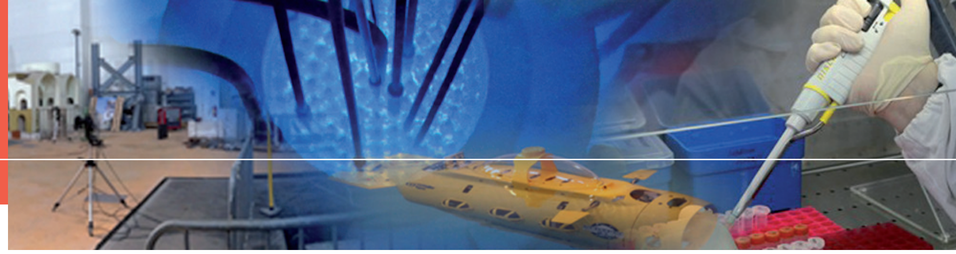

Characteristics and possible reuse of Favignana Harbor's sediments

Italy is a country with a high coastal development where multiple activities are located in sites near the coast, which makes the handling of marine sediments a topic of particular interest and socio-economic importance. At present, the excavation of the seabed and the subsequent discharge of resulting materials into the sea represents a risk due to the possible spread of contaminants in the ecosystem. National and international legislation has recognized the immersion of contaminated material into the sea as an event of perturbation to the environment while promoting alternative management options and introducing the concept of sediment as a "resource" and not as a "waste". There is a wide range of treatment technologies available and they significantly influence the reuse of dredged material. In the present work, a site-specific conceptual model of the small harbour of Favignana is presented and, on the basis of some preliminary analytical tests on superficial samples, the assumptions of management options are predicted. One of them is particularly interesting as it could be applied to other cases where, for reasons of safety of navigation, small volumes of slightly contaminated sand (less than 25,000 m^3) must be dredged and, after removing chlorides, they may be used on land to create sporting centres and increase tourist capacity

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S. Cappucci, F. La Marca, R. Ferrantini, M. Maffucci

Introduction

Sediments are suspended or deposited solids, acting as a main component of a matrix, which has been, or is susceptible to being transported by water [1]. With the raise of tourist flows, sediment is becoming an important natural resource for the economic development of many countries, and its correct management is playing a crucial role in the environmental, social and economic sectors (Figure 1).

From the social point of view, sediments form beaches and are distributed along coasts. So, their abundance strongly influences the capability to contrast flooding, in order to facilitate recreational and cultural events. From the economic point of view, especially in small islands, the accommodation capacity of tourists is affected by the number of berths, the safe navigation within harbor that should not be affected by siltation [3, 4]. From an environmental perspective, the sediments also play a vital role in the health of aquatic ecosystems as a result of interactions with pore water and the water column

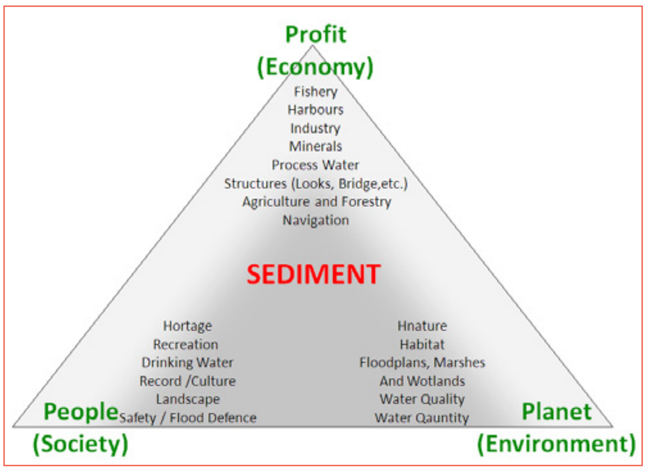

FIGURE 1 The three fields of sustainable development and their interaction in relation to sediment. Modified from [2]

