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“Bringing together Research and Industry for the Development of Glider Environmental Services”

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DELIVERABLE D2.1
“Design Guidelines of a Deep Glider”

Abstract

D2.1: Design guidelines of a deep glider to support long-term in-situ exploration and protection services of the coastal and deep ocean [M12]

This work package aims to identify stakeholders in marine science and the offshore economy for deep gliders and their sensors and then describe their requirements in terms of realistic and workable services that can be provided by these gliders. Stakeholders will be Individuals and Entities that will actively interact with the platform once it is operational and in use. Standards, Protocols, Procedures, Regulations may also influence the use and operation of a deep glider or a fleet of them. Requirements for platform endurance, on-board autonomy, modularity, sensing and sampling missions, communications and data processing and dissemination will be identified from stakeholders in key target markets.

This deliverable provides a summary of the requirements found from different stakeholders; it discerns the degree of modularity that can be accomplished by interchangeable sensing systems and on-board autonomy; it defines specific sampling missions to the specific targeted services and, finally, it suggests on-site data processing procedures to maximize the information content of the collected data. This information is fed into the design and integration of the glider vehicles and sensors in order to maximise the market potential of the BRIDGES project.

This document will be continuously assessed and updated throughout the BRIDGES project with a final version submitted in M42 (September 2018).

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STATUS		DISSEMINATION LEVEL	
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S4	Under preparation		

TABLE OF CONTENTS

CONTENT

1 Introduction

1.1 Document Purpose

This document provides design guidelines of a deep glider based on identified needs and requirements stakeholders in marine science and the offshore economy. This deliverable will be continually assessed and updated during the BRIDGES project based on the evolving needs of the marine markets. The final version will be submitted at the end of the BRIDGES project.

These design guidelines are developed in coordination with BRIDGES work packages for the development of the glider platforms (WP4) and sensor packages (WP5), feeding current market information into the design process to ensure successful and wide-spread market application at the end of the project.

The design guidelines are arranged based on an analysis of five targeted markets within the BRIDGES project:

- Marine Science and Essential Ocean and Ecosystem Variables
- Marine Strategy Framework Directive (MSFD) and Copernicus
- Living Resources
- Offshore Oil and Gas Industries
- Subsea Mining and Raw Material

These guidelines are described in terms of realistic and workable *services* that could be provided by a deep glider in each of the targeted markets. A glider 'service' is a standardized service that employs a predefined payload that results in a dataset product that meets the dataflow standards of the market. For example, by offering standardized data products as inputs to regional and global observing systems, or standardized missions that allow repeatable and glider fleet operations by offshore industry with a high degree of scalability. This work package focuses on identifying the services needs in key markets, while another BRIDGES work package is focusing on meeting national and international standards and quality requirements for resulting glider and sensor data, software, hardware and system components.

The identified services are described in this deliverable for each key market, including definitions of:

- Purpose and application
- Required platform endurance
- On-board autonomy and intelligence
- Payloads and sensing sampling
- Communications
- Data processing and dissemination

1.2 Overview

The primary focus of the BRIDGES project is to develop and bring the deep-sea glider vehicles – the DEEP and ULTRA-DEEP EXPLORERS – to the market, targeting existing markets, emerging markets and future markets. Glider technology is ready to move from a research environment into the commercial mainstream of the ocean industry, and industries are ready to embrace their potential.

The BRIDGES project has defined key markets where deep gliders can provide exploration and monitoring services by offering an advanced suite of integrated sensors that can be tailored to the specific needs of the user. The needs of these markets must be taken into consideration when designing the glider vehicles and sensor packages to maximize the potential uses and market applications of these innovative platforms.

For the mature market of **marine science** exploration, these vehicles open up opportunities in deep sea exploration by extending capabilities from 1,000m (~20% of world oceans) to 5,000m (~75% of world oceans), improving the scientific capacity to observe and understand the deep sea water column and seafloor through the development of cost-effective, in-situ, relocatable and sustained monitoring technologies for obtaining meaningful information on environmental descriptors and processes. Social and economic demands are pushing scientists and engineers to better observe the deep ocean environment. With at best 5% of the seafloor mapped, environmental characteristics and resources from abyssal regions have remained largely unknown until now. Technological developments are enhancing human capabilities to access and operate in these extreme environments. However, uncontrolled exploitation of ocean resources can significantly jeopardize these environments with unpredictable consequences for the human population. For this reason, close attention to an optimum use of resources with minimum impact is being paid to enable a sustainable exploitation of resources. Exploration and monitoring are fundamental to achieve this scope.

For the growing market of **environmental monitoring (e.g. the MSFD)**, by providing suitable and cost-effective sensing platforms, BRIDGES will help Member States and stakeholders to implement their monitoring programmes to provide a detailed assessment of the state of the environment, in particular for the MSFD working towards a definition of “good environmental status” and the establishment of clear environmental targets and monitoring programmes.

The maturing market of **oil & gas** services is viewed as the segment with the highest potential for growth. Several glider demonstration missions have been successfully performed recently for major oil and gas operators, fuelling the need for glider service providers across the globe (e.g. CSCS in Cyprus, BlueOcean Monitoring in Australia, Prooceano in Brazil). The BRIDGES vehicles will improve upon current glider capabilities with the greatly extended depth range and sensing capabilities. These new deep-sea vehicles could deliver cost-effective services for exploration and prospecting an allotted licensed zone, with intelligent autonomous detection of natural hydrocarbon seeps using several vehicles to sweep a vast area. BRIDGES could also be the solution for risk management (environmental monitoring and intervention in crisis for spill and dispersant prediction) providing answers to key issues related to produced waters, drill cuttings, early warning of hydrocarbon spills or deep leakages. This includes deep environmental impact assessment during all phases of field development: before activity takes place, at production, after and as well as post incident monitoring to record effects. In case of incident, the gliders will be useful for both tracking spills and monitoring the effect, and for providing hydrographic data that when assimilated into operational ocean models, significantly improve their predictive capabilities, thus helping for mitigation. Globally, it has to be noted that with half of all top oil majors located in the EU, the export potential is substantial for providers of technology and service.

Finally, the growing market of **subsea mining** has been identified as a key target market for the application of deep sea gliders. Marine minerals mining, although described as at infancy stage, is expected to mine 5% of its world's resources by 2020. So far, there are about 150 known sites worldwide. This activity has a very challenging characteristic which is its operating depth distributed between deep and ultra-deep waters. For obvious reasons of technological development, the first phase of subsea mining will start with the easier "seabed" to mine located at depth from 1 600 m to 2 500m, before going deeper. In those conditions, gliders able to access the working depth to perform exploration or site monitoring are still missing. Uncertainties and concerns remain in terms of the unknown environmental consequences. Main environmental problems relate first to what happens on the seabed and second in the water column due to the discharge of waste water from mining ship.

2 Marine Science and Essential Ocean and Ecosystem Variables

2.1 Market Overview

The applications and benefits of gliders for marine science research and monitoring are well known within the international scientific community and they are increasingly being used to gather cost-effective and high quality data. Glider expertise has been strongly developed across European marine research institutes, due in particular to European funding programmes for research, leading to well organized glider activities and infrastructures (for example, the EGO network) that provide valuable information to regional and global observing programs. As the next logical step from the very successful Argo programme, gliders are on track to being applied in larger numbers and in coordinated networks, towards achieving continuous, high-resolution coverage of the ocean environment, in particular in coastal areas and the continental shelves.

The BRIDGES gliders offer significant advancements on current glider inputs to marine research programs by increasing the maximum operational depth from 1000m to 5000m and offering a larger capacity for sensors per glider, resulting in the opportunity to offer further-reaching services with greater results.

This section describes the core parameters required by observing programs and some example services of how these required inputs could be delivered by BRIDGES gliders. It is also noted that these gliders and sensors can be applied extensively to marine science programmes in many different configurations, customisable to project requirements, and offer an excellent platform for the application of numerous new miniaturized sensors as they are developed.

Among all of the oceanic variables to be measured, the Essential Ocean Variables (EOV) have been underlined as being essential for ocean observation in a global context. An EOV is a concept adopted by the Global Ocean Observing System (GOOS, http://www.ioc-goos.org/) to provide a standardised approach to collect, analyse and distribute data for the implementation of coordinated observing systems. They include ocean physics, biogeochemistry, ocean biology and ecosystems, and address the variables to be measured, the approach to measuring them, and how their data and products will be managed and made widely available. EOVs are an intrinsic way of describing the natural system of the ocean and its physical, chemical, and biological properties (see Figure 2).

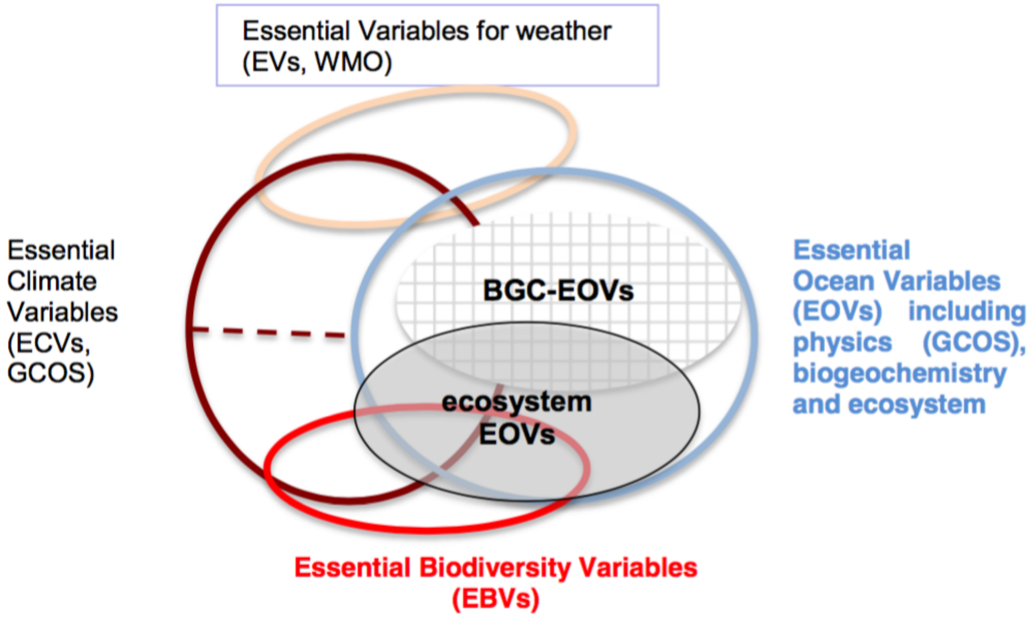

Figure 2. ***A Conceptual Overlap of Essential Ocean Variables (EOVs),*** *including the physics, ecosystem and biogeochemistry EOVs, related to other Essential Variables (climate, weather and biodiversity). [Source: Annex D]*

Describing the variables that are 'essential' to address societal issues and major scientific questions (rather than particular essential observing systems) allows for innovation and evolution of the observing techniques, while maintaining a constant output of the system, and maintaining consistency of the overall system which is composed of many sub-systems. In particular, ecosystem EOVs (eEOVs) focus on collecting information about the biotic aspects of the marine environment, enabling scientists to comment on the present status of marine habitats and ecosystems.

