MIDAS

MANAGING IMPACTS OF DEEP SEA RESOURCE EXPLOITATION

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MIDAS MANAGING IMPACTS OF DEEP SEA RESOURCE EXPLOITATION

Integrated modular systems for monitoring of ecosystem functions in deep-sea habitats with relevance for mining

Deliverable 10.3

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1. Introduction

1.1 Aim of this report

This report aims to describe different measurable biotic/abiotic processes that allow characterisation of important ecosystem functions in deep-sea areas that could potentially be mined. In a following step we aim to use these functions to assess the level of disturbance and recovery after mining has taken place. Focus is given to methodologies that can provide 'quantifiable' indicators (descriptors) for site-specific ecosystem functions. We focus on in-situ measurements and experiments, ex-situ analyses and subsequent modelling approaches in areas containing manganese nodules (MnN) as well as seafloor massive sulphide (SMS) deposits (Figure 1).

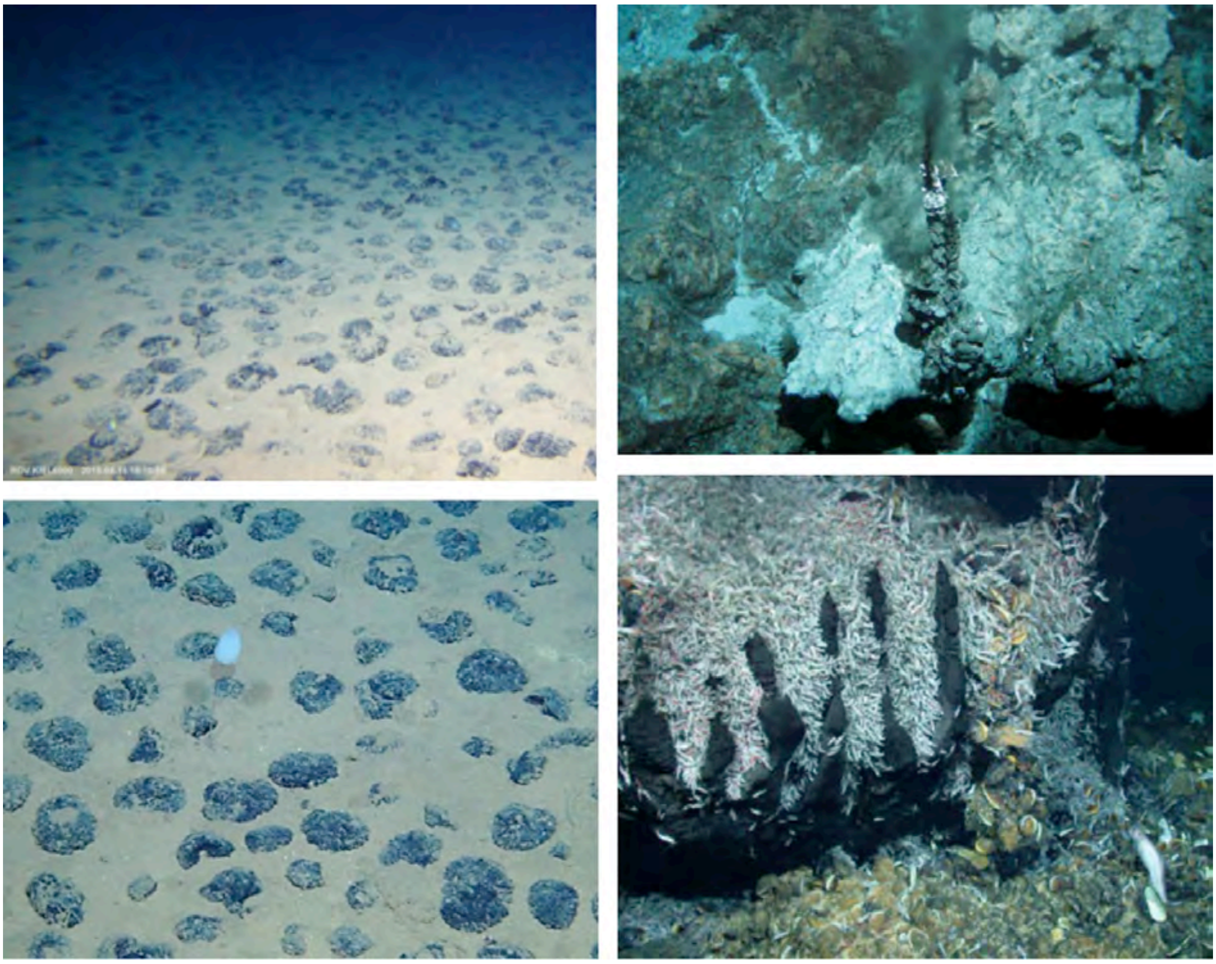

Figure 1: Examples of Mn-nodules in the CCZ (left) and hydrothermally active areas in the Atlantic (right). All images courtesy GEOMAR.

In this report, in-situ experimental technologies are defined as those capable of measuring a given physical or chemical parameter (e.g., O_2 concentration) from which it is possible to derive a measure of ecosystem functioning (e.g., sediment respiration). Whilst they do not measure a chemical or physical parameter at the seafloor, photographic methods (e.g., towed or stationary camera platforms) can also be classified as an in-situ technology for assessing ecosystem functioning since photographs and video record numerous biological parameters (e.g., bioturbation features at the seafloor) that can inform researchers about specific functions. In-situ technologies designed to measure basic ecosystem functioning parameters (e.g. respiration) can also be used to artificially modify or manipulate an environment to the point where other functions become quantifiable. Good examples of these types of technologies include baited cameras for measuring scavenging activities (Sweetman et al. 2014a), and benthic chambers where oxygen concentrations can be manipulated (Sommer et al., 2008) and substrates added (e.g., isotopically labelled algae, lumniophores). Using the latter, the fate of the added organic substrate or distribution of luminophores can then be measured to quantify rates of C- and N-cycling, and estimate rates of bioturbation, respectively. In-situ sampling methodologies are described as those capable of retrieving samples from the seafloor, which can then be used to measure chemical, biological or physical parameters for estimating ecosystem functioning. A good example of this is a megacorer