;
- origin and condition of test organisms and handling before placement in test chambers, together with results from chemical analyses documenting background levels;
- principles for quality assurance routines in the field and in the lab, including any documented participation in intercalibration / intercomparison exercises for relevant methods;
- if relevant accreditation status and proof, together with documentation of control of results (chemical analyses) should be included in an appendix;
- description of chosen statistical methods including reasons for choosing them;
- information on where and how the processed material (samples, databases) is stored, and where the responsibility lies for the material and results and their availability.

### *Results and discussion*

This chapter presents and discusses the results of the survey.

Results for each station or sampling area should as far as possible be presented in tables and figures. The observations and average results obtained for all the parameters analysed should be described. Other characteristics of the station or sampling area of significance for the discussion should also be presented.

If information is available, geographical trends, time trends and changes should be presented. The questions listed below should be discussed:

- Which responses can be detected?
- How do biological responses correspond with exposure parameters and with gradients in natural and anthropogenic environmental variables?
- How do the results relate to those of earlier surveys in the same area?
- How do the results relate to those of relevant surveys of nearby areas?
- Do the results reflect the discharge history in the area?

### *Overall evaluation and conclusions*

This chapter should include final remarks on the environmental status and trends in the sample area and in the region.

### *Knowledge gaps and future development*

Recommendations for the next survey should be made based on the results of the current survey.

The chapter should include a discussion on knowledge gaps connected to methods and analytical parameters that are used or should have been used for monitoring the water column. Recommendations should be given regarding studies to be conducted or measures to be taken in the period until the next field survey, potentially as a part of the next field survey, with the purpose to further develop the monitoring methodology.

### *Appendices*

The appendices should be delivered electronically and include as a minimum:

- the monitoring programme decided upon in cooperation with the Agency
- complete field logs with date, time, position (GMS and UTM, which reference grid is used; grid zone must be specified), depth, number of samples and weather conditions presented in table format for each station or sampling area;
- analysis report including tables with analytical data.

If the data appendices are too large, they should only be provided in electronic format (CD accompanying the report).

## **3 Monitoring of soft sediment habitats (grab sampling surveys)**

The purpose of the sediment monitoring is to describe the horizontal extent of impact to surface sediments of an area as a result of releases from offshore oil and gas activities. This work will normally be a part of the environmental impact assessment (EIA) study for the individual field or for the region as a whole.

### **3.1 Timeframe**

#### **3.1.1 Programme development**

A programme proposal for sediment monitoring should be submitted to the Sudanese Authority for comments no later than six months before the field survey is to be conducted. The final programme must be sent to the Sudanese Authority for approval no later than three months before the field survey is to be conducted.

#### **3.1.2 Execution**

Field surveys of soft sediments should be carried out during the winter season, preferably in November-February, when the temperature is acceptable for field work. All fieldwork should be conducted around the same period of the year every time so that results are comparable.

#### **3.1.3 Reporting**

A quality assured draft report from the sediment survey together with associated analysis results shall be submitted to the Sudanese Authority no later than nine months after the survey was conducted, allowing the Authorities minimum three months for evaluation and comments of the draft report. All comments must be answered as a part of the final report which shall be delivered to the Sudanese Authority no later than three months after the comments from the Authorities to the draft report was



received. Sudanese Authorities can after application from the operator provide extended deadlines for the reports.

If results obtained during the field surveys or sample processing deviate substantially from the expected status or trend, this must immediately be reported to the Sudanese Authority.

## **3.2 Survey frequency and sampling pattern**

### **3.2.1 Baseline surveys**

A baseline survey must be established before the area is opened for petroleum activities. The regional stations are intended to provide information on the normal background levels for the area of study with regard to the monitoring parameters. Baseline surveys must also be carried out prior to production drilling. The requirements apply to all types of installations. A baseline survey is valid for six years or for as long as decided by the authorities after consulting relevant expert bodies.

### **3.2.2 Site-specific surveys**

The field-specific stations are intended to provide information on trends in the environmental status near the facilities being monitored. As a general rule, the same survey frequency is required for all types of fields and developments.

- Monitoring of a field site starts with the first regional survey for the region in which the field/site lies.
- Site-specific monitoring surveys should be conducted every 3 years (or another frequency decided by the Sudanese authority).
- Changes in the frequency of field-specific surveys must receive prior approval by the authorities.
- After the end of the production phase at a field/site, two extra site-specific surveys are required at 3 year intervals (or another frequency decided by the Sudanese authority).
- The need for further monitoring of a field after this is assessed and decided upon by the competent authority.

## **3.3 Station network**

The monitoring of benthic sediment habitats has both a local and a regional focus. Within each region, the objective of field-specific monitoring is to reveal the impacts of individual installations on the surrounding area. The established set of regional stations is intended to reflect normal benthic conditions in the region but may also be used to detect whether the oil and gas activities have a more widespread impact in the region.

The locations of regional stations must be coordinated with the locations of the field-specific stations in the same region. The positioning of both types of stations must be based on information about:

- depth and topography;
- currents and dispersal patterns in the area in question;
- sediment conditions and sedimentation patterns;
- discharge history of fields;
- presence of pipelines and other petroleum industry installations on the fields.

It is the operators' responsibility to make use of this information to revise a station network or establish a new one. Data on currents must cover a range of depths and the different seasons of the year. It is particularly important to obtain data for the depths immediately above the seabed where discharges are planned/ expected. Further elements to be considered when selecting either field-specific or regional stations are described below.

### 3.3.1 Selection of stations for baseline surveys

#### *Regional stations*

When a first regional survey is to be carried out, a representative selection of at least 10 regional stations should be established to provide a general picture of background benthic conditions in the region. The regional stations should therefore be located in areas that are not expected to be affected by discharges from the offshore oil and gas industry, either at the time or later. If a regional station proves to be affected by a later field development, a new regional station must be established.

The following elements must be considered when positioning regional stations:

- they should cover all the main types of sediment seabed in the region (sand, silt, clay, etc.);
- if the water depth in the region varies, the stations should be located in such a way that typical depth intervals can be described;
- the stations should cover all parts of the region where there are field developments or where developments are expected.

When a baseline survey is carried out for a field, at least three of the regional stations should be associated with the field in question. They should be as representative as possible of background conditions on the field. They should be reasonably close to the oil or gas field in question and have similar seabed type and depth. If necessary, more regional stations can be established near the field for this purpose. The same regional stations must be used from year to year both in the baseline survey and for later monitoring surveys of the field. Results from the regional stations are to be used as reference values for assessing possible effects observed at nearby field-specific stations.

#### *Field-specific stations*

When a baseline survey of a field is carried out, the field-specific stations should preferably be established using a radial transect design that is expected to be permanent for the monitoring surveys of the field. The stations are to be placed at increasing distances from the discharge point (according to the geometric series 250 m, 500 m, 1000 m, 2000 m, etc.). Stations less than 250 m from the installations should be established if practicable and acceptable in terms of safety. If the final position of the oil or gas field has yet not been determined, a grid design may be used for station positioning across the field.

If the geographical characteristics of a field development indicate that a radial transect design will not be optimal, another design may be selected and used in the subsequent monitoring surveys. The operator must give grounds for doing this, and the station network must be agreed upon with the Sudanese Authority. The stations must cover as much as possible of the entire area that will later be included in the monitoring programme. The orientation and surface of the station network should be determined based on the expected area of influence estimated with the help of likely discharge quantities and dispersal modelling (using the same assumptions as the EIA carried out for the field).

The operator must be able to document the grounds for the selected station positioning, based for example on water current patterns, depth intervals etc. The stations must be located so that it is possible to determine the degree to which benthic habitats are affected by discharges from the oil or gas field. Each station must be given a unique designation consisting of a maximum of four characters. The same designation must be used on maps, in tables and in the text. If a station is later moved by more than 50 m, it must receive a new designation. Any such changes must be specified in the report and the station history must be shown in a table.

During a baseline survey of a field, samples should be taken from a minimum of three regional stations, which are expected to become the regional stations associated with the field (see the last paragraph under Regional Stations above).

It can be difficult to maintain a radial transect or grid design of the stations when carrying out baseline surveys in deep water (>600 metres). In such cases, the stations should be positioned as optimally as possible in relation to the discharge pattern, expected dispersal patterns and benthic conditions.

### 3.3.2 Monitoring surveys

After drilling and discharges to the sea have started, the station network used for the first monitoring survey of a field should as a general rule be the same as that used for the baseline survey. However, depending on the overall monitoring activity in the region in question, certain stations may be omitted and new ones added in consultation with competent authorities. The monitoring programme must reflect the discharge pattern on the examined field. To make it possible to compare results between years, the positions of specific stations must not be changed. The deviation in position should not exceed  $\pm 50$  metres.

If it is unfeasible to collect representative samples at a station, the person responsible for the survey may decide to leave the station without taking samples. Any such deviations must be described as explained in during survey reporting.

#### *Field-specific stations*

When a final decision has been made on the location of the installation(s) and of any discharge points, a permanent network of monitoring stations is established using the baseline survey as a starting point.

