International Environmental Modelling and Software Society (iEMSs)
2012 International Congress on Environmental Modelling and Software
Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany
R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.)
http://www.iemss.org/society/index.php/iemss-2012-proceedings

DM2: A Software Tool for Dredged Material Characterization and Management

Alla Khosrovyan[1], Araceli Rodríguez-Romero[2], T. Angel DelValls[1], Inmaculada Riba[1]

[1]*University of Cadiz, Faculty of Marine and Environmental Sciences, Physical Chemistry, UNESCO/UNITWIN/WiCop, Puerto Real, Spain (alla.khosrovyan@uca.es, angel.valls@uca.es, inmaculada.riba@uca.es)*

[2]*Institute of Marine Sciencies of Andaluzia, Department of Ecology and Coastal Management, Puerto Real, Spain (araceli.rodriguezromero@uca.es)*

Abstract: A new software tool - Decision Making on Dredged Material (DM2) - for dredged material quality assessment and management is developed. Based on Spanish recommendations for dredged material management of 2008, it analyzes different lines of evidence of sediment contamination by metals and organic micro-pollutants. Particularly, chemical load in sediments is compared to the admissible concentration limits of these contaminants as adopted in Spain; sediment toxicity is estimated based on the responses of organisms to contaminant exposure. Integrated assessment of the sediment quality is done by assigning categories from A to C depending on the severity of contamination. The same categories also serve as management options with regard to the fate of the sediment after dredging. The options vary from allowing free disposal in the open sea to prohibiting it until proper remediation actions are applied. A case-study on three different ports of Spain is conducted with the help of the tool showing the state of contamination and management decisions associated with dredging activities in the ports.

Keywords: Software tool; decision-making model; weight-of-evidence; toxicity.

1. INTRODUCTION

Increased understanding of contaminant exposure pathways in aquatic sediments has brought about necessity of integrated sediment quality assessment. Previous reliance on sediment quality guidelines only (verification of exceedance of them) has proven its insufficiency for comprehensive assessment of sediment contamination state and associated threats to aquatic organisms as shown e.g., by Chapman et al. [2002] and Crane [2003]. Instead, multiple lines of evidences (sediment chemistry, toxicity, bioaccumulation, biomarkers) and their interactions have already been proven to successfully serve this purpose. They formed weight-of-evidence framework (WOE), which is nowadays a commonly recognized approach for assessing marine sediment quality, according to Beiras et al. [2003], Casado-Martínez et al. [2007], Chapman and Anderson [2005], DelValls and Conradi [2000], Riba et al. [2006], Sarmiento et al. [2011].
While many countries have adopted the WOE approach, lack of a handy tool enabling to integrate multiple lines of evidences (LOEs) still impedes wide application of it by environmental practitioners including decision-makers and managers.

This work addresses the need for improving environmental management process by providing a handy easy-to-use software tool for sediment quality assessment built on WOE framework.

2. WEIGHT-OF-EVIDENCE METHODOLOGY USED IN THE SOFTWARE DEVELOPMENT

Any WOE methodology intends to find causative links between different LOEs (contamination, toxicity tests, etc.). In the present work, the WOE methodology used is the new Spanish framework for dredged material management suggested by CEDEX [2008]. It represents a branched decision-making flowchart, in which physico-chemical characteristics of sediment and toxicity responses obtained after exposure to the sediment are used for estimation of its quality (Figure 1).
The physico-chemical characteristics include physical properties (sediment grain size, organic carbon content) and chemical concentrations in the sediment matrix. The chemicals are the metals and organic pollutants listed as priority hazardous substances by OSPAR Convention and EU directive 2008/105/EC on environmental quality standards in the field of water policy.

