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Environmental complexity of a port: Evidence from circulation of the water masses, and composition and contamination of bottom sediments

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ABSTRACT

Ports are complex environments due to their complicated geometry (quays, channels, and piers), the presence of human activities (vessel traffic, shipyards, industries, and discharges), and natural factors (stream and torrent inputs, sea action, and currents).

Taking these factors into consideration, we have examined the marine environment of a port from the point of view of the circulation of the water masses, hydrological characteristics, distribution of the sediment grain-size, mineralogical characteristics, and metal concentrations of the bottom sediments. Our results show that, in the case of the Port of Genoa (north-western Italy), the impact of human activities (such as a coal power-plant, oil depots, shipyards, dredging of the bottom sediments, etc.), natural processes (such as currents, fresh water and sediment inputs from the torrents), and the morphology of the basin, are important factors in the sediment, water, and metal distributions that have given rise to a complex environment.

1. Introduction

Marine ports are complex environments due to their composite geometry caused by the presence of quays, channels, piers, and the multiplicity of activities conducted there. This geometry also complicates the current circulation inside. Then, currents are hindered in their mean circulation by the port infrastructures, with the consequent modification in the velocity field and the generation of eddies and/or forced flows (Grifoll et al., 2009). Port infrastructures and the complex geometry also produce low circulation and stagnant waters in the inner part of the basin, causing anoxia and eutrophication of the water column and bottom sediments (Reis et al., 2011). Moreover, the relatively shallow depth of the water column inside port basins increases the effect of wind stress on the mass water circulation, further complicating its dynamics (Smith and Jacobs, 2005). The characteristics of the water masses and bottom sediment inside the port are not only strongly influenced by the port morphology, but also by external factors and inputs, such as wind and wave conditions (especially at the port entrances), and the inputs of rivers and torrents that enter the basin.

Due to the many activities that take place in a port, sediments and waters are often contaminated by different kinds of chemicals, such as hydrocarbons, dioxins, pesticides, nutrients, and metals. The contamination rate of a port basin is site-specific and depends on the sources of contamination in the nearby urban system, such as city discharges and sewers, river intake, vessel traffic, factories (Garcia-Orellana et al., 2011; Spencer et al., 2006; Taylor and Owens, 2009), as well as the port system itself. Moreover, two important sources and vehicles of contaminants are: a) anthropogenic road-deposited sediments derived from the runoff of the port and city area, and natural road-deposited sediments derived from rivers and torrents, and b) airborne particulate matter and sediments (Taylor and Owens, 2009).

Another activity that can increase the environmental complexity of a port is dredging. In fact, dredging activities (a) increase turbidity and dispersion of suspended sediments that can cause stress for the surrounding aquatic environment (Cutroneo et al., 2013; Je et al., 2007), (b) release contaminants contained in the dredged sediments that can cause chemical disturbances to marine organisms (Caplat et al., 2005; Lohrer and Wetz, 2003), and (c) move new surface sediments that contain different concentrations of contaminants from the pre-dredging bottom sediments to the bottom (Garcia-Orellana et al., 2011; Liu et al., 2016).

Therefore, a detailed study of both the water column and sediments and an understanding of the external forcing (torrent inputs, city discharges, etc.) are necessary to determine the sectoriality of a port basin. The aim of the present study is to increase our knowledge of the complexity of a port basin recently subjected to capital dredging, using analyses conducted on both the water column (measurements of currents and chemical and physical characteristics of the water column) and bottom sediments (dimensional, mineralogical, and metal content analyses).

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2. Study area

The Port of Genoa (Fig. 1) is situated at the apex of the Ligurian Sea in the north-western Mediterranean Sea and has a total port area of about $7 \cdot 10^6$ m^2 and 47 km of shipping lanes, and handled $2.2 \cdot 10^6$ TEU (Twenty-foot Equivalent Unit) of containers, $51.3 \cdot 10^6$ tons of goods, and 6000 vessel moorings in 2015.

The port is characterised by the presence of several commercial activities that have contributed, over the years, and still contribute today, to the contaminant accumulation in both the water column and the bottom sediments. The port basin (Fig. 1) includes the mouth of several streams and the mouth of the Bisagno and the Polcevera Torrents (catchment area surfaces 93 km^2 and 140 km^2, respectively) along the banks of which can be found several small towns, quarries, factories and the suburbs of the city of Genoa. There are a range of activities inside the port: a ferry terminal, different container terminals, marinas, dry docks, the coal power-plant of Genoa (built in 1952, total power of 155 MWatt; ENEL, 2016), the bulk terminal of the port (dry bulk: coal, rock salt, sands, cement, fertilizers, minerals, biomass, steel products; liquid bulk: vegetable oils and fats, mineral oils, chemical products), shipyards, different wastewater treatment plant discharges (http://www.porto.genova.it/), and a steel mill (since 1953; Mazzei et al., 2006). Furthermore, the Port of Genoa is an urban port with the city of Genoa (land area of 243.6 km^2 and population of 600,000) overlooking the entire port basin.

