I QUADERNI

Environmental aspects of relict sand dredging for beach nourishment: proposal for a monitoring protocol

Luisa Nicoletti, Daniela Paganelli, Massimo Gabellini

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ICRAM

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O mer, nul ne connaît tes richesses intimes

C. Baudelaire, L'homme et la Mer

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FOREWORD

The Italian coasts occupy a length of 8.000 km and therefore represent a most important strategic resource: they are among the most populated areas, and host intense economical activities, mainly linked to urban, tourism-related, harbour, and industrial settlements. At the same time, coasts also house some of the most precious and fragile habitats in Europe. The increasing exploitation of such areas, combined with the effects of natural events – i.e. sea level variations, the increased frequency and intensity of extreme atmospheric events, also resulting in increased erosion phenomena (global climate change) – determine the degradation of coastal resources. Such degradation inevitably results in social, economical and environmental consequences that are not to be neglected by the community. Therefore, all modifications involving these areas, caused by natural events or human activity, should be carefully evaluated, taking into account the possible effects they might induce on the marine environment (loss of habitats, decrease in biodiversity, etc).

In such context, the theme of coastal "recovery" and, consequently, the need to supply the material necessary for beach nourishment, has taken on worldwide importance in the last years.

Coherently with what has been going on in Europe and in the rest of the world for many years, in Italy too, the use of marine relict sands coming from offshore sand deposits is considered a possible solution. Although such practice has already been carried out for many years, the current reference legal framework in force is still partially in progress: according to said framework, local administrations are responsible for dredging authorizations. Furthermore, no *ad-hoc* reference protocol exists on the matter.

The above mentioned activities involve the extraction of great quantities of sediment (millions of cubic meters), therefore, on top of the technical and economical aspects, it is of major importance that a particular attention be paid to all environmental aspects, especially in a such peculiar and environmental-emergency rich environment as the Mediterranean basin. As a consequence, we experience a great need for regulations based on solid, correct technical and scientific assessments, which, on the other hand, need to cope with the simplicity of the operations. In such frame, ICRAM offers its experience, deriving from years of research and discussion at an international level on environmental monitoring of dredging activities and, more in particular, on such activities aimed at beach nourishment with relict sands (Nicoletti *et al.*, 2002, 2004a; Nonnis *et al.*, 2002; Pulcini *et al.*, 2002; Paganelli *et al.*, 2005).

If badly planned or managed, this kind of activity may cause relevant environmental effects, which, in turn, may lead to important economical spin-off. For that reason, and also due to the great geographical and environmental variety of the Italian coasts, further studies and thorough analyses are undoubtedly in order.

Our proposal for a monitoring protocol, specific for relict sand dredging and beach nourishment, is based, in particular, on ICRAM's pluriennial experience, developed by working on the planning and the carrying out of the environmental studies that precede and accompany such activities. Because of their innovative approach, most of these studies were considered pilot projects, thus allowing ICRAM to acquire experience, and to take part in European projects on this very matter.

We also need to mention that most of the experience achieved by ICRAM on these specific issues was gained thanks to the local authorities' appointment. In particular, ICRAM boasts a long-term cooperation in the field of monitoring activities with the "Regione Lazio" local authority since 1999. Such activities enabled ICRAM to acquire a relevant amount of data for each of the variables taken into account. The information gathered over time allowed ICRAM to develop an increasingly experimented and perfected monitoring procedure. Due to the originality of the studies carried on in this area, ICRAM was invited to participate in the Interreg IIIB European project "Beachmed". By taking part in this project, ICRAM could compare its work with that of other European partners, coming from different environments ad geographical areas. As a result, ICRAM obtained prestigious outcomes, that it is sharing with some European regions (namely Latium, Tuscany, Liguria and the Generalitat Valenciana) a methodological protocol focusing on specific environmental studies on the relict sand dredging for beach nourishment at a European level (Protocol ENV1). Perfected and optimized throughout the years through studies and experimental applications, the protocol represents a major reference point, also in relation to the subsequent legal developments.

Today, monitoring studies linked to such activity are the object of a new Interreg IIIC European project called "Beachmed-e" in which ICRAM is the leader of a specific sub-project titled: "Sharing, defining and applying the ENV1 protocol to dredging and nourishment activities carried out with relict sands, and specific applications for turbidity studies (EuDREP)".

Working in the same field of environmental studies, conceived to support the removal activity of marine sediments, ICRAM, in collaboration with APAT developed a "Manual for marine sediment removal", published by the Ministry for the Environment and the Protection of Landscape and Sea, General Direction for Nature Protection. This was the first official document to deal with the specific issue of relict sand nourishment.

The document presented in this "Quaderno ICRAM" represents a further step forward, and since neither the experiences already carried out, nor the operational methodologies, are yet consolidated, every new on-field experience may carry suggestions that may improve the protocol in question. This makes the protocol increasingly capable to meet the needs of technicians and administrators, also in relation to extremely diversified environmental emergencies, as it is the case in the Italian coasts.

Further, such document also corresponds to ICRAM's proposal to set up guidelines on the mobilization of sea floor and of its neighboring environments – for the latter, a volume on port dredging has already been published (Pellegrini *et al.*, 2002).

Since this document is addressed to a heterogeneous readership, including experts and researchers on the one side, and administrators and technicians on the other, the "Quaderno ICRAM" is organized in two main parts.

Accompanied by a thorough bibliography, the first one (Chapter 1) has a more scientific character and studies the environmental aspects that emerged from the study of national and international scientific and technical literature, and that are linked to relict sand dredging for beach nourishment.

Divided in four chapters, the second part opens up with the treatment of the general aspects that lie at the basis of its configuration (Chapter 2). This chapter is particularly useful for those who need (or wish) to understand the general structure, i.e. the areas of interest, the study plan and parameters. The following two – more specific – chapters explain the protocol in detail, in relation to the characterization study (Chapter 3) and the monitoring study (Chapter 4), respectively. These two chapters are structured so as to provide local administrations – and all actors involved in coastal defense – with a useful tool. Finally, in order to provide further help to those who will be operationally dealing with such issues, the last section (Chapter 5) carries concise charts and diagrams, explaining the procedures needed for this kind of study in an extremely simplified way. Eventually, the specific experiences carried out by ICRAM are reproduced in *ad hoc* boxes, within each chapter.

Based on the abovementioned remarks, we also would like to pinpoint that this study represents an important departure point as well as a remarkable contribution for all of Italy's different, central or peripheral realities. This "Quaderno ICRAM" was produced in the frame of the "**Interreg IIIB European project Beachmed**" and of the "**Activity program for the revision of the knowledge framework on the quality of sea and coastal environments" (Ministry for the Environment and the Protection of Landscape and Sea, General Direction for Nature Protection)**. Its aim is to become a technical reference document on the matter, in order to favor the development of the environmental issues related to the removal of sea sediments for the nourishment of coasts in erosion, as well as a support tool for the administrations dealing with coastal defense and for all the other actors involved.

The English edition of this volume was produced in the frame of the "**Interreg IIIC European project Beachmed-e, EuDREP subproject**".

Introduction

INTRODUCTION

Coastal erosion has become an internationally acknowledged problem, and it is being studied and managed with increasing care (Carter and Woodroffe, 1994; Preti, 2002).

Most Italian coasts are currently subject to evident erosion phenomena, while only very few coastal stretches are stable or in progradation (Aucelli *et al.*, 2006).

A beach's growth/erosion rate varies with the seasons, and depends on the sedimentary balance between material input on the coast and relative losses. The input is mainly composed of material carried by rivers and distributed on the coast by wave motion and currents, whereas the output is due to the departure of material along the shore by means of flooding (littoral drift). A more in-depth analysis reveals that material losses can also occur seawards, as an effect of particularly relevant extreme events. Erosion can be aggravated by the natural subsidence of the coast, deriving from natural geological processes, general sea level rise, and from the effects of excessive coastal anthropogenic activities (Boesch, 1982; Louis Berger Group, 1999; Green, 2002).

Further, the development of dams and river restoring structures, combined with the construction of hydroelectric and/or irrigation lakes, contributed to a remarkable decrease in sediment input from the water streams, thus interfering with and enhancing natural coastal erosion processes. Other factors also contribute to an increase in erosion phenomena: the hardening of the coastline due to the development of maritime structures (which interfere with longitudinal transport), the extraction of underground fluids (with the consequent intensification of the costal stretch's natural subsidence processes), dune immobilization or leveling, and sand removal from the beach due to trampling (Herbich, 1990, 1992a, 1992b; Preti and Albertazzi, 2003).

Coastal Protection

Traditionally, in order to restore and protect eroding beaches, transversal (groins) and longitudinal (breakwaters, adherent structures and barriers) hard structures were built perpendicular or parallel, respectively, to the shoreline. Such interventions are, even today, generally well accepted, due to the availability of effective design techniques and of relatively reliable cost projections. They do, however, give rise undesired effects under environmental and landscape perspectives and, most importantly, they may unpredictably affect coastal dynamics at a local level (Capobianco *et al.*, 1999).

After many such interventions for coastal protection have demonstrated their technical and economical limitations, in the last twenty years, a "soft" technique called "nourishment" took over thanks to its ability to guarantee a better response in relation to environmental, landscape, and economic aspects.

Nourishment

Nourishment is a coastal protection intervention consisting in the restoration of the eroded beach through the use of appropriate material. The latter can have different origins, coming for instance from riverbeds, quarries, coastal environments (river mouths and navigable canals dredging) or from relict sand deposits.

When compared to other coastal protection techniques, nourishment turns out to be more easily modulated, while also offering other benefits in term of environmental impact and use of the beach. Nourishment allows to minimize the negative effects often associated with the use of hard structures (Adriaanse and Coosen, 1991; Correggiari *et al.*, 1992). If managed correctly, nourishment does not alter the landscape and environmental features of the area of intervention, nor does it modify littoral dynamics (Preti, 2002).

For these reasons, beach nourishment increasingly developed as one of the main tools for coastal management. Ever since its first experimental applications, the use of beach nourishment has constantly grown both in Europe and in the USA. Nevertheless, this engineering process was often considered to be in need of further improvements, and was preferably used in "mixed" coastal defense interventions, i.e. in combination with other defense interventions (Benassai *et al.*, 1997; Capobianco *et al.*, 1999).

Today, nourishment represents an increasingly appreciated solution to contrast the erosion problem (Capobianco and Stive, 1997).

In order to consolidate and disseminate nourishment as a coastal management instrument, great amounts of low cost sand must be available (Preti, 2002). Such need is connected to the fact that the restrictions linked to material assembling in emerged areas (deposits, riverbeds, etc.) tend to become stricter and stricter, and this highlighted the need to find new sources of the material itself. A possible solution to this problem consists in using relict sand deposits, a common practice in Italy since the 1990s.

Relict Sands

Relict sands are non-diagenized sedimentary deposits situated along the continental shelf in conditions of disequilibrium with the actual sedimentary dynamics. The removal of such sediments, occurring offshore at high depths, does not affect the wave motion regime nor, therefore, coastal dynamics.

Such deposits can generally be ascribed to paleo-beaches, whose formation is ascribed to the low sea level conditions during the last glacial period, or to the subsequent rising phase that characterized the Holocene. Some 22 thousand years ago, during the last glacial period, the sea was situated at about -120 m on the current level. The subsequent global warming determined the melting of the glacial coats, bringing the sea to a rapid rise, up to a level close to the current one, which was reached 6 thousand years ago. This brought to the formation of series of different littoral environments along the continental shelf. Relict sand deposits along the continental shelf may be covered by pelitic sediments of recent deposition, or, alternatively, by outcropping sediments.

Despite relict sand deposits are present along the continental shelf at depths ranging between 30 and 130 m, the optimal exploitation zone for nourishment purposes is currently comprised between 50 and 100 m in depth (BEACHMED, 2003).

In some cases, however, the use of relict sands is hardly feasible, especially for economic reasons. Such difficulties are linked to the existence of peculiar conditions, such as a thick pelitic layer, limited thickness of fine sediments (sediments with an average diameter of < 63 microns), or deposits located at excessively high depths.

Currently, in order for a relict sand deposit to have mining value, the following conditions (Colantoni and Gallignani, 1980; Curzi *et al.*, 1987; Chiocci and La Monica, 1999; BEACHMED, 2003) need to be met at the same time:

- the deposit should ideally be constituted by sands with the suitable grain size;
- the deposit must have significant thickness, higher than 3-4 m;
- the deposit must outcrop or have a limited pelitic layer, lower than 3-4 m;
- the deposit must be located in areas whose depth is not higher than 100 m;
- the deposit must be of significant volume, generally higher than 3.000.000 m^3;
- the deposit's surface must be free of encrusting formations.

Nourishment Activity through Submerged Marine Sands

The first nourishment activities carried out through marine sands date back to the first decades of the past century – the nourishment of Coney Island (NY) beach took place in 1922-1923 (Domurat, 1987; Dornhelm, 1995). However, such practice experienced significant developments only in the last two decades, spreading out in particular in Northern Europe (Holland, Belgium, Denmark, Germany, etc.). In Italy, the first documented nourishment activities with relict sands on eroding coasts are related to the nourishment operations in the Cavallino and Pellestrina (Venice) beaches, involving an overall sand volume of 6.000.000 m^3, removed from marine deposits ascribed to paleobeaches and found at 20 m in depth in an area comprised between the Tagliamento River's mouth and the Adige River's mouth (Cecconi and Ardone, 1999).

The first experiences of such kind in the Tyrrhenian Sea are related to the 1999 nourishment of the Ostia coasts, carried out using relict sands from a marine deposit located offshore Anzio (Rome). In particular, along the Latium continental shelf, there are many nourishment-suitable sand deposits (BEACHMED, 2003). Such deposits, which became the object of a study from "La Sapienza" Rome University (Chiocci and La Monica, 1999), are ascribable to depositional bodies of different nature, generally characterized by prevailing medium-coarse granulometry. The deposits, described by Chiocci and La Monica (1999), are generally covered with Holocenic pelitic sediments, brought to the basin by streams (Tevere and Volturno-Garigliano Rivers) and redistributed by shelf currents. In this case, the most suitable deposits for nourishment are synthetically referable to five main typologies: coastal paleo-bars, marine depositional cusps, fluvial-marine depositional cusps, river paleobed fillings, and low sea level cusps.

Other nourishment activities have been conducted in Italy, in particular along the coasts of Emilia-Romagna (Adriatic Sea), through the use of sand deposits located offshore Ravenna (Preti, 2002). In fact, the presence of relict sand is documented along the whole Adriatic shelf. Such deposits, of extremely variable thickness and shape, and partially covered with fine sediments of recent deposition, are generally located offshore, and result from the progradation of the Holocenic transgression upon coastal deposits (Brambati *et al.*, 1973; CNR, 1978; Coltellacci, 1980; Preti, 1985, 1990; Curzi *et al.*, 1987; Correggiari *et al.*, 2002, 2003). In the Adriatic Sea, the thickest deposits are located in correspondence to dunes and submerged bars such as those found to the north of the Po river delta (Brambati and Venzo, 1967; Colantoni *et al.*, 1979) or offshore Emilia-Romagna (Curzi and Gallignani, 1982; Preti, 1985, 1990).

Legal Reference Framework

The specific legal framework in force in Italy for relict sand dredging for beach nourishment purposes is partially still in progress.

Article 35 of Law n. 152 of 11 May 1999 ("Provisions on the protection of water from pollution, and implementation of the European Directive 91/271/EEC concerning the treatment of urban waste water and of Directive 91/676/EEC on protection of water from nitrates originating from agriculture"), updated following a series of corrections and integrations, including the Legislative Decree n. 2558 of 18 August 2000) deals with *"the input into the sea of material from excavation activity, and the laying of marine cables or pipes,"* of materials defined as *"excavation material from sea bottoms or brackish bottoms, or from emerged littoral land; inerts, inorganic geological material and artifacts (only those meant to be used in this kind of activities), with proven environmental compatibility and harmlessness; organic and inorganic material of marine or brackish origin, produced during fishing activities carried out in the sea, lagoon or brackish marshes"*. In particular, the law provides that *"the authorization to the immersion in the sea of the materials mentioned at paragraph 1, letter A), is granted by the relevant authority only if the preparatory study shows the technical or financial impossibility of their use for nourishment purposes…"* (the same provision is mentioned at article 109 of Legislative Decree 152/2006). Furthermore, this law also provides for the preparation of a technical document (article 35), in order to manage, by means of a circumstantial account, all bottom removal activities. Since the preparation of the technical document is still in progress, nourishment with relict sands is still regulated by Ministerial Decree of 24, January 1996 (preliminary work and authorization requests) and by Law n. 179, 31 July 2002, which regulated the jurisdictional shift from the State to the Regions.

Article 21 (authorization for protection activities of coastal zone) of Law n. 179, 31 July 2002, has in fact established that the Region is the relevant authority for the preparation and granting of the authorization, as per art. 35 par. 2 of Legislative Decree 152/1999, as far as nourishment activities on coastal zones are concerned. If the materials originating from sea bottom removal are used for beach nourishment purposes, when the preliminary work for the authorization granting starts, the Region must obtain the advice of the Consultative Committee on Fishing and inform the Ministry for the Environment and the Protection of Landscape and Sea.

Furthermore, in order to assess the possible environmental impacts caused by relict sands dredging activities or by beach nourishment, the Region shall request an EIA (Environmental Impact Assessment) at a regional level, as per European Directive 85/377/EEC and Presidential Decree 12 April 1996. Such activities fall under the project types listed at Attachment II of Directive 85/377/EEC, because they are classifiable as: *"coastal works aimed at contrasting erosion and maritime works aimed at modifying the coast by means, for instance, of dams, peers, castings and other sea protection works, except the maintenance or the reconstruction of such works"*, and as *"excavation of minerals by means of marine or fluvial dredging"*.

A last observation concerns the legislation more strictly connected to marine sediment quality, with specific regard to Ministerial Decree 367/2003 ("Regulation concerning the establishment of quality standards for marine coastal environment", as per article 3, par. 4, Legislative Decree n. 152 of 11 May 1999), focusing on quality standards for marine coastal environment. The Decree determines the quality standard for coastal-marine sediments, with regard to some dangerous and priority substances, as per Regulation 2455/2001/EC; the text also explains that the limits set are not binding, but they shall support the measures to be undertaken in order to safeguard the water body, and these limits lose their value if the standard is overcome in correspondence of some ascertained geochemical provinces. Although it is not a specific tool meant to assess the shelf sediment conformity, M.D. 367/2003 is still today the only national point of reference for sea environment protection.

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1 ENVIRONMENTAL ASPECTS OF RELICT SAND DREDGING FOR BEACH NOURISHMENT

Relict sand dredging activities for beach nourishment produce a number of effects on specific areas of the marine environment. The areas involved are (***Figure 1.1***):

- the portion of the continental shelf containing the mined relict sand deposit; henceforth, **dredging area**;
- the portion comprised between the dredging area and the nourishment area; henceforth, **transport area**;
- the beach area where the actual nourishment will take place; henceforth, **nourishment area**.

Figure 1.1 - Areas involved in relict sand dredging and nourishment activities.

The study and evaluation of dredging-related environmental problems must therefore consider the characteristics of the different areas involved. The main problems in dredging and nourishment activities concern the morphological and bathymetric changes of the sea bottom and shoreline, the geotechnical and textural characteristics of superficial sediments, the input of significant quantities of suspended fine sediment, and changes induced directly on benthic organisms as an effect of defaunation and burying. It is also important to consider the disturbing effects these activities may have on the environment, and the significant impacts on economic activities, such as fishing (***Figure 1.2***).

This chapter will illustrate the effects of relict sand dredging and nourishment on the areas surrounding the dredging area.

The problems related to the effects caused on the environment by removal of sediment containing dangerous substances will not be analyzed in this work, because the regulations in force in Italy provide that beach nourishment should only be carried out with good quality material, i.e. exclusively with non-contaminated sediments. It is also important to consider that, because of their geological characteristics and attitude, relict sands can rarely be a preferential vehicle for pollutants present in the sea, and they are generally good quality sediments.

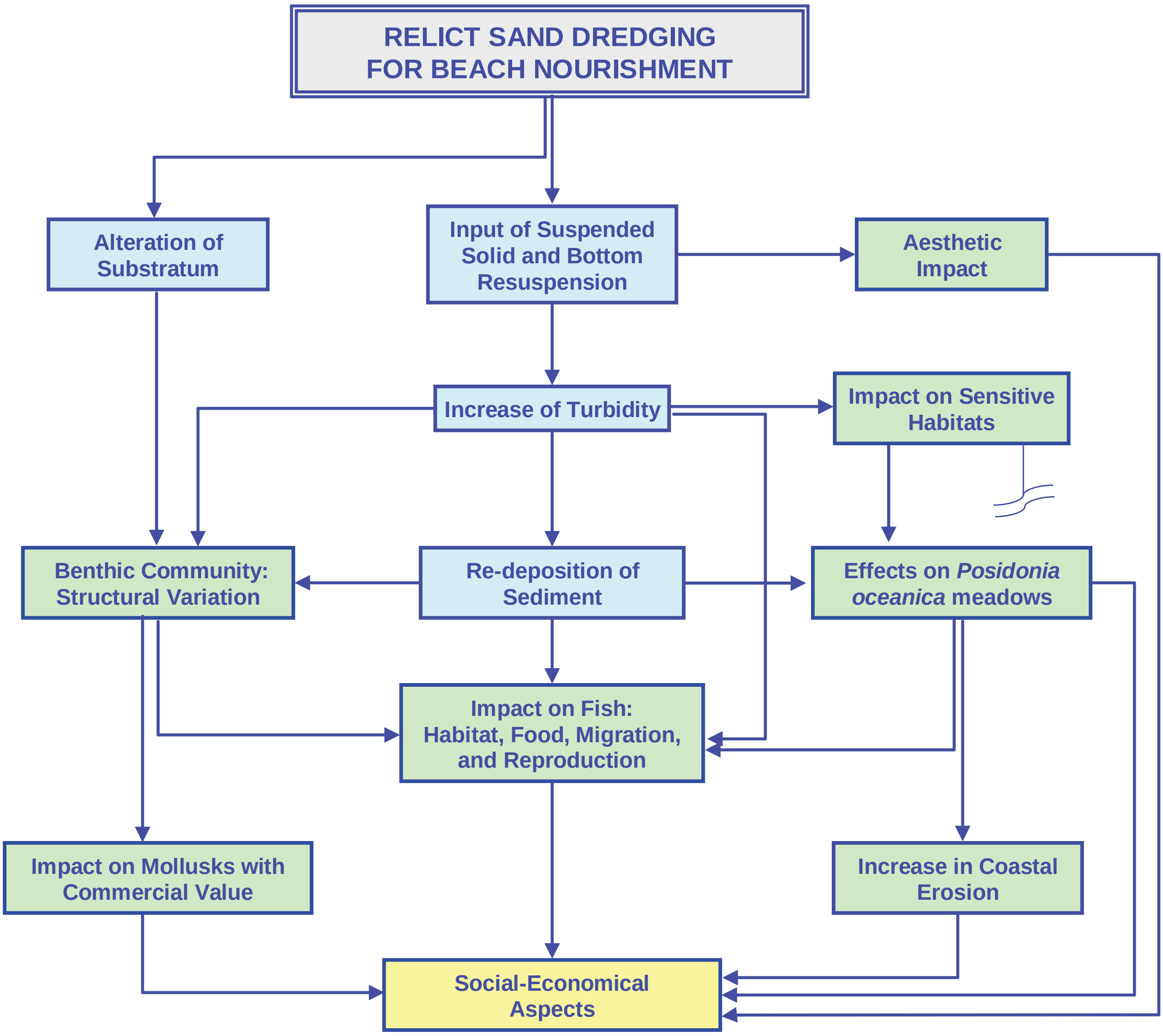


Figure 1.2 - Dredging for beach nourishment: environmental disturbances and economic relapses.

