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Integrated coastal zone management at Marina di Carrara Harbor: sediment management and policy making

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ABSTRACT

Sediment management is becoming a critical issue around the world, particularly where the development of Harbor facilities, the conservation of coastal environments and needs of tourism compete for sustainable use of sediment resources. In order to apply an Integrated Coastal Zone Management policy, new approaches for management of the dredged harbor material need to be considered by the scientific community and local stakeholders. The information contained in the Italian Ministry of the Environment Acts related to dredging of Carrara Harbor determined the sediment volume dredged between 1993 and 2008 (849,500 m^3) and allows us to estimate an average rate of material dredged from the harbor mouth (10,000–13,000 m^3/yr). Different management options were chosen by the authorities based on the contamination level of dredged sediment: nourishment (344,500 m^3), offshore dumping (305,000 m^3), disposal in landfill (10,000 m^3) or in Confined Disposal Facilities (215,000 m^3). The present study's goal is to determine the sedimentary budget of the Apuo-Versilian coast and to use the result to guide a compensation strategy to reduce the sediment deficit caused by the disposal of sediments out of the sand-sharing system. In particular, the present study provides a detailed reference frame that can lead to adopt a compensation strategy to balance the eroding evolutionary trend of the coastline adjacent to shallow water dredging areas. The procedure described in the paper is a policy initiative based on scientific results and could provide a model for other jurisdictions developing their own sediment quantitative estimation within an ICZM approach and a sustainable development of sedimentary resource's management.

1. Introduction

The management of sediments in coastal areas suffering of erosion requires special attention (Apitz et al., 2005a,b; Veloso-Gomes and Taveira-Pinto, 2003; Xue, 1999). Because of the high complexity of both coastal system's evolution and sediment managing, several studies carried out in recent years (Apitz et al., 2006; Borja, 2005; Ducrotoy and Elliott, 1997; Elliott et al., 1999) have highlighted a new economical, physical, ecological and social approach. In particular, the policy of sediment management is divided into two main categories: construction or navigational dredging characterized by a removal of large volumes of sediment (economically driven); hot spot or environmental cleanup of contaminated sediments characterized by smaller volumes of sediment (socially driven) (Apitz et al., 2006). In this framework, the planning of extensive dredging and disposal operation is moving forward in several areas where the harbor and inlet deepening and maintenance exacerbate beach erosion (Montague, 2008). Many harbors are characterized by bathymetric constriction at their mouth that influences sediment exchange with the coastal system (Buynevich and FitzGerald, 2003). The net exchange of bed-load and suspended solids affects conditions along the axis of the harbor mouth (De Ruig, 1998; Van Rijn, 1986; PIANC, 2008), as well as the sediment budget on adjoining coast (Rózyñski et al., 2005; Veloso-Gomes and Taveira-Pinto, 2003). Harbor inlet deepening frequently leads to a capture of the littoral sand drift (Finkl, 2004; GESA, 2006; Taylor Engineering, 2001; Vittori et al., 2005). Together with the diversion of eroded sand into ebb shoals adjacent to jetties, this sand deficit contributes to increased beach erosion (Dyer and Huntley, 1999). Furthermore, offshore and onshore disposal of material dredged from harbor basin could result in a large net loss from the sand-sharing system (Pachecoa et al., 2007; Seabergh and Kraus, 2003). In the presence of coastal structures, sediment bypasses will not restore this deficit because

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they simply relocate sand within the system (Montague, 2008; U.S. Army Corps of Engineers, 2002).

Quantification of the volume of sediment dredged in the harbor area as a mean of determining the anthropomorphic evolution of the seafloor has become fundamental in the framework of institutional activities and scientific research (Anfuso and Martìnez del Pozzo, 2005; Frodsøe and Deigaard, 1992; GESA, 2007; Van Rijn et al., 2005; Walstra et al., 1999, 2002; Xue, 1999). A regional understanding of littoral cell boundaries and sand budgets within those cells is important in coastal engineering management in order to find a solution to the erosion problem, particularly when both dredging and offshore or onshore disposal play key role (Garcia et al., 2000; Kraus and Horikawa, 1990; Rosati and Kraus, 1999). Thus, environmental interest among the scientific community has been focused on the dredged sediments (Apitz et al., 2006; Burroughs, 2005; Pellegrini et al., 2002) by groups of stakeholders (De Ruig and Roeland, 1997; GESA, 2006, 2007, 2008; European Sediment Network, 2010; Slob and Gerrits, 2007) because many human activities (fisheries, maritime transportation and development of infrastructure along the coast) may significantly influence coastline evolution. In terms of sustainable development, the different actions implying a change of extension of the emerged beaches should consider the economic value of the coast and the demand of sand necessary to contrast coastal erosion (Houston, 1995, 1996, 2008). Through the analysis of the information contained in the Italian Ministry of the Environment and Port Authority Acts related to Carrara Harbor dredging authorizations from 1993 to 2008, the proposed research approach allows a better understanding of the average annual dredging volume and a classifications of the different management options chosen by the Authorities.

The approach is a valuable instrument for approximating littoral drift rates at specific locations within littoral cells, as well as changes in these rates over time due to human impacts on the sediment budget. The paper is organized as follows. The introduction to the study area is followed by the methodology used to collect information on sediment properties and management and to create a geodatabase in ARCGIS®. Results are presented in four different subparagraph: (a) sediment properties and distribution (b) contamination level of sediments recently characterized within the National Programme of Land Reclamation (c) history of dredged-and-fill operation between 1993 and 2008 and (d) calculation of sand deficit from the sand-sharing system. The discussion is then presented with the following subparagraph: (a) history of sediment management and quantification of infilling process (b) restrictions on sediment management due to contamination (c) factors influencing sediment, port and coastal management in the studied area and (d) compensation strategy suggested by the Authors as a policy initiative to guarantee the sustainable development of harbor traffic and tourism. The compensation strategy has been imposed to mitigate the negative consequences of sediment dumping (or their disposal on land) on coastal erosion. Due to the multi-dimensional environmental issues that need to be resolved, we strongly believe that such strategy will reduce conflicts between stakeholders and guarantee a sustainable economic development in the area. The described methodology represent a benchmark against which other jurisdictions, with their own sediment quantitative estimation, could develop a sedimentary resources management based on scientific principles.

2. The study area

The Apuo-Versilian coast of northwest Italy lies along a physiographic unit of about 50 km located between the mouth of the Magra River to the north and a rocky outcrop in the south, near Livorno (Cavazza, 1977; Cortemiglia, 1977). The entire physiographic unit, where Viareggio Harbor was built in 1606 and Marina di Carrara Harbor in 1924 (Fig. 1), is characterized by sandy beaches.

The prevailing winds in the area blow from the west and the southwest during spring and summer, while in autumn and winter, north–northeast winds progressively increase in frequency (Melito et al., 2006).

The maximum tidal variations are of the order of 0.3 m, so that wave-induced currents can be considered the only driving forces for harbor sedimentation. In order to understand wave dynamics within the harbor and the resonance phenomena, a monitoring network was installed by the Port Authority of Carrara in 2005. A directional accelerometric buoy (model Datawell Directional Waverider MKIII), anchored at a depth of 13.5 m, at about 600 m from the harbor inlet, measures wave with periods between 1.6 s and 30 s since November 2005. Wave climate is almost monodirectional and all the incoming relevant waves come from 220 to 240°N, as a result of the geographical fetch distribution (Fig. 2), as swell are sheltered by the Corsica and Elba islands to the South and by Ligurian and Tuscan coast to the North and East.