The catchment areas of the Bisagno and Polcevera torrents cover terrain in which different lithologies occur, and the torrents contribute to the release of a large quantity of detrital minerals in the port. In fact, the geological basin of the port comprises ophiolitic rocks (basalts, gabbros, and serpentinites), metamorphic ophiolitic rocks, and sedimentary rocks, mainly calceschists and shales (Città Metropolitana di Genova, 2015a, 2015b).

Dredging operations were conducted in the port area from July 2009 to October 2014, the areas dredged lying in the innermost part of the port basin, along the inside of its entire protective breakwater and in the area outside the eastern port entrance ($3 \cdot 10^6$ m^3 of sediments). The disposal areas for the sediments were Bettolo and Derna quays inside the port (Fig. 1).

Winds affecting the City and the Port of Genoa come from two principal directions: the NE (the most frequent wind) and the SE, with a mean velocity of 3.1 $m \cdot s^{-1}$ from both directions, as reported by Castino et al. (2003).

The Port of Genoa is located in the middle of the Ligurian coast: this area is characterised by the presence of a permanent cyclonic current with meanders and eddies that develop along its limits (Pinardi and Masetti, 2000). Inside the port, as shown by Capello et al. (2010), water masses generally tend to concentrate in the inner part of the port when the wind blows from the S, and flow out of the port when the wind blows from the N. More precisely, with a NE wind, currents flow to the SSW along the Sampierdarena channel and the Airport channel (Fig. 1), with a velocity up to 50 $cm \cdot s^{-1}$. The complexity of the circulation inside the port highlights that, in the case of a SE wind, a double flux is generated at the eastern port entrance (Fig. 1): currents enter the port along the landward side of the entrance and exit along the internal side of the port breakwater (Cutroneo et al., 2012).

The sea temperature in the port varies from 12 to 14 °C in February to 14–26 °C in July, in accordance with the local seasonal temperature variations. The salinity is at its maximum in summer and winter (37–38) and minimum in early spring and autumn (36–37), affected by the seasonal rainfall distributions. In general, the temperature values are influenced by exchanges with the open sea through the port entrances, while salinity is more related to torrent water inputs and rainfall events (Ruggieri et al., 2011; Capello et al., 2015).

3. Materials and methods

3.1. Data and sample collection

Sixteen sediment sampling points (stations from 1 to 16) were made in the port basin, with the higher numbered stations in the western part of the port, off the mouth of the Polcevera Torrent (Fig. 1). The distribution of the sampling stations is shown in Fig. 1. The sediments were sampled using a 5-L Van Veen grab and stored in new wide-necked HDPE jars.

The current velocity and direction data were collected using a Teledyne RDI 600-kHz Workhorse® current meter (Vertical Acoustic Doppler Current Profile - V-ADCP) with a bottom-track function and navigational data received from an external global positioning system (GPS). The V-ADCP was an over-the-side-mounted model using a 316 L stainless-steel bracket.

A conductivity-temperature-depth (CTD) multiparametric probe (IdromarAmbiente) equipped with a turbidimeter (Turner Designs) was used to obtain the hydrological parameters of the water layer near the bottom at each station. The salinity was determined using the Practical Salinity Scale, the temperature was expressed in °C, and the turbidity in Formazin Turbidity Units (FTU) in a range between 0 and 25 FTU.

All samples and measurements were taken on the 8th July 2015, nine months after the end of the dredging activities, in the presence of a strong SE wind (maximum wind velocity 11.7 $m \cdot s^{-1}$) and slight SE sea.

3.2. Laboratory analysis and data processing

The sediment samples were homogenised and then divided into three subsamples on the basis of the grain-size distribution, mineralogical composition, and chemical content analyses.

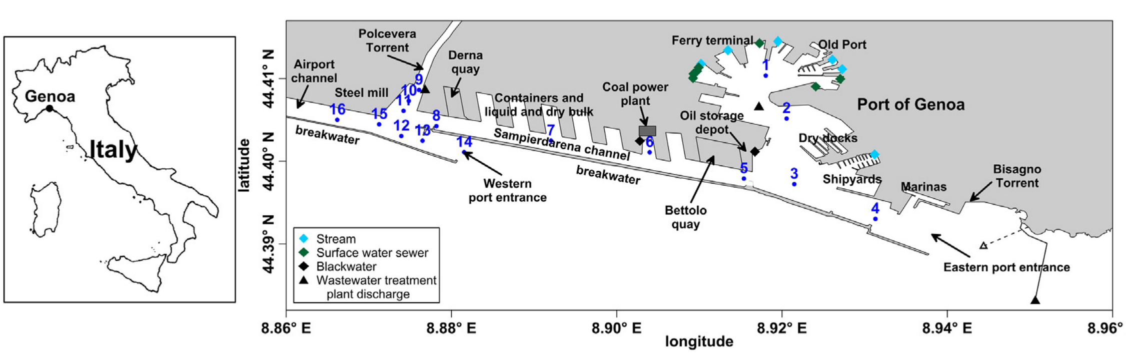

Fig. 1. Port of Genoa: localisation of the sampling stations (blue dots) and main features and activities of the port. The black dotted line with white triangle shows the old sewer duct outside the eastern port entrance, while the black continuous line with black triangle shows the new sewer duct (from 2014). The different discharges inside the port are shown with rhombus and triangles; the grey rectangle, close to the sampling station 6, represents the coal power plant of Genoa. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)