1.1 DREDGING AREA

Dredging on coastal areas can have significant implications on beach evolution, and it is therefore regulated by important restrictions both near the coast – in areas relevant for coastal sedimentary transport – or in areas with coastal protection functions, such as shoals, sand spits, and bars.

On the opposite, the changes produced on the environment by relict sand dredging activities do not involve relevant modifications on sedimentary dynamics, though local transport and sedimentation conditions may vary. The particular nature of relict sands (i.e. sediments that developed at sea levels lower than the recent ones, and which therefore lie outside the actual depositional dynamics) is such that sand removal will not interfere with the coast's sediments dynamics.

During the complex dredging activity processes, however, more significant alterations may take place, on both a physical a biological level.

Concerning the physical aspects, two main features can be identified (MMS, 2001):

- *Substratum*. The variations in the substratum may involve both morphological and bathymetric features, as well as the characteristics of superficial sediments (grain size, compaction degree, dissolved oxygen, and organic substance content). Morpho-dynamics and superficial sediment characteristics are strongly correlated;
- *Water column*. The water column may undergo variations, including changes in the chemical-physical characteristics and in the concentrations of the suspended particulate matter. It is also important to consider that these aspects are strongly influenced by the area's dynamic characteristics (waves, currents and tides). In the specific case considered, currents are the only relevant dynamic features because wave characteristics are negligible in this area, due to the offshore position of the relict sands, and because tides in the Mediterranean only have local significance.

Concerning sea organisms, dredging activities directly affect benthic communities. The most relevant effect is caused by the complete removal of the superficial sediments, which brings to the area's direct defaunation. The effects of dredging can also affect the whole trophic chain, affecting fish assemblages as well.

Particular attention must be paid to the species of commercial value, in order to minimize the possible negative effects on fishing activities, which could have a significant economic impact, especially at a local level.

The portions of the continental shelf containing sand deposits that are potentially exploitable for nourishment may also be regulated by different legitimate uses of the sea, such as the presence of Marine Protected Areas (MAPs), large infrastructures (offshore structures, cables, pipes, oil pipes), anthropic activity (mariculture), and specific areas with legitimate uses of the sea (due to military sites, harbour-material dumping areas, no-anchor or no-fishing zones), all of which are often incompatible with dredging activities. Therefore, in order to optimize both the environmental studies on the effects of relict sand dredging for beach nourishment and the continental shelf's environmental management, these infrastructures must be marked and mapped from the very beginning of the compatibility analysis.

1.1.1 Sea Bottom Characteristics and Morpho-dynamics

The physical impact of relict sand dredging for beach nourishment mainly consists in the modification of the morphological and bathymetric setup of the dredging area, with the creation of depressions associated with changes in the texture of the superficial sediments (ICES, 1992, 2001, 2003; Newell *et al.*, 1998; Boyd and Rees, 2003).

Among other factors, the nature and the entity of the sea bottom's physical changes depend on the deposit's mining method. Large deposits are generally mined on vast areas with limited thicknesses, while smaller deposits tend to be mined for the maximum usable thickness, which causes the development of significant hollows below the pre-dredging plain.

In Europe, the two most commonly used dredges are anchor dredges and trailer dredges (***Figure 1.3***).

To remove the sediment, the anchor dredge is anchored in single stations, in which the dredging head (***Figure 1.4***), situated at the extremity of the pipe, is fixed vertically to the bottom, allowing the suction of the sediment in question. This method is to be preferred when the deposit to be dredged presents a prevailing vertical development, or if it limited in space. The effect of this type of dredge on the sea bottom's morphological and bathymetric setup (***Figure 1.5***) consists in a series of sub-circular hollows and/or wells of variable sizes according to the type of dredge; sizes range

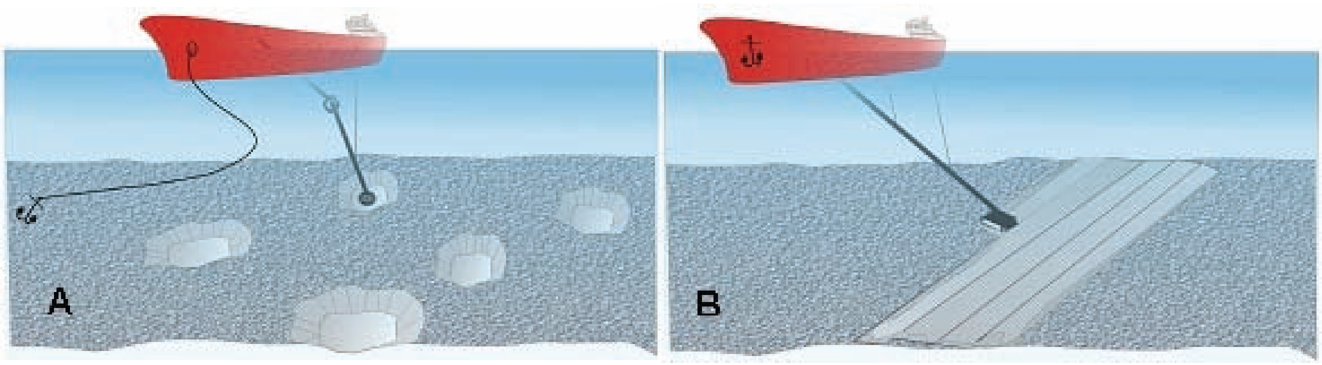


Figure 1.3 - A) Anchor dredge; B) Trailer dredge.

Figure1.4 - Anchor dredging with superficial pipe; the dredging head is visible on top of the pipe.

between 2 and 20 m in depth, and 20 to 100 m in diameter (Van der Veer *et al.*, 1985; Norden-Andersen *et al.*, 1992; Newell *et al.*, 1998; Desprez, 2000; ICES, 2003; Hitchcock and Bell, 2004; Birklund and Wijsman, 2005; ICRAM, 2005a).

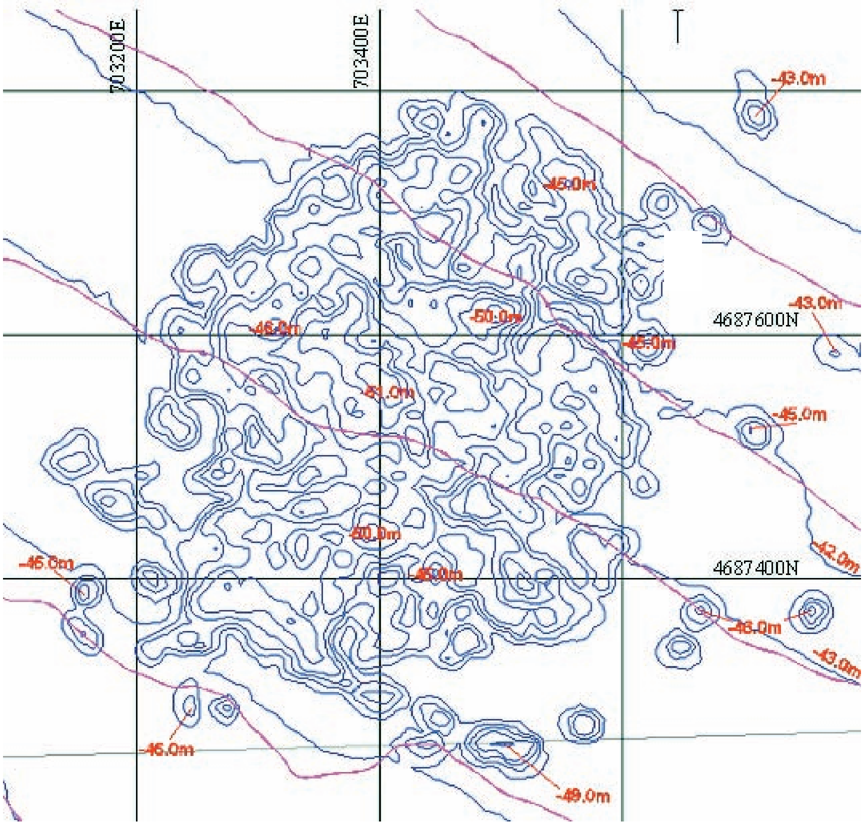


Figure 1.5 - Detail of the bathymetric survey of a sector situated in the central Tyrrhenian Sea offshore Montalto di Castro (northern Latium), dredged through an anchor dredge. The area affected by the most intense activity shows an irregular bathymetric setup, while the peripheral sectors show the single signs left by the dredging head. The purple lines correspond to the isobaths recorded pre-dredging, and the blue ones correspond to those recorded after dredging (ICRAM, 2005a).

The overlaying of a great number of sub-circular signs gives rise to a distinctly irregular bathymetric sea bottom setup, with a more or less wide hollow that is closely surrounded by local holes caused by the dredging head (***Figures 1.6*** and ***1.7***). In an area of the central Tyrrhenian Sea (northern Latium) where dredging operations were performed with an anchor dredge, morphological surveys conducted through a Side Scan Sonar have shown the presence, in the most intensely dredged area, of a sonar chaotic *facies* (***Figure 1.8***). This was due to the presence of high/low backscatter areas and sonar shades that can be associated with the steps/hollows created (ICRAM, 2005a).

In the case of dredgings carried out through trailer dredges, the sediment is extracted through one or more pipes, while the dredge slowly moves along the routes defined according to the mining plan.

The effects on sea bottom morphology and bathymetry of this kind of dredge (***Figure 1.9***) consist in a series of hollows, sub-parallel to one another, whose sizes vary according to the particular dredge used: their sizes range between 1-2 m to 4-5 m in width, and 0,5-2 m in depth (Kenny and Rees, 1994, 1996; Newell *et al.*, 1998; ICRAM, 2005b).

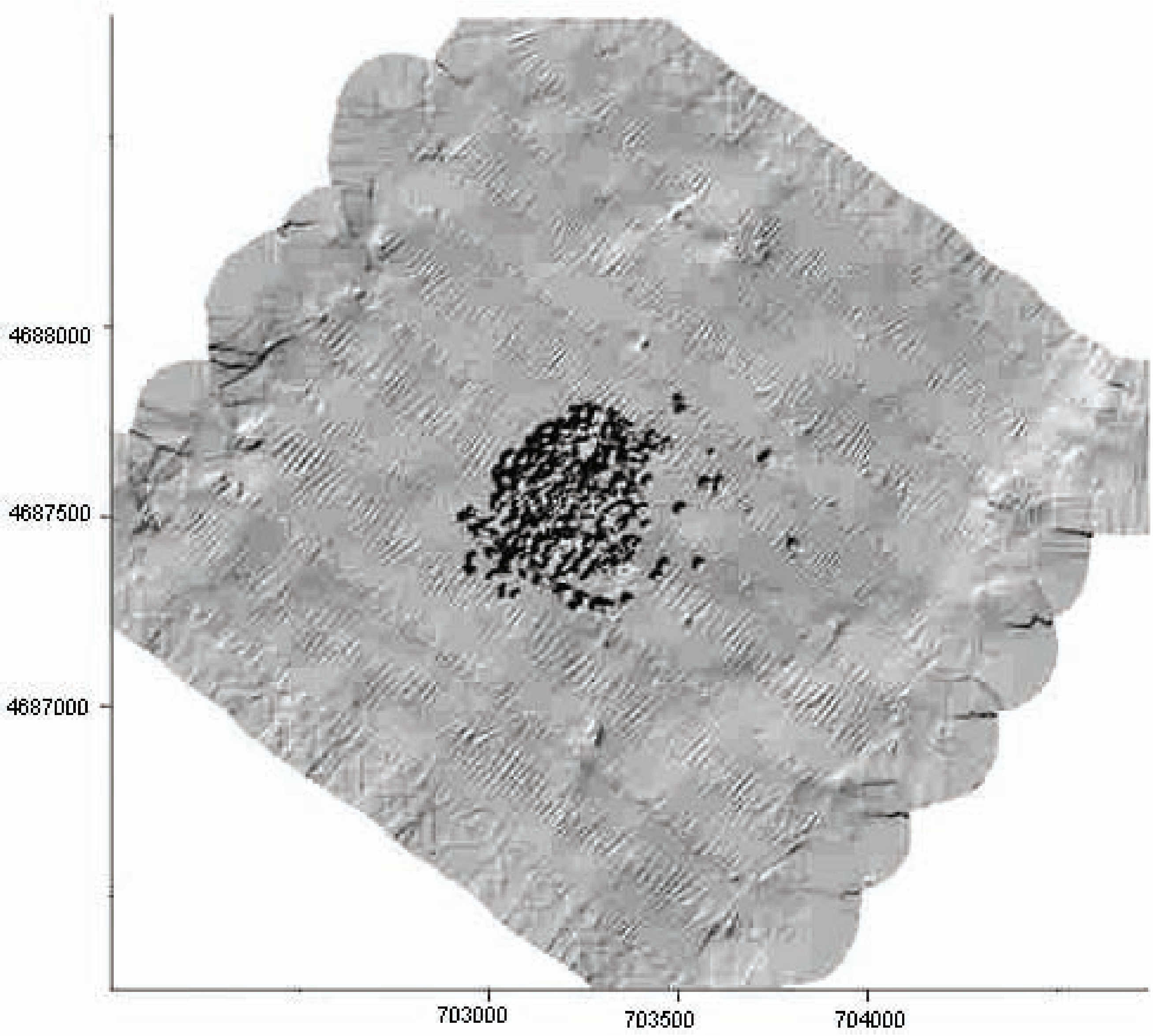


Figure 1.6 - Shaded Relief Map - derived from bathymetric surveys - of a sector situated in the central Tyrrhenian Sea offshore Montalto di Castro (northern Latium), dredged through an anchor dredge. It is possible to identify the dredged area and, in the peripheral areas, the single hollows left by the dredging head (ICRAM, 2005a).

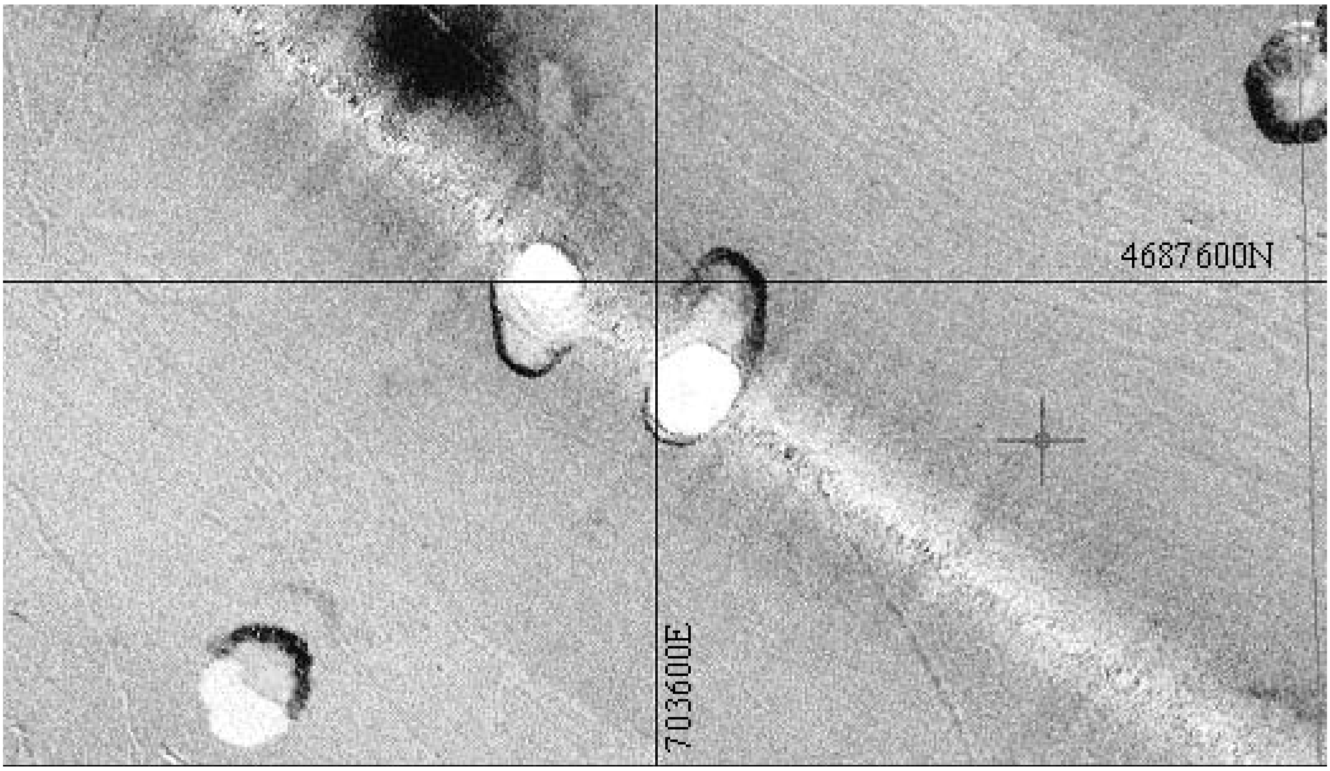


Figure 1.7 – Detail of a morphological relief of a sector situated in the central Tyrrhenian Sea offshore Montalto di Castro (northern Latium), dredged through an anchor dredge. It is possible to observe the single signs left by the dredging head (ICRAM, 2005a).

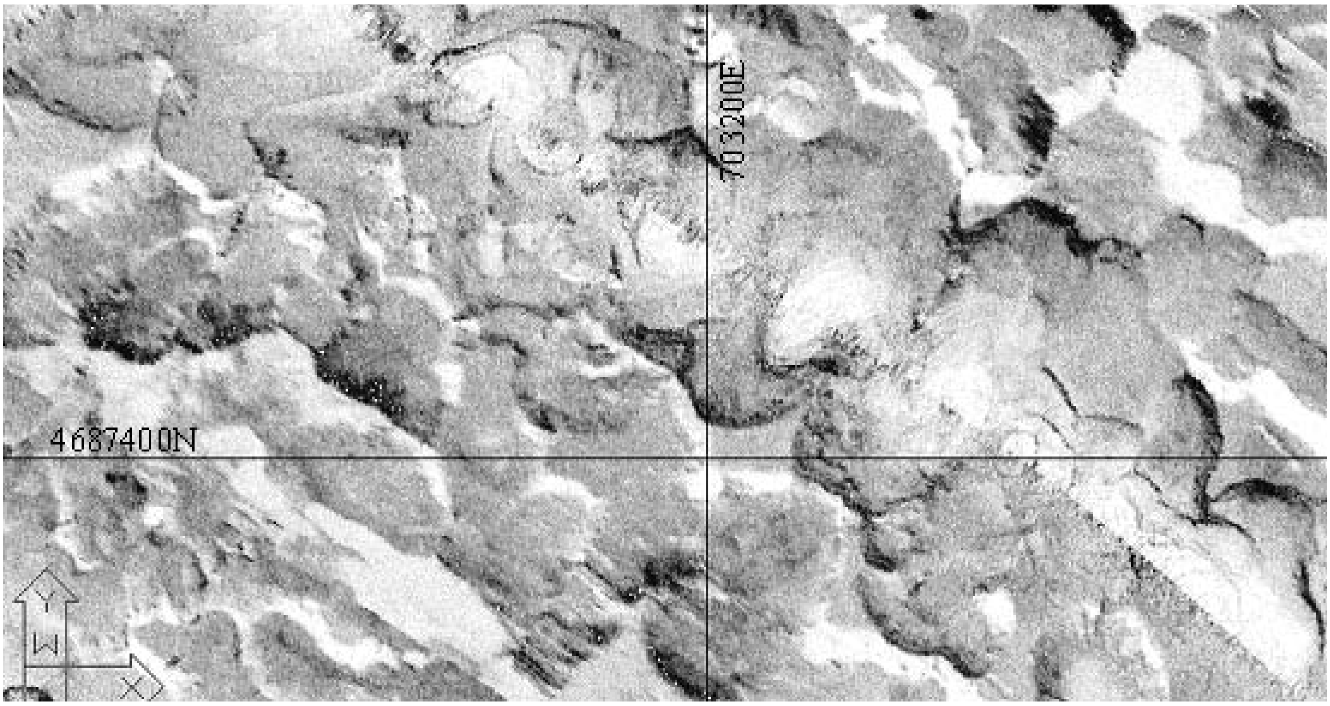


Figure 1.8 – Detail of a morphological relief of a sector situated in the central Tyrrhenian Sea offshore Montalto di Castro (northern Latium), dredged through an anchor dredge. The sonar *facies* is chaotic due to the overlapping of the holes left by the dredging head inside the area characterized by maximum dredging activity (ICRAM, 2005a).

