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Identification of hot spots within harbour sediments through a new cumulative hazard index. Case study: Port of Bari, Italy

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ABSTRACT

While numerous quality guidelines unquestionably drive the management of harbour sediments, port managers increasingly require easy-to-use tools supporting them in assessing the sediment quality. In this work, a new hazard index, named cumulative Normalized and Weighted Average Concentration (c_NWAC), is proposed, considering the concentrations of main hazardous, toxic and bio-accumulative sediment contaminants. This index is an upgraded version of the previously introduced NWAC index, which considered only the metal concentrations. The c_NWAC values range from 0 to 10 scores, and their visualization on a colour base code map leads to an easy identification of hotspots. The applicability of the new index was verified using a dataset derived from the analyses of 42 samples collected at different depths of the seabed of the Port of Bari (Italy). The concentrations of 58 parameters were considered, namely 11 metals and metalloids, 17 congeners of polychlorinated biphenyls (PCBs), 16 congeners of polycyclic aromatic hydrocarbons (PAHs), further 11 organic micropollutants, total organic carbon (TOC) and nutrients (N_{tot}, P_{tot}). For the study area, the obtained c_NWAC values resulted well correlated to the corresponding values of the commonly used mean Effects Range Median quotient (mERMq), and similar hazard categories were developed for the new index, even if the latter do not necessarily explain the real sediment toxicity, because they were derived from a different sediment dataset and different test species.

Moreover, the hazard predictive ability of the new index was verified (with satisfactory results) by testing the considered samples by eco-toxicological assays, using three different biological species, and comparing the obtained results to the corresponding hazard categories developed for c_NWAC.

1. Introduction

Sediments are an essential and dynamic part of the port; their quality and quantity are integral to ecosystem health and a fundamental component of the regional economy. Many hazardous, toxic and bioaccumulative chemicals, such as metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, chlorophenols, organotin compounds, organochlorine pesticides and aliphatic petroleum hydrocarbons are continuously leaked into the port due to shipping traffic, loading, repairs, dredging and other activities, as well as rainwater runoff, effluent discharges, dust, etc. (Guerra-Garcia and Garcia Gomez, 2005; Casado-Martìnez et al., 2009; Szlinder-Richert et al., 2012).

The contaminants, which are found only in trace amounts in water, tend to be adsorbed into both inorganic and organic material eventually settled in sediments. If the concentration of these contaminants in the water column is high enough, sediments may accumulate excessive quantities of contaminants that directly and indirectly disrupt the ecosystem. Indeed, many studies have documented the importance of sediment contamination for ecosystem quality (Burton, 2002, 2013; Chapman et al., 2002, 2013; Chapman, 2007; Schintu et al., 2015). Moreover, numerous efforts, resources and money are continuously spent in many countries in an attempt to clean up or remove contaminated sediments, in order to restore ecosystem quality and develop beneficial uses for dredged materials (Sustainable Management of Sediment Resources, 2007).

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National and international guidelines have unquestionably supported the evaluation and management of sediments (US/EPA Environmental Protection Agency, 1998, 2000a,b; EPA-905-B02-001-A, 2002), but researchers in this field are still attempting to identify easy-to-use tools that support and facilitate sediment quality assessment. The methodologies proposed in the literature to estimate the quality of sediments can be classified into two categories. The simplest one uses the ratio between the measured concentration of a given contaminant in sediment samples and the background value estimated for the area (Müller, 1969; Salomons and Forstner, 1984; Hakanson, 1990; Wolska et al., 2007). The other category of methodologies combines chemical parameters with related biological effects, valuating the toxicity degree of sediments (Long et al., 1995; MacDonald et al., 1996, 2000). Nevertheless, all such methodologies are contaminant-specific and depend upon the legislation currently in force in each specific area that usually applies specific numerical criteria (threshold levels for each contaminant) when assessing the quality of sediments. Registering an excess of concentration of a given contaminant with respect to the numerical threshold constitutes the necessary condition for assessing the pollution status of the sediment and, consequently, the development of regulatory and remedial actions.

Since none of the existing methodologies take into account the possible synergic or antagonistic effects that the simultaneous occurrence of different hazardous contaminants within sediments may present (Eggen et al., 2004), cumulative indexes that consider the concomitance of different stressors are highly recommended. However, the multidisciplinary approaches that combine multiple typology of investigation (or lines of evidence, LOEs) (Chapman, 1996; Chapman et al., 2002) are often hampered by the lack of standardized procedures for the interpretation and the integration of complicated datasets of heterogeneous results, which typically require various expert judgements (Piva et al., 2011; Benedetti et al., 2012; Regoli et al., 2013). Aiming at overcoming this inconvenience, recently, a software-assisted model has been developed to integrate and differently weight data from various lines of evidence (Piva et al., 2011).