Contact person: Sergio Cappucci
sergio.cappucci@enea.it

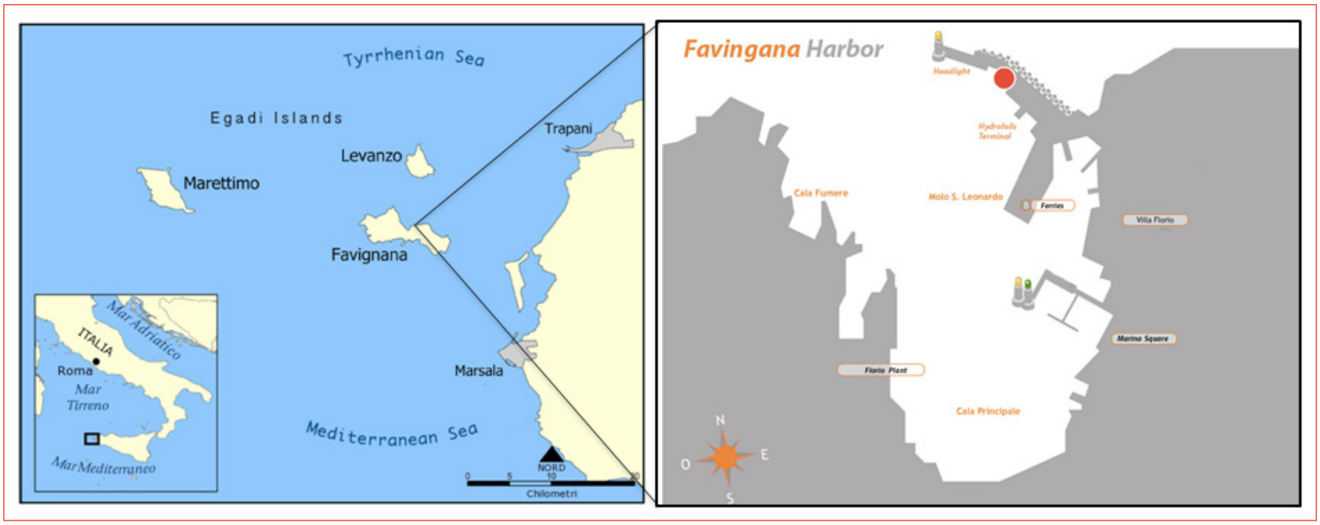

FIGURE 2 Egadi archipelago and Favignana Harbour

above them due to the direct contact of many aquatic organisms and following food web.

However, once present in water bodies, pollutants tend to be absorbed by particulate matter and to settle onto the bottom. Such process generates the formation of contaminated sediments, defined as "*soil, sand, minerals and organic matter accumulated on the bottom of a water body and containing toxic or hazardous substances at levels that may cause adverse effects on human health or the environment*" [5]. Accumulation of contaminants within sediments can derive from natural or anthropogenic sources. The natural mechanisms are identified with volcanic eruptions, forest fires, the biosynthesis performed by plants or bacteria and all phenomena that exclude human impacts. However, natural processes can lead to concentration exceeding the threshold of contamination defined by national legislation. In some sites, such abundance establishes a reference value of natural background. Anthropogenic sources, however, are represented by all the activities that produce and/or use toxic or harmful substances and that can affect the ecosystem in which they are issued [6]. Anthropogenic contaminants may enter the aquatic environment through punctual sources, such as industrial or civil discharges, or from diffuse sources, such as runoff, erosion of farmland treated with pesticides and atmospheric deposition. For this reason, the conceptual model of contamination is the preliminary part of the process of investigation and remediation of the seabed.

The Italian current legislation is based on the Legislative Decree no. 1 of 24th January 2012 (converted into Law no. 27 of 24th March 2012), in which Article 48 is referred to "Dredging Rules" and re-writes the previous detailed regulations regarding dredging, regulated by art. 5 of Law no. 84 of 1994 [7, 8, 9]. While the legislation tends to mitigate the environmental impact derived from the movement of sediments in the coastal marine environment, there are still strong references to the prevention of the disposal of dredged material that should be applied to harbour areas without the need to remove sediments at the points where they are most polluted, which often coincide with navigation channels, or internal parts of the harbour, where hot spot are more abundant. Security issues and maintenance dredging should be authorised with simplified procedures, while we still suffer to adopt best practices for sediments management in relation to low levels of contamination.

The goal of ENEA was to implement a management model of harbour sediments, which, after characterization and possible treatment, may find reuse avoiding landfilling. This strategy combines the need to avoid the silting of coastal infrastructures, ensure the maintenance and permit the transit and mooring of vessels, in order to provide the tourist industry with a valuable natural resource through periodic excavations of the bottom in compliance with the classification regulation concerning water, waste and soil [10], as well as the legislation relevant to dredging, like art. 48 of the Italian legislative decree of 24th January 2012 [7].

Favignana Harbour

The Favignana Harbour (Figure 2) is developed in the sheltered inlet of Cala Principale (north central area of Favignana Island). It is equipped with a pier about 110 m long, which extends to north-west. The smaller Molo S. Bernardo stretches for about 85 meters in a southerly direction. About 100 berths are available, 30 of which dedicated to boats of travellers/ navigators. On the seabed the *Posidonia oceanica* meadow is present. The harbour of Favignana Island is located in the Marine Protected Area, defined as "*the buffer zone between the valuable natural areas and external unprotected areas, where the activities of enjoyment and sustainable use of the sea of low environmental impact are permitted*".

