INTEGRATED OBSERVING SYSTEMS SUPPORTING CIVITAVECCHIA PORT DEVELOPMENT

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ABSTRACT

Industrial and commercial, together with touristic and ecological, are two of the main uses of the Civitavecchia coastal area that bring wealth and of course influence this marine ecosystem. The port, one of the most important in the Mediterranean Sea, recorded in the last three decades a major increment of its commercial traffic, becoming also strategic for important Mediterranean cruise routes and for passenger flow. New passenger facilities and enhanced and enlarged wharfs allowed to increment the hosted cruise liners from 50 ships in 1996 to 500 in 2003. The creation of new quays and the extension of the anti-mural dame caused on the ecosystems a direct and indirect impact due to the modification of the currents and the dispersion of the dredged materials. The characterisation and assessment of the coastal marine environment of Civitavecchia and its surroundings constitutes, since its creation in 2001, is one of the main activities of the Laboratory of Experimental Oceanology and Marine Ecology (LOSEM) of Tuscia University, who studied the impact of anthropic activities and the influence of climatic events, investigating the chemical and physical parameters of both water column and sediments. Benthic biocenoses and *Posidonia oceanica* were used to evaluate benthos geochemical and ecological characteristics and a specific effort was devoted to hypothesize the possible incidence of dredging works on the benthic ecosystem. The results of the research activities are synthetically reviewed in this paper.

Keywords: observing system, low cost, anthropogenic impact, dredging, sediments, environmental monitoring.

1 INTRODUCTION

The coastal marine environment plays a fundamental role in human life, providing essential services, such as supply of resources, food supply, the possibility of carrying out many work and recreational activities, climate regulation, and other multiple uses [1]. Due to the significant anthropic pressure (industrial, commercial, touristic etc.), and to the high population density insisting on them, coastal marine areas represent the most vulnerable areas of the marine environment and frequently suffer the different impacts of the multiple uses of natural resources [2].

Terraces and mountain reliefs characterise the two extremes of the physiographic unit to which the Civitavecchia coastal marine area belongs. The emerged lands reflect the seabed characteristics, in which rocky bottoms and reliefs are present [3]. The presence of the basins of the Fiora, Marta and Mignone rivers is also to be noted [4].

Because of the multiple role and economical interests converging on the coastal environments, the scientific community has recently addressed interest to harbour ecosystems, in order to monitor the health status of such coastal areas particularly impacted by maritime traffic and preserve their ecological integrity.

In recent years, Italian ports have reached positive performances as a European leader in Short Sea Shipping in the Mediterranean, with 218 million tons of goods transported, which represent a 36% market share. These estimates give us the measure of how strategic is to invest in maritime logistics to give impetus to Italian industry.

Built during Roman Empire, the port of Civitavecchia, in northern Latium (Italy), is one of the most important in Europe, and generates a large part of the business.

Harbours and sheltered bays are also threatened by organic materials of anthropogenic origin impacting over the sediment and constituting a source of damage to marine environment [5]. To mitigate deleterious effects related to sedimentary organic matter accumulation, it is possible to use sediment dredging (the most commonly used method) or biological and chemical systems [6].

In the period November 2012 to January 2013, relevant dredging works took place for building new docks and piers; these operations caused not only destruction of the underlying ecosystem but also sediment dispersion, whose behaviour is linked to meteorological conditions and the characteristics of the dredged material, and increases the presence of contaminants, moving and changing their state from "particulate" to "dissolved" [7].

The environmental risks caused by the dredging activities were taken into account by the Italian Ministry for Environment, Land and Sea, who prescribed various activities, including *in situ* surveys, to assess water and sediments quality and the presence of contaminants in the harbour area and its surroundings.

In this review, the main anthropogenic impacts acting on the Civitavecchia marine area were analysed, looking at area climate, marine dynamics, seawater characteristics and quality, physical and chemical sediment characteristics, and the benthic biocenoses, with particular attention to the *Posidonia oceanica*, which is a priority habitat. Mathematical models and GIS are the tools that allowed us to correlate the different studies, make impact analysis, forecasts and identify risks for ecosystems. The final goal of the study is to get an overall picture of the dredging impacts on the environmental conditions of this coastal area.

