Marine Pollution Bulletin xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Integrated environmental mapping and monitoring, a methodological approach to optimise knowledge gathering and sampling strategy

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ARTICLE INFO

Article history:
Received 6 March 2015
Revised 24 April 2015
Accepted 25 April 2015
Available online xxxx

Keywords:
Integrated environmental mapping and monitoring
Sensor platform
Decision making
Adaptive sampling
Multidisciplinary approach

ABSTRACT

New technology has led to new opportunities for a holistic environmental monitoring approach adjusted to purpose and object of interest. The proposed integrated environmental mapping and monitoring (IEMM) concept, presented in this paper, describes the different steps in such a system from mission of survey to selection of parameters, sensors, sensor platforms, data collection, data storage, analysis and to data interpretation for reliable decision making. The system is generic; it can be used by authorities, industry and academia and is useful for planning- and operational phases. In the planning process the systematic approach is also ideal to identify areas with gap of knowledge. The critical stages of the concept is discussed and exemplified by two case studies, one environmental mapping and one monitoring case. As an operational system, the IEMM concept can contribute to an optimised integrated environmental mapping and monitoring for knowledge generation as basis for decision making.

1. Introduction

Better understanding of ecosystems and how natural processes (abiotic and biotic) and anthropogenic factors might influence them has during the last decade attained increased attention from authorities, scientific community and industry. The complexity of integrated environmental management is described by Elliott (2014). Borja and Dauer (2008) describe adaptive management, as one of several management approaches, and that the results of such an approach may lead to corresponding changes in data needs, analytical procedures and interpretation. In this paper we argue that integrated environmental mapping and monitoring (IEMM), using different instrument (sensor) carrying platforms combined with proper analytical methods, are essential in creating such an understanding (Fig. 1).

Exploration and mapping of unknown areas requires that a varied and wide scope for data gathering must be applied. Mapping, or exploration, in a research context is often aiming to discover or reveal hitherto unknown objects, organisms, processes and phenomena. Although there are usually one or several features or qualities that one are particularly looking for, a general understanding of an area requires mapping of basic environmental characteristics such as topography, temperature and oxygen concentration to get an overview of an unknown environment. In an environmental management perspective, understanding of the area as part of the larger eco-system is considered important. Hence, parameters to measure, choice of sensors and sensor platforms subject to operational constraints are decisions to be made and remade in an environmental mapping process. This will supply relevant data for better accommodation of diverse and complex mission purposes with potentially multiple stakeholders, representing different needs and requirements.

Environmental monitoring is focusing on current status and any change detection of behaviour and characteristics of key parameters and objects of interest (OOI). The selection of parameters to monitor is based on the best available understanding of the

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http://dx.doi.org/10.1016/j.marpolbul.2015.04.045
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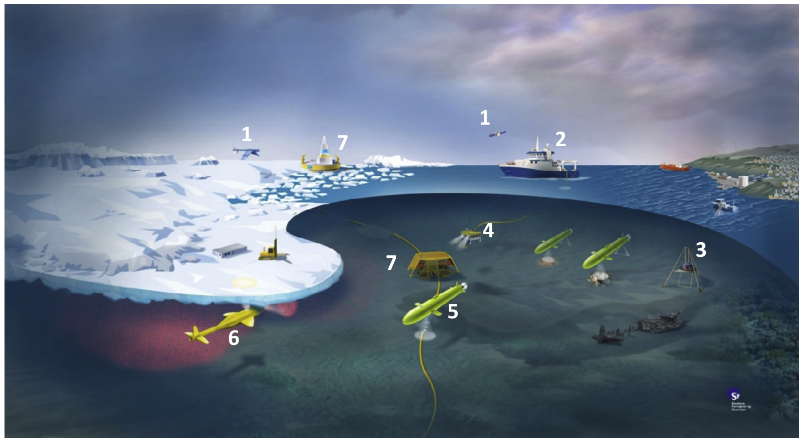

Fig. 1. Sensor platforms used in IEMM. Satellites for remote sensing (1), research vessel (2), lander (3), ROV (4), AUV (5), glider (6) with sites such as deep water coral reefs, wreck for cultural heritage, under ice studies, oil and gas infrastructure (7), water column and seabed. Image: NTNU CeO AMOS/B. Stenberg.

resources, processes and other relevant qualities present in the area of interest. Efficient monitoring depends on the ability to acquire relevant data at relevant temporal and spatial resolution to optimise information for knowledge-based decisions. For authorities and industry mapping is often conducted to establish a baseline and monitoring related to follow-up and repeat measurements of key parameters relative to the baseline data provided. This means that also parameters essential in a monitoring perspective must, as far as possible, be taken into consideration during the baseline study.

