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Comparative analysis of two weight-of-evidence methodologies for integrated sediment quality assessment

A. Khosrovyan [a,*], A. Rodríguez-Romero [b], M. Antequera Ramos [c], T.A. DelValls [a], I. Riba [a]

[a] UNESCO UNITWIN/WiCop, Physical Chemistry Department, Faculty of Marine and Environmental Sciences, University of Cadiz, Polígono Río San Pedro s/n, Puerto Real 11510, Cádiz, Spain

[b] Departamento de Ecología y Gestión Costera, Instituto de Ciencias Marinas de Andalucía (CSIC), Avda. República Saharaui s/n, Campus Río San Pedro, 11510 Puerto Real, Cádiz, Spain

[c] CEDEX Centro de Estudios de Puertos y Costas, Antonio López 81, 28026 Madrid, Spain

HIGHLIGHTS

- Toxicity of natural sediments was estimated by PCA-based and tree-based approaches.
- Both methods estimated sediment risk to benthic biota similarly, in general.
- Robustness of integrated approach to sediment quality assessment is shown.
- Tree-based methodology demonstrated its validity and viability.

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ABSTRACT

The results of sediment quality assessment by two different weight-of-evidence methodologies were compared. Both methodologies used the same dataset but as criteria and procedures were different, the results emphasized different aspects of sediment contamination. One of the methodologies integrated the data by means of a multivariate analysis and suggested bioavailability of contaminants and their spatial distribution. The other methodology, used in the dredged material management framework recently proposed in Spain, evaluated sediment toxicity in general by assigning categories. Despite the differences in the interpretation and presentation of results, the methodologies evaluated sediment risk similarly, taking into account chemical concentrations and toxicological effects. Comparison of the results of different approaches is important to define their limitations and thereby avoid implications of potential environmental impacts from different management options, as in the case of dredged material risk assessment. Consistent results of these two methodologies emphasized validity and robustness of the integrated, weight-of-evidence, approach to sediment quality assessment. Limitations of the methodologies were discussed.

1. Introduction

There is a growing awareness that the weight-of-evidence (WOE) approach is a powerful tool for comprehensive sediment quality evaluation (Chapman et al., 2002; Crane, 2003; Chapman and Anderson, 2005). Integration of different lines of evidence (chemical concentrations, toxicological responses, *in situ* surveys) lies at the basis of the WOE approach and enables an enhanced evaluation of potential sediment threats. This is of special importance when dredged sediment is a concern as resuspension of contaminated fine particulates (Grant and Briggs, 2002) can be a serious ecological problem in receiving environments.

WOE-based ecological risk assessments including site-specific sediment quality guidelines based on toxicity of sediments to benthic organisms are widely available (EC, 2002; Casado-Martinez et al., 2006; Choueri et al., 2009). However, WOE methodologies normally differ in the lines of evidence and data integration procedures. Consequently, different techniques emphasize different aspects of sediment quality. Moreover, there are controversial views regarding assessment of the impact of bio-accumulating and bio-magnifying compounds such as Hg, PAHs, PCBs (Casado-Martınez et al., 2008). Further, *in situ* toxicity testing should be intrinsic part

* Corresponding author. Tel.: +34 693604660.
E-mail addresses: alla.khosrovyan@uca.es (A. Khosrovyan), araceli.rodriguezromero@icman.csic.es (A. Rodríguez-Romero), manuel.antequera@cedex.es (M. Antequera Ramos), angel.valls@uca.es (T.A. DelValls), inmaculada.riba@uca.es (I. Riba).

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of the WOE approach as it provides realistic exposure conditions and improves accuracy of the assessment (Rosen et al., 2012). Thus, comparison of the performance of different methodologies can elucidate strengths and limitations of the approaches and help avoid possible false implications. To our knowledge, attempts to compare sediment risk assessments provided by WOE methodologies are sparse e.g., Khosrovyan et al. (2010).

The aim of this paper is to compare the potential risk of contaminated sediments by two distinct WOE methodologies, considering diverse chemicals, organisms and types of bioassays. One of the methodologies is relatively new and intended for dredged material management (CEDEX, 2008), thus the comparative analysis may corroborate its validity and robustness. The same dataset was used in both methodologies.

2. Materials and methods

2.1. Sediment sampling and analysis

Sediment samples were collected at four commercial Spanish ports: Huelva (H1, H2 and H3), Santander (S1, S2, S3), Barcelona (B1, B2 and B3) and Cadiz (CA1, CA2, CA3 and CA4) (Fig. 1). In the sites B1–B3 and S2, shipyard and traffic activity is intense; site CA2 is located in a fishing dock; Huelva sites are affected by acid mine drainage. At each site, sediments (three samples per site) were collected by 0.025 m^2 Van Veen grab from the top 20 cm. The samples were stored at 4 °C in the dark and hermetically closed no longer than two weeks. Field related work complied with quality assurance recommendations (ASTM, 1991a, b).