2 MATERIALS AND METHODS

The Laboratory of Experimental Oceanology and Marine Ecology (LOSEM) set up an integrated approach supporting the environmental management providing information and forecasts to the population and public administration which is based on an Integrated Observing System (IOS).

This systematic approach was applied to support the development of the port of Civitavecchia: the Civitavecchia Coastal Environment Monitoring System (C-CEMS) was able to evaluate possible impacts that anthropogenic activities could have on this coastal marine environment [8].

More specifically, the analysed features focused on the distribution of bacterial pathogens along the bathing zone [9], as well as on the potential impact of dredging performed within the Civitavecchia port on the benthic environments in terms of *P. oceanica* meadows, soft bottom benthic assemblages and water quality [10]. Moreover, the LOSEM developed and *in situ* tested new technologies for environmental monitoring, working at limited costs [11].

2.1 The study area

Capo Linaro and Monte Argentario are the two extremes of the physiographical unity that includes the Civitavecchia harbour, located in the northern Latium (Fig. 1). The coast hosts several urbanized and industrial areas, except for the northern part and the southern area of Cape Linaro, located in Civitavecchia.

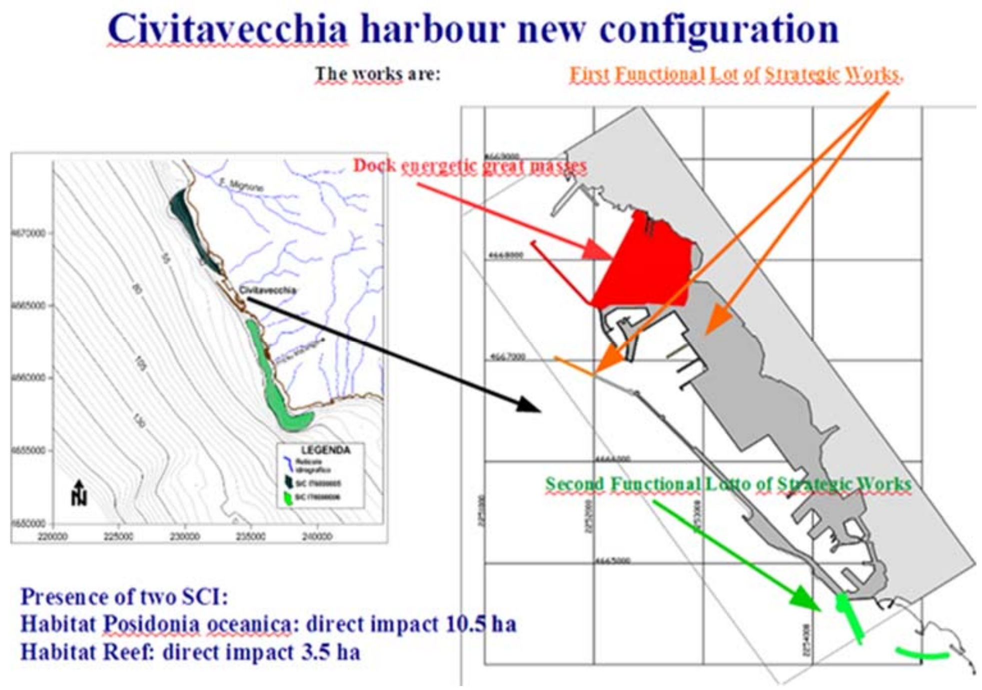

Figure 1: The Civitavecchia port configuration before 2012, the area dredged between the 1st November 2012 and the 31st January 2013 and the developments planned for the final building of the port structure.

Terraces and mountain reliefs characterise the two ends of the physiographical unity; terraces are found from the southern area of Civitavecchia to the northern area of the Mignone river mouth, while reliefs are observed in the northern extreme of the physiographical unity close to the Argentario Mount area.

Continental terrigenous inputs derived from the afferent basins and the presence of large areas showing bioconstructions and *P. oceanica* meadows influence the sedimentary processes of the considered physiographical unit. The distribution patterns of arsenic and mercury concentrations within the marine sediment of the area comprised between the Mignone river and Monte Argentario confirm the prevailing direction of currents and winds toward North West [12].