that samples seafloor sediments, which can later be used to estimate ^{234}Th or ^{210}Pb concentrations, short- and long-term bioturbation rates and mixed layer depths. We exclude ex-situ experiments as we consider them to be biased due to very strong pressure changes, quick oxygenation of sediments and bottom water, and temperature fluctuations whilst the sample is being retrieved from the deep sea (and possibly also during the experiments themselves). We exclude ex-situ experiments, but acknowledge that great efforts are being undertaken to overcome these problems. An example monitoring strategy before, during and after the mining is given for a hypothetical MnN mining scenario.

1.2 Ecosystem functioning

In this report, we adopt the definition of ecosystem functioning from Thurber et al. (2014) who describe ecosystem functioning as the interactions that occur between abiotic and biotic elements of ecosystems and habitats (e.g. the transfer of energy within the food chain, carbon cycling and/or burial in the sediment, oxygen uptake or primary production and its impact on carbon transport to the seafloor). The concepts of ecosystem functioning and ecosystem services are somewhat related, but functions are often thought of as those being outside human context that may provide ecosystem services with human benefit (Van den Hove and Moreau, 2007). We will discriminate between functions common for the sediment-covered deep sea and areas adjacent to SMS deposits. In addition, we will highlight specific conditions typical around hydrothermal vent sites as these might be influenced by nearby mining, but we assume that widespread mining of active hydrothermal vent sites will not happen.

Of main concern is the impact mining will have on organisms and the functions and services they provide to the surrounding ecosystem. It should be noted that in any imaginable mining scenario the ecosystem will be significantly altered and may be changed up to a point where it cannot recover to the pre-mining condition. Possibly the worst scenario is that changes to ecosystem functions in directly impacted areas reach far beyond these boundaries, altering supporting and regulating ecosystem services over much larger areas. In the following, a brief description of the important ecosystem functions is given and technologies and methodologies to measure them are described. Several tools, such as those for monitoring benthic activity using imaging and planar optode technologies, identifying diversity and functions of microbes with molecular tools, or monitoring and quantifying biogeochemical processes related to carbon fluxes, are described in detail in MIDAS Deliverable 10.1 ‘*Deep-sea monitoring technologies in research and industry*’. They will not be described again, but clear references are made to the D10.1 report.

