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Mathematical simulation of the suspended solids diffusion during dredging operations on the continental shelf off the coast of Lazio (Central Tyrrhenian Sea, Italy)

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ABSTRACT

Artificial nourishment is a preferred strategy to remedy coastal erosion along a sandy coast. To conduct a pilot study on the environmental impact of the use of submerged sandy deposits to artificially nourish beaches, oceanographic and sedimentological studies have been performed in potential dredging sites. The aim was to define the concentrations and characteristics of the suspended solids and the physical and dynamic characteristics of the water masses on the continental shelf (20–100 m) off the coast of Lazio (Italy) to evaluate the possibility of the diffusion and the negative impact of the suspended solids during dredging. The water masses characteristics measured enabled us to develop a predictive model for the suspended solids diffusion that was then applied to the potential sites. In evaluating the possibility of dredging, an application model is useful for determining the behaviour of the different granulometric classes in the dredged sediments and predicting the potential impact of resuspended sediments on the coastal habitat.

1. Introduction

Coastal areas have always been considered as delicate planning zones due to their vulnerability to erosion and their economic importance and of great interest for the problematic environmental processes that can influence them, such as artificial nourishment (Lupino and Riccardi, 2001; Paphiti and Collins, 2005; NOAA, 2006; OSPAR, 2008).

The sandy material of the beaches is very mobile and can easily be swept away by off-shore currents. Long-shore currents tend to shift the sand along the coast but not remove it, different from cross-shore which can remove it permanently by shifting it beyond the influence of wave action (Kennett, 1982). To remedy this situation the incohesive relict sand used for nourishment programmes are usually deposited on the beach following a steeper profile than that of equilibrium, creating a perturbation in natural planning and the transversal profile of the beach. That perturbation induces sedimentary fluxes that, over time, reduce the imbalance and bring the beach to a state of stability (Benassai et al., 1997; Colosio et al., 2007; Horn and Walton, 2007).

This nourishment technique, in use in many countries of northern Europe and the United States for more than twenty years, has had very positive results (Clark, 1983; Preti, 2002; Hamm et al., 2002; Simonini et al., 2005) for various reasons: it is the type of intervention most similar to the natural processes that have created the sandy mantle; it does not alter the scenic characteristics of the nourishment area or the coastal dynamics (Preti, 2002); it does not need exposed containment structures or create muddy or asphyxial areas along the coast, as often occurs behind artificial breakwaters (Dal Cin and Simeoni, 1987); it offers indubitable benefits in protecting the environment (Adriaanse and Coosen, 1991; Correggiari et al., 1992). The success of this restoration technique probably lies in the fact that the sand that no longer arrives through natural solid transport is substituted entirely, or in part, with sand taken from the seafloor (Browder and Dean, 2000). Soft nourishment unites the double functions of defence and reconstruction of the beach and differs projectually from nourishment combined with defensive structures (Smith et al., 2009).

The factors slowing the diffusion of this type of intervention are mainly of an economic and environmental nature (Preti, 2002; Larroudè, 2008). To compensate for the high economic cost of this type of dredging it is necessary to recover large quantities of sand of the correct granulometry, which must be free of fine fractions. In fact the fine fractions do not remain on the beach but are dispersed by wave action causing a deterioration in the water

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quality and becoming a danger for local biocoenosis, including coralligenous and meadows of *Posidonia oceanica* (González-Correa et al., 2008, 2009). *P. oceanica* is an endemic species of seagrass intolerant on increases of total suspended solids (TSS) content, recognised as a 'priority habitat' by Directive 92/43/EEC, a Site of Community Importance (SCI) in the 'Natura 2000 Sites', a habitat of great importance (Eurosion, 2004; EEA, 2005; Boudouresque et al., 2006), and protected by national and international regulations (Borum et al., 2004).

The main environmental threat that can occur during the dredging of relict sands is the release of sediments during the various phases of the work cycle, with the creation of a turbid plume and the alteration in the natural water characteristics (Anchor Environmental, 2003; HR Wallingford Ltd and Dredging Research Ltd, 2003; Wu et al., 2007). The finest sediments resuspended by dredging can be dispersed by local hydrodynamic conditions and settle a notable distance from the dredging area (ICES, 1996; Hill et al., 1999), having serious environmental repercussions if they reach sensitive habitats (Erftemeijer and Lewis III, 2006; Fanini et al., 2009), such as *P. oceanica* meadows (González-Correa et al., 2008, 2009; Montefalcone et al., 2009).

The study of the sedimentological, physical and dynamic characteristics of the water masses and the application of a mathematical dispersion model can provide useful information for predicting the direction of the diffusion of the turbid plume and the concentration of the suspended material during the dredging.