2.2 C-CEMS configuration structure

Already used in previous studies, the C-CEMS (see Fig. 2) – an observing system able to integrate data from various sources [13] – was improved to manage: 1) Meteorological parameters, waves and water quality data acquired at the harbour mouth and in a not disturbed zone; 2) Physical, chemical and biological measurements on water column and bottom sediments; 3) Soft benthic communities and *Posidonia* meadows observations; 4) Estimated water turbidity by means of satellite observations; 5) Waves and currents simulations performed using mathematical models on acquired data sets; 6) A GIS able to contain all the information collected and to provide the necessary data set to support management activities.

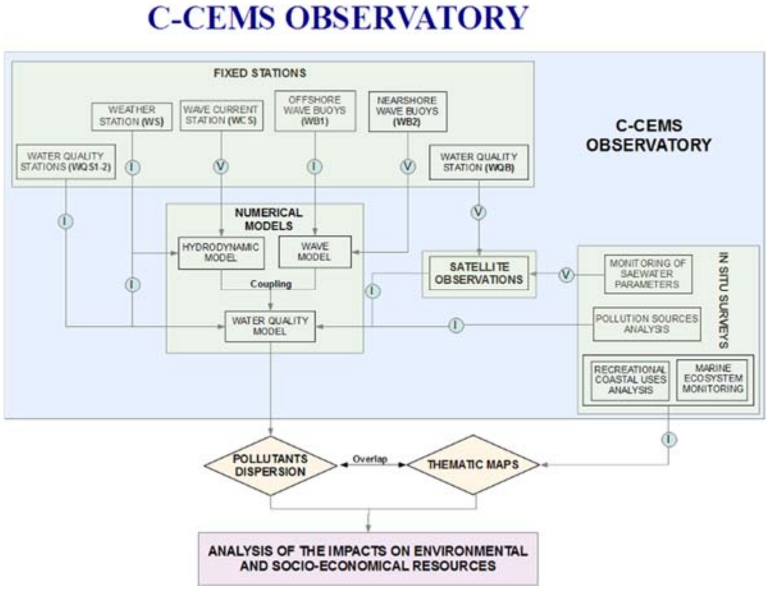

Figure 2: C-CEMS scheme.

2.2.1 Weather and wave data and seawater monitoring stations

Measurements of wind speed and direction, atmospheric pressure, solar radiation, air temperature, relative humidity and rain were performed at 10 minutes intervals by a meteorological station located in the Civitavecchia harbour. A wave buoy that was moored outside the port mouth on a 50 m depth (Lat. 42.097° N, Long. 011.744° E) provided the data to determine height, peak period and mean direction of waves (Fig. 3).

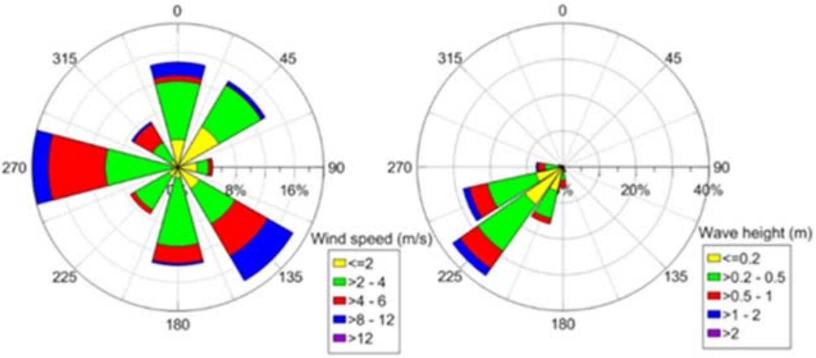

Figure 3: Wind and wave spectral analysis in Civitavecchia.

Seawater parameters (conductivity, temperature, dissolved oxygen, pH, turbidity, chlorophyll *a* fluorescence) were measured at a fixed station in the Civitavecchia harbour.

A second measurement station located 8 km south of the port of Civitavecchia in a protected area allowed the comparison with undisturbed data.