Definition of the EOVs for biological observations are not as simple as for physical and chemical properties, as the biological characteristics (*e.g.* biodiversity at different levels) of the ocean are more complex, and interactions between organisms less well-understood and observed. However, a number of suggestions converged around biological 'variables' that could be measured by in situ sensors mounted on gliders.

Commercially available imaging sensors such as the Underwater Vision Profiler (Picheral et al., 2010) have been mounted on CTD-Rosettes and deployed in all oceans to detect in-situ plankton and particles (Stemmann et al., 2012; Guidi et al., 2015). In parallel, development of in situ « ecogenomic sensors », such as the Environmental Sample Processor (ESP), have been realized and a few case studies on mooring systems and AUVs have proven to be useful to follow microbial dynamics (Seegers et al., 2015; Scholin 2010 ; Ussler et al., 2013). A challenge is to automate the acquisition and analyses making delivery of real-time data possible. An even harder challenge is to develop such sensors that could mechanically fit in gliders and consume little power. Miniaturisation of imaging systems is compatible with the life span of BRIDGES and their usefulness will be further addressed in the section below. Development of optical and imaging sensors to be available for gliders would provide the opportunity for more frequent and repeatable biological observations in a targeted area with much less effort required. Application of these sensors on the BRIDGES deep-sea vehicles would unlock the potential to closely monitor the deep-sea biological environment in a controlled and cost-effective way.

Key biological characteristics to be measured

- taxonomic diversity: proxy of phytoplankton taxonomic diversities can be measured by multispectral optical sensors to retrieve broad categories of phytoplankton (e.g. cyanobacteria, diatoms, …). Proxy for the diversity of larger plankton organisms such as phytoplankton colonies (for example trichodesmium) and zooplankton could be also monitored by in situ cameras mounted on CTD rosette (Sandel et al., 2015). Broad groups such as copepods, chaetognaths, jellyfishes can be detected (see Forest et al., 2012 for an example by UVP5). These groups or the ratio between them have also been proposed as descriptors for the MFSD (OSPAR convention, (http://www.ospar.org/)).
- size structure of organisms: Size is an important property affecting ecosystem processes such as the rate of production and use of particles/preys within the plankton food web. The slope of the plankton size distribution has been proposed to be a proxy of trophic transfer across food webs. Many physiological rates scale more with size than with taxonomy, and that, at similar biomass, an ecosystem constituted with smaller components will have higher rates and turnover than if composed with larger individuals. Size of copepods has been proposed as a potential indicator for descriptor 4 for the MSFD (OSPAR convention,).
- size structure of marine particles: marine particles are essential variables of pelagic systems because they provide food for organisms, vectors for organisms (for examples bacterial pathogens), vectors for the settlement of pollutions on the sea bed (Passow et al., 2012). Size structure of marine particles can be obtained with optical (particles<100μm) or imaging (particles >100μm) sensors.

The sustained monitoring of these somewhat synthetic EOVs using gliders would allow for a great expansion of the knowledge on functioning of the pelagic ecosystems at regional scales and the human impact on it (for example particle nepheloid layers around oil platforms).

2.2 Identified Services

2.2.1 Physical EOVs Service

The following three EOV services provide a collection of core measurements used to support global observing programs such as the Global Climate Observing System / Global Ocean Observing Program (GOOS/GCOS), the European Global Ocean Observing System (EuroGOOS) and future European Ocean Observing System (EOOS), the World Climate Research Programme's (WCRP) Climate Variability and Predictability Experiment (CLIVAR), as well as regional observing systems that support these global programs while also targeting national/regional/local observing objectives (e.g. IOOS in the US, IMOS in

Australia, MOOSE in the French North-West Mediterranean). This service provides physical EOVs that are needed by regional and global long term monitoring programmes.

Deep gliders can complement and advance the capabilities of autonomous platform contributions to global observing programs and established ocean transects (GO-SHIP), extending the nominal maximum depth from 1000-2000m (standard gliders and Argo floats) to 5000m. These platforms can provide a significant amount of high-quality and high-resolution data in key areas that are difficult to monitor to great depths due to environmental conditions or logistic efforts required, such as in the Southern Ocean and Arctic oceans, and deep regions of the Pacific and Atlantic Oceans.

This service provides a base set of sensors to measure essential variables throughout the deep water column. The activity of the sensors should be intelligently managed to ensure maximum endurance of the glider, such as activating the sampling of chlorophyll and nutrient measurements only in areas of interest (i.e. surface and potentially sea floor). As such, the resolution noted in the sensor tables (throughout this document) state the maximum resolution required.

For sensors that require significant time for sampling, such as the nutrient sensors, it should be possible that the deep glider vehicles can hold a depth position during the sampling, therefore implementing a step-pattern when descending or ascending.

To maximise the number of potential deployments of the deep sea gliders, the size and weight (and cost) should be kept to a minimum so to allow a wide variety of users and operators to access and use this technology. This includes maximising the possible methods of deployment and recovery and therefore the ability to use different vessels of opportunity, from small local fishing vessels to large ice-breakers.

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	>1000 km, 5km, > 2 mo
Temperature	CTD	1m vertical	>1000 km, 5km, > 2 mo
Salinity	CTD	1m vertical	>1000 km, 5km, > 2 mo
Oxygen	Optode	10m vertical	>1000 km, 5km, > 2 mo
Chlorophyll	Fluorometer	1m vertical	>1000 km, 5km, > 2 mo
Turbidity	Optical Sensor	1m vertical	>1000 km, 5km, > 2 mo

2.2.2 Biogeochemical EOVs Service

Similar to the Physical EOVs service, this service focuses on the biocheochmical parameters required to feed into regional and global observing programs and to complement the remote sensing measurements made at the sea surface with information down to 5000m depth.

As with the previous service, intelligent management of the sensors is required to ensure maximum endurance of the platforms, as well as controlled activation of the water sampler based on either fixed depths or triggered by the measured values of other onboard sensors.

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	>1000 km, 5km, > 2 mo
Temperature	CTD	1m vertical	>1000 km, 5km, > 2 mo
Salinity	CTD	1m vertical	>1000 km, 5km, > 2 mo
Oxygen	Optode	10m vertical	>1000 km, 5km, > 2 mo
pCO2	Optode	10m vertical	>1000 km, 5km, > 2 mo
Chlorophyll	Fluorometer	1m vertical	>1000 km, 5km, > 2 mo
pH/alkalinity	TBD	10m vertical	>1000 km, 5km, > 2 mo
Water Samples	Mini Water Sampler	As required	>1000 km, 5km, > 2 mo
Nutrients (Phosphates, Silicates)	Micro-fluidic cells	5mins	>1000 km, 5km, > 2 mo

2.2.3 Ecosystem EOVs Services

This service provides essential ecosystem variables required by regional and global observing programmes, providing information towards monitoring and assessment of the biodiversity of the water column and sea floor.

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	>1000 km, 5km, > 2 mo
Temperature	CTD	1m vertical	>1000 km, 5km, > 2 mo
Salinity	CTD	1m vertical	>1000 km, 5km, > 2 mo
CDOM/FDOM	Fluorometer	10m vertical	>1000 km, 5km, > 2 mo
Turbidity	Backscatter	1m vertical	>1000 km, 5km, > 2 mo
Large particles (>100µm) and plankton (>500µm) abundances and biomasses	Imaging system	TBD	>1000 km, 5km, > 2 mo
Passive acoustics	Hydrophone	~1min per 1hr	>1000 km, 5km, > 2 mo

2.3 References

Picheral, M. G., Stemmann, L., Karl, D. M., Iddaoud, G., and Gorsky, G.: The Underwater Vision Profiler 5: An advanced instrument for high spatial resolution *studies of particle size spectra and zooplankton, Limnol Oceanogr.-Meth., 8, 462–473. doi:10.4319/lom.2010.8.462, 2010*

Lars Stemmann, Marc Picheral, Lionel Guidi, Fabien Lombard, Franck Prejger, Hervé Claustre, Gabriel Gorsky (2012) Assessing the spatial and temporal distributions of zooplankton and marine particles using the Underwater Vision Profiler. CNRS Edition, ed. Françoise Gaill, Yvan Lagadeuc et Jean-François Le Galliard

Guidi, L., Legendre, L., Reygondeau, G., Uitz, J., Stemmann, L., and Henson, S. A. (2015). A new look at ocean carbon remineralization for estimating deepwater sequestration. Global Biogeochem. Cycles 29, 1044–1059. doi: 10.1002/2014GB005063

Seegers, B. N., Birch, J. M., Marin, R., Scholin, C. A., Caron, D. A., Seubert, E. L., Howard, M. D. A., Robertson, G. L. and Jones, B. H. (2015), Subsurface seeding of surface harmful algal blooms observed through the integration of autonomous gliders, moored environmental sample processors, and satellite remote sensing in southern California. Limnol. Oceanogr., 60: 754–764. doi:10.1002/lno.10082

Scholin, C. A.: What are "ecogenomic sensors?" A review and thoughts for the future, Ocean Sci., 6, 51-60, doi:10.5194/os-6-51-2010, 2010.

Ussler III W, Preston C, Tavormina P, Pargett D, Jensen S, Roman B, Marin III R, Shah SR, Girguis PR, Birch JM, Orphan V. Autonomous application of quantitative PCR in the deep sea: in situ surveys of aerobic methanotrophs using the deep-sea environmental sample processor. Environmental science & technology. 2013 Aug 8;47(16):9339-46.

Sandel, V., Kiko, R., Brandt, P., Dengler, M., Stemmann, L., Van-dromme, P., Sommer, U., and Hauss, H.: Nitrogen Fuelling of the Pelagic Food Web of the Tropical Atlantic, edited by: Anil, A. C., PLoS ONE, 10, e0131258, doi:10.1371/journal.pone.0131258, 2015.

Forest, A., L. Stemmann, M. Picheral, L. Burdorf, D. Robert, L. Fortier, and M. Babin, 2012. Size distribution of particles and zooplankton across the shelf-basin system in southeast Beaufort Sea: Combined results from an Underwater Vision Profiler and vertical net tows. Biogeosciences 9(4):1301–1320.

U. Passow, K. Ziervogel, V. Asper, A. Dierks. Marine snow formation in the aftermath of the Deepwater Horizon oil spill in the Gulf of Mexico; Environ. Res. Lett., 7 (2012), p. 11 http://dx.doi.org/10.1088/1748-9326/7/3/035301

3 MSFD and Copernicus

3.1 Market Overview

This section details the requirements for monitoring programs that may be generated by the Marine Strategy Framework Directive (MSFD) and Copernicus marine services implementation by member states, with respect to what ocean phenomena could be measured from gliders and with what time/space/parameter sampling strategy, with what quality assurance, and how data are likely to be provided. Glider configurations and missions are described to fulfil part of the needs of these monitoring programs.

The MSFD is currently in its fourth year of implementation. The EU member-states have revised their phase I implementation (the initial assessment of their marine environment, their definitions of good environmental status and their targets and indicators) based on a review by the European Commission, completed in 2014. Based on the implementation of Phase I, they established monitoring programmes with which to monitor the status of their marine environment, and are currently finalizing programmes of measures to ensure that the marine environment reaches or is maintained at a good status.

