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NDP State of the art study - Deep water remote sensing and monitoring

Report IRIS - 2013/103

Project number:	7911898
Project title:	NDP Remote Sensing -State of the art study
Client(s):	Chevron Norge AS
Research program:	
ISBN:	978-82-490-0820-9
Distribution restriction:	Open

Stavanger , 19.09.2013

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List of Abbreviations and Definitions

AUV – Autonomous Underwater Vehicle

CTD – Conductivity, Temperature, Density sensor array

DWH – Deepwater Horizon blowout or Macondo oil spill in the Gulf of Mexico in April 2011

EPS – Environmental Sample Processor

GOM – Gulf of Mexico

KLIF – Norwegian Climate and Pollution Agency

MBARI – Monterey Bay Aquarium Research Institute

MIT – Massachusetts Institute of Technology

MS – Mass Spectrometry

NOFO – Norwegian Clean Seas Association For Operating Companies

NTNU – The Norwegian University of Science and Technology

O&G – Oil and Gas industry

OLF – Norwegian Oil Industry association, now called Norwegian Oil and Gass

PAH - Polycyclic Aromatic Hydrocarbons

PTIL – Petroleum Safety Authority Norway

RCN – Research Council of Norway

ROV – Remote Operated Vehicle

SERS – Surface-Enhanced Raman Spectroscopy

SPR – Surface Plasmic Resonance

SRI International – an independent, nonprofit research institute conducting client-sponsored research and development for government agencies, commercial businesses, foundations, and other organizations

Biosensor - In the literature, the definition for a biosensor is generally accepted as a self contained integrated device consisting of a biological recognition element (enzyme, antibody, receptor or microorganism) which is interfaced to an analytical device that together reversibly respond in a concentration-dependent manner to a chemical species/target compound.

Remote sensing - Following Klif's HSE-regulations, Activity Regulations § 57, *Remote measurement means a system which, regardless of visibility, light and weather conditions, can detect and map the position, area, quantity and properties of acute pollution. Such a system may consist of sensors and equipment deployed in satellites, airplanes and helicopters, or on facilities and vessels with associated services and procedure;*

In situ observations - genuine measurements made by deployment of sensors on for example moorings or drifters or inserted on landers; also, measurements made subsequently to samples retrieved from water, sediment cores or even biota where sensors are inserted to provide a signal response

Summary

This report aims to give the status of current technologies and future outlook for *in situ* sensing and monitoring of the marine environment with emphasis on the deep-sea. To achieve this aim, we have used information collected from recent workshops and examined a number of technical and scientific literatures. The report covers several topics: needs and current experiences of O&G operators, experiences from oil sensing and tracking, for oil spill preparedness, reviews of existing and promising physical and chemical *in situ* sensors and biosensors/biological sensors, existing platforms with their associated sensor payloads and deep-sea observatories.

At the end of the report, we develop a conceptual approach and made an analysis to recommend further development and support R&D prioritization of sensing and monitoring techniques relevant to O&G activities.

Although many devices and instruments have been developed during the last decades, some to proof-of-concept or prototype stage, there remain challenging impediments to convert them into robust and reliable techniques able to withstand long periods at sea. Some devices have however passed the proof-of-concept and are becoming powerful tools with valuable signal output for warning of anomalies or failure (e.g. subsea leakage) as well as providing important information of several compartments of the ecosystem (e.g. baseline information, distribution and presence of species).

Generally, physical sensors are reaching a mature stage in development while chemical and even more so, biological sensors, are still under-represented in real time oceanic monitoring. However, miniaturization of instruments, micro/nanotechnology and new materials have allowed these sensors to become better suited for *in situ* monitoring of several key chemical groups. Likewise, the progress in molecular techniques and smart robotics is now giving birth to increasingly well proofed instruments capable of performing advanced *in situ* assays for species identification, providing at the same time new insights into important functions of the marine ecosystem and its overall status.

There is a clear trend to move from *in situ* fixed point monitoring to mobile observation platforms, carrying payloads of multiple sensors. These platforms are also capable of relatively long missions with extensive ranges of operation. With adaptive sampling programs integrated within these platforms, they can be extremely powerful autonomous units that can accomplish specific missions e.g. for effective localization of petroleum contamination using concurrent techniques like mass spectrometry, robotic sampling and acoustic positioning.

Sensing can be used to make important observations at a scale unprecedented by traditional monitoring practices. However, for many systems, there is still a high level of efforts to implement, validate and operate them for prolonged periods at sea, in particular the deep-sea, or integrate them safely within current O&G management operations. There is also a need for better detection, classification and quantification of petroleum substances. Issues related to size, power consumption, fouling and cost are important. Finally, networking with existing portals and stakeholder’s organizations is essential for a full integration of *in situ* sensing systems within O&G water and environmental management systems.

Acknowledgment

We are very grateful to the Norwegian Deepwater Programme (www.ndwp.org) who supported this initiative and commissioned IRIS to carry out this task. Deep-sea research, environmental sensing and real-time monitoring are areas that IRIS's own strategic document strongly supports.

Objectives and approach

The Environmental Group of the Norwegian Deepwater Program (NDP) is identifying and developing environmental technologies and competencies to support safe and environmentally sound operations in deep water (DW) areas on the Norwegian Continental Shelf. In order to set strategic direction and prioritize use of resources and investment funds efficiently, NDP wants to describe the current “State of the Art” within Environmental Technologies and Knowledge for deep water operations. Based on past initiatives and workshops at IRIS, NDP has commission IRIS to develop a State of the Art Memo on DW RemoteSensing and Monitoring.

The objectives of this report are:

1) To identify and review the state of existing technologies for remote sensing and monitoring applicable for deep-water. Both well developed “off-the-shelf” technologies and other new promising technologies potentially applicable for deep-water are discussed.
2) To describe on-going or planned industry R&D efforts and other initiatives related to remote sensing and monitoring for deep-water
3) To identify areas where knowledge and technical gaps exist
4) To provide strategic recommendations for new developments and possible deployment strategies as a basis for future R&D

The foundation of this report is based on sources of information taken from recent meetings such as the OLF and KLIF seminars as well as own IRIS workshops, and other documentation recently published like the DNV document on selection and use of subsea leak detection systems (DNV RP-F-302). Comprehensive work has been carried out by OLF gathering information on leak detection systems from the different operators and some examples are provided in this report. Additional inputs have been provided through other contacts and information searches by IRIS from national and international workshops, initiaves and websites relevant for this report. The report is not meant to give an exhaustive list of existing or promising technologies as the wide-ranging nature of sensors would make this task very challenging and beyond the scope of this work. However, this report is based on information and recent updates collected by searching documents, literature, or other events (seminar, workshop) available through scientific database access, internet access and own participation of IRIS in relevant meetings. The set of information was used to review the state-of-the-art of marine sensing and provide some recommendations for further developments and future applications with emphasis on offshore petroleum. Here, we have purposefully put emphasis on technologies for underwater, subsea observations since the present assigment is placed in the context of the deep-sea. However, remote observational techniques from above the sea surface (satellite, plane, aerial observations) are used intensely in contingency operations to map and respond to incidents occurring at deep-sea depths (e.g. Gulf of Mexico oil spill). Hence the applicaton of remote sensing for oil sensing/tracking will be briefly described in this report.

At the end of the report, a chart is available that links to information and documents used to make this state of the art memo.

1 Current challenge, requirements and general status for environmental sensor systems

Ocean research and monitoring requires an ability to distinguish between natural variability and changes related to anthropogenic activities at a variety of temporal and spatial scales. Traditionally, this is achieved by collecting discrete samples from shipboard surveys and returning them to the laboratory for state-of-the-art analytical work. This cumbersome process is neither cost-effective nor adapted to monitoring for compliance testing and water quality management given an environment which is very dynamic. Furthermore, this mode of collection and analysis does not adapt itself to the new paradigm of ocean observatories in which scientists seek to have data, not samples, returned to shore by having in-field instruments that perform their analyses *in situ*. For example, in the case of regular discharges by offshore industries, it is extremely difficult to determine the true exposure and hence the ecological risk to marine organisms from hazardous chemicals due to the lack of sampling resolution. Likewise, the coastal zone represents an area with great challenges for observation techniques, monitoring and assessment due to the close interaction between a number of natural and man-made forces.

In recent years, ocean observing systems have evolved to meet many of the problems associated with basic chemical, physical and bulk biological measurements. However, there remains a lack of resolution for a myriad of important chemical and biological parameters. This results in large data gaps and hence uncertainties regarding the assessment of anthropogenic effects on marine ecosystems. Recognizing this problem, a number of initiatives have evolved to foster development of new *in situ* detectors, sensors and deployment platforms, and the systems that are now emerging appear to hold great promise to meeting some of the long-standing challenges. Their strength ultimately resides in the constant and distributed surveillance that can be carried out to rapidly detect changes in critical environmental indicators and targets. These systems operate at scales not possible to sustain with conventional sampling methodology, thereby offering the real-time information needed for early warning systems and for event response opportunities desired by state regulatory agencies and industries.

Industry and regulatory authorities can benefit from sensors that provide continuous measurements in real- or near-real time, also giving greater access to environmental data in harsh environments like the deep-sea. However, these systems must be able to operate for extended periods of time without frequent maintenance to meet different developmental challenges related to fouling, corrosion, calibration, power supply, telemetry of sensor data and vizualisation. Miniaturization is another challenge, especially for towed and autonomous platforms that can accommodate sensor packages and payloads to expand the capabilities for spatial coverage.

A large panel of sensors and platforms exist but the stage of progress varies. Most initiatives on developing monitoring methods have been focused on fresh water applications but there is an increasing demand from industry and regulators to adapt these technologies for use in the marine environment and to harmonize their use with regulatory frameworks like the European Union's Marine Strategy Directive. Monitoring the marine environment presents a number of challenges absent in other environments: large fluctuations in physical and biological parameters like salinity, temperature and organic matter, rapid dilution of compounds which appear at low concentration in many cases, together with huge areas to cover.

For many sensors, there is still a need for addressing current challenges related to real-case application in marine conditions. Indeed, a number of sensors are still at the laboratory or prototype stage and are yet to be fully developed into commercially available products. Nevertheless, for some sensors, a stage of development beyond the proof-of-concept has been achieved, and their operation has resulted in new insights into the marine ecosystem and its processes that were not possible to obtain in the past. Many existing systems and platforms can potentially accommodate additional sensors to monitor specific marine conditions, under several exposure scenarios, each providing unique einput to integrated observations then used within marine ecosystem management.. The information provided by some systems can be easily communicated to non-specialists while others demand more data processing before communication with decision-makers or managers.

Physical and chemical sensors, capable of providing high resolution data of the surrounding environment, are reaching a mature stage in development. With miniaturization of instrumentation, *in situ* automatic analysers for measureemnts of metals, PAH or dissolved gases are becoming increasingly common. A number of biological sensors are being developed as well, but there are still many challenges due to the complex nature of the biological realm and the diversity of the trophic levels to target. Many biosensors need development and require adaptation for meeting instrumentation requirements for application to real samples and marine environmental use. However, molecular biological science is adding a new dimension. The integration of molecular probes into new autonomous platforms is making possible the identification of specific genes and proteins for microbial and planktonic species, providing valuable insights into many ecosystem processes. Advances in technology and increased mobility for these platforms, will result in an increase in the capacity for sensors to travel great distances and cover large areas in the near future.

2 The demands and challenges of deep sea sensing and monitoring for O&G industry

2.1 Compliance monitoring

For O&G activities, the major environmental target compounds that can result from accidental discharges at sea are:

- Drilling particles (density, organic vs. inorganic, mechanical disturbance)
- Hydrocarbons (including diesel, PAH and others)
- Production and utility chemicals (wax inhibitors, corrosion inhibitors, biocides, emulsion breakers, hydrate inhibitors [MEG], H_2S scavengers, O_2 scavengers, flocculants etc.).

Contaminants and marine life from both the sediments and water column need to be investigated and assessed. The main demand of the O&G industry is to have a monitoring capacity that makes it possible to fulfill the regulatory and company requirements in the areas they are licensed to operate today and intend to operate in the future. Following the relative scarcity of new oil and gas fields in currently explored marine regions, the O&G industry is moving to more challenging areas such as the Arctic and deep-sea regions where potential new resources exist. These areas are demanding new technological solutions and posing new environmental challenges. In addition to traditional leakage detection measures for subsea production systems (i.e. pressure readings downstream choke or wellhead) there is a requirement for remote detection of hydrocarbon leakages from the entire subsea production station. It is expected that the monitoring needs for the future operations will be different from today.

In Norway, Klif's regulation of remote monitoring in offshore installations indicates that "*The operator shall establish a remote measurement system that promotes sufficient information to ensure that acute pollution from the facility is quickly discovered and mapped.*" (HSE-regulations, Activity Regulations, § 57) and that use of BAT (best available technology) implies mandatory use of subsea leak detection systems and emphasized the importance of rapid leak detection. In regions with ice and at long distances from shore station or bases, KLIF will in the future put higher requirements on sustainable operations.

2.2 Baseline monitoring

Operators are required to perform monitoring investigations in defined geographic areas as part of the planning prior to installation and start up of production. Currently, this is performed by several means including benthic monitoring studies to explore biological diversity and obtain basic information on the sensitivity of the area. In some areas like those having large deep-sea coral structures, these investigations include also picture uptake from mobile platform like ROV. So far, remote sensing technologies have had a very limited use in obtaining baseline data. For example the presence of natural oil seepage, existing sources of pollution other than from petroleum, contribution from ship traffick are areas where sensing technologies could help to establish annual and long-term trends valuable to obtain baseline conditions prior to production start. This information is often non-existing, yet critically demanded in the aftermath of an accidental event

2.3 Technological challenges for deep-sea sensing

The ocean is a harsh and challenging environment for sensing which partly explains why technological development in this area is still slow compared to others. The deep-sea is even more challenging, in term of access and with extreme environmental conditions of pressure and temperature. Deploying and retrieval of instruments in the deep sea requires a minimum level of infrastructure e.g. ship, ROV and data communication /transfer is also critical to be able to respond to any event. Hence, technologies placed at remote locations in the marine and more particularly for the deep-sea should have a number of requirements including:

- Robustness (mechanical and operational): long duration of operation with no or limited human intervention
- Self-calibration: instruments with no calibration needs or able to correct alone any instrument shift
- Long service intervals: no maintenance necessary or limited maintenance over the duration of the use of the instruments

- Data logging regimes: relatively large storage capacity of data flow and possibly smart backup storage data to safeguard retrieval of data
- Easy interface with electronic loggers and telemetry: communication of data with users interrogating the instruments; possibility to interact and change instrumental parameters
- Resistance to biofouling: fouling of instruments placed at sea for long periods can be critical e,g, optical instruments. However, in the deep-sea, this can be less of problem compared to the surface/top layers with high biological production
- Low power consumption: Power is also critical and good capacity is required for long duration and monitoring. Power is also related to the frequency of sampling which needs to be carefully considered depending on the type of information wanted. Between periods of sampling, instruments should be able to shutdown power to a minimum requirement. To lower the sensor energy consumption it has been proposed to use an “adaptive sampling” algorithm able to dynamically estimate the optimal sampling frequency of the signal to be monitored. Cabled-instruments (deep-sea observatory) benefit from unlimited power supplied to their nodes.
- User friendliness: particularly important if the personnel that may have to deal with the instrumentation are not expert , also for communication and visualization of data.
- Sensitivity and detection –While instrumentation should be sensitive to any unwanted event, sensor performance should not generate unwanted warnings/false alarms. Ideally, sensitivity critieria should be fitted to legislative criteria or at least provide a warning that triggers a more detailed contingency investigation by other means (eg ROV inspection, ship survey)
- Cost: an issue which needs to be taken into consideration. For costly equipment, one can opt for their deployment at a few defined hot spots (e.g. along the line of production) and then support these units with a grid of less costly sensors.

3 Summary of outcomes from recent workshops

Provided below is a brief summary of the outcomes from recent workshops organized by KLIF and PTIL (see references in section 11).

For oil spill monitoring and detection, all operators that are members of NOFO have the possibility to use NOFOs emergency infrastructure. This includes satellite, helicopters and aircraft surveillance together with deployment of ships at the site of the accident. However, the technologies available for supporting such actions in subsea and deep-sea environmentsare less advanced, though recent progress and efforts have been made to develop systems able to target several types of leaks.