2.2.2 In situ surveys

Physical and biological seawater parameters: A strategy including periodic *in situ* surveys at fixed measuring stations allowed the continuous acquisition of marine physical and biological parameters.

A multiparametric probe (IDRONAUT 316 plus) was used for *in situ* measurements while suspended matter, nutrients and chlorophyll *a* were analysed in laboratory on water samples taken from different depths using Niskin bottles.

Bottom sediments: The characteristics of bottom sediments were obtained by *ad-hoc* sampling activities at different distances from the dredging area and within the harbour basin. Sediment samples were subjected to grain size and trace metals (As, Cr, Hg, Cu, Zn, Pb) analysis. Analytical determination was performed with ICP-MS. Effect range low (ERL) and Effect range median (ERM) for the assessment of the environmental pollution degree were used, in accordance with the Sediment Quality Guidelines (SQGs), as a basis for comparison of the measured trace metal concentrations

P. oceanica meadows and soft benthic communities: Being very sensitive to environmental conditions, *Posidonia oceanica* (a marine phanerogam) is widely recognised as a good indicator of marine water quality; in fact, a protracted reduction of light available for the photosynthesis under 7.8% of solar surface radiation causes its death, just like the bury of apical meristems due to an excess of sedimentation [14].

Before and after each dredging operation the health status of *P. oceanica* meadows in the study area was evaluated through the analysis of the number of shoots per square meter (shoot density) that, together with remote sensing data, allowed to calculate the Leaf Area Index (LAI) [15].

With the same schedule, investigations were performed to analyse possible changes in soft-bottom benthic communities composition induced by anthropogenic alterations.

In fact, ecosystem quality and sedimentary disequilibria generated by the dredging activities can be estimated observing the soft bottom benthic communities that, having a longer life cycle than planktonic populations, are able to keep memory of events spanning over a wider period, so providing indications about previous perturbations [2].

2.2.3 Remote sensing

Satellite observations were used to monitor the area under study, producing daily maps of Total Suspended Matter (TSM) and Chlorophyll *a* obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor mounted on the Aqua (EOS PM) satellite [16].

The L1-A data obtained from the NASA website (containing the raw radiance counts, satellite and instrument telemetry and calibration data) were then processed to obtain L2 parameters containing, for each pixel, the results of the geophysical measurement [17].

2.2.4 Mathematical models

Included in the SMS 11.1 (Surface-water Modelling System), the ADCIRC, STWAVE and PTM models (that are bi-dimensional mathematical models) were used to analyse in the nearby of the Civitavecchia harbour the dispersion of sediments, the wave propagation toward the coast and the marine hydrological currents.

To run the models five scenarios were chosen, of which three (“Libeccio”, “Scirocco” and “Grecale”) were based on typical winds and waves characteristics, and two (“R1” and “R2”) derived from the real meteomarine conditions recorded during the dredging operations.

The DELFT3D (a model that estimates the behaviour of a passive tracer in terms of spread and transport within a semi-enclosed area) was applied to evaluate the water renewal time inside the harbour.

To obtain the water renewal time in terms of flushing time (FT), a theoretical conservative tracer uniformly released in the Civitavecchia harbour with an initial unitary concentration was followed in its decrement due to the water exchange between the internal and external areas, where the concentration was supposed to be 0 (see Fig. 4).

The flushing time (t) can be derived from eqn (1):

$$C(t) = C_0 \,.\, e^{-t/Tf}, \tag{1}$$

where C_0 is the initial concentration of the conservative tracer, $C(t)$ is the 63% of C_0 and T_f is 1/e [18].