Methods

Based on the complexity of sediments management and the need to guarantee periodical dredging, as well as to sustain tourism in the area (harbour, sports activities and versus municipalities and tourist operators), a simple and straightforward method was implemented in four steps:

- implementation of conceptual model;
- sediments characterisation;
- technical and economic analysis of remediation technologies;
- classification of sediments and management scenarios.

Due to the low level of contamination of the Marine Protected Area and the limited extension of the harbour layout (i.e., volume to be dredged), the following assumptions have been made:

- variation of contamination level with depth is modest. It means that characterisation of superficial sediment has been carried out to reduce the cost of sampling and laboratory analysis in the first exploratory phase of the work;
- on-shore management options have been taken into account. So, the bioavailability and effects of contamination on marine organisms have been ignored as dredged material will not be in contact with coastal marine water bodies, if reused.

Implementation of conceptual model

Since marine sediments are potential targets of intentional or accidental contamination, a detailed conceptual model has been implemented. Four main contamination sources were identified around the harbour basin and, for each of them, a specific schedule of production activities was compiled: (1) Florio's factory; (2) Gas station; (3) Waste Water discharge; (4) Boat repair (*Camperia*); see Figure 3. For each of the potential source of contamination, the transfer model and the final target have been identified. The conceptual model is based on site-specific reconstruction and the description of the contamination transfer model. For each source, a schematic table describes the route of transfer of potential contamination and the following information:

- Name of the company;
- Site and type of business/production;
- Description of the area;
- Hydrogeological description;
- Type of pollutants (current and previous activities);
- Conceptual Model (sources, transfer and targets);
- Results of preliminary analysis of soils, land, groundwater, marine waters.

FIGURE 3 Florio's factory (green); Gas station (red); Waste Water discharge (purple); Boat repair (orange)

Sediment characterisation

A preliminary characterisation was carried out by analytical investigations (of chemical and physical parameters), considering only superficial sediments collected in four sampling stations deemed as representative of the harbour area having extension of about 100x90 m. The main goal of the characterization of sedimentary bodies potentially contaminated is to determine the spatial distribution (horizontal and vertical) of the concentrations of contaminants within the identified critical areas. It is very useful to define the most appropriate remediation strategies. Another set of objectives can be pursued through characterization, such as:

- textural characteristics of the material;
- possible relationship between the distribution of contaminants and grain size of the particles;
- thickness of the sedimentary layers and the morphology of the rocky substrate;
- bioavailability and effects of contamination on marine organisms and their possible transfer;
- concentration of the contaminants along the water column in sensitive areas;
- natural or anthropogenic origin of trace metals, particularly in areas where there are geological formations with abnormal levels of them.

In the present work we have chosen a deterministic strategy [11, 12], which provides the positioning of sampling stations in areas where accumulation of pollutants takes place. Four sampling stations were chosen near the dock in front of Piazzale Marina (Figure 4), which is the first barrier hindering the deposition of coastal sediments. Frequent siltation of the structure is due to the anticlockwise circulation inside the harbour generated during mistral winds.

A Van Veen grab (bucket-type) with a capacity of about 5 liters was used for sampling of superficial sediments. Samples were then collected from the bucket using sterile polystyrene/glass containers and stored in the refrigerator at 4 °C until laboratory analysis.

The physical analyses were conducted at the "Laboratory for the Exploitation of Raw Materials and Fluids" of Sapienza University of Rome. Grain size distribution was determined by using the UNI EN 933-1 method, through sieves type ASTM (American Society for Testing and Materials) E 11-70. Mesh sieves with light 1000 μm, 500 μm, 250 μm, 180 μm, 125 μm, 63 μm and 38 μm have been used. All particle fractions were subsequently dried at 105 °C, weighed and classified.

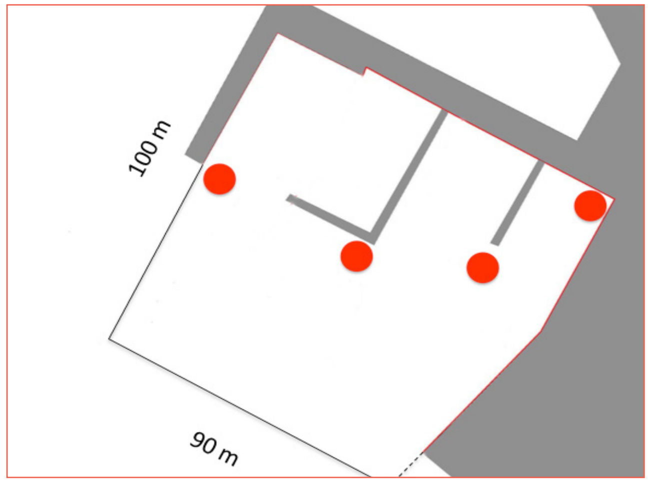

FIGURE 4 Sampling strategy for characterisation of about 10,000 m^2 of harbour seabed