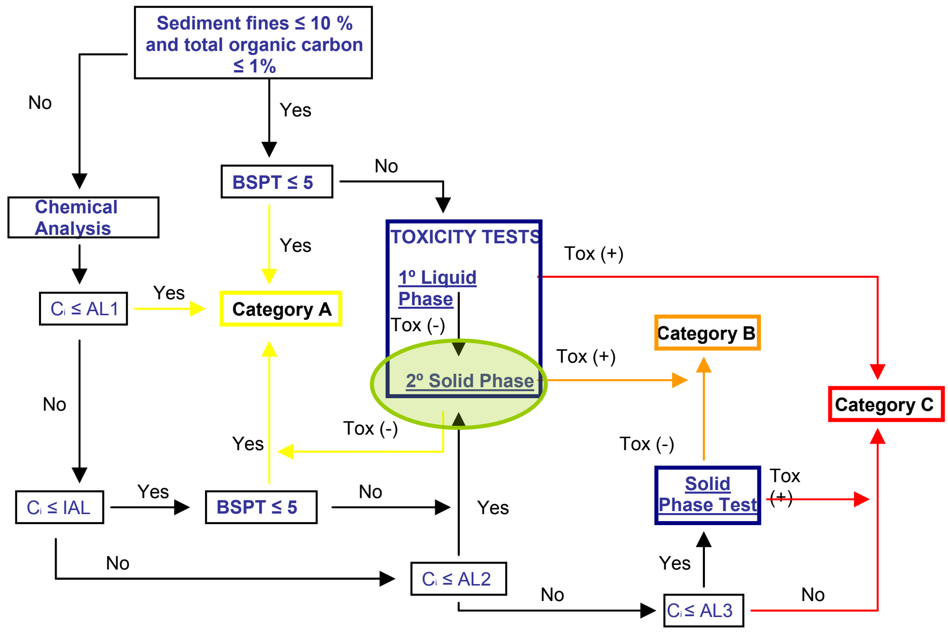

Figure 1. Spanish dredged material management framework represented as decision making flowchart proposed in 2008. C_i – concentration of the i-th contaminant; BSPT – response in Microtox® basic solid-phase test; AL1-AL3 and IAL – four different sediment guidelines adopted in Spain; categories A-C characterize sediment contamination state and also represent management options relative to dredged sediment.

Figure 1 shows that sediment physical properties play important role in transportation and availability of sediment contaminants. Sediment substrate type and carbon content are important factors affecting bioavailability and mobilization of contaminants bound to them. Fine sediments adsorb more organic matter and metal pollutants then coarse ones, as demonstrated by Bryan and Langston [1992] and Carpentier et al. [2002]. Under favorable conditions the adsorbed contaminants might be mobilized and can enter different pathways affecting aquatic organisms.

The toxicity tests allow for differentiation between various exposure pathways and consists of solid- and liquid-phase bioassays (test-battery) (Figure 1). In the test-battery first, sediment toxicity to water column-dependent species is tested. If the sediment is reported as toxic, then it represents high risk to the biota (category C) because the contaminants seem to be easily dissolved in the overlying water. If the sediment is not harmful (toxic) to water-based animals, then toxicity to sediment-dependent organisms is tested. If the toxicity is proved, then the sediment is assigned category B. Otherwise, no environmental concerns can be raised relative to the sediment in question (category A).
In the case when at least one of the contaminants has concentration above AL3 limit, then the sediment is immediately categorized as very polluted and posing a threat to living organisms (category C).
The categories also serve as management options for further action to be applied to the dredged sediment.

3. SOFTWARE DESCRIPTION

DM2 is a decision-making tool developed for PC computers using VBA (Excel) programming language and statistical software package SPSS11. Software development strictly followed the decision-making flowchart (Figure 1).
First, sediment physical properties are analyzed. If sediment is coarse and poor in organic carbon, then the response in Microtox® toxicity test is taken into consideration. If the response is below the guideline value, then the sediment lacks environmental concerns associated with its use/disposal (category A). However, if Microtox® response exceeds the guideline level, then sediment toxicity is further examined through the test-battery described above.
In the contrary case, when fine particles dominate in sediment and it is enriched in organic carbon, then the flowchart examines the sediment chemical stress. Concentrations of priority trace metals and other hazardous substances are compared to four different guideline values adopted in Spain and called Action Levels (AL) - AL1, AL2, Intermediate AL (IAL), AL3 (Table 1).

Table 1. Action level (AL) guideline values for different contaminants used in the Spanish framework for dredged material management proposed by CEDEX [2008].