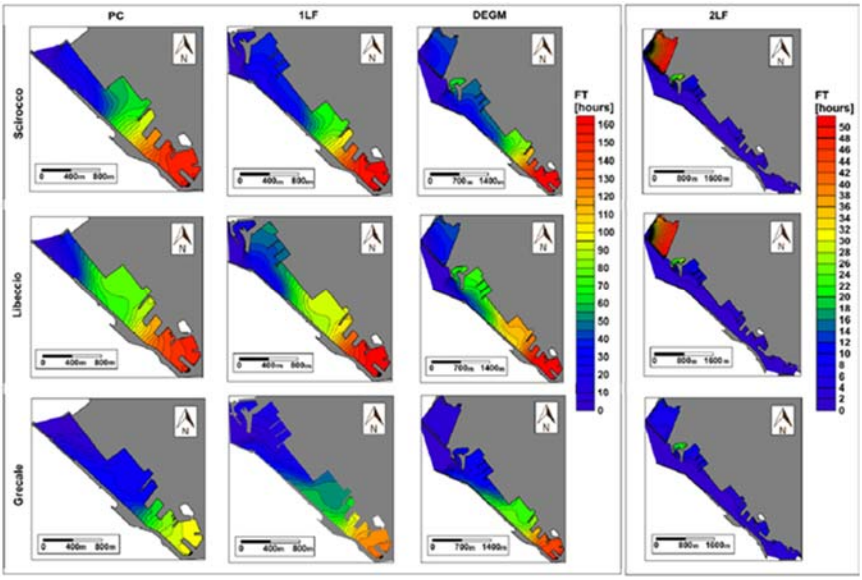

Figure 4: Estimate of flushing time (FT) related to meteorological conditions and harbour works advancement.

2.2.5 GIS

The GIS [19] (see Fig. 5) is structured in different modules such as:

- affecting coastal zone module: this module inserts in the management system information about hinterland zones affecting the marine area and so about coastal morphotypes, water and solid outflows which characterise near shore studied marine zones, geology and geochemistry and about the land use;
- sea bottom module: this module integrates detailed information about morpho-bathymetry and seabed geology and information on distribution and abundance of organisms;
- marine weather module: the marine weather data are useful to know the principal forcing conditions on the sea interface such as wind, waves, tides and currents;
- water column module: this module analyses physical, chemical and biological features measured in water column;
- uses of marine and coastal areas module: this module is crucial for planning coastal works, for monitoring and forecasting induced from potential variations.

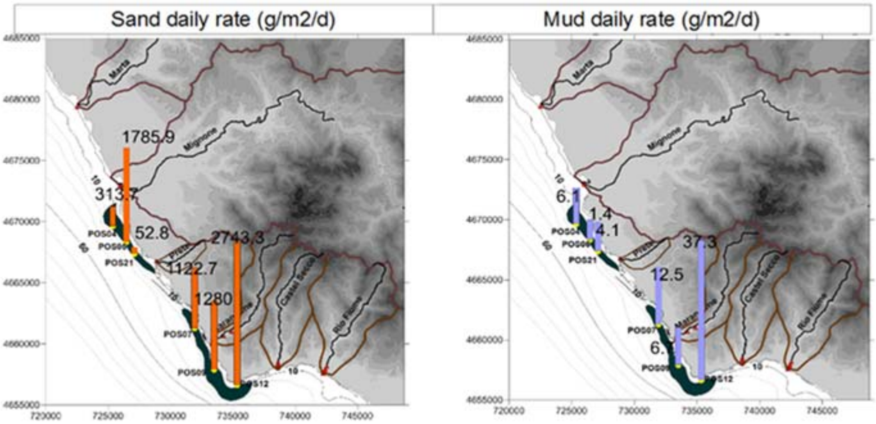

Figure 5: GIS applied to sedimentation rate analysis.

3 CASE STUDY

The final project of a first set of interventions for the harbour enhancement, including the extension of Colombo embankment and the building of docks, was approved by CIPE (Interministerial Committee for Economical Planning) with the Decisions 140/2007 and 2/2008 and with the consent of the Italian Ministry of Infrastructures and transports.

The embankment extension design is northwards-oriented (Fig. 6). An area of approximately 31,000 m^2 belonging to the access channel to the port was dredged down to -17 m; a part (123,650 m^2) of the ferry dock area was deepened to -10 m and a part (51,900 m^2) to -15 m. Globally, the dredging (lasted from 1st November 2012 to 31st January 2013) removed a volume of 918,000 m^3 of seabed.