The chemical analyses were carried out at the "Laboratory for the Exploitation of Raw Materials and Fluids" of Sapienza University of Rome, with regard to heavy metals determination, and at the laboratory of the Technical Unit Characterization, Prevention and Environmental Remediation (UTPRA/GEOC) of ENEA Casaccia Research Centre, for TBT, PAHs, PCBs and hydrocarbons (C > 12) determination. No microbiological analyses were performed on the samples. A detailed description of the methodology used is reported in the work of Ferrantini [13].

Technical and economic analysis of remediation technologies

A detailed technical and economic analysis of the treatment and remediation technologies was conducted on the basis of literature review [14], budget estimation (market research) and results of tests carried out on other contaminated sites. The most reliable sources of data and information have been catalogued, classified and, for each technology, a range of costs was determined.

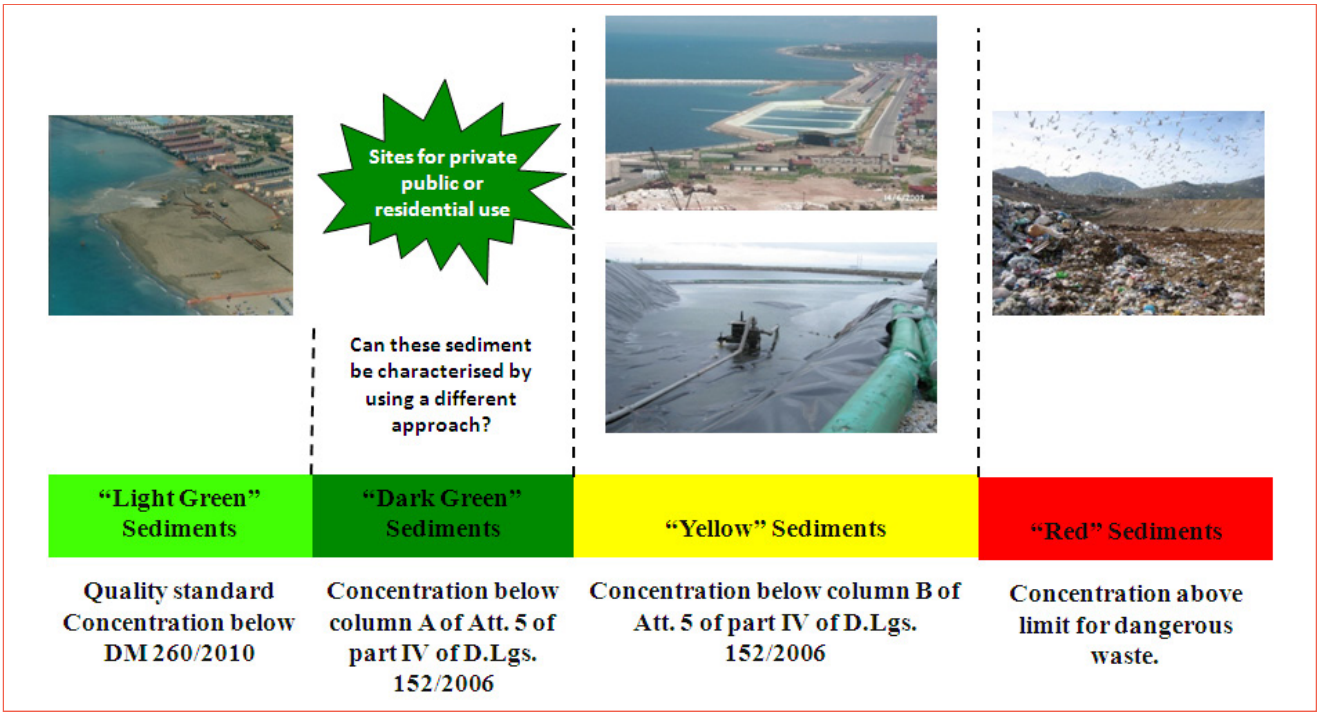

FIGURE 5 Frequent sediments management options in relation to different thresholds of contamination

Classification of sediments and management scenarios

Classification of sediments and management options are related to their level of toxicity and contamination. Usually three different colours are adopted to show with "green", "yellow" and "red" sediment dredged material that can be respectively used for beach nourishment, or disposed within Confined Disposal Facilities and landfill. In the present paper, a new "dark green" colour is adopted for sediment that shows contamination values between the quality standard suggested for coastal water directive (DM260/2010) and the contamination standard indicated by column A of Att. 5 of D.Lgs 152/2006. A schematic management option scheme is reported in Figure 5.