Along the northern part of the coast, where Carrara Harbor is located, the net transport is southward directed, whereas along the southern section, net transport is northward directed. The local sediment drift reverse point is located nearby Forte dei Marmi (Pranzini, 2004; WL | Delft Hydraulics, 2006).

The Apuo-Versilian coast suffered of intense erosion (Cipriani et al., 2001; Pranzini, 2004; Pranzini and Rossi, 1995) influenced

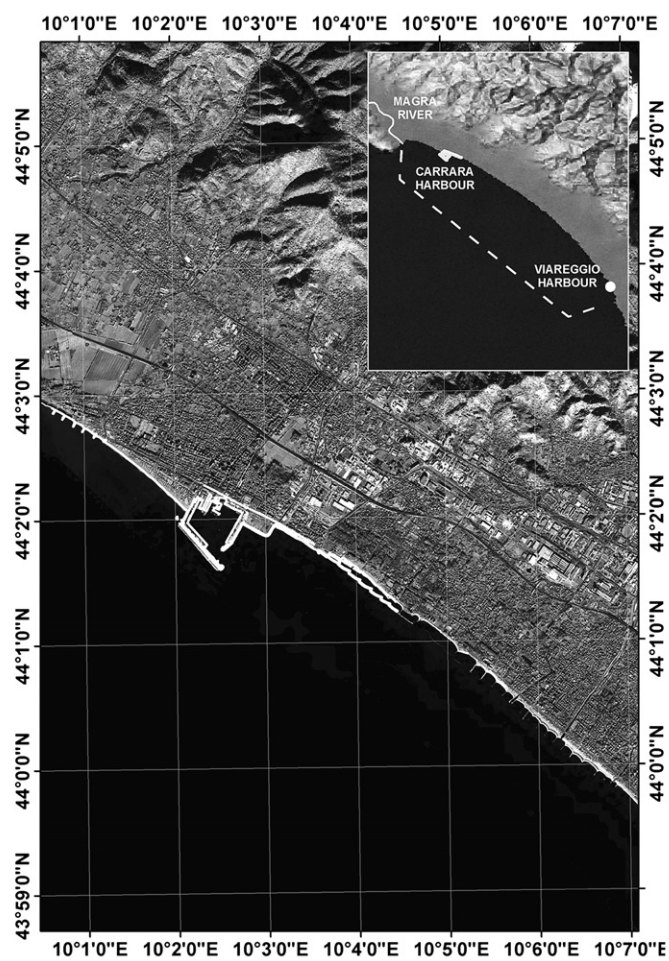

Fig. 1. Location map of the study area. Scaled view of the Apuo-Versilian cell (from River Magra mouth to the Viareggio Harbor in the South).

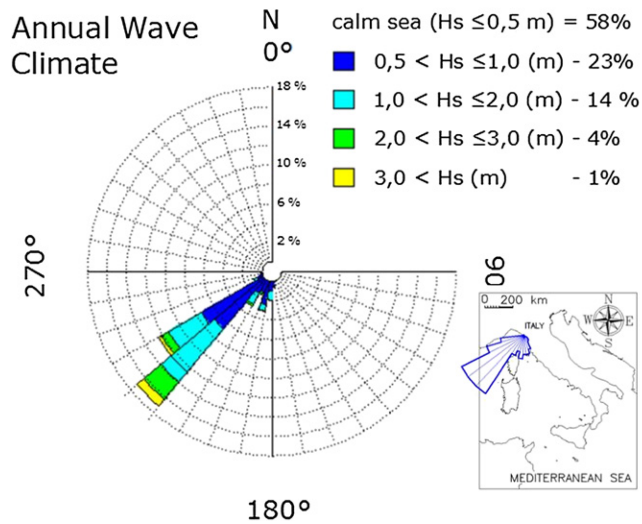

Fig. 2. Annual wave climate and geographical fetch on Carrara coast.

by human impact due to the Carrara harbor, construction of groynes field and the controlled Magra river mouth (Aminti et al., 1999, 2002; Cappucci et al., 2008). The factors influencing the morphological evolution of the coastal system have been investigated at the scale of river basins (Cappucci et al., 2005; Rinaldi and Dapporto, 2005; Rinaldi and Simoncini, 2006) and physiographic units (Pranzini, 2004; WL | Delft Hydraulics, 2006), estimating sediment volume trapped by dams (Onori et al., 2006; Piegay and Rinaldi, 2006) as well as considering the sediment management within the harbor (Cappucci et al., 2006). Since its construction, Carrara Harbor had a strong influence on the morphodynamic evolutional patterns along the coast (Fig. 3.), with sediment accretion updrift and a very high erosion rate downdrift (Aminti et al., 1999, 2002; Cipriani et al., 2001; Pranzini and Rossi, 1995; WL | Delft Hydraulics, 2006).

Through time, different types of emerged and submerged groynes and barriers have been built, transforming one of the most beautiful Italian sandy beaches into a natural 1:1 scale laboratory where the severe erosion was shifted southward, fixing the shoreline for about 7.5 km downdrift.

The Magra is the major river transporting sand to the coast through erosion of the Macigno Oligocene sandstone formation which influence the composition of sediment on the continental shelf: quartz (40%), feldspar and mica (<40%) and carbonates (20%) (AA.VV, 1997; Cipriani et al., 2001; Gandolfi and Paganelli, 1975).

Changes to significant sediment supply or loss to this coastal cell can be attributed (a) to the decrease of rivers sediment load and (b) to human activities (Cavazza, 1977; Rinaldi and Surian, 2005; WL | Delft Hydraulics, 2006). A shoreline analysis of the Versilian coast (WL | Delft Hydraulics, 2006) has found that Magra River is the main sediment's source, with a discharge of 70,000–130,000 m^3/y, reduced to 30,000 m^3/y nowadays, due mainly to the excavation of aggregates necessary for the construction of motorways in the 1970s. Cappucci et al. (2008) indicate that over the last decades the sediment input from Magra River, has varied from a minimum of 34,900 m^3/y upto 68,500 m^3/y. Despite different estimation of sediment input from the Magra River, it is estimated that the erosion process will significantly reduce the extension of the emerged beaches by 2035 if this trend continue and no nourishment is carried out (WL | Delft Hydraulics, 2006). Therefore, any sediment management strategy which increase the sediment input and reduce the sediment output from the sand-sharing system will mitigate the erosion in the future.