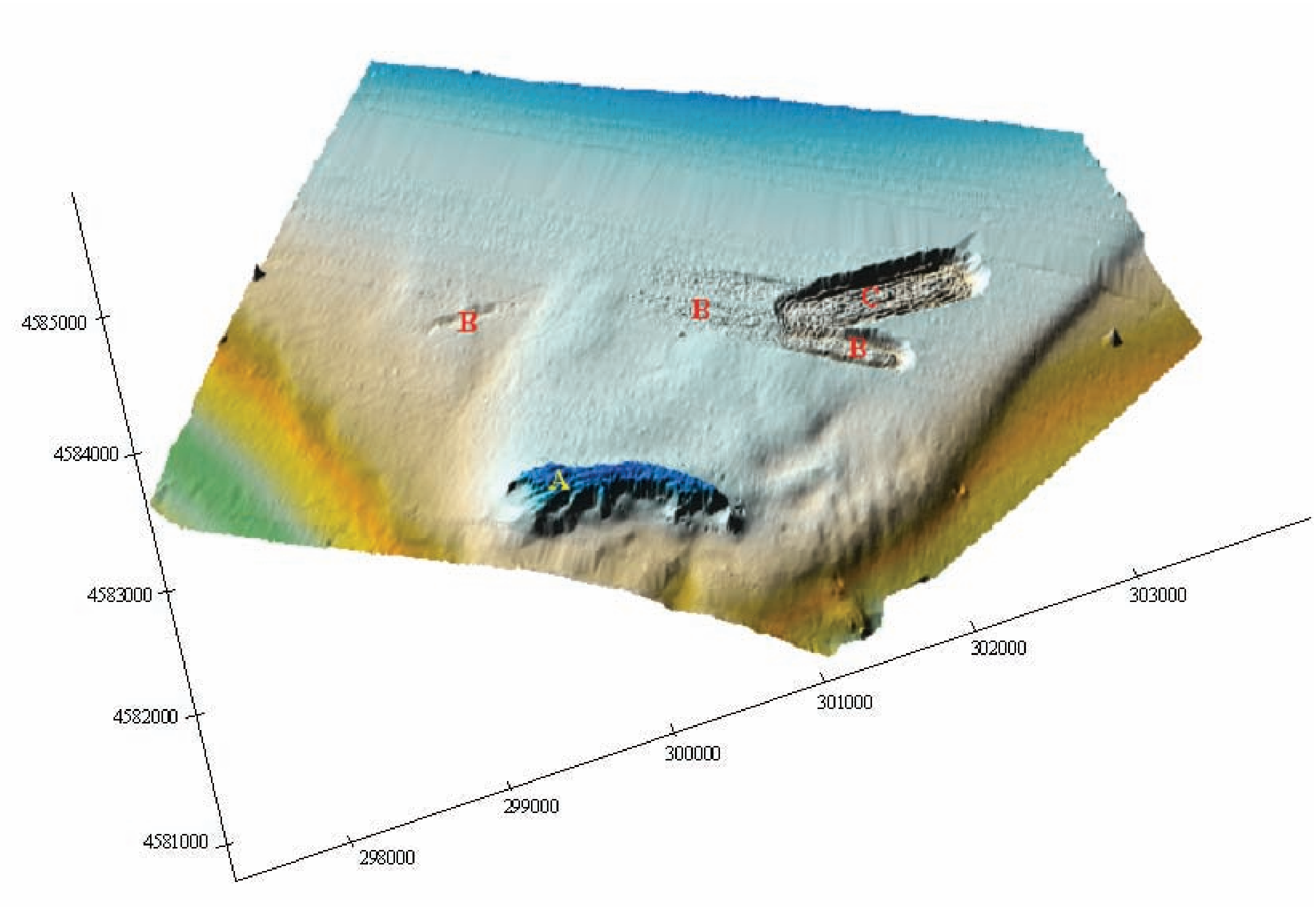


Figure 1.9 - 3D Model - from bathymetric data - of a sector situated in the central Tyrrhenian Sea offshore Anzio (central Latium), involved in repeated dredgings carried out through the use of trailer dredges. In particular, it is possible to point out the Costacurti Shoal (A), with important naturalistic value, and the areas dredged in 1999 (B) (ICRAM, 2001) and in 2003 (C) (ICRAM, 2005b).

Deeper hollows have been recorded in the Baltic Sea (Gajewski and Uscinowicz, 1993) and in the Mediterranean (Fabi *et al.*, 2003, 2004; ICRAM, 2001, 2005b), with the deepest depression found when the dredge passed repeated times (Newell *et al.*, 1998). In case of dredging carried out in the central Tyrrhenian Sea offshore Anzio (central Latium), hollows of about 5 m have been recorded (ICRAM, 2005b). The morphological surveys, carried out through a Side Scan Sonar, have shown the existence of a sonar chaotic *facies* in the areas of maximum sediment extraction, due to a great number of overlapping hollows generated by the repeated activity of the dredge, while the single signs left by the dredging head can clearly be observed in the nearby areas (***Figure 1.10)***.

Other morphological features, of exclusively local interest, a few meters in size (5-10 m), situated some tens of meters from one another (20-50 m), were identified thanks to small backscatter anomalies along the edges of the hollows left by the dredging head (***Figure 1.11***), and interpreted as primary features (*levées*) due to variations in the dredging head set up (ICRAM, 2001; Hichcock and Bell, 2004).

The recovery times of the hollows generated by dredging are extremely variable and depend both on the type of dredge used (which determines the initial size and shape of the hollow) and

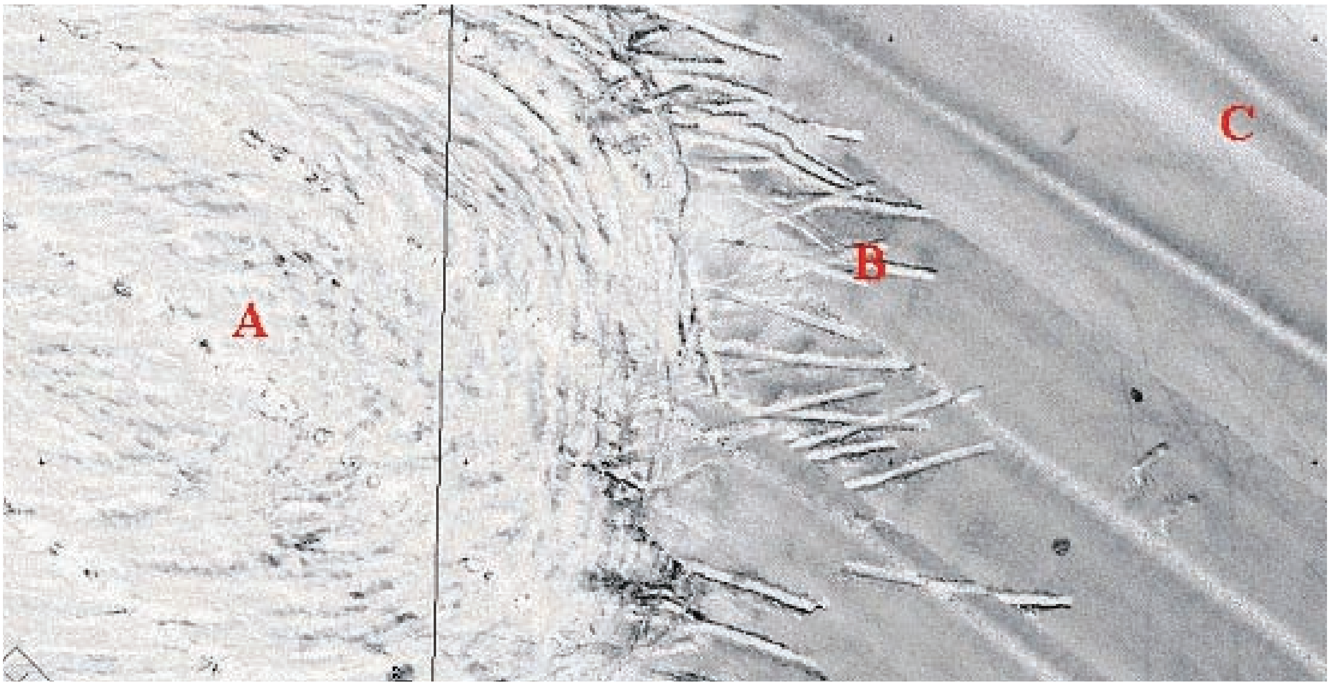


Figure 1.10 – Detail of a morphological relief of a sector situated in the central Tyrrhenian Sea offshore Anzio (central Latium), dredged through a trailer dredge. The sonar *facies* is chaotic due to the overlapping of the signs left by the dredging head inside the maximum extraction area (A), single signs (B), and undisturbed sea bottom (C) (ICRAM, 2005b).

on a site-specific combination of factors, such as the morphological set up of the surrounding area (a sub-horizontal sea bottom or a sand-banks area or ridges), the nature of the sediments (gravel or sand) and the sea bottom's stability, which depend both on whether the resource is relict or recent, and on the local hydrodynamic conditions (wave and current regimes) (Newell *et al.*, 1998; Birklund and Wijsman, 2005; SANDPIT, 2005).

Recovery times can range between 1 month and over 15 years (ICES, 2001); recovery is generally faster if the dredging activities, carried out through a trailer dredge, involve a very dynamic environment, while it is extremely slow (up to the point in which it is impossible to reach a condition of recent recovery) in case of very deep holes, such as those generated by anchor dredges, especially in the presence of a low energy environment.

The hollows produced by anchor dredges can therefore create long lasting sea bottom features that are visible even after years, which however only involve limited areas of the sea bottom (Newell *et al.*, 1998;

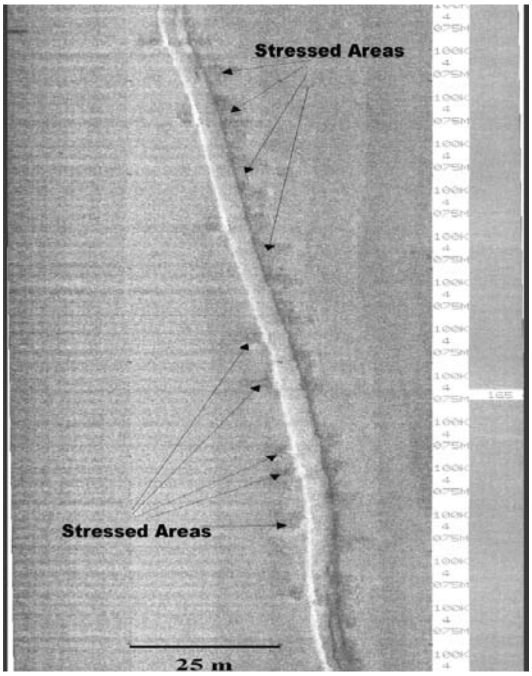


Figure 1.11 – Detail of a morphological relief of a sector situated in the central Tyrrhenian Sea offshore Anzio (central Latium), dredged through trailer dredging. It is possible to observe a furrow produced by the dredging head, characterized along its edges by small areas with backscatter anomalies, interpreted as variations in the setup of the dredging head itself (ICRAM, 2001).

Birklund and Wijsman, 2005). On the opposite, trailer dredging causes limited hollows over much wider areas (Birklund and Wijsman, 2005).

A rather large number of scientific works – illustrated below – are available on studies concerning recovery times of hollows generated by sea bottom dredging for inert material extraction (North Sea) (Kenny and Rees, 1996, 1998; Newell *et al.*, 1998; Desprez, 2000; Birklund and Wijsman, 2005).

An experimental dredging, carried out offshore North Norfolk (Great Britain, trailer dredging) for the extraction of gravel-sand sediment, generated an over-2 meters-high step, and an increase in the height of the gravel section due to the outcropping of an underlying gravel layer. After 1 year, the signs – which had further eroded – were still visible, while 2 years after dredging the traces could only be identified through a Side Scan Sonar (Kenny and Rees, 1996). Sea bottom transport reached a new equilibrium after 3 years, when the superficial sediments finally proved similar to those removed before dredging (Kenny *et al.*, 1998).

Offshore Dieppe (France), industrial dredging of coarse sediment (gravel-coarse sand) has caused the sea bottom to lower by over 5 m. Following dredging, the superficial sediments' grain size characteristics changed, and the sediments were found to be progressively dominated by fine sand due to overflow and/or bottom transport. In this area, the signs were still visible after 4 years from the cessation of dredging, and near the area dredged for industrial purposes, the Authors describe the existence of a hollow that is still visible after 9 years (Desprez, 2000; Birklund and Wijsman, 2005).

In the Dutch tide plains (North Sea), deep hollows produced by an anchor dredge used for sandy sediment extraction remained such for over 13-14 years; within these holes, the accumulation of sediments finer than the surrounding ones was reported, and the presence of organic substance concentrations was observed (Birklund and Wijsman, 2005).

In an experimental marine deposit, situated at the Seine's estuary (France), a sea bottom lowering by 5 and 12 m was produced following dredging of sandy sediments; after 15 years, while the deeper section had not undergone any filling phenomena, the shallow portions showed a modest filling of fine sand-silt, ascribable to bottom transport processes and/or to the collapsing of the cavity's wall (Desprez, 2000).

Still in the North Sea, off the Suffolk coasts of England, the moderately deep (only 20-30 cm) furrows produced by the trailer dredges were visible for at least 4 years, while the bottom features generated by the dredgings carried out in the Bristol Channel were only visible for 2 or 3 tidal cycles thanks to the high local mobility of the sediment (Newell *et al.*, 1998).

Recent studies carried out in the frame of the SANDPIT (2005) European Project also highlight how the recovery times of depressions generated by dredgings performed with anchor dredges strongly depend on the influence exerted on local circulation by the presence of hollows. Dredging activities, in fact, modify the pre-existing bathymetry of the dredging area by creating hollows, which cause a subsequent increase in the water column's depth. The altered morphology of the sea bottom may modify the local hydrodynamic conditions, and the change in hydrodynamic conditions can determine variations in the depositional system (Birklund and Wijsman, 2005).

When a current crosses the area occupied by the hollow, its velocity decreases as an effect of the increase in water depth generated by the hollow itself, with subsequent decrease in the water's transport abilities. As a consequence, the bottom load may deposit – together with a certain rate of suspended load – in proximity to the hollow and inside of it (SANDPIT, 2005). If sediment input is not sufficient to fill the hole, the morphological lowering persists in time. In this case (i.e. if the hollow lasts in time, as a result of a persistent alteration of the bottom's bathymetry) there may be an effect on the bottom currents, and this could determine the alteration of the hollow itself and the removal of fine sediments (Birklund and Wijsman, 2005).

All these effects are a function of different factors, such as size of the hollow, the angle between the main axis and the current's direction, the local current's friction power and the bathymetric characteristic around the hollow (SANDPIT, 2005). Generally, however, the hollow's sizes are such that its effects are limited to its adjacent area, and effects on circulation on a wider scale (macroscale) have not been reported (SANDPIT, 2005).

In general, hollow upfilling occurs both thanks to lateral wall collapse (slumping) (***Figure 1.12***), and to fine particulate matter transported by bottom currents, for which the hollow acts as a sedimentary trap. Upfilling is therefore a function of both the local hydrodynamic characteristics, and the dredging activity's intensity, intended as the number of repeated actions of the dredge on a same area, also known as pitting capability (Van der Veer *et al.*, 1985; Gajewski and Uscinowicz, 1993; Newell *et al.*, 1998; Fabi *et al.*, 2004; ICRAM, 2005b).

In the Adriatic Sea, monitoring of a site dredged (through trailer dredging) for extraction of outcropping relict sands, has shown how, 2 years after dredging, the combined effects of the walls' collapse, and re-elaboration of sandy sediments by means of the bottom currents, has been such as to significantly reduce the hollows generated by dredging, as recorded through bathymetric surveys carried out with a Multibeam (Fabi *et al.*, 2004).

Within the frame of studies and simulations carried out to evaluate the effects of sand extraction on the coastal environment, it has been possible to record how hollows situated at depths that are higher than 25 m do not produce effects on wave motion in proximity to the coast, they do not affect the coast's dynamics, and they do not produce measurable variations on the shoreline. It has also been observed that the hollow's impact on the bottom currents is smaller in case of forms

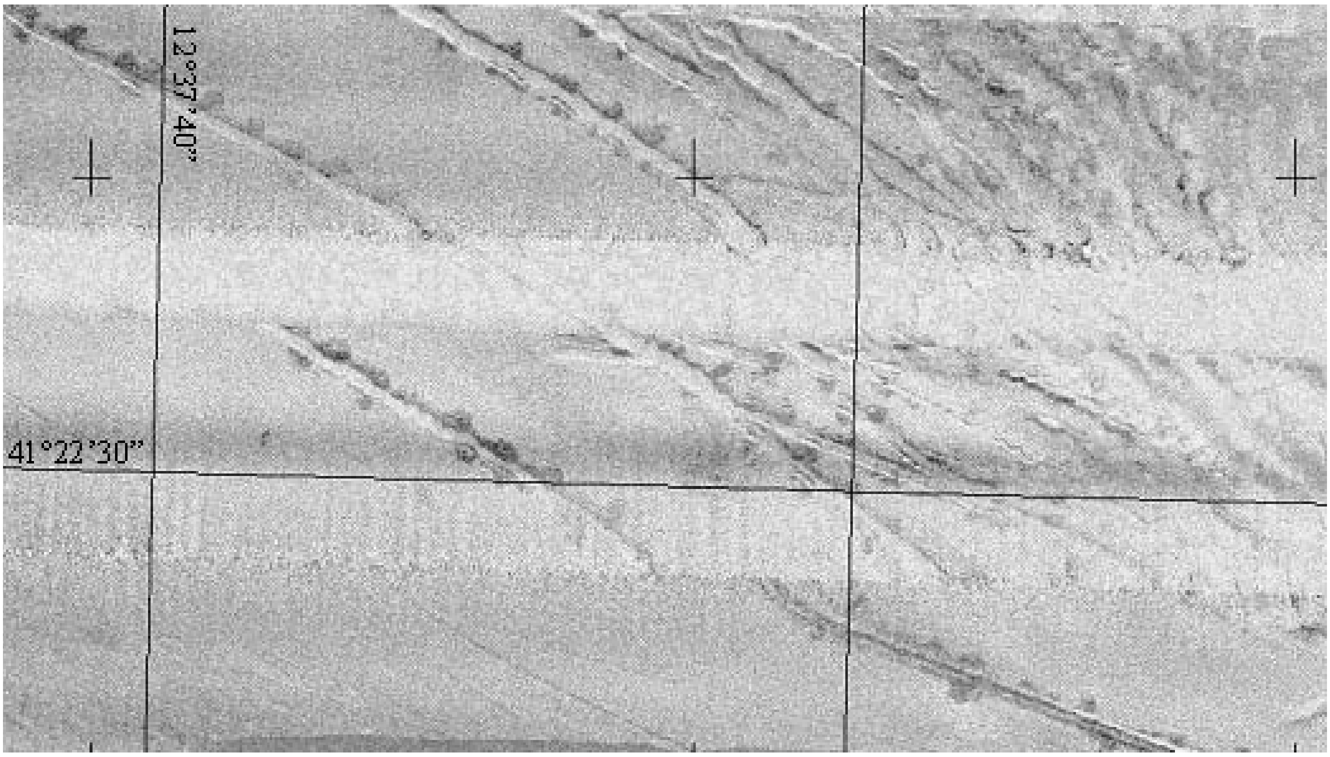


Figure 1.12 – Detail of a morphological relief of a sector situated in the central Tyrrhenian Sea offshore Anzio (central Latium), dredged through trailer dredging. The backscatter anomaly areas on some of the depressions' edges refer to small-scale instability phenomena with collapses along the edges (ICRAM, 2005b).

situated at higher depths, and that the area where the bottom currents are affected by the hollow's presence is sensibly reduced for small hollows situated at high depths (SANDPIT, 2005).

This very case applies to relict sand dredging, as these deposits are not in equilibrium with the actual pelitic sedimentation and, being situated at high depths with low hydro-dynamics, the changes in elevation do not significantly alter circulation, except at a local level.

In particular conditions (e.g. accentuated negative relief, low circulation and sedimentation of fine clay particles) anoxic conditions can develop within the hollows, with the development of heavy metal-rich sediment levels (heavily anoxic sediments), with subsequent worsening in water quality (Newell *et al*., 1998; Louis Berger Group, 1999; Hitchcock and Bell, 2004; SANDPIT, 2005). All of this can present non-negligible effects on marine organisms, resulting in the settlement of communities that are significantly different from those present before sediment extraction (Newell *et al*., 1998).

The importance of fine sediments in filling, and, more in general, in the coating of the forms created by the dredge's action, is confirmed by acoustic surveys. In a relict sand dredging under a thin pelitic layer of recent deposition, carried out in the central Tyrrhenian Sea offshore Anzio (central Latium), Side Scan Sonar surveys performed 3 years after the end of dredging, have not shown evident backscatter differences between the dredging areas and the surrounding sea bottoms, although a sonar chaotic *facies* was visible inside the dredged area (ICRAM, 2005b).

In addition to strictly morphological changes, the sea bottom dredging may generate grain size variations in the superficial sediment. At times, coarse sediment removed by dredging may be substituted with finer sediments (Newell *et al*., 1998; Desprez, 2000; Birklund and Wijsman, 2005); or, within the hollow, an increase in grain size can be observed due to the outcropping of deeper sediment layers, characterized by higher granulometry (Kenny and Rees, 1994, 1996; ICRAM, 2005b).

Therefore, concerning the sediment's characteristics, the bottom's removal can determine, on the one side, the outcropping of the underlying sediment layers, while on the other side it can favour the formation of a new superficial level characterized by high hydration, whose development is due to re-deposition of sediment put into suspension by dredging. In both cases, the new superficial sediment can differ from the original one, in terms of grain size, compaction degree, water contents, shear resistance, and concentration of dissolved oxygen (Brambati and Fontolan, 1990; Desprez, 2000; MMS, 2001; Hitchcock and Bell, 2004).

As a consequence, the variations induced on the superficial sediments in the dredging area are more evident when the dredging causes the outcropping of sediments other than the originally present superficial sediments.

In the specific case of two relict sand dredgings carried out in the central Tyrrhenian Sea offshore Montalto di Castro and offshore Anzio (northern and central Latium, respectively), a pelitic cover of recent deposition can be observed on top of the relict sand deposits, with a thickness that varies between a few centimetres and a few meters: inside the areas dredged, a significant increase in sandy fraction was observed, as a result of sandy deposit outcropping following dredging (ICRAM, 2001, 2005a, 2005b).

In both cases considered, before dredging the sediment considered was characterized by a prevalence of the pelitic component (always > 60%) over the sandy component, while after dredging the sandy fraction present in the superficial sediment was over 90% of the total contents (ICRAM, 2001, 2005a). This can be explained by considering that for the mining of the relict sand deposit it was necessary to remove the superficial cover, constituted by fine sediments of recent deposition, with subsequent outcropping of the underlying coarse deposits.

A comparison between the results observed in case of dredgings carried out in the same area of the Tyrrhenian Sea offshore Montalto di Castro using both trailer and anchor dredges highlighted that, in the first case, outside the dredged areas the superficial sediments presented a modest increase in the fine fractions, while the use of anchor dredges did not seem to cause significant textural variations outside the area subjected to dredging (ICRAM, 2006).