Parameter	Unit	AL1	IAL	AL2	AL3
Hg	(mg/kg)	0.18	0.71	2.84	14.2
Cd	(mg/kg)	0.6	2.4	12	60
Pb	(mg/kg)	47	188	752	3760
Cu	(mg/kg)	34	136	680	3400
Zn	(mg/kg)	150	410	1640	8200
As	(mg/kg)	30	70	280	1400
Ni	(mg/kg)	39	78	234	1170
Cr	(mg/kg)	81	324	1296	6480
PCB	(μg/kg)	22	88	440	2200
PAH	(μg/kg)	940	3760	18800	94000
TBT	(μg/kg)	100	200	1000	5000

If all contaminants have concentrations lower than AL1 limits, then, despite the potential flux of contaminants from sediment to water, the sediment is said to be not posing a risk to living organisms (category A). However, if concentration of at least one of the contaminants exceeds AL1 limit, then comparison to the next action level (IAL) is necessary. If IAL limits are not exceeded, then the result of Microtox® test is taken into account. Depending on it, the sediment can be categorized as clean (category A) or the responses in the test-battery should be further considered. The latter is also used when any contaminant has concentration exceeding IAL limit but staying below AL2 limit.

Finally, when all the contaminants have concentrations exceeding AL2 but staying within AL3 guideline values, then the toxicity responses of sediment-dependent organisms are evaluated. If sediment toxicity is confirmed at such high levels of contaminant concentrations, then the sediment is apparently harmful for biota (category C). Otherwise, the sediment is characterized as of moderate risk (category B).

The program development pursued the objective of creating simple and user-intuitive interfaces, which are enhanced by capability of generating an informed decision about sediment quality. For this purpose, a commonly used data entry format was chosen – MS Excel spreadsheet.

The informed decision that is based on the applied WOE methodology requires numerous comparisons between environmental variables and biological effects (toxicity responses). While the overall process is time-consuming and error-prone, if done manually, the software tool quickly performs all tedious comparisons. Besides, any error caused by human factors is excluded.

The tool has its critical content password-protected. The critical content includes columns names in the spreadsheets which are supposed to prompt the user about the required content on each spreadsheet. The password-protection eliminates the risk of occasional or unwanted editing of the critical content.

The tool is distributed as an MS Excel file with embedded macros and 2 text files containing scripts for statistical analysis. Statistical package SPSS11 is implied to be available to the end-user.

The software has been tested in WinXP, Win7 Starter and Win7 Home Premium OSs with MS Excel 2003, 2007 and SPSS11 statistical package.

In order to check the reliability of the program, the output was compared to the manually obtained results. They were totally identical. In case of wrong and missing inputs the program issues a warning and stops execution.

The program was first released in 2011 in Spanish version. Program size is around 100 KB.

4. SOFTWARE USING

The program is a MS Excel file containing 4 spreadsheets. Each spreadsheet is provided with self-explanatory name hinting about the required input (Figure 2). For example, the program starts with the main spreadsheet “PhysChem”, which name prompts about the type of data to be entered here - sediment chemical and physical properties. Other spreadsheets are named as “solid-phase”, “liquid-phase”, “microtox”. As the names suggest, they are intended for entering responses obtained from the corresponding toxicity tests.

Each spreadsheet comes with the predefined content. The latter is the table in which some columns are named and protected from occasional editing. For example, the toxicity response spreadsheets contain two columns names “Replica 1” and “Replica 2”. It is supposed that the column names prompt the user that here replicated measurements should be entered. Then the user is allowed to add as many columns as necessary to include all replicated data (Figure 3).

One of the spreadsheets (hidden) contains sediment guidelines (Table 1) to which the observed data are compared. The guidelines can be edited, if need be.

The software is run by pressing button “Start” on the main spreadsheet. By this, all required comparisons are made and one-way ANOVA Dunnett ($p<0.05$) statistical test is run on SPSS11 without any user intervention. Upon completion of the program, the categories for each sample are added as the new column in the main spreadsheet (Figure 4).

If during the program execution an erroneous situation occurs the user is prompted about it and a corresponding action is suggested.

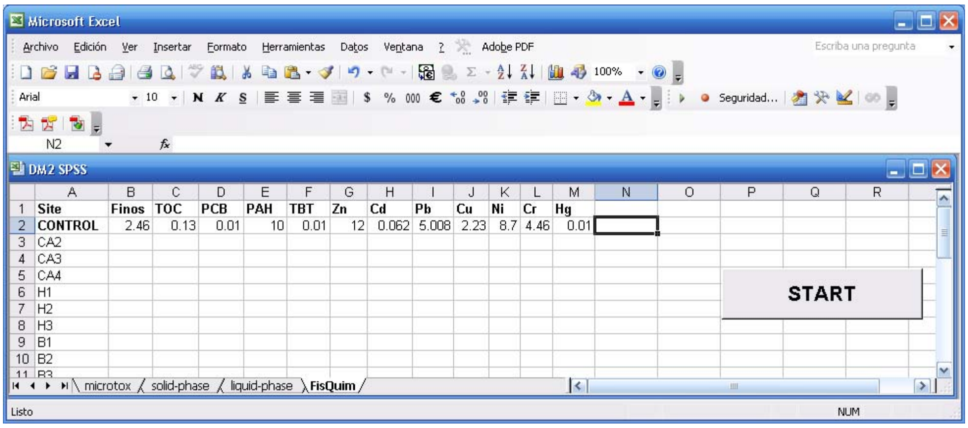

Figure 2. DM2 computer program initial interface.