All analytical procedures were described in detail in Rodriguez-Romero et al. (2013). In brief, the sediment granulometry analysis was done in accordance with UNE 7050-3 guidelines (UNE 7050, 2010) and recommendations by Thain and Bifield (2001). The following classification by particle size was used: >2 mm – coarse, 0.063–2 mm – sandy and <0.063 mm – fine sediment (henceforth – fines). Total organic carbon content (OC) expressed as percentage was estimated according to MAPA (1998). Determination of the chemical content of the sediments included total concentrations of select metals (Hg, Cd, Pb, Cu, Zn, Ni, Cr), metalloid (As) and organic micro-pollutants. The latter included 7 polychlorinated biphenyls (PCBs: 28, 52, 101, 118, 138, 153, 180), 9 polycyclic aromatic hydrocarbons hydrocarbons (PAHs: anthracene, benzo(a)anthracene, benzo(ghi)perylene, benzo(a)pyr-ene, chrysene, fluoranthene, indene (1,2,3-cd) pyrene, pyrene and phenanthrene), 13 organochlorine pesticides (POCs: HCH, aldrin, DDT, dieldrin, endosulfan, endosulfan-sulphate, endrin, endrin-aldehyde, heptachlor, heptachlor epoxide, hexachloro-1,3-butadiene, hexachlorobenzene, lindeno) and tributyltin (TBT).

The accuracy of all analytical procedures was verified using the reference materials MESS-1 NRC and CRM 277 BCR for metals, and NRC-CNRC HS-1 for PCBs and PAHs, with a percentage of recovery higher than 90%. Detection limits ranged between 0.001 and 0.008 mg kg^{-1} and 10–20 μg kg^{-1} dry weight of sediment for metals and PAHs, respectively, and were 0.5 μg kg^{-1} dry weight of sediment for PCBs and 2 μg kg^{-1} dry weight of sediment for TBT.

Fig. 1. Map showing the locations of the sampling sites. Marked areas show clean sites used to collect species for assaying.

2.2. Battery of toxicity bioassays

The battery of toxicity bioassays consisted of whole-sediment (solid-phase) and liquid-phase tests (SP and LP, respectively). The 10-d acute static SP tests using crustacean amphipods *Ampelisca brevicornis* and *Corophium volutator* were described in detail by Riba et al. (2003) and Khosrovyan et al. (2013) and test of polychaete *Arenicola marina* by Thain and Bifield (2001). Briefly, the amphipods *A. brevicornis* and *C. volutator* were collected from clean areas located on the coasts of Cadiz and Galicia (Casado-Martinez et al., 2007 and Morales-Caselles et al., 2007, respectively) by sieving the sediment through 0.5 mm mesh. *A. marina* were collected by hand-digging from a clean zone on the Cantabric coast (Casado-Martınez et al., 2008). The SP tests were conducted in triplicate and the percentage of mortality at the end of exposure was selected as the toxicity endpoint.

Another SP test, Microtox BSPT using luminescent marine bacteria *Vibrio fischeri*, was conducted according to the protocol detailed by Morales-Caselles et al. (2008). Dry sediment concentration causing 50% inhibition of luminescence by *V. fischeri* was determined and transformed into toxic units (TU) as 100/IC50 used as the toxicity endpoint.

The species *Paracentrotus lividus* selected for LP bioassays (egg fertilization and embryogenesis) were collected at a reported clean area located in the Bay of Algeciras (SW Spain) at a depth of about 1.2 m (Carballeira et al., 2011). For both bioassays gametes were obtained by dissecting mature organisms and direct extraction by a pipette. Sediment elutriates were obtained by mixing wet sediment samples with clean sea water (at a ratio 1:4) with the help of a rotator at 50 rpm for 30 min at room temperature. Sperm was exposed to sediment elutriates for 60 min prior to the egg fertilization test. Embryogenesis assay was performed upon completion of the egg fertilization test. Both tests were conducted in 5 replicates. More details are provided elsewhere (Khosrovyan et al., 2013).

The percentage of abnormally fertilized eggs (not surrounded fully or partially by a fertilization membrane), or failure rate, in 200 eggs was considered as a toxicity endpoint in the acute LP test. The percentage of abnormally developed plutei (those not having four well-developed arms), or failure rate, per 100 organisms was the endpoint in the chronic LP test.

For each test, clean filtered sea water was used as a negative control to verify the acceptability of the tests. Station CA1 from Cadiz, where no chemical concentrations exceeded AL1 limits and toxicity responses were the lowest, was used as a reference site.

The protocols, quality assurance and control procedures for fertilization and embryo development assays were detailed by Fernandez and Beiras (2001) and Volpi Ghirardini et al. (2005), respectively.

2.3. WOE methodologies

The first WOE methodology was used in the Spanish dredged material management framework (CEDEX, 2008). This methodology is based on a decision tree, which allows sediment categories to be derived that also represent management options (Fig. 2). The categories determine the potential threat of the sediment to biota by linking sediment chemical and physical parameters with biological responses in acute and chronic toxicity tests conducted in different sediment phases (solid and aqueous). Species of *A.*