In the subsequent monitoring of the areas dredged in the central Tyrrhenian Sea, a modest increase in the pelitic fraction was observed. This increase can be ascribed to re-deposition processes following the dredging phase (ICRAM, 2001, 2005b). In some of the dredged areas, in particular, the creation of a high hydration and fluidity pelitic layer has been observed, and its geotechnical characteristics were significantly different from the underlying pelitic or sandy sediment, which presents lower hydration and higher density (ICRAM, 2001).

On the opposite, in the case of dredgings carried out in the central-northern Adriatic Sea for extraction of outcropping relict sands, the outcropping sediment had similar characteristics to the originally present one, and no significant granulometry variations were reported, as shown by post-dredging monitoring, carried out in a 3-year period (Fanelli *et al.*, 2003; ICRAM, 2005c).

Finally, in intensely exploited areas (repeated dredging activities), it can be hard to point out significant trends for dredging area recovery, also because of accidental material losses (***Figure 1.13***), identifiable through the bottom's acoustic survey, which can alter, however lightly, the grain size characteristics of superficial sediments (ICRAM, 2005b).

Concerning the sediments' chemical aspects, it is known that their mobilization may involve the re-mobilization of chemical species, if present, with possible effects on the marine ecosystem (Puig *et al.*,1999; Bottcher *et al.*, 2003).

Because of their grain size, geological and attitude characteristic, relict sands do not generally present concentration anomalies due to human action, and, when present, the pelitic coverage protects the sands from possible pollutants. Nevertheless, before dredging, it is always advisable to verify the sand's natural conditions.

By nature (i.e. an elevated specific surface), the recent fine sediments that often cover relict sands present a great affinity to accumulation of chemical species, and re-suspension, which occurs when the shear resistance is high enough to win the material's cohesion, is the most frequent way for contaminants to be re-introduced in the water column and in the particulate cycle (Kim *et al.*, 2004).

Therefore, the aspect we must consider is mainly linked to re-suspension of fine superficial sediment, which could have significant effects on the environment.

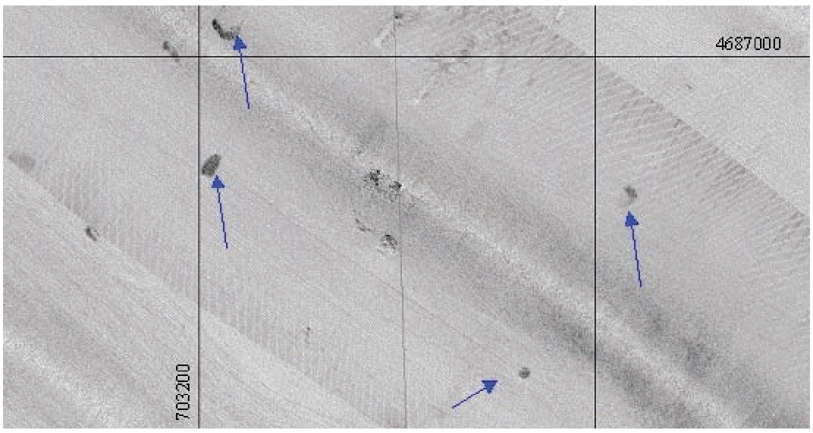


Figure 1.13 – Detail of a morphological relief of a sector situated in the central Tyrrhenian Sea offshore Anzio (central Latium), dredged through a trailer dredge. Backscatter areas ascribable to sand material losses are caused by the dredge's motion (ICRAM, 2005b).

In the specific case of relict sand nourishment, a few considerations are necessary:

- nourishment should only be carried out with sediments that have good chemical qualities, and that do not show concentration anomalies of undefined origin;
- relict sand dredging does not occur in conditions of need or emergency, as is the case, for example, in harbours, where dredging is carried out for the survival of the port itself;
- relict sand deposit research should be performed in areas that are not suffering from pollution phenomena.

Dredging activities with relict sands, with the possible involvement, in the removal phase, of the recent pelitic cover, should only be performed if the characterization phase has revealed and confirmed that the sediments undergoing dredging are natural and not affected by pollution.

1.1.2 Water Column

During relict sand dredging operations, and in different phases of the process or at different depths, sediment may be released along the water column, resulting in the creation of a turbidity plume and subsequent alteration of the natural hydrologic characteristics. The spatial distribution – both horizontally and vertically – of the turbidity plume has an important role in the marine environment's protection. The plume is a temporary phenomenon caused by the input of dredging-suspended solid into the water column, determining a local increase in turbidity. The plume's extension and duration depend on the volume of the mobilized sediment, on the dredge's characteristics and on the local hydrodynamic conditions. Generally, dredging activities lead to the formation of both a superficial plume and a bottom plume (benthic plume).

The superficial plume (***Figure 1.14***) is generated following the overflow of a water/fine sediment mix that occurs mainly during the dredge's loading phase, as an effect of unloading of the excess water sucked in together with the sediment. After the loading phase has been completed, overflow can continue for a few tens of minutes as the vehicle leaves the dredging area.

The plume's long-term permanence, even in the case of good quality sediments with homogeneous textural characteristics, causes a physical alteration, both in the dredging area itself and in the proximal zones. The finest sediments, suspended by dredging, are in fact dispersed in function of the local dynamic conditions, and they can also be deposited at a great distance from the dredging site (ICES, 1996; Hill *et al.*, 1999). This may lead to the creation of a bottom layer, generally constituted of fine sediment, whose thickness varies in function of the volume of mobilized sediment and of its dispersion degree (Louis Berger Group, 1999).

The turbidity level and, therefore, the plume's characteristics, depend on the following variables (Herbich, 2000; Hitchcock and Bell; 2004):

- dredged material characteristics (texture, geotechnics, rheology and microbiology);
- characteristics and procedures of

Figure 1.14 – Superficial plume generated during dredging activities.

dredging operations (size of the area involved, volume of removed sediment, duration of the operation and technical characteristics of the dredging);

- hydrology of the water column in the intervention area, in particular, presence or lack of thermocline, concentrations of suspended solid;
- hydrodynamic characteristics of the intervention area (velocity of current, turbulence, etc.).

In the descending movement of the plume towards the bottom, two phases can be observed: the "dynamic phase", in which the plume rapidly descends downwards as a density current, and a "passive dispersion phase", activated with a certain delay from the overflow moment, as a result of its crossing he water column and of its impact with the sea bottom (Whiteside *et al.*, 1995; Hitchcock *et al.*, 1999). The plume's characteristics and dispersion processes, as well as the area involved in this phenomenon, depend both on the type of sediment involved and on its quality, as well as on the hydrological and dynamic characteristics of the water masses (Hammer *et al.*, 1993; Newell *et al.*, 1998). While the coarser fraction of the sediment is deposited quite quickly, fine sediment remains in suspension, also because of the turbulence produced by the dredge. Observations carried out in the Mediterranean also highlight the development of plumes situated by the thermocline (***Figure 1.15***), with the creation of elongated tails oriented in the current's direction (Toumazis, 1995; ICRAM, 2004; Barbanti *et al.*, 2005). The densest portion of the material released on the surface rapidly descends toward the bottom, while the fine sediments, lighter and therefore less dense, descend slower, forming the plume.

The currents acting along the water column deflect the sediment's descent path, they influence mixing phenomena, and favour the diffusion of the plume in the direction of the current. The denser waters present below the thermocline tend however to act as an obstacle for the bottomwards descent of the finer sediments, partly circumscribing the dispersion phenomena to less dense waters situated above the thermocline.

During dredging, Hitchcock *et al.* (1999) also observe the formation of a smaller plume situated in proximity to the bottom (benthic plume), generated by the effect of the dredging head on the bottom's sediments. The Authors also describe the formation of secondary bottom plumes in which the dredged material, which has just newly deposited, is newly mobilized by tidal currents.

The size of the bottom plume is generally 4 or 5 times lower than that of the superficial plume, from which they are usually incorporated in their descent toward the bottom (Hitchcock *et al.*, 1999).

The size of a dredging-generated plume may also be influenced by pre-existing bottom alterations, caused, for example, by repeated dredgings and/or by trawl fishing. These conditions can determine the amplification of phenomena of sediment re-suspension, which was already altered in its mechanic characteristics. A similar phenomenon

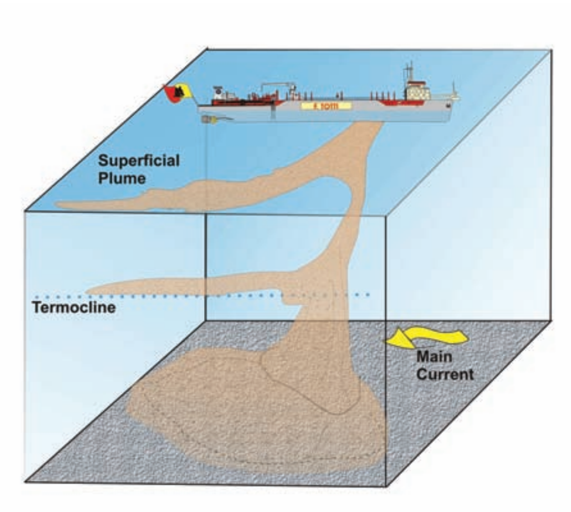


Figura 1.15 - Formation and dispersion processes of a plume generated during overflow. In particular, it is possible to observe the formation of plume situated on the thermocline and elongated in the direction of the current (redrawn from Toumazis, 1995).

has been observed in the Hong Kong territorial waters (Sea of China), subjected to extensive and repeated dredging for the extraction of material for the construction industry (Morton, 1996).

Various studies have been carried out to evaluate both the size of the plume area and the recovery times. Estimates for sandy deposits, calculated on a Gauss diffusion model (Louis Berger Group, 1999), show extremely variable values, from 50 m for coarse sands to 11 km for very fine sands (Newell *et al.*, 1998). Similar estimates carried out for fine sediments indicate distances higher than 20 km, with sediments that remain in suspension for up to 4-5 tidal cycles (Newell *et al.*, 1998).

The experimental observations carried out, however, indicate sizes that are generally lower that those calculated through the above mentioned models, with values comprised – in the case of sandy or silty sediments – between 200 and 500 m in Poiner and Kennedy (1984) and in Hitchcock and Drucker (1996) for dredgings carried out in Queensland (NE Australia) and in East Anglia (United Kingdom) respectively. Also when plumes are mainly composed of fine sediments, experimental observations confirm lower plume sizes than those estimated with various models, which can vary from 1 to 4-5 km (Hitchcock and Bell, 2004).

Hitchcock and Drucker (1996) also illustrate the deposition processes of sediment transported by the plume (total fraction and fine fraction), studying the concentrations of suspended solid through traditional water sampling and transmissometric surveys at different depths and distances (***Figure 1.16***).

Examining the effects of the plume's dispersion in the water column's superficial layer (8 m) 40 minutes after dredging, Whiteside *et al.* (1995), too, report similar discrepancies between the values obtained by the model and the experimental data.

By analyzing the attenuation of light, analyses carried out in the Baltic Sea on the effects of dredging on the re-suspension of suspended solids have shown that the width of the plume was not higher than 50 m and that sediment deposition becomes irrelevant at 150 m (Gajewski and Uscinowicz, 1993). The results of this study are summarized in ***Figure 1.17***.

It has been acknowledged that other factors of biological and physical nature intervene in regulating the transport and re-deposition processes of sediments carried by the plume, thus determining a general increase in sedimentation velocity, corresponding to a decrease of the area interested by the plume (Louis Berger Group, 1999). These factors can be:

- biological processes that mainly involve the particles' ingestion by organisms, with the subsequent development of denser fecal pellets (Louis Berger Group, 1999);
- physical processes concerning the flocculation and aggregation of suspended material of higher sizes (Asper, 1987; Aldridge and Gottschalk, 1988; Hay *et al.*, 1990);
- physical processes generated by the cohesive forces acting on small particulate matter, determining the development of density currents, which are denser, and therefore faster (Newell *et al.*, 1998).

Another process occurring during the plume's formation has been described by Hitchcock *et al.* (1999) and Newell *et al.* (1999). This process consists in the destruction of the biotic component present in the dredged sediment, with subsequent release in suspension of organic matter, in the form of lipids and carbohydrates, whose interaction with the suspended sediment has not yet been well defined. The proposed mechanisms hypothesizes that the presence in suspension of lipids and carbohydrates might reduce the sedimentation rate of fine material, thus favouring the permanence of the plume's visible portion for great distances. The distal portion of the plume has only been recorded by acoustic techniques (Continuous Backscatter Profiling, or CBP, and Acoustic Doppler Current Profiling, or ADCP), while traditional surveys (such as water

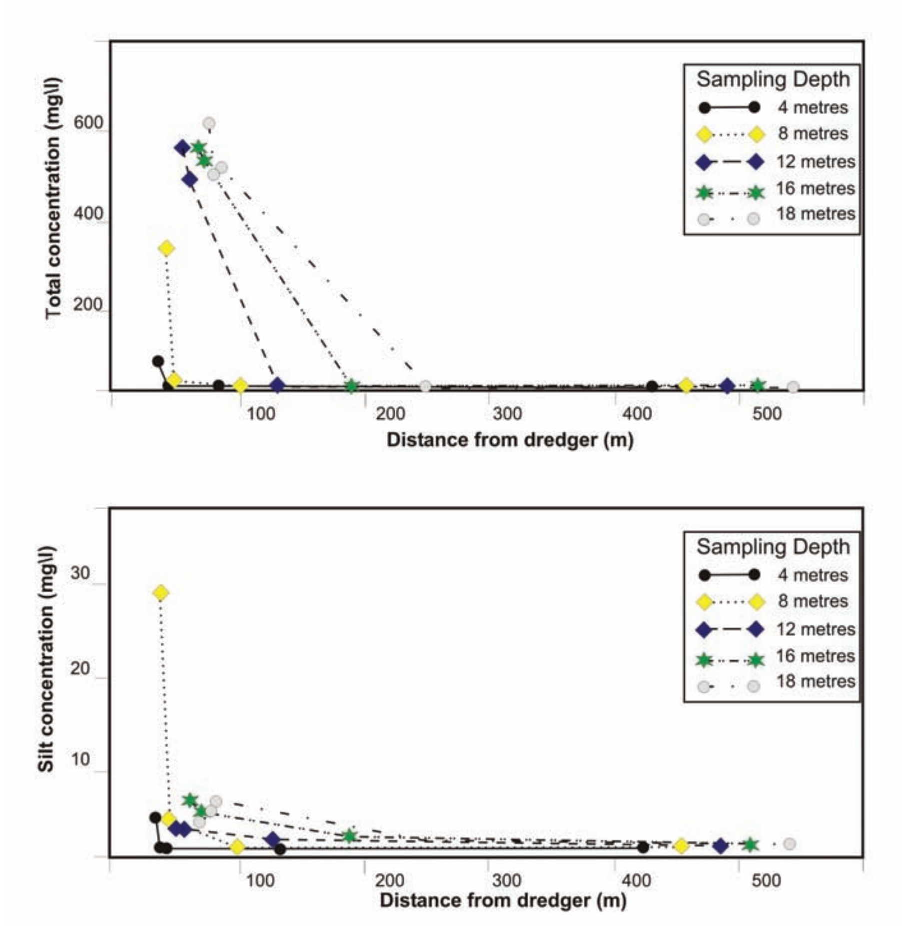


Figure 1.16 – Concentrations of total suspended solid (top) and of the silty fraction alone (bottom) recorded along the water column at different depths and at growing distances from the dredging area, measured through water sampling and optical transmissometry (modified from Hitchcock and Drucker, 1996).

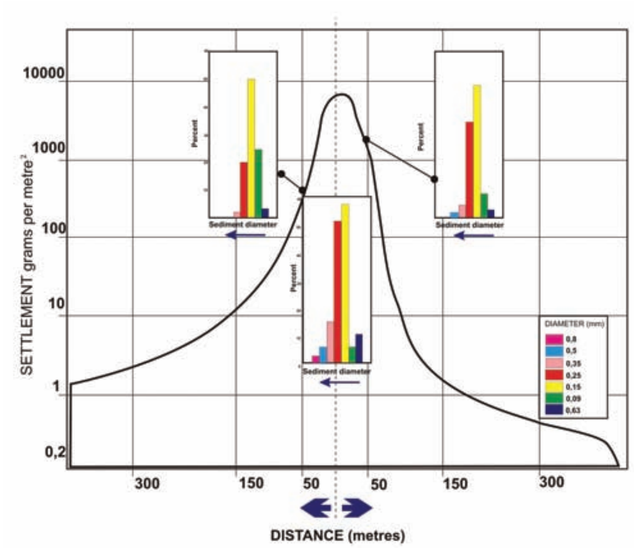


Figure 1.17 – The diagram illustrates the characteristics of the newly deposited sediment following dredging activities carried out in the Baltic Sea through trailer dredging. In particular, the figure shows the grain size distribution graphs of sediment that re-deposited inside the dredging hollow at a 50 m distance. It is possible to observe that most of the sandy sediment mobilized and put in suspension as overflow is deposited within 150 m from the dredging furrow (modified from Gajewski and Uscinowicz, 1993).

samplings and transmissometric measurements) have proven ineffective, as this phenomenon cannot be traced back to anomalous concentrations of suspended solid.

In dredgings carried out offshore the English East Anglia coasts, Newell *et al.* (1998) highlight that on a 22 m bottom, the plume's extension is equal to 400 m when calculated as suspended solid concentration, and 3,5 km when evaluated through acoustic analysis.

The plume is a temporary phenomenon, whose duration is regulated by the same factors governing the sediment's dispersion modes, and it is therefore extremely variable. Newell *et al.* (1998) reported that most of the sediment in suspension is deposited after a time ranging between 20 and 30 minutes. Louis Berger Group (1999) reports that the concentration of suspended sediment decreases quite rapidly during the early dispersion phases, with significant decreases after 1 hour. On the basis of these considerations, we can conclude that the impact generated by the plume is site-specific, and also depends on the season in which the dredging activities are carried out.

PLUME MONITORING DURING RELICT SAND DREDGING ACTIVITIES

In order to evaluate and monitor the turbidity generated by relict sand dredging activities, ICRAM carried out specific studies during the sand extraction activities performed by Regione Lazio (May 2004) on the Latium continental shelf, offshore Montalto di Castro (VT). With this aim, an Acoustic Doppler Current Profiler (ADCP) was used, together with a CTD (Conductivity, Temperature, Depth) multi-parameter probe coupled with turbidity measurement instruments (optical scatterometers or transmissometers) (BEACHMED, 2004).

The use of this method allowed to:

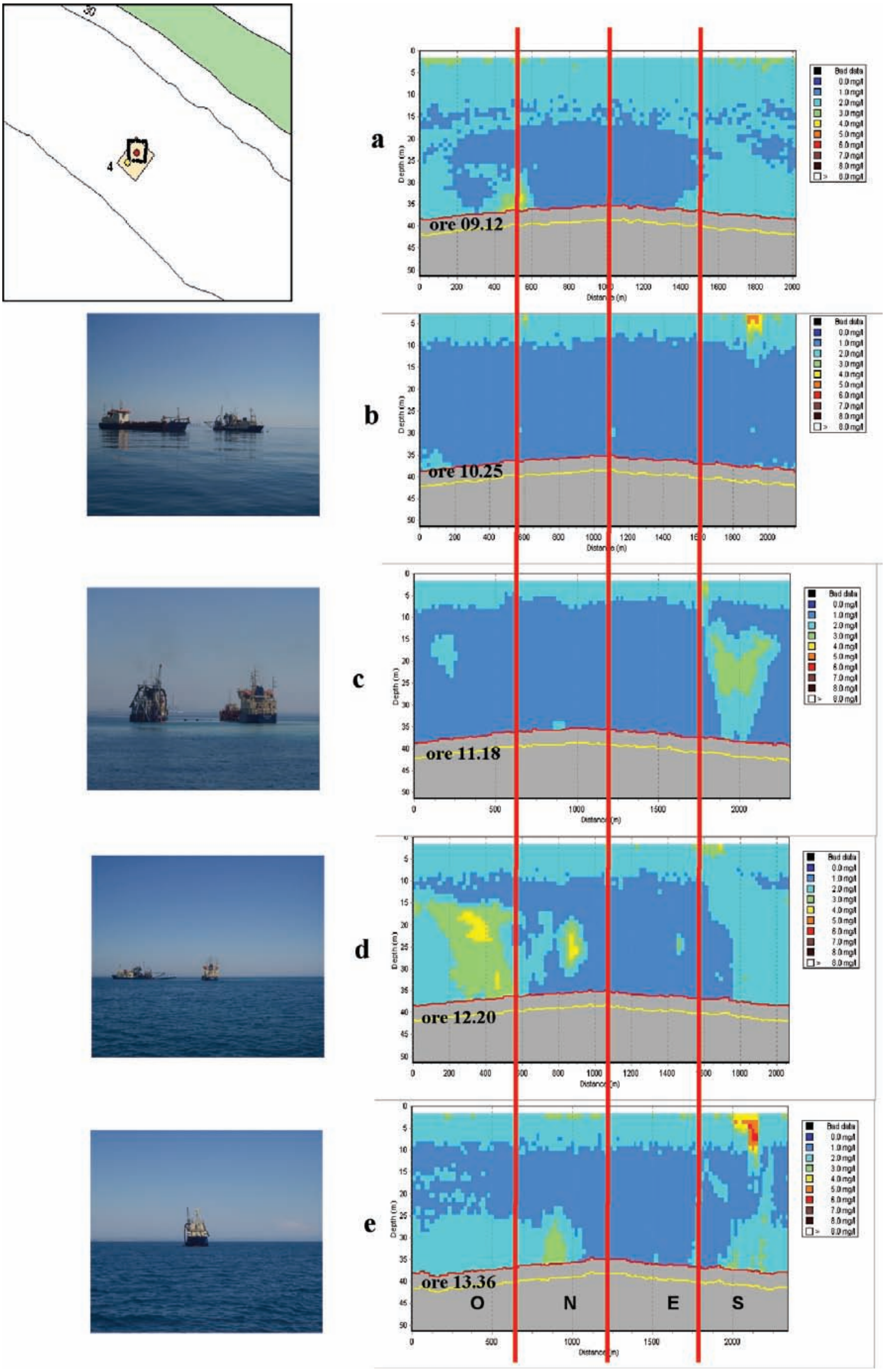
- pinpoint the plume's main direction of dispersion and its relative permanence in time in function of the local hydrodynamic conditions;
- evaluate the entity of dredging-induced disturbance in terms of concentration of solids suspended in the water column;
- verify the possible involvement of sensitive habitats (*Posidonia oceanica* meadows) present in proximity to the dredging area.

