Research needs in sediment bioassay and toxicity testing

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1. Introduction

Research on the toxicity of chemicals in sediments has increased considerably over the past decade (Burton, 1991). This is because scientists and environmental regulators have recognised that aquatic sediments may play an important role in storing contaminants from, or releasing them into, the water column (Shea, 1988; Power & Chapman, 1992). Much of the research in this area has been performed by North American workers. Recently, however, there have been several European initiatives in the field of sediment toxicity assessment, funded by the European Commission (Pascoe *et al.*, 1992; Crane *et al.*, 1993), Paris Commission (PARCOM, 1994) and national regulatory bodies (eg Barrett & Dohmen, 1992). There is always the danger of repeating the mistakes, or duplicating the studies of other workers during the early stages of research. Members of SETAC-Europe therefore felt that a workshop to produce guidance on standardising sediment toxicity assessment was timely. This paper describes the research needs that were identified during the course of that meeting.

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2. Workshop on Sediment Toxicity Assessment (WOSTA)

This workshop was held at Renesse in the Netherlands from 8th to 10th November 1993. Forty participants from industry, academia and government were invited, based on their expertise and involvement in European sediment toxicity initiatives. Representatives were also invited from North America, so that relevant experience from the United States and Canada could be considered.

The participants were split into seven working groups chaired by an individual who had been briefed on the scope of his group's topic area. The seven topics that were discussed during the meeting were:

i) The collection and preparation of physical materials;
ii) Chemical spiking and analysis;
iii) Organisms and end points;
iv) Test system and experimental design;
v) Statistics;
vi) Interpretation of sediment toxicity tests;
vii) Interpretation of sediment bioassays.

Each group explored questions within each of these topics and brought their answers to plenary sessions for further discussion. The results of the meeting have been published in a SETAC-Europe Guidance Document (Hill *et al.*, 1994), which contains details on currently accepted standard practice for testing sediment toxicity. This included a summary of research needs, which is expanded below.

3. Research needs

3.1 Decision-making frameworks

Environmental managers need clear guidance on an appropriate hierarchy of test systems for toxicity evaluations (Parkhurst *et al.*, 1988). This is true for both toxicity tests, in which sediments are spiked with a known contaminant, and bioassays, in which organisms are exposed to field sediments potentially contaminated by one or more chemicals.

Sediment toxicity tests have a variety of uses, but their overall scope is:

i) The classification, ranking and labelling of new and existing substances.
ii) Risk assessment and risk management of substances and preparations that are expected to reach sediments.
iii) Setting Environmental Quality Standards for substances known to be found in sediments.

Sediment bioassays also have various uses, but their overall scope is:

i) The ranking and classification of relative toxicity.
ii) For determining whether toxicity-based sediment quality criteria have been exceeded.
iii) The regulation and risk management of the use or discharge of chemicals, especially when multiple-consented discharges may exert jointly toxic effects in sediments.

Simple tests such as the Microtox liquid-phase assay often predict toxicity as adequately as acute whole-sediment invertebrate exposures and cost considerably less to perform in both time and materials (Becker *et al.*, 1990; Chapman *et al.*, 1991; Ho & Quinn, 1993). The recently introduced Microtox solid phase assay may improve still further on the liquid phase method. It therefore seems sensible to propose that rapid screening tests are used initially in any sediment toxicity assessment. This is especially important when the spatial variability and heterogeneity of sediment toxicity in bioassays are considered (Stemmer *et al.*, 1990). However, experience in the Netherlands indicates that short-term screening tests may not have the desired discriminatory power in sediment management strategies. Here long-term bioassays are recommended (van de Guchte, 1992).

There is clearly an urgent need for a decision-making framework to enable specific recommendations to be made on when to use whole sediment bioassays rather than water phase bioassays.

