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How can we quantify impacts of contaminants in marine ecosystems? The ICON project

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ABSTRACT

An international workshop on marine integrated contaminant monitoring (ICON) was organised to test a framework on integrated environmental assessment and simultaneously assess the status of selected European marine areas. Biota and sediment were sampled in selected estuarine, inshore and offshore locations encompassing marine habitats from Iceland to the Spanish Mediterranean. The outcome of the ICON project is reported in this special issue as method-oriented papers addressing chemical analyses, PAH metabolites, oxidative stress, biotransformation, lysosomal membrane stability, genotoxicity, disease in fish, and sediment assessment, as well as papers assessing specific areas. This paper provides a background and introduction to the ICON project, by reviewing how effects of contaminants on marine organisms can be monitored and by describing strategies that have been employed to monitor and assess such effects. Through the ICON project we have demonstrated the use of an integrating framework and gleaned more knowledge than ever before in any single field campaign about the impacts contaminants may have in European marine areas.

1. Introduction

Marine ecosystems and organisms are influenced by many internal and external factors, including ecological processes and their interactions, fisheries, a changing climate, habitat modification, eutrophication and inputs of toxic chemicals. Exposure to contaminants[1] has the potential to affect cellular and physiological processes in marine organisms, as well as fundamental processes in marine ecosystems (Fleeger et al., 2003; Hylland et al., 2006b). The health of individuals or integrity of ecological processes will depend on many environmental factors, not only the presence of contaminants (see e.g. Hylland et al., 2009; Vestheim et al., 2012). Moreover, the consequences of contaminant exposure for the health of individual marine organisms will depend on the species, whether it is being exposed as adult, larvae, or embryo, and the life history of that species. Marine ecosystems are by nature dynamic and, particularly in temperate and polar regions of the globe, there is a pronounced annual seasonality in both abiotic and biological processes that modulate both partitioning of contaminants and effects caused by exposure to contaminants (Gagné et al., 2008;

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[1] As Paracelsus published in 1538: "dosis facit venenum" – it is the dose that makes the poison; any chemical will be toxic at some dose and although that the term "contaminant" does not imply effects, it is widely used in ecotoxicology and will be used here to describe chemicals that may cause toxicity in marine ecosystems.

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Jørgensen and Wolkers, 1999; Vijayan et al., 2006). Although it is close to impossible to single out how they influence marine organisms in any particular moment, it is important for regulatory reasons to be able to assess the extent to which contaminants actually cause effects and, whenever possible, to pinpoint the responsible contaminant(s). To this end it is crucial to be able to separate contaminant-related effects from changes caused by other environmental influences (see e.g. Hylland et al., 2009; Laane et al., 2012). In addition, we would ideally be able to compare effects across species and preferably identify and focus on the most sensitive species and endpoints for any particular contaminant. This is clearly a long-term endeavour, but significant progress has been made over the past couple of decades, and some ways to handle this challenge are reported in this special volume (e.g. Vethaak et al.; Hylland et al.).

In the past, European countries chose different strategies by which to monitor concentrations and effects of contaminants in marine habitats. As a result of both national interests and international agreements, countries with a coastline initially implemented monitoring programmes that targeted concentrations of chemicals in marine organisms. The objectives of the early monitoring programmes were typically twofold: to ascertain that humans do not consume contaminated food and to quantify the presence and spatial extent of elevated concentrations of selected contaminants for regulatory purposes. Effects of contaminants on marine organisms were not at the forefront of concerns in most countries, but initial effect-oriented monitoring programmes were pioneered in the early 1980s in some European countries. Somewhat different strategies were chosen, depending on national priorities and both national and international scientific advice. A range of science-based activities was put in place from the 1980s onwards to investigate the applicability of biological effects techniques to quantify the impacts of contaminants on marine organisms, the GEEP workshop in Frierfjord, Norway (Bayne et al., 1988), the Bremerhaven workshop in the southern North sea (Stebbing et al., 1992), the Bermuda workshop (Addison and Clarke, 1990) and the workshop on contaminant effects in pelagic habitats, BECPELAG (Hylland et al., 2006b). Selected biological effects techniques were tried out, validated and subsequently made available for monitoring activities through the preparation of standardised protocols and setting of assessment criteria. Guidelines were subsequently established for international organisation with a monitoring role, i.e. OSPAR,[2] HELCOM[3] and MEDPOL.[4] This activity has over the past two decades resulted in a harmonisation of the effect component of European contaminant monitoring programmes. At the moment, there is a process by which existing procedures and strategies are being carried over into the implementation of the Marine Strategy Framework Directive (MSFD), see e.g. Burgeot et al. (this issue), Law et al., 2010, Lyons et al. (2010; this issue), Thain et al. (2008), Vethaak et al. (this issue).