The sampling plan involved carrying out current surveys and analyses to characterize the suspended particulate matter and the main hydrologic parameters along appropriately identified transepts. The area's measurement survey has been carried out on 4 consecutive days.

On the first day, before the beginning of dredging activities, the concentrations of suspended solid and the main hydrologic parameters were measured along shoreline-offshore transepts, in order to identify the reference values.

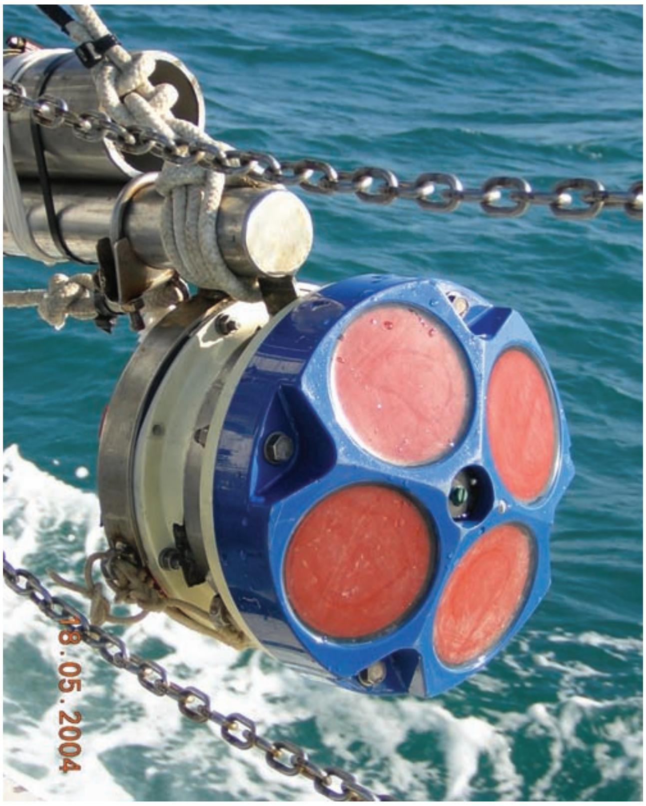
Subsequently, in order to follow and quantify the size of the dredging-generated plume, a series of transepts of variable length, distance and orientation were placed. It was therefore possible to identify the areas interested by the plume in real time and through the visualization of the ADCP.

Turbidity plume observed during relict sand dredging off Montalto di Castro (VT)



Temporal variability of the plume, expressed as concentration of the suspended solid (mg/l)

In order to verify the possible impacts on nearshore habitats (*Posidonia oceanica* meadows), further analyses were performed on the area's currents, hydrology, and suspended particulate matter, along measurement transepts placed on the lines going from the plume's generation point to the involved areas. Finally, the plume's temporal variability was analyzed, carrying out square transepts every hour for total 5 hours, at an average distance of 250 m from the dredge. These transepts have allowed to monitor a whole working cycle of the dredge.
The increase in turbidity generated by the dredging activities appeared to be of low intensity, even in close proximity to the dredge (250 m) where values of 5-6 mg/l were recorded, i.e. higher values compared to the bottom values of about1 mg/l. Such increase was found to not be very persistent: despite the area's low dynamicity conditions, within about 2 hours (less than the time between two consecutive dredging cycles) conditions analogous or not very different from the natural ones were restored in the dredging area.
In this study, the disturbance generated by dredging proved to not be constant in time, but rather highly discontinuous; also, such disturbance only involved limited portions of the water column. In particular, turbidity increases were recorded in well-defined layers: on the surface, as a direct consequence of overflow, on the thermocline, for a 2-4 m width, and on the bottom as a direct effect of sand suction.
Finally, it was also proven that, at about 2 km distance, the turbidity increase due to dredging became indiscernible from the bottom values (blank) recorded for the site, and that the areas to the east-northeast of the dredging area, in which *Posidonia oceanica* meadows were present, were not subject to turbidity increases ascribable to dredging.
It is important to highlight that the results reported cannot be generalized as they are not site-specific: the plume's spatial distribution and evolution depend in fact on the chemical-physical characteristics of the water column characterizing the area at the time of dredging, on the granulometry characteristics of the mobilized sediment, and on the technology used for sand removal.



Acoustic Doppler Current Profiler

1.1.3 Sea Organisms

Two great domains can be identified in the sea environment: the benthic domain, represented by the sea bottoms, and the pelagic domain, constituted by the overlying water masses. The first is characterized by sea bottom organisms (benthos) and the second one by pelagic organisms (plankton and nekton) (Ghirardelli, 1981).

Other particularly relevant groups in terms of environmental studies are nektonic animals such as marine mammals and other endangered sea species (sea turtles and some cetacean species), and sensitive marine habitats (as defined according to the Directive 92/43/EEC), i.e. marine habitats populated by rare, endemic, vulnerable or endangered species.

1.1.3.1 Benthos

Benthic organisms are all the organisms that have any kind of more or less close and constant relationship with the substratum. The substratum may present a great variety of aspects: it may be composed essentially of rocky outcroppings, reefs, piers, etc. (hard bottoms), or it may be composed of non-diagenised incoherent sediment, such as sand and/or mud (soft bottoms).

Relict sand dredging activities and nourishment directly mainly affect soft bottom benthic organisms. Hard bottom benthic organisms, if present near the dredging areas, may instead only indirectly suffer from the effects of such activities.

The main impact produced by relict sand dredging consists in the partial or complete removal of benthic communities present in the dredging area, and in the disturbance induced on such organisms from nearby areas, as an effect of both substratum alteration (granulometry, sediment stability, shear resistance) and of the siltation of the sediment put into suspension in the water column (Snyder, 1976; Auld and Schubel, 1978; Salen-Picard *et al.*, 1997; Harvey *et al.*, 1998; Boyd and Rees, 2003; Diaz *et al.*, 2004). In these latter areas, which are not directly affected by dredging operations, the sediment suspended can damage the filtering apparata of suspensivorous organisms, and the alteration of the substratum's characteristics may determine a change in the microscopic fauna living in the substratum (such as diatoms, bacteria, protozoa, commonly known as the microbial film), which is an important food source for many benthic organisms (Turner and Todd, 1991). The substratum alterations caused by dredging operations, and in particular, the increase in the muddy component, have been found by some Authors (Bonvicini Pagliai *et al.*, 1985; Hitchcock *et al.*, 1999) to be one of the main causes for alteration of the normal biological cycles of benthic organisms, because such an increase affects the recruitment and settling of larvae in the substratum.

Another factor that may influence the dredging area's benthic assemblages is the high quantity of suspended sediment in the water column, put into suspension during the activity, which could affect the photosynthetic processes of autotrophic organisms by altering water limpidity. Nevertheless, in case of relict sand deposits, which are generally situated at high depths (often beyond the euphotic zone limit), the vegetal component of benthic communities is close to zero, and light does not therefore represent a limiting factor.

The studies performed on benthic communities in areas dredged in Great Britain have highlighted that, such activity results in a variation of the assemblage's original structure, with significant decrease in the number of individuals, biomass and diversity (Kenny and Rees, 1994; Newell *et al.*, 1998; Green, 2002; Boyd and Rees, 2003; Newell *et al.*, 2004).

Surveys carried out in Holland by Van Moorsel and Waardenburg (1990, 1991) and Van Moorsel (1993) highlight, right after dredging, a reduction in the abundance values (70%), biomass (80%), and number of species (30%). These Authors state that within a year of dredging, density and number species return to the pre-dredging values, while biomass takes a longer time (2 years) to recover. In the case of dredgings carried out on sandy bottoms off the Australian coasts, Poiner and Kennedy (1984), too, report a decrease in specific diversity, richness, and abundance in the dredged area, but, at the same time, they observe an increase in the surrounding assemblages as a response to the increase in resources (nutrient release) generated by sediment re-suspension. However, the effects produced on organisms by sediment in suspension, decrease with the increase in the distance from the disturbance source (Gray *et al.*, 1990).

The consequences observed on benthic communities situated outside the dredged areas are therefore considered to be of light entity (Blake *et al.*, 1996; Newell *et al.*, 1998; Hitchcock *et al.*, 1999). Surveys carried out along the Tyrrhenian coast in Italy, have shown that, in general, the effects of sediment removal are more evident in “sensitive communities” than in communities that have already been compromised and disturbed before (Aliani *et al.*, 1994). According to Bellan *et al.* (1985), too, the least disturbed communities are the ones that most suffer from the action of the various disturbance factors, and therefore show the effects before others do.

Table 1.1 illustrates some examples of the effect of dredging on benthic communities in different habitats, evaluated according to the changes in their main structural parameters (number of species, number of individuals and biomass). The biomass and number of individuals seem to be the parameters that are most influenced by the dredging activities, while the number of species appears to be more variable and strictly influenced by the type of habitat considered.

Table 1.1 - Effects induced by dredging on benthic communities settled in different habitats, expressed as the variation of the main structural parameters (number of species, number of individuals, and biomass) (modified from Newell *et al.*, 1998).

Location	Type of Habitat	% reduction after dredging			Bibliography
		Species	Individuals	Biomass	
Goose Creek, Long Island, NY, USA	*Shallow lagoon mud*	26	79	63-79	Kaplan *et al.*, 1975
Klaver Bank, Dutch Sector, North Sea	*Sands-gravels*	30	72	82	Van Moorsel, 1994
Lowerstoft, Norfolk, UK	*Sands-gravels*	30	72	82	Newell and Seiderer, 1997a
Tampa Bay, Florida, USA	*Oyster shell*	40	65	90	Connor and Simon, 1979
Dieppe, France	*Sands-gravels*	50-70	70-80	80-90	Desprez, 1992
Moreton Bay, Queensland, Australia	*Sands*	51	46	-	Poiner and Kennedy, 1984
Hong Kong, Japan	*Sands*	60	60	-	Morton, 1996
Lowerstoft, Norfolk, UK	*Gravels*	62	94	90	Kenny and Rees, 1994
Chesapeake Bay, USA	*Coastal embayment muds-sands*	70	71	65	Pfitzenmeyer, 1970

An interesting study was carried out in the Gulf of Fos, France (Salen-Picard *et al.*, 1997), where researchers observed the long term variations produced on macrobenthic fauna at different depths: low-depth communities proved to be the ones that most suffered from alterations, with the occurrence, after the end of the activities, of a assemblage that was very different from the original one, with non-equilibrium conditions after 2 years from the end of the operations. On the opposite, the deeper communities showed no evident variation.

Right after the end of the dredging activities, the dredging area experiences re-colonization processes through the migration of adult organisms from the surrounding areas and/or the settling of larval forms (Bonvicini Pagliai *et al.*, 1985; Van der Veer *et al.*, 1985; Rees and Dare, 1993; Newell *et al.*, 1998; Hitchcock *et al.*, 1999; Wilber *et al.*, 2003; Nicoletti *et al.*, 2004b). In the first phases of recovery process, the benthic community will mainly be constituted by individuals of small sizes which generally populate the most superficial layer. Some Authors state that organism mobility in particular is an important factor in the re-colonization process, therefore the first organisms to re-populate the area would be errant polychaetes, followed by crustaceans and mollusks (Stickeney and Perlmutter, 1975; McCauley *et al.*, 1977).

Concerning the times for re-colonization, numerous studies report times varying between 1 month and 1 year (Green, 2002). The first organisms to arrive belong to pioneer and/or opportunist species, such as polychaetes of the *Streblospio*, *Capitella*, *Owenia*, *Scolelepis*, and *Chaetozone* geni, amphipods *Corophium* and *Ampelisca*, and mollusk *Corbula gibba* (Bonvicini Pagliai *et al.*, 1985; Curini Galletti, 1987; Crema, 1989; Crema *et al.*, 1991; Newell *et al.*, 1998; Seiderer and Newell, 1999; Nicoletti *et al.*, 2004b). In particular, as observed in surveys carried out in a site offshore Capo di Anzio (Rome), along the Tyrrhenian continental shelf, *Corbula gibba* can rapidly colonize the defaunated substratum following dredging activities, acting as a pioneer species and taking on the typical role of opportunist species. This species develops quickly thanks to its high reproductive potential, and to the absence of competitors (Nicoletti *et al.*, 2004b).

On the opposite, the presence of organisms with low reproductive rates and slow growth present longer recovery times, as is the case for communities living in the cold waters of the Arctic, where latitude and temperature influence the species' biological cycle, bringing the dredged areas' recovery times to 10-12 years (Wright, 1977; De Groot, 1979; Aschan, 1988).

Bonsdorff (1980) describes a process of re-colonization of the sea bottoms dredged in polluted areas (Raisio Bay, Finland), describing three phases: the first phase is characterized by the presence of few opportunist species, with high abundance; the second phase, by an increase in the number of species, both in terms of abundance and biomass, and finally, the third phases is characterized by the assemblage' stabilization, with a general decrease in abundance and biomass.

The dominance of opportunist species in the initial phases of the re-colonization seems to be linked to the presence of material of recent sedimentation, which has not consolidated (Newell *et al.*, 1998, 2004); not always, however, do sedimentary instability and enrichment in organic material (associated to the increase in suspended solid) seem to be sufficient conditions to determine the high abundance observed in some species after dredging (Nicoletti *et al.*, 2004b).

The species settling on the dredged substrata give rise to a succession characterized by different assemblages, up to the complete recovery of the area. Newell *et al.* (1998) consider that a community has recovered only when at least 80% of the initial specific diversity and biomass are reached. In Ellis and Hoover (1990) and C-CORE (1996), recovery is defined as the arrival to a final stage where there is one community that is similar to the pre-dredging one in terms of species composition, assemblage density and biomass.

The structure of the benthic community observed after dredging, does not always present characteristics similar to the original one (Louis Berger Group, 1999). In various areas it was in fact observed that the post-dredging assemblage reaches similar values of total abundance and specific diversity, but not the same specific composition (Van Dolah *et al.*, 1984; Wilber and Stern 1992; Green, 2002).

The recovery times of the communities dredged are quite variable and strictly depend on the type of habitat, sediment grain size composition and degree of hydro-dynamism (Van Dolah *et al.*, 1984; Evans, 1994; Kenny and Rees, 1996; Newell *et al.*, 1998, 2004). In addition to the size of the dredged area, the duration of dredging operations, too, has a direct influence on the recovery of the benthic communities involved: small interventions – in terms of space and time – allow for a relatively fast recovery, while large dredgings have a long-lasting effect (Van Dalfsen *et al.*, 2000).

Table 1.2 illustrates the data gathered in literature on the recovery times of some benthic communities settled in different habitats.

Table 1.2 - Post-dredging recovery times of the benthic fauna in different habitats (modified from Newell *et al.*, 1998).

Bibliography	Location	Type of habitat	Recovery times
Bonsdorff, 1980	Raisio Bay, Finland	*Shallow brackish water*	2 years
Clarke *et al.*, 1990	Mobile Bay, Alabama, USA	*Channel Muds*	6 months
Courtnay *et al.*, 1972	Florida, USA	*Coral reefs*	> 7 years
Crema & Valentini, 1998	Cagliari Gulf, Italy	*Fine sands, silt and clay*	30 months
De Groot, 1979; 1986	Dutch Coastal Waters, Netherland	*Sands*	3 years
Desprez, 1992	Dieppe, France	*Sands-gravels*	> 2 years
Desprez, 2000	Dieppe, France	*Sands-gravels*	> 28 months
Diaz, 1994	James River, Virginia, USA	*Freshwater semi-liquid muds*	3 weeks
Kaplan *et al.*, 1975	Goose Creek, Long Island, NY, USA	*Lagoon muds*	> 11 months
Kenny & Rees, 1994, 1996	Lowestoft, Norfolk, UK	*Gravels*	> 2 years
Maragos, 1979	Hawaii, USA	*Coral reefs*	> 5 years
McCauley *et al.*, 1977	Coos Bay, Oregon, USA	*Disturbed muds*	4 weeks
Bonvicini Pagliai *et al.*, 1985	Cagliari Bay, Italy	*Channel muds*	6 months
Pfitzenmeyer, 1970	Chesapeake Bay, USA	*Muds and sands*	18 months
Rosenberg, 1977	Byofiord, Sweden	*Fjord-like estuary*	1 year
Sardà *et al.*, 2000	Bay of Blanes, Catalan Coast, Spain	*Shallow soft bottom*	> 2 years
Taylor & Saloman, 1968	Boca Ciega Bay, Florida, USA	*Shells-sands*	10 years
Van Dalfsen *et al.*, 2000	Torsminde, Denmark North Sea	*Coastal assemblage*	2-4 years
US Army Corps of Engineers, 1974	Tampa Bay, Florida, USA	*Oyster shell*	> 4 years
Van Moorsel, 1994	Klaver Bank, Dutch sector, North Sea	*Sands-gravels*	1-2 years
Wright, 1977	Beaufort Sea, Canada, USA	*Sands-gravels*	12 years
Van Dalfsen *et al.*, 2000	Tershelling, Netherland North Sea	*Coastal assemblage*	2-4 years
Van Dalfsen *et al.*, 2000	Daurada Coast, Spain	*Infralittoral open sandy coast*	> 4 years

Other essential factors in the recovery process are the type of community present and its degree of adaptation to disturbance (Newell *et al.*, 1998). It is well-known that some taxonomic groups are more tolerant to dredging-induced disturbance than others (Morton, 1996; Harvey *et al.*, 1998; De Grave and Whitaker, 1999). It has been observed that the recovery of the equilibrium conditions in a relatively short time is possible when there are benthic communities that have already adapted to dynamic equilibrium conditions with periodic disturbance of the sea bottom (Evans, 1994), or to high hydrodynamic conditions. The recovery of communities in dredged areas can occur after 3 months from dredging (Van Dolah *et al.*, 1984) or within 2 years (Kenny and Rees, 1996), but the values of abundance and specific diversity observed are still lower than the initial ones.

Some Authors hold that dredging only causes temporary effects, and that it takes up to 2 years for the sedimentary cover and community to recover, reaching conditions similar to the initial ones (Harvey *et al.*, 1998); other Authors, instead, hypothesize relevant effects lasting for a very long time (100-125 years) or, in case of mobilization of great quantities of material, even irreversible effects (Toumazis, 1995).

Another factor regulating the processes and reaction times of benthic communities in dredged areas is seasonality (i.e. the season in which the dredging operations are carried out). In temperate seas, seasons can in fact affect the colonization process, because many benthic species' reproductive period almost always coincides with a particular period of the year (Brown and Swearingen, 1998; Lin and Shao, 2002; Taylor and Wilson, 2003).

The study of benthos is a useful instrument for marine environmental monitoring, and it has proven to have a great importance in impact studies related to relict sand dredging. Benthic communities are in fact widely used as descriptors of the environmental characteristics and as indicators of the marine environment's alterations induced by human activity, as they have the following characteristics:

- They are generally sedentary organisms that reflect the local environmental conditions;
- They have relatively long life cycles;
- They include various species with different life cycles, different trophic roles and different degrees of tolerance in stress conditions;
- They play a crucial role in the exchange of nutrients and materials between the sediment and the water column;
- They present close relationships with the main environmental parameters (substratum, temperature, oxygen, salinity and depth).

Through the study of structural modifications of benthic communities and of inter-specific interactions, it is possible to trace the main influence and disturbance factors induced by sediment mobilization.

Knowing the ecology of the single species also allows to identify particular species or groups thereof, that can be used as biological indicators, because their presence or absence indicates a particular environmental condition (Della Croce *et al.*, 1997; Occhipinti *et al.*, 2003). In order to study the effects on benthos of sediment removal, the variables used (as structural indices) are not all equally effective. For example, in a study carried out in the Gulf of Saint Lawrence (Canada) on the effects on the benthic communities of dredged material discharge, Harvey *et al.* (1998), highlight the higher effectiveness of some indices, such as the number of families, specific richness (d) and the relationship between trophic groups, in relation to total abundance and to diversity (H') and evenness (J) indices. In case of relict sand dredging offshore the Tyrrhenian Latium coast, however, the use of the main structural indices (number of species, number of individuals, specific richness index, evenness index and specific diversity index) proved particularly effective to identify the disturbed area and to evaluate the entity of the effects of sediment extraction (ICRAM, 2005a; Marzialetti *et al.*, 2006). Numerous studies carried out to evaluate the environmental effects of human activities have shown that benthic organisms belonging to specific systematic groups are more sensitive to environmental alterations than others (Roberts *et al.*, 1998). It is therefore possible to use them both as generic disturbance indicators and as indicators of specific disturbances (Salen-Picard *et al.*, 1997). The systematic groups that are most represented – both in terms of number of species and of number of individuals – in the soft bottom benthic assemblages are, generally, polychaetes, gastropods and bivalve mollusks and malacostracan crustaceans (decapods and amphipods). Many polychaetes species are good indicators as they are particularly fit for environmental monitoring studies (Bellan, 1984); these organisms occupy highly diversified food niches, thus positioning themselves at different trophic levels in the macrobenthic communities and therefore representing effective descriptors both functionally (Bianchi and Morri, 1985) and structurally (Gambi and Giangrande, 1985). Mollusks, too, can be considered effective descriptors of the ecological conditions of the marine coastal environments as they are strongly linked to the sediment's texture (Gambi *et al.*, 1982). Concerning the crustacean group, amphipods, with their richness in species and individuals, present a great ethological-functional variability, thus covering a wide array of ecological conditions (Scipione, 1989; Scipione and Fresi, 1984).

MONITORING OF THE BENTHIC COMMUNITIES

ICRAM has carried out numerous environmental impact studies related to relict sand dredging for beach nourishment. The survey's procedures to evaluate environmental compatibility and the possible impact generated by dredging and nourishment activities were subdivided into three phases:
1) before (characterization of macroarea and of intervention site);
2) during (monitoring during the activities);
3) after (monitoring after the activities or *post operam*).