In the case of single installations, a radial transect design should preferably be used, with one axis along the prevailing direction of current flow just above the seabed and one perpendicular to this. This is the preferred design even in cases where a grid pattern was used for the baseline survey. In such cases, as many stations as possible from the grid should be retained. In the case of a complex field development (e.g. in cases with many subsea installations) it may be necessary to deviate from this design, as stations must be located in a way that makes it possible to monitor the scale of the impacts of the installations. Most of the stations should be located downstream of the installations with respect to the prevailing current direction. If no prevailing current direction can be identified one of the two transects should run north-south.

Regardless of whether a grid or radial transect design is used, the station network should always include at least one station in each of the four main directions, even if there is no indication of chemical contamination or biological impact on the field. If the chemical contamination (for Ba 2 x LSC is used as the boundary) or biological impact detected on a field extends beyond the outermost stations in the network, new stations must be established outside these for the next monitoring survey. New stations must be placed along the axes, at geometrically increasing distances. If later surveys (after the baseline survey and the first monitoring survey) show elevated values for any of the impact parameters analysed at the first two stations downstream of the discharge point, chemical analyses must be carried out at all the innermost stations (along the other three radial transects). Analyses of THC and Ba (or an equivalent weighting agent) are required at all stations. A full metal analysis is to be carried out if this will not result in significantly higher costs.

The scope of the monitoring surveys in each region and each field must reflect the level of activity, discharge history, and the results of the previous surveys. If there is no measurable biological impact or chemical contamination, the station network can be reduced when the next benthic survey is carried out. As a general rule, the outermost stations sampled must always be unaffected (no biological impact or chemical contamination).

If there are no measurable impacts, it may also be permissible to extend the time between surveys of a field, e.g. to six years or longer.

#### *Regional stations*

As a general rule, a regional monitoring survey must include all the established regional stations. In new regions where there are few fields to be monitored, regional surveys may in special cases be limited to the regional stations that are associated with the active fields. A gradual reduction of the number of stations originally established as reference stations may also be considered in areas where fields are being closed down.

In the case of regional stations, all chemical samples must be analysed for calculating LSC. This must be done during at least three surveys (ca. 10 samples). If the analyses indicate a stable level during

several years, it is possible to only analyse one sample at a time. However, all samples must be collected at all times and analysed only if the one representative sample indicates variations compared to previous years.

### **3.4 Sediment sample collection and processing**

Standardised procedures should be used for sample collection and sample processing of sediments in the field (including vessel requirements, keeping field logs, choice of sampling equipment, collection procedures, etc.). The sampling programme in each sediment survey must be adapted to the site-specific and region-specific oceanographic and ecological characteristics.

#### **3.4.1 Sample collection**

The soft sediment sample collection should be performed by use of an approved grab type sampler; but in cases when the studies include sediment sections, a sediment corer that allows sediment sections to be separated should be used.

In some other cases the use of grab may not be suitable, such as in areas where the seabed is dominated by corals, rock, stones, gravel or other hard bottom substrates and with only small soft-bottom areas in-between. In such areas, visual surveys will be needed, using diver transect surveys (shallow sites) or remotely operated or towed observation gear. The use of visual surveys is required in areas that are defined as vulnerable. Visual surveys using diving transects and Reef Check method principles should be performed in shallow areas containing corals (see section 4).

For baseline surveys of soft-bottom habitats, there should be chosen appropriate quantitative sampling equipment (grab or box corer) that can be used for the collection of both biological and chemical samples. The equipment must sample a minimum area of 0.1 m<sup>2</sup>. Benthic samples must be taken with suitable equipment to avoid sediment compression. The equipment used to subtract subsamples for metal and hydrocarbon/drilling fluid analysis must not contaminate the samples. For analysis of metals and hydrocarbons/drilling fluid, separate samples are taken from the upper 0–1 cm of the sediment in each grab sample. Each sample must be packaged, stored and analysed separately. For sieving of macrofauna samples in the field, sieves should have round openings and a mesh opening of 1 mm (consult also the NS-EN ISO 16665 procedure).

#### **3.4.2 Sample storage and preservation**

Sediment samples that are to be analysed for TOM, grain size, hydrocarbons, synthetic drilling fluids and metals must be stored at a minimum temperature of -20°C until they are analysed.

For preservation and storage of fauna samples processed from sediment one may consult NS-EN ISO 16665.

Accurate species identification is of fundamental importance for the reliability of the statistical analyses of fauna samples. Experience has shown that quality control of species identification of the macrofauna is important. One way of improving the quality assurance of macrofauna species identification is to build up a reference collection by retaining selected biological material from the surveys. The responsibility for the storage and curation of reference materials should be assigned to competent experts associated to the national universities in Port Sudan or in Khartoum or within regional scientific organisations such as PERSGA. The oil companies/monitoring-consultants should enter into agreements with these experts to ensure that the same procedures for sample selection, storage and curation are used in all surveys.

### **3.5 Analytical parameters**

This chapter describes the parameters or group of parameters required to be analysed for sediment samples obtained from benthic baseline and monitoring surveys. An overview of requirements regarding numbers of samples, analytical parameters, sample storage, etc. is given in Table 5 below.

The Sudanese Authorities may request analysis of additional parameters on the basis of information on discharges in a region or an individual field.

Table 5: Sediment samples, sample sizes and analyses

Parameter	Sample depth	Baseline and first follow-up survey	Subsequent surveys	Sample storage and size
TOC/TN	0-5 cm	Mixed sample from 3 grab samples for all stations	Mixed sample from 3 grab samples for stations where fauna is analysed	≤ -20°C <sup>1</sup> 100 g
Grain size	0-5 cm	Mixed sample from 3 grab samples for all stations	Mixed sample from 3 grab samples for stations where fauna is analysed	300 g
THC	0-1 cm	3 samples	3 samples	≤ -20°C <sup>1</sup> 300 g
	1-3 cm <sup>2</sup>	1 sample	1 sample	
	3-6 cm <sup>2</sup>	1 sample	1 sample	
Drilling fluid	0-1 cm			≤ -20°C <sup>1</sup> 300 g
NPD and PAH	0-1 cm	1-2 samples	1-2 samples	≤ -20°C <sup>1</sup> 300 g
Metals -Ba <sup>3</sup> , Cd, Cr, Cu, Pb, Zn, Hg	0-1 cm	3 samples	3 samples	≤ -20°C <sup>1</sup> 50 g
Macrofauna		5 samples	5 samples	10 % formalin <sup>4</sup> Bengal red / Eosin
Meiofauna <sup>5</sup>				

<sup>1</sup> As stated in ISO 5667-19:2004 and ISO 16665:2013.

<sup>2</sup> Profile samples to be taken only on a selection of fields/stations.

<sup>3</sup> And/or equivalent main component in the weighting agent (e.g. ilmenite contains titanium-iron, Ti).

<sup>4</sup> Formalin may be replaced by less harmful stabilization liquids when testing of these is in place.

<sup>5</sup> This can be relevant in areas where conventional sampling equipment cannot be used.

### 3.5.1 Sediment appearance on sampling

The characteristics of a sample should be described immediately after collection. These may include:

- the presence of drill cuttings, empty shells or other objects;
- the presence (or absence) of conspicuous fauna;
- smell (for example H<sub>2</sub>S or oil).
- sediment description (sand, clay, gravel etc.) and stratification of layers;
- colour (according to Munsell's colour charts for soils and sediment).

It is also recommended to log the number of unsuccessful grab loads.

In the case of visual surveys, classification of sediments must follow the specifications of a standardised procedure which is developed and suitable for this purpose (for the monitoring at the Norwegian shelf this is procedure NS 9435).

### 3.5.2 Physical and chemical sediment analyses

#### *Total organic carbon (TOC)/ total nitrogen (TN)*

TOC is to be determined in samples from all stations in baseline surveys and the first follow-up sediment monitoring surveys. TOC should subsequently be determined in samples from stations where biological analyses are carried out. The same applies to TN-analyses, if these are included. The Sudanese Authorities may require continued analysis of TOC/TN if this is considered necessary.

### *Grain size distribution*

Analysis of grain size distribution is required for all stations in baseline surveys and first monitoring surveys, and subsequently it is required at stations where biological analyses are carried out. As a minimum, the percentages of silt/clay (<63 µm), sand (63-2000 µm) and coarse sand/gravel should be presented for all biological surveys as a supporting parameter for interpretation of soft-bottom fauna data.

### *Hydrocarbons and synthetic drilling fluids*

As a general rule, analyses must include the groups of substances specified below. Certain analyses may be omitted if the operator can document that there have been no discharges of the substances in question. The operator must also take into account the discharge status on the field and in the region and assess whether other parameters should be analysed.