By integrating mapping and monitoring into the same operational framework in terms of tools for data acquisition and knowledge production, the relevance of data for different purposes should increase. As gathering of data is time-consuming and often also expensive, it is essential to spend the time and money available in a cost-effective manner according to relevant data gathering and expectations. Easy access to already existing data from the area of interest is also an important aspect in this context.

The spatial and temporal coverage and resolution needs will vary dependent on mission purpose (e.g. processes, organisms of different sizes) and the different decision-makers may have individual needs and requirements. In general, the requirements from authorities are often related to status and trends; e.g. has the area of influence from a particular activity increased or decreased since last sampling? For industry this knowledge may have less value as long as the information may be reported months or even years after an occurrence. To make monitoring data useful in industry's daily operations, data sampling must be adjusted to the activity of interest (Hepsø et al., 2012).

While surveys have traditionally been performed as ship campaigns with temporal and spatial resolution limited to the capabilities of the ship with its installed sensors, a variety of fixed and mobile sensor platforms now enables gathering of vast amounts of, more or less, continuous or online real-time multisensory data. This is reflected through several initiatives where authorities e.g. MAREANO (MAREANO, n.d.), industry e.g. the PEMCA project (Johnsen et al., 2014; Salgado et al., 2010) and academia e.g. AMOS (AMOS, n.d.) and NORUS (NORUS, 2011) have supported multi sensor and multiplatform approaches by the use of a variety of sensors mounted on different types of instrument platforms to measure parameters of interest (Hepsø et al., 2012; Schofield et al., 2010). Sensor platforms can typically be fixed e.g. buoys, moorings (Berge et al., 2009; Johnsen et al., 1997) and landers (Ocean Network Canada, 2014; Statoil, n.d.), or mobile e.g. Remotely Operated Vehicles (ROVs) (SERPENT, n.d.), Autonomous Underwater Vehicle (AUVs) (Kukulya et al., 2010; Maxson et al., 2011; Moline et al., 2005) and gliders (MBARI, 2014).

The problem of undersampling (Munk, 2000), have to some degree been alleviated by advances in technology (Godø et al., 2014), but still huge scientific efforts are in general necessary to fill the knowledge gaps and understanding of marine ecosystems. Many recent developments in platforms and sensors have been guided by needs in the marine sciences, seeing end-users with specific applications often involved in the engineering process (Bellingham, 2014; Glenn et al., 2005; Moline et al., 2005). As new technologies helps to fill knowledge gaps in the understanding of the environment, the level of complexity regarding data management and processing also increases. When the amount of data increases, the work necessary to transform these data to useful information increases accordingly. The scientific community, authorities and industry are at present struggling with optimising the use of these data and to utilise the opportunities of enhanced knowledge that can be obtained from combining multi sensor data (Fagerås, 2011; Hepsø et al., 2012; Johnsen et al., 2011). The time aspect is also of great importance as data must be transformed into information in due time for decisions or as input for dependent operations and processes. The increased volume and diversity in gathered data, including on-line data, requires better analytical tools to meet requirements for rapid data analysis and immediate action.

This paper presents an IEMM concept for data acquisition, processing and knowledge production. The challenges related to availability of analytical tools and data processing that must be solved to provide users or decision makers with relevant data in due time will be discussed. The use and functionality of the concept will be illustrated by a generic model showing steps and sequences, and two case studies using new technologies relevant for marine environmental mapping and monitoring purposes. In Case study 1 the IEMM concept is exemplified by scientific knowledge production from an arctic research project. Case study 2 shows the IEMM concept for a monitoring project initiated by the oil and gas industry.

2. Methodological approach

The methodological approach in IEMM is proposed to be generic and therefore relevant for authorities, industry and academia. Furthermore, it may be applicable independent of the operational environment, e.g. terrestrial and marine environments *in situ*, including laboratory experiments.

Using the systematic approach described in this section will aid users and decision makers to identify essential elements for consideration when planning a mission, help in selecting enabling technology (sensor, sensor platforms, software, etc.) for sufficient

Please cite this article in press as: Nilssen, I., et al. Integrated environmental mapping and monitoring, a methodological approach to optimise knowledge gathering and sampling strategy. Mar. Pollut. Bull. (2015), http://dx.doi.org/10.1016/j.marpolbul.2015.04.045