Generally, there are a small number of systems that are reliable enough to be deployed at the sites of installations and for subsea monitoring. These are mainly related to leakage, mostly oil as well as gas. Some techniques have earned the confidence of several operators and are currently implemented or being tested at a number of sites and installations. Basic technologies based on pressure drop and mass balance measurements are routinely used while others like acoustics (active or passive) are gaining acknowledgment. Nevertheless, a number of challenges still exist and operators cannot rely 100% on these systems for safeguarding their current activities and compliance to current or future regulation. Because of this, there is a clear statement that a combination of several technologies will be needed and that a broader range of sensors than those currently in use will be needed to address these challenges. Likewise, there is a perception that industries should share their experience, and are willing to jointly support new development and FoU activities in this field.

4 Experience with sensing from some O&G fields in deep-sea

4.1. Norske Shell Ormen Lange

Norske Shell is the operator of Ormen Lange, a large gas field located at depths between 850 and 1100 meters off Kristiansund in the Norwegian Sea. Two ALVD`s (Acoustic Leak and Vibration detector) are currently installed and commissioned. One other unit was planned to be mounted in 2012 and another one in 2013. In addition to these, one ALVD is installed in the onshore Gas compression test pit. The supplier is Naxys.

During commissioning it was proven that the detector could detect in all sectors around the installation. Sound recordings from liquid and gas leaks were used for this testing.

4.2. Statoil Vega

Likewise, Statoil ***Vega*** acoustic leak detection system is based on leakage and vibration monitoring sensors. Statoil experienced problems with background noise giving false alarms and required ROV inspections to respond to these alerts.

4.3. Eni Norge Goliat

Significant development of leak detection and remote sensing have been made since 2003 and Eni Norge wish to obtain a state of the art leak detection and remote sensing for this field. The objectives of the Goliat remote sensing system are:

1. Provide early detection of acute spills of significance according to regulation and requirements in discharge permit

2. Be able to classify and track the movement of acute spills

3. Give decision support during spill combating (no action/mechanical recovery/dispersion)

Eni Norge will use a number of platforms with different sensors to detect acute spills and for the monitoring of the movement and characteristics of a spill. The signals from these sensors will be integrated to provide and share with relevant parties a holistic picture/information on spills, available at all times through internet connection and with on-shore support systems. The sensor package currently planned for leak detection is composed of several technologies combining offshore (surface, subsea) and aerial detection monitoring, and both process and external sensors:

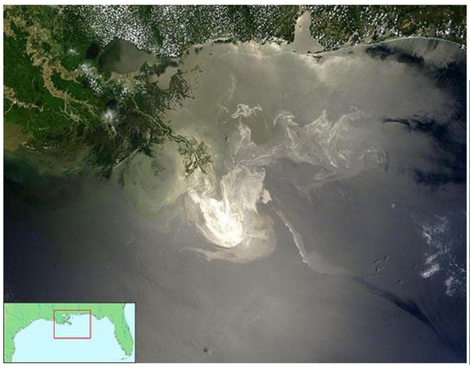
- ✓ Satellite
- ✓ Plane and helicopter (SAR,SLAR, IR)
- ✓ FPSO (radar, IR)
- ✓ Safety stand-by and supply vessel (radar, IR, AIS-boys)
- ✓ ROV on safety stand-by vessel

- ✓ Sensors on the templates (capacitance and passive acoustic sensor)
- ✓ Land based Hi Frequency radar that can measure surface currents. Pilot is being evaluated

5 Experience with oil sensing and tracking for oil spill preparedness

Following the Deep Water Horizon blow-out, a joint industry (JIP) for oil spill preparedness and response task force has made some recommendations regarding the use of remote sensing and tracking systems for oil.

During the last decades, airborne remote sensors have been developed into operative instruments for surveillance of oil pollution. The most common "airborne sensor package" is a combination of side-looking radar (SLAR) and IR/UV (Infrared/Ultraviolet) line scanner. In addition, there is the support of large scale satellite imagery and high frequency radio waves like the Coastal Ocean Dynamics Applications Radar (CODAR). Both remote sensing techniques were extremely useful in tracking the DWH spill. In addition to satellite/airbone sensing, deployments undersea with ROV and AUV were undertaken to monitor deep-sea plumes not possible to reach by remote sensing.



Exemples of airborne remote sensing and system deployed from ship.

Even though considerable adavances in remote sensing, oil tracking and trajectory modeling were made, there remains slow progress in some areas such as subsea plume modeling. Techniques like synthethic aperture radar or Doppler shift radar have made outstanding progress but are not routinely included as a response option. In the DWH spill, submerged Acoustic Doppler Current Profilers (ADCP) were used to help subsea oil tracking. In addition, the presence of hydrocarbon concentrations was detected with *in situ* fluorometers although quantification was a challenge.

According to the JIP evaluation, some valuable areas to improve should include:

- Use of remote sensing for surface and undersea to obtain information on oil concentration and fate to support contingency actions
- Subsurface tracking to create high-resolution 3D maps of subsurface plumes and currents
- Use of various satellite imagery and other tools in combination to direct offshore operational resources like:
    - Infrared cameras
    - Hyperspectral satellite-bases imagery
    - ADCP
- Development of new fluorometers to estimate oil thickness
- Oil sensing systems mounted on moored buoys. Drawback is that oil distribution will change according to the is dynamic and movement of the seawater current. One alternative is to use drifter or mobile underwater platforms capable of following the path of long distance with the oil plume

6 Monitoring systems for O & G industry with emphasis on leak detection systems/real-time monitoring

In this section, we review some currently available and promising sensing technologies most relevant for O&G monitoring. In addition, the table in Appendix A (end of report) gives a short description of these technologies and other cutting edge instruments/platforms together with an evaluation of their development stage, relevancy, general assessment and adaptability to deep-sea.

6.1 Currently available systems used or tested by operators

First, we summarized some of the current industry experiences based on the work reported in the 2010 DNV-RP-F302 document by Det Norske Veritas (See reference list, section 10) A selection of detectors for subsea leak detection systems with focus on templates and manifolds is reported (see figure xxx). For more details of each technology, refer to the DNV-RP-F302 document. The technologies currently used by operators can be divided into two categories:

6.1.1. Point sensing underwater detection systems

These systems are based on contact or close proximity of the target substances with the detectors

✓ Mass balance methods are based on monitoring the pressure drop between two or more pressure sensors currently installed in the subsea production system.

Other used systems include:

✓ Capacitance sensors that measure changes in the dielectric constant of the medium surrounding the sensor. The dielectric constants of seawater and hydrocarbons are very different, hence a change of these constants will be shown if oil gets in contact with the sensor. These sensors are currently the most frequently used on installations ,

✓ Fluorescence sensors are based on excitation/emission of light. They use a light source at a certain wavelength for excitation of the target molecules which emit light at a different wavelength that can be detected. Some of these systems are able to find leaks in sub-sea pipelines by sensing the fluorescence signal of leaking dye introduced during pipeline commissioning along the suspect pipe or associated controlling lines. It can be controlled from a ROV at a depth of 600 m and below. For deep-sea application, the enviroFlu-DS - 6,000m deepsea version of enviroFlu-HC fluorometer sensor is designed to detect oil-in-water and PAH . See also http://www.trios.de ; http://www.chelsea.co.uk; or the Chelsea Technologies Group Ltd http://www.chelsea.co.uk/)

✓ Gas sniffers function using principles often based on diffusion through a membrane and then detection via a secondary system. Companies like Contros (http://www.contros.eu/) and Franatech (http://www.franatech.com)/ are offering products that can detect CO2 (dioxide carbon), CH4 (methane), H2 (Hydrogen) and H2S (Hydrogen Sulfide). See also SubCtech (http://subctech.eu/).

✓ The BiotaGuard platform (http://www.biotaguard.no/) is also included as a "point sensing technology". However, in Biota Guard, the sensing principle is based on the responses of organisms (currently mussels but other organisms are being tested) to changes of condition in their surroundings. See also 6.4.4.

6.1.2. Regional sensing underwater detection systems

In regional sensing, the detectors are capable of measuring a signal from a further distance to the target.These systems includes several technologies

✓ Acoustic methods: echosounders emit pulses of sound at a certain wavelength and the sound is reflected by boundaries with a different "impedance" e.g. fluids of different density or solid particles in the water; hydrophones are passive acoustic detectors capable only to receiving sound from their surroundings. The systems supplied by Naxys (http://www.naxys.no/) are implemented on some O&G installations.

✓ Fiber optic methods are used for locating and measuring mechanical disturbances at acoustic frequencies along a continuous optical fiber that can be caused by e.g. leaking gas or fluids.

✓ Optical cameras are used for the surveillance of subsea installations and are typically used in ROV during inspections.

The DNV-RP-F302 report emphases that a combination of several types of sensors can provide more confidence in the responses given by individual sensors. Although the afore mentioned technologies are some of the most frequently used, based on todays knowledge and industry experiences, these subsea leak detection systems are not yet recognized as "safe" and a number of false alarms exist. Hence, integrating the responses from several sensor types is warranted to help avoid the unnecessary and expensive shutdown of operations or ROV inspections.

Examples of some of the sensor package used or tested by Norwegian O&G operators. From left to right: Contros HydroC sniffers for gases, Naxys hydrophone and the Biota Guard platform.

6.2 Other existing or potential sensors relevant for O&G target compounds/effluents

A number of techniques exist for detection of crude oil, hydrocarbons, gases and particles. However, for other target compounds (production chemicals, MEG etc…) related to O&G drilling or production activities, the choice is much less broad.

For particles (e.g. drilling particles), turbidity sensors are most common. Turbidity sensors are relatively unspecific and can be affected by other suspended particulate matter e.g. from planktonic organisms or "marine snow". Other submersible field portable particle/sediment size analyzers capable of measuring the size and also the shape of particles includes the LISST laser instrument from Sequoia Scientific Inc (reword this sentence to clarify). (http://www.sequoiasci.com/products/Particle.aspx)

With regards to production and utility chemical compounds from O&G, there is to our knowledge no specific instrument available at the moment. Recently, the CHEMINI (CHEmical MINIaturized) analyser was developed by IFREMER as a new generation of *in situ* chemical analyser. A deep-sea version of this system is capable of characterizing the chemical composition of extreme environments like hydrothermal vents where protoypes were tested, deployed on ROVs. The analytical performances are comparable to the reference methods carried out in the laboratory. The instrument is able to perform high frequency measurement (30-60 analysis/hour) including unstable chemical species with *in situ* calibration protocols. CHEMINI uses colorimetric and fluorimetric detection methods. Measurements of dissolved iron and sulphides at depths of 1500 m have been made.

6.3 Supportive and auxiliary sensors

In addition to sensors targeted to specific O&G effluents, other well developed sensor technologies are used as auxiliary sensors, alone or often in arrays so that multiple parameters of the marine environment can be obtained. These sensors provide generic information about the condition of the marine environment where they are placed. This "generic sensor package" consists of instruments like Conductivity, Temperature, Pressure, Turbidity, Currents, Passive acoustics, Acoustic backscatter and Oxygen. Likewise, pH sensors, pigment and chlorophyll sensors, ammonia and nitrate sensors are included in this package. Most of these sensors are commercially available and often available as sensor package like the CTD + auxiliary sensors. In Norway, Aanderaa data instrument AS (AADI http://www.aanderaa.com/) is commercializing a number of these sensors such as the oxygen optode that utilizes luminescent technology. These generic sensors are particularly important to obtain baseline information at the site of production or before production is started.

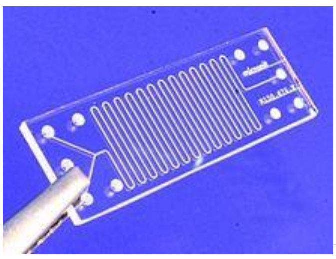
6.4 Other promising systems not currently used by O&G

Several technologies and developments exist which have the potential to address leak detection or on-line environmental monitoring for oil and gas installations. These developments are presently at different stages of maturity but offer possibilities for application towards O&G monitoring. Adaptation for deep-sea operations will be needed andthese technologies require further development before they become actually operational at great depths. Rapid advances have been made in miniaturization, electronics and nanotechnology which allow the production of robust, compact and portable instruments for use at sea.

Here, we present some which are relevant to the monitoring of O&G activities.

6.4.1 Microsensors

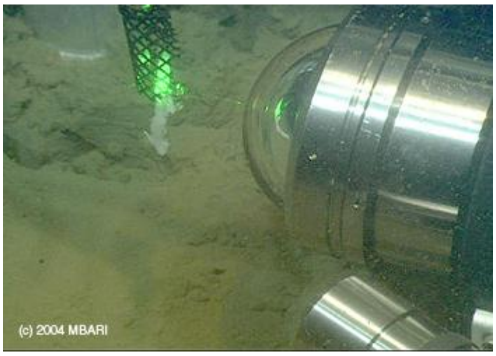
Microsensors are generally able to offer better sensitivity, accuracy, dynamic range, and reliability, as well as lower power consumption, than their larger counterparts. Also, they can provide non-destructive measurements as they can be placed into tissue, sediment, biofilm, etc and perform measurements that leave the study targets unchanged. Microsensors consist of very small sensors with physical dimensions in the submicrometer to millimeter range. They can be customized and adapted for microprofiling and micromeasurements in the field using lander systems and benthic chamber incubations for multiple parameter study. Microsensors for oxygen, H_2, N_2O, pH, H_2S can be deployed in deep-sea. These systems are high pressure resistant and the tip membranes of microsensors are unaffected by changes in hydrostatic pressure of up to several hundred bars. Such deepsea lander systems are commercialized by companies like Unisense (http://www.unisense.com)



Other systems based on lab-on-a-chip technologies integrate one or several laboratory functions on a single chip of only millimeters to a few square centimeters in size. These systems use extremely small test fluid and utilise the state of the art development of microfuidics for the detection of multi-parameters like O_2, pH, alkalinity etc but could equally be adapted to a range of different compounds.

6.4.2 Automatic analysers

Raman spectroscopy



In situ systems based on Raman spectroscopy exist and significant progress is being made in the application of these systems to the deep marine environment and for the detection of organic compounds. However, the technology still requires further development for in situ applications. Nevertheless, surface-enhanced Raman scattering (SERS) holds great promise towards *in situ* detection of organic traces of molecules like PAH in sea-water as well as gas (CO_2). One key challenge remains the sensitivity and the development of specific SERS active sensor membranes for trace detection of analytes amplifying the Raman signals of interest. Current initiatives for testing and integrating SERS into *in situ* analytical platforms are underway at several institutions (IFREMER, MBARI) and through the EU SenseNet network. MBARI'S DORISS is a deep-ocean laser Raman in-situ spectrometer constructed with pressure housing for deployment on ROV to depths of up to 4000 m and temperatures down to 2°C in the ocean.

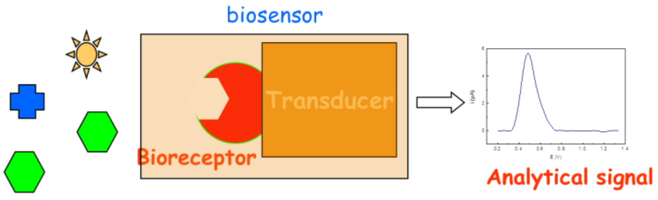
Underwater mass spectrometry

Underwater mass spectrometry (MS) holds great promise for O&G monitoring. Instruments have been developed and tested at different ocean depths. An example is provided by the membrane inlet mass spectrometers (MIMS) for *in situ* measurements of dissolved gases and volatile organic compounds including light hydrocarbons. The Massachussets Institute of Technology (MIT), SRI, St. Petersburg's Chemical Sensors group and the department of applied ocean physics and engineering of WHOI (Woods Hole Oceanographic Institution) have made large advances on operating portable underwater mass spectrometers. An *in situ* quadrupole mass spectrometer is commercialized by Spyglass Bio (California, USA). MS has been tested in a wide range of applications and deployments including shipboard depth profiling, stationary moored deployment for time series chemical monitoring and AUV/ROV platforms for 3-D chemical mapping. The TETHYS mass spectrometer developed by WHOI has been used with success for in-situ fingerprinting of well leaks and more recently in relation to the DWH. Power consumption, weight and volume are engineering challenges in AUV-based MS design and the same groups of scientists are also working on the development of novel and/or miniature power sources for marine applications of their MS. Many of these developments still need improvement, for example, large molecular weight compounds are not detected with the current versions. Nevertheless, underwater MS combined with acoustic

positioning technology offers great potential for rapid localization of seafloor petroleum leakage.

