Marine Pollution Bulletin 60 (2010) 2026–2042

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Application of bioassays in toxicological hazard, risk and impact assessments of dredged sediments

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ARTICLE INFO

Keywords:
In vitro
In vivo
Bioassay
Hazard and risk assessment
Dredged sediment
Dioxins
TBT
Licensing system

ABSTRACT

Given the potential environmental consequences of dumped dredged harbour sediments it is vital to establish the potential risks from exposure before disposal at sea. Currently, European legislation for disposal of contaminated sediments at sea is based on chemical analysis of a limited number of well-known contaminants for which maximum acceptable concentrations, action levels (ALs), have been set. The present paper addresses the issue of the applicability of *in vitro* and *in vivo* bioassays for hazard, risk and local impact assessment of dredged polluted sediments to be disposed of at sea. It discusses how and to what extent selected bioassays can fill in the gaps left open by chemical analysis and the way in which the bioassays may contribute to the present licensing system for disposal. Three different purposes for application were distinguished: the most basic application (A) is a rapid determination of the hazard (potential toxicity) of dredged sediments which is then compared to ALs in a licensing system. As with chemical analysis on whole sediment extracts, the bioavailability of the chemicals is not taken into account. As *in vitro* assays with sediment extracts are not sensitive to matrix effects, a selection of specific *in vitro* bioassays can be suitable fast and standardized additions for the licensing system. When the outcome of (A) does not convincingly demonstrate whether the sediment is clean enough or too polluted, further bioanalysis can help the decision making process (B). More aspects of the mostly unknown complex chemical mixtures are taken into account, including the bioavailability and chronic toxicity focusing on ecologically relevant endpoints. The ecotoxicological pressure imposed by the dredged sediments can be quantified as the potentially affected fraction (PAF) based on chemical or biological analysis of levels of contaminants in sediment or biota. To validate the predicted risk, the actual impact of dumped harbour sediments on local ecosystems (C) can be determined using a dedicated set of *in vitro* and *in vivo* bioassays as well as bio-indicators selected based on the information obtained from (A) and (B) and on the characteristics of the local ecosystem. Conversely, the local sediment impact assessment (C) can direct fine-tuning of the selection of chemical and bioassay analyses and for setting safe levels in the licensing system. It is concluded that *in vitro* and *in vivo* bioassays and biological indicators are useful tools in the process of hazard, ecotoxicological risk and impact assessment of dredged harbour sediments, provided they are consciously chosen and quality criteria for assay performance are defined.

1. Introduction

Sedimentation of suspended particles in delta areas such as those in the Netherlands is a natural process that provides the primary food source for filter-feeding macro invertebrates (Wood and Armitage, 1997). However, in harbours and waterways, frequent removal of sediment is required to prevent obstruction of important shipping activities. An average of 26 million cubic meters of sediment has to be dredged every year (Table 1) from eight major tidal harbours along the Dutch coast (Fig. 1). Annually, over 90 million tonnes are disposed of at sea within the OSPAR maritime area (OSPAR, 2005) and hundreds of millions of tonnes are disposed of worldwide (Lauwert et al., 2006; Witt et al., 2004; Bolam et al., 2006). World wide, harbour sediments are contaminated with persistent organic pollutants (POPs), including polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), tributyltin (TBT), mineral oil, and toxic metals like mercury, and several other sometimes unidentified chemicals which pose a hazard for the receiving marine systems (Stronkhorst and Van Hattum, 2003c).

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doi:10.1016/j.marpolbul.2010.07.018

Table 1
Yearly volumes of dredged material for disposal at sea for different Dutch harbours and the % of dredged material that exceeds the action limit (AL) for disposal at sea.

