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Development of site-specific sediment quality guidelines for North and South Atlantic littoral zones: Comparison against national and international sediment quality benchmarks

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ABSTRACT

We aimed to develop site-specific sediment quality guidelines (SQGs) for two estuarine and port zones in Southeastern Brazil (Santos Estuarine System and Paranaguá Estuarine System) and three in Southern Spain (Ría of Huelva, Bay of Cádiz, and Bay of Algeciras), and compare these values against national and traditionally used international benchmark values. Site-specific SQGs were derived based on sediment physical–chemical, toxicological, and benthic community data integrated through multivariate analysis. This technique allowed the identification of chemicals of concern and the establishment of effects range correlatively to individual concentrations of contaminants for each site of study. The results revealed that sediments from Santos channel, as well as inner portions of the SES, are considered *highly polluted* (exceeding SQGs-high) by metals, PAHs and PCBs. High pollution by PAHs and some metals was found in São Vicente channel. In PES, sediments from inner portions (proximities of the Ponta do Félix port's terminal and the Port of Paranaguá) are *highly polluted* by metals and PAHs, including one zone inside the limits of an environmental protection area. In Gulf of Cádiz, SQGs exceedences were found in Ria of Huelva (all analysed metals and PAHs), in the surroundings of the Port of Cádiz (Bay of Cádiz) (metals), and in Bay of Algeciras (Ni and PAHs). The site-specific SQGs derived in this study are more restricted than national SQGs applied in Brazil and Spain, as well as international guidelines. This finding confirms the importance of the development of site-specific SQGs to support the characterisation of sediments and dredged material. The use of the same methodology to derive SQGs in Brazilian and Spanish port zones confirmed the applicability of this technique with an international scope and provided a harmonised methodology for site-specific SQGs derivation.

1. Introduction

Dredging activities can cause several negative impacts to the aquatic ecosystems, such as the elimination of benthic habitats and resuspension of nutrients and contaminants. Special concern arises on the disposal of the dredged material; the simple discharge in marine waters implies several environmental consequences, including physical disturbance (burrowing, smothering) of benthic communities [1] and chemical contamination [2].

There are different options to deal with dredged material, which include [3,4]: (i) beneficial uses—land creation and improvement, beach nourishment, agricultural uses, wetlands restoration, creation of nesting islands, etc.; (ii) disposal in ocean or continental waters; (iii) treatment, such as the separation of sediment contaminated fractions; and (iv) discharge into confined disposal facilities. The selection of the best management option is in a great extent dependent on the quality of the dredged material. Therefore, a reliable assessment of the sediments to be dredged is needed to assure that the disposal of such material will be environmentally harmless as well as cost-effective.

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Despite experts have been claiming that the use of biological testing is crucial to adequately understand the hazard posed by contaminated sediments [5–7], decision-making on the management of dredged materials commonly relies on a simple comparison between levels of contaminants measured in the sediments against national sediment quality criteria or classical sediment quality guidelines (SQGs) (e.g. effects range-low and effects range-median – ERL and ERM; threshold effect level and probable effects level – TEL and PEL).

The SQGs provide a basis to identify the concentrations of chemicals that can potentially cause adverse biological effects [8]. Nevertheless, the bulk concentrations of contaminants may not correlate well to the bioavailability [9] inasmuch as several factors affect the availability of contaminants from sediments to the biota (and consequently the toxicity), such as sediment grain size, pH, salinity, organic matter content, acid volatile sulfides (AVS) contents, among others [10–13]. Consequently, national guidelines, which are intended to predict toxic effects of contaminant levels for different environments and sediment types, may not suitably address the specificities of each local and situation in national and wide geographic areas. In the other hand, sediment quality guidelines derived based on site-specific data is able to better predict the toxicity of contaminants in each specific coastal environment.

The development of the SQGs can be performed by employing different approaches, which can be divided in the two broad categories [14]: (i) mechanistically or theoretically, based on theoretical understanding of the partitioning of chemicals in the sediments and the toxicity of the dissolved contaminants in the interstitial water (e.g. equilibrium partitioning – EqP [15]); (ii) empirically based, derived from databases of concentrations of specific contaminants and their correspondence with observed biological effects (e.g. ERL and ERM [16,17]; TEL and PEL [18]; apparent effects thresholds – AET [19]). Besides, a third approach, so-called “consensus approaches”, was developed recently with the attempt of providing a synthesis of multiple guidelines into a single SQG or a range of SQGs [14], mainly focused on polycyclic aromatic hydrocarbons [20] and polychlorinated biphenyls [21].