6.4.3 Biosensors

In biosensor, a biological recognition element (enzyme, DNA, protein, cell) is incorporated with a device that is able to analyse changes in some properties of the biological element following interactions with target compounds. Often, biosensors are indeed used to detect single or multi-compounds in complex matrices after specific interactions with the biological receptor.



Other systems using higher-order organisms connected to sensors (e.g. the BiotaGuard platform or the BiotaTools; see 6.4.4) are often refered as to "biological sensors" but are also commonly described as "biosensor" for practicality.

The incorporation of emerging micro- or nanotechnology systems into environmental biosensors is now perceived to have applications for the marine environment. For example, immunosensors are currently being developed as alternative means for environmental PAH assessments.

Immunosensors

In immunosensors, the bioreceptor is an antibody that can bind specifically to an analyte (e.g. PAHs or groups of structurally similar PAHs and related compounds). Hence, the response of these sensors relies on antibody molecules, which exhibit excellent sensitivities, so that low-level detection can be accomplished using aqueous samples without extraction or pretreatment. The disadvantage to this characteristic, however, is that the active targets are not easily released from the antibody after the measurement has been made. Several strategies have been used to design inexpensive sensors around this characteristic. These strategies include the use of disposable sensors or sensing materials that can be detached from the detection instrument or the use of a flow cell configuration where the immunochemicals can be partially removed from a stationary sensor prior to the next measurement. Systems for rapid, on-site, quantitative assessments of dissolved PAHs have been tested for field applications but to our knowledge not for deep-water. Surface plasmon resonance biosensors (SPR) are one type of immunosensors that appear particularly promising as monitoring devices. In SPR, the analyte in the matrix (e.g. seawater) binds to a recognition element (antibody or protein conjugate) at the metal surface of the sensor resulting in a detectable change of the refractive index which can be related to the concentration of analyte in the sample

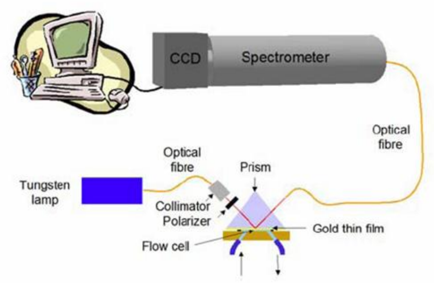


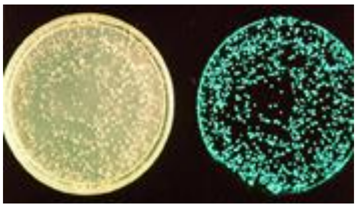
Figure 1: The SPR biosensor

DNA-based biosensors

DNA-based biosensors have been used for the detection of chemically-induced DNA damage and to measure toxic aromatic amines, oxidative damage, and bioactivated benzo(a)pyrene. The size and simplicity of these biosensors make them very suitable for on-site monitoring or deployment underwater after integration in a waterproof device. However, there are issues regarding regeneration of the recognition surface after the binding and real-time measurement capability. The incorporation of micro-fluidic systems is a promising avenue. These systems can incorporate pre-concentration, sorting and filtration steps for sample preparation for existing lab-on-a-chip micro-fluidic detection systems. Nevetheless, these devices must achieve operational characteristics e.g. be resistant to chemical and biological fouling and be designed to operate for long periods in the marine environment.

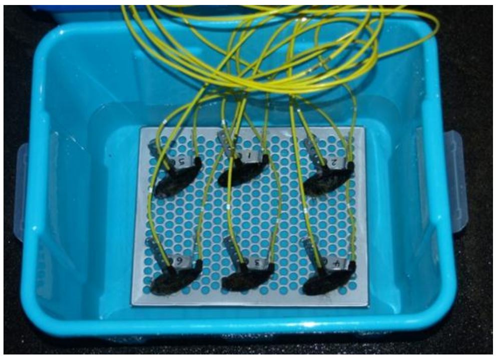
Cell-based biosensors

Regarding microsensors, cell-based biosensors for environmental applications exist. These biosensors typically use bacteria, yeast or algae. These biosensors can be used to detect the presence of pollutants or even investigate biological effects at a cellular level. Their simplicity, their link with current standardized ecotoxicological procedures and their sensitivity to several sources of pollutants make them powerful tools. For example, “bacterial reporters“ offer a possible alternative method for the detection of bioavailable hydrocarbons in the environment, and have the advantage of being sensitive to very low hydrocarbon levels, and specific to the compounds of interest. Systems for the detection of alcanes, BTEX and naphthalene have been developed and tested. In bacterial reporters, bacteria are genetically engineered by fusing a promoter responsive to a particular compound with the luminescence producing luciferase gene. Hence, the response of these biosensors can be quantitatively analysed by measuring the intensity of the light emission using a luminometer which will reflect the concentration of the target compound. This technology offers the advantages of being quick, cheap and easy to use and allows direct assessment of samples at the site of interest. One challenge in using this approach is that genetically engineered bacteria (GEMs) are most often used in this type of biosensors. This may pose an environmental issue when considered for field applications.



6.4.4 Instrumented organisms and biological sensors

Here the biological recognition element is a high-order organism and the sensors are measuring physiological responses of different types (respiration, pumping or swimming etc…).



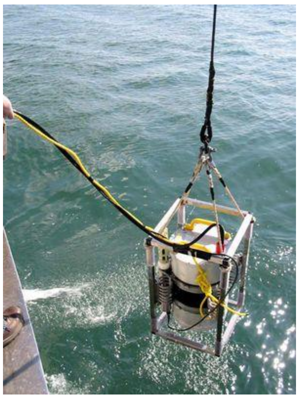
In the Biota Guard system, the "standard sensor package" consists of sensors for registering the heart rhythm and the degree (and frequency) of shell opening and closing in invertebrate organisms like mussels. However, a multi-sensor approach combining biological sensors with other contextual chemical and physical sensors is used. Upstream, the system is able to effectively and rapidly process the data on-line, performing multivariate analyses which are then communicated through a portal for management and reporting of the data signals.

In the system currently developed and tested by Biotatools (http://biotatools.com), the goal is to develop and test a new generation of sensors targeted at key fitness parameters (e.g. growth, feeding etc) and condition assessment of the organisms (currently mussels and Arctic scallops). The company is also involved as a sensor technology partner for the Biota Guard platform.

6.4.5 Detection of biomass and speciation

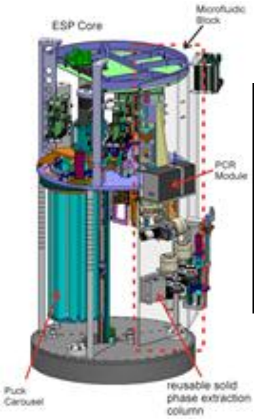
Flow cytometry

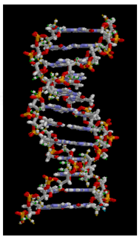
Technologies based on flow cytometry measurements are supplied by Cytobuoy (http://www.cytobuoy.com). In flow cytometry, a stream of particles and/or cells in water is directed at high speed through a powerful laser beam. Particles and cells pass in single file, one by one and by measuring the scattering of the laser light while each particle passes, and detecting possible fluorescence emitted by intracellular pigments, the particles can be identified and counted, as each particle leaves a footprint characteristic for its shape and internal structure. For the deep-sea, the CytoSub version can be used on a cable or in a submarine vessel for depths up to 200 meters below surface. Cytosub is actually more a platform that a sensor but can be integrated as one unit of a sensor payload. The high pressure of the water at these depths is held separate from the flowcell, which operates at normal pressure. The CytoSub can also run on a fully preprogrammed operation with sampling at preset times or depths (using the pressure sensor). The equipment can be used on a cable or in a submarine vessel like a ROV. Applications towards water quality monitoring are possible e.g. counting of particles in seawater, determination of particle optical characteristics, monitoring the physiological status of living cells.



Hyperspectral imagery (HI) is a well-established method to study the distribution of oxygenic phototrophic communities, and their physiological status. Underwater HI is an innovative optical sensor that can be deployed on various platforms for underwater mapping and monitoring of objects of interest (OOI) based on defined wavelengths for excitation. A prototype constructed at Ecotone (http://www.ecotone.no/) exists as proof-of-concept and has been tested for several applications relevant to environmental moniotoring both in the water column and on the sea floor (e.g. coral reef speciation & physiology). Other applications related to O&G include leakage detection & areal coverage.

Genosensors

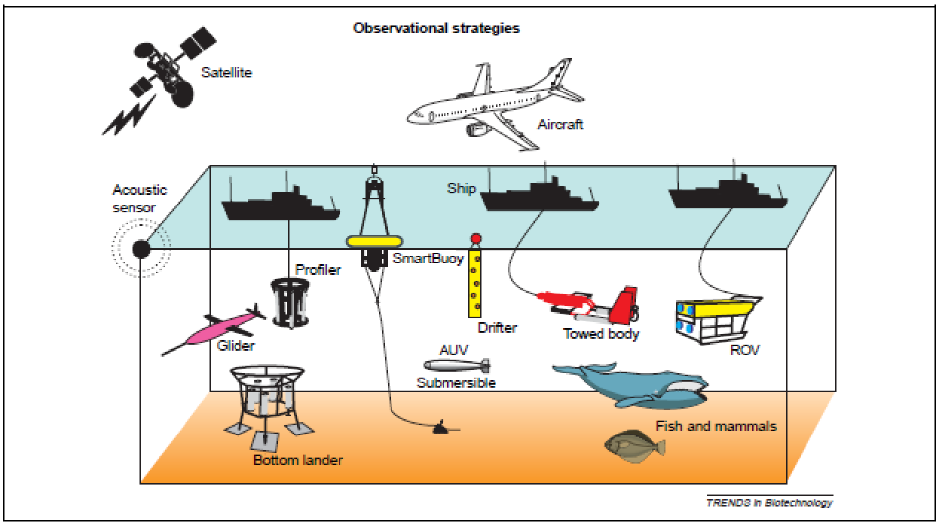




Genosensors also called "genomic sensors" use molecular markers as sensing elements. These sensors rely on DNA or RNA analytical methods based on the latest advances from the field of molecular biology rapidly increasing during the last years. Significant progress on the use of molecular probes for the detection of microbial, phytoplankton and zooplankton species has been made by several groups and several sensing principles have been developed. Today MBARI has likely developed the most advanced operative platform for *in siu* species detection. Their ESP (Environmental Sample Processor) will be described further in the next chapter. DNA/RNA fingerprinting and molecular chemistry integrated in the ESP can provide very useful information about marine habitats and assemblages, and their condition.

7 Currently available sensor platforms

The sensor platforms currently available can be divided into several categories and several approaches are used depending on the set of objectives to be achieved. Each unit has the potential to be equipped with a range of sensors targeting several compounds or organisms of the ecosystem.

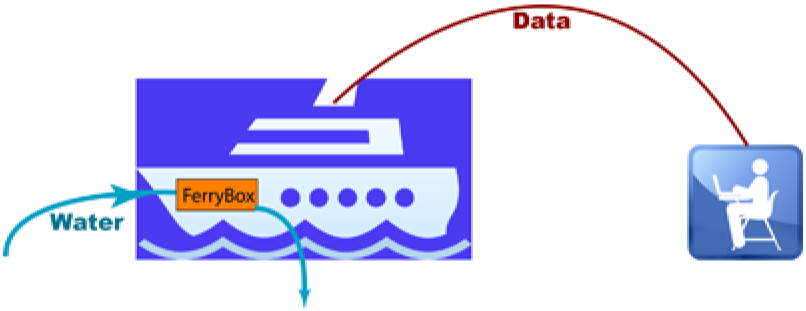


Available marine observational platforms. AUV:autonomous underwater vehicle; ROV: remotely-operated vehicle. From Kröger and Law (2005).

7.1 Surface sensor platforms

The Cefas Smartbuoy devices are moored, "intelligent", automated, multi-parameter recording platforms used to collect marine environmental data. These devices collect timeseries of surface (at 1 metre) salinity, temperature, turbidity, chlorophyll fluorescence and nitrate concentration and a broad sensor payload is used (e.g. CTD, fluorometer, *in situ* nutrient analyser etc…). The high temporal resolution of this instrument provides useful insight in seasonal or sudden change events not possible to capture by shipboard sampling.

In the Ferry-box system, a different approach is used to solve the inherent problem with *in situ* sensor maintenance, calibration as well as biofouling requiring retrieving and cleaning of sensor surfaces. Each Ferry-box element consist of automated instrument packages installed on ships of opportunity i.e. the sensors are under controlled conditions, energy consumption and mechanical dimensions are not critical, maintenance is cheaper and easier than on offshore installations. The operational standard sensors package includes CTD measurement in addition to turbidity. Other sensors include chlorophyll pigment, pH, nutrients. Genomic sensors are "on the outlook" of the Ferry-box sensor modules.



Ferrybox consist sensor packages installed on board ship of opportunity.

7.2 Towed bodies, vehicles and other biological platforms

Towed vehicles constitute an important class of observational platforms that can be complimentary to point-based observing networks and provide rapid high resolution maps of physical, chemical and biological parameters to track and guide identification of special features. Of particular interest are the towed undulating vehicles (TUV) as these allow the critical limitation of this platform type of fixed depth sampling to be overcome. TUV are an effective ocean observing platform able to carry several water quality sensor packages including CTD, fluorometers and other optical sensors (e.g. optical plankton counter), current profiler etc … Commercially available undulating systems exist (e.g. http://www.chelsea.co.uk/marine). Despite their utility and suitability for conducting high resolution, rapid and integrated physical-chemical-biological assessment of an area, their drawback is the need for a ship support and expertise in handling the vehicles.

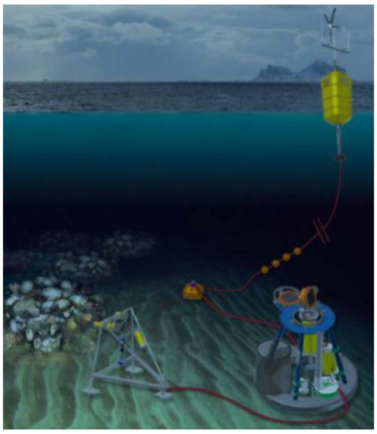
Sensor technology using marine mammals and tagged animals as "vehicles of opportunity" is one way to allow for environmental data collection under natural and somewhat challenging conditions. These "biological platforms" can cover extensive areas and geospatial patterns of the ocean which otherwise are inaccessible or very expensive to explore using other means. They can also be used to identify areas or events of importance in the ocean, for example, as baseline information and for installation planning. Tagging devices that can provide valuable data like the effects of human activities on fish behavior or stock migrations patterns. Current sensor technology using marine mammals include temperature, depth, conductivity and optical measurements. Potential advances include passive and active acoustics or fluorescence measurements. There are however a number of limitations similar to those related to the miniaturization of the sensor technology itself, attachment issues, longer tag life and improved data recovery methodologies and the need for specialised skills. Also, there might be regulatory obstacles for O&G to use animals to convey sensors.

7.3 Bottom landers and fixed platforms

Bottom landers and fixed platforms are of particular interest when measuring environmental responses over long periods of time for baseline studies or for individual events that occur less frequently or accidentally.

7.3.1 Bottom landers

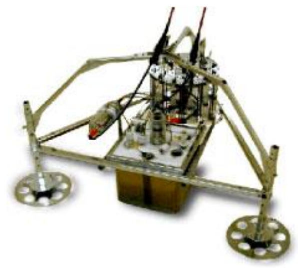
Sensor technologies applicable to examining and monitoring the seabed, including the near-bed benthic boundary layer and surface sediment layer, are deployed on adapted platforms that remain on the bottom to collect time-series measurements or vertical profile pictures of the upper layer of the sediment system. These tools use *in situ* optical and acoustic sensors to simultaneously measure physical, chemical and biological parameters. Highly flexible tools, they are application-specific but can be built and deployed for a variety of monitoring and survey tasks.