The far-reaching scope of the MSFD includes diverse aspects of the marine environment, such as biodiversity and food webs, as well as many major human activities that impinge on the seas, such as fisheries, eutrophication, alterations, and noise pollution. Moreover, it is implemented throughout the marine space over which member-states are or intent to exercise jurisdiction, which in some cases includes the entire Exclusive Economic Zones. The great demands on baseline knowledge, new investigations, and the space over which these have to be conducted, present a challenge to the member-states, as well as an opportunity for new technologies to respond to that challenge.

Copernicus is the European effort at establishing a permanent environmental service for land, atmosphere, marine, and security sectors. Established through a sequence of European projects, the current Copernicus Marine Environmental Monitoring Service (CMEMS, http://marine.copernicus.eu/) is now funded to operationally provide global and regional ocean hydrodynamic forecasts, re-analyses, and remotely-sensed products, and is managing in situ observations sent to them on a volunteer basis (CMEMS, 2016). The data collected by underwater gliders may contribute to the demands of the GOOS and the future European Ocean Observing System (EOOS) through the establishment of dedicated glider program in the GOOS and EuroGOOS. Currently, GOOS is supporting the coordination of a number of marine observation efforts (floats, research vessels, drifting buoys, and sea level stations). Gliders are soon to be an official part of GOOS and naturally share many of the same capabilities, and some unique ones, that can meet the goals of GOOS: to provide accurate descriptions of the present state of the oceans, including living resources; continuous forecasts of the future conditions, as well as the basis for forecasts of climate change (GOOS, 2016).

3.2 Identified Services

3.2.1 Water Column Habitat Service

The water column habitats service provides information on the major physicochemical conditions of the water column and phytoplankton and zooplankton/micronekton standing stocks and composition. In terms of the MSFD, three descriptors are relevant: 1 – Biodiversity, 4 – Food webs, and 5 – Eutrophication. The related monitoring programs are Biodiversity: fish and cephalopods, Biodiversity: water column habitats, and Eutrophication. Each member state must define the Good Environmental Status (GES) regarding these descriptors and establish the monitoring programmes and programmes of measures needed to achieve GES. In some cases, member states may show that no action is necessary, and therefore no “programme of measures” nor even monitoring is justified. However, every coastal state is likely to require some monitoring of the water column for the purpose of habitat characterization. In addition, the Copernicus Marine Monitoring Service is expected to actively support in situ observations through various regional ocean observation systems and perhaps the European Ocean Observing System (EOOS). This will require marine monitoring for "biodiversity and environmental protection" applications, as well as "agriculture, forestry, and fisheries." Note that this service does not consider anoxic deep sea habitats which will require a different suite of parameters.

In order to provide this service, the D- and UD-Explorers should measure the following parameters as follows. Example sensors and orders of magnitude for sampling resolution are provided.

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, > 1 mo
Temperature	CTD	1m vertical	100 km, 5km, > 1 mo
Salinity	CTD	1m vertical	100 km, 5km, > 1 mo
Oxygen	Optode	10m vertical	100 km, 600 m, > 1 mo
Nutrients (Nitrates, Phosphates)	Micro-fluidic cells	5mins	100 km, 300 m, > 1 mo
Chlorophyll-a	Fluorometer	1m vertical	100 km, 300 m, > 1 mo
CDOM/FDOM	Fluorometer	1m vertical	100 km, 300 m, > 1 mo
Turbidity	Backscatter	1m vertical	100 km, 5km, > 1 mo
Large particles (>100µm) and plankton (>500µm) abundances and biomasses	Imaging system	TBD	100 km, 300 m, > 1 mo

The sampling design recommended in this case is a simple 3-D survey covering the area of interest evenly. Each member state would need to determine what areas and times are of interest depending upon local needs. Data collected from gliders need to be accompanied by water samples for laboratory analysis at control stations on a regular basis. Each of the parameters above is associated with an internationally recognized sampling and laboratory protocol. Data should be provided in community-accepted standard (EGO NetCDF format: *EGO gliders User's manual,* Carval T. et al. (2013)) in time-based trajectory and profile formats. Raw and corrected data and quality control information should be included when possible, along with calibration data and other metadata describing the glider mission and processing. When comparison with water samples is not possible, a standard protocol is recommended in order to compare sensors to each other and over time. For example, a standard solution or set of solutions that have a known fluorescence response can be used to calculate phytoplankton biomass as in Davis et al. (2008) in which the chlorophyll fluorometer before and after each mission are characterized in the lab with a set of dilutions of pure Chl-a (Sigma C6144), and raw counts are then converted to DCFE: dissolved Chl-a Fluorescence Equivalents. One DCFE is the signal produced by 10 micrograms/L of the pure Chl-a in 90% acetone.

3.2.2 Hydrographic Service

The above service largely supersedes the fundamental hydrographic service that is expected of gliders. Historically, gliders have performed well providing this service in national research facilities in order to support the assessment of hydrographic conditions in the water column for many reasons. In terms of MSFD, it is important to note that the installation, presence, and maintenance of human structures may impact circulation and, consequently, residence times, which in turn may affect temperature, salinity, oxygen concentrations and turbidity. The relevant descriptors are: 1 – Biodiversity, 4 – Food webs, 6 – Seafloor integrity, and 7 – Hydrographical conditions. The member states may implement monitoring programmes for Biodiversity: water column habitats, Biodiversity: seabed habitats, and Hydrographical changes to evaluate their programme of measures. These require the Hydrographic Service that could be provided by gliders as follows. As above, the Copernicus Service requires the same service for Biodiversity and Environmental Protection.

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, > 1 mo
Temperature	CTD	1m vertical	100 km, 5km, > 1 mo
Salinity	CTD	1m vertical	100 km, 5km, > 1 mo
Oxygen	Optode	10m vertical	100 km, 600 m, > 1 mo
Sea Currents	ADCP	2m vertical	100 km, 300 m, > 1 mo
Turbidity	Backscatter	1m vertical	100 km, 5km, > 1 mo
Large particles (>100μm) and plankton (>500μm) abundances and biomasses	Imaging system	TBD	100 km, 300 m, > 1 mo

3.2.3 Oil and Gas Service

The oil and gas service supports activities related to the exploration and extraction of hydrocarbons and their accidental/incidental release into the marine environment. This is discussed further in the next market section on Oil & Gas services. It is important to note here, however, that the MSFD is relevant because of descriptor 8—Contaminants and the monitoring programme of the same name. Again the Copernicus Application Domain “Biodiversity and Environmental Protection” is also relevant here. The following service is recommended for the D and UD SEA EXPLORERs.

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, > 1 mo

Temperature	CTD	1m vertical	100 km, 5km, > 1 mo
Salinity	CTD	1m vertical	100 km, 5km, > 1 mo
Oxygen	Optode	10m vertical	100 km, 600 m, > 1 mo
Crude and Refined Oil	Fluorometers	10m vertical	100 km, 5 km, > 1 mo
Emulsified and Suspended Oil	Imaging system	10m vertical	100 km, 5 km, > 1 mo
Turbidity	Backscatter	1m vertical	100 km, 5km, > 1 mo
CDOM/FDOM	Fluorometer	1m vertical	100 km, 300 m, > 1 mo

It is emphasized that true concentrations are very difficult to achieve and gliders will mostly provide a qualitative indication of regions that need further attention, thus economizing efforts for ship-board sampling. Also, it is important that the above parameters are measured near to the seafloor, where oil blowouts and sediment plumes may be generated. For this reason, it is advantageous for the glider to fly horizontally using the propeller. As discussed in (Daly et al., 2016), oil aggregates with marine particles to form larger marine snow type particles which can be seen by the imaging sensor to be developed in BRIDGES.

3.2.4 Climate Change Service

The climate change service can provide information on the major components of the marine ecosystem affected by climate change: (a) temperature, and (b) the carbon cycle and acidification. While the MSFD and the Commission Decision issued thereafter did not identify specific Descriptors to address this global issue, subsequent reporting requirements included provisions that suggest that this pressure will be formally include in MSFD-related activities in the future. In particular, Descriptor 1—Biodiversity and the related monitoring programme for Biodiversity: water column habitats are directly related. The Copernicus Marine Monitoring Service also addresses the issue through the Application Domain “Biodiversity and Environmental Protection” and “Climate and Energy.”

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, > 1 mo
Temperature	CTD	1m vertical	100 km, 5km, > 1 mo
Salinity	CTD	1m vertical	100 km, 5km, > 1 mo
Oxygen	Optode	10m vertical	100 km, 600 m, > 1 mo

pCO2	Optode	10m vertical	100 km, 5 km, > 1 mo
Methane for Greenhouse Gas Emissions	METS	10m vertical	100 km, 5 km, > 1 mo
pH/alkalinity	TBD	10m vertical	100 km, 5km, > 1 mo
Large particles (>100µm) and plankton (>500µm) abundances and biomasses	Imaging system	TBD	100 km, 5km, > 1 mo

It is important that the observations above parameters are strictly quality controlled and are collected by regularly-calibrated instruments in order for comparison with the global inventory of climate-related parameters. This also makes it important for the format to be a widely-accepted one (EGO NetCDF, which meets the NetCDF Climate and Forecast metadata conventions). Partial pressure of carbon dioxide, methane, and pH measurements from gliders are in their infancy, so quality is not yet acceptable in some cases, but this is already changing as seen in a recently-released pH sensor (Fluidion).

3.2.5 Underwater Noise Service

The underwater noise service supports the collection of baseline and source-specific information on underwater noise. The relevant MSFD Descriptor is 11—Noise, with the monitoring programme of the same name. To the Hydrographic service, an acoustic listening device (hydrophone) should be added with the proper characteristics to measure background sound pressure levels (1 Hz-100 kHz). It should be noted that hydrophones could also be used to characterize marine mammal populations (distribution and abundance) which is notoriously difficult from other platforms. An example is a recent tender released by the Department of Fisheries and Marine Research of Cyprus to characterize cetacean population and distribution using a visual and acoustic survey. Even though the terms of reference were specific to ship-based surveys, at least one bidding team has included a Passive Acoustic Monitoring-capable glider in its plans. This work will be co-funded by the European Maritime and Fisheries Fund (EMFF) and the Republic of Cyprus. Recent advances in processing have allowed gliders to identify and report specific detections in some cases, even in near real time (Klinck et al., 2012, Bogue and Luby 2011, Hurst et al. 2012)).

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, > 1 mo
Temperature	CTD	1m vertical	100 km, 5km, > 1 mo
Salinity	CTD	1m vertical	100 km, 5km, > 1 mo
Oxygen	Optode	10m vertical	100 km, 600 m, > 1 mo

Ambient low frequency sound	Omnidirectional Hydrophone	~1min per 1hr	10 km, 5km, > 1 mo
Chlorophyll-a	Fluorometer	1m vertical	100 km, 300 m, > 1 mo

For acoustic measurements, the glider should spend a large portion of time in the sound channel, typically a mid-depth region of maximum sound speed. This will increase the sensitivity to low frequency sounds from a wide range of sources and not just local sources. Parameters oxygen and chlorophyll are retained, being relatively easy components of the water column habitat service.

3.3 References

CMEMS, 2016. The European Programme for the establishment of a European capacity for Earth Observation, http://www.copernicus.eu/ accessed, 1 March 2016.