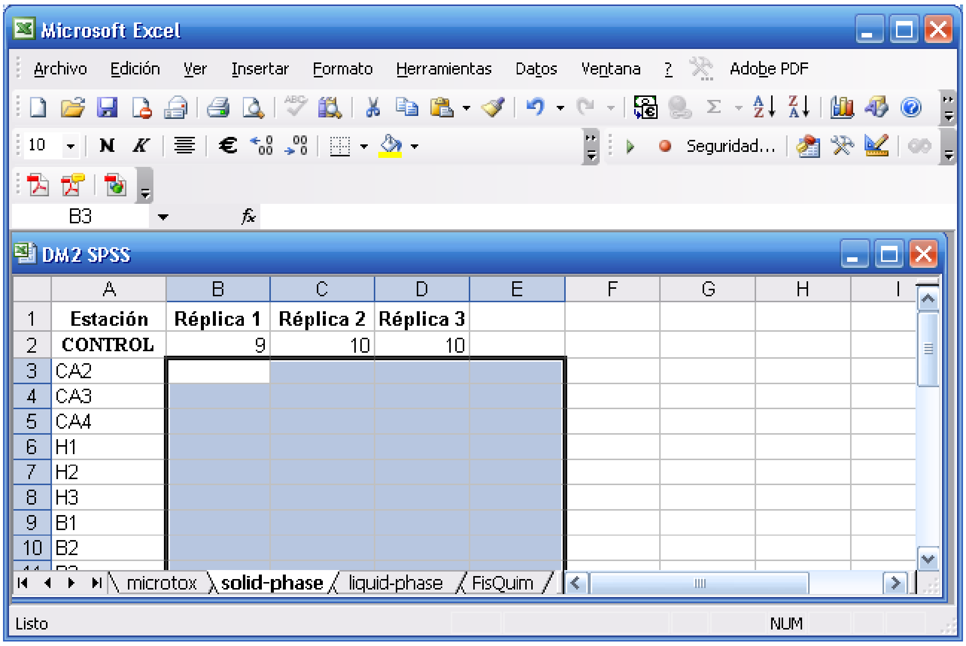

Figure 3. Spreadsheet for entering responses in solid-phase toxicity test.

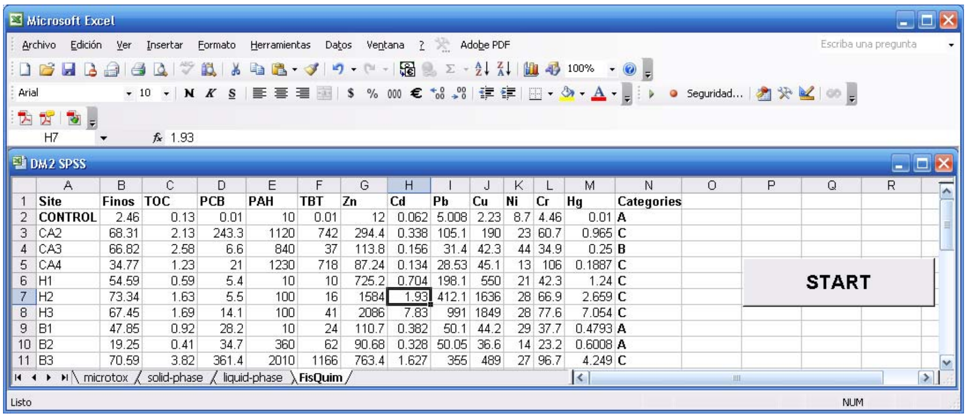

Figure 4. Outcome of the DM2 program represented as the new column with sediment categories.