1.2.1 MnN areas, an oxygen-rich sedimentary deep sea ecosystem

Manganese nodules (MnN) are common in abyssal areas with very low sedimentation rates and very little to no terrigenous input. Across MnN areas and other abyssal regions where particulate organic carbon (POC) flux to the abyssal seafloor has been measured (e.g. in the equatorial Pacific) strong linear relationships between POC fluxes and the abundance and biomass of bacteria, macrofauna and megafauna have been observed (e.g., Smith and Demopoulos 2003, Smith et al. 2008). Sediment community respiration or C-oxidation by these organisms, and the depth and intensity of bioturbation by metazoans, decrease rapidly with declining POC flux and are key ecosystem functions in these areas (Smith and Rabouille 2002, Smith et al. 2008). In particular, organic matter mineralisation and bioturbation affect provisioning services such as nutrient regeneration, carbon burial and rates of calcium carbonate dissolution at the seafloor (Thurber et al. 2014), which ultimately modulates CO_2 levels in the atmosphere and pH levels in the ocean (Wenzhöfer et al. 2002). Both functions are thus seen as vitally important to measure in terms of baseline values and for detecting changes when the abyssal seafloor are mined for Mn-nodules.

Because POC flux typically declines north of the equator and in a westerly direction in the CCZ, respiration and bioturbation are likely especially important in the central and eastern parts of the CCZ, and should therefore be monitored carefully when mining takes place. Often, the methods used to study ecosystem functioning at the abyssal seafloor measure cumulative processes. For example, sediment community respiration is a combination of microbial respiration, metazoan respiration and chemical respiration. Measuring cumulative functions may mask subtle changes in ecosystem processes, which make it necessary to employ methods that can measure these cumulative functions, as well as those that can quantitatively tease apart individual functions. One method for teasing apart subtle ecosystem processes, and for quantifying the role of different organism classes (e.g., meiofauna, macrofauna) in a food web is the use of isotope labelling experiments (Middelburg et al. 2000, van Oevelen et al. 2006). These can be used to assess baseline C-flows through a food web and detect how a specific stressor (e.g. mining disturbance) modifies these processes (Sweetman et al. 2010, 2014b). The uptake of labeled elements (e.g. ^{13}C, ^{15}N) is tracked into sediment dwelling organisms and abiotic components, making it possible to quantify individual decomposition processes.