Hermes lander illustration by Institute of Marine Research

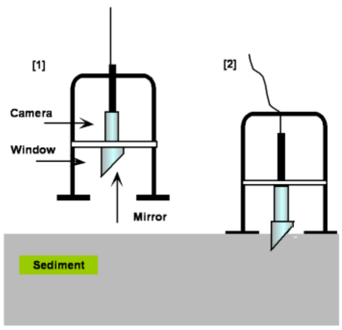
Landers

In Norway, the "Hermes-lander", deployed by Institute of Marine Research (IMR) with support from Statoil, was located on the seabed outside Vesterålen next to a coral reef. The objective of the lander is to obtain basic knowledge about the dynamics and function of the ecosystem in the area, in particular to collect data about the coral reef and recruitment to the large fish stocks. The Hermes lander was instrumented with horizontal and vertical echo sounders, camera, sediment trap, broad band microphone, light and chlorophyll sensor, CTD and ADCP. Power supply was provided by batteries.



The MiniChamber Lander system (http://www.unisense.com) is designed for shallow-water chamber measurements down to 300 m with multiple microsensors. The system allows completely automated in situ chamber incubations to study multiple benthic parameters including oxygen, H_2, N_2O, pH, H_2S etc A version for microprofiling and incubation studies in the deep sea to depth 6000 m is available. The DeepSea Lander is released from a ship at the ocean surface and falls freely to the ocean floor. At the sediment surface, the internal computer starts the measurements. After measurements, the computer causes the release of the ballast and the DeepSea Lander floats up to the surface.

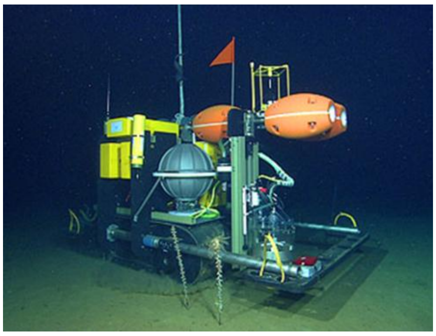
Optical sensors with insights into sediment



The planar optode module enables in situ exploration of the oxygen dynamics at the sediment surface. The sediment oxygen distribution is recorded as a 2D-image with a high temporal resolution giving insight to the spatial heterogeneity and its evolution over time.

The sediment profile imager (SPI) is a useful tool for rapidly collecting data and analyzing a suite of seafloor parameters. SPI is a rapid, *in-situ* technique, which takes vertical profile pictures of the upper 20cm of the sediment system using a camera mounted to operate like an inverted periscope. The tool can be used quickly and easily to take pictures of the top layers of the seafloor. Applications of SPI include: sediment grain size, camera prism penetration depth (an indirect measure of sediment density), roughness of the sediment-water interface, transition between oxygenated surface sediments and underlying sediments with little or no oxygen (called the apparent redox potential discontinuity layer), biological successional stage, and presence of methane gas bubbles, burrows, fauna, and dredged material. The information from SPI can be easily communicated to non-specialists and can provide clear insight into the relationship between benthic communities and the sediment. It is a useful technique using high-quality images to study *in situ* seafloor organisms and processes that cannot be directly observed using other equipment (for example, grabs).

Advanced multi-task seafloor robot



Deployment issues related to bottom landers include potential changes such as spatial variability the lander may encounter when reaching the bottom surface. Benthic landers can incorporate into their deployment strategy mobile autonomous platforms. The benthic rover (http://www.mbari.org/mars/science/rover.html) at MBARI was designed to monitor the impact of climate change on deep-sea ecosystems. This robot is basically a mobile physiology lab that can travels across the seafloor to measure how much oxygen seafloor animals are using, record oxygen levels into the sediment and use acoustics to scan deep into the sediment for large animals like worms.

7.3.2 Fixed advanced platforms

For species detection with insights into ecosystem processes/interactions

The MBARI Environmental Sample Processor (ESP) provides on-site collection and analysis of water samples. This advanced technology is a standalone platform deployed at sea that allows for autonomous application of molecular probe assays. ESP is a complete molecular biology laboratory packed inside a pressure housing. It is completely self-contained, performing sandwich hybridization assays on both RNA and protein, as well as qPCR assays for signal amplification. Assays are developed in containers called “pucks”, which are miniature surrogates for the laboratory bench. Real-time detection chemistries currently rely on DNA probe (and if needed protein arrays) to detect a wide range of target bodies like microorganisms species and their genes. CCD pictures of the *in-situ* array results are broadcast via radio telemetry to a remote location for near-real time interpretation. The ESP has been deployed on moored or drifting platforms for water column monitoring andROVs for site monitoring. Future platforms planned for the ESP include AUVs and profiling floats. A deep-water version of the ESP (D-ESP) has successfully been tested and deployed on MARS cabled-observatory.

Likewise, the Autonomous Microbial Genosensor (AMG) developed by the University of South Florida is capable of RNA extraction and NASBA amplification prior to specific organism detection by hybridization technique. NASBA amplification allows detection of active target genes indicative that the organism was alive and metabolically active at the time of sampling. Both ESP and AMG are flexible genetic sensor platforms that have the potential to find applications within deep-water O&G monitoring. Potential field target identification is a requirement for development into this area as adaptation of these platforms is guided by target choice.

Biota Guard - Integrated environmental monitoring

The Biota Guard system has been designed to meet oil industry standards and criteria for marine operations. In addition to sensors and ”instrumented” organisms, ”passive” (not instrumented) mussels are collected on an as needed basis for more detailed laboratory analysis of health condition. The environmental sensor payload consist of both physical (CTD) and chemical (sniffers) sensors while the current biosensors are valve gape and heart frequency measured on macro-organisms like mussels. Field tests using using Biota Guard have been performed offshore.

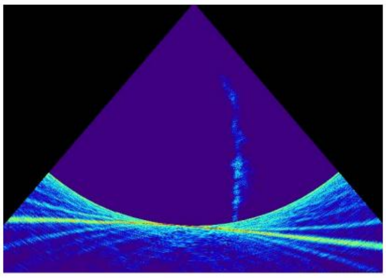
7.4 Mobile platforms for water column monitoring: AUV, AUV glider and ROV

Remotely operated vehicles (ROV) are tethered underwater vehicles linked to a ship by a tether (= umbilical cable), that carries electrical power, video and data signals back and forth between the operator and the vehicle. ROVs are most common in deepwater industries for video observations, inspections and deep-sea operations. There is a large range of ROV models with different maneuverability, operating depth, horizontal speed and size that can carry a multitude of sensors, payloads and instruments like CO2 or hydrocarbon sensors, and seawater samplers which can be manipulated by the operator aboard the vessel. In 2012, SubCTech (http://subctech.eu/) launched an ROV-based multisensor platform integrating several sensors for like CO2, PAH, H2S, dye fluorometer and CDOM, CTD easily exchangeable depending on the needs.

New generation of mobile platform with their payload of sensors appears one promising solution for environmental surveillance and rapid data information flow. Autonomous underwater vehicles (AUVs) provide the industry with a tool to begin to address these challenges. AUVs carrying a payload of sensors targeted at the detection of critical compounds are potentially able to provide a detailed multi-layered view to track the source of a leakage. Unlike ROVs, which require a tethered umbilical, AUVs are able to cover significantly more area per unit time. Depending on the vehicle, both the duration and sensor payloads have significantly increased in recent years. This combination of duration, spatial coverage and payload capacity make AUVs an ideal platform to monitor and obtain 3D mapping both of the seafloor and the water column. Nonetheless, the real-time analysis of contaminants and organisms in sediment is not feasible with current AUV technology, so the major application of these platforms is to conduct water-column measurements.

Two types of mobile platforms, AUV with propeller-driven power and AUV gliding vehicle driven by changes in buoyancy, exist. The Kongsberg Hugin-1000 AUV (http://www.km.kongsberg.com/) vehicle is a propeller-driven platform that can operate at depths down to and below 1000m, with high payload capacity and mission duration on the order of 70+ hours. High accuracy navigational systems allow for highly resolved spatial sampling (sub-meter). An example of AUV-glider is the Teledyne Webb (http://www.webbresearch.com/) glider deep AUV (rated to 1000m). This type of platform requires less power and can be deployed for months. Limited navigation capabilities of these gliders make high precision and close-area inspection difficult. However, the average speed of gliders is slow, producing measurements on the spatial scales of 10 meters that could be valuable for monitoring over relatively long transects e.g long pipeline spans. Typically, AUVs with propeller-driven power can carry a larger panel of sensors compared to AUV glider. However, both can integrate sensor payloads of interest for the O&G like the Contros HydroC™ CO2/CH4 sensor; http://www.contros.eu/ . The HUGIN AUV leakage detection sensor payload consists of:

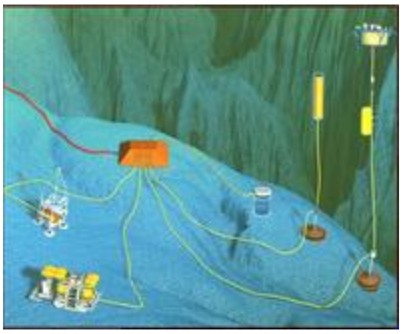
1. Acoustic leakage detectors
    a. Multibeam echosounder
    b. Synthetic aperture sonar
2. Digital still camera
3. CTD
4. Contros HydroC for CH4 and PAH selective measurements



Above - The HUGIN 1000 from Kongsberg Maritime; Below - HydroC™ CO_2 Carbondioxide Sensor from Contros.

The development of new platforms and capabilities is vital for future mapping and monitoring applications. In Norway, Ecotone (http://www.ecotone.com) is also working to develop new capabilities in Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicle (AUV) for sensor integration and for increasing resolution of "objects of interest". Ecotone is a partner in AUR-Lab for verification and prototyping of new underwater robots [e.g. Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicle (AUV)] and integration of new sensor packages.

8 Deep-Sea observatories



Deep-sea observatories may represent the future way of carrying out environmental studies in the marine environment. However, the technology of deep water scientific cabled observatories is still at a relatively early stage of development. The idea behind deep-sea observatories is to establish next generation infrastructure for a permanent interactive presence in the ocean to enable sustainable monitoring and management in the marine environment. Extending electrical power capability and data connections for new research instruments in the deep-sea is at the base of deep-sea observatory development.

Currently, some limitations of traditional ocean observation methods include:

- ✓ “snap shot” approach=point sampling
- ✓ Difficulty capturing rare and extreme events
- ✓ Coarse data resolution (time intervals and spatial distribution)
- ✓ Difficulty observing and documenting long-term changes in ocean climate
- ✓ Inaccessibility of the deep ocean
- ✓ Power and bandwidth limitations
- ✓ Logistically heavy and costly

Consequently, there is a lack of long-term data that can be used to improve predictions and deviations due to natural or man-made impacts.

The cabled observatory approach can provide researchers and industries with new capabilities beyond the reach of traditional oceanography:

- ✓ Interaction with ocean instruments
- ✓ Immediate and continuous (24/7/12) data collection
- ✓ Internet access to data for all collaborators
- ✓ Long-term data return and living archive
- ✓ Shore-based power and high bandwidth

Towards the offshore industry, cabled-observatories can provide a large amount of valuable baseline data that can be used to establish the status of environmental conditions before the presence of O&G dep-sea installations and then continue to operate monitoring conditions during actual operations. Aligning industry plans for development in new and challenging areas like the deep sea to technology and research development for ocean observatories appears advisable.

One issue regaring benthic observatories is the potential changes that such infrastructure may have on the local environment (“artificial reef” colonized by/attracting organisms, changes in sediment properties). Hence, measurements should be obtained at some distance from the observatory, preferably with mobile robot units similar to the benthic rover described in 6.3.1 or using techniques that leave the environment unchanged e.g. with microsensor profilers that allow measurement of chemical environments at the scale of the sensor tip –a few micrometers.

8.1. Exemples of cabled-observatories.

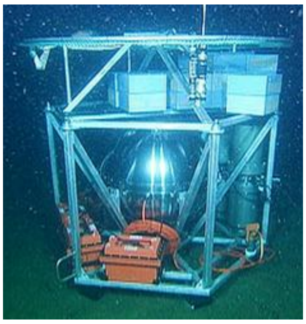
8.1.1. LoVe observatory project

Under the initiative of Statoil, the LoVe project for a cabled observatory infrastructure in the Lofoten/Vesterålen is not yet completed –However, work is ongoing to have it installed late 2012/early 2013 dependent on the procurement process and time of delivery for certain components. This project is now part of the Integrated Environmental Monitoring(see section 9.2).

8.1.2. Neptune Canada observatory

The Neptune Canada is the world's first regional-scale cabled observatory network, and is located off the west coast of Vancouver Island, British Columbia. A rich constellation of instruments deployed in a broad spectrum of undersea environments. Instrument types include physical (conductivity, temperature, current meters, hydrophones, chemical and gas "sniffers" etc …), visual (high resolution cameras) and biological (microbe, plankton samplers and incubators, sediment traps etc) technology which can be removed and new instruments added, often by "plugging in" via wet-mate connectors on nodes and platforms at the seafloor.

8.1.3. MARS observatory



The MARS Ocean Observatory system consists of a 52-km undersea cable that carries data and power to a "science node" 891 meters (2,923 feet) below the surface of Monterey Bay (USA). More than eight different science experiments can be attached to the main hub with eight nodes. Relevant instruments currently tested in MARS initiative are physical sensors like CTD sensors, a seafloor echo sounder and biolumisnescence sensor to detect marine life, the Deep-Sea Environmental Sample Processor (d-ESP), an automated DNA-based platform that enables the specific detection of marine organisms (from microbes to planktonic organisms) in the deep sea and the benthic rover, a mobile platform covering relatively large distances and equipped with a battery of sensors for the study of important deep-sea processes.

8.1.4. DELOS

DELOS - Deep-ocean Environmental Long-term Observatory System is one initiative supported by BP to increase the understanding of the deep water areas BP are gradually extending into in West-Africa. The system consists of a main sea floor docking station and several observatory modules designed to be placed into the sea floor docking module by ROV. The modules include camera, oceanographic sensors (current velocity profiler, pressure, CTD, fluorometer and turbidity sensor for organic matter content), passive and active acoustic sensors and a sediment trap module.

8.1.5. The Integrated Ocean Observing System

The Integrated Ocean Observing System (IOOS) is a federal, regional, and private-sector partnership working to enhance the ability to collect, deliver, and use information in US coastal waters, Great Lakes and the oceans. IOOS helps deliver data and information needed to increase understanding of the oceans and coasts, facilitating the ability to make informed policy decisions and to monitor and predict changes in coastal and ocean ecosytsems and environments.

9 Some examples of R&D initiatives

9.1 EU

In Europe, ESONET (European Seas Observatory NETwork http://www.esonet-noe.org) aims to promote the implementation and the management of a network of long-term multidisciplinary ocean observatories in deep waters. This network is tightly connected to the EMSO European deep-sea observatories (http://www.emso-eu.org/) equipped with a common set of sensors for basic measurements and other specific sensors including physical, chemical and biological sensors relevant for the offshore O&G industry. This program is likely to benefit new or future O&G initiatives on the Norwegian margin. Supported by R&D actors and cooperation with leading companies and SMEs in the field of underwater engineering, ESONET goals are to provide the necessary steps to new cost effective developments and implementation of permanent observation capabilities at the European level and to enhance capacity building in the context of long term operation of observatory systems. There is also a clear objective to develop standard interfaces to ease the interoperability on the various European observatories. ESONET is integrated with other initiatives and experiences from the offshore O&G industry.

New developments of *in situ* sensor technology for the marine environment are ongoing through the SENSEnet EU Framework 7 funded Marie Curie Initial Training Network (http://www.eu-sensenet.net). This network aimed at developing a group of young scientists to position the European Community at the forefront of *in situ* sensor development. SENSEnet is organized around 3 scientific work packages:

- ✓ Optical sensor development
- ✓ Autonomous sensors, analysers and microsystem technology for chemical monitoring
- ✓ Infrastructure and interface issues

9.2 O&G initiatives

Some initiatives by O&G operators with relevance for environmental remote sensing and monitoring technique are reported herein. However, this list is not exhaustive.