At the end of analytical investigation, the material has been classified by identifying exceedances of the thresholds for green areas and public housing. From available information a preliminary draft has been prepared, taking into account the outcome of various scenarios resulting from a more detailed environmental characterization. A detailed review of technologies available for the remediation of contaminated sediments has been conducted, and some of them were considered eligible for the case study. In the present paper, all the steps required to implement the dredging operations were considered, as follows:

1. Boundaries of the harbour;
2. Preparation of the characterization plan;
3. Sample collection;
4. Analytical investigations;
5. Processing of the obtained data;
6. Dredging and transport;
7. Storage and handling;
8. Checks of bottom depths after excavation;
9. Dredging of hot spots;
10. Cost-benefit analysis of different scenarios for sediment reuse.

Results

Conceptual model

The implementation of the conceptual model allowed to identify four potential sources of contamination, facing the harbour basin: the gas station in front of the quay, the Florio industries where tuna processing was performed, the *Camperia*'s building (where boats storage and maintenance was performed and, finally, a discharge of untreated wastewater. A flow diagram of conceptual model for contamination is reported in Figure 6.

Sediments characterisation

The characterisation of superficial sediments allowed to determine both physical and chemical properties of particles. The grain size revealed a percentage of silt and clay of about 1% and a D_{50} of approximately 0,215 mm (Figure 7). The analytical tests detected a moderate exceedance of limits, indicated in columns A and B of Annex 5 to Part IV of Legislative Decree no. 152/2006, for Cadmium, Arsenic, Lead, Tin, IPA and TBT. The exceedances have led to classify sediments with "yellow" color, i.e. with values of analytical tests that fall within the 90% limit imposed by the column 5 of Annex B to Part IV of Legislative Decree no. 152/2006 (Table 1) [15].

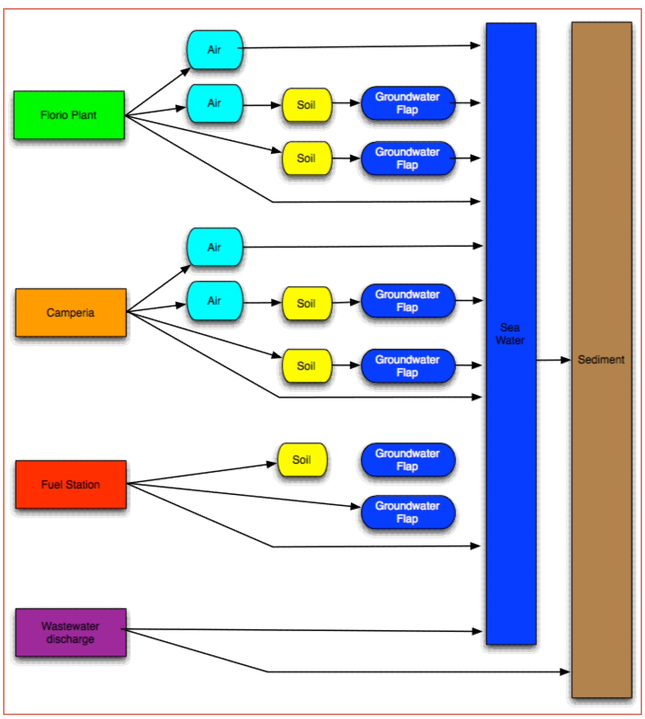

FIGURE 6 Conceptual model of contamination for sediments within Favignana's Harbour

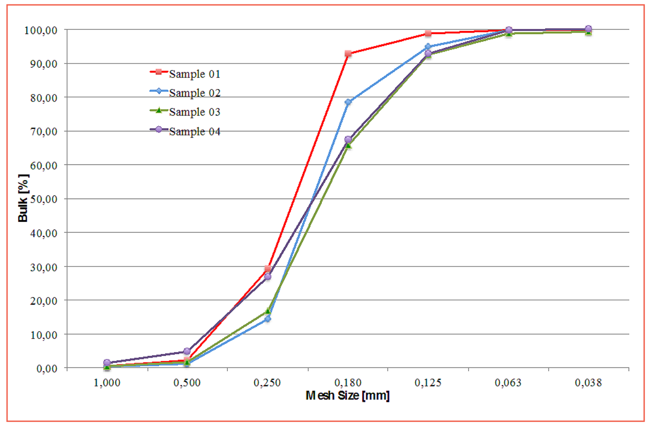

FIGURE 7 Cumulative grain size determined for each of the all 4 samples

Technical and economic analysis of remediation technologies

In the present work, the list of technologies considered are biological, physical-chemical and electro-thermal. The most common know-how is organised following the approach proposed by Bortone and Palumbo (2007), in order to identify the Best Available Technologies (BAT) for each different treatment approach. A summary of results is presented in Table 2, which shows the range of costs in €/m^3 and possible investment costs.