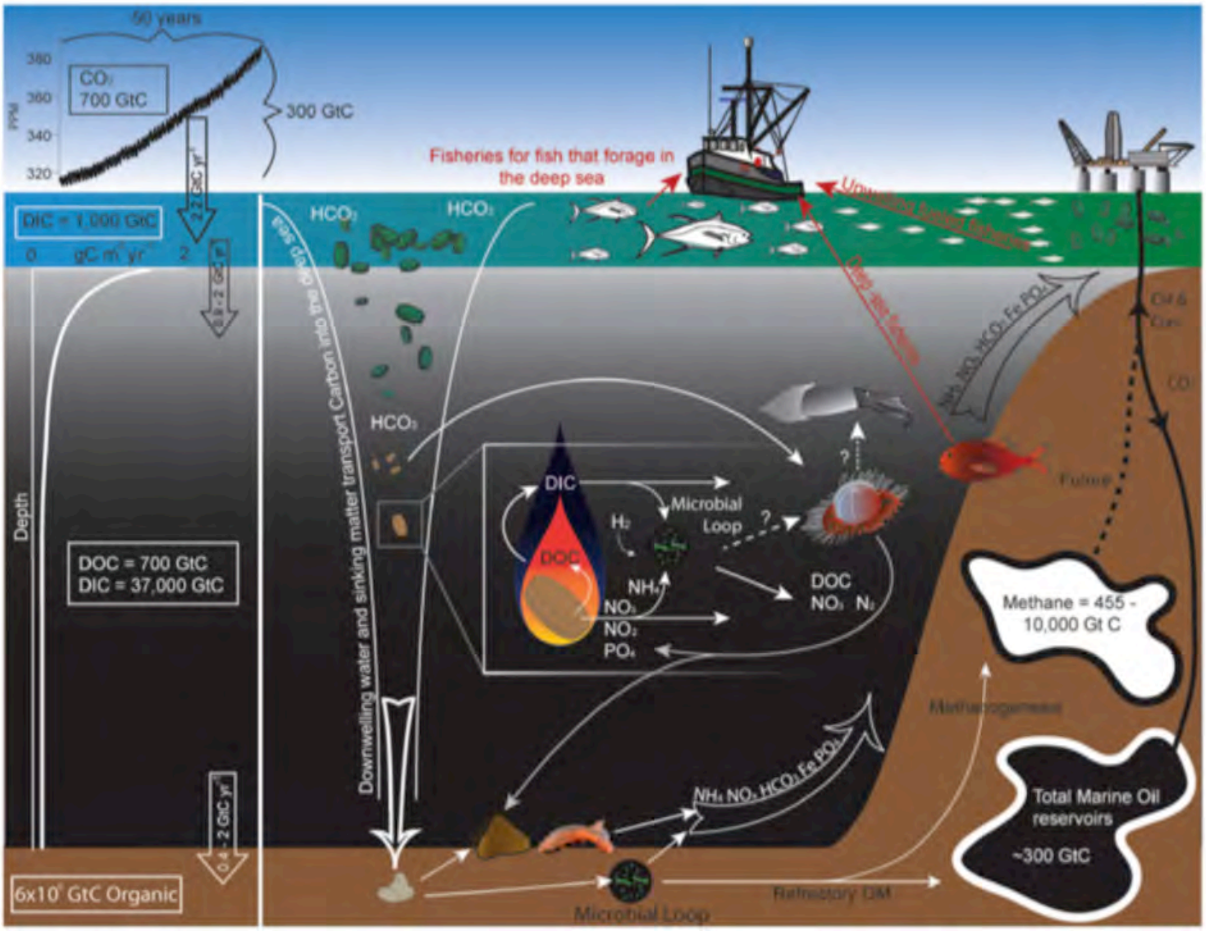

Figure 2: Schematic of carbon flow from the sea surface to the deep and a subset of the resources and functions of the deep sea (from Thurber et al., 2014).

1.2.2 SMS areas, hard rocks covered with sulphidic sediments

With the exception of some areas where active vent sites will be mined for massive sulphides (e.g. Solwara 1), inactive vent fields are likely to be the main focal area for mining massive sulphide deposits. Inactive vents are different to active hydrothermal vent systems. At active vents, dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) are used by microbial communities in-situ: they use fluid-supplied H_2S and nutrients as energy sources and additional compounds to produce organic material. Inactive vent communities and fauna in the surrounding sediments most likely rely on the downward flux of phytodetritus from sunlit layers for energy (De Busserolles et al. 2009, Levin et al. 2009, Sweetman et al. 2013) and/or exported chemosynthetic production from nearby active vents (Dymond and Roth 1988, Sweetman et al. 2013). Important ecosystem functions provided by inactive vent communities include community respiration and C-oxidation, nutrient release and secondary production. In contrast to the abyssal plains it is difficult to make measurements in many of these areas because of the rugged terrain and likely hard or impenetrable seafloor. Ecosystem functions provided by sediment-dwelling communities close to inactive vent deposits can be measured using similar approaches to those in manganese nodule fields. Whole community respiration (and changes to it) may be measured using eddy covariance techniques (Berg et al. 2007), though the approach may only be suitable for use in areas characterised by limited sediment coverage since sediment community respiration may mask subtle changes in hard substrate community respiration. Secondary production may be possible to measure by assessing changes in the size of various fauna (e.g., corals) using video/time-lapse photography.