Statoil

Recently, Statoil has launched a large program – the Integrated Environmental Monitoring program - with the aim of making possible the measurement of physical, biological and chemical sensing data during operations and to integrate these data in the planning and management of their routine activities. Kongsberg Maritime Subsea, IBM and DNV, will each contribute with technolgy and competance within several areas including, sensor technology and sensor platforms development, data capture and communication infrastructure, information access and integration of real-time environmental monitoring data in operational management, advanced environmental analysis.

Statoil, together with Chevron and Total, was also involved in the SERPENT project (http://www.serpentproject.com/). SERPENT provides a tool to bring the most up-to-date scientific approaches into the monitoring and assessment process, whilst exploring the ecology of some dedicated areas and seeking to develop new methods for assessment and monitoring. After connection to the SERPENT, the companies were able to utilize expertise and services during exploration drilling on a case by case basis. This collaboration combined existing environmental monitoring methodology with development of novel methodology. In the SERPENT project, several sampling technologies (camera, luminophore tracer techniques, sediment push cores) and platforms (ROV) were used to study physical, chemical and biological disturbance of the seafloor at deep-sea research locations both in the North Sea and in the Barents Sea. The intention of this project was to improve internal industry control systems and lead to new measures, better methods of analysis and also provide input to mathematical models for forecasting the potential effects of operations.

Total

In West Africa, Total has a number of R&D initiatives using AUV monitoring in all deep-water field development projects to obtain high resolution sea floor geophysics maps for deep-water environmental assessment. Acoustic and very high resolutiuon digital cameras are used. Future AUV requirements for the company include upward looking sonar for Arctic applications (ice management) and a hydbrid AUV/ROV (called SWIMMER) for performing intervention, maintenance and repair (IMR) tasks on deep¬water offshore installations.

OGP

The International Association of Oil and Gas Producers in support of the Arctic Oil Spill Response Technology – Joint Industry Programme (JIP) has launched several initiatives seeking Expressions of Interest (EoI) to conduct research investigations in oil spill detection and mapping in low visibility and ice. The overall objective of this project is to advance and expand the oil and gas industry's oil spill remote sensing and mapping capabilities and technologies with emphasis in arctic conditions. The goal of this project is to identify the most promising technologies to be used for remote sensing of oil in low visibility and under various ice scenarios. Two topics have high priority in this initiative:
- Focus on surface remote sensing (satellite-borne, airborne, ship-borne, and ON-ICE)
- Focus on undersea remote sensing (mobile-ROV or AUV-based, and fixed)
Desktop projects within these two topics have now been selected and launched.

9.3 RCN

The COSMOS initiative was proposed in 2010 by the Norwegian Ocean Observatory Network (NOON www.oceanobservatory.com) for establishing a cable-based ocean observatory infrastructure in Norway. Sites in the Vesterålen area and south of Svalbard were proposed to establish a permanent seafloor infrastructure with multi-sensor platforms connected to land stations by cable. Infrastructure connected to the Snøhvit operation site was envisaged as well. The COSMOS initiative didn't get funded but integration of deep-sea monitoring technologies and offshore operational management is embedded in the Integrated Environmental Monitoring program by Statoil

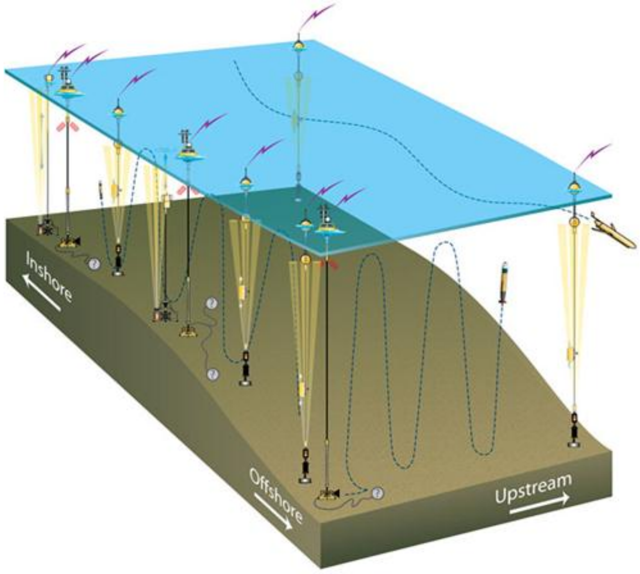
Petromaks and DEMO2000 programmes of RCN are intended to participate in the goals assigned by the OG21 strategy (http://www.og21.org), an initiative established by the Oil and Energy Minister of Norway in 2001. Lately, these programmes have received a stronger focus on technical environmental issues related to O&G. OG21 is divided in several Technology target areas (TTA). In TTA1, remote sensing technology, environmental monitoring and leak detection systems have been recognized as important areas to further develop/test for the O&G industry. Examples of on-going environmental sensing projects relevant for O&G include:

- The Biota Guard Arctic (Biota Guard AS)- A Real time environmental effect monitoring system for offshore drilling and production operations in the Arctic – The goal is to adapt the Biota Guard system for deployment in Arctic conditions. This adaptation is made through the use and test of Arctic species for the real-time biomonitoring of several end points.

- The Moab project (IRIS) - Molecular-based technical adaptation using oil-degrading bacteria for autonomous leakage detection – The goal is to adapt a robotic platform (Environmental Sample Processor, ESP) developed by MBARI to the detection of oil-degrading microbes by using advanced *in situ* near-real time molecular-based analytical assays.
- Real time underwater wireless sensor network for the monitoring of ice drift in the Northern area. Together with Kongsberg Maritim, Statoil, Sintef and NTNU, Nortek will develop a real-time monitoring sensor network system able to receive and measure important data for operations at sea and in the air in the Northern areas.

9.4 Other initiatives

Hydroid, a wholly owned subsidiary of Kongsberg Maritime, has recently started their ocean observatory initiative (OOI) with the REMUS AUVs. A site located in a state-of-the-art facility in Pocasset, Massachusetts, has been selected. The OOI shall be capable of fully autonomous AUV operations for up to 120 days, fully autonomous dock operations for up to 210 days and up to 1250 AUV operational hours during deployment. Communication with an operations center for data loading and re-programming is planned. The sensor payloads onboard the AUV instrumentation will comprise CTD, O2, DOM, current velocity, nutrients salts and PAR (photosynthetically available radiation). The OOI is optimized for medium water depth applications and today’s applications include both military and commercial use.



10 Some conclusions and outlook

10.1 General consideration

Future challenges for remote sensing and leak detection systems have been identified by KLIF with special emphasis on vulnerable areas/close to shore/arctic conditions. In these areas, the subsea system will need to fullfil higher requirements like:

– Critical with early detection
– Possibility to observe leakages on the sea surface during periods of reduced daylight and/or rough weather conditions
– Larger focus on technologies able to detect early signals from small and medium sized leakages and for further monitoring of corrective actions

Monitoring methods based on sensing and biosensors are gaining acceptance as new methods within a regulatory context, receiving accreditation and status as recommended methods of analysis. In future regulations, and for new fields, KLIF wishes to see subsea leak detection system implemented in the design of the operational system and encourages the operators to contribute towards future developments through several means, including the regular research programmes based on petroleum activities (Petromaks, OG21)

What do resource managers and industry need from different sensors and what needs to be done to ensure new sensors are accepted by the resource management community? There is a suite of criteria needed for resource managers and operators to obtain and monitor before and during oil field operation and eventually in the aftermath of an incident. Detection and location, spatial extent and thickness, movement and tracking as well as state of the oil and sources are among the critical criteria operators need for proper oil spill response. *In-situ* sensors must collect data in real-time and be rapidly accessible to first responders and operators. Sensor technonology may inevitably provide an overload of data which is challenging for first responders to turn into counteractions. Hence, "user-friendly" data interpretation is vitally important to managers and first responders to determine the most effective emergency response and data integration together with existing interfaces is suggested as a solution. Linking the signals from sensors to models and entering the data into real-time Geographical Information Systems (GIS) are two ways towards effective integration of sensor signals into management systems.

Following the Deepwater Horizon (DWH) incident, a conclusion from the Joint Industry Oil Spill Preparedness & Response Task Force (JITF) was that oil sensing and tracking was a critical element in the spill response. A variety of methods for the remote sensing of surface oil were successful applied at the DWH incident, even if it is recognized that there are still opportunities for improvement. The JITF concluded that a *methodology for subsurface remote sensing does not exist and is needed*. Areas for improvement and preliminary recommendations were provided by the JITF. Here, we summarize some related to undersea remote sensing:

- investigate opportunities to further develop appropriate oil sensing and tracking emergent technologies.

- Developing technologies specifically related to hydrocarbon detection in deep waters is recommended, as responders need a clear understanding of the oil's fate and transport from deep and ultra-deep releases.
- evaluating existing capabilities for subsurface tracking, and investigating the need for and ability to create high-resolution 3D maps of subsurface plumes and currents. AUV deployment for subsurface plume tracking is recommended as little research to develop those types of technologies for oil tracking exist. Acoustic (sonar) approaches could cover more area than the current scope of their approach but translating acoustic data to oil concentration and/or presence is currently a challenge
- studying the potential modifications to fluorometers that would extend the range and volume of water that could be sampled..

10.2 New sensor technology

In DNV-RP-F302, a certain number of functional requirements for subsea leak detetion systems are suggested. Regarding the environmental parameters to monitor, a missing target for subsea remote systems appears to be the marine ecosystem including seafloor, water column and subsurface biological components. Incorporation of these components would comply better with future marine management practice and directives requiring that a holistic, ecosystem management approach be adopted. As reported here, there are a number of current or promising technologies/initiatives which could be integrated into management plans, contingency response and aftermath monitoring by O&G operators. Nevertheless, there are presently only a limited number of *in situ* sensors that allow for the long-term determination of key events related to the biological compartment and key species of the marine environment. The development of novel sensors to fill this gap should be prioritized. Innovations in non-ocean technology sectors together with the recent development in genomics, proteomics, functionalisation methods, optics and nanotechnology open up a range of opportunities for the development of automated intelligent biological and chemical in situ sensors.

There are a number of laboratory techniques which have real potential for marine *in situ* environmental applications. Nevertheless, good operational characteristics must be first achieved. Challenges are related to salinity, pressure and other factors like durability, selectivity, extended concentration range and resistance to biofouling, which are all key issues that need to be addressed before obtaining recognition and integration within operative management systems for the O&G industry.

A conversion of bench devices to autonomous in situ systems appears benefitial and is recommended. To take existing bench-top micro-system analysers and modify them to allow coupling to present platforms including AUVs, ROVs, and buoys appears as a challenging but advisable R&D strategy. This includes adaptation and field-testing of these systems at sea over extended periods of time under all conditions.

In situ sensors will also have problems with biological fouling, and as we move towards deep-sea and coastal observatories, the ability to deploy sensors for long periods of time will be limited unless we address this complex issue. There are existing technologies for reducing or preventing fouling.. In situ sensors will likely continue to experience significant obstacles to widespread acceptance by regulators and operators if these issues and those others described above are not effectively resolved.

10.3 Increase usage of AUV and glider with sensor payload and adaptive sampling strategy

During the Gulf of Mexico DWH spill, high-resolution mapping of the deep oil plume was obtained by MBARI's Dorado AUV by acquiring water samples fromthe oil plume at 1180 m depth with 10 gulpers. The AUV was equiped with optical sensors including coloured dissolved organic matter (CDOM) fluorescence and optical backscaterring at different wavelengths.

MBARI's Dorado AUV with Gulpers for water automatic water sampling. © MBARI.

From an environmental response perspective identifying the source location is the most important consideration. A tiered "nested grid" approach with mobile platforms appears appropriate e.g. Glider AUV (phase I - screening) and Hugin-1000 (phase II – detailed mapping). This "nested grid" approach using multiple platforms can provide a number of advantages over the single platform approach. The two phased monitoring and mapping (informs the main effort of the oceanographic conditions) not sure about this sentence. and possible locations of leaks in phase I, with phase II providing the highly resolved information needed to respond to a leak.

The payload of AUV gliders is restricted due to limited power supply and sensor accommodation but they can cross large areas while vertically undulating for long periods of time (from weeks to months). Propelled AUVs can carry a larger payload and are more precise in their mission, lasting usually for 1-2 days. Alternatively, long range autonomous underwater vehicles (LRAUV) that can accommodate a sensor payload, could be used on command to cruise between hot spot areas.

Cost, high-tech engineering, support assistance, operational requirements and maintenance issues are among the barriers to routine utilization of AUV/gliders. Nevertheless, the potential advantages of these platforms for deep-sea O&G activity are real, including:

- Increase of spatial and temporal coverage
- Operation in harsh, hazardous or difficult-to-access places
- Capability for strategic, target and routine sampling
- Rapid near-real-time wireless response
- Adaptive sampling with "smart" self-directed sensors and peak signal algorithms
- Payload sensors covering both chemical, physical and biological measurements

10.4 Outstanding issues with sensing

- Broad scale acceptance and integration of technologies into a regulatory context and environmental monitoring programs as part of company policy in the areas they are licensed to operate
- Sensing drift and biofouling for long-term deployment – Need for suitable AQ/QC → data must carry the necessary Quality Assurance, giving confidence to end-users to invest in transforming observations into useful operational products.
- Operation and maintenance requirements, system costs → Maintenance of long-term *in situ* observations: Aspects of the technical and financial challenges inherent in maintaining long-term *in-situ* ocean monitoring devices, often in inaccessible and harsh ocean conditions, need to be assessed.
- Sensing data can be overwhelming. There is a need for suitable management system including data-sharing strategies, integration of sensor data with other existing data (how to harmonize)
- Decision-making based on sensing – Which criteria. How to define alarm levels. Should they be harmonized with current criteria defined for biomarkers (see separate report). This will then require a comparative study. Sensing validation is an important issue for integration into water management control programs for O&G.
- Harmonization with current sensors and biosensors in support of EU Directives is also recommended.
- Sensitivity towards actual field concentrations – Combining passive samples and sensing should be explored as one possible alternative. The time integrated nature of passive sampling offers the advantage of continuous, and therefore more representative, monitoring of water bodies in which pollutant levels fluctuate or are transient. Also, contaminants accumulated over the exposure period should result in higher concentrations in the extract for analysis than in a spot water samples, thereby enhancing the capability for sensing detection.
- Need for instrumental comparison and assessment like that performed by the Alliance for Coastal Technologies (ACT - http://www.act-us.info/evaluations.php)
- A way to input real-time information directly into trajectory modeling programs of surface sensing & tracking technologies is needed.

10.5 Specific recommendations for further development/test of observing systems and forward look with emphasis on O&G activities.

10.5.1 Surface and subsurface

- Shipboard observations including:

  - *In situ* high frequency measurement on regular transects (e.g. supply boats) like the Ferry-box system integrating systems for immunosensor multichannel devices targeted at O&G
  - *In situ* point measurement for accurate diagnosis using simple & portable devices (handheld) e.g. DNA-based, cell (bacterial/algal)-based biosensors
- Satellite or Airborne sensors for large scale surveillance and supporting actions e.g. to complement other shipboard observations.

10.5.2 Water column

For the monitoring of O&G activities in deep-sea regions, there are a certain number of constraints and limitations of using airborne or ship-based observation techniques. These techniques such as infrared cameras, laser fluorescence or side-scan sonar have proven to be effective and reliable in detection capability for surface to subsurface oil and aromatic hydrocarbons, for example in the recent Deep Water Horizon (DWH) spill. Other techniques based on hyperspectral imagery can also be recommended in combination with improved mapping tools to visualize oil plume trajectory and help in spill response plans. However, there are critical limitations with water depths which need to be circumvented.

Underwater techniques based on video surveys from ROVs are possible but are time-consuming, requiring the processing of a huge amount of observations, and they are also limited to operation in waters with good visibility.During the DWH, one finding was that a continuous plume of oil, more than 35 km in length, was present at depth of ca. 1000 m for months and that the concentration of several aromatic hydrocarbons, potentially hazardous for the fauna, exceeded background levels. The use of an AUV-based mass spectrometer, fluorometer and robotic sampling with self-controlled peak-capture algorithm was extremely useful to reveal the extent of this plume with a very high resolution.