Classification of sediments and management scenarios

A preliminary project was prepared in order to allow the local authorities to allocate the necessary budget for dredging operations within Favignana's Harbor according to the procedures indicated by the national legislation (e.g. characterisation of sediment up to 1-2 m of depth). The project considered all phases of sediment removal and management, and particular attention was given to the presence of protected marine species, such as *Posidonia oceanica* meadow. Therefore, two options were identified, considering different volume

		Sample 1	Sample 2	Sample 3	Sample 4
Arsenic (As)	(mg/kg)	16,0	10,0	15,0	15,0
Cadmium (Cd)	(mg/kg)	1	1,0	1,0	1,0
Chromium (Cr)	(mg/kg)	3,1 ± 0,3	3,5 ± 0,2	3,4 ± 0,2	3,5 ± 0,2
Copper (Cu)	(mg/kg)	4,5 ± 0,3	6,7 ± 0,1	3,6 ± 0,3	4,0 ± 0,1
Mercury (Hg)	(mg/kg)	0,014 ± 0,2	0,015 ± 0,2	0,015 ± 0,2	0,013 ± 0,2
Manganese (Mn)	(mg/kg)	24,3 ± 0,7	25,1 ± 0,4	22,1 ± 0,5	22,2 ± 0,5
Nichel (Ni)	(mg/kg)	4,0	3,0	3,0	7,0
Lead (Pb)	(mg/kg)	51,9 ± 3,9	27,3 ± 3,7	24,1 ± 4,2	16,8 ± 1,9
Pond (Sn)	(mg/kg)	7,0	13,0	7,0 ± 1,3	10,0
Zinc (Zn)	(mg/kg)	5,5 ± 0,1	5,3 ± 0,2	5,4 ± 0,2	6,1 ± 0,1
Σ PCB	(mg/kg)	0,00188	0,00168	0,00198	0,00314
Hydrocarbons > 12	(mg/kg)	20,50	17,90	14,10	15,10
TBT	(mg/kg)	0,013	0,002	0,003	0,002
Naphthalene	(mg/kg)	0,02047	0,01934	0,05532	0,00172
Acenaphthylene	(mg/kg)	0,00366	0,00317	0,01107	0,00033
Acenaphthene	(mg/kg)	0,00266	0,00157	0,00201	0,00280
fluorene	(mg/kg)	0,00466	0,00548	0,03512	0,00203
Phenanthrene	(mg/kg)	0,08615	0,08095	0,95973	0,04596
Anthracene	(mg/kg)	0,02237	0,02621	0,31414	0,01595
Fluoranthene	(mg/kg)	0,15712	0,19309	1,38100	0,08831
Pyrene	(mg/kg)	0,12960	0,16220	1,21418	0,07168
Benzo (a) Anthracene	(mg/kg)	0,08118	0,11568	0,49921	0,05538
Chrysene	(mg/kg)	0,08605	0,12345	0,50628	0,06198
Benzo (b) Fluoranthene *	(mg/kg)	0,10484	0,13916	0,57700	0,07399
Benzo (k) Fluoranthene	(mg/kg)	0,04437	0,06000	0,22512	0,03077
Benzo (a) Pyrene	(mg/kg)	0,11939	0,15600	0,80023	0,07965
Indeno (1,2,3-c, d) Pyrene	(mg/kg)	0,05606	0,06779	0,31878	0,03753
Dibenzo (a, h) Anthracene	(mg/kg)	0,01749	0,01837	0,06260	0,01053
Benzo (ghi) Perylene	(mg/kg)	0,05075	0,06078	0,28455	0,03356
Σ PAH	(mg/kg)	**0,98682**	**1,23324**	**7,24635**	**0,61218**

TABLE 1 Concentration of contaminant determined in samples

of sediment to be dredged (option 1: 22,000 m^3; option 2: 12,400 m^3), different level of contamination ("green" or "yellow" sediments), and possible presence of about 50% in volume of biomass buried below the sandy seabed [16, 17]; Figure 8.