2. Measuring ecosystem functions

2.1 Basic concepts of measuring ecosystem functioning

When studying ecosystem functioning in the deep sea it must be acknowledged that the ecosystem under investigation is not homogeneously distributed, nor constant in time. For example, food web dynamics at hydrothermal vent systems can change over centimetre scales (Limén et al. 2007, Sweetman et al. 2013), and sedimentary processes in abyssal regions fluctuate on intra- and interannual time-scales (Smith et al. 2013). Understanding these spatio-temporal variations at respective mining sites is thus of utmost importance and needs to be an integral part of any ecosystem function study. A baseline study thus needs to be established to assess ecosystem functioning status prior any mining. In particular, for MnN mining, the depth of many claim areas leads to sedimentary faunal communities being very small, which makes benthic fauna and the ecosystem functions that sedimentary organisms carry out (e.g. sediment oxygen demand or respiration) extremely sensitive to mining related disturbance (e.g. sediment plumes and smothering). Moreover, previous studies have revealed that benthic ecosystem functioning is exponentially related to biodiversity (Danovaro et al. 2008), so even slight modifications to sediment biodiversity may have catastrophic impacts on benthic ecosystem functioning. The respective baseline knowledge needs to be generated for each location and time of analyses, and it should not be based on desktop studies using literature information. In addition, a detailed understanding about the distribution of different habitats is essential for any baseline survey, and how functions change with variations in the habitat (e.g., changes in nodule abundance). As a first step, geological/sedimentological facies can be derived from ship/AUV-based bathymetry and backscatter analyses, deep-towed or AUV-based side scan sonar mapping, visual observations from ROV, AUV, and towed camera platforms, and sediment sampling (see MIDAS Deliverable 10.2).

2.2 Methodologies used in science and applicability for industry

Several methodologies and techniques exist for quantitatively or semi-quantitatively investigating ecosystem functions. They range from complex physical measurements with Eddy Covariance lander technologies that can assess respiration over hard substrate SMS deposits (e.g., Glud et al. 2010), to deployments of benthic chambers, profiling microelectrodes, and more simple observations using camera systems for studying processes at the seafloor or in the upper parts of the sediment column (e.g., sediment profiling imaging technologies [SPIs]). In the following table, methodologies are separated into in-situ observations, measurements and experiments, as well as ex-situ measurements. Additionally, baited cameras can be used to assess megafaunal functions (e.g., scavenging dynamics and activities).

Table 1: Methodologies for ecosystem functioning

Target function	Instruments and main tool	Contact persons and institutes	Reference
1. In-situ observations/measurements			
Biogeochemical benthic fluxes and large scale respiration	BIGO lander, benthic chambers with incubation capabilities and oxygen supply, subsampling	Stefan Sommer, GEOMAR, Germany	MIDAS Deliverable 10.1 chapter 4.1.1 & 4.2.1
	ROV deployable benthic chamber module	Frank Wenzhöfer, AWI/MPI, Germany	
	ROV or crawler deployable microprofiler module, oxygen penetration measurements	Frank Wenzhöfer, AWI/MPI, Germany	
	Eddy Correlation lander or modules	Dan Jones, NOC Southampton, UK; Filip Meysman, NIOZ, Netherlands; Frank Wenzhöfer, AWI/MPI, Germany, Peter Linke, GEOMAR, Germany	
Technologies/ methods to measure seafloor biological activities and bioturbation	MoLab lander system, central and satellite landers equipped with ADCPs, CTDs, time laps cameras	Peter Linke, GEOMAR, Germany	MIDAS Deliverable 10.1 chapter 3.1.2, 3.1.4, 4.2.1
	Bathysnap lander; camera	Henry Ruhl, NOC Southampton, UK	
	Deep Sea Observatory System; camera & ADCP and CTD	Peter Linke, GEOMAR, Germany	
	Sediment Profile Imaging lander; camera	Martin Solan, NOC Southampton, UK	
	AUV, ROV or towed camera based seafloor observations	Jens Greinert, GEOMAR, Germany	MIDAS Deliverable 10.2
2. In-situ experiments			
Megafaunal feeding activities (e.g., scavenging)	Baited trap lander	Henri Robert, RBINS, Belgium; and below	MIDAS Deliverable 10.1 chapter 5.1.3
	Baited trap camera lander	Andrew Sweetman, IRIS, Norway; Gerard Duineveld, NIOZ, Netherlands; Henry Ruhl, NOC Southampton, UK	
Carbon and nitrogen transfer in food webs	Food pulse chamber lander with stable isotope labelled organic matter	Andrew Sweetman, IRIS, Norway	MIDAS Deliverable 10.1 chapter 4.2.2
	Chamber system CUBE with stable isotope labelled organic matter	Dick v. Oevelen, NIOZ, Netherlands	
Megafauna respiration	ROV deployable Benthic Incubation Chamber System	Henry Ruhl, NOC Southampton, UK	Description below
3. Ex-situ measurements			
Bioturbation	^{234}Th and ^{210}Pb analyses in sediment cores	Henko De Stigter, NIOZ	Maire et al., 2008 Lecroat et al., 2010
4. Ex-situ modelling			
Benthic food web conditions	Modelling based	Dick v. Oevelen, NIOZ, Netherlands	MIDAS Deliverable 10.1 chapter 4.2.3