Hence, based on this experience, we would strongly recommend the use of innovative methods combining advanced *in situ* chemical sampling/tracking, robotic sampling and acoustic positioning with AUV control systems, for efficient localization and characterization of near-seafloor petroleum contamination.

A recommended list of underwater sensor payloads to test further for *in situ* chemical sampling is given below (not exhaustive list):

- Fluorometers including hyperspectral and time-resolved fluorescence sensors
- Mass spectrometer
- Surface-enhanced Raman Spectrometry (However, the technology and its *in situ* application, as well as a full characterisation of elements of interest in the deep-sea is in its infancy)
- Immunosensors (e.g. SPR-based)
- Sniffers (e.g. HydroC or Franatech)
- Multi-parameters electronic tongue
- Lab-on-a-chip technology

Regarding robotic sampling for efficient sampling and characterization of specific water masses or specific anomaly features (such as in the case of a leakage):

- AUV/gulper autonomous sampler capable of collecting discrete water samples and bringing them back for further analyses at the laboratory.
- Near-real time sample processing of seawater using autonomous robotized platforms with integrated molecular/biochemical diagnostic procedures like the ESP of MBARI
- Further use of surface plasmon resonance-based biosensors
- Flow-cytometry after improvement of well-defined criteria for classification

AUV control systems:

- Accurate positioning using acoustic control
- Adaptive triggering method of sampling and autonomous real-time re-tasking for capturing and detailing anomalies e.g. if concentration of target compound is above a certain threshold (need to make appropriate assumption for the triggering threshold)

Combination of mobile platform with glider and AUV mission

- For regular monitoring or sampling mission plan, we would recommend a tiered Nested surveys approach combining the use of high-coverage long-duration glider with “sniffers” (screening) and lower-speed high resolution short mission duration AUV to detail and pinpoint spill/leakage/petroleum source location and obtain accurate fingerprint and tracking of gas/hydrocarbon composition.

The advantages of this approach compared to conventional spill survey practices are:

- Large spatial coverage
- High spatial resolution
- Qualitative information i.e. classification and identification from ambient background levels (relevant in regions with natural oil seepage)
- Quantitative information
- Geo-referenced high accuracy spill location in real-time
- Adaptive operation i.e. to autonomously trigger robotic sampling at peak hydrocarbon signals by embedding real-time sensor data interpretation and decision making processes into the AUV feedback control system (=re-tasking)

10.5.3 Seafloor based monitoring

- Microsensors on benthic landers for further chemical species characterization such as organic matter, nutrients, metals
- Direct insights into sediment structure and species within the sediment like the sediment profile imagery (SPI) camera system
- Development a hyperspectral imagery system for in situ benthic studies (high temporal and spatial coverage. Also possible to include this technology in a submersible, that could allow the mapping of sediment surfaces (see e.g. Ecotone)
- Further development of planar optodes: With planar optodes it is possible to obtain photos of the oxygen distribution at micrometer scale, for example at the sediment water interface.

10.5.4 Integration of sensors on deep-sea observatories

- Deploying sensors on long-term observatory systems connected directly to a production line present several advantages such as access to a secure power supply, communication capabilities and also direct integration in existing production activities and management. For O&G, this appears to be a good strategy to follow.

11 Literature, workshops and document sources used in this compilation

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12 Appendix A – An assessment methodology for sensing technologies - Prioritization of the identified remote sensing and monitoring R&D opportunities

Contents

Summary

Following a review of remote and monitoring technologies relevant for O&G with emphasis on the deep-sea, we present herein the results of a technology evaluation made to support the NDP group to support R&D efforts prioritization. This evaluation is based on five criteria (maturity, criticality, flexibility, sensitivity and effort) decided beforehand with the NDP group. A technology assessment tool was made based on a combination of weighting values and numerical rank assigned for each criterion to provide a classification and scoring of technologies. Four classes were determined: 4=mature and operative technology, 3=proof-of-concept established and technology tested in aquatic environment, 2= technology concept with potential for aquatic application, 1= technology concept.

Following this assessment, a number of technologies fall in class 3. These technologies were defined as promising where R&D focus appears advisable. They were ranked further to provide an order of priority from LOW to HIGH.

Based on the technologies classified with a HIGH priority, we concluded that SPR, SERS, BiotaT, MS and Hyp are recommended cutting-edge sensor technologies that can address more or less specific targets and complement already existing off-the-shelf technologies (class 4) currently tested on installation. Likewise, BiotaG and AUV/AUV gliders are seen as promising sensing platforms in the water column for future deep-sea activities. At the seafloor, technologies based on d-ESP and landers are recommended.

Further, we clustered "class 3" technologies according to different scenario discharges and to propose more pragmatically their context of application. The clusters provide an overview of technologies which are promising for applications in several O&G scenarios but technical and operative challenges are not reported thoroughly and should have more emphasised as a follow up of this work. Some technologies (e.g AUV) appear to have a wide coverage of application within several scenario types.

From this work, it appears justified to put future efforts on some of the technologies scored with a HIGH priority, consider others for more specific scenarios and follow up on already existing, operative technologies currently tested or implemented in the O&G context. This would provide a set of innovative and relevant tools represented by interplay of physical, chemical and biological sensing applicable in the context of water- and ecosystem based management emphasised by current regulative frameworks.

Background

A report on "**State of the art for remote sensing and monitoring**" was produced by IRIS and delivered to the NDP group in November 2012. Complementary information regarding the use of these technologies for different scenarios of discharge and priority of R&D initiatives was requested thereafter.

Norsk Olje og Gass (NOG) is also working on a document evaluating technologies related to airborne, ship-based and subsurface sensing for oil leakage detection. A merging of information may be considered between the present document and that produced by NOG. The present evaluation includes some of the technologies (subsurface) currently evaluated by NOG

Objectives of this report and perspective

In this report, the goal was to add information to the main report "**State of the art for remote sensing and monitoring**" delivered to NDP in November 2012. The intent is to support the NDP group with assessing a number of criteria used to prioritize future R&D efforts within sensing technologies. Hence, this report aims at identifying important gaps and needs in sensors, platform technology and larger infrastructure (e.g. observatories), and advise the NDP group on those showing a promising future for application in the O&G context.

Ocean observation (collection and use of marine data) is becoming the new challenge for all marine activities including those encompassed in O&G activities. This responds to a change in compliance needs from regulative authorities and also societal demands to safeguard the marine ecosystem, the services they provide e.g. the maritime resources they represent for humans. This calls for a coordinated action and the development of initiatives enabling a view of the "big picture". Sensor development faces a number of challenges and outstanding issues, particularly for those used in the marine environment. This has already been described in the main report. Among other factors, a general and broad scale acceptance of sensing as monitoring tools complementing other existing monitoring methods is required. Then, integration of these technologies into a regulatory context and environmental monitoring programs are necessary to initiate and drive new developments. This report seeks to provide guidelines to companies aiming to operate in challenging environment like the deep-sea.

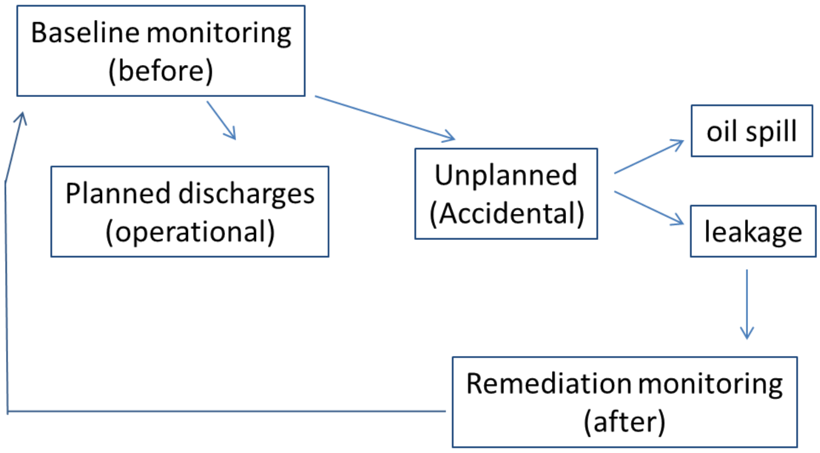
All current trends in environmental management point towards the same objective: the development of Ecosystem Based Management (EBM). The focus on ecosystems implies a more holistic approach to ocean management, which should not be restricted to selected ecosystems (e.g. deep-sea, Arctic, coastal, offshore) or separate human activities (e.g. O&G), but account for the cumulative effects of different anthropogenic and natural stressors on the whole Marine Ecosystem. Consequently, this means that an assessment from regional petroleum-related influence to larger scale ocean fluctuations should be envisioned in future management plans. Sensing initiatives and future prioritization should reflect this vision.

A model of sampling strategy and integration of sensing in management plans for O&G could follow that coming from current EU initiatives and expert group discussions aiming to define a European landscape of marine research infrastructure and sensor technologies organized at national and pan-European levels.

After defining the relevant scenarios where sensing can be applied, this report is presenting the results of technology evaluation and recommendations for follow up in R&D initiatives.

Definition of relevant scenarios of application for sensing techniques described in the report

The following scenarios will be covered and used as the context for this evaluation. The technologies will be clustered according to their relevancy for each of these scenarios[1].



Choice of relevant decision criteria for the prioritization of the R&D efforts

A list of criteria we used to rank the different technologies is shown in table 1. These criteria have been used to analyse the properties of each technology. The choice of these criteria was made together with the NDP group (meeting Oslo November 2012) and in the follow up discussions. One needs to recognize that this choice was important for the following analytical approach and the final evaluation. The choice of other or additional criteria might have given a different assessment and classification of the technologies. However, the conceptual approach can be preserved.

Following the meeting with NOG in January 2013, it was suggested to apply a weighting value on the proposed criteria as it is assumed that some criteria can have a greater influence on the prioritization efforts than others. As a result, IRIS has first divided each criteria into four categories ranked from 1 to 4 to obtain a range of classes from low score to high score. Further, each criterion was assigned a weighting value ranging from 1 to 3 according to their expected importance for the evaluation process: 1=expected low importance; 3=expected high importance

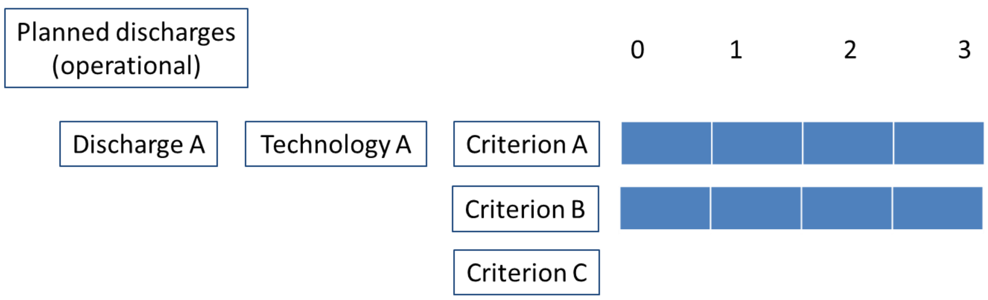
1 It was proposed to divide the oil spill scenario in two sub-units: detection of spill and monitoring of spill. However, this may complicate the analysis if we have too many sub-units for each proposed scenarios. Hence, IRIS have provided sensing & technology prioritization tables without division in sub-units for the oil spill scenario. A modification can be considered later if needed.

Table 1 – List of criteria (n=5), their range (n=4) and weighting value allocated (from 1 to 3) used for the present technology assessment

CRITERIA	WEIGHTING VALUE	RANKING
- **Maturity**	**3**	
○ High technical maturity or TRL>5 (Technology Readiness Level)[2]		4
○ Known integration in management system		3
○ Adaptability to O&G needs		2
○ Technology concept		1
- **Criticality**	**3**	
○ Compliance to regulation		4
○ For management		3
○ Supportive information		2
○ General documentation		1
- **Flexibility**	**2**	
○ Possibility for adaptation towards different targets/scenarios		4
○ Suited from surface as well as deep-sea		3
○ Suited for surface only		2
○ Very targeted technology/specific scenarios		1
- **Sensitivity**	**2**	
○ Low response time/ High sensitivity		4
○ Actual quantification of target		3
○ Only relative abundance or presence/absence		2
○ High response time/ Low sensitivity		1
- **Cost or level of efforts required**	**1**	
○ User-friendly operation		4
○ Easy installation and maintenance		3
○ High servicing requirements		2
○ Operated by skilled personnel		1

Analytical approach

The type of matrix obtained to assess each technology is exemplified in the drawing below.



2 http://en.wikipedia.org/wiki/Technology_readiness_level

For each technology, the criteria defined above have been summed up and visualized on a star graph as illustrated in figure 1.

These plots have then been used to:

- screen clusters of technologies with similar features.
- Make a prioritization classification based on a quantitative integration of the five criteria scoring into a simple index. This index combined weighting values and ranking into a value varying from 1 to 4 calculated as
  Index=Σ(rankingxweighingvalue)*n*/Σ(weightingvalue)*n*

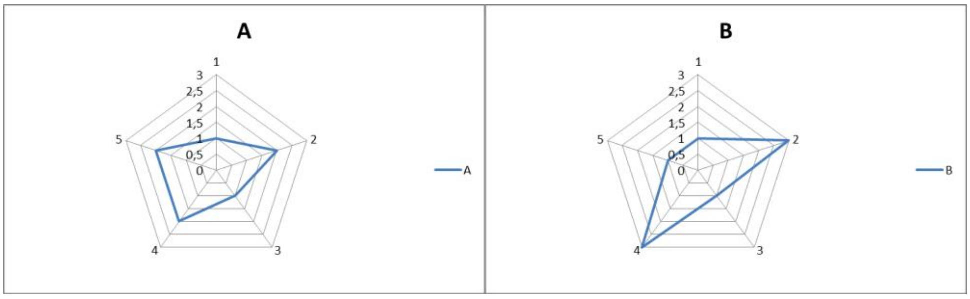


Figure 1 – Example of star plot for two technologies A & B and 5 criteria 1-5 ranked from 0 to 3. A large area means a technology scoring high for all selected criteria.

Results of evaluation

General assessment

Table 2 shows an example of the scoring for two technologies reviewed in the initial NDP report and the complete panel of technologies is attached in the appendix at the end of this report.

For each technology, an equivalent assessment was made and the index calculated.

All index values are ranged between 1 and 4, where 1 represents a technology with a poor score for the combined criteria and 4 represents a technology with a high score. According to this classification, class 4 includes technologies already well developed, tested and operative. Some technical modifications may still be necessary but the goal of this assessment is rather to look at other promising technologies in a R&D perspective. Hence, the candidate technologies mostly appropriate for R&D prioritization are those falling under class 3.For technologies in classes 1 and 2 there might be too many challenges at the moment and the R&D efforts would need to be large to make them operative in one or the other scenario.

Based on our analytical method, none of the technology was found under class 1 and most technologies were found in class 3. Some technologies were classified as “4”. This result is not completely surprising as we had already made a kind of selection of the technologies most relevant for O&G scenarios in the original NDP report delivered in November 2012.

As many of the technologies were classified under 3, we have again made a sub-division in 3 categories for the R&D prioritization to obtain LOW, MEDIUM, HIGH priority classes. (table 3).

All technologies falling into class 3 (yellow coding) are promising technologies according to our definition and criteria. However, within this category, some technologies will need more efforts than others to reach full technical maturity and operative status for O&G. Table 2 is reflecting that by assigning a priority from LOW to HIGH. This ranking is not meant to exclude completely technologies with LOW or MEDIUM priority. Rather this is providing a range of priority and also more emphasis on some technologies (those with a HIGH priority) where larger R&D incentives are recommended. Nevertheless, technologies with LOW to MEDIUM priority may be particularly appropriate to some scenarios as referred in page 2 of this report.

Assessing the outcome & importance of deleting the criteria "flexibility"

During the last NDP meeting (02.05/2013) it was discussed whether the criteria "flexibility" was relevant and important for this assessment. We ran the analysis once again by putting a 0 value to the weighting value of the "flexibility" criterion and assessed the outcome of that for the technology index values. There was no major difference in the classification and ranking of the technologies when the "flexibility" criterion was assigned to 0. As an example, we show the results for the cutting edge sensor technology (table 4).

