Marine Pollution Bulletin xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Review

Marine water quality monitoring: A review

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ARTICLE INFO

Keywords:
Marine pollution
Sea protection
Marine conventions
Marine governance

ABSTRACT

Marine water quality monitoring is performed for compliance with regulatory issues, trend detection, model validation and assessment of the effectiveness of adopted policies. As the end users are managers and policy makers, the objectives should be of practical interest and the answers should reduce the uncertainty concerning environmental impact, supporting planning and decision making. Simple and clearcut answers on environmental issues require synthesis of the field information using statistics, simulation models and multiple criteria analysis (MCA). Statistics is easy to apply whereas simulation models enable researchers to forecast future trends as well as test different scenarios. MCA allows the co-estimation of socio-economic variables providing a compromise between scientists' and policy makers' priorities. In addition, stakeholders and the public have the right to know and participate. This article reviews marine water quality monitoring principles, design and data analysis procedures. A brief review of international conventions of regional seas is also included.

Contents

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http://dx.doi.org/10.1016/j.marpolbul.2013.09.012

Please cite this article in press as: Karydis, M., Kitsiou, D. Marine water quality monitoring: A review. Mar. Pollut. Bull. (2013), http://dx.doi.org/10.1016/j.marpolbul.2013.09.012

1. Introduction

Quality assessment of the marine environment is routinely performed by measuring causes (pollutants) and effects (ecosystem impact) in the sea. If this practice is based on a sound experimental design and lasts over a number of years it is called "monitoring". Data collected during a monitoring program serve a number of objectives. They can be used for either compliance monitoring to ensure that both pollutants and ecosystem impacts from specific activities do not exceed standard values set by the authorities or relevant legislation or for model validation and verification to access whether possible effects on the marine environment are within acceptable limits set at the onset of the activity. They can also be used for trend monitoring to identify environmental changes on a long term basis. A monitoring definition given by MIT (1970) suits rather to trend monitoring defined as the "systematic observation of parameters related to a specific problem designed to provide information on the characteristics of the problem that changes with time". A monitoring program may fulfill one or more of the above mentioned objectives depending on monitoring targets; the set of data collected through the program can support conceptual and numerical modeling (future prospects), time series analysis (trend monitoring), statistical comparisons (impact assessment) as well as synthesis and interpretation (NRC, 1990). The difference between a monitoring system and individual research activities is that a monitoring system is an integrated system producing information for environmental management (NRC, 1990). In spite of the long experience acquired by high cost monitoring programs, they have been criticized that they do not provide information sound enough to form the baseline for decisions on environmental management. Many historical pollution monitoring programs have failed because they have not taken into account the key concept that the changes to be identified through monitoring should be significant to the marine environment and therefore be able to support management needs (Segar and Stamman, 1986).

In addition to ecosystem complexity, water quality monitoring programs suffer from variability due to design, sampling, laboratory (analytical) errors and data manipulation practices. The number of sampling sites, the number of samples per site, the number of replicate samples and the frequency of sampling, are factors that have to be taken into account as monitoring programs are usually compromising between requirements of science and budget availability by the authorities. Experimental designs based on statistically valid procedures would optimize the outcome; however, in most monitoring programs the design is based rather on "*judgment sampling*" rather than on statistically sound procedures, the latter being rather an exception to the rule (Erickson and Strickland, 1995; Kitsiou et al., 2001).

In spite of the shortcomings mentioned above, environmental marine water quality monitoring forms a platform for policy making and management. Without field measurements, the creation of regulatory issues and the application of management practices to protect human health and marine water quality would not have been successful. The long term collection of data from the marine environment at regular intervals, their use in addressing hypotheses and their interpretation provides the policy maker with the objective means to make decisions (Wolfe et al., 1987). Monitoring has been characterized as the "central element in the rational policy making" (de Jonge et al., 2006). Monitoring became a powerful and decisive tool in environmental policy since the governance of regional seas and coastal areas was supported by a number of international conventions, treaties and laws over the last few decades (DiMento and Hickman, 2012). Monitoring and assessment are the fundamental components required for effective marine management (Katsanevakis et al., 2011). Monitoring marine waters also provides information on the efficiency of implementation of measures decided for mitigating marine pollution and deterioration (Douvere and Ehler, 2011).

Initially the practice in monitoring programs in the marine environment was mainly focused on measuring concentrations of hazardous compounds such as heavy metals and petroleum hydrocarbons. Currently, the information collected by marine water quality monitoring is far more extensive and complex, including physical, chemical and biological variables (UNEP, 1997). In addition, information on social and economic aspects is often required along with the environmental information. Furthermore, data processing procedures are getting more multifaceted, including use of statistical methods on designing and analyzing the information (Chapman, 1996; Zuur et al., 2007; Kitsiou and Karydis, 2011), use of ecological indices for assessing ecosystem health (Magurran, 2004; Karydis, 2009), methods of Multicriteria Analysis (Kitsiou et al., 2002), spatial analysis methods (Janssen, 1992; Kitsiou and Karydis, 2011), simulation models (NRC, 2003) as well as integrated approaches, have introduced a high level of complexity in handling and assessing information acquired from monitoring data.

The objective of the present work is to review the practices followed on the structure and design of water quality monitoring programs as well as their potentiality and shortcomings in assessing marine water quality. A brief review on the monitoring components of international conventions for regional seas and European Union Directives is also presented.

2. Marine water quality monitoring: setting objectives

Clarity in the objectives is a crucial step when marine water quality monitoring programs are designed (Table 1). The user of the monitoring outcome is a decision maker, who needs the information to protect human health, to make sure that there is no unacceptable impact either on ecosystems or on marine resources and finally make decisions concerning disposal of pollutants in the marine environment. Monitoring is successful when the results can be used directly for effective management decisions. This assumes a two way communication between scientists and policy makers: the policy makers should realize beforehand the limitations of monitoring concerning the necessary information for decision making, whereas the scientists should know what kind of questions are of practical interest to policy makers. It is well known that both policy makers and the public need simple and practical answers to environmental problems. The most common questions are: (a) is the water quality in an area improving or not? (b) Is fish and shellfish biomass increasing? (c) Are fish and shellfish safe to eat? (d) Are coastal waters suitable for swimming?

The "holistic approach" should be the final goal of every environmental manager. Monitoring processes for the policy maker aim also to enable environmental managers to set standards, to use predictive models effectively by verifying predictions or if necessary, readjusting the model, to ensure that there is compliance with legislative requirements, otherwise to take necessary measures and to set an early warning system in view of future problems In addition, they aim to improve knowledge on structure and function of ecosystems (this target is especially feasible if the monitoring program is linked with relevant research projects) and to establish a better understanding about the health of the marine environment. However, not all monitoring programs are successful as both managers and politicians tend to ignore three basic principles (Segar and Stamman, 1986; de Jong, 2006; Katsanevakis et al., 2011) that there is no human activity without environmental impact, monitoring programs cannot always detect possible environmental impact and finally a slight impact may be

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