The following analyses are required for samples from all stations in baseline surveys and first follow-up monitoring surveys:

- THC
- main components of synthetic drilling fluids (if used)
- NPD and PAHs (see appendix I)

Depending on the degree and extent of contamination, the analytical programme for field-specific stations can be reduced from the second monitoring survey onwards:

- THC (and possibly synthetic drilling fluids): all stations
- NPD and PAHs: all regional stations and as a minimum, the two downstream field-specific stations closest to the discharge point; and also stations:
  - where significantly high values were found in the previous survey,
  - where THC levels (mean of three grabs, including olefins) is higher than 50 mg/kg,
  - where biological impacts have been registered.

If significantly high values for THC or NPD/PAHs are found at the two closest downstream stations in one monitoring survey, NPD/PAH analysis should be reintroduced in the next survey for the three downstream stations and the inner stations around the installation in the three remaining directions.

Sediment samples from different soil layers (0-1, 1-3 and 3-6 cm) should be taken for THC analyses on a few fields. These may include fields where drilling with oil-based fluids was previously conducted, fields where leakages from injection wells were registered, and fields where dredging operations have been carried out. Particularly which fields and what number of stations are to be investigated is determined after consulting with the competent Sudanese Authority. Taking profile samples is not required when conducting baseline studies unless there are suspicions of past contamination from previously drilled exploration wells in the area.

### *Metals*

For baseline and first monitoring surveys, analyses of the following metals are required for all stations: Ba or an equivalent weighting agent, Cd, Cr, Cu, Pb, Zn and Hg. Depending on the degree and extent of contamination, the analytical programme can be reduced from the second monitoring survey onwards. Metals should be analysed in samples from all regional stations and as a minimum, samples from the two downstream stations closest to the discharge point/installation. Metals must also be analysed in samples from stations:

- where significantly high values were found in the previous survey (2 x LSC is used as the limit for Ba);
  - where the concentration of THC (mean value of three grab samples, including olefins) is higher than 50 mg/kg;
  - where biological impacts have been registered.
-

If significantly high values are found at the two closest downstream stations in one monitoring survey, all metals should be analysed in the next survey for the three downstream stations and the inner stations around the installation in the three remaining directions.

If the previous monitoring survey has not found elevated metal concentrations, these analyses can rest as long as no drilling activity was undertaken since, and there are no other relevant factors of importance for metal concentrations in the sediments.

### **3.5.3 Biological analyses**

A thorough analysis of the soft-bottom macrofauna is required, including taxonomical identification and number of specimens belonging to each species. The purpose of the investigation is to reveal potential impacts on the fauna as a result of discharges and contamination on the field. Calculations of biomass are not required.

In some cases it may be needed to investigate meiofauna in the sediment samples in addition to or instead of macrofauna. This may be relevant in areas where conventional sampling equipment cannot be used. Where such analyses are appropriate, the methodology and relevant fauna groups should be discussed with appropriate expert groups.

Samples for biological analyses are taken at all stations during baseline surveys and first regional surveys. In subsequent surveys, biological analyses are required for the regional stations and the field-specific stations closest to each installation, preferably at a distance of 250 m.

If a survey finds biological impacts or values of THC > 50 mg/kg at field-specific stations, the minimum requirement for the subsequent survey is to take samples at each station where a biological impact was found and the next station in the series (further out from the installation).

## **3.6 Analytical methods**

Analytical methods for which there are updated international standards should be used. All results of the chemical analyses of sediment are to be standardised against weight per kg dry weight of sediment.

### **3.6.1 Physical and chemical sediment analyses**

Before chemical analysis of sediment samples, all stones larger than 5 mm should be removed from the subsamples.

#### *TOC/TN*

There is no international standard available for analysing TOC in sediments. Common to the methods in use today is the removal of inorganic carbon with acid and subsequent combustion. Detection is however different. It is recommended that analysis of TOC is performed with instruments that have a hot wheel detector (HWD). In this way, TN can also be determined in the same batch, without significant additional costs.

#### *Grain size distribution*

The methodology for determining grain size distribution in the range 2000 to 63 µm is described in Bale & Kenny (2005). No further subdivision of the fraction < 63 µm is required.

The weight of each fraction is determined (to the nearest 0.01 g) and cumulative percentages by weight are calculated for each station. The results are further used to determine the median particle diameter and standard deviation, together with the skewness and kurtosis of the grain size distribution.

#### *Hydrocarbon analyses*

Hydrocarbons are to be determined in all samples from all stations. Methods with a high hydrocarbon extracting efficiency from sediment samples must be used. The analytical laboratory must be able to document this on request.

THC analyses should be performed using a gas chromatography/flame ionisation detector (GC/FID) in the retention window C12 to C35. A reference oil sample should be used as an internal standard for the quantification. The reference oil in use is EDC 95/11. If this is replaced, intercalibration /intercomparison exercises using equivalent reference oils are required. NPD and PAHs should be determined by means of gas chromatography/mass spectroscopy (GC/MS), and results should be reported for individual components, sum NPD and sum PAH. If the drilling fluid used contains organic components (ethers/esters), the samples must also be analysed for these substances.

Detection limits should meet the following minimum requirements:

- THC: 1 mg/kg dry sediment (the quantification limit must be given in the report);
- NPD/PAHs, individual components: 1 µg/kg dry sediment.

Assessment of development trends over time of THC concentrations and size of the contaminated area must be carried out based on field-specific data. Similarly, analyses of development trends over time at the regional stations should be done. These analyses are to be carried out using a suitable statistical tool.

The Sudanese Authorities should consider the option of establishing a national database for systematic storage of data sets from monitoring surveys in order to facilitate trend analyses. In Norway sediment monitoring data are stored in the so-called MOD database.

#### *Synthetic drilling fluids*

The sediment samples are to be analysed for the main component content in synthetic drilling fluids. The analytical method must be adapted to the relevant substances. Where appropriate; extraction and further processing of the sediment samples for these analyses may be conducted together with those for hydrocarbon analyses.

#### *Metal analyses*

The samples are to be analysed after digestion with nitric acid, HNO<sub>3</sub>. The following metals should be determined: Ba, Cd, Cr, Cu, Pb, Zn and Hg. If other weighting agent except Ba was used during drilling (e.g. Ti) the relevant parameter must also be analysed. For determination of Hg, the samples should be freeze-dried or dried at 40 °C before sieving and digestion.

All parameters should be analysed using ICP-MS or other well documented instrumental methods of high sensitivity that provide sufficient accuracy of the results. This needs to be documented in the laboratory's quality assurance system. Hg concentration may be determined using cold vapour technique/Hg-analyser. Detection limits for metals are shown in appendix II.

Analyses of development trends over time should be carried out for any metals with recorded values exceeding the background level. Metals with values below LSC may be left out in the illustrations included in the report.

#### *Limit of significant contamination and interpretation*

LSCs are calculated based on the results recorded at regional stations. Before LSC values are calculated, a principal component analysis (PCA) of the chemical data should be carried out, both for the current year alone and for all available data (as a minimum data from the three last surveys in the regions). The results of the PCA will clarify whether it is necessary to split the region into sub-regions. If sub-regions are used, they must be the same for THC and for the weighting agent used (e.g. barite or ilmenite). LSC values are to be calculated both for the current year's data set alone and using the complete data set from all surveys in the region.

The values obtained with different calculation methods are compared and assessed to choose the relevant LSC (for the whole region or sub-regions).

LSC values are calculated from mean values, using a unilateral t-test and a significance level of 5 %. LSC values must contain a significant number of digits. The formula for calculating LSC values is given in the appendix III.



As a general rule, the LSC values obtained on the basis of all available data are quite robust and vary only slightly from one survey to another.

### 3.6.2 Biological analyses of sediment living fauna

Species identification of sediment living fauna should only be carried out by professionally qualified personnel operating in accordance with standardised procedures for species identification. Documentation of quality assurance routines must be available on request. As a general rule, taxonomic resolution should be at species level.

Databases like Worms ([World Register of Marine Species](#)) or ERMS ([European Register of Marine Species](#)) should be used to provide consistency in terms of species identification so that data is comparable.

The taxonomic resolution should as a minimum be the same in the monitoring surveys as in the baseline survey.

The following data are required for each station:

- complete lists of recorded species (species name and number of specimens of each species);
- total number of species;
- total number of specimens standardized to a sediment surface area of 0.5 m<sup>2</sup>;
- table with the ten most abundant species (species name, number of specimens and percentage from the total number of specimens at the station), also showing the total number of species found at the station;
- H' (species diversity as Shannon Wiener index on a log<sub>2</sub> base);
- ES<sub>100</sub> (expected number of species per 100 individuals)
- NSI
- ISI
- NQI1

All the results above should be standardized to a sediment surface area of 0.5 m<sup>2</sup>.

The following analyses are required for all stations on a field, including the regional stations associated with the field, and in addition for all the regional stations as a group:

- Cluster analyses based on the Bray-Curtis dissimilarity index (Bray and Curtis, 1957), followed by group average sorting
- Ordination by non-metric multidimensional scaling (MDS)

The multivariate analyses should be carried out based on the values obtained by summing up the five samples from each station. Multivariate analyses should also be used to investigate the correlation between chemical and biological parameters. It is important that the results are presented and interpreted in a satisfactory manner, given the aim of the survey.