Subsequently, four management scenarios based on beneficial reuse of sediments were predicted; all of them exclude landfill disposal. For each management scenario, a cost-benefit analysis was prepared, considering several information and results of specific quotation in order to determine reliable costs of:

- Characterisation, (characterisation plan, sampling, analysis and data elaboration);
- Dredging (mob de-mob, turbidity curtains, monitoring and after-dredging analysis);
- Transport (capacity load of trucks, daily rent of vehicles and number of trips);
- On-shore deposit (preparation, impermeabilisation);
- Treatment (soil washing, land farming);
- Other costs (safety, taxes and unexpected costs).

So, the following scenarios were identified in order to have an economic, social and environmental advantage (Figure 8). They can be briefly described as follows:

A - Sport Facilities: execution of an area dedicated to sports activities, such as beach volley and/or beach soccer;

B - Coastal restoration: accommodation of sediments at the cliff's foot along 110 m of back shore;

C - Harbour layout: building of a Confined Disposal Facilities (CDF) in order to spill over the dredged contaminated sediments and enlarge the current Harbour layout;

D - Sediment sale: sale of dredged sediments to proper industrial sectors.

Discussion

Dredging within Favignana's Harbour is periodically needed to ensure the safety of navigation and an adequate depth through time. With the present layout, the entrance to the harbour is often compromised by

TECNOLOGY		€/m³ in situ	Investment costs	Notes
Relocation (incl. dredging, transport, disposal)		1,5-5		
Capping		4-6		
Up-land disposal	Outdoor	10-75	Isolation, added mat	Depend on scale and local taxes
	CDF	8-36		
Mechanical dewatering Belt press /Filter press (incl. Waste Water Treatment)	Belt press / Filter press	7-31	Equipment	Fixed installation
		9-42	Equipment	Mobile installation
Geotubes		4-13	Equipment	Excl WWT
Sand separation (>50% sand)	Settling basins	1-8		Exc dewatering
	Hydrocyclones	3-11	Equipment	Excl dewatering, disposal fines, Waste Water Treatment
		7-26		Including dewatering and Waste Water Treatment
METHA treatment (incl capital cost and personal)		18	Equipment	Large scale and long term
Active lagooning and ripening		10-25	Equipment, land	
Landfarming		5-15	Land	
Bioreactor		50-100	Equipment	
Artificial Cement		35-50	Equipment, added mat	
In situ immobilisation/stabilisation		60-100	Equipment, added mat	SSI
In situ consolidation		10-20	Equipment	Vacuum with horizontal drain
Thermal desorption		25-45	Equipment, Energy	Excl dewatering
Chemical extraction		55-150	Equipment, added mat	
Thermal immobilisation (incl. treatment)		16-58	Equipment, energy	Without product valorisation
Washing	With chemical additives	45-70		
	Without chemical additives	10-20		

TABLE 2 Cost of main treatment technologies and investment. Modified from Bortone and Palumbo [10]

the waves and their propagation within the basin, particularly during Mistral winds. Navigation is limited, especially close to the docks, due to sand transport under the effect of anticlockwise circulation that reduces the depth of the seabed to the extent that some emerging beach can be observed during wintertime. To solve this problem, two strategies can be followed.
The first one is a structural modification of the harbour layout, changing the position and the extension of the present piers, which would modify the water circulation (i.e. oxygenation), but would probably create significant impacts on the *Posidonia oceanica* meadow. In case of damage, a compensation strategy should be planned (see Cappucci *et al.*, this volume), but on the other hand the dock surface and the number of vessels would be increased.

The second approach is to plan maintenance through periodic dredging operations around the dock of *Cala Principale*. In both cases, particular attention is required to protect the *Posidonia oceanica* meadow and marine life during dredging by using turbidity curtains.

The four classes considered in Figure 3 and Table 1 are better described as follows:

1. "Light green" - this material can be beneficially used for beach nourishment or other intervention along the coast, in direct contact with the seawater as no contaminants are found and all concentration are below the thresholds indicated for quality standards of marine coastal water.
2. "Dark green" - These sediments have concentration levels higher than the limit of intervention, but lower than the thresholds of private public or residential sites. Seabed dredging is not mandatory, but in case of removal they should not be in direct contact with the seawater.
3. "Yellow" - These sediments have concentration values between private, public or residential sites and industrial areas. They should be dredged urgently and disposed within Confined Disposal Facilities (CDF).
4. "Red" – These sediments are highly contaminated and concentration values are above the limit for dangerous waste. Immediate removal should take place to avoid transfer of contamination from the seabed to the water column, flora and fauna. Subsequent disposal should be guaranteed according to current legislation.