3. Methods and data

One of the aims of the study is to understand how the different sediment management options adopted along the Apuo-Versilian coast by the Italian authorities have influenced the overall sediment balance in the last 17 years. In particular, we approximate, the littoral drift rates over time due to human impacts highlighting the importance of integrating in the same dataset dredging volume and

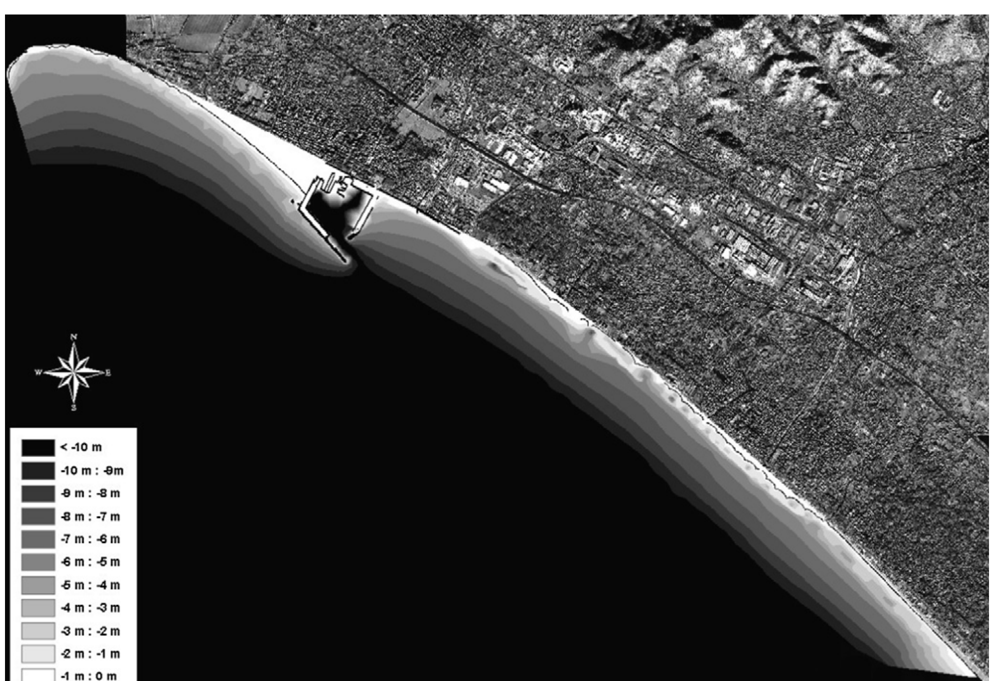

Fig. 3. Bathymetry (2004) of the submerged beach around the Carrara Harbor to 10 m of depth.

areas, management option and sediment characteristics. Therefore, the following assumptions have been made:

- in the time interval 1993–2008 variations of wave climate, sea level and natural littoral drift have not been considered and the dredged volume is the overall moved material (sediment input, transfer and output) in the time interval. Different destinations of dredged material have contributed to either a sediment transfer or output from the coastal system.
- sediment transfer is the amount of dredged material placed between the shoreline and the closure depth for shoreface nourishment.
- sediment output is the volume of dredged material lost from the coastal system for offshore dumping beyond the closure depth, or placed within a Confined Disposal Facility (CDF), or into a landfill. The concentration threshold for some contaminants adopted to support these decisions are presented in Table 1 and later argued in the discussion.

Table 1
Threshold values of contaminants in relation to the present sediment management within the Contaminated Site of National relevance of Carrara, according to the present legislation. First column: general value for quality standard of coastal water bodies (Decree of the Ministry of environment n.56 of 14th April '09); Second column: threshold levels for contamination, above which suitable reclamation measures have to be carried out, up to full removal of sediments from the water body. These values are site-specific and determined on the basis of Probable Effect Level (PEL) related to toxicity, persistance, bioaccumulating potential, natural background (Long et al., 1995). Third column: 90% of the concentration thresholds for contaminants within industrial areas (Italian Law 471/1999, confirmed by L. 152/2006). Since 1999 such values have been used to authorize the disposal of contaminated sediments into CDF. Fourth column: concentration thresholds for dangerous waste. Since 2008 such values have been used to authorize the disposal of contaminated sediments into specific landfill. See Discussion for further details.

Contaminants	Quality standards (mg/kg ss)	Intervention values Carrara (mg/kg ss)	Soil criteria (industrial areas) (mg/kg ss)	Limit for dangerous waste (mg/kg ss)
As	12	42	45	≥1000
Cd	0.3	0.8	13.5	≥1000
Cr	50	250	720	≥1000
Hg	0.3	0.8	4.5	≥500 org ≥1000 inorg
Ni	30	200	450	≥10,000
Pb	30	105	900	≥5000
Cu		65	540	≥25,0000
Zn		192	1350	≥1000 (chromate) ≥50,000 (chloride) ≥10,0000 (sulfate)
TBT	0.005	0.07	0	≥2500
Benzo(a)pyrene	0.03	0.76	9	≥100
Anthracene	0.045	0.245	0	
Fluoranthene	0.11	1.5	0	
Naphtalene	0.035	0.39	0	≥10,000
∑PAH	0.8	4	90	
Aldrin	0.0002	0.005	0.09	≥10000
Alpha-HCH	0.0002	0.001	0.09	≥10,000
Beta-HCH	0.0002	0.001	0.45	≥10,000
Gamma-HCH	0.0002	0.001	0.45	≥30,000
DDT	0.001	0.005	0.09	≥1000
DDD	0.0008	0.005	0.09	≥10,000
DDE	0.0018	0.005	0.09	≥10,000
HCB	0.0004	0.005	4.5	≥1000
Dieldrin	0.0002	0.005	0.09	≥1000
∑PCDD/F + PCB(TEQ)			0.00009	≥0.01
PCB	0.008	0.19	4.5	≥50
	Nourishment	Confined disposal facilities		Landfill

- the closure depth, that in the coastal engineering time frame is taken as the boundary of the sand-sharing system (Dean and Darlimple, 1991), has been calculated with Hallermeier's (1981) formula:

$$d_c = 2.28H_{12} - 68.5\frac{H_{12}^2}{gT_p^2}$$

where d_c [m] is the closure depth; H_{12} [m] is the average wave height not exceeding for more than 12 h a year; g [m/s^2] is the gravity acceleration; T_p [s] is the peak period associated to H_{12}. These parameters have been calculated considering the 3-hourly data from the Port Authority buoy for the years 2006 and 2007.

Based on the above assumptions, the complexity of sediment dynamics and the long lasting conflicts among local authorities in the area (port authority, versus municipalities and tourist operators), a simple and straightforward method was implemented in five steps (Fig. 4):

(1) Two sediment grain size datasets were considered in order to quantify the granulometric fraction that contributes to the sedimentary balance of the coastal cell. The first one, provided by "Regione Toscana", includes the granulometric characteristics of the sediments outside the harbor basin for the period 1997–1998. More than 200 superficial sediment samples were collected with a lightweight Van-Veen® grab from submerged beach at the depth of 0, 2, 4, 6 and 8 m along transects perpendicular to the shoreline, with 500 m offset (Gao and Collins, 1992). Grain size distribution was then interpreted in order to apply the Gao & Collins model and produce the final sedimentological maps (Pranzini, 2004).

The second one includes the characteristics of the samples collected on the survey by the Marina di Carrara Port Authority in 2005, as prescribed by the Ministry of Environment (ICRAM, 2004) in order to authorize the remediation of contaminated hot spots. Topmost 10 cm superficial sediment was sub-sampled from 67 vibro-cores. Most of them were located within Carrara Harbor and this dataset has been considered to estimate the abundance of sand, silt and clay fraction and contamination of seafloor (ICRAM, 2004).

(2) A research has been carried out in the archives of the Ministry of Environment – Life Quality and Nature Protection Directorates – in order to collect the authorization decrees concerning the dredging activities of the Carrara Harbor area. A summary of the most relevant information contained in each authorization decree is presented as a result of the present study (Section 4.2), as it is not possible to submit copy of original documentation (in Italian).