The method used to identify stations with disturbed fauna should be described in the report's chapter on method description, as do the reasons for choosing it.

Other analytical methods than those specified above may also be used, provided that they come in addition to those listed above.

### 3.6.3 Estimation of affected area

A conservative estimate of the maximum area with THC-contaminated sediment (as defined by LSC) is required. In addition, the maximum area with THC over 50 mg/kg and the area with disturbed bottom fauna are to be estimated. The calculations are based on the assumption that affected areas are elliptical, and that the entire area within the innermost unaffected stations is considered contaminated (see Figure 5, in appendix). The calculation method is described in appendix IV. The calculated surface should be compared with those of previous surveys. This can be done provided that information is given on which wells and installations are used in the calculations, for example in a

table. If stations are omitted from a survey, resulting in the impossibility to calculate the affected area, it is assumed that the results of the previous year's survey are still valid.

### **3.7 Reporting of sediment surveys**

The purpose of offshore environmental monitoring is to provide an overview of the environmental status and of trends over time seen in relation to offshore oil and gas activities. It is important therefore that the survey results are assessed taking into account the state of the marine environment as registered in previous investigations as well as the discharge history in the area. With this in mind, one should assess the condition of and potential impacts on the environment as part of the reporting process.

The results are to be presented in a technical report and a summary report with authorities and the general public as the main target groups. A more detailed description of the expected report design follows below.

Each report is to be submitted electronically and in five paper copies in addition (unless other numbers of copies are stated). Final reports from conducted field surveys/monitoring will be published at open access sites once the Sudanese Authority has approved them.

One report should be prepared for each regional survey. The report should provide an overview of the main environmental trends in the region and on the individual fields investigated. All raw data and results derived from these should be available to the authorities in the form of electronic appendices to the reports.

It should be stated in the report where the collection of the data for all fields and regions is stored, as well as who is the responsible contact person.

Two separate reports from the monitoring surveys should be delivered; a summary report in English and Arabic language, and one main report in English. The raw data files, including the cruise log, must be provided as appendices to the main report.

A CD which contains the executive summary and the main report and all raw data should be delivered together with the main report.

Unless special instructions on the number of printed copies required, five printed copies of each report should be sent to the Sudanese authorities.

#### **3.7.1 Summary report**

The summary report should be maximum 20 pages long. The target group for the report includes the oil and gas companies, environmental authorities, and the general public.

The summary report should include the following elements:

- A one-page summary with a brief goal description, with tables or figures showing environmental status and trends in the region
- a brief description of the field work
- presentation and discussion of the most important results (illustrated with figures and tables);
- main trends and comparison with earlier surveys, as well as uncertainty aspects connected to that
- illustrations of seabed areas where contaminated sediments and biological impacts have been found should be included for each field and for the region as a whole
- conclusions and recommendations.

### 3.7.2 Main report

The target group for the report includes oil and gas companies, environmental authorities, research institutions and consultancy firms. The survey and results must be presented in such a way that they also make sense for professionals who have not participated in the actual monitoring. The final scientific report should contain a complete documentation of the completed monitoring survey, focusing on:

- analytical parameters
- analytical methods and quality assurance
- the results and conclusions of the survey;
- trends within individual fields and the region as a whole;
- issues that should be given priority in future surveys.

The main report should include the elements described in the following.

#### *Summary*

A brief description (no longer than one page) of the survey, similar to that in the summary report.

#### *Introduction*

The following should be described for each field and, if relevant, for the region as a whole:

- the area expected to be affected by discharges from oil and gas activities, according to the EIA
- drilling and discharge history and other activities that may have affected chemical and biological conditions up to the time of the survey
- earlier surveys (table)
- main trends in pollution levels up to the moment of the current survey
- specific goals and priorities for the current survey.

#### *Methods*

The methods section should include the following:

- map of stations showing coordinates, map scale, depth contours, existing installations;
- reasons for the choice of stations (if any changes from earlier surveys);
- table with overview over station changes;
- brief description of the completed field work, including time frame for conducting the survey, number of stations, positioning system, sampling programme at each station and any problems or deviations from the programme and these guidelines, with reasons (complete field log in appendix);
- the report should mention whether sampling was not performed at a station or whether samples were rejected due to high stone or sponge spicule content in the sediment. Include a discussion on whether and /or how results were affected.
- brief description of the laboratory procedures (physical, chemical and biological analyses): description of any deviations, with reasons, and an evaluation of how they affect the results;
- detection limits, quantification limits and LSC must be reported for chemical analytical methods;
- principles for quality assurance routines in the field and laboratory, including details on participation in intercalibration / intercomparison exercises for relevant methods
- accreditation status and proof, together with documentation of quality control of the results (chemical analyses) should be included in an appendix;
- which formulae for indices and which statistical methods were used, etc.;
- procedure and criteria for identifying stations with disturbed fauna;
- information about any supplementary analyses and reasons for conducting them;
- where and how the processed material (samples, reference collections, databases) is stored, responsibility for the material and results and their availability.

*Results and discussion*

This chapter presents and discusses the results of the survey. The elements to be included are summed up in Table 6 and further discussed below.

Table 6: Physical/chemical and biological parameters that should be included in report

<b>Physical/chemical characterization</b>	<b>Biological characterization</b>
<ul style="list-style-type: none"> <li>• grain size distribution divided as a minimum in silt/clay (&lt; 63µm), sand (63-2000µm) and gravel,</li> <li>• for grain size, median particle diameter and standard deviation should be provided,</li> <li>• colour and smell appearance,</li> <li>• total organic carbon (TOC), total nitrogen (TN) - voluntary,</li> <li>• table with average value of all parallel samples as well as standard deviations of chemical results from all previous surveys</li> <li>• graphs showing relevant chemical data against year, presented with mean values (any high standard deviations to be marked with * and commented upon in the text),</li> <li>• LSC calculated based on results from regional stations for the current year's data set alone and for the entire data set (at least the three last surveys) i order of priority, for one of the following:               <ul style="list-style-type: none"> <li>- the whole region (all regional stations)</li> <li>- sub-regions if used (based on selected regional stations)</li> <li>- a selection of regional stations associated with each field in the region,</li> </ul> </li> <li>• concentrations that are significantly different from background levels,</li> <li>• THC-contaminated areas for the fields and the region (both significantly over background level and over 50 mg/kg).</li> </ul>	<ul style="list-style-type: none"> <li>• number of species and specimens standardized to a sediment surface area of 0.5 m2 sediment (per station)</li> <li>• community indices (H', ES100, NSI, ISI NQI1),</li> <li>• the 10 dominant species with density and percentage of total,</li> <li>• similarity between stations, grouping by means of multivariate analyses,</li> <li>• geographical distribution of station groups;</li> <li>• description of station groups based on:               <ul style="list-style-type: none"> <li>- depth</li> <li>- sediment characteristics</li> <li>- content of organic matter</li> <li>- content of hydrocarbons</li> <li>- content of metals</li> <li>- biological parameters,</li> </ul> </li> <li>• analysis of correlation between community indices, density of selected species, physical properties of the sediment, and hydrocarbon and metal content (the significant correlations should be further analysed to identify potential cause-effect relationships),</li> <li>• area with recorded faunal disturbance.</li> </ul>

Similarities and differences in terms of chemical condition and faunal structure between field-specific and regional stations should be scientifically assessed on the basis of the biological results and multivariate analyses. It is important that the results from the reference samples and the uncertainty estimations are taken into account in the discussion. This provides important information about the extent to which trends can be identified or whether identified changes are within acceptable uncertainty limits for the methods used.

*Description of individual stations*

Tables and figures should so far as possible be used to present the observations and the average results obtained for all physical, chemical and biological parameters and all indices required. Any classification of these should be explained and reasons for its use given. Other characteristics of the station that are of significance for the discussion should also be presented. All relevant information given in figures and tables should also be mentioned in the discussion. The same results should however not be illustrated in both tables and figures.

*Description of individual fields*

- mean values, range (min.–max. and SD or SE), geographical gradients of concentrations, and biological indices across the field;
- comparison with corresponding characteristics for the associated regional stations
- results of multivariate analyses on the similarity between groups of stations (Clarke et al., 2008).
- to what degree the physical/chemical characteristics could explain the observed biological pattern
- specification of the areas where chemical contamination and biological impacts have been recorded
- trends over time on the individual field for the characteristics listed in the bullet points above.

*Description of the region*

- mean values, range (min.–max. and SD or SE), geographical gradients of concentrations, and biological indices across all regional stations;
- results of multivariate analyses on the similarity between groups of stations, installations, etc.;
- to what degree the physical/chemical characteristics could explain the observed biological pattern;
- specification of the total areas in the region where chemical contamination and biological impacts have been recorded;
- changes in any of the points above since the previous survey.

The points listed in Table 6 should be included in the results and discussion chapter. They should also provide the starting point for answering the questions listed below.