3.2 Equilibrium partitioning timescales

The relationship between hydrophobicity and the time required to reach equilibrium partitioning needs to be investigated for a range of sediment properties and contaminant types. Models for the partitioning of nonionic organic chemicals in sediments have already been developed (Di Toro *et al.*, 1991). These models can be used to predict bioavailable concentrations of toxic materials for comparison with Water Quality Criteria. However, bioturbation of natural sediments affects contaminant partitioning to such an extent that complete equilibrium may be prevented (Green *et al.* 1993). Other kinetic processes may also occur in field situations, and such phenomena could have major implications for physico-chemical equilibrium modelling approaches. The uptake kinetics of very hydrophobic chemicals also brings into question the relevance of short-term toxicity testing.

3.3 Development of comprehensive normalisation procedures

Reliable normalisation procedures are needed for chemicals other than neutral hydrophobic organics, such as heavy metals and surfactants. Methods are available for measuring acid-volatile sulphide (AVS), a controlling phase for heavy metals (Green *et al.* 1993). However, measurement of AVS does not provide a complete explanation of heavy metal toxicity (Di Toro *et al.*, 1990, Ankley *et al.*, 1991a; Carlson *et al.*, 1991).

3.4 Standardisation and validation of pore-water and elutriation techniques

Testing of extracted pore-waters or elutriates is sometimes used as an alternative to whole sediment tests. Further comparative studies (i.e. whole sediments versus pore waters and elutriates) are required before the general use of pore-waters or elutriates as surrogates can be recommended. Some studies have shown that extracted pore-waters do provide a good indication of chemical toxicity to invertebrates (Ankley *et al.*, 1991b; Ankley *et al.*, 1993; Burgess *et al.*, 1993; Green *et al.* 1993). However, elutriates may not be as effective as pore waters in predicting bulk sediment toxicity to benthic organisms (Ankley *et al.*, 1991b).

There is also a need for standardisation of sediment pore-water extraction and elutriation methods because these may contribute substantially to the variability between test results in these systems.

3.5 Spiking procedures

Standardised procedures need to be developed for spiking chemicals into sediments. Most techniques for spiking hydrophobic organic chemicals involve the use of organic solvents such as acetone (Ditsworth *et al.*, 1990). Further information is needed on the maximum no-effect levels in sediments of organic solvents that may be used during sediment spiking procedures.

3.6 Physico-chemical variability of natural sediments

If natural sediments are used in toxicity tests, the degree to which confounding factors, such as organic carbon content and grain size, contribute to variability needs to be investigated so that recommended limits can be set (Ankley *et al.*, 1994). Normalisation of results in relation to organic carbon content, or another known controlling phase, may reduce the effects of variability, but some factors that affect chemical bioavailability in sediments remain poorly understood (Suedel *et al.* 1993).

The tolerance ranges of test species to environmental variables like pH, O_2, NH_3 and NO_3^- should also be known so that effects data can be interpreted correctly (van de Guchte, 1992). It should also be recognised that biological factors, such as differences in resident faunal density in environmental samples, may also confound bioassay results (Reynoldson *et al.*, 1994).

3.7 Use of artificial sediments

Because of the problems identified in 3.6, there is a need to develop an acceptable artificial sediment for toxicity tests so that confounding factors can be minimised. Some recent progress has been made in this area, with artificial sediments constructed from combinations of *Sphagnum* peat humus, quartz sand, kaolinite and other materials (Suedel & Rodgers, 1994; Watzin *et al.*, 1994). The ability of such sediments to predict chemical fate and effects in natural environments should now be assessed.

3.8 Long-term test methods

There is a general need for new test designs that use small animals with short life-cycles, and good growth and reproduction in laboratory sediment systems. Freshwater sediment tests with *Chironomus* and *Lumbriculus* spp. fulfil these criteria (Kosalwat & Knight, 1987; ASTM, 1993; Phipps *et al.*, 1993; van de Guchte *et al.*, 1993).