Due to the low level of contamination determined in the present study (Table 1) and the volume to be dredged (Figure 6) the overall cost for interventions is expected to be between ~50.000 € and ~1 Ml €, depending on the extent of treatment to be adopted (soil washing, dewatering, land farming, desalination). The results of this preliminary work allowed ENEA to propose three possible types of interventions on the territory (Figure 9): Sports facilities; Coastal restoration; Harbour (scenarios A, B, C of Figure 8), as we assumed that the large part of dredged material will be classified as dark green sediment. Sediment sale has not been considered due to the heterogeneity of physical and chemical characteristics.

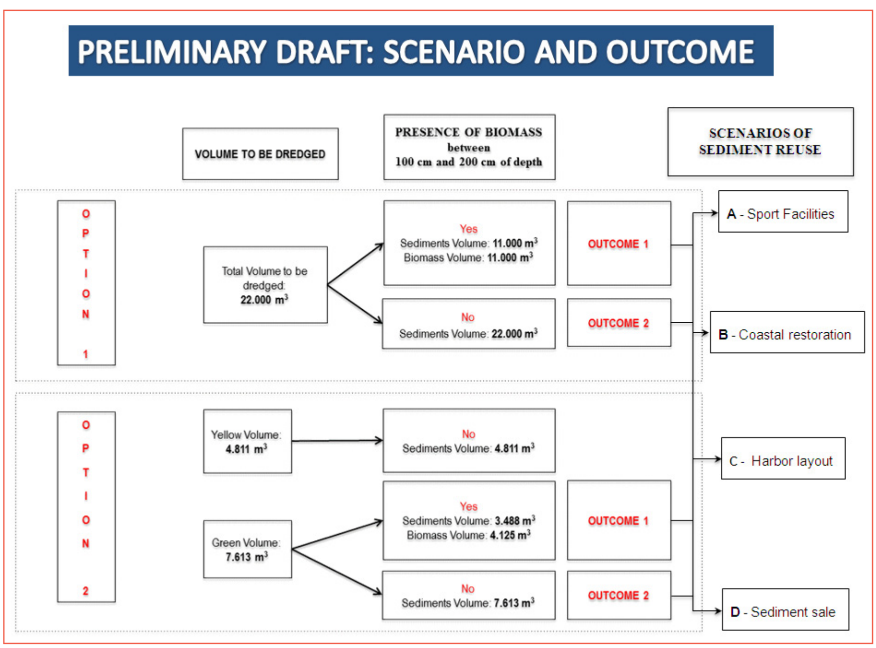

FIGURE 8 Schematic flow diagram which describes the possible options of contamination, subsequent dredging volume and management scenarios

Conclusions

Handling, treatment and reuse of sediments are topics that encompass many disciplines, which are necessary for the successful implementation of the dredging operations aimed at a beneficial reuse of sedimentary natural resource. Therefore, the regulatory framework is very complex. The Italian legislation is continuously evolving, but still does not consider risk analysis as a decision tool for dredging the contaminated sediment. Law no. 27 of 24th March 2012 sets out the criteria for the classification of sediments and their possible reuse or disposal. These changes and the Ministerial Decree of 7th November 2008 offer a more comprehensive regulatory

FIGURE 9 Pictures of some of the management options chosen in relation to the volume and quality of sediments to be dredged from Favignana's Harbour

framework for contaminated sites, but areas outside the contaminated sites of national interest still require a specific attention, as specified by § 8, art. 48 of the Italian Legislative Decree of 24th January 2012 [7]. In Favignana, where the Marine Protected Area is almost uncontaminated, dredging of sediment from the Harbour whit low contamination levels is necessary to facilitate sailing. Following the presentation of the preliminary results obtained in the present study, the local authorities showed interest in the following management scenarios:

a) nourishment along the coast; these sediments should be classified with a "light green" color, due to concentration levels similar to those indicated for the quality standard of marine waters;
b) on-shore recreational activities like soccer and beach volley fields; these sediments should be classified with a "dark green" color, due to concentration of contaminants below the thresholds indicated for public and private soils, and chlorides should be previously reduced to avoid aquifer salinization.

Both of them were appositely designed to favor the reuse of sand after treatment and to increase the amount of goods and tourism services. The possibility to realized beach nourishment will be strongly influenced by eco-toxicology behavior and the presence of the *Posidonia oceanica* meadow in shallow water (close to the shore line and within the active zone of the submerged beach), meanwhile the low level of chemical contamination (PAH) is promising for dredged sand to be reused on shore after reduction of salt content.

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Sergio Cappucci[1], Floriana La Marca[2], Riccardo Ferrantini[3], Massimo Maffucci[1]
[1] ENEA, Sustainable Territorial and Production Systems Department
[2] University of Rome "Sapienza", Department of Chemical Engineering, Materials & Environment (DICMA)
[3] Ergon Group Srl

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