Davis, R.E., Ohman, M.D., Rudnick, D.L., Sherman, J.T., Hodges, B., 2008. Glider surveillance of physics and biology in the southern California Current System. Limnol. Oceanogr. 53, 2151–2168.

Daly, Kendra L., Passow, Uta, Chanton, Jeffrey, Hollander, David, Assessing the impacts of oil-associated marine snow formation and sedimentation during and after the Deepwater Horizon oil spill.Anthropocene http://dx.doi.org/10.1016/j.ancene.2016.01.006

GOOS, 2016. The Permanent Global System for Observations, Modelling, and Analysis of Marine and Ocean Variables to Support Operational Ocean Services Worldwide. http://www.ioc-goos.org/ Accessed 1 March 1, 2016.

Ussler III, W., Preston, C., Tavormina, P., Pargett, D., Jensen, S., Roman, B., Marin III, R., Shah, S.R., Girguis, P.R., Birch, J.M., Orphan, V., Scholin, C. (2013). Autonomous application of quantitative PCR in the deep sea: In situ surveys of aerobic methanotrophs using the Deep-Sea Environmental Sample Processor. Environmental Science and Technology 47, 9339-9346

Scholin, C.A., 2010. What are "ecogenomic sensors?" A review and thoughts for the future. Ocean Science 6, 51-60.

Seegers, B.N., Birch, J.M., Marin, R., Scholin, C.A., Caron, D.A., Seubert, E.L., Howard, M.D.A., Robertson, G.L., Jones, B.H., 2015. Subsurface seeding of surface harmful algal blooms observed through the integration of autonomous gliders, moored environmental sample processors, and satellite remote sensing in southern California. Limnology and Oceanography 60, 754-764.

Guidi, L., Legendre, L., Reygondeau, G., Uitz, J., Stemmann, L., Henson, S.A., 2015. A new look at ocean carbon remineralization for estimating deepwater sequestration. Global Biogeochem. Cycles 29, 1044-1059.

Ziervogel, K., D'Souza, N., Sweet, J., Yan, B., Passow, U., 2014. Natural oil slicks fuel surface water microbial activities in the northern Gulf of Mexico. Frontiers in Microbiology 5.

Joye, S.B., Crespo-Medina, M., Hunter, K., Asper, V., Diercks, A., Passow, U., Montoya, J., Benitez-Nelson, C., Moore, W., Demopoulos, A., Highsmith, R., 2013. Increased sedimentation and altered nutrient cycling in the aftermath of the Macondo oil well blowout. Abstracts of Papers of the American Chemical Society 245.

Passow, U., Ziervogel, K., Asper, V., Diercks, A., 2012. Marine snow formation in the aftermath of the Deepwater Horizon oil spill in the Gulf of Mexico. Environmental Research Letters 7.

Forest, A., Stemmann, L., Picheral, M., Burdorf, L., Robert, D., Fortier, L., Babin, M., 2012. Size distribution of particles and zooplankton across the shelf-basin system in southeast Beaufort Sea: combined results from an Underwater Vision Profiler and vertical net tows. Biogeosciences 9, 1301-1320.

Sandel, V., Kiko, R., Brandt, P., Dengler, M., Stemmann, L., Vandromme, P., Sommer, U., Hauss, H., 2015. Nitrogen Fuelling of the Pelagic Food Web of the Tropical Atlantic. PloS one 10, e0131258-e0131258.

4 Living Resources

4.1 Market Overview

This section describes the potential services of deep-sea gliders for services regarding living resources in the water column and at the seafloor.

Glider configurations and missions are designed for exploration, monitoring and mapping of different scales of marine life. The deep-sea platforms allow deeper monitoring opportunities for marine mammals, included here because it is becoming a mature application for standard gliders with passive acoustics, as well as for microorganism diversity throughout the water column.

Glider services are also identified for the exploration of pelagic marine microorganisms for marine resource exploitation and management. As benthic habitat can provide resources, but can also be affected by marine activities like offshore aquaculture, glider missions with hybrid propulsion at the bottom are also considered.

4.2 Identified Services

4.2.1 Marine Mammals Service

The deep glider vehicles will provide an excellent platform for passive acoustic monitoring due their ability to glide through the water column silently. The vehicles also offer the opportunity controlled flight to an area and/or depth of interest and then silently ‘parking’ to record ambient noise over a period of time, for example resting in the SOFAR channel or at the sea-bed. This marine mammal monitoring service is closely aligned with the Underwater Noise service of the previous market segment on MSFD services.

A single glider can be used to detect and confirm the presence of certain marine mammals, whereas a fleet of 2-4 gliders could be used to further precise the locations of the sound sources. This will require reasonable post-processing for time synchronisation and correction of the measurements, and dead-reckoning and current compensation for vehicle positioning.

This service could be used to complement existing marine mammal monitoring programs (European Cetacean Monitoring Coalition, Whalesafe LIFE programme) as well as collision prevention alerting in important shipping channels (Right Whale Listening Network, US).

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	1000 km, 5km, > 2 mo
Temperature	CTD	1m vertical	1000 km, 5km, > 2 mo
Salinity	CTD	1m vertical	1000 km, 5km, > 2 mo
Ambient low frequency sound	Omnidirectional Hydrophone	~1min per 1hr	1000 km, 5km, > 2 mo

4.2.2 Micro/Macro-Organisms Service

This service focuses on the detection and analysis of micro and macro organisms in the deep water-column. BRIDGES is further researching the possible applications of deep gliders for this service in collaboration with leading institutes in the field such as the European Marine Biological Resource Centre (EMBRC), LECOB in France and IMR in Norway. Continued research by BRIDGES is also underway in further defining possible services for genomic sampling (MBARI Environmental Sample Processor) and biotechnology/pharmaceutical applications (European Centre for Marine Biotechnology).

This example service provides a demonstration deep-sea payload that could be used to complement such exploration, and will be subject to continued research and refining based on industry feedback.

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, > 1 mo
Temperature	CTD	1m vertical	100 km, 5km, > 1 mo
Salinity	CTD	1m vertical	100 km, 5km, > 1 mo
Oxygen	Optode	10m vertical	100 km, 5km, > 1 mo
pCO2	Optode	10m vertical	100 km, 5km, > 1 mo
Chlorophyll-a	Fluorometer	1m vertical	100 km, 5km, > 1 mo
CDOM/FDOM	Fluorometer	1m vertical	100 km, 5km, > 1 mo
Large particles (>100µm) and plankton (>500µm) abundances and biomasses	Imaging system	TBD	100 km, 5km, > 1 mo

4.2.3 Benthic Habitats Service

The Benthic Habitats service offers an example for monitoring and mapping of the benthic environment and biodiversity of the sea-bed down to 5000m depth. This service is enhanced by employing the hybrid flight mode of the glider to conduct short horizontal surveys along the sea floor.

Modern technologies have changed our view of the deep seafloor, providing exploration to allow insight into the diversity and density of deep-sea habitats. Benthic communities have been found to flourish due to geological features throughout the worlds oceans, such as subsea canyons and mountains that provide paths for nutrient-rich brines to reach deeper waters, and hydrothermal vents, a ground-breaking discovery in 1977 (Scripps Institute, WHOI, 1977), which emit superheated fluids loaded with metals and gases into the benthic waters and result in a bloom of biological activity and have proven that such communities can grow based on chemosynthesis rather than photosynthesis. Deep gliders can effectively be applied to detect and monitor such geological and biological activity to help map and preserve these communities throughout the world oceans.

Deep-water corals and sponges take tens of thousands of years to grow in very stable conditions (The Biology, Ecology and Vulnerability of Deep-water Coral Reefs, Rogers, 2004). These habitats are very fragile to subtle environmental changes such as temperature and ocean acidification, as well as more destructive operations such as bottom trawling. Monitoring of these habitats and the water column near the seafloor (demersal zone) would provide critical information on the status and changes of these environments with high temporal and spatial resolution.

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, > 1 mo
Temperature	CTD	1m vertical	100 km, 5km, > 1 mo
Salinity	CTD	1m vertical	100 km, 5km, > 1 mo
Oxygen	Optode	10m vertical	100 km, 5km, > 1 mo
Turbidity	Backscatter	1m vertical	100 km, 5km, > 1 mo
CDOM/FDOM	Fluorometer	1m vertical	100 km, 5km, > 1 mo
Methane	TBD	10m vertical	100 km, 5km, > 1 mo
Large particles (>100µm) and plankton (>500µm) abundances and biomasses	Imaging system	TBD	100 km, 5km, > 1 mo
Water Sampler	Sampler	As required	100 km, 5km, > 1 mo

5 Offshore Oil and Gas Industries

5.1 Market Overview

This section details the requirements and potential users within the oil and gas industry, to enable safe and environmentally sound subsea operations. This includes monitoring in connection with baseline studies, operational monitoring during exploration and drilling, production and after decommissioning. Measurement scenarios consist of detection of natural and accidental leaks, discharge of drill cuttings, produced water, and inspection. Stakeholders can roughly be divided into two groups: operators and regulators. Both of them will likely use sub-contractors for glider operations.

Gliders have a potential in the oil and gas industry, as already demonstrated for specific application, particularly if the technology offers a cost-efficient way of collecting data relevant to operations and environmental status. The cost-efficient aspect has become even more significant after the dramatic reduction in the price of oil since 2014. Gliders can also become an important component in the move from the current discontinuous off-line monitoring regime to a continuous near real-time monitoring regime.

The move to higher latitudes and deeper waters accentuates the need for knowledge and adequate monitoring technologies (Lloyd's, 2012). Operational constraints to protect vulnerable habitats and biological life cycles, as well as securing safe operation under challenging conditions, require both basic background knowledge and real-time monitoring of processes that are not currently available or sufficiently cost-effective to implement.

Subsea gliders have been successfully demonstrated in a few applications for the oil and gas industry. The main applications so far have been related to oil-spill responses and oil-spill preparedness, and some operational uses of gliders have been shared publicly (Rutgers University, http://rucool.marine.rutgers.edu/deepwater/). The main advantages of gliders are low cost and long mission duration capabilities. Monitoring tasks too costly to carry out with conventional equipment such as large vessels, ROVs, or traditional AUVs, can become feasible with gliders. The combination of long endurance and low cost can facilitate many applications of gliders throughout the life of an oil/gas field, applications which are either too expensive or not possible using the equipment available today.