However, current procedures for assessing the acute toxicity of whole marine sediments favour the use of macrobenthic invertebrates such as amphipods (ASTM, 1992; Environment Canada, 1992; Roddie *et al.*, 1994). These animals are simple to handle and can be easily separated from sediment at the end of a test. Their use is a cost-effective approach to acute toxicity testing. However, large invertebrates tend to have relatively long life-cycles (Environment Canada, 1992). This means that chronic tests with these animals must also be lengthy if they are to cover a significant proportion of the normal life-cycle.

Meiofaunal invertebrates may provide an answer to this problem (Coull & Chandler, 1992). The meiobenthos consists of metazoans that pass through a 0.5 mm sieve but are retained by a mesh size $\leq$ 0.1 mm. Recent work with meiobenthic copepods has shown that toxicity tests can be conducted on complete life-cycles within 21 days (Chandler, 1990; Chandler & Scott, 1991; Strawbridge *et al.*, 1992). Meiofaunal polychaetes have also been used successfully in sediment toxicity tests (Chandler & Scott, 1991).

Reliable long-term, sublethal endpoints with a wider range of species are also required for sediment toxicity tests and bioassays. Some physiological indices, such as faecal pellet production (Stromgren *et al.*, 1993), have proved useful, but others should be developed with a range of species. Recent work on biomarkers in fish exposed to contaminated sediments has shown that subcellular indices such as DNA integrity and ethoxyresorufin-*O*-deethylase (EROD) activity are useful indicators of pollutant exposure (Theodorakis *et al.*, 1992; van der Weiden *et al.*, 1993).

3.9 Field validation of laboratory predictions

There is a need for effects data on chemicals in sediments obtained under both laboratory and field conditions. This will allow the development of sediment-specific application factors. Few studies have been performed in which laboratory results are compared with data for the same species deployed *in situ*. Those few that have been performed suggest that the toxicity of sediments transferred to the laboratory may be either higher or lower than the toxicity of sediments retained *in situ* (Sasson-Brickson & Burton, 1991; Skalski, 1991; Jacher & Burton, 1993).

There is also a need to generate data from multispecies sediment tests or surveys in the field to provide validation of predictions and extrapolations made from laboratory-based sediment bioassays (eg Swartz *et al.*, 1994). The use of experimental microcosms and mesocosms would be a useful method for testing laboratory predictions under controlled semi-field conditions (Drenner *et al.*, 1993; Watzin *et al.*, 1994).

4. Conclusions

The research needs outlined above fall into three categories. Regulatory frameworks for sediment assessment procedures are clearly an important managerial tool. Without such a framework, regulators are unlikely to make the most cost-effective use of available techniques or to recognize the strengths and weaknesses of the bioassay/toxicity test approach (Luoma & Carter 1993). The second category of research needs is the development of established methodologies for spiking chemicals, removing pore-waters, examining the usefulness of artificial sediments, and testing the predictive power of laboratory assays in field systems. The final category, that of basic research needs, remains the most challenging. The fate, distribution and behaviour of chemicals in natural sediments are still far from well understood. The long-term effects of polluted sediments on biota is also an area where considerable effort should be focused.

5. Summary

A recent increase in European research activity in the field of sediment toxicity assessment led to the organization of a workshop in the Netherlands in November 1993. The Workshop on Sediment Toxicity Assessment (WOSTA) brought together European, and some North American, scientists from academia, industry and government to develop a

guidance document for performing sediment bioassays and toxicity tests. Several important research needs were identified during the workshop. These were the need for, i) regulatory decision-making frameworks for choosing appropriate tests, ii) research on equilibrium partitioning timescales in the environment, iii) the development of normalisation procedures for a range of chemical classes, iv) standardisation and validation of pore-water and elutriation techniques, v) standardisation of chemical spiking techniques, vi) further investigation of confounding factors in natural sediments, vii) development of an internationally acceptable artificial sediment, viii) development of chronic test methods, and ix) field validation of laboratory predictions.

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