5. APPLICATION AREA

A case-study on three commercial ports of Spain is provided to demonstrate the software use and derived categories (which are also management options) characterizing sediment contamination status.
The data were collected during June-July 2008 from ports of Huelva (H1, H2, H3), Barcelona (B1, B2, B3) and Cadiz (CA1, CA2, CA3, CA4).
The following chemicals were measured: 8 metals (Hg, Cd, Pb, Cu, Zn, As, Ni, Cr), 7 polychlorinated biphenyls (PCB congeners 28, 52,101, 118, 138, 153, 180), 9 polycyclic aromatic hydrocarbons (PAHs: anthracene, benz(a) anthracene, benzo(ghi)perylene, benzo(a)pyrene, chrysene, fluoranthene, indene (1,2,3-cd) pyrene, pyrene and phenanthrenes) and tributyltin (TBT).
Determination of chemical concentrations and physical properties of the sediments were done according to the predefined procedures by Casado-Martinez et al. [2006a]. Toxicological tests were performed using species of amphipod *Ampelisca brevicornis* (solid-phase test), sea urchin *Paracentrotus lividus* (liquid-phase test) and marine bacterium *Vibrio fischeri* for Microtox® basic solid-phase test. All tests followed the approved protocols described by Morales-Caselles et al. [2008], Riba et al. [2003].
Toxicity test responses are evaluated to identify statistically significant differences from the reference. Additionally, other approaches can be applied as well. For example, in this study for the solid-phase test, one-way analysis of variance (ANOVA Dunnett test, $p<0.05$) was used. For the liquid-phase test, arithmetic difference between reference and sample means of more than 20% is applied, in addition to the statistics-based test as suggested by Casado-Martınez et al. [2006b], Riba et al. [2004].
Sample CA1 was used as a reference due to the least chemical concentrations compared to other sites (far below AL1 limits) where for most of the contaminants concentrations were not even detected.
The results of the program (Figures 4, 5) show that some samples e.g., CA2, CA4, H1-H3 are highly-polluted (category C). Indeed, they had high chemical load and/or low survival of the biological organisms. The selected ports of Cadiz (CA2, CA4) are known for intensive shipyard and ship movement activities. Ports of Huelva (H1-H3) have had highest metal content in the sediment, compared to the other ports. Thus, if any of these ports is to be dredged, disposal of the dredged sediment will not be allowed without prior cleaning treatment. In the contrary, some ports e.g., B1 and B2 are shown to be very low-contaminated (category A), and dredging activities here are not associated with environmental concerns.

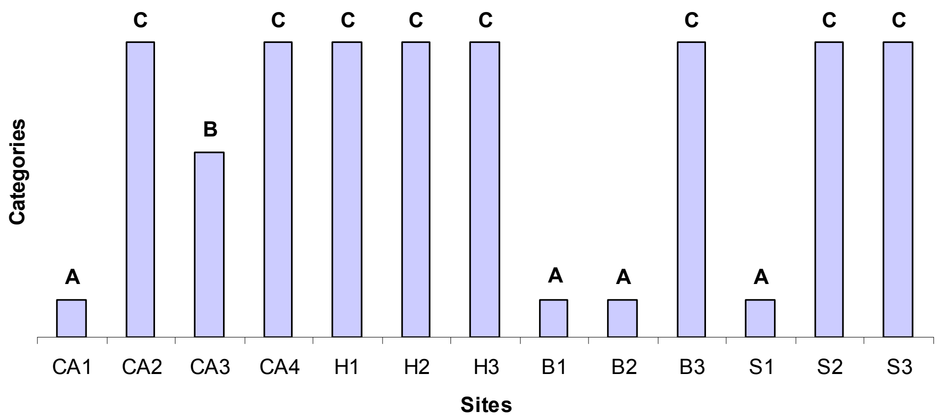

Figure 5. Comparative plot of categories derived according to the decision-making flowchart by CEDEX [2008].

The software may have a wide application area. While the case-study shows its use in environmental decision making, particularly for dredged material management, it can be successfully used in ecotoxicology or environmental monitoring as well. The data collected by the corresponding authorities can be immediately evaluated from the point of view of environmental risk and therefore escalated in due time to the interested parties for their fast response.

6. CONCLUSIONS

Weight-of-evidence methodology is intended for understanding chemical causation of biological effects in such a complex system as marine sediment. However, the data obtained in the context of this methodology are not always easily managed by many practitioners including those engaged in environmental monitoring, management, eco-toxicology. This development work addresses the need for improving environmental management. It empowers relevant authorities with a tool for better information management, which will in turn improve environmental practice and environmental outcomes.