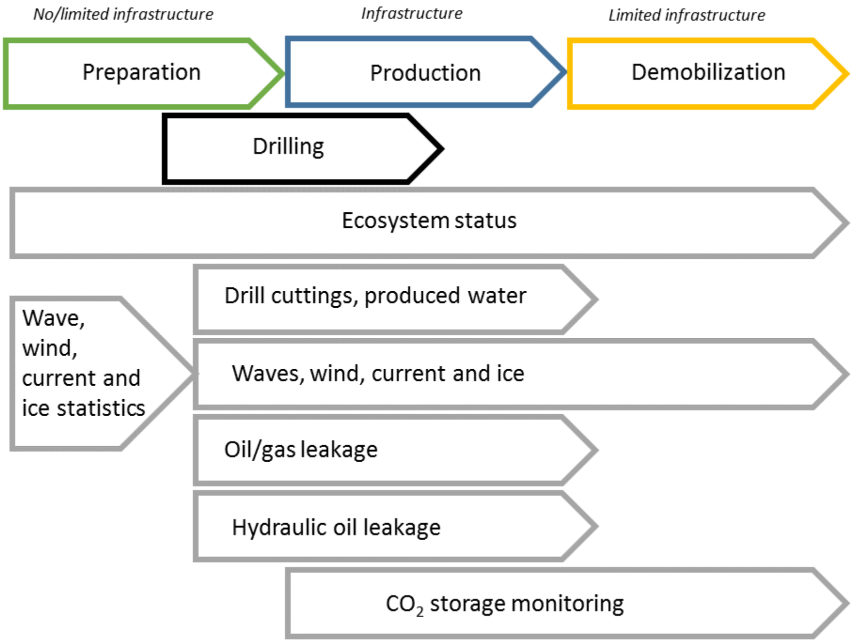

Figure: Lloyd's, 2012. ARCTIC OPENING: Opportunity and Risk in the High North, 60pp.

5.2 Identified Services

5.2.1 Pre-Exploration Service

The pre-exploration service provides data to capture the baseline conditions of the marine environment prior to any industrial activity or operations. This data is needed by national regulators and operators who will utilize the data (e.g. current measurements) in designing their operations.

5.2.1.1 Baseline Environmental Conditions

Environmental monitoring in the preparation, production and demobilization phases are governed by national regulatory bodies and international agreements. Environmental monitoring of offshore oil and gas activities includes monitoring of the water column and of benthic habitats (sediments, soft-bottom fauna and hard-bottom fauna). Current monitoring regimes and legislation for benthic and water column monitoring relies on established technologies (best available practices/best available techniques), with few methodological and technological advances over the last decades. See e.g. OSPAR Guidelines for Monitoring Environmental Impact of Offshore Oil and Gas Activities (OSPAR, 2004) or the implementation in the Norwegian sector (Miljødirektoratet, 2015). The development of technology and methodology for improved environmental observations are up to the operators, and new methodology can not be included in regulations if it relies on one particular technology from one manufacturer. In recent years it became clear that natural sources of hydrocarbons, such as methane seepages, are more common than was previously thought. The identification of natural sources is in the interest of the operators and with sensors under development, gliders are likely to be useful in that mission.

Currently baseline environmental surveys are typically conducted by a third party prior to exploration drilling in new areas and before production drilling. The surveys are basically sea floor habitat survey and consists of seafloor samples, sediment analysis for heavy metals and hydrocarbons in addition to study the biodiversity in the soft-bed fauna composition. Visual surveys might be conducted as well, particularly in areas with vulnerable sea floor fauna like corals and sponges.

5.2.1.2 Baseline Operational Data

The collection of high-quality in situ MetOcean data are important for the success of offshore oil and gas projects. These data are required to assure a safe and cost-efficient design as well as installation and operation. The most important data being wind, waves, and currents at the location of the installation. Depending on the location and operations other factors such as ice conditions, conductivity, air pressure, temperature (air and sea), and visibility might also be important. MetOcean data is collected by private industry often under contract to oil and gas operators, in addition to the majority of MetOcean observations, which is collected by research institutions and governmental organizations. This data collection, prior to permanent infrastructure, is costly and to a large degree rely on the use of moorings and vessels. This data is used directly, as input to oceanographic and atmospheric models or to implement in or validate hind cast. This data is relevant for preparation for environmental events, for example prevailing currents will dictate where to have ships for case of spills.

Gliders are well suited for baseline operational data such as CTD and currents, as has been demonstrated by several groups. Gliders are not the optimal solution for the majority of the current regulated baseline environmental sampling. However, for visual and acoustic seabed mapping, especially in deep water, gliders can be cost-efficient alternative to ROVs and AUVs. Hybrid gliders will be even more suitable for these tasks. Gliders can also provide additional measurements currently not required under the environmental sampling regimes and contribute to a more persistent presence, at relatively low cost, for example chemical sensing in the water column.

- Required platform endurance: 2-3 weeks
- Required platform modifications: no modifications are required
- On-board autonomy and intelligence: no modifications are required
- Payloads and sensing sampling: hydrographic (including currents) and biodiversity packages
- Communications, and Data processing and dissemination: no modifications are required

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, 2-3 wks
Temperature	CTD	1m vertical	100 km, 5km, 2-3 wks
Salinity	CTD	1m vertical	100 km, 5km, 2-3 wks
Current	ADCP	2m vertical	100 km, 300m, 2-3 wks

5.2.2 Exploration, Development and Extraction Monitoring Service

Environmental monitoring during production consists of regular field-specific and regional monitoring surveys, usually commencing after production drilling has started. Field-specific monitoring surveys are part of the regional program, and are carried out at the same time. E.g. the Norwegian continental shelf is divided into eleven geographical regions for monitoring of benthic habitats, and as a general rule, each region should be surveyed every third year, and the surveys should alternate between regions. Basic components of the benthic and water column monitoring are similar for the Atlantic, North Sea and the Mediterranean.

The benthic sampling consists of samples of sediments and the benthic fauna, collected using an approved grab sampler. In cases where a grab sampler may not be suitable (e.g. depths exceeding 500 m), visual surveys using remotely operated or towed observation gear should be used.

Water column monitoring shall document whether and to what degree marine organisms are impacted by pollution generated by offshore petroleum activities. The monitoring should include oceanographic measurements, analysis of chemical parameters and investigations of both field transplanted organisms placed in cages and wild caught organisms. The oil and produced water stream contain heavy metals, naturally occurring radioactive material and organic substances, some of which are discharged with the produced water after treatment. As the fields age, produced water becomes more dominant. The need for further development of methodology and technology for water column monitoring are acknowledge by regulatory bodies. The development of these methods and technologies are however left with the operators.

The move to higher latitudes and deeper waters accentuates the need for increased, and preferably continuous, environmental monitoring. In order to document Good Environmental Status, the reporting requirements under the Marine Strategy Framework Directive will potentially drive the implementation of further monitoring related to oil and gas activity.

- Purpose and application: Data is needed to (1) monitor the environment; (2) identify environmental hazards (e.g. leak detection)
- Required platform endurance: 2-3 weeks
- Required platform modifications: no modifications are required
- On-board autonomy and intelligence: on-board processing of certain sensor is required, and upon detection of hazard an immediate surfacing
- Payloads and sensing sampling: hydrographic (including currents), biodiversity, oil and gas packages
- Communications, and Data processing and dissemination: no modifications are required

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, 2-3 wks
Temperature	CTD	1m vertical	100 km, 5km, 2-3 wks
Salinity	CTD	1m vertical	100 km, 5km, 2-3 wks

Oxygen	O2	10m vertical	100 km, 5km, 2-3 wks
Crude/refined oil	Cyclops 6K	10m vertical	100 km, 5km, 2-3 wks
Turbidity	Cyclops 6K	1m vertical	100 km, 5km, 2-3 wks
Current	Indirect	TBD	100 km, 5km, 2-3 wks

5.2.3 Leakage/Discharges Service

In the event of an oil or gas spill, the primary goal is to minimize the impact of the spill on humans, communities and the environment. Oil and/or gas leakages can occur in different sizes and from a range of sources such as subsea installations, wellheads, pipelines, risers and vessels.

Considerable effort has been put in to leakage detection and containment methodology and technology after the Macondo Well blow-out. The need for, preferably near real-time, leakage detection is also vital for petroleum activities in vulnerable marine areas (e.g. Arctic region, deep water, areas with corals and sponges). The trend in leakage detection is towards permanently installed leakage detection systems (depending on infrastructure), often combined with the use of autonomous vehicles.

Most leakages are considered to occur within a radius of 500 m of a subsea petroleum installation (Det Norske Veritas DNV, 2010 – based on reported leakages on the Norwegian sector), though many leakages beyond this radius may not have been found. The largest hydrocarbon leakages statistically occur when the operation is unsteady, such as during start-up, shut down, and maintenance. DNV's recommended practice for the selection and use of subsea leak detection system (DNV, 2010) will be revised under the current Oil Spill Response Joint Industry Project (OSR-JIP).

Leakage detection is in many cases not specified in the laws and regulations, but requirements regarding detection capabilities can be addressed. The US "Transportation of Hazardous Liquids by Pipeline" requires that an operator must have a means to detect leaks on its pipeline system. Norwegian Activity Regulations (PTIL, 2015) requires operators to establish remote sensing systems to detect and map the position, area, quantity and properties of acute pollution. This sensing system should be as independent of environmental conditions as possible (e.g. visibility and weather conditions). The operators shall also cooperate in establishing a system ensuring detection and mapping of acute pollution that has driven away from the facility. Requirements of the Climate and Pollution Agency (Klif) states that acute pollution shall be detected as soon as possible, and at the latest within 3 hours from when the pollution took place for manned installations and operations, 1-hour detection criteria on installations close to vulnerable areas. For unmanned subsea installations, detection within 6-24 hours. EU has the IPPC (Integrated Pollution Prevention and Control) directive 28, with the objective to prevent and limit pollution from the industry. BAT-Best Available Techniques is one of the four main principles in IPPC. Permissions for industrial installation shall be given following this directive and be based on the BAT principle. There are no universal frameworks for conducting BATs. Regardless of the regulation, it is beneficial for the operator to identify leaks as soon as possible, thus the operators are expected to adopt any available cost-effective measure to identify and deal with leakages.

In the event of an uncontrolled discharge the event must be verified and the scale of the discharge and its potential impact must be estimated. Gliders can provide a cost-efficient way of **detecting** and **tracking** underwater oil spills, which has been demonstrated e.g. in the Gulf of Mexico (Section 1.2). In addition to detecting hydrocarbons in water the gliders can also provide data on additional important variables throughout the water column (e.g. CTD, currents). These variables can be assimilated in operative numerical models and improve their predictive capabilities.

- Purpose and application: Tracking spills and discharges
- Required platform endurance: up to 14 days
- Required platform modifications: hybrid capabilities (propeller)
- On-board autonomy and intelligence: on-board processing of certain sensor is required, and ability to navigate the platform
- Payloads and sensing sampling: hydrographic (including currents), oil and gas packages
- Communications, and Data processing and dissemination: short-range fast communication

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, 2 wks
Temperature	CTD	1m vertical	100 km, 5km, 2 wks
Salinity	CTD	1m vertical	100 km, 5km, 2 wks
Oxygen	O2	10m vertical	100 km, 5km, 2 wks
Crude/refined oil	Cyclops 6K	10m vertical	100 km, 5km, 2 wks
Turbidity	Cyclops 6K	1m vertical	100 km, 5km, 2 wks
Large particles (>100µm) abundances and biomasses	Imaging systems	TBD	100 km, 5km, 2 wks

5.2.4 Decommission Service

Many oil and gas installations in e.g. the North Sea are projected to be decommissioned over the next decades; Douglas-Westwood (Douglas-Westwood, 2016) estimates the decommissioning of 150 installations over a 10-year period. This will require new and improved methods and technologies for monitoring. Operators are required to demonstrate that the environmental conditions are back to normal (or near normal) before approving the abandonment successful.