(3) As an authorization does not imply the effective realization of the intervention, all available documents certifying the end of the dredging as well as bathymetric surveys carried out before and after the interventions have been considered. Through the analysis of these documents the overall sediment volumes actually managed between 1993 and 2008 have been calculated, using the approach recently proposed by Montague (2008) where dredging and beach nourishment databases are used to reveal sand disposal dynamics and to calculate sediment deficit.

(4) A geodatabase was implemented in ARCGIS® to elaborate and spatially analyse the available official information within the same datum (WGS 84 UTM zone 32). All information were analysed by using the scientific principle reported within the assumption, to distinguish the volume of sediment transferred or removed from the coast.

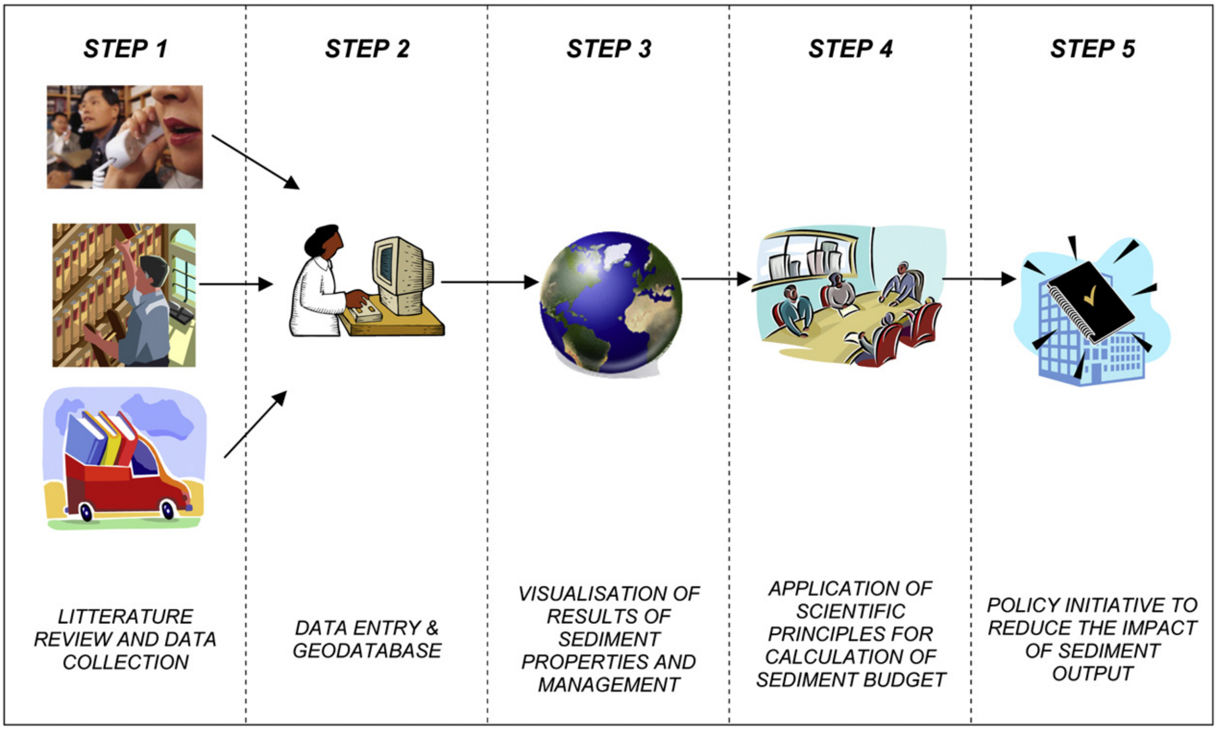

Fig. 4. Visualization of different steps carried out during the research activities.

(5) Finally, a policy initiative based on scientific and sustainable development principles was developed to support the Ministry of Environment.

4. Results

The integrated dataset has been used to examine the cumulative effect of the dredging activities on the sand-sharing system in order to quantify the volume of sediment of each component.

4.1. Sedimentological evidence of infill process

As a first result, the two sediment grain size dataset highlight the sedimentological evidence of the infilling process at the harbor inlet (Figs. 4 and 5).

The sediment analyses carried out in 2005 on 67 stations show that the topmost 10 cm of sediment has a sandy fraction of 90% by weight, with a minimum of 40% inside the harbor (Fig. 5). The other dataset (Fig. 6), referring to previous sampling campaigns carried out by *Regione Toscana*, shows that superficial (about 20 cm) offshore sediments are finer and the average grain size distribution shows that finer particles bypass the Carrara Harbor under the effect of the longshore (NW to SE) drift (Fig. 6). This suggests that the final budget loss estimation includes silt and clay fractions that do not contribute considerably to the sedimentary balance of sandy beaches, because their deposition in shallow water is negligible.

4.2. Contamination level

The 2005 campaign also evaluated the contamination of the sediment through chemical and ecotoxicological analysis in the 67 stations (Fig. 7). At Carrara Harbor, as in every contaminated sites of national relevance, the Ministry of Environment established site-specific threshold levels for contamination, above which suitable reclamation measures have to be carried out (Intervention values in Table 1).

The contamination thresholds corresponding to suitable sediment management options have been updated through years. It has to be noted that from 2008 the disposal in the CDF is allowed even for sediments exceeding the threshold concentrations values for industrial soils, under prescribed condition for the impermeable facilities (*K*-coefficient $< 10^{-7}$ cm/s for at least 1 m of sediment thickness at the bottom and all around the structure) and including a risk analysis to allows the future use of the completed CDF (Italian Law n. 296/2006 art. 1, *comma* 996). The analysis of the sediment cores shows that the spatial distribution of contaminated sediments exceeding the intervention values within the Contaminated Site of Carrara is mainly related to the presence of Hg, Pb and DDT in the top most 100 cm within the Harbor basin and inlet (Fig. 7).

4.3. Time history of dredge-and-fill operations

The dredging operations and the consequent destinations of the sediments to be dredged in the Carrara Harbor area were authorized with 10 decrees by the Ministry of Environment and 2 additional projects by local administrations in 2000 and 2006. Details of the document's contents, chronologically sorted, are described as follow and represented in Fig. 8 and Table 2.

4.3.1. 1993

The decree 780/ARS/DI/AC/DR of 02 July 1993 authorized the Genio Civile per le Opere Marittime di Genova to dump offshore the capital dredging material of the Carrara Harbor. The sediment dumping authorization, upto a volume of 780,000 m^3, was valid for a period of 22 months. The dumping area, located 29 km offshore at a depth of 50 m, was about 1 km in diameter and was centered at the geographic coordinates: 43°53′N 09°44′E (Fig. 8a). A bathymetric survey carried out at the end of the dredging operation revealed that only 305,321 m^3 of sediments were removed from the

Fig. 5. This figure shows the sand (1) and silt (2) content of surficial sediments. Around the harbor area the sand content varies from a minimum of 40% (inside the harbor) to a maximum of 90% (downdrift) with an average value of 70%.

harbor basin (file n. 3050/MS Genio Civile per le Opere Marittime di Genova).

4.3.2. 1995

The decree 2151/ARS/DI/AC/DR of 01 March 1995 authorized the Genio Civile per le Opere Marittime di Genova to dredge and dump sediment from the Carrara Harbor in two different areas. Sediment dredged nearby the harbor quays was dumped in the same offshore area authorized by previous decree (780/ARS/DI/AC/DR in 1993). At the end of the project the Genio Civile per le Opere Marittime di Genova (file n. 3050/MS) stated that 85,956 m^3 were dredged from the central part of the harbor and the entire volume was dumped for shoreface nourishment at a depth of 5–7 m on the submerged beach of Marina di Massa, downdrift the Carrara Harbor, in order to replenish the coastal area that was affected by strong erosion (Fig. 8b).