REFERENCES

Beiras, R., J. Bellas, N.J. Fernandez, I. Lorenzo, and A. Cobelo-Garcıa, Assessment of coastal marine pollution in Galicia (NW Iberian Peninsula); metal concentrations in seawater, sediments and mussels (Mytilus galloprovincialis) versus embryo–larval bioassays using Paracentrotus lividus and Ciona intestinalis, *Marine Environmental Research,* 56, 531–553, 2003.

Bryan, G.W., and W.J. Langston, Bioavailability, accumulation and effects of heavy metals in sediments with special reference to United Kingdom estuaries: a review, *Environ. Pollut.,* 76, 86–131, 1992.

Carpentier S., R. Moilleron, C. Beltran, D. Herve, and D. Thevenot, Quality of dredged material in the River Seine basin (France). I. Physico-chemical properties, *Sci Total Environ.,* 295 (1), 101– 113, 2002.

Casado-Martınez, M.C., J.L. Buceta, M.J. Belzunce, and T.A. DelValls, Using sediment quality guidelines for dredged material in commercial ports from Spain, *Environ. Int*., 32, 388-396, 2006a.

Casado-Martinez, M.C., J.M. Forja, and T.A. DelValls, Direct comparison of amphipod sensitivities to dredged sediments from Spanish ports, *Chemosphere*, 68, 677–685, 2007.

Casado-Martınez, M.C., R. Beiras, M.J. Belzunce, M.A. Gonzaŕlez-Castromil, L. Marin-Guirao, J.F. Postma, I. Riba, and T.A. DelValls, Inter-laboratory assessment of marine bioassays to evaluate environmental quality of coastal sediments in Spain: IV. The whole sediment toxicity test using crustacean amphipods, *Cienc. Mar.,* 32, 149–157, 2006b.

CEDEX (Centro de Estudios de Puertos y Costas), Gestión ambiental del material de dragado, V seminario de ingeniería y operaciones portuarias, Concepción, Chile, 2008.

Chapman, P.M., and J. Anderson, A decision-making framework for sediment contamination, *Integr. Environ. Assess. Manag*., 1, 163–173, 2005.

Chapman, P.M., K.T. Ho, W.R. Munns, K. Solomon, and M.P. Weistein, Issues in sediment toxicity and ecological risk assessment, *Mar. Pollut. Bull*., 44, 271–278, 2002.

Crane, M., Proposed development of sediment quality guidelines under the European Water Framework Directive: a critique, *Toxicol. Lett.,* 142, 195–206, 2003.

DelValls, T.A., and M. Conradi, Advances in marine ecotoxicology: laboratory tests versus field assessments data on sediment quality studies, *Cienc. Mar*., 26, 39–64, 2000.

Morales-Caselles, C., J. Kalman, G. Micaelo, A.M. Ferreira, C. Vale, I. Riba, and T.A. DelValls, Sediment contamination, bioavailability and toxicity of sediments affected by an acute oil spill: Four years after the sinking of the tanker Prestige (2002), *Chemosphere,* 71, 1207–1213, 2008.

Riba, I., M.C. Casado-Martınez, J.M. Forja, and T.A. DelValls, Sediment quality in the Atlantic coast of Spain, *Environ. Toxicol. Chem*., 23, 271–282, 2004.

Riba, I., R. Beiras, L. Saco-Álvarez, and T.A. DelValls, Interlaboratory assessment of marine bioassays to evaluate the environmental quality of coastal sediments in Spain. III. Bioassay using embryos of the sea urchin Paracentrotus lividus, *Cienc. Mar*., 32(1B): 139–147, 2006.

Riba, I., T.A. DelValls, J.M. Forja, and A. Gor'mez-Parra, Comparative toxicity of contaminated sediment from a mining spill using two amphipods species: Corophium volutator (Pallas, 1776) and Ampelisca brevicornis (A. Costa, 1853), *Bull. Environ. Contam. Toxicol.,* 71, 1061-1068, 2003.

Sarmiento, A.M., A. DelValls, J.M. Nieto, M.J. Salamanca, and M.A. Caraballo, Toxicity and potential risk assessment of a river polluted by acid mine drainage in the Iberian Pyrite Belt (SW Spain), *Sci Total Environ*., 409, 4763–4771, 2011.