Decommissioning contain many environmental concerns which must be taken into account in from planning to shutdown and waste disposal. Environmental monitoring is necessary e.g. to assess the impact of moving contaminated sediments in the decommissioning process.

Currently visual or acoustic methods, or a combination of the two, may be used during decommissioning, after decommissioning benthic surveys and as in the preparation and production phase (grab sample surveys) are the norm.

Gliders has a potential for providing valuable data during decommissioning in the form of visual, turbidity, CTD, and current data collection.

- Purpose and application: Data is needed for evaluation of the environmental condition upon decommission
- Required platform endurance: 2-3 weeks
- Required platform modifications: no modifications are required
- On-board autonomy and intelligence: no modifications are required
- Payloads and sensing sampling: hydrographic and biodiversity packages
- Communications, and Data processing and dissemination: no modifications are required

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, 2-3 wks
Temperature	CTD	1m vertical	100 km, 5km, 2-3 wks
Salinity	CTD	1m vertical	100 km, 5km, 2-3 wks
Oxygen	O2	10m vertical	100 km, 5km, 2-3 wks
Crude/refined oil	Cyclops 6K	10m vertical	100 km, 5km, 2-3 wks
Turbidity	Cyclops 6K	1m vertical	100 km, 5km, 2-3 wks
Current	Indirect	TBD	100 km, 5km, 2-3 wks
Large particles (>100µm) and plankton (>500µm) abundances and biomasses	Imaging system	TBD	100 km, 5km, 2-3 wks
Acoustic/camera	TBD	TBD	100 km, 5km, 2-3 wks

5.2.5 Pipelines Services

A vast network of pipelines on the seafloor transport a large volume of oil and gas over short and long distances. Oil and gas is transported from the production wells to the processing plants and consumption sites. The integrity of these pipelines may be affected by degradation over time and impacts from outside force. Subsea pipeline surveying is of interest to monitor the integrity of the pipeline (e.g. cathodic protection, corrosion, wall thickness, coating), movement of the seafloor, weather the pipeline is buried or not, damage by external forces, and possible leakage of oil and gas into the water column.

Today both large AUVs and ROVs are successfully used with different sensors for pipeline inspection, and considered mature technology (depending on the sensors). State-of-the-art AUV pipeline inspection consists of a first pass with a lateral offset from the pipeline for wideswath high resolution imaging and bathymetry and side-scan data collection, if accurate pipeline position is not available, followed by a second pass directly above the pipeline with data collection using cameras and active acoustics (e.g. multibeam echosounder). Leakages can be detected with the acoustic equipment and/or chemical sensors.

Gliders with hybrid capabilities, USBL navigation, and up to date pipeline position with hydrographic (CTD, current) and “sniffer” sensors (PAH, CH4, …) can potentially become a cost-efficient alternative or addition for pipeline leakage detection. Addition of active acoustic sensing capabilities would be a bonus. For pipeline integrity capacitive sensors as well.

- Purpose and application: Identify leakages from pipelines
- Required platform endurance: 2-3 weeks
- Required platform modifications: (1) hybrid capabilities (propeller); (2) navigation using USBL
- On-board autonomy and intelligence: upon detection of leakage fix-point location and immediate surfacing
- Payloads and sensing sampling: hydrographic and oil and gas packages
- Communications, and Data processing and dissemination: no modifications are required

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, 2-3 wks
Temperature	CTD	1m vertical	100 km, 5km, 2-3 wks
Salinity	CTD	1m vertical	100 km, 5km, 2-3 wks
Oxygen	O2	10m vertical	100 km, 5km, 2-3 wks
Crude/refined oil	Cyclops 6K	10m vertical	100 km, 5km, 2-3 wks
Turbidity	Cyclops 6K	1m vertical	100 km, 5km, 2-3 wks
Current	Indirect	TBD	100 km, 5km, 2-3 wks
Acoustic/camera	TBD	TBD	100 km, 5km, 2-3 wks

5.2.6 Operational Oceanography Service

Operational numerical models are in use by different organizations, including governmental and academic institutes and commercial companies. These are used for various applied purposes, such as safety of transportation and for search and rescue. Specifically, in case of oil and gas spills, these models are used estimate and predict the wind, wave, hydrographic conditions, and ocean current fields, which determine the dispersion of the oil and gas.

By using in-situ observations (conducted from ship, mooring, satellites, gliders, etc.) and a process called ‘data assimilation’, the predictive capabilities of these models are improved, especially near the sources of the assimilated observations. In case of incident, gliders will be useful for providing hydrographic data from all depths, that when assimilated into operational ocean models, significantly improve their predictive capabilities, thus facilitating a more efficient response and mitigating the effect.

The operational system can also prove useful for all stages of the lifetime of oil and gas infrastructure, and not just for oil spill response. By performing data assimilation in near real time, the present and future conditions are well known and ocean “storms” can be predicted with accuracy thus assisting off shore operational decisions. Data assimilation also provides background climatology of currents and hydrography when performed over years of glider data collection. Instead of measuring currents directly, it is possible that calculating depth-average currents with the glider navigation model and at the same time hydrodynamic currents based on assimilation is more accurate and reliable. It also provides 3-D currents in a large region around the glider, and for a multi-day time period. It was shown in Hayes et al (2013) how the assimilation of glider data south of Cyprus dramatically changed the current structure by including the effect of a large mesoscale feature, the Cyprus eddy.

- Purpose and application: Acquire data for assimilation into circulation and spill models
- Required platform endurance: 2-3 weeks
- Required platform modifications: no modifications are required
- On-board autonomy and intelligence: no modifications are required
- Payloads and sensing sampling: hydrographic package
- Communications, and Data processing and dissemination: no modifications are required

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, 2-3 wks
Temperature	CTD	1m vertical	100 km, 5km, 2-3 wks
Salinity	CTD	1m vertical	100 km, 5km, 2-3 wks
Current	TBD	TBD	100 km, 5km, 2-3 wks

5.2.7 Monitoring Carbon Capture and Storage (CCS) Sites for CO_2 leakage

CCS is gaining momentum with large projects and investments underway in Europe and the rest of the world. Sub-seafloor CO_2 injection is both an important tool for enhanced oil recovery as well as an important climate action by reducing to emission of CO_2 into the atmosphere. Cost-efficient monitoring of these sites is still a challenge that must be addressed to enable safe and full-scale sub-seabed CO_2 storage in geological formation. As with any subsea leakage monitoring strategy wide area coverage combined with sensitive detection thresholds are required.

CO_2 storage sites have generally a large spatial extent and a large overlaying volume of water. E.g. the Utsira Formation, where CO_2 is injected from Sleipner, covers an area that is 450 km in North-South direction and 90 km in East-West direction. The Lula field with the deepest CO_2 injection well and CO_2-EOR project in operation is located in the Santos Basin, with depths exceeding 2 km and an area exciding 300 km^2.

Monitoring such sites with traditional platforms (large AUVs, ROVs) and/or from vessels are costly. In addition to the geographical extension, the potential leakage sources may be localized and/or dispersed, which makes subsea CO_2 monitoring highly challenging. Gliders can offer observations over large areas at a relatively low cost thus providing a cost-efficient addition for detecting leakage from CO_2 storage reservoirs.

The CO_2 leakage detection application require standard oceanographic sensors (CTD, current) in addition to sensing capabilities for CO_2 in water. CO_2 may be found dissolved in water, in gas form (bubbles) or in liquid form depending on environmental conditions. CO_2 leakages may also have precursor fluid release of sediment pore fluids and aquifer brines; of which each has unique chemical signatures. Active acoustic methods are well suited to detect CO_2 in bubble form. pH/CO2 sensor can be used to detect pH/CO_2 changes in seawater, if the changes due to release of dissolved CO_2 exceed natural variation (methods for detection of releases below this threshold are being developed e.g. through H2020 project STEMM-CCS). CTD and current measurements are valuable additions.

- Purpose and application: Detecting leakage from injection well or into the water column through the protecting caprock
- Required platform endurance: >14 days
- Required platform modifications: hybrid capabilities (propeller) preferable for adaptive sampling
- On-board autonomy and intelligence: on-board processing of certain sensor is required, and ability to navigate the platform for adaptive sampling
- Payloads and sensing sampling: hydrographic (including currents), CO_2 sensing capabilities (chemical sensors – point sensor, and/or acoustic sensor – generally high power consumption but potentially large area/volume coverage, or optical sensor – e.g. camera, short range and require light.), potentially brine/pore fluids
- Communications, and Data processing and dissemination: no modifications required

Parameter	**Sensor (examples)**	**Resolution**	**Coverage (xy,z,t)**
Depth (water pressure)	CTD	1m vertical	50 km, <=3km, > 14 d
Temperature	CTD	1m vertical	50 km, <=3km, > 14 d
Salinity	CTD	1m vertical	50 km, <=3km, > 14 d
Current	TBD	TBD	50 km, <=3km, > 14 d
pCO_2 (dissolved phase, gas phase, *deep: liquid phase*)	Dissolved: CO_2, e.g. SAMI-CO_2, optode. Gas phase: active/passive acoustic sensor	10m vertical	50 km, <=3km, > 14 d
pH	E.g. Sami pH, Fluidion	10m vertical	50 km, <=3km, > 14 d
Precursor fluids (aquifer brines, sediment pore fluids)	TBD	TBD	50 km, <=3km, > 14 d

5.3 Examples of current and past Oil and Gas Industry related glider missions

5.3.1 DOF Subsea – Current Monitoring for Operational Support

DOF Subsea is a provider of subsea services to the oil and gas industry, and an early adopter of unmanned underwater vehicles for such services.

The company purchased three Slocum G2 Gliders (DOF Skandi Explorers) in 2014, which are described by the company as a cornerstone of their “Ocean Observation System (OOS)” «due to its ultra-efficient, low-power ability to collect data for up to nine months before requiring a battery change». The gliders are equipped with an Environmental Characterization Optics (ECO) sensor, a Conductivity, Temperature, Depth (CTD) sensor, and a Teledyne Acoustic Doppler Current Profiler (ADCP) for current profiling (using the shear method see e.g. Ordonez *et al*., 2012, and Thurnherr, 2015 for implementation on gliders). Operational control of the gliders is accomplished via remote satellite communications with DOFs onshore-based Ocean Observation team at their Houston centre.

One of the applications of the DOF gliders has been for Loop current studies in the Gulf of Mexico, with the gliders carrying an oceanographic sensor package consisting of CTD and ADCP and additional sensors. The Loop Current is a fast-moving ocean current that transports warm Caribbean water through the Yucatan Channel between Cuba and Mexico. Monitoring of currents are in general vital for a range of offshore operations, and knowing where the Loop Current and its eddies are, and are likely to go, is critical for subsea operations in the area. The Loop current can disrupt offshore operations, as in 2014 when many deep-water drilling rigs were put on hold for months in the Green Canyon, Mississippi Canyon and Walker Ridge.

In the fall of 2015 DOF subsea began a glider-based real-time environmental program in the Gulf as a subscription-based data service. The glider collects data along the Gulf Loop current, observations include current velocity profiles, and salinity and temperature from the surface to approximately 1000 m depth. The main objective of the service is to provide data for subsea operations in the Gulf, to aid decision making with *in situ* observations at a much lower cost than conventional vessel based ADCP surveys.