One of the most employed indexes is the mean Effects Range Median quotient (mERMq) (Long et al., 2006), which estimates the toxic effect of selected pollutants on a wide variety of benthic organisms. Furthermore, Gredilla et al. (2014) recently calculated the Normalized and Weighted Average Concentration (NWAC) that, however, takes into account only metal content (14 metals and metalloids) in estuarine systems.

In this paper, an upgraded version of NWAC is proposed, named cumulative NWAC (c_NWAC), able to examine the multiple effects of three categories of contamination indicators: metals and metalloids, persistent organic pollutants and TOC, and nutrients, such as N_{tot} and P_{tot}. We applied the upgraded index to the Port of Bari (southeast Italy) using sediment cores collected at three depths (50 cm, 100 cm and 150 cm) from 23 sampling stations. The predictive ability of the new proposed index was ascertained by comparing the c_NWAC ranges of hazard with the results obtained from three amphipod survival tests.

2. Materials and methods

2.1. Features of the study area

The Port of Bari is located in the southeast of the Italian Adriatic coast, at the centre of the Apulia region (Fig. 1). The coastal area under study forms part of the westward extension of the carbonatic plateau of the Murge, the lithological platform of southern Italy. Its low-profile morphological features are characterized mainly by sandy sediments with beaches only partially preserved from human intervention. The coastal tract of the metropolitan city of Bari is currently heavily modified by large-scale artificial burying. Numerous ephemeral watercourses, parallel to each other and perpendicular to the coast, form the characteristic hydrographic network that nourishes the coast with terrigenous sediments.

The Port of Bari is one of the most important ports settled along the Adriatic coast and is located within the urban area of the metropolitan city of Bari. It is a multipurpose stopover equipped with docks for handling a range of goods and freight. Water depth in the port varies from 6.9 m to 14.9 m, allowing the movement of large ships and vessels. Several quays for various types of commercial traffic (solid and liquid bulk, containers, packaged goods, steel products, forestry products, etc.), as well as Ro-Ro docks for ferries and cruise ships platforms are used daily. High-level port activity seriously impacts the quality of the port and, therefore, the quality of harbour sediments, that act as a final sink for all contaminants entering the port within the water column. Regarding the contamination history of the study area, two important events should be mentioned. The first one is the activity of the National Hydrogenation Fuels Company at the north of Bari which had caused significant impact to the local area, until it ceased activity in 1974, and consequently affected the quality of the port area nearby, in which the waste water was dumped. The concerned area has only recently been subjected to reclamation work in order to eliminate residual hydrocarbons. The second event was the bombing campaign during the Second World War that involved directly the port basin.

2.2. Sampling area and sampling design

Sediment samples were collected during a sampling campaign between 2010 and 2011 from the most significant basins in the port area (see Fig. 1): at the Ro–Ro terminal (sites 42–51), the Container Terminal (sites 53–61), the Passenger Traffic zone (cruise and scheduled shipping – sites 68–90) and at the access channel of the port (sites 124–130). A total of 23 core samples were taken from different sampling sites, using a PF2 vibrocorer, equipped with a liner. The vibrocorer operated with the support of a vessel endowed with a differential GPS system for the positioning of core samples. Each core was sectioned into 50 cm length sub-cores and samples were collected at different depth levels up to 150 cm. When the final sub-core was less than 100 cm long, due to the presence of rock on the seabed, only superficial sediment was considered. The letters A, B and C were assigned to each core sample indicating the core depth at 50 cm, 100 cm and 150 cm respectively (Table S1). Aliquots of 250 g of wet sediments were taken from each sub-core and transported in cleaned plastic containers, available for the analyses. Part of the analyses was performed on wet-sediments (microbiological analyses, bioassay tests), while aliquots useful for the other analytical analyses were stored at −20 °C.

Supplementary Table S1 related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2015.07.024

2.3. Analytical methods

Before analysis sediments that were stored at -20° C after sampling, were dried at 40 °C for 48 h. Each sediment was classified according to Shepard (1954) into four classes: gravel: >2 mm; sand: 2–0.063 mm; silt: 0.063–0.002 mm; clay: <0.002 mm. A set of ASTM sieves and a granulometer laser were used for the granulometrical separation (Romano and Gabellini, 2001).

The trace metal concentrations were measured by inductively coupled plasma mass spectrometry (ICP/MS X Series Thermo Fisher Scientific) after sample mineralization by total acid digestion (HCl, HNO_3 and HF). The fraction <63 μm dried at 105 °C was used for the