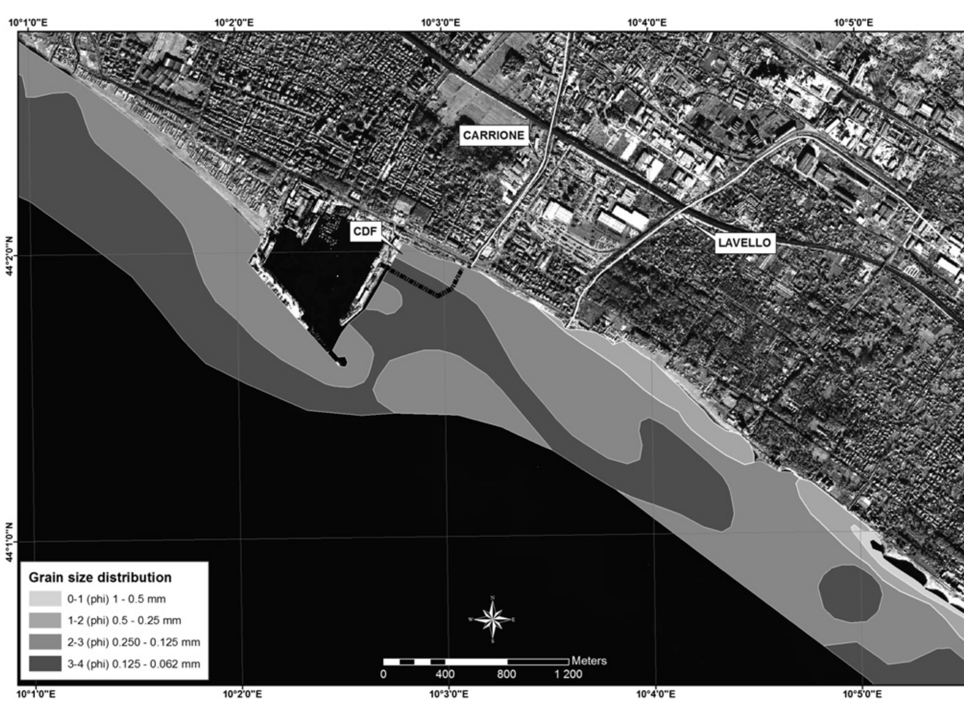

Fig. 6. This figure highlights the mean grain size of sediments in four different classes, showing that the area around the Carrara Harbor is characterized by fine sand (>0.062 mm).

Fig. 7. Spatial distribution of contaminants revealed after characterization carried out by Port Authority of Carrara Harbor in 2005. Gray areas indicates concentration above the intervention values for (a) Hg within level 0–50 cm; (b) Pb within level 0–50 cm; (c) DDT within level 0–50 cm; (d) within level 50–100 cm.

4.3.3. 1997

The decree 5334/ARS/DI/AC/DR of 17 January 1997 authorized the Genio Civile per le Opere Marittime di Genova to dredge about 100,000 m^3 of sediments from an unspecified “harbor area” in order to perform a shoreface nourishment. The dumping area was located in front of Marina di Massa beach, at a depth of 5–7 m (Fig. 8c). Such operation was confirmed afterwards by the decree 5519/ARS/DI/AC/DR of 27 February 1997.

4.3.4. 1999

In 1999, 101,500 m^3 of sediment were dredged within the harbor at different steps and were all dumped along the coast for shoreface nourishment.

The decree 11491/ARS/DI/AC/DR of 17 May 1999 authorized the Port Authority of Marina di Carrara to dredge 66.500 m^3 of sediments from the harbor and its navigation channel, in areas identified in Fig. 8d. The dumping area was located between Frigido River and Marina dei Ronchi (Fig. 8d). A second decree, ref. 12208/ARS/DI/AC/DR of 13 December 1999, authorized the Port Authority of Marina di Carrara to dredge 35,000 m^3 of sediments from the harbor (Fig. 8d). The dumping area is the same as indicated in the previous decree.

4.3.5. 2000

The decree 12800/RIBO/DI/AC/DR of 25 May 2000 authorized the Port Authority of Marina di Carrara to dredge 12,000 m^3 of sediments from a specific area located inside the harbor (Fig. 8e). Such material was used for shoreface nourishment, dumped in the same area indicated in the decrees of 1999 and for filling of the Buscaiol quay, located in the northeast part of the basin.

In addition, other 190,000 m^3 were dredged from inside the harbor and disposed into the Confined Disposal Facility (CDF) called “Piazzale Città di Massa” realized by the Port Authority to increase the available surface for handling and stocking goods (Fig. 8f). No decree is available for this operation as this project was not authorized by the Ministry of Environment, but only by local administration of Massa Carrara.

4.3.6. 2001

The decree 47/02 of 10 April 2001 authorized the Nuovi Cantieri Apuania S.p.A. to dredge and dump 2000 m^3 of sediment from the seafloor in front of their working area in order to launch a ship. Sediment was deposited close to the Buscaiol’s quay and then transferred in the “Piazzale Città di Massa” CDF (Fig. 8g).

4.3.7. 2002

The decree 340/3/02 of 12 September 2002 authorized the Port Authority of Marina di Carrara to dump 10,000 m^3 of sediments due to an emergency dredging action to re-establish the operational depth. Such sediments were dredged from the harbor inlet and dumped for shoreface nourishment in an area between the Carrione and Lavello rivers (Figs. 6 and 8H).

4.3.8. 2004

The Port Authority of Marina di Carrara required an emergency approval to dredge the harbor inlet to guarantee the operational depth for allowing the entrance of ships having a draft of more than 10 m. The decree DEC/DPN/1719 of 24 September 2004, authorized the Port Authority to dump 10,000 m^3 of sediment dredged from the topmost 0.4 m within the navigation channel. Such sediments should have been dumped at a depth of 16.5 m in an area of 0.3 Nautical Miles in diameter and centered at 43°58’30"N 10°01’30"E, but the Provincia di Massa Carrara (file no. DD/8685/2004 of 27 September 2004) authorized to dump sediment in a different area (Fig. 8i), already indicated by the decree DEC/340/3/02 of 12 September 2002, in order to carry out a shoreface nourishment.

4.3.9. 2006

The Port Authority of Marina di Carrara required another emergency approval in order to dredge 10,000 m^3 from the inlet (Fig. 8l).

Given the contamination of the sediment (Fig. 7), the only possible management, according to the recent national legislation (D.gls.471/99 and L. 152/06), has been the disposal of dredged sediments into an onshore landfill (file N. 2106/06 of 07 March 2006).