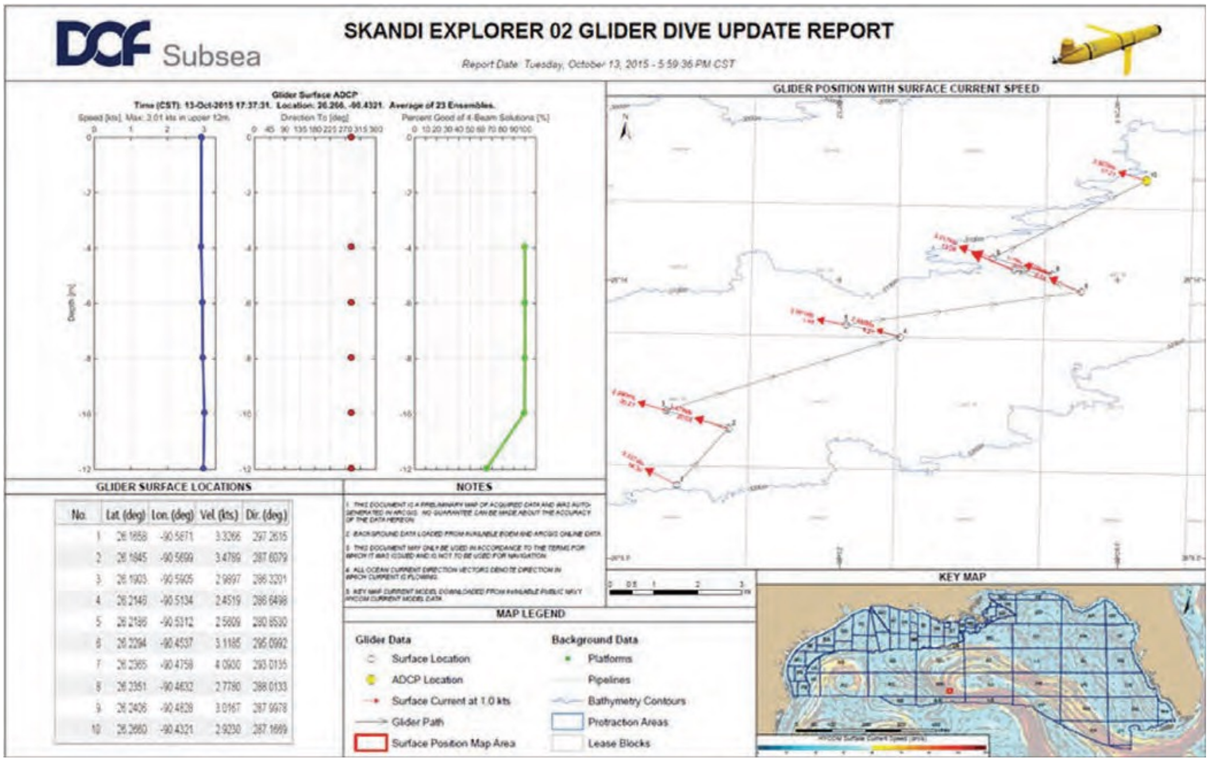

Figure: DOF Subsea – Glider based monitoring in the Gulf of Mexico.

5.3.2 Other Recent Oil & Gas Applications

Shell is using the Kongsberg (former iRobot) SeaGlider for operations along the Gulf Coast. A new underwater robotic vehicle is collecting important data along the Gulf Coast today, as a result of a partnership among Shell Oil Company, the U.S. Integrated Ocean Observing System, and NOAA's National Data Buoy Center (NDBC). Scientists recently launched an iRobot SeaGlider approximately 24.1 kilometres east of Shell's Auger platform in the Gulf of Mexico. The iRobot SeaGlider collects data on temperature, salinity, conductivity, dissolved oxygen, dissolved organic matter, pressure, turbidity, chlorophyll, and backscatter down to 1,000 meters in various parts of the northern Gulf of Mexico. The glider is piloted by NDBC, and has collected more than 250 profiles of data. NOAA and Shell signed an agreement in 2008 to work together in the Gulf of Mexico to provide consistent, high quality data for weather forecasters and the National Hurricane Center. This agreement included several tasks, such as hardening meteorological systems on oil production platforms, providing separate power sources, and creating satellite transmission capability to provide data during platform evacuations due to severe weather. This current effort with the glider emerged from the initial agreement.

Ashtead Technology has signed a global asset management agreement with Blue Ocean Monitoring to store, maintain and supply underwater gliders for ocean data monitoring. Blue Ocean Monitoring stated that, "initially used extensively for academic and military applications, these gliders are now increasingly being embraced by the oil and gas community for a wide range of purposes. "Oil and gas applications include pipeline leak detection, oil spill response, decommissioning studies, dredge/construction plume monitoring, environmental monitoring and MetOcean studies.

5.3.3 Project Azul, Brazil

In Brazil, the eleventh greatest oil producer in the world, Project Azul has been started in 2012. This project is funded by a private O&G operator (BG-Brazil), and as part of the project, gliders are used to (1) better understanding of oceanic features such as the Cabo Frio Eddy, and (2) to provide near real-time data for assimilation in numerical oceanic circulation models. Project Azul utilizes two SeaGilder equipped with CTD, optode, and a WetLabs Eco Triplet sensor, and tens of missions have been conducted. Data from these gliders were use for various purposes, including derivation of geostrophic velocities, and glider data has been assimilated in numerical models, showing great impact.

5.4 References

OSPAR 2004. OSPAR Guidelines for Monitoring the Environmental Impact of Offshore Oil and Gas Activities. Reference number: 2004-11

Miljødirektoratet 2015. Environmental monitoring of petroleum activities on the Norwegian continental shelf, Norwegian Enrivonment Agency, 2015

DNV, 2010. Selection and use of subsea leak detection systems, DNV-RP-F302, 36pp

PTIL, 2015. Regulations relating to Conducting petroleum activities (the activities regulations). Amended 18 December 2015. Available at: http://www.psa.no/activities/category399.html

Douglas-Westwood, 2016. North Sea Decommissioning Market Forecast Prospects, Technologies, Markets 2016-2040. DW report number 570-16.

Hayes, D., 2013. The CYCOFOS operational flow forecast: now assimilating glider data. Presented at the Coastal and Shelf Seas Task Team - International Coordination Workshop 2 (COSS-ICW2), Lecce, Italy.

Ordonez, C. and Halpin, S. 2016. Commercialization of Glider Operations and Data Products for Offshore Oil and Gas - Experience from Loop Current Monitoring in the US Gulf of Mexico. Seabed Mapping and Inspection 2016, 9th-12th February 2016, Geilo, Norway.

Ordonez, C. E., Shearman, R. K., Barth, J. A., Welch, P., Erofeev, A., & Kurokawa, Z. (2012). Obtaining absolute water velocity profiles from glider-mounted Acoustic Doppler Current Profilers. In 2012 Oceans - Yeosu (pp. 1–7). IEEE. doi:10.1109/OCEANS-Yeosu.2012.6263582

Thurnherr, A. M., 2015. Processing explorer ADCP data collected on Slocum gliders using the LADCP shear method. In 2015 IEEE/OES Eleventh Current, Waves and Turbulence Measurement (CWTM) (pp. 1–7). IEEE. doi:10.1109/CWTM.2015.7098134

Francisco Alves dos Santos et al., Projeto Azul: Operational Oceanography in an

Active Oil and Gas Area south-eastern Brazil, in “Coastal Ocean

Observing Systems”, Edited by Liu, Kerkering and Weisberg, Elsevier, 2015.

6 Subsea Mining and Raw Material

Worldwide, the production of mineral resources has increased tremendously during the last 20 years or so (see figure below).

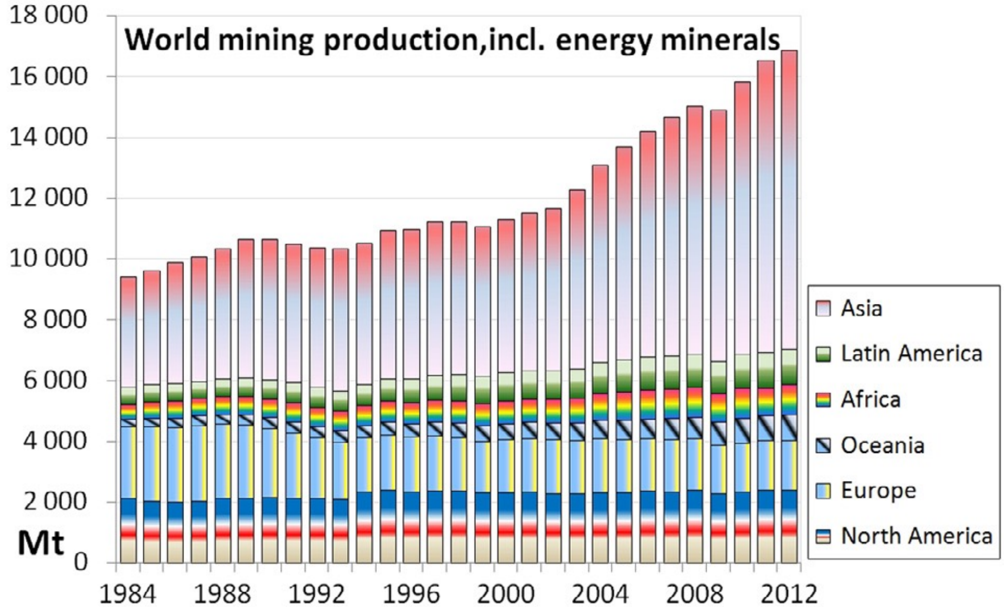

Figure: Annual mineral production by continent (reproduced from Ramirez-Llodra et al., 2015)

Deep-ocean mining is an emerging industry with national and international regulations under development now (Mengerink et al., 2014). Large companies like Nautilus Minerals are now commercially exploring the seafloor for massive sulphide systems. The deep-sea also provides a wealth of resources, including elements and energy reserves that are currently being extracted and will be increasingly important in the near future. With increasing societal demands for mineral resources, subsea mining at the global scale is in a phase of rapid growth particularly in the Asian countries.

This section provides the detailed requirements and potential uses and users for subsea mining and raw materials extraction and prospecting, providing safer and more environmentally sound subsea operations. Use in prospecting by imaging, necessary baseline studies, operational monitoring during extraction, crushing and waste (tailings and gray rock) placements on the sea floor has been explored. Measurement scenarios with hybrid propulsion at the bottom are particularly focused on turbidity, particle counter technologies, video imaging and acoustic active sensors for sea-bed properties.

6.1 Identified Services

6.1.1 Prospecting Service

For exploration and prospection of potential new fields, vast areas need to be covered while acquiring data on the seafloor properties to recognize seamounts and sea-bottom structures of interest. Deep gliders present multiple advantages when facing these challenges including their autonomy and ability to cover large areas while gathering high temporal data.

During the initial prospecting phase of target generation, a surface vessel will survey an area by yo-yoing a CTD rosette and other sensors through potential plume sites looking for chemical signatures (see following figure). This effort could be easily replaced by a deep glider following its native flight pattern of yo-yoing autonomously across a region of interest. Furthermore, a fleet of glider with appropriate sensor payloads could autonomously survey a large region and identify area that qualify for the next phase of target testing (ie ROV operations).