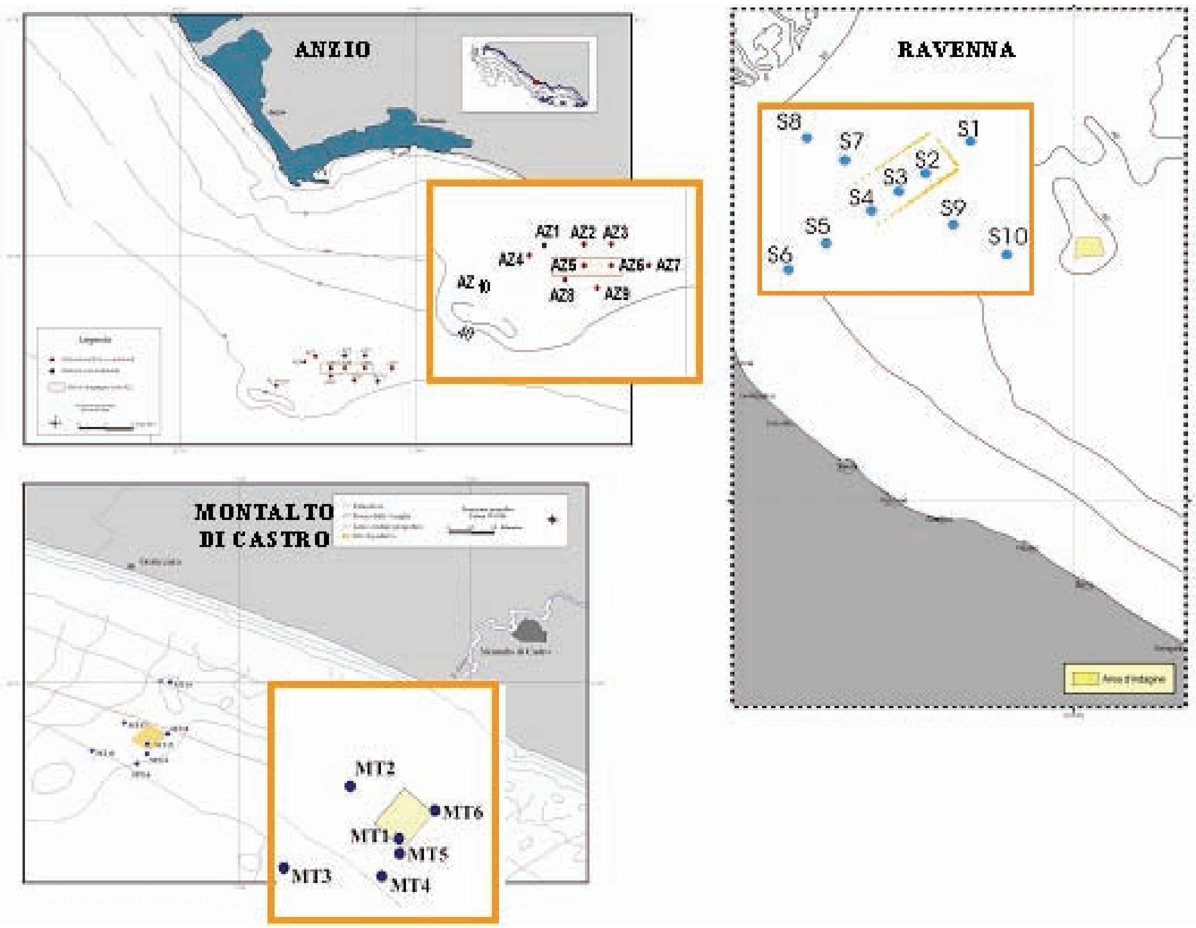
The following illustrates a synthetic summary of the post-dredging monitoring studies in three different areas of the Italian continental shelf: offshore Capo di Anzio (2001) and Montalto di Castro (2004) (central Tyrrhenian Sea) as commissioned by the Regione Lazio, and offshore Ravenna (2002) (northern Adriatic Sea), commissioned by ARPA Emilia-Romagna. For each study area, a specific sampling plan was defined, articulated in different time cycles, and performed according to the dredging area's chemical-physical and biological characteristics to the technical characteristics of the dredging operations (size of dredged area, volume of sand extracted, type of dredge used).

The samplings were carried out in every station, using a Van Veen grab (grab area of 0.1m^2), with two replicates of each sampling in each station. The organisms found were identified on a species level, and then counted.

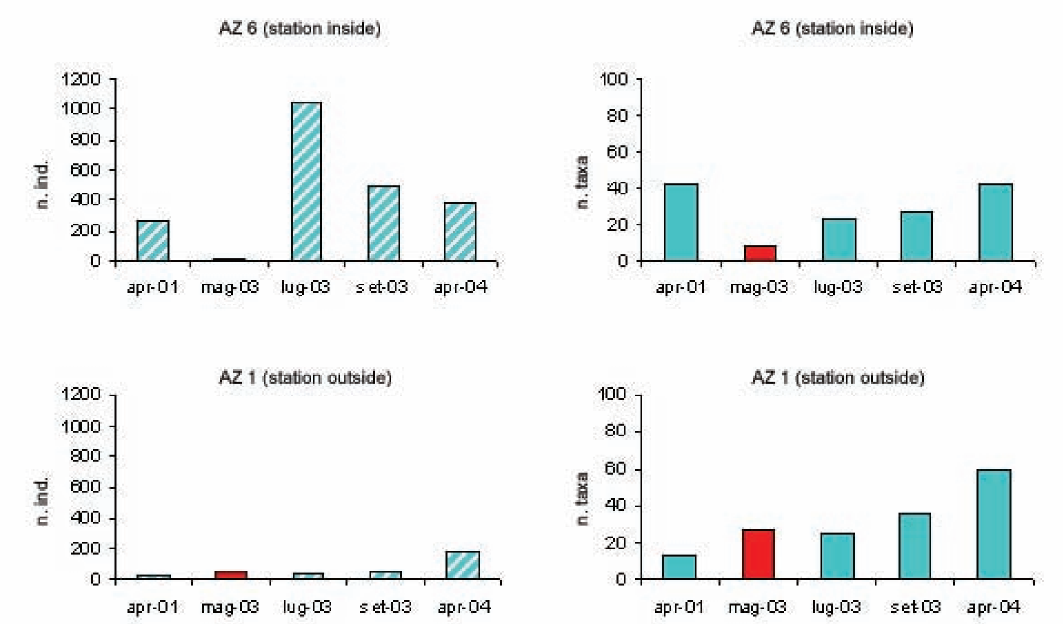
The results obtained for the different areas highlight that the impact on benthic assemblages is generally limited to the area directly involved in dredging, or to strictly neighbouring areas. The benthic communities' recovery times were found to be different in each area: offshore Ravenna, recovery of the initial conditions was observed after 18 months from the cessation of dredging; offshore Capo di Anzio, the benthic assemblage appeared to be well-structured after 11 months from dredging, though its specific composition was different from the original one; offshore Montalto di Castro, only 2 months after dredging the communities showed species richness values similar to those observed before dredging, however with lower abundance values.

The results obtained in this study lead us to the observation that the procedures and times of recovery processes in benthic communities generally depend on both environmental factors and technical characteristics of the dredging operations, such as the survey area's size, the dredging period and duration, and the volume of sand dredged.

Benthos sampling by means of a Van Veen grab



Study areas and sampling stations



Number of individuals and taxa collected in stations AZ6 and AZ1 offshore Capo di Anzio. Sampling carried out during dredging operation is in red

1.1.3.2 Plankton

Plankton is composed of animal or plant organisms (zooplankton and phytoplankton) that are unable to carry out sufficient autonomous movements to oppose waves and currents, and are therefore passively transported by them. On the basis of the organisms' life cycle's characteristics, a distinction can be made between holoplankton – organisms that spend their whole life in suspension – and meroplankton – organisms that are planktonic for just a part of their existence (eggs and larval stages of animals leading a benthic or nektonic life as ad adults, or, on the opposite, adult stages of organisms, such as some jellyfish, with benthic youth stages) (Ghiradelli, 1981).

Concerning the effects on plankton of relict sand dredging activities, the specialized literary production on the matter is not very abundant.

The (controversial) effects on plankton of sand dredging are mainly linked connected to the increase in suspended solid, and, therefore, in turbidity, generated by the re-suspension of sediment in the plume. For this reason, considering that the plumes are generally limited in size, and that they have limited duration, various Authors only record minimal, short-term effects (Hammer *et al.*, 1993; Hardaway *et al.*, 1998), that are considered of acceptable entity (MMS, 2001).

In particular, zooplankton is directly affected by the suspended sediment load, which causes abrasion and congestion in the organism's branchial apparatus (Snyder 1976; Auld and Schubel 1978); according to Jones and Lee (in Louis Berger Group, 1999), however, such effects are to be considered negligible even in case of very high concentrations of the suspended solid.

The main disturbances involving phytoplankton are always connected to an increase in turbidity, which may inhibit the organisms' photosynthetic ability (Louis Berger Group, 1999); in this framework, Lee and Jones (1992) state that such decrease is rarely able to generate a significant impact on these organisms.

1.1.3.3 Nekton

Nekton is the group that includes all water organisms who live their whole life (or part of their life) suspended in the water (many nektonic fish have planktonic larval stages and youth phases), and that are able to actively swim, winning over the power of currents. Nekton is mainly composed of fish, but also includes crustaceans, cephalopod mollusks, and a relatively small number of reptiles (turtles, snakes), birds (penguins), and mammals (cetaceans and pinnipeds) (Ghirardelli, 1981).

The effects of dredging on nektonic organisms mainly affect demersal species (i.e. nektonic species with a more or less constant relationship with the sea bottom). These species are in fact strictly linked to the sea bottom, on both a trophic and reproductive level, and are therefore more sensitive to variations in the sea bottom's characteristics. Such variations are mainly connected to the suspension of sediments in the water column and to the sediment's subsequent re-deposition on the bottom (ICES, 2000). Repercussions at a trophic level also affect demersal species if the dredging operations result in a decrease in benthic organisms, with subsequent reduction in food availability for nektonic species (Oakwood Environmental, 1998). Demersal species may also strongly suffer from the presence of great quantities of suspended solid, with effects like the removal of the protective mucus covering their bodies due to abrasion phenomena, and the occlusion of their branchial apparatus (ICES, 2000).

Also, the decrease in light penetration along the water column resulting from the increase in suspended solid can cause a reduced eyesight in fish, influencing their behaviour and reducing their efficiency as predators. It has been observed that the demersal fish assemblages' distribution in dredged areas is linked to the recovery rate of the benthic assemblages (Green, 2002). Authors have observed a greater availability of food during and right after dredging, at least at a local level, and this has represented an attraction for the fish species present in the area. For non-sedentary species who spend only a part of their life cycle in these areas, the impact can be considered minimal or non-existing (Hammer *et al.*, 1993; Louis Berger Group, 1999).

When the dredged area is very wide, and when the dredging operations last for a very long time, the sea bottom mobilization activities could influence some fish's migration behaviour, especially if the activities occur in critical periods of their life cycle (ICES, 2000).

As a consequence, the effects of dredging may be reduced and/or avoided by suspending the dredging activity during the phases in which organisms are most sensitive, i.e. during deposition and recruitment (OMOE, 1994; ICES, 2000). The concept of environmental windows is based on this principle (Dickerson *et al.*, 1998) and it derives from the concept of seasonal restriction by Schubel *et al.* (1978). Environmental windows represent the optimal periods in which dredging can be performed with an acceptable impact on biological resources.

1.1.3.4 Sensitive Habitats

"Sensitive" marine habitats (Directive 92/43/EEC) are characterized by endemic, rare, vulnerable, or endangered species that are particularly sensitive to the variations in the abiotic parameters (light, salinity, temperature, turbidity, etc.) and to environmental stress, be it natural or anthropic. In the specific case of the Mediterranean Sea, these habitats are mainly to be ascribed to the maërl *facies* of the Coastal Detritic biocoenosis, to the Coralligenous biocoenosis, and to the biocoenosis of *Posidonia oceanica* meadows. Maërl bottoms are characterized by the persistent presence of *Corallinaceae* algae *Lithothamnion corallioides* and *Phymatolithon calcareum*, both considered species with community value in the Habitat Directive (92/43/ECC), which also recommends that their removal be compatible with their conservation (Bressan *et al.*, 2001; Nicoletti *et al.*, 2003).

Hard bottom benthic communities (Coralligenous biocoenosis) and *Posidonia oceanica* meadows that are not directly involved in sand extraction activities can indirectly suffer from the increase in turbidity caused by the mobilization of the surrounding sea bottoms. This mobilization could in fact limit light penetration, thus damaging autotrophic organisms. Also, re-deposition of fine materials put into suspension by dredging activities could damage many of the organisms present in sensitive habitats.

Particular attention must be paid to the *Posidonia oceanica* meadows (an endemic species in the Mediterranean), recognized as a "priority habitat" according to the Directive 92/43/EEC (Habitat Directive), therefore included in the special areas of conservation called "Natura 2000" (as a Site of Community Importance, SCI). In the event of interventions to be carried out on a SCI or in its surroundings, an assessment of implications must be performed following the "precaution principle", as nationally provided for in art. 6 of the Italian DPR 12 March 2003 n.120 (G.U. n. 124 30 May 2003).

The environmental and regulatory aspects linked to safeguarding *Posidonia oceanica* meadows are examined in detail in paragraph 1.3.3.3 (nourishment area, sensitive habitats).

1.1.3.5 Sea Mammals and other Endangered Species

The only possible risk for sea mammals and other endangered species lies in the possibility that they may hit the nautical vehicles operating during dredging, associated with the risk connected to disturbances linked to the activity itself (for example, noise). It is well known that collision risks are directly correlated to the duration of the operations and to the size of the dredged area. Therefore, at least in the event of dredgings for nourishment carried out in the Mediterranean Sea, this risk is certainly negligible, while the same cannot be said in the event of repeated dredgings carried out for the management of navigable channels or for the extraction of inert materials for industrial purposes (Louis Berger Group, 1999).

1.1.4 Legitimate Use of the Sea

In the environmental studies related to relict sand dredging activities, great attention must be paid to the identification and characterization of the legitimate uses of the sea present in the dredging area. Some of these legitimate uses do not allow to carry out dredging activities.

The sea's legitimate uses include areas of naturalistic and/or archaeological value, protected by specific regulations and/or conventions, ministerial resolutions, etc., such as for example Marine Protected Areas (MAPs), national parks, special areas of conservation called "Natura 2000" and marine archaeological areas. In particular, it is important to mark the presence of valuable natural areas wherever sea bottom removal is scheduled, in order to correctly plan dredging activities, and to possibly design appropriate measures for the mitigation of the effects (Pellegrini *et al.*, 2002).

Other uses of the sea that could induce important limitations to dredging activities are linked to the presence of human activities, such as mariculture, infrastructures like offshore structures, cables, pipes or oil-pipes, as well as areas with particular uses such as authorized areas for harbour-material disposal.

It is therefore essential to identify these areas during the planning and definition phases of relict sand dredging programs.

1.2 TRANSPORT AREA

The alterations produced on the physical environment during relict sand transport operations from the dredging area to the nourishment site are quite limited in space and time. Such alterations essentially concern the water column (chemical-physical characteristics and suspended solid concentrations), because of the turbidity generated by the dredge's overflow (turbidity plume), and the substratum, due to the deposition of the material carried by the plume. In general, these effects are very limited and they can be considered negligible. The effects on biological resources will therefore also be limited and may be considered irrelevant. Particular attention must be paid when the transport area or its immediate surroundings include sensitive habitats, such as *Posidonia oceanica* meadows, and/or if the area is a known crossing path for marine mammals.

The activities' planned duration is a factor that shall not be underestimated. If transport takes a considerable amount of time, the sum of the effects deriving from the single events may determine the persistence in time of anomalous turbidity levels, with possible relapses on the sensitive habitats present.

Figure 1.18 – Turbidity plume generated during sand transport from the dredging site to the nourishment site.

1.2.1 Water column

The changes in the physical environment caused by sand transport are mainly generated by the roiling of the water column, produced by the plume generated by overflow during sand transport from the dredging sites to the nourishment sites (***Figure 1.18***). As previously discussed (paragraph 1.1.2), the plume's impact is definitely temporary and governed by the factors that also regulate its size and shape (suspended sediment concentration and grain size distribution, characteristics of the current at surface and in depth at the time of transport, velocity, and the dredge's route). The suspended sediment plumes produced during relict sand dredging operations are generally rather limited in size, and they vary in a way that is inversely proportional to the grain size of the sediments in question (Hammer *et al.*, 1993; Newell *et al.*, 1998).

The plume, caused by overflow processes, is born during the loading phases, and its intensity tends to decrease with time, and therefore as the space covered increases.

1.2.2 Sea Organisms

As far as the transport area is concerned, the most important effects generated by sand transport are the ones produced on sensitive habitats and/or marine mammals. For these effects, see paragraph 1.3.3.3 on *Posidonia oceanica* and paragraph 1.1.3.5 on sea mammals.

1.3 NOURISHMENT AREA

Nourishment activities can produce important modifications, both in the sea bottom's morpho-dynamics and characteristics, as well as on the water column.

Concerning biological resources, the most relevant effects involve benthic assemblages – with particular reference to sensitive habitats situated in proximity to the beach – and fish assemblages. The effects are mainly associated to the coating process generated during sand replenishment, to the difference in geotechnical characteristics and grain size between recently deposited sediments and the pre-existing ones, and to the temporary increase in water turbidity (***Figure 1.19***).

Figure 1.19 – Turbidity plume generated by sand replenishment on the beach.

Particular attention must be paid to the presence of benthic organisms such as mollusks that are the object of professional fishing, because the effects of nourishment on mollusk assemblages can have significant social-economic relapses (paragraph 1.3.3.1).

1.3.1 Sea Bottom Morpho-dynamics and Characteristics

Nourishment activities, which allow for the re-modelling of the whole beach profile, begin with sand replenishment on the emerged portion of the beach (B.N.P., 1995). From here, sediment is distributed seawards by wave motion, along the submerged beach and down to the maximum depth where wave motion is active (closure depth of the active beach), and it is finally deposited along the new equilibrium profile. The material mobilized along the coastal area can also give rise to the development of temporary elements (bars) that disappear following the natural action of wave motion.

The grain size and composition characteristics of the sediment used for nourishment, as well as the volume of spilled material are important factors in the definition of the effects produced on the beach's physical environment.

Therefore, the beach's physical alterations in terms of sea bottom characteristics (morphology and composition) include:

- changes in the shoreline which, if modified, can determine significant variations on the wave motion refraction phenomena, therefore modifying local sedimentary transport;
- variations in the sedimentation rates;
- changes in the sediments' geotechnical and granulometric characteristics.

Variations in coastal bathymetry and morphology can also be caused by the movement of finer material which, right after sediment deposition on the beach, may be transported seawards and/or along the coast, giving rise to the development of temporary elements (bars), which will disappear following the action of wave motion.

Since nourishment involves the input of new material, significant variations of the beach's physical environment may be observed even when nourishments are carried out with sediments whose composition and grain size distribution are similar to the initial sediment; these changes are due to variations in certain parameters such as compaction degree, shear resistance, and humidity contents (Nelson and Dickerson, 1988; Green, 2002).

The changes in the beach sediment, related to the textural, geotechnical, and compositional characteristics, can also cause the grains to assume different aesthetic characteristics (size, nature and colour) from the original sands. In particular, while the sands' grain size distribution is an essential aspect in order to maintain the beach's equilibrium profile (and is therefore appropriately studied in the planning phase), other characteristics such as the contents in sea shell detritus, the type of sediments and/or its colour may be of great importance, especially in the case of beaches of particular landscape value.

1.3.2 Water column

Sand replenishment on the beach produces effects on the water column due to the temporary increase in suspended load, and therefore of turbidity. These effects' entity is not relevant compared to the natural turbidity variations observed in this environment.

During nourishment activities, turbidity is high in the immediate proximity of the sand discharging pipes, and it disappears a few hours after the end of the operations (Van Dolah *et al.*, 1984; Green, 2002); 97-99% of the suspended load is deposited within a few tens of meters from the discharge spot (Schubel *et al.*, 1978).

In the case of high wave motion, right after nourishment an even more sensible increase in suspended particle load is observed. This is caused by the movement of the fine fraction, also favoured by the low compaction degree of the just deposited sediment. Turbidity, however, soon returns to values close to the previous ones (Green, 2002).

1.3.3 Sea organisms

The existing literature on the effects of nourishment on sea organisms shows that the most relevant effects involve the benthic and demersal fish assemblages, while the effects on the other biological components (such as plankton) are negligible, and will not therefore be discussed.

1.3.3.1 Benthos

Nourishment activities on beaches may produce significant impacts on the benthic communities present (Green, 2002), though the disturbance's entity is much lower than that observed in the dredging site. The effects' duration is in fact significantly lower, and the communities involved may go back to levels similar to the pre-nourishment ones within a few months (Van Dolah *et al.*, 1984; Green, 2002).

The studies performed only showed temporary alterations in abundance, diversity and specific composition of the intertidal fauna, the changes lasting between a few weeks and a few months (B.N.P., 1995). Most of the areas involved in nourishment are re-colonized by the same species present before the activity (Green, 2002; Wilber *et al.*, 2003).

The main disturbances on the organisms present are directly linked to the spill of materials on the beach, to the worsened water quality as an effect of the increase in turbidity, and to the subsequent decrease in light penetration.

The effects of sand replenishments include:

- suffocation and burying;
- alteration of the sea bottoms in which the assemblages settle;
- alteration of the assemblage dynamics (with important effects on nursery and reproduction areas);
- decrease in the trophic resources.

During nourishment, most of the sand is delivered on the emerged beach and, with time, it travels towards the submerged portion of the beach by means of wave motion. Such displacement may determine the forming of a new sediment layer in the intertidal area, whose thickness can vary between a few centimetres and over a meter. In order to survive, the organisms living along the beaches undergoing nourishment will have to be able to migrate vertically, crossing the sandy cover deposited along the way (B.N.P., 1995). The main issue in evaluating the effects of nourishment is therefore not the temporary loss of the organisms present on the beach, but rather these communities' recovery speed after nourishment has been completed.

The recruitment mechanisms taking place after nourishment were described by Van Dolah *et al.* (1984): migration of adults and youths from the adjacent areas, vertical migration of organisms through the coat of sediment deposited, and input on the beach of organisms transported with the sediment. The success of these mechanisms strictly depends on the thickness of the sandy cover and on the granulometry of the spilled sediment, as well as on the movement ability of the species involved.

Most of the organisms inhabiting the beaches are burrowing species that adapt well to periodic changes and to a stressed environment. The larger and more mobile organisms are the ones that best survive nourishment, by temporarily abandoning the area. This is the case for phantom crabs from North Carolina, which leave the area both because of the physical modifications on the environment, and to search for new food sources (B.N.P., 1995).

Other species, from an intertidal and/or sub-tidal environment, survive nourishment through vertical migration, burrowing through the sand cover (Maurer *et al.*, 1981a, 1981b, 1982, 1986; Green, 2002).

Where nourishment activities brought relevant modifications in terms of the substratum's granulometry, important variations were observed also in the composition of benthic animals, with subsequent alterations in the beach's ecology (Rakocinski *et al.*, 1996).

Sediments with different grain size distribution or sediments that were well-compacted during the delivery operations may determine a decrease the beach's re-colonization velocity but, mainly, they can affect the new assemblages' specific composition (Van Dolah *et al.*, 1984; Green, 2002). The variations on the beach's benthic communities can also have important financial implications if the species involved are of commercial value (B.N.P., 1995).