In Brazil, sediment quality criteria to orientate dredged material management are given by the Resolution no. 344/2004 from the National Council for the Environment – CONAMA [22]. Such values were established based on the American and Canadian SQGs [23–25]. In Spain, the document *Recommendations for the management of dredged material in ports of Spain* [26] proposes sediment quality guidelines based on geochemical considerations [27] and it has been applied in the characterisation of the sediments dredged in Spanish ports; however, this document does not establish statutory contaminant concentration limits.

The aim of this work was to develop site-specific SQGs through the integration of sediment physical, chemical, ecotoxicological, and macrobenthic invertebrate community data using multivariate analysis for two estuarine and port zones in Southeastern Brazil (Santos Estuarine System and Paranaguá Estuarine System) and three in Gulf of Cádiz, Southern Spain (Ría of Huelva, Bay of Cádiz, and Bay of Algeciras), and compare these values against national and traditionally used international benchmark values. The areas under study are ecologically important and they are affected by different sources of pollution, such as domestic sewage, industrial effluents, urban runoff, as well as contamination due to the port activities [5,28–30]. The establishment of site-specific ranges of contaminants concentrations related to biological responses (ecological and toxicological) will better subsidise the management of the dredged material in the studied zones and the comparison of site-specific SQGs against general SQGs gives an insight into the adequacy of the use of national criteria or international guidelines for assessing dredged material and sediment quality in different coastal environments in South and North Atlantic. Furthermore, the use of the same method to derive SQGs for Brazilian and Spanish port zones aimed to assess the viability of application of this technique with an international scope and providing an internationally harmonised methodology for site-specific SQGs derivation.

2. Material and methods

2.1. Approach

In this study, site-specific sediment quality guidelines were derived for two areas in Southeastern Brazil: Santos Estuarine System (SES) and Paranaguá Estuarine System (PES) (Fig. 1a and b); and three areas in Gulf of Cádiz (GC), Southern Spain: Ría of Huelva, Bay of Cádiz, and Bay of Algeciras (Fig. 2a–c).

All areas of study present prominent port activities besides ecologically important ecosystems (especially mangroves and Atlantic Rainforest in Brazil and salt marshes in Spain). In SES, dense industrialisation and urbanisation has affected the quality of the environment, as reported before [5,31–36]. In PES, the major environmental threats are port activities, uncontrolled landfills, untreated domestic sewage as well as agricultural practices. Among Spanish areas, previous studies reported that Ría of Huelva is heavily contaminated mainly by industrial and mining activities [5,29,37]; in Bay of Cádiz, despite the presence of activities such as shipyard industry, industrial aquaculture as well as the urban concentration, previous studies revealed that sediments from the bay are not toxic. However, some contamination (PCBs) was found in the vicinities of the Port of Cádiz [5]. The Port of Algeciras is the most important Spanish port, situated in Bay of Algeciras, at the estuary of the Guadarranque River. The stream receives the discharges of industrial effluents from Algecira’s petrochemical industrial complex. Previous investigations reported high sediment toxicity caused by metals and PAHs in this zone [5,38].

The matrices of data for SQGs derivation included sediment physical–chemical characteristics (granulometry, levels of metals and organic contaminants), toxicity (elutriates, sediment–water interface and whole sediment) and benthic community structure information of each area of study. In SES, data from thirty one sampling stations were utilised (Fig. 1a); in PES, five sampling stations were set (Fig. 1b); in GC, three sampling stations were located at Ría of Huelva (Fig. 2a), two at Bay of Cádiz (Fig. 2b), and three at Bay of Algeciras (Fig. 2c). Details of sediment and benthic macrofauna sampling, analytical procedures, methodology employed for the toxicity tests, and quality assurance/quality control procedures were described in Cesar et al. [5], Choueri et al. [28], and Abessa et al. [39].

2.2. Multivariate analysis

The integration of different Lines-of-Evidence was performed by means of a Factor Analysis, with the application of Principal Component Analysis (PCA) (Varimax normalised rotation) as an extraction procedure. This methodology establishes and quantifies the correlations among the variables in the original data set in order to reduce the number of variables to a smaller set of components and therefore making easier the interpretation of the data [40].

Two different data sets (SES ‘a’ and SES ‘b’) were used to derive SQGs for Santos Estuarine System and PCA was applied individually in each of the original data matrix. Thus, some contaminants’ SQGs are duplicated for this area. The following variables were integrated in the analyses: (i) SES ‘a’—number of species (S), density of organisms (N), Margaleff’s richness (R), Pielou’ evenness (J'), Shannon’s diversity (H'), and Simpson’s dominance (D) values, concentrations of Cu, Ni, Pb, V, Zn, PAHs, and PCBs, total organic carbon (TOC), % of fines, and amphipods mortality (%). Concentrations of Cd and Co were measured but not included in the PCA because their concen-