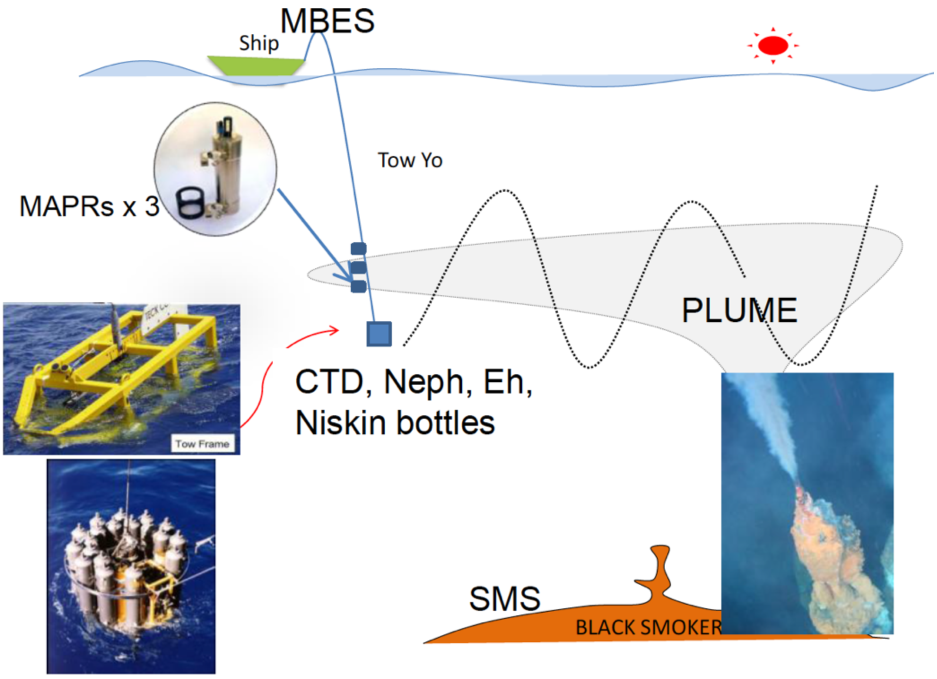

Figure: Target generation looking for chemical signatures (Nautilus Minerals 2010)

In Norway, a recent project will explore data acquired with the first deep-sea Underwater Hyperspectral Imagery (UHI, Ecotone) camera sensor and will be used to develop a classification method optimized for seafloor minerals. Further development and miniaturization may be needed to integrate such sensors onboard a deep glider, however gliders can provide complementary monitoring information during these operations to describe the surrounding chemical environment. With the added use of sea-bed penetrating acoustics, deep gliders could chemically detect an area of interest and then intelligently survey the sea-bed properties in the area using a hybrid horizontal flight mode.

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, < 1 mo
Temperature	CTD	1m vertical	100 km, 5km, < 1 mo
Salinity	CTD	1m vertical	100 km, 5km, < 1 mo

Turbidity	Backscatter	1m vertical	100 km, 5km, < 1 mo
Hydrocarbon/Methane	Optical Sensor	10m vertical	100 km, 5km, < 1 mo
Sea-Bed Properties	Active Acoustics	As required	As required

6.1.2 Baseline Study Service

As with all mining operations, deep-sea mining raises questions about potential environmental impact on surrounding areas. Hence, before any operational activities is in place for deep-sea mining, it is of outmost importance to establish baseline physical, chemical and biological conditions for the area that is in prospect. Often baseline data are missing so that in case of impact or changes in the environment, it might be challenging to quantify the actual effects as there is no sufficient reference data available. The sensor package for baseline monitoring will include critical oceanographic parameters but will also describe the background level and season variations pattern for turbidity.

Seafloor ecosystems are very dependent on the flow of organic particles produced in the upper layer. It is expected that with season, turbidity and fluorescence may change as will change the production in the upper layer. Likewise, the diversity of organic food, debris that sediment from the top layers are also important to measure for baseline.

Hard-substratum fauna such as cold-water corals or sponges should be particularly studied, as these taxa have been qualified as essential ecosystem components, ecosystem engineers and essential habitats for a diverse variety of organisms including commercial fish. Laboratory experiments have demonstrated that these organisms can be impacted under exposure of increasing concentration of suspended sediments and drill cuttings while no studies related to mine tailings has been conducted yet.

Likewise, the water column over the mining area should be investigated as it can also be affected from operations on the seafloor re-suspending material and possibly toxic metals and chemicals

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, > 1 mo
Temperature	CTD	1m vertical	100 km, 5km, > 1 mo
Salinity	CTD	1m vertical	100 km, 5km, > 1 mo
Turbidity	Backscatter	1m vertical	100 km, 5km, > 1 mo
Chlorophyll-a	Fluorometer	1m vertical	100 km, 5km, > 1 mo
Nutrients	Micro-fluidic cells	5 mins	100 km, 5km, > 1 mo
Hydrocarbons	Optical Sensor	10m vertical	100 km, 5km, > 1 mo
Micro particles and organisms	Octopus Imaging	TBD	100 km, 5km, > 1 mo

6.1.3 Operational Monitoring Service

Subsea mining operations may "severely damage" the sensitive biological communities that live near under-sea mountains, hydrothermal vents and mineral-rich nodules on the sea floor. Several major categories of operational impact from mining can be identified. Among them, over-sedimentation, metal toxicity, process chemicals (if used), changes in organic content, grain size and angularity of sediment particles, sediment plumes and turbidity, and materials re-suspension (Ramirez-Llodra et al., 2015). Re-suspension of particles will smother a relatively wide area of the seafloor affecting potentially particularly all sessile organisms. Operations may risk damaging sensitive habitats that should be carefully monitored and the species diversity evaluated.

By using turbidity sensor on the deep glider, one should be able to evaluate the potential impact of the mining activities over a relatively wide area and identify hotspots areas or plumes that can represent a risk for neighbouring seafloor habitats. When data are communicated after surfacing of the deep glider, this should trigger a number of counteractions to reduce and manage activities in a more sustainable manner.

Changes in species biodiversity and abundance should be monitored at regular interval of time during the duration of operations.

By integrating these data into management systems and other sea bottom models for current that the mining industry will operate, the glider and sensor payload will provide an effective tool to provide forecast, mitigate the effects of any incidents and hence document operations in a sustainable manner to the legislative authorities.

A proper operational monitoring would consist of visiting an area at frequent interval with the Glider over the extraction period of the minerals, and explore particularly the extend and dispersal of particle plume arising from re-suspension of material from the seafloor. One strategy would be to use adaptive sampling with smart sensors redirecting the trajectory of the Glider in case of critical variables like turbidity over a certain threshold (e.g. 3 NTU) or to identify a plume, followed by surfacing to transmit data in hazard situation.

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, > 1 mo
Temperature	CTD	1m vertical	100 km, 5km, > 1 mo
Salinity	CTD	1m vertical	100 km, 5km, > 1 mo
Turbidity	Backscatter	1m vertical	100 km, 5km, > 1 mo
Micro-organisms	Octopus Imaging	TBD	As required

6.1.4 Post-Operation Monitoring Service

Re-assessing population connectivity and colonization potential is also critical when estimating recovery potential of potentially affected area after cessation of discharge operations. Industries will be required to document that the environmental conditions are back to normal (or near normal) in a very similar way as it is practised for oil and gas abandonment of installations. While acute smothering from particles can have immediate impacts on soft and hard-bottom benthic species, subtle chronic effects on individual may appear long after the cessation of operations and recolonization of species from damaged habitats needs to be evaluated to document and mitigate the environmental footprint of deep-sea mining industries.

The sensor payload is expected to be pretty much the same as for the operational monitoring services and no modification are required.

By revisiting the same area after cessation over several time intervals, the deep glider will provide a time series data that can reveal the potential long-term environmental impact of the mining exploration.

Parameter	Sensor (examples)	Resolution	Coverage (xy,z,t)
Depth (water pressure)	CTD	1m vertical	100 km, 5km, > 2 mo
Temperature	CTD	1m vertical	100 km, 5km, > 2 mo
Salinity	CTD	1m vertical	100 km, 5km, > 2 mo
Turbidity	Backscatter	1m vertical	100 km, 5km, > 2 mo
Fluorescence	Fluorometer	1m vertical	100 km, 5km, > 2 mo
Micro-organisms	Octopus Imaging	As required	100 km, 5km, > 2 mo

6.2 References

Ramirez-Llodra, E., Trannum, H.C., Evenset, A., Levin, L.A., Andersson, M., Finne, T.E., Hilario, A., Flem, B., Christensen, G., Schaanning, M. and Vanreusel, A. (2015) Submarine and deep-sea mine tailing placements: A review of current practices, environmental issues, natural analogs and knowledge gaps in Norway and internationally. Marine Pollution Bulletin 97(1-2), 13-35.

Mengerink, K.J., Van Dover, C.L., Ardron, J., Baker, M., Escobar-Briones, E., Gjerde, K., Koslow, J.A., Ramirez-Llodra, E., Lara-Lopez, A., Squires, D., Sutton, T., Sweetman, A.K. and Levin, L.A. (2014) A Call for Deep-Ocean Stewardship. Science 344(6185), 696-698.

7 Summary

The BRIDGES project represents an opportunity for EU enterprises to lead the development of the deep-ocean glider technology and miniaturized subsea sensors to deliver a range of industrialized innovative gliders targeting the key markets identified in this document. The DEEP and ULTRA-DEEP EXPLORER vehicles will open new fields of applications and market opportunities by integrating different suites of deep-sea sensors targeted at providing innovative and cost-effective services.

This document has identified specific services that could be provided by deep gliders to emerging and established marine markets, offering innovative and cost-effective methods of exploration and monitoring to extreme depths and with complex sensor payloads.

The deep gliders should be capable of at least 2 months endurance with a simple payload for the minimum possible vehicle size and weight. Special consideration should be made to explore options to reduce the size and weight and aiming for a low-cost platform. These factors will be essential to ensure the greatest impact across all markets.

The deep gliders should be capable of smart behavior depending on the environment and sensing needs. The hybrid horizontal flight mode will be a real advantage for all sea-bed surveying services (benthic habitats, subsea mining). In addition, the deep glider should be able to rest at a fixed depth while sensors requiring long-sampling times can effectively take a reading, resulting in a step-pattern during ascent or descent.

To summarize the service payloads, the following sensing capabilities are suggested for the deep gliders based on the identified services:

- CTD (Depth, Temperature, Salinity)
- Oxygen
- Nutrients (Nitrate, Phosphate, Ammonia, Silicate)
- Chlorophyll-a, CDOM
- Hydrocarbons (crude oil, refined oil)
- Turbidity
- Methane
- pH
- Water Sampling
- Optical Imaging (organisms, particles, oil droplets)
- Passive acoustics
- Active sea-bed acoustics
- Current (ADCP, post-processing)

This document will continue to be assessed and updated throughout the BRIDGES project based on the needs of the evolving marine markets. The design needs identified in this deliverable have been communicated to the vehicle and sensor design work packages to maximize the market impact of the BRIDGES design, and this iterative process will continue throughout the BRIDGES project as new needs come to light.