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Assessment of sediment contamination and sampling design in Savona Harbour, Italy

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ABSTRACT

A method for assessing environmental contamination in harbour sediments and designing the forthcoming monitoring activities in enlarged coastal ecosystems is proposed herein. The method is based on coupling principal component analysis of previous sampling campaigns with a discrete optimisation of a value for money function. The objective function represents the utility derived for every sum of money spent in sampling and chemical analysis. The method was then used to assess actual contamination and found to be well suited for reducing the number of chemicals to be searched during extended monitoring activities and identifying the possible sources of contamination. Data collected in Savona Harbour (Porto Vado), Italy, where construction of a new terminal construction is planned, were used to illustrate the procedure. 23 chemicals were searched for within a total of 213 samples in 68 sampling points during three monitoring campaigns. These data were used to test the procedure. Subsequently, 28 chemicals were searched for within 14 samples in 10 sampling points and collected data were used to evaluate the experimental error and to validate the proposed procedure.

1. Introduction

Assessment of environmental pollution at harbour sites with different and sometimes unknown previous histories of operation and contamination is a challenging problem. When new harbour infrastructure is constructed, contaminants and sediments generated during construction and dredging activity can cause a rapid deterioration of water quality with drastic consequences on the marine coastal ecosystem. In such cases, attention must be devoted to design monitoring activities that assess water quality and chemical contamination of sediments prior to construction, during construction and some years after the project has been completed. Monitoring activities should take into consideration a zone larger than the harbour itself since the impact of new construction on coastal ecosystems could be higher than predicted because of the possibility to enhance desorption or transport of chemicals in marine waters during handling. Accordingly, even if national or international directives impose limits for samples taken inside the harbour area, the extension of monitoring activities to a larger area comprising a significant coastal zone is desired. Moreover, the impact to the ecosystem must be evaluated by analysing chemicals in the biological components (from the plankton to the top predators as cetaceans) in order to evaluate the short and long-term effects on different ecosystem compartments, monitored using selected indicator species. To accomplish this, it is necessary to consider that plankton abundance is deeply correlated with water quality and nutrients concentration and that monitoring activities should therefore include benthonic fauna, mussels, fish and mammals. However, the search for contaminants in a large sampling area over a long period, in several environmental matrices, and in different biological species leads to very high monitoring costs.

The decision to extend monitoring activities, and consequently their costs, in addition to those imposed by law, rests with the government that decide to grant permission to work. If the extension (in terms of area, chemicals and ecosystem compartments) is considerable, the costs of monitoring campaigns carried out by regional government may not be sustainable, therefore they should be reduced. This can be done in different ways: by limiting monitoring time and consequently the number of sampling campaigns, reducing the sampling points by focusing on specific target areas, limiting the number of monitored biological species or chemicals to just a few samples or sub-areas; all in order to reach a good compromise between costs sustained by the community and advantages in terms of environmental protection. A possible approach could be the reduction of the number of chemicals to be searched for in the extended area with a method that takes into

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consideration the existence of differently polluted sub-areas. The reason of this choice is that sediment pollution in a harbour is also spatially complex and correlated owing to the possibility of small accidents during cargo handling and ship loading, changes in the location of terminals during the harbour life, differences in transport properties of the materials, and heterogeneity of the sediments. Complexity is increased if pollution coming from industrial plants (energy production, factories, waste water treatment) situated in the neighbourhood of the harbour is present.

Multivariate statistical methods have largely been used for organising, grouping and reducing the dimension of observed environmental data. These methods include principal component analysis (PCA), cluster analysis, discriminant analysis (DA), fuzzy analysis and neural networks (Astel et al., 2007; Sarbu and Pop, 2005; Wilks, 2006; Wunderlin et al., 2001; Zou et al., 2007). PCA has been largely applied to environmental assessments (Alves et al., 2010; Idris, 2008; Kuo et al., 2012; Pio et al., 1989; Zitko, 1994) and also used for dimension reduction and source identification (DelValls et al., 1998; Duffy and Brandes, 2001; Loska and Wiechu, 2003; Reid and Spencer, 2009; Yang et al., 2009), optimal design of networks and planning (Hajkowicz and Collins, 2007; Nunes et al., 2004; Saunier et al., 2009; Shin and Lam, 2001) and study of ecological indicators (Primpas et al., 2010).