To study the possible environmental impact of the use of relict sand deposits lying on the continental shelf off the coast of Lazio (Central Tyrrhenian Sea, Italy), for artificial nourishment, the University of Genoa, the Institute for Environmental Protection and Research (ISPRA, formerly ICRAM) of Rome, and the University of Naples “Parthenope” have examined the sedimentological characteristics of the seafloor and the physical and dynamic characteristics of the water column in the area and applied their results to a mathematical model for the simulation of the diffusion of the turbid plume.

In this article we present the results of the characterisation of the water masses and the particulate matter lying at depths of 20–120 m on the continental shelf off Montalto di Castro (Lazio, Italy) and their application to the mathematical model.

The present work and others on different aspects of the environmental monitoring of dredging along the coast of Lazio (La Porta et al., 2009; Maggi et al., 2009; Nicoletti et al., 2009; Nonnis et al., 2011) have been conducted within the framework of the European Project INTERREG IIIC BEACHMED-e (http://www.beachmed.eu).

2. Characteristics of the study area

The width of the continental shelf of Lazio varies from 30–40 km in the northern and southern sectors to only 20 km in the central: the study area lies in the northern sector (Fig. 1). The average slope is slightly less than 0.5°, increasing from N to S. The margin of the shelf is well defined and lies at a depth of 120–150 m, where the continental slope begins. The geometry of the off-shore basins has been determined by tectonic alignments with a prevalently NW–SE direction (Chiocci and La Monica, 1996).

The study area includes the Fiora River (mean flow of 7.9 $m^3 s^{-1}$), which flows through Montalto di Castro and two torrents (the Arrone and Marta, with mean flows of 2.3 and 7.3 $m^3 s^{-1}$ respectively) to the south of the city (Fig. 1). From a sedimentological point of view the coast is characterised by sandy and sandy-pelitic sediments with an increase in the silty–clayey fraction off shore. At greater depths, the sedimentation, which cannot be correlated with the bathymetry, has been influenced by river-silt dispersion processes, particularly in the central and southern sections of the shelf (Tortora, 1989; Chiocci and La Monica, 1996). The sediments transported off shore are primarily sandy–clayey, and only the major rivers that flow into this area are able to provide a significant fraction to the coastal sandy sedimentation (Evangelista et al., 1996).

The cyclonic circulation that distinguishes the Tyrrhenian area is characterised by a strong interaction with the wind and is reinforced, above all in winter, by the effect of the dominant winds coming from the SW and NW (Ovchinnikov, 1966; Budillon et al., 2000). In the coastal zone the general circulation is distinguished by a NW flow parallel to the coast, which generally has a good correlation with the wind (Bignami et al., 1996). During the summer, distinguished by the stratification of the water column, the current can flow perpendicular to the coast. The study area is subject to wave action coming mainly from the S, SW and W; the winds from the south cause littoral drift towards the NW, while the winds from the SW create two currents that move towards the SE in the northern sector of the coast and the NW in the southern (Bignami et al., 1996).

The distribution of *P. oceanica* meadows along the northern part of the coast of Lazio appears to be very heterogeneous, with two typical situations:

(a) ample zones of dead matte interspersed with biogenic rocks, patches of sand with sparse bundles of *P. oceanica,* sometimes, patches of more consistent *P. oceanica;*

(b) or mosaics of sand, biogenic rocks and patches of *P. oceanica* alongside ample sandy zones or shallow with biogenic rocks and large meadows of dead matte, with live sparse of *P. oceanica* (Diviacco et al., 2001; ISMAR, 2009). At the macro scale the meadows are interrupted near the mouths of the torrents and the Fiora River (Fig. 1).

The sand sampling site of this study lies at a depth of 35–55 m on the continental shelf, 4.5 nautical miles off the coast of Montalto di Castro (Fig. 1).

3. Materials and methods

During four oceanographic campaigns, conducted in 2002–2003 (February, April and September 2002, and November 2003) aboard the R/V Astrea, we measured the physical parameters, sampled the water masses and took current measurements at 40 stations each campaign (Fig. 2) with the aim of determining the background conditions of water masses before the beginning of the dredging activities.

The hydrological measurements were taken with a multiparameter “SBE 9/11 plus” probe from Sea-Bird Electronics, equipped with a Carousel “SBE 32 unit” with six 10-litre bottles, to determine the evolution of the physical characteristics of the water masses (temperature, salinity, light transmission or turbidity).

We collected 298 water samples from three depths, when possible, (surface, intermediate and bottom) for the analysis of the TSS. The water samples were collected directly from the spigot of a Niskin bottle with a 25-cm Tygon® tube.

The TSS determination was made with HA 47-mm diameter Millipore filters having a nominal pore size of 0.45 μm, following the method in Capello et al. (2009).

The determination of the inorganic fractions (IF) of the TSS was determined adding some acetone drops (Carlo Erba®, minimum assay 99.8%) to dissolve the cellulose filters, and then reducing to ash in an ISCO muffle (ISM320 mod.) at 550 °C for 3 h, to completely remove the organic fraction (OF); the unburned fraction was weighed and used as the inorganic fraction (IF)