- Can one group stations across the field or in the region based on a geographical or other pattern?
- How far from the discharge point/installation are chemical contamination (above LSC) and biological impacts statistically detectable?
- How big is the area with measured THC-concentrations above 50 mg/kg?
- How do the responses correspond with gradients in natural and anthropogenic environmental variables?
- How do the results correspond with those of earlier surveys?
- How do the results correspond with those of relevant surveys in nearby areas?
- Are the effects correlated with the discharge history of the field or region?

The extent of the area with chemically contaminated sediments and the area with disturbed fauna should be illustrated both in tables (km<sup>2</sup> for chemical contamination and biological disturbance) and in maps for the field/region in question.

*Overall evaluation and conclusions*

This chapter should contain concluding remarks on the environmental status and trends on individual fields and in the region, discussed in relation to EIA predictions and results of previous surveys. The most important trends regarding the benthic habitat both on individual fields and in the region should be described. The chapter must also identify areas where there are particular problems.

If visual surveys were carried around the same time as the benthic habitat survey or relatively recently, the results of these should be taken into account in the evaluation and interpretation of the survey results.

*Recommendations*

The report should include thoughts on future environmental monitoring based on this year's work:

- suggestions for future surveys based on current results.
- suggestions for improvement, modernization and rationalization of the monitoring methodology.

*Appendices*

The appendices to the report should be delivered electronically and should as a minimum include the following:

- final programme for the surveys as established together with the Authorities
- complete field logs: date, time, position (GMS and UTM, which reference grid is used; grid zone must be specified), depth, number of grab samples and weather conditions presented in table format for each station;
- analysis report;
- tables of all analytical data ;
- raw data files in Excel format.

## 4 Visual monitoring of hard bottom habitats (coral reefs)

A range of environmental issues and possible conflicts emerge when oil & gas industrial activities take place in or close to coral reef areas. Adaptation of the industrial activities to Best Environmental Practice routines involves avoiding physical destruction of reef habitats and minimising the exposure of reef communities to discharges and accidental spills. Baseline studies in the area done prior to the industrial development must be followed up with monitoring. The monitoring provide documentation of the efficiency of implemented protection measures or demonstrate cases of impact as early as possible so better protection measures can be enforced. The ideal model for coral reef monitoring will involve at least two levels of quality: a community based, relatively broad-brush monitoring programme carried out by teams of scientists and community members, e.g. Reef Check methods, and a high resolution programme carried out by pure scientific teams. In this monitoring guideline, use of the Reef Check method is recommended as these reef assessment principles already are regionally implemented as core methods for monitoring in the RSGA area.

### 4.1 Previous coral reef monitoring in Sudan

The Regional Action Plan for the RSGA region which was published in 2003 defines a set of priority actions aimed at protecting to the regions coral reefs (PERSGA/GEF, 2003a). Regional coral reef surveys were conducted in 2002 and 2008 (PERSGA, 2010; PERSGA/GEF, 2003b). The latter survey used a suite of “Reef Check” survey protocols (PERSGA/GEF, 2004) which previously had been adapted to the field conditions in the RSGA area. In the Sudanese waters, the following reef sites were surveyed during the 2002 and 2008 campaigns:

	2002	2008
O’Seif (Eastern of O’Seif Prot jetty)	-	X
Arkiyai (Reef off Arkiyai fishing village)	-	X
Wingate SSE	X	-
Sanganeb SSW	X	-
Sanganeb NNE	X	-
Port-Sudan (Abou Hashish – Reef off Port-Sudan fish market)	-	X
Tawartit (Nemrose wreck)	X	-
Suakin (Reef off Suakin Port)	X	X
Tala Tala Saghir (South)	X	-

As shown above, only the reef off the Suakin Port was surveyed both in 2002 and 2008, thus limiting the possibility of trend identifications. However, further survey activities in Sudanese waters have most likely been performed recently although the reef condition results have not been made properly available. E.g. according to official sources, reef condition data in Sudanese waters have recently been collected at a total of 22 sites in the two Marine Protection Areas: four sites in Sanganeb Marine National Park (SMNP), and 18 in Dungonab Bay National Park (DBNP) (Ahmed Abdel Aziz Ahmed, personal info).

## **4.2 Reef survey protocols based on “Reef Check” principles**

The “Reef Check” assessment methods are described in short below. For more comprehensive descriptions of the Reef Check procedures the PERSGA Standard Survey Method collection (PERSGA/GEF, 2004) should be consulted. All the method instructions and data sheets that are required for a Reef Check reef assessment study are provided in PERSGA/GEF (2004), which also include some adaptations of the procedures and data sheets in order to fit the conditions in the RSGA area.

The Reef Check methodology was originally developed by the non-profit Reef Check organisation (Hodgson, 1999; Hodgson and Stepath, 1998) and is designed for a rapid, broad scale condition assessment at shallow coral reef locations. The assessment/monitoring parameters addressed include distribution and abundance of a selected fish and invertebrate species that are known to be either indicators of reef health or susceptible to overexploitation. In addition, the method also provides a simple quantitative assessment of benthic substrata, including corals, and data concerning different types of impact or impact symptoms, such coral damage, coral bleaching and amount of litter.

A central idea behind the Reef Check methodology is to provide a simple field assessment method which at the same time is meaningful with regard to impact assessment. The simplicity is meant to enable non-scientist parties, such as recreational divers, to contribute to reef condition assessment and monitoring activities on a voluntary basis, typically in collaboration with scientists. The results can voluntarily be submitted to the Reef Check organisation and added to the organisation’s database that includes condition data from reefs all around the world. The more volunteers that join the more reef sites can be included in the monitoring system and this public participation is an important principle for strengthening general public awareness related to the health of the world’s coral reefs.

Interestingly, environmental NGOs and diving organisations that operate in the Red Sea, such as Red Sea Environmental Centre (RSEC) (Dahab, Israel), offer both training courses in coral reef conservation matters and diving trips that are addressing Reef Check methods.

In the PERSGA Standard Survey Method collection (PERSGA/GEF, 2004), the recommended method for coral reef monitoring is based on the Reef Check methodology, but with some adaptations in order to adapt it to conditions in the RSGA area. A full description of the Reef Check methods can be obtained from the Reef Check website:

[http://reefcheck.org/ecoaction/Monitoring\\_Instruction.php](http://reefcheck.org/ecoaction/Monitoring_Instruction.php)). A more popularised method description was provided by Hodgson & Stepath (1998), and the method description given below is largely based on that paper, but with adaptations to Red Sea conditions as described in the Standard Survey Method collection for the RSGA area (PERSGA/GEF, 2004) and the most recent regional coral reef survey in the RSGA area (PERSGA, 2010).

## **4.3 Reef Check method**

### **4.3.1 Site selection and basic design**

It is of key importance for the quality of the reef monitoring programme to establish a set of appropriate reef sites and fixed diving transects to use in connection with repeated reef monitoring activities. The suite of fixed diving transects must be established already during the baseline study at the site which must be conducted before the potentially harmful activity/developments have taken

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place. The selection of diving transects is a key component of the preparation of the site specific monitoring plan.

It is recommended that at least one of the selected diving transects should be representative for the most biodiverse part of the reef, as this will facilitate the discovery of impacts at the reef site. Furthermore, it is recommended that at least one of the selected diving transects should be located in the sub-area of the reef which from the environmental factors (e.g. prevailing sea current direction) is most likely to be affected by the human/industrial activity at the location. It is also recommended that at least one diving transect is placed with a large enough distance to the possible stressor source to provide regional background reference data, i.e. that can represent a “no-effect” sample.

The planning document should describe all the activity-related and environmental factors which have been taken into consideration in the site selection process. As discussed earlier, oil & gas industrial developments constitute a diverse field of accomplishments and infrastructures (see Figure 1 for a simplified overview) and each of these may represent highly variable sources of stress to the habitats and natural populations of organisms at the site or in the region. Certain activities/stressors, such as seismic surveys and occurrence of a significant oil spill, represent stressors that may affect large areas whereas other activities, such as local deposition of drill cuttings at the seabed, will affect a smaller area.

The goal is to survey two depth contours, 3 m and 10 m below chart datum (lowest low water). However, on many reefs, the highest coral cover will not be found at these exact depths. Therefore, choose the depth contour with the highest coral cover within the following ranges: Shallow (2 - 6 m depth), Mid-reef (7 - 12 m depth). Note that particularly for the shallow transect, the tide should be taken into account.

Along each contour, a transect survey line must be deployed. The total length of the line is 100 m, which include four 20 m long transect-segments each separated by a 5 m space (Figure 4). As transect line, the use of a single 100 m fiberglass measuring tape available from hardware and survey equipment supply stores is recommended. The distance between the start of the first transect and end of the last transect will be  $20 + 5 + 20 + 5 + 20 + 5 + 20 = 95$  m.