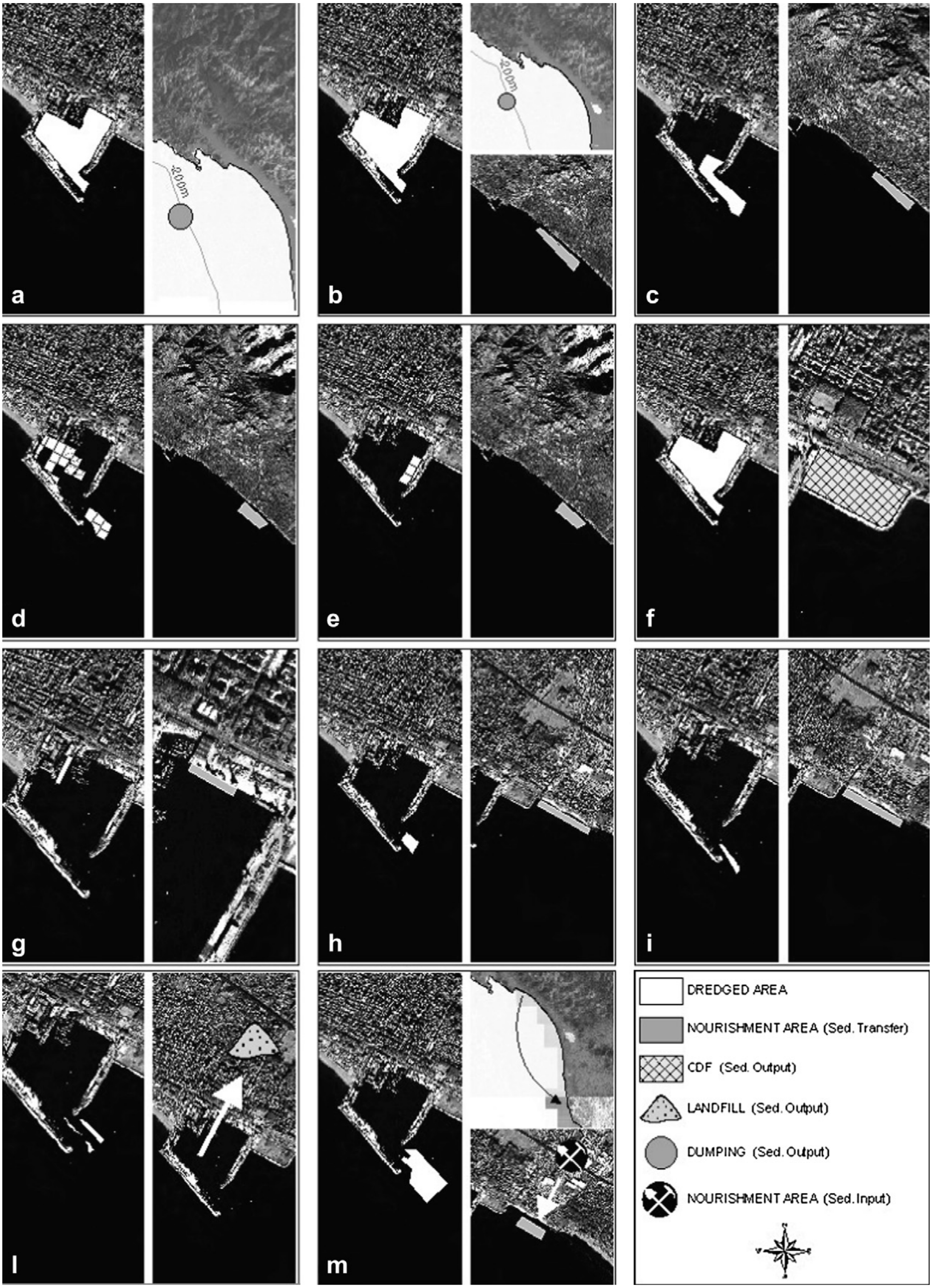

Fig. 8. Dredging areas (white) and destination sites (gray) used in: 1993 (a); 1995 (b); 1997 (c); 1999 (d); 2000 (e); 2000 (f); 2001 (g); 2002 (h); 2004 (i); 2006 (l); 2007 (m).

Table 2
References, years, dredging and destinations volumes. Please note: only in 2007 the sediment output of 25,000 m^3 has been compensated by a shoreline nourishment of the same volume.

Reference	Year	Dredged volume (m^3)		Destination (m^3)			
				Sediment transfer and input	Sediment output		
		Basin	Inlet	Shoreface nourishment	Offshore dumping	CDF	Landfill
Dec. 780	1993	305,000			305,000		
Dec. 2151	1995	86,000		86,000			
Dec. 5334	1997	100,000		100,000			
Dec. 11491	1999	66,500		66,500			
Dec. 12208	1999	35,000	–	35,000			
Dec. 12800	2000	12,000	–	12,000			
CDF project	2000	188,000				188,000	
Dec. 47/02	2001	2000	–			2000	
Dec. 340	2002	–	10,000	10,000			
Dec. 1719	2004	–	10,000	10,000			
File 2106/06	2006	–	10,000				10,000
Dec. 4010	2007	–	25,000	25,000		25,000	
Total		849,500		344,500	305,000	215,000	10,000

4.3.10. 2007

In the most recent decree (file N. 4010 of 18 October 2007) the Ministry of the Environment authorized dredging of 25,000 m^3 from the inlet. Due to the presence of an irregular, but diffuse contamination in the dredged material (Fig. 7), the entire volume was disposed in the CDF of the Livorno Harbor.

The same volume of well-matched uncontaminated sand was taken from an upland quarry and dumped for shoreface nourishment in the area indicated by the 2004 decree between Carrione and Lavello rivers (Figs. 6 and 8M).

4.4. Calculations pertaining to the sand deficit

The authorization documents, the chronology and the volumes of dredging interventions inside the harbor basin and at the harbor inlet are summarized in Table 2.

From this data, it can be demonstrated that, from 1993 to 2008, the dredging of 1.300,500 m^3 of sediments has been authorized. However, the volume that has been dredged, on the basis of the dredging works documents, is 850,500 m^3 (Table 2), for an average value of 56.7 m^3/y, considering the 1993–1995 capital dredging.

The dredged material has been managed in four different ways: (1) shallow water disposal for shoreface nourishment; (2) offshore dumping; (3) filling of Confined Disposal Facilities and (4) placement in onshore landfill.

Only option 1 is considered as a sediment transfer within the sand-sharing system, because the dumping was carried out within the estimated closure depth, which in the present study is calculated at about 7.7 m. This value is the minimum value estimated also by De Filippi et al. (2008) for the same physiographic unit at the Magra river mouth, while the same authors estimate a maximum depth of about 14 m.

The need for frequent dredging is strictly related to the filling of the harbor inlet (Fig. 8) as in the last years the phenomenon was so prevalent to not allow the entrance of ships having a draft of more than 10 m.

Options 2, 3, and 4 are considered as sediment outputs because, once dredged and put in Confined Disposal Facilities, or dumped 29 km offshore, sediments can definitely be considered subtracted to the sedimentary budget of the littoral cell.

The volumes corresponding to the different management options are summarized in Fig. 9.

Most dredged material was placed outside the coastal sand-sharing system: the authorized volume for dredging and offshore dumping is nearly 300,000 m^3, while the volume designated to fill in the CDF is 215,000 m^3 (190,000 m^3 to the CDF named "Piazzale Città di Massa" and 25,000 m^3 to the CDF of Livorno).

The calculated deficit due to disposal of dredged sediment outside the sand-sharing system during the study period is shown in Fig. 10. The large-volume interventions, carried out in 1993–1995 and 2000, hadn't been replaced completely by later nourishments. This is clear from the sub-parallel trends of the cumulative curves shown in Fig. 10.