For this reason, specific surveys were carried out along the Latium coast to evaluate the effects of nourishment activities on some species of bivalve mollusks with commercial interest. The analyses carried out highlighted that the species *Donax trunculus* (surf clam), living at depths comprised between 0 and 2 m, is initially strongly influenced by the sandy sediments' spilling, however managing to colonize the new sediment in a very short time; on the opposite, the species *Chamelea gallina* (clam), preferably distributed between 2 and 7 m in depth, seems to not be affected by the effects of nourishment.

One of the solutions proposed in order to minimize the impacts of nourishment on biological resources and, in particular, on benthic communities, lies in not letting such activities coincide with the phases in which organisms are more sensitive to disturbance (for example during recruitment and reproduction periods), therefore applying the previously discussed concept of environmental windows to nourishment, too (paragraph 1.1.3.3).

1.3.3.2 Nekton

The possible effects generated by nourishment activities on demersal fish assemblages in coastal areas are varied, and may involve the decrease of abundances during sand replenishment operations, as a result of damage to the fish's branchial apparata (due to turbidity increase), reduced food availability, and burying of demersal species (Green, 2002). However, specific surveys do not highlight alterations in the composition and abundance of communities (Nelson and Collins, 1987; B.N.P., 1995). Some Authors observe in fact that the nektonic organisms living in these areas are highly mobile and they can easily leave the areas that directly involved in nourishment activities (Green, 2002; Wilber *et al.; 2003*).

In general, nourishment-generated effects on nektonic assemblages are of short-term nature, and nekton does not seem to suffer from the disturbance, unlike the beach's benthic communities.

EFFECTS OF NOURISHMENT ACTIVITIES ON COASTAL BENTHIC COMMUNITIES

In order to evaluate the possible interactions between nourishment activities and coastal benthic assemblages, ICRAM, in collaboration with Regione Lazio, recently performed an exploratory study on some bivalve mollusks of commercial interest, such as the surf clam (*Donax trunculus*) and the clam (*Chamelea gallina*), both present along the Latium coast. These bivalve mollusks are the object of professional fishing in all local fisheries, and they represent an important financial resource. Especially in some phases of their life cycle, these animals are extremely sensitive to the modifications of the environment they live in, in particular to sediment grain size variations.
The survey was carried out along several beaches of the Latium coast, before, during, and after the nourishment activities scheduled for 2003.


Bivalve mollusks of commercial interest: *Donax trunculus* (surf clam) and *Chamelea gallina* (clam)

The studies, carried for about 1 year before nourishment interventions, allowed to identify the main species present along the soft bottom in the superficial infralittoral zone, an environment characterized by strong wave motion and sediment instability. In particular, for the species *Donax trunculus* and *Chamelea gallina*, distribution, density (number of individuals per square meter), assemblage dynamics, and reproductive and recruitment periods were studied. In general, the results obtained showed that *D. trunculus* prefers the bathymetric interval comprised between 0 and 2 m, and a sediment characterized by an average diameter comprised between 125 and 250 micron. The results have also shown a long recruitment period, from July to September, sometimes extended until the following winter. The recruitment of the youth stages occurs between 0 and 0,5 m of depth and the individuals move towards higher depths as they grow.
Right after the nourishment operations, *D. trunculus* disappears, probably suffocated by the new sand placed on the beach. In all studies, the arrival of young individuals was reported within a few months (3-4) from nourishment, after a period of sediment adjustment and during the species' recruiting period.
Concerning *C. gallina*, the research highlighted that this species is mainly distributed at depths comprised between 2 and 7 m; recruitment occurs in September and – though at a lower rate – in May. Overall, *C. gallina* assemblages do not seem to be affected by nourishment activities.
This study highlights how important it is to know the reproduction and recruitment periods of the main bivalve mollusks species with commercial interest, in order to minimize effects in case of nourishment activities. A management suggestion could be to carry out the nourishment activities before the recruitment of the species in question (for example the summer period for the *D. trunculus* assemblages present along the Latium coasts), so as to allow the settlement of the youth, after an appropriate adjustment period of the new sediment spilled.

1.3.3.3 Sensitive Habitats

Among the sensitive habitats, the ones that mainly suffer from the effects of nourishment activities are, in the specific case of the Mediterranean, the *Posidonia oceanica* meadows. The high turbidity and the suspended load potentially associated to the initial phases of nourishment can in fact inhibit or significantly reduce photosynthetic activity, with potential effects to the meadows themselves and to the ecosystem they belong to (Goldberg, 1988; B.N.P., 1995).

Posidonia oceanica *L. Delile meadows*

Posidonia oceanica (L.) Delile is a marine phanerogam, analogous to terrestrial superior-plants, and is therefore organized in a stem (rhizome), leaves, and roots. The stem (rhizome) can grow both horizontally (plagiotropic growth) and vertically (orthotropic growth) escaping, within certain limits, the progressive rise of the bottom, and giving rise to a typical "terrace" development, called "*matte*" using the French word.

The *matte* is formed by a strongly compacted tangle composed of various layers of old rhizomes and roots, mixed with trapped sediment. The *matte*'s vertical growth is estimated in an average of 1 m every 100 years.

In the upper portion of every rhizome there is the vegetative apex from which the leaves originate, organized in clusters: every cluster is composed of 6-7 ribbon-shaped leaves arranged in a fan shape, with the oldest leaf located externally, and the youngest situated in the more internal areas.

P. oceanica forms wide meadows (***Figure 1.20***) whose depth ranges between 0 and 40 m (Pérès and Picard, 1964). The meadows are composed of an upper margin (minimum depth at which the meadow is found), more sensitive to activities involving the coast, and a lower margin (the lowest depth reached by the meadow itself).

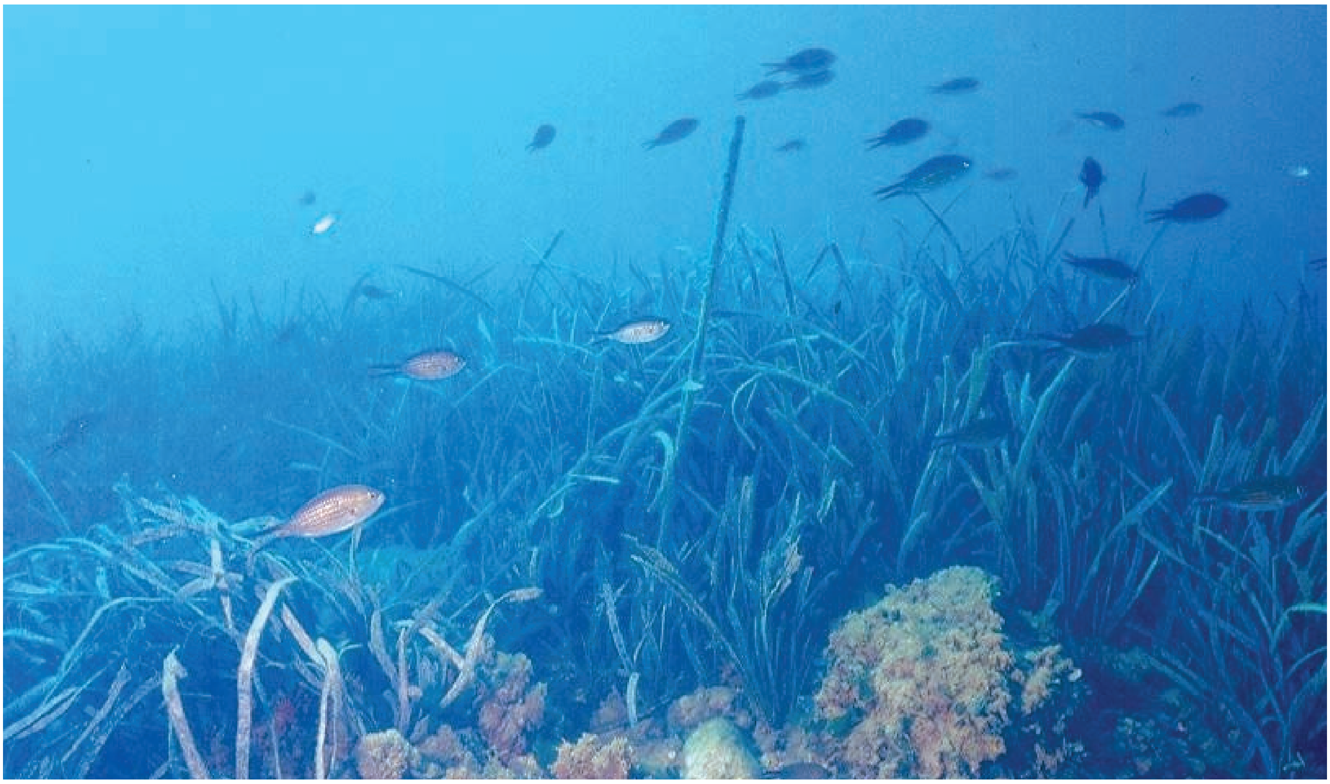


Figure 1.20 - Posidonia oceanica meadows

Posidonia oceanica meadows, which in the Mediterranean cover an area estimated between 2,5 and 5 million hectares (Pergent *et al.*, 1995), are one of the main components of the equilibrium and richness of the shallow coastal environment.

This phanerogam plays in fact an extremely important ecological role in the sea, which can be summarized as follows (Ott, 1980; Blanc and Jeudy de Grissac, 1984; Jeudy de Grissac and Boudouresque, 1985; Mazzella *et al.*, 1989; Chimenz *et al.*, 1996; Francour, 1997; Guidetti and Bussotti, 1998; Tunesi and Boudouresque, 2006):

- it produces oxygen: 1 m^2 of meadow in good conditions produces between 4 and 20 litres of oxygen in 24 hours;
- it produces and exports biomass: with about 38 tons of dry weight per hectare per year (of primary production), *P. oceanica* beds are considered the most important producers of living prime matter in the Mediterranean. A part of this production, in the form of dead leaves, is transported by waves and currents to other ecosystems;
- it constitutes an extremely rich and diversified environment: the assemblage associated with *P. oceanica* is characterized by the presence of sessile fauna (mainly animal and vegetal epiphytes), sedentary, vagile and mobile fauna;
- it represents an important reproduction and nursery area for many species of fish and invertebrates;
- it stabilizes soft bottoms and it defends coasts from erosion. Waves and currents are cushioned by the *matte*'s and leaves' braking action, and the sediment in transit is partly held back by *P. oceanica*'s leaves and rhizomes.

Posidonia meadows represent the largest and most common vegetal assemblage in the infralittoral Mediterranean zone, and they are generally used as biological indicators (Pergent, 1991; Pergent *et al.*, 1995) due to their high sensitivity to changes in environmental characteristics and to anthropic impacts (Ardizzone and Pelusi, 1983; Augier *et al.*, 1984; Porcher, 1984, Bourcier, 1989; Peirano and Bianchi, 1995).

The general characteristics of *Posidonia oceanica* beds, such as for example the percent cover, leaf density and the lower limit's maximum depth, can be used as indicators of possible anthropic and/or natural impacts (Pergent *et al.*, 1995).

Their position near the coast exposes the meadows to effects caused by anthropic activities on the coastal zone, such as the presence of artefacts and infrastructures, dumping areas (generally rich in eutrophic substances and pollutants), as well as trawl fishing and anchoring sites. Besides, the development of certain types of structures, such as groins (often associated to nourishment), can locally modify the behaviours of waves and currents, interacting with coastal transport mechanisms governing the distribution of sediments at sea, with possible relapses on the marine environment in general, and on the *P. oceanica* beds in particular. The latter can in fact suffer from the effects of:

- coastal erosion processes (reduction of the meadow's sandy substratum down to the exposure of rhizomes);
- coastal dredging with possible erosion effects on neighbouring submerged beaches;
- dredging of offshore sands, mainly as an effect of overflow;
- construction of marine structures, with subsequent development of erosive and depositional processes, and variations in the sediment dynamics and water clearness;
- artificial beach nourishment, with the possible development of localized and temporary sedimentary flows that did not exist before.

In case of nourishment, the effects expected on *Posidonia oceanica* beds are essentially linked to the water's turbidity increase and to the plants' possible burial. The latter is linked to the higher motion of the bottom sediments following sand replenishment, especially due to poor compaction of recently deposited sediment. The effects of burying on the meadows could be expected where the active beach's closure depth in the nourishment (the maximum depth at which the sediment still suffers from the action of wave motion) is situated at a higher depth than the higher limit of the meadow itself.

Specific surveys have been carried out by Manzanera *et al.* (1998) to study the effects on meadows of hyper-sedimentation following the development of coastal structures. These Authors observed that the plant's response strongly depends on the intensity and duration of hyper-sedimentation; even modest burials (5 cm) can in fact produce significant leaf mortality. The problem of hyper-sedimentation was also addressed in a study by Gambi *et al.* (2005) carried out on a *P. oceanica* meadow in the Maronti Bay (Isola di Ischia, Naples). It is known in literature, and has been confirmed by lepidochronological studies, that the decrease in luminosity generated by the increase in fine sediments in suspension determines a decrease in the meadow's leaf production, which could be followed, with the persistence of the alteration, by a reduction in density and a regression of its lower limit (Guidetti and Fabiano, 2000).

Recent studies, carried out along the Spanish coast in an area interested by the construction of a harbour (Ruiz and Romero, 2003), have shown how these factors can only explain 20% of the decline observed in the *P. oceanica* beds present. The meadow's health condition is also linked to other factors, such as nutrient release – which, on the one side, acts on epiphytes and macro-algae, while on the other it acts on the quality of sediment, mainly as a result of siltation – and to the development of anoxic conditions (Ruiz *et al.*, 1993; Ruiz and Romero, 2003).

In the specific case of nourishment with relict sands, the increase in turbidity and the related decrease in luminosity should not produce significant effects on the meadows, for the following reasons:

- the phenomenon is certainly temporary and has reduced entity because the sediment used for nourishment is normally sandy, and the fine fraction, responsible for the turbidity's long duration in time and space, is practically absent;
- the operations' expected duration, referred to the single stretches involved, is relatively short;
- most activities are generally carried out in the winter-spring period, that is, in a time of the year in which turbidity levels are generally higher.

A monitoring study along the coasts of Tarquinia (central Tyrrhenian Sea), carried out by ICRAM in collaboration with "La Sapienza" University in Rome and the Regione Lazio on the occasion of a beach nourishment intervention with relict sands occurred in May-July 2004, is described in Nicoletti *et al.*, 2005.

In conclusion, a last aspect that needs to be considered is the relationship existing between the coast's stability and the presence of *P. oceanica* meadows. The loss of meadows (even by just one meter) can cause significant erosion on the littoral environment, even by many meters (Della Croce *et al.*, 1997). According to some Authors, the recovery of the beach has a positive role in increasing the stability of *P. oceanica* beds, while sedimentary deficit favours their regression (Ballesta *et al.*, 2000). An improvement in the meadows's general health conditions, deriving from the beach's stabilization, can even increase the protection of the beach itself. This leads to the assumption that a well-planned nourishment intervention could favour not only the beach's stability, but also an improvement in the health of the adjacent *P. oceanica* meadows, both directly and indirectly (Ballesta *et al.*, 2000).

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2 MONITORING PROTOCOL

2.1 WHERE, WHEN, HOW AND AT WHICH SCALE SURVEYS SHOULD BE CONDUCTED

The need for a methodological instrument useful to carry out monitoring studies related to beach nourishment activities with relict sands brought ICRAM to formulate the present protocol proposal (***Figure 2.1***). The protocol was "designed" by virtually answering the different questions related to the time and methods with which the environmental surveys must be carried out, and which researchers and/or administrations must answer before starting every survey of this kind:

- Where?
- When?
- How?
- At which scale?

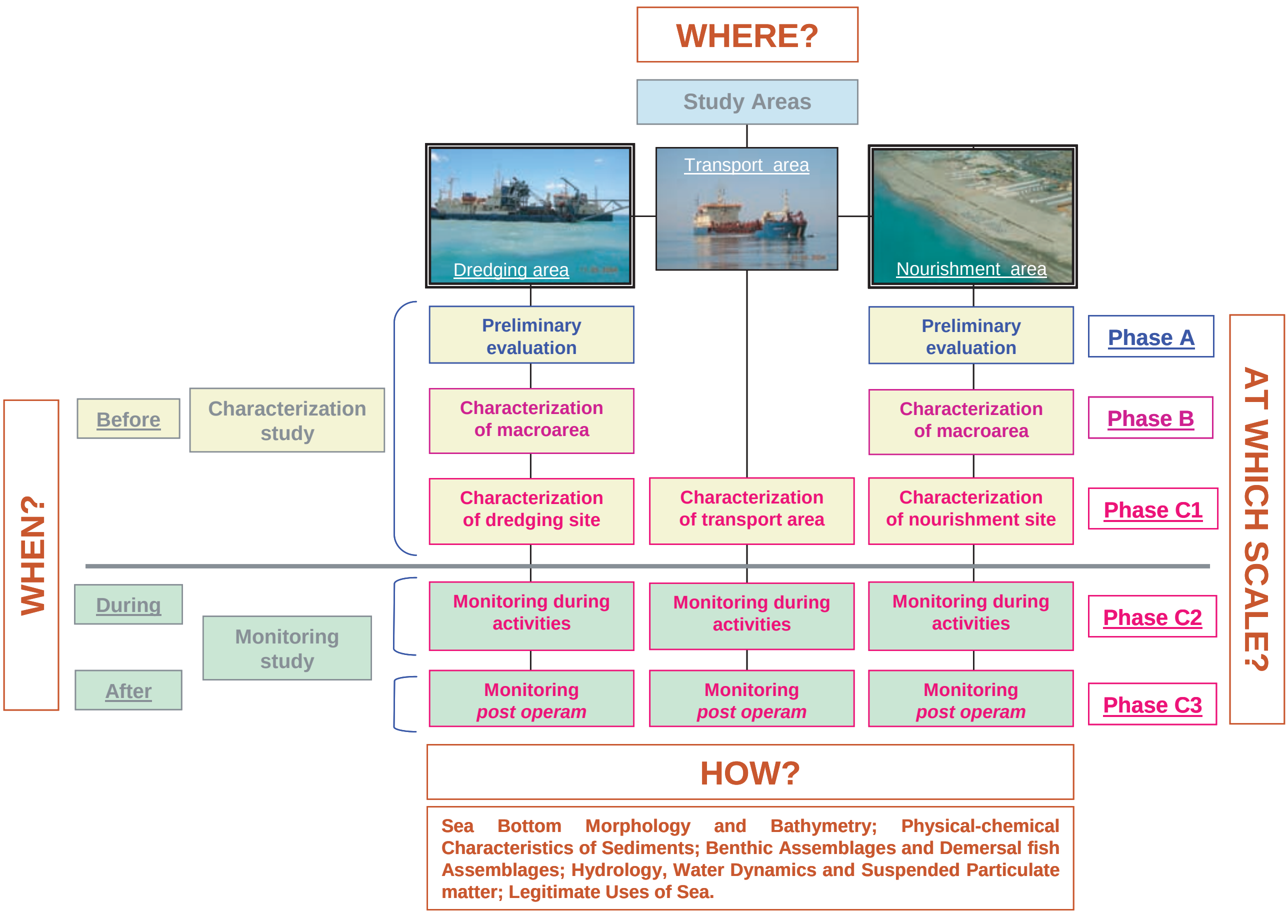

Figure 2.1 - Diagram of the monitoring protocol.

The answer to the first question (**Where?**) requires the definition of the specific field of application. Relict sand dredging activities for beach nourishment involve the performance of specific and distinct activities: dredging, sand transport and nourishment. These activities determine, therefore, the identification of different spaces fields in which the activities take place: the continental shelf (dredging) and the beach (nourishment) or both (transport). The dredging area is the portion of the continental shelf that contains the relict sand deposit to be mined; the transport area coincides with the possible sand transfer routes, and it stretches from the dredging site to the nourishment site; the nourishment area includes the stretch of coast where the actual nourishment will take place.

The areas involved therefore differ from one another in terms of environmental characteristics and type of activity, and consequently, in the effects they undergo following sediment removal. The effects of sand extraction in the dredging area involve both the physical compartment (substratum and water column) and the biological one, with particular reference to the effects on benthic assemblages, and to the possible relapses on fishing activities. In the transport and nourishment areas, on the opposite, the most relevant effects, deriving from sand removal, are the ones potentially produced on the sensitive environments present, both due to the temporary increase in suspended sediment, and to the re-deposition of new sediment.

The answer to the second question (**When?**) requires the study's subdivision in two main areas:

- an environmental characterization study, to be carried out before the beginning of the sediment removal activities;
- an environmental monitoring study, to be carried out during and after the activities have been completed.

Each of these two parts has very specific and well-differentiated aims depending on the survey's nature.

The environmental characterization study involves investigations carried out in subsequent phases and at different scales, aimed at progressively more focused analyses. This study aims at evaluating whether the bottom removal activities may be carried out with environment-sustainable effects, evaluating whether the performance of such activities requires appropriate and specific prescriptions in relation to the performance techniques used.

The environmental monitoring study is specific for each case involved, and it is subdivided into:

- monitoring during activities, which investigates the effects on the environment during the single activities;
- monitoring *post operam*, which analyzes the possible effects on the environment after the activities have been completed, up until recovery of the equilibrium conditions.

In the monitoring during activities phase, it is possible to stop the operations at any time, should the researchers notice any significant effects on the environment, especially on the sensitive habitats.

The answer to the third question (**How?**) requires the identification and choice of the parameters that will have to be used to study the effects of relict sand dredging and beach nourishment on the marine environment. The parameters have been selected on the basis of bibliographical information related to the environmental problems linked to these activities, and re-elaborated on the basis of direct experience witnessed in situ by ICRAM. These parameters concern:

- *Morphology, bathymetry and physical-chemical characteristics of sediments.*

  The bottom's morphological and bathymetric setup is obtained through Side Scan Sonar (S.S.S.) and Multibeam surveys, respectively. This type of survey firstly allows to define the general setup of both the area in which the relict sand deposit was identified (dredging area) and of the nourishment area, and to pinpoint the possible presence of rocky substrata and/or sensitive habitats. At the end of the activities, it also allows to identify the important variations generated by dredging, and to define the size of the dredged area in detail.

The physical analyses performed on superficial sediments aim at describing the sediments' textural characteristics, and to evaluate the quantity of fine fraction that could be put into suspension during bottom removal activities. Also, in the specific case of the dredged area, the physical analyses on the superficial sediments, carried out after dredging, help define the area involved by sediment re-deposition.