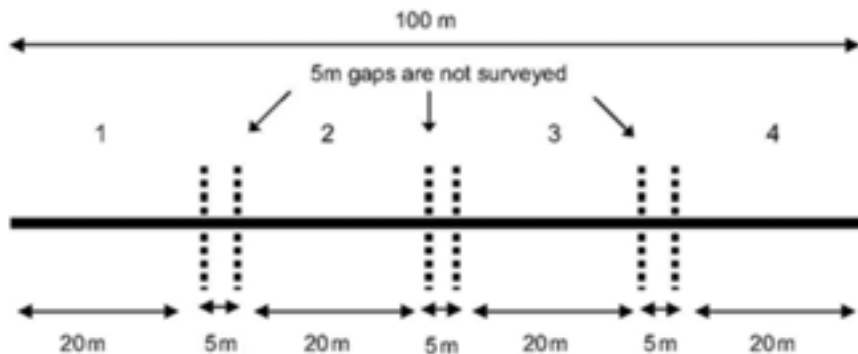


Figure 4: A 100 m long line or measurement tape is a key tool for performing the Reef Check assessment. This 100 m line is divided into four 20 m segments with a 5 m gap in between them to ensure sample independence. Illustration from <http://www.reefcheck.org/>

In choosing the depth contours practical issues of time and safety must be considered. Reefs in many areas are not suitable for being surveyed at both depths. In this case, just survey one depth contour. The full transect line as well as the segments that are to be examined must be properly marked.

In locations where reefs are broken into patches with large areas of sand/rock in between, it may be necessary to separate the different transect into 20 m segments.

The data sheets that are required for performing Reef Check surveys can be obtained from the appendix in the PERSGA Standard Survey Method collection (PERSGA/GEF, 2004), or from the Reef Check website. Along each transect line four types of data are to be recorded, these are:



1. Site description data, rapid assessment: Anecdotal, observational, historical, locational and other data should be recorded on the Site Description sheet.
2. Fish belt transect: Four 5 m wide (centred on the transect line) by 20 m long transects will be sampled for fish species that typically are targeted by spearfishing, aquarium collectors, and dynamite or cyanide fishing procedures. The fish transect must be carried out first.
3. Invertebrate belt transect: Same four 5 m wide (centred on the transect line) by 20 m long transects as above will be sampled for invertebrate species typically targeted as food species or collected as curios.
4. Point-intercept line transect: For quantitative assessment of benthic substrate. The same four 20 m long line transect segments are point sampled at 0.5 m intervals to determine the benthic substrate types lying beneath the transect line.

The Reef Check fish indicators that should be recorded at the Reef Check data form are: Butterflyfish, Sweetlips (*Haemulidae*), Snapper (*Lutjanidae*), Broomtail wrasse (*Cheilinus lunulatus*), Grouper >30cm (give sizes in comments), Bumphead parrotfish (*Bolbometopon muricatum*), Humphead wrasse (*Cheilinus undulatus*), Any parrotfish (>20cm), Moray eel.

The Reef Check invertebrates are: Banded coral shrimp (*Stenopus hispidus*), *Diadema* urchins, Pencil urchin (*Heterocentrotus mammillatus*), Sea cucumber (edible only), Crown-of-thorns star (*Acanthaster planci*), Giant clam (*Tridacna*), Triton shell (*Charonia tritonis*), Lobster.

For the assessment of benthic cover, the following substrates (with codes) are to be recorded: HC hard coral, SC soft coral, DC dead coral, FS fleshy seaweed, SP sponge, RC rock, RB rubble, SD sand, SI silt/clay, OT other.

In addition to recording data on the standard forms, it is important for each group to document the transect location, survey results and findings using a combination of still photos and videography both on land and in the water.

#### **4.3.2 Preparations, team size, training and Quality Assurance**

Coral reef survey teams should consist of a minimum of three trained personnel. This allows for rotation among the three team members to form a dive team of two with one person to handle the boat. Larger teams clearly can accomplish more field and laboratory work, and the teams should be expanded as funding and resources permit.

Each team of must have a Team Leader who is experienced in the Reef Check methodology and who is formally responsible for the planning, practical preparations, training of team members, performance of the diving activity, and the handling and reporting of the recorded data. A description of the logistics and equipment required for performing a Reef Check survey is provided in the PERSGA Standard Survey Method collection (PERSGA/GEF, 2004).

The training needed for each diving team will depend on their experience and knowledge level. In case of non-experienced team members, it is recommended that at least a half-day training session on land is conducted prior to the dive. The preparation session should be supplemented with a brief review on the dive day.

It is most important that a system of quality assurance is developed, to minimize errors in the data collected. This is achieved through initial training courses in the field methods, followed with regular refresher courses. Where logistics permit, it is highly advantageous to enter field data directly onto a portable computer in the field at the end of each day. This provides the opportunity to check for any obvious errors immediately. Various statistical tests are available to check for different forms of bias in the field data.

There are three field data sheets (pro-forma) for the core protocols, the Site Description sheet (rapid assessment), Belt Transect sheet (reef fish and reef invertebrates) and Point intercept line transect sheet (benthic substrata/ coral cover data). The data sheets must be printed by use of underwater paper or a plastic writing slate.

Photos of the different indicator species should be downloaded and printed in colour and either laminated or placed inside a plastic "zip-lock" bag so they can be carried underwater for reference.

One buddy pair of divers should lay out the 100 m long transect line along the specified contour (2-6 or 7-12 m). After deployment, the entire length of the line should be examined to ensure it is not snagged or floating too high off the bottom.

Permanent stakes can be installed in the start position and end position of the transect line to make it easier to locate for the next monitoring survey. GPS (Global Positioning System) coordinates should be taken at both start and end of each transect. The compass direction from the start to the end marker of each transect should be recorded.

### 4.3.3 Site description – Rapid assessment

Various descriptive types of information are recorded using a rapid assessment method on standard site description data sheets that are obtained from the PERSGA Standard Survey Method collection (PERSGA/GEF, 2004). The recorded data are meant to assist the understanding of the present status of the site and for ease of relocation in future surveys. For coral reefs, these data include:

- Reef name or other identifier (number etc.)
- Sample identity code (ID) – a unique site descriptor number for each site that is placed on all data sheets used at a particular site, linking site description with benthic cover and biodiversity survey results.
- Location – GPS position, compass bearings, maps etc.
- Survey observers' names
- Reef type – e.g. fringing, patch, barrier, atoll
- Date
- Time of survey
- Tide
- Distance to nearest town
- Presence of human litter or rubbish or fishing gear above and/or below water  Weather conditions – approximate amount of cloud cover, wind speed
- Level of reef development (as ranks, see later)
- Degree of exposure to waves (as ranks, see later)
- Average angle of reef slope (nearest 10 degrees to horizontal)
- Underwater visibility
- Present status – any recent impacts
- Type(s) of survey method used: Reef Check, Lifeform, Video, Biodiversity
- Anecdotal information – local knowledge about the site
- Other observations and remarks. Following the underwater surveys, additional site description information is recorded:
  - The presence of any unique or outstanding biological features, such as particularly large corals or unusual community compositions
  - The presence of bleached corals (partial or total loss of pigments on living corals)
  - The presence of coral predators and other cause(s) of coral mortality.

Following the underwater surveys, additional site description information is recorded:

- The presence of any unique or outstanding biological features, such as particularly large corals or unusual community compositions
- The presence of bleached corals (partial or total loss of pigments on living corals)
- The presence of coral predators and other cause(s) of coral mortality.

#### 4.3.4 Fish belt transect assessment

The data sheet and more detailed instructions for the fish belt transect assessment is obtained from the PERSGA Standard Survey Method collection (PERSGA/GEF, 2004) and must be printed on underwater paper.

The fish belt transect assessment is the first transect assessment performed after the transect line is deployed. Before starting, the transect area should be left undisturbed for at least 15 minutes. Estimated time to complete a full transect line is 1 hour.

The maximum height above the transect line to record fish is restricted to 5 m. The diver(s) assigned to count fish will swim slowly along the transect and then will stop to count target fish every 5 m, and then wait 3 minutes for target fish to come out of hiding, before proceeding to the next stop point. This is a combination timed and area restriction survey, four sections x 20 m long x 5 m wide = 400 m<sup>2</sup>. At each depth contour, there are sixteen "stop-and-count" points, and the goal is to complete the entire 400 m<sup>2</sup> belt transect in 1 hour.

Target fish: The Reef Check fish indicators that should be recorded at the Reef Check data form are: Butterflyfish, Sweetlips (*Haemulidae*), Snapper (*Lutjanidae*), Broomtail wrasse (*Cheilinus lunulatus*), Grouper >30cm (give sizes in comments), Bumphead parrotfish (*Bolbometopon muricatum*), Humphead wrasse (*Cheilinus undulatus*), Any parrotfish (>20cm), Moray eel.

The target fish have been selected as some of the top fish typically removed from reefs by spear or line fishing or other methods. Given the magnifying effect of water, divers should practice estimating sizes using the transect line or measured sticks (hand-held or floating tethered to a small weight) before attempting the fish surveys. A note should be made of any sightings of rare animals such as large manta rays, sharks and turtles, and if these are off-transect records, they should be written at the bottom of the slate under "Comments".