5. Discussion

The created databases provide a record of dredging and sediment placement activities over the last 17 years. It is complete enough to examine both the different management options as well as the cumulative effect on the sand-sharing system. In particular, the integrated database considers both local and national managed authorization (including specific ones done for beach nourishment

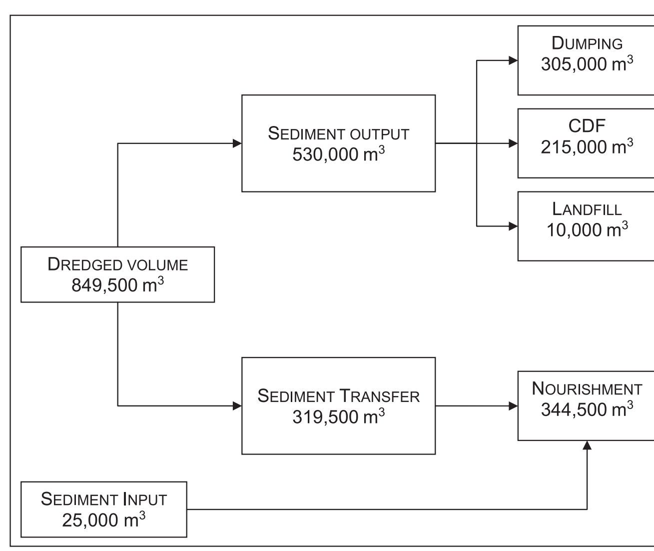

Fig. 9. Schematic diagram showing a summary of the sediment management which has occurred at the Carrara Harbor. Note that the sum of sediment input, sediment transfer and sediment output (869,500 m^3) is greater than the sediment dredged between 1993 and 2008 (849,500 m^3), because the ministry of Environment has recently required the Port Authority of Marina di Carrara to balance the transfer of sediment (25,000 m^3) from the navigation channel to the CdF with a beach nourishment project of the same volume.

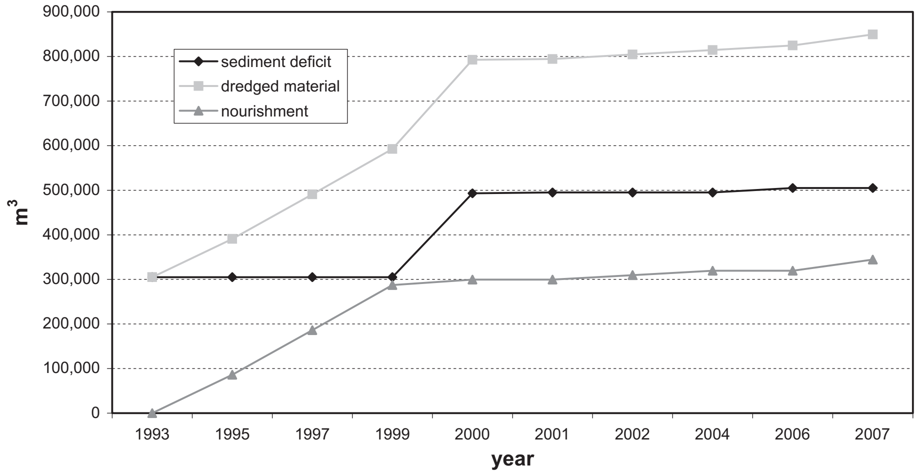

Fig. 10. The sedimentary deficit caused by the recent dredging of the harbor inlet to a depth of 10 m and delivery of the sediment to a CDF. Also shown are records of dredged material transferred annually during the last century via dredging activities associated with harbor and channel construction and maintenance as well as beach nourishment.

or harbor and inlet deepening combination). The results prove different solutions that usually lay hidden by the different data source, due to the fact that national and local Administration have different database related to their specific institutional responsibilities, and highlights that the filling of CDF, an increasing management option in Italy (and Europe), is contributing to the deficit of sediment budget along Apuo-Versilian Coast, due to the presence of contamination's hot spots.

5.1. *History of sediment management and quantification of infilling process*

In the reference period, through the estimation of dredged volumes and relative management options, the sediment losses from the littoral was calculated.

The last four dredging interventions out of 12 were carried out only at the harbor inlet, suggesting that, if the harbor inlet trapped the whole longshore sediment transport around the Carrara Harbor, it could be estimated at 10,000 m^3/y. This result has been confirmed by the estimates of Port Authority of Marina di Carrara, which indicate dredging rate, at the harbor inlet, from a minimum of 5000 m^3/y to a maximum of 25,000 m^3/y, with an average value of about 13,000 m^3/y (Contini et al., *pers. comm.*, 2006).

Such findings are necessary to aid planning harbor layout variations compatibly with sedimentary circulation (Van Rijn, 1991) and suggest that the methodology adopted in the present study form the basis for the Authorities that need to plan both overall shoreline management and harbor development.

5.2. *Restriction on sediment management due to contamination*

Given the volumes handled to maintain the size (width and depth) required for channel access, two issues has to be considered: (i) the recent restrictions indicated by new legislation (Italian Law 471/1999, confirmed by L. 152/2006 and L. 296/2006 art. 1, *comma* 996) that will reduce the chances of beneficial sediment's use and (ii) an high cost of chemical, physical and ecotoxicological characterization that leads to a longer time to complete dredging interventions. Based on these issues and on the spatial distribution of contaminants inside the Carrara Harbor, the inlet-dredged sediments are often subtracted from the littoral sedimentary budget, contributing to coastal erosion. This scenario will be even worse in the future for the following reasons.

Given the contamination level of the sediment, dredged material can be managed as waste and the management options, available under current and rapidly evolving legislation, are the filling of a CDF (in this case the CDF of Carrara – in 2000 – and Livorno Harbor – in 2007 – which is 57 km to the south) or a landfill (file 2106 of 2006 and n. 4010 of 2007; Fig. 8l and m). The decisional process of these two management strategies was set in a first law frame only in 1999 (First National Program on Land Reclamation). As a result, in the disposal authorizations, and not only at the Carrara Harbor, offshore dumping is a solution that is no longer favored because many Port Authorities are expanding existing layouts and allocating contaminated sediments into CDF that are used for different purposes once completed (i.e., handling or storage areas). In this way, both cleanup interventions and enlargement of existing infrastructures are allowed. Since 2006, due to contamination recently explored in Carrara according to the *Reclamation Program*, sediment dredged from the basin and the inlet cannot be used for beach nourishment and sometimes they cannot even be disposed into a CDF (file N. 2106/06 of 07 March 2006). To mitigate negative consequences of such restrictions and guarantee the economic development of harbor activities as well as coastal conservation and tourisms, a scientifically based management approach need to be adopted.

5.3. *Factors influencing sediment management in Carrara*

In general, seafloor sediments inside harbor basins can represent a "potential resource" that can be exploited, following the directives of the environmental laws in force, even for nourishment (the most feasible management option). This option is particularly recommended when the downdrift coast has sediment deficit and the shoreline retreat is exposing people to a higher risk of flood or when natural habitats, like coastal dunes, are suffering severe damage. Therefore, instead of exploiting offshore sand pits, the sediments dredged from harbor basins, compatibly with their physical, chemical, biological and toxicological characteristics (Pellegrini et al., 2002; European Sediment Network, 2010), can contribute to re-establish the sedimentary balance within each littoral cell (Pranzini, 2004).