As can be seen from Table 1, most of the applicable technologies have been described in the MIDAS D10.1 report. Some of these technologies have existed since the late 1970s, when autonomous benthic chamber deployments were conducted successfully in deep-sea environments to study in situ benthic respiration/total oxygen uptake (TOU), carbon turnover and bentho-pelagic coupling (Viollier et al., 2003; Wenzhöfer and Glud, 2002; Witte et al., 2003, and references therein). More recently, benthic flux chambers were deployed at cold seeps, e.g., at Hydrate Ridge (Sommer et al., 2006), in the Gulf of Mexico (Sommer et al., unpubl. data), at the Hikurangi Margin (Sommer et al., 2010), and at mud volcanoes off Costa Rica (Linke et al., 2005) and in the Gulf of Cadiz (Sommer et al., 2009). However, it was only recently that benthic flux chambers were deployed to study the effect of mining on the deep-sea ecosystem (Cruise Report SO242/2 Boetius et al., 2016)

To trace TOU during chamber or lander deployments, sequential water samples are taken automatically - for example, by a glass syringe water sampler from the overlying water in the chamber. These water samples are analysed ex-situ for oxygen concentration using Winkler titration. In recent years, oxygen concentration has also been monitored using in-situ using optical sensors, optodes. Some of the chamber systems have been equipped with a gas-exchange capability to ensure the transfer of dissolved oxygen from a reservoir containing sterile-filtered aerated seawater into the chamber, thus keeping the oxygen concentration constant during the incubation. For example, this is performed in the Biogeochemical Observatory (BIGO) to enable longer and/or multiple TOU measurements (Sommer et al., 2008). Benthic chambers to measure megafauna respiration have recently been used during cruise SO242/2 by MIDAS partners (Boetius et al., 2016). They were deployed to measure the normal respiration of megafauna (e.g. holothurians) but also to study changes in respiration and animal behaviour when exposed to additional sediment load (simulating a plume scenario) and toxins (simulating exposure to crushed Mn nodules). A description of benthic chambers can be found in Cruise Report SO242/2 (Boetius et al., 2016) and in Hughes et al. (2011).

2.2.1 Modular lander platforms

From the methodologies described above, it is evident that in-situ studies with observation systems moored at the seafloor (landers) or modules deployed by an ROV are needed to quantitatively understand ecosystem functions. A multipurpose frame/lander system for deploying various tools in free fall (dropped at the seafloor surface) or TV-guided mode (video controlled targeted deployment at the seafloor) is considered the best option for many baseline and monitoring studies. Such a modular system, e.g. the Deep-sea Observation System (DOS), can be equipped with a wide range of sensors, sampling and experimental gear. Sensors include stereo camera systems, current meters (ADCPs), CTDs or thermistors (for physical oceanography investigations needed as important additional system parameters), chemical sensors for O_2, pH, Eh, ORP, optical turbidity sensors (transmissometers, backscatter sensors and fluorometers), sediment traps, and colonisation and feeding experiments. The attached sensors are state-of-the-art and can be bought off the shelf from various suppliers. The frame layout itself is used by several research institutes in Europe (AWI, GEOMAR, IRIS, University of Aberdeen) and is also available from commercial companies. The DOS-lander itself has been successfully deployed around the world at cold-water coral settings in the Porcupine Seabight (Linke et al. 2006) and at cold seep settings to contribute to food web studies (Niemann et al., 2013). Other institutes have developed similar multi-purpose and modular lander systems and the same frame is often used for deploying benthic chambers (e.g. of the BIGO lander). Using a modular frame system has great advantages with respect to upscaling the number of systems to allow for simultaneous studies at different locations/habitats.