Harbour location	Number of harbour sections	Harbour area (m^2)	Yearly average volume dredged (m^3)	Yearly average volume dredged as dw (kg/dw)	% Exceeding AL	Samples analyzed (1999–2005)
Delfzijl	11	2.074.729	1.863.175	1,453,276,500	1.9	66
Harlingen	21	195.220	1.477.919	1,152,776,820	1.8	48
Den Helder	15	506.495	955.671	745,423,380	0.7	42
IJmuiden	30	208.798	2.908.735	2,268,813,300	2.1	128
Scheveningen	9	191.322	290.000	226,200,000	1.2	33
Rotterdam Rijnmond	234	62.664.047	17.037.650	13,289,367,000	11.7	1030
Vlissingen	11	4.451.785	772.156	602,281,680	0.4	15
Eemshaven	5	1.794.066	832.236	649,144,080	0.3	28
Total	331	72.086.462	26.137.542	6,795,760,920	2.5	1390

Fig. 1. Tidal harbours along the Dutch coast where sediment samples were collected.

Given the potential environmental consequences of dumped dredged harbour sediments, it is vital to establish the potential risks before disposal at sea.

Therefore, minimum quality criteria are set for harbour sediments to be disposed of at sea, to ensure that the chemical impact on the receiving environments is zero or acceptably low (Stronkhorst et al., 2003b; Lauwert et al., 2006). Currently, legislation for disposal of contaminated sediments at sea is based on chemical analytical standards for a limited number of well-known contaminants (OSPAR, 2004; Alvarez-Guerra et al., 2007b) for which maximum acceptable concentrations, action levels (ALs), have been set. This approach, however, focuses on local acute toxic effects which are unlikely to occur because of the major dilution of the chemicals in the water phase of marine and estuarine environments during disposal. Actually, at the disposal location, the physical covering of the local benthic ecosystem with meters of dredged sediment often poses a much greater acute threat than toxic chemicals (Stronkhorst et al., 2003a; Bolam et al., 2006). On the other hand, several of the sediment-associated, persistent, bioaccumulating and toxic (PBT) chemicals known to induce chronic sub-lethal effects are bound to the small sediment particles and transported to locations far away from the original dumping site (Sonneveldt and Laane, 2001). Given the potential chronic environmental consequences of these PBT chemicals and their bioaccumulation in the food chain, it is vital to improve the assessment of the full environmental risk posed by contaminants in disposed dredged material, including the risk for chronic effects at locations at a long distance away from the disposal site.

A number of shortcomings are associated with the current chemical analytical approach. No ALs exist for more recently identified contaminants found in sediments, including priority substances such as polybrominated diphenyl ethers (PBDEs), perfluorinated chemicals (PFCs) such as perfluorooctane (PFOS) and perfluorooctanoic acid (PFOA) and phthalates (EU, 2006). In addition, dredged sediments with concentrations of contaminants below the individual lower ALs are dumped in North Sea coastal waters, although potential additive toxicity of the identified and unidentified chemicals present is not known. On the other hand, if levels exceed the upper limit of ALs, the dredged material has to be stored in costly repositories, although exceedance of the ALs does not necessarily mean that upon disposal environmental damage will occur.

To prevent unexpected environmental damage but also unnecessary costs, policy- and decision-makers must be able to characterize the real environmental risks of the disposal of dredged sediments at sea. For this purpose, it was suggested to include bioassays in the decision making for disposal. Bioassays in this context are biological assays that determine the toxic potency of whole sediment or sediment extracts. The main added value expected from bioassays is the detection of yet unknown chemicals and mixture effects. Bioassays can be performed with whole animals (*in vivo*) or with isolated parts (*in vitro*) such as cells, proteins or enzymes. *In vivo* bioassays with full sediment are expected to take the bioavailability of the chemicals into account (Maas and Van den Heuvel-Greve, 2005). Further, the possible local impact of dumping dredged sediments can be monitored. In addition to application of bioassays to the local sediment, local biological indicators can be used. These bio-indicators are local species or groups of species whose population or health status can be used to determine environmental integrity. Such organisms can be monitored for specific changes (biochemical, physiological, or behavioural)