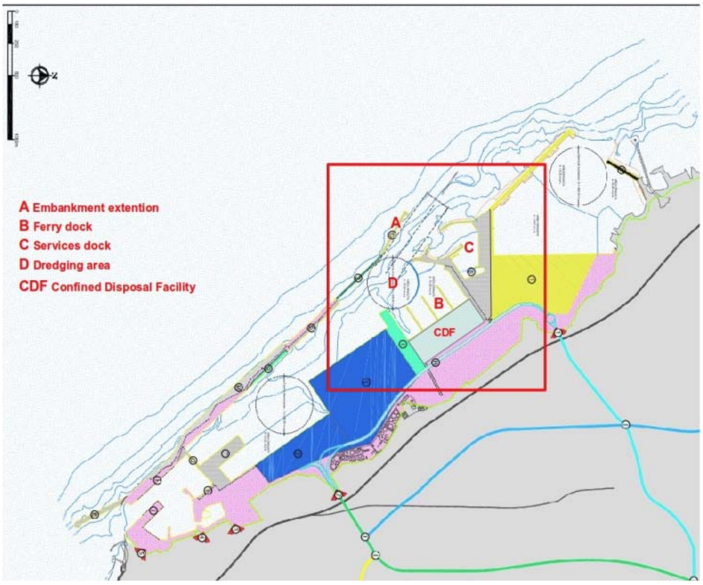

Figure 6: Design of the different harbour changes.

4 CASE STUDY RESULTS

C-CEMS was used to examine the impact of the dredging inside and around the Civitavecchia harbour area (see Table 1).

Table 1: Geochemical dataset of the Civitavecchia harbour situation before the dredging (B) and after operations (A). Pelite (Pel), Sand and Pebble (Peb) content are reported as % of the total composition. Trace metals values are expressed in mg/Kg.

	ST	Pel	Sand	Peb	Al	As	Cd	Cr	Ni	Pb	Cu	Zn
	01PT	46.7	53.3	0	8280	12.8	0.26	15.2	20.0	12.0	11.5	63.6
B	02PT	74.7	25.3		50620	19.5	0.95	38.6	33.7	38.4	24.3	110
	03PT	66.8	33.2		70050	22.8	1.2	52.7	47.0	50.3	29.5	121
	01PT	14.4	81.2	4.4	3190	15.5	0.12	5.9	3.3	5.5	3.0	13.8
	02PT	82.01	17.99		17520	1.3	1.0	74.1	69.3	50.1	44.1	165
A	03PT	94.3	5.7		13200	14.1	0.42	29.3	25.4	28.7	19.7	140
	01PT	3.48	96.52	0	5716	14.4	0.16	11.5	8.5	9.1	7.5	12.7
	02PT	68.12	31.88		19638	4.5	1.2	72	63.1	55.7	45.1	162
	03PT	90.63	9.37		13560	14.9	0.43	30.0	26.3	28.7	19.6	147

4.1 Effects of the dredging on bottom sediments around the Civitavecchia harbour area

A significant temporal variation of the particle size fractions was recorded during the sedimentological study performed in three sampling campaigns. The fine particle size fraction decreased progressively at the sampling station closer to the coast, increasing at the one located farther away. This trend of variability was related to the resuspension of sedimentary materials consequent to seabed remobilization caused by the dredging activities, as shown by previous studies [20].

Generally, the particle size fraction consisting of coarse grain undergoes to a quick precipitation to the bottom, while the smaller fractions remain in suspension through the water column and can be transported far from the dredging site [21]. The trace metals concentrations compared with the SQGs numerical indices ERL and ERM pointed out that the levels of contamination varied in relation with the increase of the pelite fraction. The affinity between finer particle size fractions and the trace metals bound to their surface, that further follow their sedimentary fate, could explain this observation [22]. These studies confirm the usefulness of the fine sediment particle fraction in the evaluation of contamination and in the assessment of the anthropic pressure acting on coastal areas.

4.2 Effects on the coastal marine ecosystem around the Civitavecchia harbour area

In addition, the potential impacts on *Posidonia oceanica* meadows and soft-bottom benthic communities of the dispersion of fine sediments caused by the dredging were examined using the C-CEMS.

The high rates (963 Kg/s) of lost fine sediments, potentially harmful to the sensitive marine environment, were caused by the high dredged volume (918,000 m^3) and the short period of release (92 days).