In poor visibility, or when there are large numbers of fish, we suggest that two divers survey half the 5m wide belt each. One diver can cover one side of the transect line and record fish in a 2.5 m wide strip with the buddy recording the other side (together the 5m wide belt will be surveyed). A measured 2.5 m coloured wire or rod can be used to help estimate the 5 m belt transect width.

During the fish transect work, the other team members should be gathering descriptive site data and one should be responsible for filling out the Site Description form. Only one form of each type is filled out per site.

#### 4.3.5 Invertebrate belt transect assessment

The data sheet and more detailed instructions for the belt transect survey for invertebrates is obtained from the PERSGA Standard Survey Method collection (PERSGA/GEF, 2004) and must be printed on underwater paper.

The belt transect survey for invertebrates is performed after the fish belt transect survey. The same transect line is used and, like the fish belt, the invertebrate belt transect is 5m wide with 2.5 m on either side of the transect line.

The Reef Check invertebrates to record are: Banded coral shrimp (*Stenopus hispidus*), *Diadema* urchins, Pencil urchin (*Heterocentrotus mammillatus*), Sea cucumber (edible only), Crown-of-thorns star (*Acanthaster planci*), Giant clam (*Tridacna*), Triton shell (*Charonia tritonis*), Lobster.

If the work is split between two divers, with each diver records data along a 2.5 m wide strip on each side of the transect line.

Estimated time to complete this work is 1 hour. Total survey area will be 20 m x 5 m = 100 m<sup>2</sup> for each transect, for a grand total of 400 m<sup>2</sup> for each depth contour.

In addition to recording indicator organisms, each group should note the presence of coral bleaching or unusual conditions (e.g. that might be diseases) along the transect. Team members should be encouraged to look in holes and under overhangs to detect species, such as lobster, that may be hiding.

#### **4.3.6 Point intercept line transects for assessment of benthic substrate**

The data sheet and more detailed instructions for the point intercept line transect survey for benthic substrate type is obtained from the PERSGA Standard Survey Method collection (PERSGA/GEF, 2004) and must be printed on underwater paper.

After completing the invertebrate belt transect, the point intercept sampling of the benthic substrata under the transect line is performed. The estimated time to complete this work is 30 minutes.

The substrate type will be recorded at 0.5 m intervals along the line, i.e. at: 0.0 m, 0.5 m, 1.0 m, 1.5 m etc. up to 19.5 m (40 data points/20 m transect).

In cases where the tape is hanging above the substratum, it may be useful to carry a metal object tied onto a nylon string for use as a plumb-line. The object is dropped at each designated point and it touches only one substrate type which can be recorded.

For the assessment of benthic cover, the following substrates (with codes) are to be recorded: HC hard coral, SC soft coral, DC dead coral, FS fleshy seaweed, SP sponge, RC rock, RB rubble, SD sand, SI silt/clay, OT other.

#### **4.3.7 Replication of transect assessments**

An important measure to increase the quality of reef assessment data is to ensure that a sufficient number of replicat assessments are performed. A more elaborate discussion of this issue is included in PERSGA/GEF (2004). The level of replication at the site level on individual reefs is related to reef geomorphology and exposure and to logistical constraints. Ideally, at least two sites should be surveyed in each exposure regime (e.g. fore reef, back reef) on each reef. Levels of replication at the reef level depend on the types of reefs present, whether fringing, patch, barrier or atoll.

The sampling design should have balanced levels of replication for:

- Different depths within the reef site: e.g. 3 - 5 replicate transects at one or two depths.
- Different sites within the reef: at least two sites in each of the different areas (e.g. fore reef, back reef) per reef.
- Different reef types within a reef area: e.g. fringing, patch, barrier, atoll.

For the Reef Check core methods recommended in PERSGA/GEF (2004), pilot studies have determined an appropriate level of within-site replication:

- Reef fish and invertebrate belt transects: 4 x 100 m<sup>2</sup> (5 m wide x 20 m long) replicate transects at each of two depths per site, centred on the line transects (Hodgson, 1999).
- Point intercept line transects: 4 x 20 m long replicate 'segments' (transects) at each of two depths at each site (Hodgson, 1999).

Beside the Reef Check methods also several other reef assessment methods are described in the PERSGA Standard Survey Method collection; including Lifeform line transects assessments, Video belt transect assessments and Biodiversity assessments by use of timed scuba-swim searches. Details of these methods can be obtained in PERSGA/GEF (2004).

#### **4.3.8 Seasonality and time of day**

In site monitoring programmes that last over several years, repeated monitoring surveys should be carried out at comparable time points within each season (time of year, time of day).

In reef monitoring programmes that include multiple reefs, all sites should (if possible) be surveyed within a single season, to avoid or minimize inter-seasonal effects.

#### **4.3.9 Post Dive Tasks**

The team scientist is responsible for gathering the slates and data together as soon as the survey is completed and reviewing them immediately with the team members. The purpose is to make a quick

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assessment of the data to determine if some error has been made that can be corrected while the team is still on site, and the transect is in place.

Typical errors that could be corrected would be "double-counting" of fish, misidentification of organisms or mis-labelling the slate. When an error is suspected, a resurvey should be made to check or to correct it.

Before departing from the site, the team scientist is responsible for ensuring that all required data have been collected, and that the slates have been filled out properly, in particular with each individual's work identified.

As soon as possible after the dive, the data should be entered into the automated Excel Spreadsheets which have been obtained at the Reef Check organisation's website and properly stored (with minimum one backup copy) and further used for statistical tests and the monitoring report.

#### **4.3.10 Comments to use of Reef Check for Long-term Monitoring**

Reef Check core methods are meant to be flexible, and can be adapted to meet local management needs and ability level of the survey team members. While these methods were designed for use by volunteer recreational divers, they are presently increasingly used also by scientists.

The three most important considerations for using Reef Check for long-term monitoring are taxonomic specificity, temporal and spatial replication. Team scientists are encouraged to add indicator organisms that may be of particular importance in their area. Adding taxonomic specificity, i.e. requiring species level identification of some organisms may also be useful.

The original Reef Check methods were designed to be carried out once per year at each site. This level of temporal replication is typically sufficient to characterize changes in reef corals and other sessile invertebrates.

To use Reef Check methods for long-term monitoring of fish and mobile invertebrates, additional temporal replicates should be made of the fish and invertebrate belt transects. A pilot study could be carried out to determine the variability of fish and invertebrate populations at a given location. A suggested rule of thumb would be to carry out three replicate surveys at each site (i.e. three repeat surveys of one transect deployment), and then to resurvey each site at quarterly intervals.

## **4.4 Reporting on Coral reef surveys**

In this guideline, the use of visual monitoring surveys has been limited to status assessment of coral reefs. Guidelines and requirements for visual monitoring and data reporting may change as more surveys are carried out in the marine waters of Sudan and more experience is gained about the presence and condition status of Valued ecosystem components in these waters. A suggestion of points that should be included in the reports from coral reef assessment surveys is listed below:

### **4.4.1 Executive summary:**

An executive summary must be produced in both English and Arabic language. The target group for executive summaries includes the oil and gas companies, the public administration and the general public. An executive summary should include the following elements:

- a brief description of the goals;
- a description of the methodology and field work;
- presentation and discussion of the most important results;
- main trends and comparison with any earlier surveys;
- conclusions and recommendations.

#### 4.4.2 Main report:

The target group for the main report (in English) includes the oil and gas companies, environmental authorities, research institutions and consultancy firms. This is the final scientific report on a survey and should therefore include complete documentation of the survey, focusing on:

- field methodology and implementation;
- analytical parameters;
- analytical methods and quality assurance;
- results and conclusions of the survey;
- assessment of the analytical methods and proposals for improvements
- issues that should be given priority in future surveys.

The main report must include the following elements:

**Summary:** A brief description of the goals, identical to that in the executive summary. Tables or figures must be used to illustrate the environmental status and trends in the studied area.

**Introduction:** The following should be described for the region or area sampled:

- projected area to be affected by discharges from oil and gas activities, according to the EIA;
- drilling and discharge history and other activities that may have affected the biological conditions as investigated in the survey;
- earlier surveys (table);
- goals and priorities for the current survey.

**Methods:** The method section should include the following:

- map showing coordinates, scale, depth contours, installations;
- reasons for the choice of stations and transects (in the event of any changes from earlier surveys);
- brief description of the completed field programme, including time frame for conducting the survey, number of stations or survey areas, equipment, positioning system, the sampling programme at each station and any problems or deviations from the programme, with reasons (complete field log in the appendix);
- brief description of the visual analytical procedures for the benthic substrate and fauna associated to the inspected habitats (e.g. coral reefs), together with a description of any deviations, with reasons and an assessment of how results are affected;
- principles for the quality assurance routines used in the field (brief);
- documentation of any accreditation should be included in an appendix;
- where and how the processed material (transect data sheets, still images, video transects, databases) is stored, responsibility for the material and results and their availability.