Table 2 – Example of scoring evaluation for two technologies according to the methodology used and index calculation. The overall index rank (=class) corresponds to 4=mature and operative technology, 3=proof-of-concept established and technology tested in aquatic environment, 2= technology concept with potential for aquatic application, 1= technology concept. See complete table in appendix.

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Index=Σrankingxweighingvalue*n* /Σweightingvalue*n*

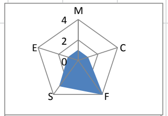
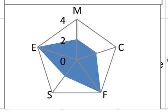
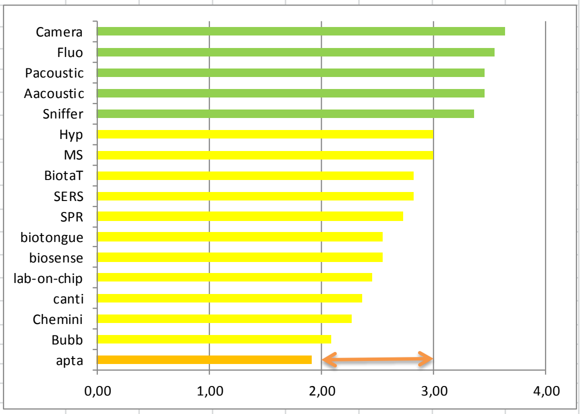
Sensing element/platform	Short description	target	Stage of develop-ment	Relevance/Adaptability to field measurements: Mobilized (on-site)	Relevance/Adaptability to field measurements: Continuous (in situ real-time)	General assessment: Advantages	General assessment: Challenges	Current/potential adaptability to deep-sea	Maturity (M)	Criticality (C)	Flexibility (F)	Sensitivity (S)	Efforts (E)	star plot	INDEX
								WEIGHTING VALUE	3	3	2	2	1		
								RANKING	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1		4 3 2 1
Cutting edge sensors															
Aptamers (apta)	Oligonucleotides (DNA or RNA molecules) or peptides that can bind with high affinity and specificity	a wide range of target molecules - LEAK & MONIT	(1)	As biocomponents in biosensors based on molecular recognition:		Specificity	Immobilization procedure	Currently not possible unless integrated with microfluidic sensing device in combination with other mooreed or mobile platforms	1	1	4	3	1		1,9
DNA biosensors/biosensors (biosense)	Affinity biosensor based on of nucleic acids (DNA or equivalent) for as use as genosensor (e.g. DNA binders, mutation detection)	PAH, oil, chemicals - LEAK & MONIT	(2)	Suitable for surface/sub-surface	Possible adaptation in micro-fluidic systems	Simple, cheap and easy to use	Sensitivity, specicity	same as above	2	2	4	2	4		2,5

Table 3 – List of sensor and platform technologies with their raw and rounded index.

Left panel – Classification of the technologies based on the weighted criteria index – raw and rounded index classification. The rounded index classification has been assigned to 4 colours indicating the 4 priority classes. Technologies falling into class 3 were divided again in LOW, MEDIUM and HIGH priority following the raw index value to provide the final assessment.

Right panel - The yellow bars on the figures indicate technologies falling into class 3 (index between 2 and 3; arrow). For a description of the technology, see IRIS report “**State of the art for remote sensing and monitoring**” and complete table in appendix.

	INDEX			PRIORITY CLASSES (4, 3, 2, 1)
	raw	rounded		(color-based)
Cutting edge sensors				
apta	1,91	2,00		2
Bubb	2,09	3,00	LOW PRIORITY	
Chemini	2,27	3,00		
canti	2,36	3,00		
lab-on-chip	2,45	3,00	MEDIUM	
biosense	2,55	3,00		3
biotongue	2,55	3,00		
SPR	2,73	3,00	HIGH	
SERS	2,82	3,00		
BiotaT	2,82	3,00		
MS	3,00	3,00		
Hyp	3,00	3,00		
Sniffer	3,36	4,00		
Aacoustic	3,45	4,00		
Pacoustic	3,45	4,00		4
Fluo	3,55	4,00		
Camera	3,64	4,00		
Cutting edge platforms for water column				
Ferry-box	2,27	3,00	LOW PRIORITY	
Cytosub	2,36	3,00		
Smart	2,45	3,00		
ESP	2,73	3,00	MEDIUM	3
AMG	2,73	3,00		
BiotaG	2,82	3,00	HIGH	
glider	2,91	3,00		
AUV	3,18	4,00		4
BiotaGA	2,18	3,00	LOW PRIORITY	
SPI	2,45	3,00		3
rover	2,73	3,00	MEDIUM	
d-ESP	2,91	3,00	HIGH	
lander	3,18	4,00		4
Cutting edge platforms for deep-sea/bottom				
d-observatory	2,1	3,00	LOW PRIORITY	3



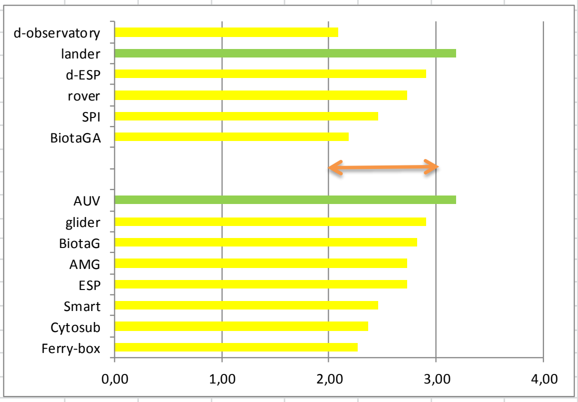
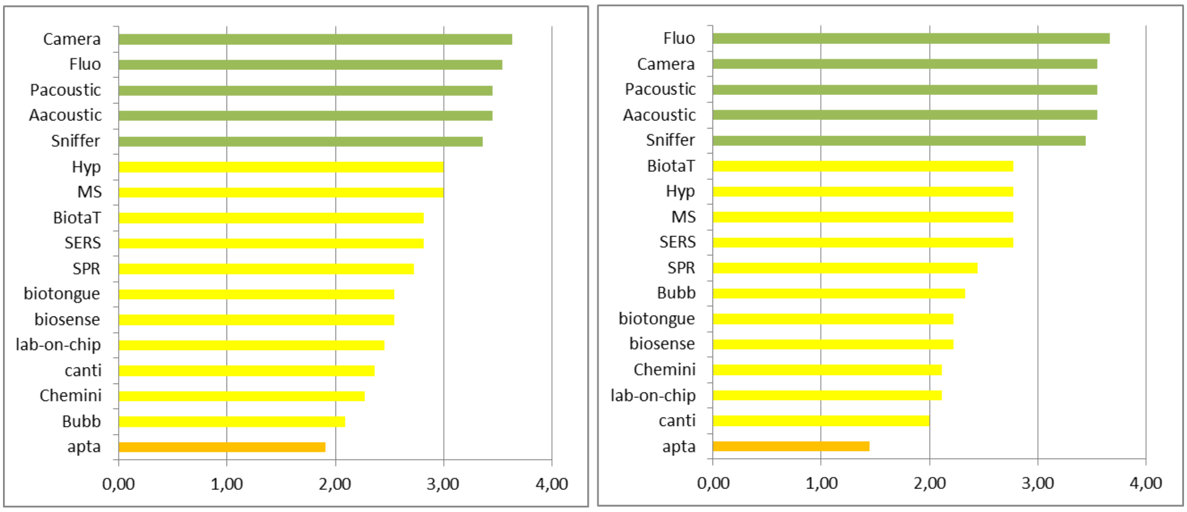


Table 4 –Results of the index scoring with (left panel, weighing value=2) or without (right panel, weighing value=0) the “flexibility” criteria. The technology index scoring is slightly modified but the general classification of each technology is not modified.



Conclusions and recommendations

General assessment and recommendation for R&D priority

From table 3 here, we have identified the technologies with the highest priority for R&D which we recommend to follow up. The selection of these technologies is based on their high integrated index value (2.7<index<3.2).

Regarding the sensor technologies, we recommend to put the prioritization on SPR, SERS, BiotaT, MS and Hyp technologies (table 5).

Regarding the platforms for the water column where R&D efforts are recommended, we found that BiotaG and AUV/AUV glider should be particularly pursued for their use in the context of deep-sea O&G. Also at the bottom, technologies belonging to d-ESP and landers are recommended. Although AUVs and landers are under class 4, they are scored in the lower range of this class and hence they have been retained in our recommendations: they still need some improvements to be fully integrated in management by O&G operators.

Deep-sea observatories are seen as potentially interesting infrastructure in relation to O&G, but maturity, criticality and level of effort still need consideration at the moment.

Table 5 – Final recommendation for high R&D priority for sensor technology and sensor platforms in the water column and at the seafloor. For more details, see main report "**State of the art for remote sensing and monitoring**"

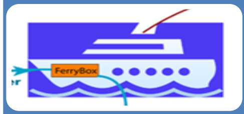
Clustering of technology with respect to scenarios

We have taken into account both technologies with HIGH priority and others falling into class 3 that can be particularly relevant for some scenarios. Below, we have tried to cluster these technologies according to needs and relevance for the different scenarios[3]. We have added short bulleted comments for future development of some technologies.

1) Baseline monitoring

Technologies capable of collecting data over relatively long periods of time or repeatedly, appear most appropriate for baseline monitoring.

3 The technologies falling into class 4 (not included in this clustering) are mostly tested and operated in the context of leak detection (accidental discharges).



sensor technology

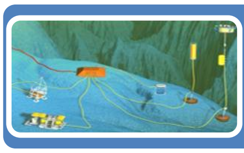
- Ferry-box
  - develop standardized "container type" sensor package to be mounted on supply ships sailing from land to planned installation site

sensor platform (water column)

- Cytosub
- Moorings/smart buoy
  - focus on deep ocean mooring design and deployment
- ESP
  - define specific targets

sensor platform (seafloor)

- d-ESP
- landers
  - select relevant sensor arrays



Cabled seafloor observatories

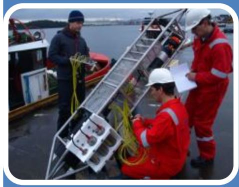
- integrated into the development and management plan of installation

2) Operational discharges

Operational discharges are characterized by a complex mixture of compounds from activities related to drilling, hydrocarbons or oil-related compounds, and production and utility chemicals (e.g. wax inhibitors, corrosion inhibitors, biocides, emulsion breakers, hydrate inhibitors [MEG], H_2S scavengers, O_2 scavengers and flocculants).

sensor technology

- SERS (Raman spectroscopy)
- MS (Mass spectrometry)
  - sensitivity and compliance to regulative discharges
- BiotaT
  - long-term effects on species fitness and input to management model

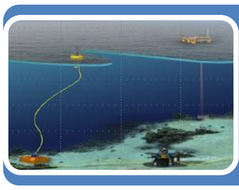


sensor platform (water column)

- BiotaG
  - same as BiotaT
- AUV
  - broader ranges of spatial and temporal resolution to define
  - broader suite of sensors to target complex discharges

sensor platform (seafloor)

- d-ESP
  - define specific targets
- landers



Cabled seafloor observatories

- integrated into the development and management plan of installation

3) Accidental discharges

3.1 Leakage

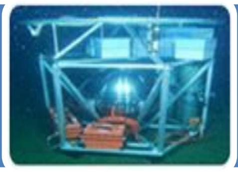
Operators are presently using underwater technologies for leakage detection which are scored in class 4. Technologies in class 3 indexed with a HIGH priority that could be particularly relevant for leakage scenarios in the water column or on the seafloor are SPR, SERS, MS for direct chemical detection and gene-based detector like the ESP (oil-degrading bacteria) for indirect detection and chemical aging.

sensor technology

- SPR (surface plasmic resonance)
- SERS (Raman spectroscopy)
- MS (Mass spectrometry)
- Hyp (Hyperspectral imagery)

sensor platform (water column)

- BiotaG
- AUV/AUV glider
  - multi-array Leakage Detection sensor package for oil, gas etc
- ESP
  - adaptation to mobile platform for larger coverage



sensor platform (seafloor)

- d-ESP
- landers
  - identify more precisely "hot spots" along installation units

3.2 Oil spill

Easy to deploy (mobilized) technologies for identification of chemical pollution (Lab-on-a-chip, biotongue, SPR, SERS, MS) and first screening for biological effects (DNA/cell-based biosensor, AMG (hand-held)). Also AUV/AUV gliders: improvement related to quick release from docking underwater stations around platform/subsea installation or supply boat

sensor technology

- lab-on-chip
- biosense
- biotongue
- AMG (hand held version)
  - design robust portable ready-to-use version

sensor platform (water column)

- AUV/AUV glider
  - AUV oil-targeted sensor package
  - rapid release from docking underwater stations around platform/subsea installation or supply boat

sensor platform (seafloor)

- sensor payload integrated to AUV/ROV for inspection and collection of samples

4) Aftermath monitoring

Technologies should be able to confirm return to original conditions e.g. following accidental discharge. They should be applicable for short-term (to control the effectiveness of contingency response) as well as for longer term monitoring as some changes, particularly on the biological side, may appear delayed in time following the accidental event. Hence a combination of technologies for baseline monitoring and accidental (oil spill) monitoring appears appropriate.

Summary table of technologies reviewed in this assessment

Table of technologies reviewed in the NDP report "**State of the art for remote sensing and monitoring**" and completed with the scoring index to provide recommendations regarding possible R&D efforts.

For each technology, we provided a short description, whether the technology is fitted for leakage detection (LEAK) or monitoring (MONIT), the suitability for *in situ* field measurements and the stage of development. The stage of development of each technology was scored from 1 to 3 where 1=under development, 2=proof-of-concept/prototype existing, 3=sensing platform/technology tested and operational for marine monitoring. ? = no information found.

For the relevance/adaptability to field measurements, *continuous monitoring* means that the technology can be used or adapted for *in situ* real (or near real-) time e.g. baseline monitoring or regular operations. *Mobilised monitoring* refers to portable technologies that can easily be taken on the site for measurements e.g. for routine checks or after an acute discharge.

The overall index (=class) gives an assessment based on the weighted sum of the pre-determined technology criteria (Maturity, Criticality, Flexibility, Sensitivity and level of Efforts) used to provide the final recommendation and priority. The classes are coded as: 4=mature and operative technology, 3=proof-of-concept established and technology tested in marine environment, 2= technology concept with potential for marine application, 1= technology concept. A colour is also attributed to each criterion to facilitate the reading of the table.