High values of TSM recorded at the water quality station near the Civitavecchia harbour mouth constitute a tracer for the fine sediment dispersion; the maximum turbidity level, according to the biological and physical data acquired during the periodic *in situ* samplings, was recorded on November 26th, when wind and waves from the fourth quadrant spread southwards the dredging products.

Also, the results of the mathematical model run in the “Grecale” scenario showed the quick southwards spread of the sediments released at the harbour mouth, that accumulated and concentrated in the water column in a wide area. Meteomarine data showed that during the operation period the northwards-oriented conditions (“Libeccio” and “Scirocco”) had a higher frequency than Grecale, coming southwards from the fourth quadrant. So, the potential impacts on soft-bottom benthic community and on *P. oceanica* were influenced by these conditions, characterising the “Real” scenario. The results of the simulations reproducing the above indicated conditions showed that the largest accumulation zones caused by the dredging – and resulting in environmental damages – were found inside the dredged area (i.e. eradication of *P. oceanica* shoots) and in correspondence of Punta S. Agostino (i.e. change of the benthic community from fine well-sorted sands to coastal terrigenous muds at depths comprised between -10 m and -20 m).

The sediment plume caused by dredgings extended up to 80 m away from the coast, showing higher values of suspended sediment nearshore than offshore, where it was possible to observe *P. oceanica* meadows. The effects on the seagrass lawn nearer the port confirmed the reliability of the simulations. In spite of the increment in turbidity caused by the dredgings, it was possible to record an increased density of *P. oceanica* shoots, from 453. 125 to 468.75 shoots/m^2. A link probably existed between the low number of shoots measured in the northern lawn zone, in which a decrement of dredged suspended materials was observed, and the presence of Mignone and Marta rivers, with their sediment plumes.

4.3 Effects on water quality inside the Civitavecchia harbour area

The conspicuous difference in the maximum wind speed measured in the real scenarios R1 (8 m/s in the 22/11/2008–2/12/2008 period) and R2 (16 m/s in the 17/12/2008–28/12/2008 period) seemed to have little influence on the FT values in the inner and central part of the Civitavecchia harbour. So, it can be said that the direction of the external current induced by wind is the most important forcing driving the inner harbour hydrodynamism, and consequently the flushing time. As reported in earlier study, a low circulation inside the harbour is related to the external northward current, while a southward one, able to directly influence the internal hydrodynamism, produces higher speeds.

The calculation of flushing time values under the three idealized scenarios of “Scirocco”, “Libeccio” and “Grecale” confirmed the influence of the direction of external current on water exchange between the open sea and the inner harbour, to which the persistence, enrichment or dilution of contaminants is strictly related.

Furthermore, the relation between the Enrichment Factor (EF) of a metal present in port sediments used as a tracer and the FT was investigated, observing a notable positive correlation between hydrodynamics and contamination index in harbour waters constituting a sheltered basin: the higher is the flushing time, the bigger is the EF; this because the contaminants have more time to link to suspended fine particles before reaching the bottom.

The influence of the direction of external current is remarked by the observation of the correlation between FT and EF estimated in presence of winds from NE. The manipulation of iron materials inside the port, with related release of Cr and Ni, can explain the values of Enrichment Factor found in the port.

5 DISCUSSION AND CONCLUSION

In close relationship with the increasing economical role of harbours, important ecological issues dealing with the possible impacts of anthropogenic activities are being arising in recent years. Choosing the Civitavecchia harbour as a study site to assess the impacts of dredging activities, this study has proven that the C-CEMS is a powerful facility to investigate the consequences of the dispersion of dredging products in and near a port basin. Moreover, it suggested that the Flushing Time is a reliable parameter to assess the occurrence of contamination from trace metals and the consequent worsening of water quality.

The above described instruments and acquired know-how can be used to reach and preserve the Good Environmental Status (GES) in port areas. Last, but not least, the study of Flushing Time distribution should always be performed as a preliminary step for the assessment of harbour basins.

Globally taken, the results of this research show that the dredging activities did not produce significant impacts on the water and sediment quality as well as on the benthic community of the marine environment within and around the Civitavecchia harbour.

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