Here, we propose a simple optimisation procedure based on PCA that allows reduction of costs while taking into account source distribution by reducing the dimension of chemicals in different groups. The procedure uses the nested discrete optimisation algorithm of a value for money (VFM) function coupled with PCA applied to both chemicals and sampling points. Planning based on VFM functions not only considers the minimum cost (search for the minimum of a defined cost function) but also the maximum efficiency of the results (Sorenson et al., 2008). The adoption of VFM functions usually involves the solution of minimax optimization problems. The VFM objective function here proposed represents the utility derived for every sum of money spent in sampling and chemical analysis evaluated in terms of information (variance) obtained on the investigation of the environmental contamination of the site.

In this study, polycyclic aromatic hydrocarbons (PAH) and heavy metals concentrations of samples collected in Savona Harbour, Italy, where construction of a new terminal is planned, were used to validate the procedure. The results were then used to plan the forthcoming monitoring activities.

2. Materials and methods

2.1. Site and data description

The case study area is located in Liguria, Italy. Vado Ligure municipality comprises about 24 km^2, including about 4 km on the waterfront including the harbour area (Porto Vado) and Torrente Stagno Valley.

The municipality is bordered by Savona to the northeast, Bergeggi to the south and Valleggia and Quiliano to the northwest, and includes the hamlets of Porto Vado, San Genisio, Sant'Ermete, Valle di Vado and Segno. Vado Ligure presents an intense urbanisation in the area delimited by the coast and the first kilometre inward. The distribution of industry is very complex, with Vado Ligure being the most important industrial site in the Savona area and containing 600 small or average factories. The principal plants related to pollutant releases to the environment include a thermal power plant (600 MW, coal), a petroleum additives production plant, two plants for hydrocarbons coastal storage and treatment; there are also coal, minerals, fertilisers and chemicals handling and storage sites.

The harbour is very important to trade, tourism and industry. There are two landing terminals for the drainage of oil-bearing products, a landing terminal for discharging anthracite and flours that are also used to embark coke, the ferry terminal, and quays for containers, fruit and cars landing. A new platform will be located between the jetty used for refuelling and supplying ships (west) and the ferries terminal (east). Ligurian harbours, including Savona (Porto Vado), are not located within estuaries and show significant gradients from coastal sites towards open sea. Moreover, Vado Ligure is placed on the edge of a submarine canyon, which extends 12 miles southward flowing into the great Genoa submarine canyon. So we can presume that industrial and port activities effect correlations among pollutants more than natural factors do. Under these conditions we can suppose to obtain a statistically valid information using methods based on the analysis of sediment contamination distribution.

The study area and sampling points are shown in Fig. 1.

The red[1] line in Fig. 1 borders the extended area on which we suggested to apply the results of the proposed procedure, carried out with data collected in the smaller area. We did not suggest to limit attention to the more sensitive ecological components since the extended area comprises the Marine Protected Park of Bergeggi, characterized by a large variety of habitat and biological diversity, hosting flag species like the Mediterranean black coral, Mediterranean sea grass beds and bottlenose dolphins. Monitoring these protected species, in particular Posidonia oceanica and coralligenous assemblage, could be fundamental to assess environmental quality since these species concentrate chemicals and heavy metals, so recording the environmental levels of persistent contaminants.

Three complete sampling campaigns have been carried out in the area of interest defined by law, i.e. the area comprising the new terminal (see Fig. 1, blue line) and the harbour (see Fig. 1, green line): the first in 2006 (April), the second in 2008 (between May and July) and the third in 2009 (February). In this study, we used data obtained from the analysis of 23 chemicals (11 metals, 9 polycyclic aromatic hydrocarbons + total PAH and hydrocarbons with $C < 12$ and $C > 12$) in 68 sampling points for a total of 213 samples (with 3 or 4 replicas for each sample point). Sediments have been collected using a box corer and in the area of interest (Fig. 1, green line) they are mainly constituted by very fine sand/silt. The underwater geomorphology of the zone and the characteristics of the harbour waterfront are reported in Rovere et al. (2011) and Gatti et al. (2012).

The analyses were conducted by Environmental Regional Agency (ARPAL) in accordance with D.L. 152/06 of Italian law, with the following analytical methods: n. 248 21/10/99; Met II, 1-2-3 + Met XI + Met XII + EPA (metals) and Met II, 1 + EPA 3545 + EPA 8270D (metals, HC and PAH).

2.2. Theoretical background

2.2.1. Classical principal component analysis

PCA is a bilinear projection technique in which the original *m*-dimensional measurement space described by matrix [X] (*n* samples and *m* variables) is projected into a lower, A-dimensional space. PCA can be used to reduce a data set containing a large number of variables to one containing a reduced number of new variables that are linear combinations of the original ones, and these linear combinations can then be used to represent the maximum possible fraction of variability contained in the original data (Jolliffe, 2002).

[1] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.

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