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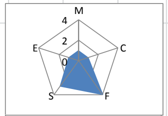
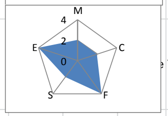
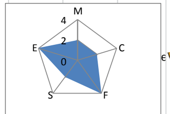
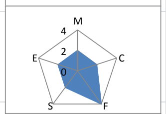
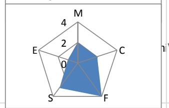
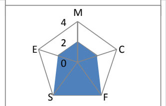
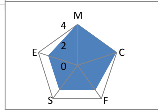
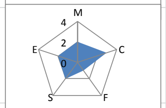
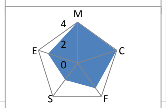
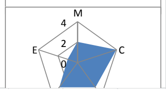
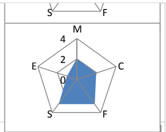
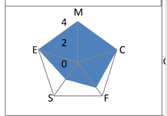
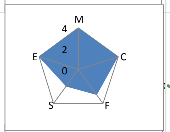
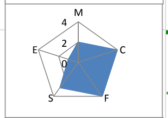
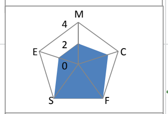
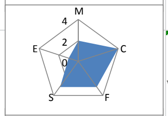
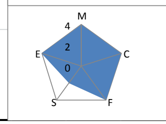
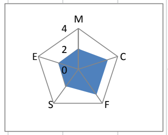
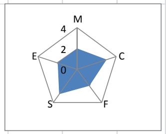
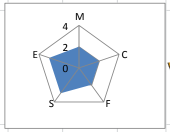
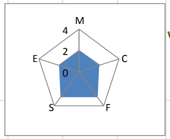
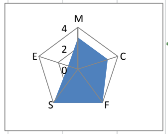
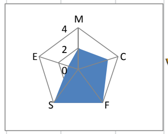
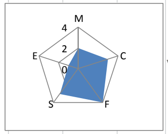
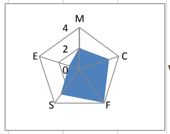
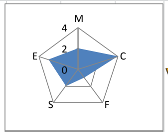
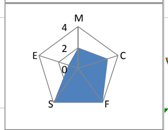
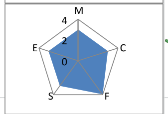
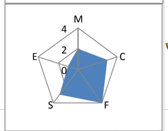
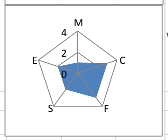
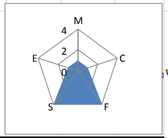
WEIGHTING VALUE	3		3		2		2		1	Index=Σrankingxweightingvaluen/Σweightingvaluen			
CRITERIA	Maturity	M	Criticality	C	Flexibility	F	Sensitivity	S	Efforts	E	4	3	2	1
RANKING	4 3 2 1		4 3 2 1		4 3 2 1		4 3 2 1		4 3 2 1		star plot		INDEX

Sensing element/platform	Short description	target	Stage of develop-ment	Relevance/Adaptability to field measurements: *Mobilized (on-site)*	*Continuous (in situ real-time)*	General assessment: Advantages	Challenges	Current/potential adaptability to deep-sea	Maturity	Criticality	Flexibility	Sensitivity	Efforts	star plot	INDEX
Cutting edge sensors															
Aptamers (apta)	Oligonucleotides (DNA or RNA molecules) or peptides that can bind with high affinity and specificity	a wide range of target molecules - LEAK & MONIT	(1)	As biocomponents in biosensors based on molecular recognition:		Specificity	Immobilization procedure	Currently not possible unless integrated with microfluidic sensing device in combination with other mooreed or mobile platforms	1	1	4	3	1		1,9
DNA biosensors/biosensors (biosense)	Affinity biosensor based on of nucleic acids (DNA or equivalent) for as use as genosensor (e.g. DNA binders, mutation detection)	PAH, oil, chemicals - LEAK & MONIT	(2)	Suitable for surface/sub-surface	Possible adaptation in micro-fluidic systems	Simple, cheap and easy to use	Sensitivity, specicity	same as above	2	2	4	2	4		2,5
"Bioelectronic tongue" (biotongue)	Multi-array of poorly selective sensors - combined with patter recognition (biometric)	PAH, oil, chemicals - LEAK & MONIT	(2)	Suitable for surface/sub-surface	Possible adaptation in micro-fluidic systems	Simple, can be used for detection of several sources (chemometry)	System shift, fouling	same as above	2	2	4	2	4		2,5
Cantilever platform (canti)	Use of capture molecule monolayer created on silicon-based cantilever	a wide range of target molecules - LEAK	(2)	possible: ready for testing; portable version	Possible - work in progress	High sensitivity, Specificity, can work with microfluidic channels	Robustness. Reproducibility to be demonstrated. Difficult read-out for arrays.	same as above	2	2	4	2	2		2,4
Lab-on-a-chip with on-chip detection (lab-on-chip)	Biosensor microsystem integrating sensors, detectors, flow system, electronics and data processing on a compact device.	a wide range of target molecules	(2)	possible: ready for testing; portable version	Can be used for sample preparation before sensing	Instant "POCT" (point-of care testing) diagnostic	Fully integration has high degree of complexity	same as above	2	2	4	3	1		2,5
SPR Surface plasmon resonance (SPR)	Real-time detection of refractive index variations due to molecular interactions for specific biological or chemical parameters	PAH, proteins, organisms - LEAK & MONIT	(2)/(3)	Good (compact, portable version)	work in progress in combination with sample preparation module	No major matrix effect, robustness, regeneration, Multi-analyte capabilities for high throughput	Sensitivity constrains for some applications	same as above	2	2	4	4	2		2,7
Fluorescence sensors (Fluo)	Use absorption and reflectance properties of organic compound	oil - LEAK	(3)	can be mobilized at the site for acute situation	Deployed	Easy technique	Interference with other natural substances	Good	4	4	3	3	3		3,5
Bubble sensors (Bubb)	Use of frontal illuminated videos and optical flow determination	Gas - LEAK	(2)	-	Prototype Tested	Robust and easy	Camera movement	Good	2	3	1	2	2		2,1
CO2/Methane sniffers (sniffer)	Gas diffusion through a special membrane and measurement using non-dispersive infrared spectrometry	Gas - LEAK	(3)	-	Tested/Deployed	Sensitivity	calibration issues	Operational depth down to 2000 m and below	4	4	3	2	3		3,4
SERS - Surface-Enhanced Raman Scattering (SERS)	Surface sensitive technique that results in the enhancement of Raman scattering by molecules adsorbed on rough metal surfaces	PAH, chemicals - LEAK & MONIT	(2)	can be mobilized at the site for acute situation	Tested	Robust and sensitive	Sensing layers (use of nanostructures) to enhance signal detection of targets	Good	2	4	3	3	1		2,8

Sensing element/platform	Short description	target	Stage of develop-ment	Relevance/Adaptability to field measurements		General assessment		Current/potential adaptability to deep-sea	Maturity (WEIGHTING VALUE 3)	Criticality (WEIGHTING VALUE 3)	Flexibility (WEIGHTING VALUE 2)	Sensitivity (WEIGHTING VALUE 2)	Efforts (WEIGHTING VALUE 1)	star plot	INDEX (Index=Σrankingxweighingvalue*n*/Σweightingvalue*n*; 4, 3, 2, 1)
				Mobilized (on-site)	*Continuous (in situ real-time)*				RANKING 4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1		
Chemini (Chemini)	Chemical analyser based on flow injection analysis and colorimetric detection	metals & chemicals - LEAK & MONIT	(2)	-	Deployed	*In situ* calibration and high frequency (30-60 analysis/hour)	?	Develop for deep-sea use (hydrothermal vents)	2	2	3	3	1		2,3
Active acoustic (Aacoustic)	Use the backscattering signals to detect objects with acoustic impedance different than water	gas (CO2, methane), oil - LEAK & MONIT	(3)	-	Deployed	Immediate, high frequency/resolution analysis - Also large area coverage, little affected by turbidity	Shadowing effect by the subsea structure, needs to have sufficient difference in impedance water/target = better for gas detection	Good	4	4	3	2	4		3,5
Passive acoustic (Pacoustic)	Measure only pressure wave=sound in the surrounding from different sources (e.g. mechanical rupture, animal sound)	control/failure of installation structure, gas (CO2, methane), oil - LEAK & MONIT	(3)	-	Deployed	Immediate, high frequency/resolution analysis - little affected by turbidity	Sensitive to background noise, sound over a certain level	Good	4	4	3	2	4		3,5
Mass spectrometry (MS)	Allow measurements of dissolved gases and volatile organic compounds including light hydrocarbons	PAH, gas, chemicals - LEAK	(2)	can be mobilized at the site for acute situation	Deployed	Allows for sensitive simultaneous detection of multiple chemical detection with high sensitivity	Needs expertise, calibration issues (pressure, salinity); only small molecular weight compounds	pressure tested to 200 bar (2000 m depth)	2	4	4	3	1		3,0
Hyperspectral imagery (Hyp)	Hyperspectral sensors look at objects using a vast portion of the electro-magnetic spectrum (spectral signature).	speciation, mapping - MONIT	(2)	can be mobilized on site from ROV	Deployed	Can differentiate key species and assess physiological state	Cost and complexity. Need sensitive detectors, and good analytical power.	Applicable at fixed location or on board mobile platforms	2	3	4	4	2		3,0
BiotaTools (BiotaT)	new generation of sensors targeted at key fitness parameters	PAH, gas, chemicals - MONIT	(1)	-	Monitoring of discharges around oil rig/platform	provide direct insights into key fitness parameters and condition of organisms	need to have good insights into the basic physiological conditions and influence of seasonnality	Not yet evaluated	2	4	3	3	1		2,8
Camera (Camera)	Direct video observations	oil, subsea installation - LEAK & MONIT	(3)	can be mobilized at the site for acute situation e.g. from ROV	Deployed	Provide direct easy-to-communicate vizualization	Sensitive to turbidity; for inspection on ROV, only for near-range	Good	4	4	4	2	4		3,6

Cutting edge sensor/platform	Short description	Stage of develop-ment	Stage of develop-ment	Relevance/Adaptability to field *Mobilized (on-site)*	*Continuous (in situ real-time)*	General assessment		Adaptability to deep-sea monitoring	WEIGHTING VALUE	3	3	2	2	1		
									CRITERIA	Maturity (M)	Criticality (C)	Flexibility (F)	Sensitivity (S)	Efforts (E)	star plot	INDEX
Cutting edge platforms for water column						Advantage	Challenge		RANKING	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1		
Biota Guard (BiotaG)	Complete system for real time continous monitoring. Use of "instrumented" whole organisms, physical and chemical sensors in its adaptive sensor arrays.	PAH, oil, chemicals - LEAK & MONIT	(3)	-	Deployed (below surface)	Holistic approach. Use of sensor data as well as 2nd and 3rd party data. Easy/robust to understand biological sensors (high trophic organisms)	The Biota Guard system now focus on futher development in order to integrate with subsea installations. Project ongoing.	Current development with deep-sea species (see Biota Guard Artic)		2	3	3	2	2		2,5
Smarbuoy/instrumented buoy (Smart)/moorings	Moored platforms combining wide range of water quality parameters (fluorescence sensors, O2, ToxN, suspended particular matter, chlorophyll fluorescence etc plus returned water nutrients of phytoplankton analysis)	PAH, oil, chemicals, primary production - LEAK & MONIT	(3)	-	Deployed (at surface) often with bottom landers (mini pod) or instrumented mooring line to provide depth profile.	Easy/robust multi-equiped platform for water quality paramaters. Real time telemetry of data to shore.	Only sub-surface information (if stand-alone), few biological parameters (unless returned water samples are analysed in detail)	No		2	3	2	3	2		2,5
Ferry-box (Ferry-box)	automated instrument packages installed on ships of opportunities	PAH, oil, chemicals - MONIT	(3)	can be mobilized at the site for mapping surface pollution	Continuous inflow to sensor "package" from below the ship surface	Easy to maintain and control. No long contact of the sensing elements with seawater	Dependent on well established shipping routes	No		2	2	2	3	3		2,3
Cytosub (Cytosub)	Uses flow cytometry analytical measurements to detect and count fluorescence emitted by particles.	particles, micro-algae - MONIT	(3)	portable and compact benchtop versions exist	Deployed in fixed location (on a cable) or in a submarine vessel	Fast and accurate method for sorting and classifying particles	Needs to have validation with other techniques (e.g. microscopy)	Down to 200 m		2	2	3	3	2		2,4
AUV (AUV)	Mobile sensor platform with the ability to operate autonomously in remote places. AUV are self-propelled	pending on the sensor payload - LEAK & MONIT	(3)	Can be rapidly mobilized from shore or boat in case of acute situation	Near-real time surveillance, data transmission and instrument tracking using wireless communication	Can incorporate a large sensor payload. Precise, rapid naviguation;	Short duration missions. May require a boat with lifting device for deployment	From subsurface to deepwater		3	3	4	4	1		3,2
AUV glider (glider)	Mobile sensor platforms with the ability to operate autonomously in remote places. AUV gliders are driven by buoyancy	pending on the sensor payload - LEAK & MONIT	(3)	Can be rapidly mobilized from shore or boat in case of acute situation	Near-real time data transmission and instrument tracking using wireless communication	Can travel long distance	AUV glider can only incorporate a limited number of sensor; Navigation less maneuverable than AUV	From subsurface to deepwater		2	3	4	4	1		2,9

Cutting edge sensor/platform	Short description	Stage of develop-ment	Stage of develop-ment	Relevance/Adaptability to field: *Mobilized (on-site)*	Relevance/Adaptability to field: *Continuous (in situ real-time)*	General assessment: Advantage	General assessment: Challenge	Adaptability to deep-sea monitoring	Maturity (M)	Criticality (C)	Flexibility (F)	Sensitivity (S)	Efforts	star plot	INDEX
								EIGHTING VALUE	3	3	2	2	1		
								RANKING	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1		
Cutting edge platforms for water column															
ESP Environmental sampling processor (ESP)	Autonomous platform for detection of several marine species and genes by molecular probing (rRNA-targeted DNA probes) using SHA method (sandwich hydridisation assay).cELISA for protein identification	detection of a wide range of organisms - LEAK & MONIT	(3)	-	Deployed (below surface). Possible to deploy off a pier or platform with a pipe to the sea	Modular, standalone platform: sample archival, several parallell assays. Automates qPCR opening up for adaptive response (target genes)	Cost and complexity of instrumentation	Fully adaptable - See d-ESP below	2	3	4	3	1		2,7
AMG Autonomous Microbial Genosensor (AMG)	Autonomous platform for detection of bacteria or algal species based on real time NASBA technique (RNA amplification technique) and stabilized reagents.	currently micro-algae and microbes - MONIT	(2)/(3)	Hand-held versions exist	Deployed (below surface). Also possible to deploy off a pier or platform	Same as for ESP but based on slightly simplified technology - mRNA (gene expression) of viable cells is targeted	Current detection of one species but device can be tailored to many different targets - No sample archival	Adaptable with appropriate casing	2	3	4	3	1		2,7

Cutting edge sensor/platform	Short description	Stage of develop-ment	Stage of develop-ment	Relevance/Adaptability to field measurements *Mobilized (on-site)*	*Continuous (in situ real-time)*	General assessment: Advantage	Challenge	Adaptability to deep-sea monitoring	Maturity (M)	Criticality (C)	Flexibility (F)	Sensitivity (S)	Efforts (E)	star plot	INDEX
								WEIGHTING VALUE	3	3	2	2	1	4 / 3 / 2 / 1	
								RANKING	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1		
Cutting edge platforms for deep-sea/bottom						**Advantage**	**Challenge**								
Planar optodes and SPI (Sediment profile Imagery) (SPI)	2D pictures of sediment-surface interface (photography). Secondary information (such as bioturbation index or degree of oxygenation, available through advanced image analysis)	sediment and fauna - MONIT	(3)	-	Deployed for Water-sediment interface and ca. top 20 cm sediment.	Fast return of qualitative easy to communicate data	Accuracy, response time and image treatment	Yes	2	4	1	2	3		2,5
D-ESP Environmental sampling processor (d-ESP)	Deep version of the ESP described above	detection of a wide range of organisms - MONIT	(3)	-	Possibility for data storage or wireless communication with surface buoy	see ESP above	see ESP above	Yes	2	3	4	4	1		2,9
Bottom landers (Lander)	Multi array sensor units for monitoring at the seafloor and into the sediment	- MONIT	(3)	-	Deployed on ocean bottom	Longevity, duration, multiparametric acquisition	Maintenance, fouling, data communication	Yes	3	3	4	3	3		3,2
Rover (Rover)	mobile autonomous platform that can travels across the seafloor to measure several parameters	- MONIT	(3)	-	Deployed on ocean bottom	can cover large areas for long periods and perform multitasks eg. Sampling, measurements	advanced costly platform	Yes	2	3	4	3	1		2,7
Biota Guard Arctic (BiotaGA)	Same as Biotaguard but new species for Arctic and deep-sea	PAH, oil, chemicals - LEAK & MONIT	(1)	-	Yes, data storage and on-line communication with the core Biota Guard platform	Same as Biota Guard	Find measurable and sensitive end-point biological parameters in key species	Yes	1	3	3	2	2		2,2
								WEIGHTING VALUE	3	3	0	2	1		
Deep-sea observatory						**Advantage**	**Challenge**	CRITERIA	Maturity (M)	Criticality (C)	Flexibility (F)	Sensitivity (S)	Efforts (E)		
								RANKING	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1		
d-obervatory	next generation infrastructure for a permanent interactive presence in the ocean	MONIT	(3)	-	Deployed on ocean bottom	Extension of electrical power and data connections with other instruments; plug in-plug out capability	complexity, costly infrastructure	Yes	1	1	4	4	1		2,1