For example if the sediment dumped offshore after the capital dredging carried out in 1993 (300,000 m^3) was used to nourish the downdrift beaches, their erosion rate could have been significantly reduced. Basically, it can be stated that nourishment management options in Carrara must be considered the most favorable to reduce the impact of sediment output even if, in the last four years, it was not considered due to restrictions imposed by the recent National Program of Land Reclamation.

Unfortunately, the excavation of the accreting, "uncontaminated", updrift beach, no matter if it is created by material that could not reach the downdrift side, is another option that can hardly be considered because the physiographic unit or the littoral cell does not correspond with the administrative limits of different local stakeholders. This is mainly due to the disagreeing local Authorities that have not been able trough time to dredged sediment updrift before they spilled over the inlet of Carrara Harbor and get contaminated by hot spot. The emergency conditions caused by reduced draft at the entrance of the Harbor does not allow safe navigation and impose to apply emergency action without a long term management scheme.

Another factor influencing the sediment management in Carrara is the economic value placed on beaches (in Italy it ranges from 800 €/m^2 to 2500 €/m^2; according to NOMISMA, pers. comm.), which creates strong local interest in the short term evolution of the shoreline (Fischer, 1990; Landry et al., 2003; Pendleton and Kildow, 2006). Therefore, bottom–up decision making process contrasts with the long term and large scale management of littoral sediments within the physiographic units.

Based on our interpretation, we can state that a solution that would allow sediment to completely bypass the Carrara Harbor would be the best option, as it would lead towards an equilibrium condition where no operational dredging would be required to maintain the inlet depth, but changing the present harbor layout extending the breakwaters offshore and streamline the inlet, as seen in some Danish harbors (Broker et al., 2007), would imply a massive enlargement of the harbor structures. The state-of-the-art design criteria should include the analysis of the influence that a coastal structure can have on the littoral drift, studying if and how the coastal sediments could bypass the structures (Soulsby, 1997; Van Rijn, 1991; Van Rijn et al., 2005) but the design of a new Carrara Harbor's layout, able to mitigate local conflict, is still an unresolved issue that is beyond the aim of the present study.

5.4. Policy making and future development for the compensation strategy and nourishment

Due to the reluctance of the local authorities to set a long term strategy to dredge updrift uncontaminated sediments, the Ministry of Environment in 2007, based on our findings, adopted the compensation strategy as a top–down approach to nourish downdirft beaches exposed to erosion every time that dredging of sediment around the port leads to a sediment output from the sand-sharing system. Many factors and restrictions influencing sediment management in the study area, where co-governance between central and local authorities is not successful lead the top–down approach adopted by Ministry of Environment to be an effective policy making to mitigate coastal erosion even it is applied for small dredging operation ($<$50,000–100,000 m^3). In fact, according to WL Delft Hydraulics (2006), it is estimated that a sand nourishment requirement of about 30,000 m^3/y is necessary until 2035 in order to maintain the overall 2005 shoreline position downdrift of the existing coastal protection scheme.

Anyway, a compensation strategy imposing downdrift nourishment when dredging generates sediment output has to be further investigated as the long term as well as large scale sustainability of such criteria require further understanding.

Estimation of the sand volume available offshore and inland, cost/benefit analysis of characterization and transport (including CO_2 emissions related to the transfer of sediment) are some of the topics under investigation by the authors. One of the main concerns is the applicability of such a compensation criterion in cases of capital dredging, particularly in cases where large scale (hundreds of thousand of m^3 of sediments) are involved. Will it be possible for the Port Authorities to find and buy suitable sand from sites close by? How long it will take to complete the required nourishment for compensation? Will it be possible to negotiate access to areas required for nourishment with the local authorities and other stakeholders? Should planning management have a bottom-up or a top–down approach?

In terms of Integrated Coastal Zone Management these issues are particularly important because they allow sustainable development of coastal infrastructures and tourism and these principles are in line with EU recommendations, Barcelona Convention and the recent legislative proposals presented to the European community by the partners of the programme Beachmed-e (2010).

We can argue that the planning of long term strategy in sediment management can be viable only under a well defined law frame (i.e., the Law tool proposed by Beachmed-e partners to the European Community). In fact, there is no law that regulates the eligibility criteria for marine sediment dredging and management. This is dramatically evident for nourishment intervention: even if it is obvious that sediment characteristics varies from site to site both chemically and physically, the authorities still do not have a decision making tool to regulate nourishment interventions and often technicians are called to assume responsibilities for the legislator. There have been some cases in Italy in which, to avoid legal problems, the technicians have given too restrictive limitations (even about the sand color) for nourishment material characteristics. The regulatory Authority wasn't able to find such materials at an affordable cost to the community; therefore, the necessary nourishment has not been carried out. This is partially due to restrictions imposed by the National Program of Land Reclamation (like others) that are not easily accepted by the regional authorities that are in charge of authorization procedure for beach protection and restoration.

In summary, we believe that implementation of a clear and simple law is essential to avoid that divergences of Authorities on Land and Marine Spatial Planning could affect technical and scientific issues of coastal management. That is to say that what is required to make the downdrift compensation nourishment strategy a winning option is the definition of the normative frame reference for sediment management that considers all the scientific activities and knowledge of marine geologist (sedimentary resources), biologists and ecologists (environmental restrictions and impact of human activities), coastal engineers (hard and soft defense strategies) and the policies on the use of the sea (local and national authorities).

6. Conclusion

A comprehensive study, including bibliographic research, database implementation and GIS elaboration was carried out in order to quantify the impact of dredging on the sediment budget of the Marina di Carrara littoral cell considering the authorizations for sediment management and the sedimentary characteristics in a specific period (1993–2008). The method used in the present study is straightforward, but the results are extremely useful to quantify the annual sedimentation rate at the harbor inlet and to estimate the sediment deficit due to the disposal of sediment out of the sand-sharing system.

The Carrara Harbor will always need periodic dredging in order to maintain the inlet depth at 10–12 m, considering that the natural equilibrium depth of the harbor inlet would be about 7 m, a value close to the minimum estimated closure depth.

In Italy the Port Authorities were established in 1994 (Law 84), but the Port Authority of Marina di Carrara has been charged with seabed maintenance and dredging only since 1999. Starting from the year 2000, the introduced nourishment option made possible to reduce the impacts of dredging required to maintain the depth of the navigation channel of the Carrara Harbor to ensure safety of navigation (−10.5 m). But dredged sediments have been only partially used for downdrift nourishment, with a rate of 21,300 m^3/y. In the year 1993, the capital dredging and consequent offshore dumping and then, in the year 2000, the disposal into the CDF amplified the sediment deficit.

Starting from 2006, the application of strict limitations on reuse of sediment within contaminated sites of National Interest made the community think about the risk of worsening erosion.

Based on the method presented herein, an effort to reduce the impact of the sediment loss within the Versilian Coast was made by the 2007 authorization of the Italian Ministry of Environment. It includes an important obligation: the 25,000 m^3 of sediment dredged at the harbor inlet has to be “compensated” by downdrift nourishment of the same (or higher) volume. Even though the volume nourished in 2008 (25,000 m^3) did not totally equate the overall sediment deficit of about 520,000 m^3 accumulated in 17 years of not sighted sediment management, the schedule of nourishment planned to meet the compensation criteria is expected to improve, or at least to balance the eroding evolutionary trend of the downdrift beaches. The 2007 compensation criteria represent an innovative policy initiative, based on scientific results that could be applied by other jurisdiction.

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