Although the process described above has had a particular focus on effects, it has been clear throughout that measurements of concentrations of selected contaminants in appropriate matrices would need to be included (Hylland, 2006; Thain et al., 2008). A framework for integrated chemical and biological monitoring of contaminants has recently been developed and is described in Vethaak et al. (this issue). The framework describes a comprehensive programme, aimed at identifying and quantifying both the presence and the effects of known and unknown contaminants. The framework comprises the main groups of chemical contaminants and a wide range of effect responses in selected marine organisms. The selection of effect methods for the framework was the result of comprehensive reviews by international working groups over the last two decades (summarised in Davies and Vethaak, 2012).

An international workshop on marine integrated contaminant monitoring (ICON) was initiated to test the above framework in practice on a Europe-wide scale. ICON was initially planned to evaluate effects of contaminants in the North Sea with Iceland as a reference area, but was later extended to the Baltic, France (Seine Bay) and Spanish Mediterranean waters.

This paper provides a background and introduction to the ICON project, by reviewing how effects of contaminants on marine organisms can be monitored and by describing strategies that have been employed to monitor and assess such effects. In addition to testing an implementation of the suggested monitoring framework, the ICON project aimed at providing an integrated assessment of selected estuarine, inshore and offshore marine areas encompassing European coastal waters from Iceland in the north to the Mediterranean in the south.

2. Monitoring effects of contaminants on marine organisms

A large volume of scientific literature produced over the past decades addresses how and whether chemicals affect marine organisms and how such effects may be detected and monitored. The overarching concepts for including biological effects in marine monitoring activities has been discussed in e.g. Depledge et al. (1993), Hylland (2006), Hylland et al. (2006a), Laane et al. (2012), Vethaak & ap Rheinallt (1992) and in international working groups, particularly ICES WGBEC.[5] Over the past three decades, there have been a vast number of studies that show a relationship between exposure to some stressor or contaminant and biological responses under controlled conditions in the laboratory, but this does not necessarily mean that the same method would be useful to monitor effects of contaminants in nature. The implementation of methods in environmental monitoring programmes is a sequential process from scientific discovery, through validation and verification to actual use. As for any other assessment tool, some degree of formalisation is required, as monitoring results will feed into a regulatory process, which could imply substantial costs for national authorities or commercial interests. As a rule of thumb, the following criteria should be met for any effect-based method prior to implementation on a national or international level (developed from ICES WGBEC, 2010): (i) the method should be able to separate contaminant-related effects from natural processes or the influence of other stressors, including knowledge of confounding factors, (ii) there should be some knowledge of dose-dependency, (iii) the mechanism of toxicity should at least partly be understood, (iv) quality assurance should be established, and finally (v) assessment criteria must be established for responses in relevant species.

Any method that is to be used to quantify effects of contaminants in nature must enable a separation of contaminant-related responses from changes caused by other exogenous or endogenous factors. There has therefore been a focus on identifying effect responses that are highly responsive to contaminant stress while not being strongly affected by other endogenous or exogenous factors. It is however important to remember that contaminant-related responses in an organism do not take place in a vacuum, but in biological systems with internal feedback and regulation. It is therefore to be expected that other physiological processes affect

[2] OSPAR: Oslo and Paris Commissions, http://www.ospar.org.

[3] HELCOM: Helsinki Commission, http://www.helcom.fi.

[4] MEDPOL: the marine pollution assessment and control component of the Mediterranean Action Plan (UNEP), http://www.unepmap.org.

[5] ICES Working Group on Biological Effects of Contaminants; http://www.ices.dk/community/groups/Pages/WGBEC.aspx.

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