2.2.2 Specialized modules

Some of the measurements mentioned above require direct interaction and can only be carried out using a work class ROV. Although possible to deploy as stand-alone free fall lander, Eddy-Correlation (EC) measurements benefit from a gentle and targeted deployment, particularly in rugged areas near SMS deposits, where chamber and microprofiler measurements can be easily compromised or fail entirely. The module frame itself needs to be thin-legged so as not to disturb currents and introduce additional turbulence, but at the same time the fast-responding oxygen electrodes are extremely fragile and benefit from a gentle, ROV-guided deployment (e.g. Rovelli et al., 2015). Since these measurements are obtained under natural hydrodynamic conditions and characterise large areas of the seabed, the measurements integrate much of the site-specific spatial and temporal variability and provide a robust measure of benthic O_2 exchange of heterogeneous benthic communities (Rovelli et al., 2015). As Eddy-Correlation is a non-invasive method of measuring oxygen fluxes across a larger area, it is of utmost importance to characterise the biological and geological character of this area. A complete photomosaic of the entire area would give the ideal level of knowledge, helping to correctly interpret the acquired data. Respiration measurements of megafauna in benthic chambers are not possible without ROV intervention. Such measurements are needed for some of the key species in a given area in order to discriminate between sediment and megafauna oxygen uptake and the ratio between these two oxygen sinks.

2.2.3 Advanced 4D lander system

With respect to upscaling in-situ observatories, the MoLab system provides an example of advanced monitoring of the ecosystems in space and time. It consists of two oceanographic moorings, one master lander and three satellite landers, all connected by acoustic modems for data connection and transfer. The moorings and landers are equipped with ADCPs, CTD, and chemical and optical sensors (oxygen, pH, redox, fluorometer, turbidity). In contrast to the smaller and very close to the bottom located satellite landers (upward looking ADCP, CTD and O_2 sensor) the much taller master lander is additionally equipped with a sediment trap, downward-looking ADCP and a stereographic camera system monitoring the space between its legs. Time-lapse pictures, sensor commands and data can be transmitted via an acoustic modem to a sea surface modem, enabling quasi real-time data transfer to the ship or via satellite to the shore. Receiving some sensor data will be important for monitoring during mining activities. Near real-time data will ensure the correct functioning of all system components and will give quality assurance. At the same time the system can be re-programmed to work with a higher/lower data sampling rate and additional data can be requested to assure that thresholds for certain environmental parameters have not been exceeded. In the case of MoLab, all landers have video-guided deployments by a launching system, enabling a targeted and soft deployment at specific sites.

2.3 Baseline and monitoring strategies

Establishing a sound knowledge about the ecosystem functions and a good knowledge about the ecosystem will be an essential part of all EIA baseline studies prior any mining activity. During mining, key sites may need to be monitored at regular intervals, and selected ecosystem functions measured in the baseline survey will need to be periodically re-analysed. Key sites should be spatially distributed so that they cover areas at the mine site (where the technologies may need to be temporarily dismantled), in the mining impact area (sediment plume deposition area) and outside the assumed impacted area. Monitoring of ecosystem functioning after mining should be initiated once the mining activities have ceased, with monitoring taking place at increasing intervals after that (e.g., 2 to 5 years). With a build-up of knowledge the frequency of monitoring can be adjusted accordingly. Post-mining monitoring will also be required outside of the heavily impacted areas to determine long-term and cumulative impacts.

3. Data management, access and independent interpretation

No extra requirements exist for storing data from ecosystem function measurements when compared to other oceanographic datasets. In general, it needs to be stressed that a very detailed description including all metadata information needs to be part of the data repository, particularly for experimental data. This needs to include a geological description of the areas in which the measurements have been taken. With repeated measurements during monitoring, possible changes of the geological/ sedimentological conditions need to be part of the ecosystem functioning dataset or clearly linked to the relevant data.

With respect to image data, although they might not be the most essential data acquired for ecosystem functioning, some important parameters should be recorded. For long-term monitoring accurate descriptions of the system (type of camera, lens and lights) are needed. Metadata information should include calibration parameters of stereographic camera systems, and a description of image processing tehcniques applied to the finally stored images (e.g. fish-eye lens distortion correction, colour corrections, scale adjustments). Date, time, location (latitude, longitude, depth), scale (e.g. pixel per meter) and camera parameters should be stored in the EXIF header and a description of the header information must be part of the metadata.

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