**Results and discussion:** This chapter presents and discusses the results of the survey, including: depth gradients, sediment characteristics and benthic substrates, characteristics of the fauna, and level of anthropogenic impacts throughout the field;

**Description of individual fields:**

- comparison with corresponding characteristics recorded at the associated reference sites in regional stations;
- estimated area where biological impacts have been recorded.

**Overall evaluation and conclusions:** This chapter should contain concluding remarks on environmental status and trends for the individual fields and the region being monitored.

**Evaluation and recommendations:** An evaluation of the survey and the analytical methods used is required, with comments and proposals for improvements. Recommendations for the next monitoring survey based on the results of the current survey.

**Copies:** Unless special instructions on the number of printed copies are given, five printed copies of each report should be sent to the Sudanese authorities.

**Appendices:** The appendices to the report should be delivered on a CD and as a minimum include the following:

- complete field logs: date, time, position (GMS and UTM, which reference grid is used; grid zone must be specified), depth, transect length and weather conditions presented in table form for each station;
- edited video presentations from each field showing transects, benthic habitat type, fauna and conclusions;
- tables with registered and analytical data;
- still images;
- results in GIS format;
- raw data files in Excel format.

The same CD should also contain the executive summary and the main report in Word or PDF format.

## 5 Monitoring of other Valued Ecosystem Components

The Sudanese coastal zone include a number of high-priority Valued ecosystem components (VECs) which may fall outside the suggested monitoring programmes described for the water column, sediment areas and coral reefs, but which still must be given appropriate protection attention in situations of oil and gas developments. In particular these VECs include:

- Mangrove stands
- Seagrass areas
- Saltmarshes
- Dugongs and other sea mammals
- Sea turtles
- Local seabird colonies
- Fisheries resources
- Rare or endemic marine species of particularly high value

Some of the most valuable areas within the Sudanese coastal zone are given special protection as National Marine Park areas (Sanganeb and Dunganab Bay area) and several others are on the list for consideration of such a special protection status. However, as the Sudanese coast is so ecologically valuable, many other sites will most likely include ecological values that yet are undiscovered or not fully characterised.

In cases of planned industrial developments, the baseline and EIA study which must be conducted in the early planning phase should include a thorough characterisation of all the VECs that could be present in the given site or area, and the potential for damage to these resources as a result of the planned activity must be clarified by appropriate expertise. Based on this information, the responsibility for decisions regarding whether or not to forward development plans into actions rests with the appropriate Sudanese Authority.

When it is found to be necessary for nature conservation reasons, Sudanese Authority can demand that appropriate measures are developed by the operator(s) to avoid or minimise significant damaging influence on VECs and also to develop suitable programmes that are capable to monitor the status and stability of the VECs in question.

The structure and content of this present guideline can also be used, at least to some degree, to assist the development of monitoring plans and monitoring activities for important VECs like those noted above. Further recommendations of methods and study-approaches to use for development of specially targeted monitoring activities are given in the PERSGA Standard Survey Methods manual for key habitats and key species in the RSGA area (PERSGA/GEF, 2004).

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## 8 Appendices

### 8.1 Appendix I – Analysis parameters: main PAH compounds

Table 7: US Environmental Protection Agency (EPA) list of 16 main PAH compounds identified in relation to the presence of pollution

PARAMETER	STORET No <sup>1</sup>	CAS No <sup>2</sup>
Acenaphthene	34205	83-32-9
Acenaphthylene	34200	208-95-8
Anthracene	34220	120-12-7
Benzo (a) anthracene	34526	56-55-3
Benzo (a) pyrene	34247	50-32-8
Benzo (b) fluoranthene*	34230	205-99-2
Benzo (ghi) perylene	34521	191-24-2
Benzo (k) fluoranthene*	34242	207-08-9
Chrysene**	34320	218-01-9
Dibenzo (a, h) anthracene	34556	53-70-3
Fluoranthene	34376	206-44-0
Fluorene	34381	86-73-7
Indeno (1,2,3-cd) pyrene	34403	193-39-5
Naphthalene	34696	91-20-3
Phenanthrene	34461	85-01-8
Pyrene	34469	129-00-0

<sup>1</sup> Storage and Retrieval number (EPA)

<sup>2</sup> Chemical Abstract Service registry number (American Chemical Society)

\* Figures for benzo (b, j, k) fluoranthenes are reported together

\*\* Chrysene is reported together with triphenylene

### 8.2 Appendix II – Detection limits for metals

The detection limits are established with regard to both the sensitivity of the measuring instruments and the background values registered in the sediments in the North Sea. These detection limits (mg/kg dry sediment) depend on the quantities of sediment that are weighted. The values provided in the table below are valid for a quantity of weighted sediment of minimum 1 g.

Table 8: Detection limits for different metals

<u>Element</u>	<u>Detection limit</u> <u>mg/kg (dry sediment)</u>
Ba	1.0
Cd	0.03
Cr	0.5
Cu	0.6
Hg	0.01
Pb	0.5
Zn	2.0

### 8.3 Appendix III – Formula for calculating LSC

$$LSC > \bar{R}_{**} + t_{\alpha(1)N_r} \cdot s \cdot \sqrt{1 + \frac{1}{N_r}}$$

$\bar{R}_{**}$  = average of the station mean values for the regional stations

$t_{\alpha(1)N_r}$  = critical value from the t-distribution with one-sided t-test with level of significance  $\alpha$  (=0.05) and  $v = N_r - 1$  degrees of freedom

$s$  = standard deviation of sedimentation between station averages

$N_r$  = number of regional stations

The standard deviation  $s$  is calculated as 
$$s = \sqrt{\frac{\sum_{i=1}^{N_r} (\bar{R}_{i*} - \bar{R}_{**})^2}{N_r - 1}}$$

where  $\bar{R}_{i*}$  = mean values on the parallels of regional station nr.  $i$ .

## 8.4 Appendix IV – Methods for delimitating affected areas

Two affected areas are to be calculated for each field: one where there is significant chemical contamination (as defined by LSC values, to be calculated for THC and Ba as a minimum), and one where there are impacts on the benthic fauna. The areas should be given in km<sup>2</sup>. The calculations are based on the assumption that the affected areas are approximately elliptical. The radii of the ellipse depend on the distance along each transect where effects can be detected. The calculations are conservative, i.e. they give an estimate of the maximum area affected. The radii must therefore be calculated as the distance from the centre of the ellipse to the innermost station where no effect is found. In many cases, this will result in an asymmetrical ellipse (see the figure below). The area is calculated in the same way in both cases:

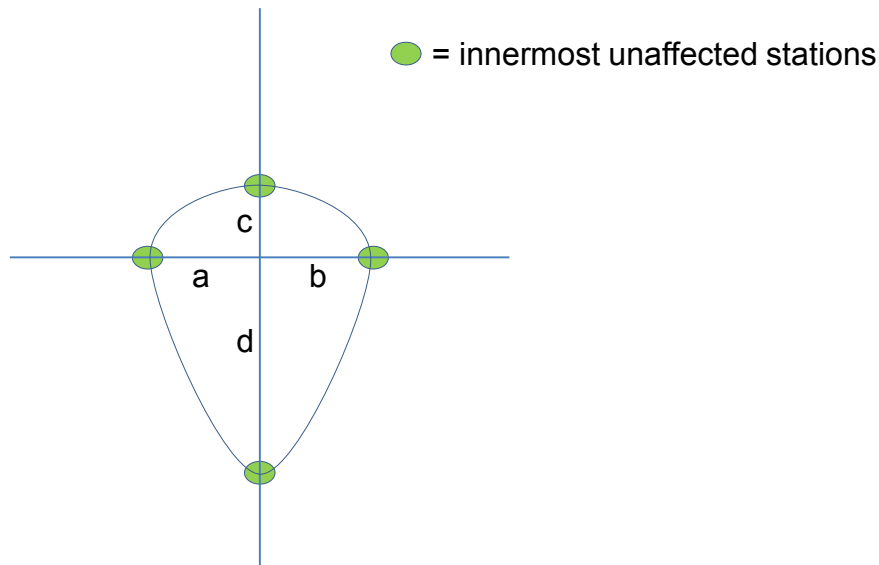


Figure 5: The circle of innermost unaffected stations defines the affected area in connection with sediment monitoring.

The affected area is calculated by the formula:

$$\text{Area} = \pi * (a+b)*(c+d)/4$$

If no stations have been sampled along a transect, the radius is defined as the distance from the centre to the nearest station where no effects were found in the most recent survey that covered the transect in question.

If a transect has never been surveyed, the radius is defined as the average of the other radii.

On complex fields where there are many installations and overlapping station networks one common elliptical area should be defined for the entire field. The radii should normally be the distance from the centre to the nearest station where no effect is found, but in most cases some assessment will also be needed to define the most suitable area.

The calculation method (chosen ellipse and how the axes are defined) must be documented in the report.

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