The sediments' chemical analyses (trace metals and organic micropollutants) provide information on the quality of the sediment to be removed. The sediment that often covers relict sand deposits is a fine sediment (pelitic cover of recent deposition) and, because of its high specific surface (high surface/volume ratio), it constitutes a preferential vehicle for dangerous substance accumulation. Since it is impossible to use contaminated* sediments in nourishment, chemical characterization has the aim of verifying the sediment's good quality. In particular, since the trace metals present in the sediment can be of natural or anthropic origin, the chemical analyses must be able to highlight this provenance and ensure that the values recorded can be referred to background concentrations.

Sediment sampling is preferably carried out by means of a box-corer. This instrument allows to sample undisturbed sediments, and therefore allows to sample both superficial sediments and the underlying levels, and to visualize the stratification of the first 20-30 cm of sediment. Granulometric analyses must be carried out so as to allow a representation of the frequency distribution of the granulometric classes with an interval of 0,5 phi**.

- *Hydrology and dynamics of water masses.*
  Sediment removal has relevant effects on water quality, due to the input of possibly significant quantities of suspended solid. In order to evaluate the diffusion of the suspended particulate matter caused by removal activities, it is therefore important to gather information on both the concentrations of suspended solid that are naturally present in the area, and the chemical-physical and dynamic characteristics of the water column. Since hydrology and dynamics of water masses are parameters that are subject to significant seasonal variations, various surveys will have to be carried out, including at least two extreme seasons, i.e. winter and summer.
- *Benthic assemblages.*
  The study of benthic assemblages provides information on the general conditions of the environment. Due to their close relationship with the bottom and their low vagility, these organisms represent an efficient instrument to study natural and/or anthropogenic changes in the marine environment. The analysis of benthic assemblages and their evolution following removal activities (dredging and beach nourishment) allows to study times and modalities with which the area removed tends to reach new equilibrium conditions. In the specific case of the nourishment area, in the presence of particularly important benthic species – such as those with a commercial value, like bivalve mollusks –, the characterization study must allow to identify the reproduction and recruitment periods of these species. The Van Veen grab is the most commonly used instrument for benthos sampling.
- *Demersal fish assemblages.*
  The characterization of demersal fish assemblages is important in order to highlight particular situations such as the presence of sensitive species or critical phases in their life cycle. The demersal species' close relationship with the sea bottom makes them more directly affected by possible

* *For the Italian law, the removal of contaminated sediments is only possible for certain uses. In particular, these sediments cannot be used for beach nourishment (Ministerial Decree 24 January 1996).*

** $phi = -\log_2 \frac{\text{grain size diameter (mm)}}{\text{1 mm}}$

environmental alterations generated by sediment removal activities. Studies on demersal fish assemblages will have to be performed seasonally through trawl fishing surveys, setting up a stratified sampling design aimed at identifying theses species' nursery and reproduction areas.

- *Legitimate Uses of the Sea.*
  Areas characterized by legitimate uses of the sea that are not compatible with bottom removal (restrictions) may be present, limiting or significantly affecting these activities. The presence of these areas must therefore be marked in the area in question: these areas include Marine Protected Areas (MAPs), national parks, marine artificial reefs, mariculture zones, dumping areas for harbour-materials, pipes, offshore structures, no-anchor or no-fishing areas and military sites. The relict sand dredging area also should fall within 3 nautical miles from the coast, or within the zone comprised within 50 m of depth, should such depth be reached within 3 nautical miles from the coast. This area is in fact the most sensitive to sediment removal, as stated in Law 963/1965 and in the DPR 1639/1968, both related to trawl fishing activities.

The answer to the fourth question (**At which scale?**) requires the identification of three phases, corresponding to the three survey levels: on a regional scale (Phase A), characterization of macroarea (Phase B), characterization of intervention sites (Phase C) (***Figure 2.2***). Phase A, which must be carried out for the dredging and nourishment areas, aims at providing a framework – that should be as complete as possible – of the currently available knowledge for the various disciplines related to the marine domain, and it is carried out on a regional level. This phase involves an area that is sufficiently wide to include the intervention areas and the surrounding ones for a wide range, and it consists in the critical analysis of the existing data present in literature. In particular, Phase A is especially useful for regions having many different sand deposits and erosion problems on wide coastal stretches, and it helps design an accurate and efficient plan for coastal management and protection interventions. Phase B, which must be carried out both for the dredging and for the nourishment areas, provides a detailed picture while filling in the possible bibliographical gaps highlighted in Phase A, and it consists of direct surveys aimed at characterizing the two macroareas; the macroarea containing the dredging site should possibly be placed between the area including the sand deposit and the coast. It is in fact important to consider that, in general, geological surveys aimed at the characterization of sandy deposits should be carried out together with environmental surveys. As a consequence, during the surveys for the characterization of the macroarea containing the dredging site (Phase B), the information about the deposit's location and characteristics are, in most cases, still general. In the subsequent pre-operation (*ante operam*) phase, on the dredging site (Phase C1), instead, the dredging site (defined as the area within the sand deposit that will actually be dredged) and the sands' characteristics and their destination (nourishment area) are known in detail. In general, Phase C involves a detailed characterization of intervention sites, to be carried out before (C1, characterization of site), during (C2, monitoring during activities) and after (C3, monitoring after activities or *post operam*) the activities in questions. This last phase's objective is to pinpoint the possible changes on the environment caused by dredging and nourishment operations, as well as the recovery times and methods for the areas in question.

In the dredging and nourishment areas, Phase C1 is always performed, while in the transport area it is only carried out if there are sensitive habitats.

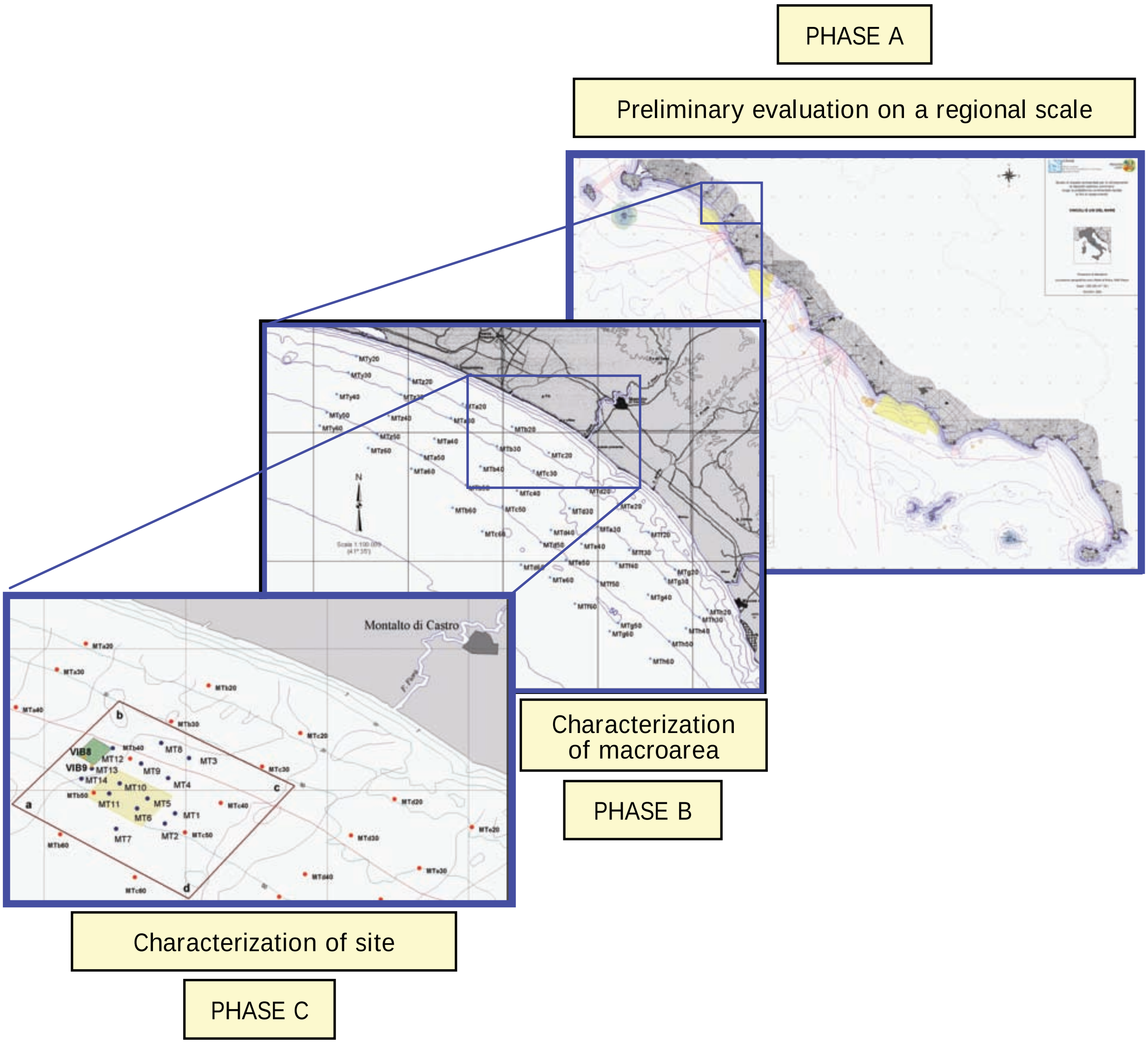

Figure 2.2 -Survey scale. Dredging area.

2.2 GENERAL STRUCTURE

On the basis of the experience gathered by ICRAM, since 1999, in the environmental studies related to beach nourishment activities with relict sands, this "Quaderno ICRAM" provides a monitoring protocol aimed at aiding the studies that should accompany such nourishment activities. These studies are essential for a correct management of the coastal belt.

Elzinga *et al.* (2001) define the monitoring process as “the collection and analysis of observations or measurements repeated in time, with the aim of evaluating possible changes, and/or developments towards the management objectives”. More in general, for Margoluis and Salafsky (1998), the definition must include the periodic data-gathering related to both the predefined objectives and to the project’s activities.

Monitoring must therefore be considered a fundamental process in adaptive management* (Wilhere, 2002), as it allows to verify whether the management actions, accurately planned, applied and verified at predefined intervals, are congruent and compatible with the desired results, and, consequently, whether management is proceeding correctly (***Figure 2.3***).

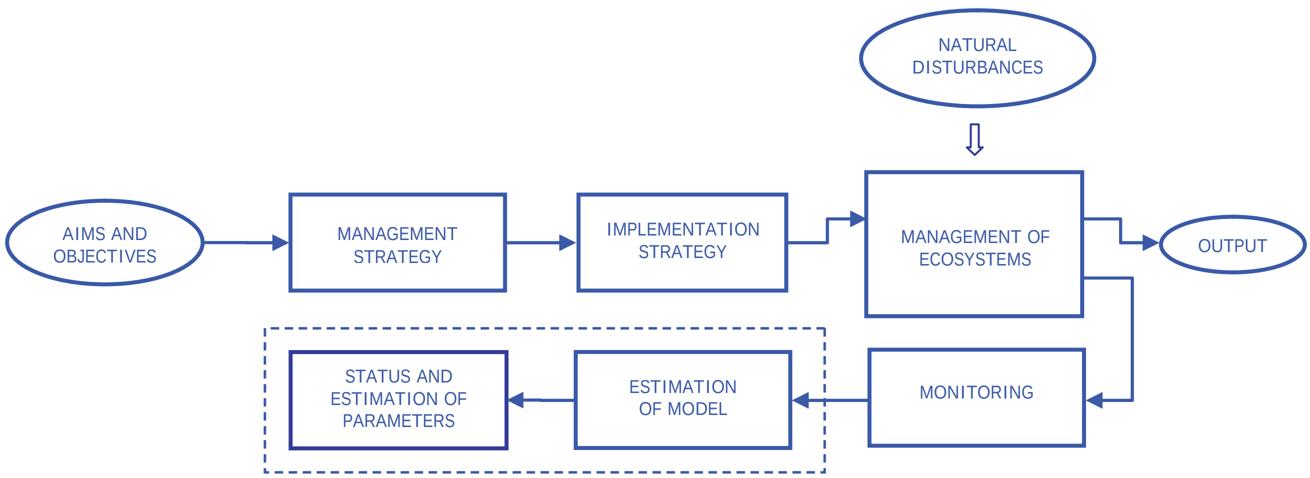

Figure 2.3 - Flow chart of the adaptive management process (modified from Wilhere, 2002).

In an adaptive management context, monitoring measures progress, or the fulfillment of objectives, and provides the necessary elements to change or maintain management actions; in other words, it allows to evaluate whether the activities composing the management action (dredging and nourishment, in this case) are carried out with acceptable effects on the environment or whether it is necessary to intervene with modifications (for example by suspending dredging operations or proposing alternative transport routes).

* *The process of systematic acquisition and subsequent application of reliable information, in order to improve management efficiency in time.*

Monitoring is an efficient instrument, in order to (Ciucci, 2004):

- increase the knowledge base in the environmental field;
- spot long-term trends;
- pinpoint potential crises (variations), in time;
- assess the outcome of management interventions.

The concept of "nourishment with relict sands" generally refers to a fairly complex operation, articulated in different activities, each specific for one of the different environments: i.e., dredging on the shelf environment; transport, from the relict sand deposit to the beach to be nourished, and coinciding with the dredge's navigation routes; and nourishment, which involves the coastal stretch that must be replenished. For the purposes of an environmental study aimed at monitoring how these activities affect the marine environment, specific research and/or surveys will have to be carried out in each of the areas involved, and their definition and organization is the object of this protocol.

In order to monitor the effects of relict sand dredging and beach nourishment on the marine environment, specific surveys must to be performed while activities are in progress (monitoring during activities), and at the end of the activities (monitoring *post operam*). In particular, the monitoring *post operam* process will have to last long enough to allow researchers to obtain reliable data on the changes in the environment, and to determine the recovery times and procedures in the areas involved.

The need to set up an appropriate monitoring plan demands an accurate knowledge of the area's environmental conditions prior to the beginning of the activities (bottom morphology and bathymetry, sediment granulometry, hydrology and dynamics of water masses, nature and distribution of marine organisms) and in the different territorial-fields involved. If this information is not available, a specific project must be developed for the area's environmental characterization or basic monitoring (Morrison, 2002).

Below is a synthesis of the protocol's structure by phase (Phase A, B and C1 of the characterization study, and Phase C2 and C3 of the monitoring study) and for each area involved (nourishment, dredging and transport areas). The appropriate charts, referred to in the text, can be found in Chapter 5.

The characterization study (Phases A, B and C1)

The characterization study consists in gathering basic data (biotic and abiotic characteristics of the areas involved, legitimate uses of the sea) that will be used as comparison data in the subsequent monitoring studies. This study must be performed on all the territorial-fields involved (dredging area, transport area and nourishment area), and it is articulated in three phases: Phase A, involving the collection of bibliographic data concerning a wide area, possibly extending to the whole physiographic unit; Phase B, requiring the collection of experimental data on a wide area (macroarea) surrounding the possible intervention sites; Phase C1, involving experimental surveys within the areas that will actually be mobilized and in their close proximity. The results obtained in this last phase will be used to establish the environmental compatibility of the activities estimated.

PHASE A

Phase A, the first phase of the environmental study, consists in gathering and analyzing the data available in literature, which is necessary for the environmental characterization of all the areas involved, from the relict sand extraction site to the beaches to be nourished.

Dredging area (chart n. 1) and nourishment area (chart n. 2)

When an environmental study related to relict sand dredging for beach nourishment begins, it is firstly necessary to start gathering bibliographic material, and, more specifically, data and information pertaining to the relevant parameters linked to a sufficiently wide area, which includes both the continental shelf containing the relict sand deposits, and the beach waiting to be nourished (paragraphs 3.1.1 and 3.1.2). On top of the physical characteristics (the bottom's morphological and bathymetric characteristics, granulometry and chemical characteristics of superficial sediments, hydrological and dynamic characteristics of the water column), these parameters also concern the areas' biological features (characteristics of benthic assemblages and demersal fish assemblages and of the main sensitive habitats present), as well as all the aspects pertaining to the legitimate uses of the sea. The latter must be especially clear, both in terms of presence of protected areas, and in relation to areas with specific uses that are not compatible with sediment removal activities, as is the case for harbour material dumping zones. By gathering and processing this data, we can outline a first information framework on the environmental feasibility of the activities in question. This process can count on the help of territorial information systems, which are useful both for the creation of specific databanks – which can later be updated with the experimental data collected from the subsequent characterization phases – and for the development of thematic and combined maps, to be used to also plan the subsequent survey phases, such as the *"environmental compatibility maps"* for dredging activities (paragraph 3.1).

This phase will provide a first comparative evaluation about the dredging activities' environmental compatibility, obtained by combining bibliographic data with the first information available in this phase, regarding the characteristics of the relict sand deposit (such as the assumed location and size of the deposits).

It is important to highlight that, for some of the parameters investigated, e.g. the demersal fish assemblages and the water mass characteristics, it will be necessary to obtain seasonal data, as these parameters are subject to important variations according to the season.

For example, in the case of the water column's hydrological characteristics, one of the most relevant aspects in the Mediterranean is linked to the presence of a summer thermocline. The existence of this strong thermal gradient results in the identification of two well-defined water masses, separated by a strong discontinuity. In the case of sediment removal, the presence of the thermocline determines a different sediment diffusion behaviour from that observed along a homogenous water column. For instance, in the presence of the thermocline dispersion plumes have been observed, not only on the surface and on the bottom, but also in correspondence to the thermocline itself (Toumazis, 1995).

As far as demersal fish assemblages are concerned, on top of the general information on the assemblage's characteristics, particular attention must be paid to the space-time identification of nursery areas, i.e. concentration areas of juveniles of fish species. The presence of nursery areas is strongly related to the reproductive period, and is therefore defined in time. For these reasons, the parameters related to these assemblages should bear precise seasonal reference, which will prove especially useful in the activity's planning and design phases, according to the environmental window concept (paragraph 1.1.3.3).

PHASE B

After gathering bibliographic data for a wide area – possibly extended to the physiographic unit and concerning both the shelf area hosting the relict sand deposits and the beaches waiting to be nourished – the experimental surveys provided for in Phase B may begin, if necessary. This phase's aim is to characterize the areas of interest, in order to fulfill the possible gaps and to update information, obtaining a characterization with an adequate survey scale, for both the dredging area and the nourishment area. On top of providing the necessary information to formulate the first environmental compatibility hypotheses of dredging operations, this phase will set the basis for the characterization of intervention sites, which is carried out in Phase C1.

Dredging area (chart n. 3)

In the dredging area, the characterization study (paragraph 3.2.1) characterizes the area, integrating experimental data both with the corresponding data gathered in the previous survey phase, and with all information related to the characteristics of the previously identified relict sand deposits (geographic location and deposit's size).

The study area must therefore be large enough, and it needs to include a wide area containing all the potentially usable relict sand deposits (during the macroarea characterization study, the dredging corridor – i.e. the relict sand deposit, or a part thereof, which will actually be dredged – is generally not yet known in detail).

In this framework, experimental surveys to obtain original data must therefore be performed. These will concern: granulometry and chemical aspects (trace metal and organic micropollutant contents) of superficial sediments, hydrological and dynamic characteristics of water masses, suspended particulate matter, benthic assemblages (biocenotic characterizaton) and demersal fish assemblages (identification of nursery areas).

As previously mentioned, seasonal surveys must be also planned for the study of the hydrological and dynamic characteristics of water masses, suspended particulate matter, and for the study of fish assemblages.

In this phase, particular attention must be paid to the analyses on the characteristics of superficial sediments, with special reference to trace metal contents (henceforth, metals). The surveys usually carried out on the sediments' metal contents (study of total abundances) do not always allow to define with certainty whether the metal concentrations found are actually ascribable to natural phenomena, and most of all, what their mobility is. For this reason, should significant concentrations of certain elements emerge in this phase, such results shall be used to possibly plan in-depth chemical analyses on metal mobility, to be carried out in the next focus phases, which concern the dredging corridor's environmental characteristics.

Nourishment area (chart n. 4)

Similar to what happens for the dredging area, this phase (paragraph 3.2.2) has the aim of characterizing the area, integrating experimental data with analogous data gathered in the previous survey phase. Particularly important is the characterization of the sensitive habitats present, such as *Posidonia oceanica* meadows, which could significantly be affected by the operations, especially due to the input in suspension of large quantities of sediment.

If necessary, the experimental surveys will be carried out in a wide area of the nourishment site that includes the site to be nourished; in particular, surveys will have to be planned to collect data on the benthic assemblages and on the demersal fish assemblages, with special reference to the identification of the nursery areas.

PHASE C1

The study performed in this phase characterizes the intervention sites, and its objective is to gather all the information necessary to define the interventions' environmental sustainability for each one of the areas involved.

Dredging area (chart n. 5)

The dredging site's characterization process (paragraph 3.3.1) aims at determining the environmental compatibility of dredging. For this reason, it will be necessary to examine the physical and chemical* characteristcs of the sediments to be removed, and – in case of outcropping relict sands – their microbiological characteristics. For all these reasons, the study area must necessarily include the area that will actually be dredged (dredging corridor). In particular, the sampling design must include a minimum of 11 stations, at least 3 of which must be situated inside the dredging corridor; the area's hydrodynamic characteristics recorded from the previous survey phases will have to be considered as well.

The experimental survey will aim at investigating, over the whole area studied, the textural (granulometry) and chemical characteristics of the superficial sediments (organic substance, metals, and organic micropollutants), the hydrological and dynamic characteristics of the water masses, the particulate matter and the benthic assemblages.

In the dredging area itself, it will also be necessary to acquire morphological and bathymetric data concerning the granulometric characteristics and the metals' chemical characteristics of the deep sediments constituting the relict sand deposit. This should be done in at least 3 sampling stations.

All this data will finally be integrated with the data obtained in the previous phases according to both geological and sediment characteristics of the relict sand deposit, and to the specific dredging techniques.

Transport area (chart n. 6)

The characterization study in the transport area is only carried out if sensitive habitats are present along and/or near the routes chosen for sand transport from the dredging area to the nourishment area.

Sensitive habitats can in fact be significantly affected by the sediments' input into suspension, which results from both overflow and accidental spillings (paragraph 3.3.2). Therefore, this phase's aim is to find the sand-transfer preferential routes that will minimize the possible effects on sensitive habitats and marine organisms in general. For these purposes, in this phase specific surveys are to be carried out in the whole area potentially subject to dredging activities, in order to study the sensitive habitats present.

The obtained data will finally have to be analyzed in function of all the technical information concerning the characteristics of the dredging operations and materials.

Nourishment area (chart n. 7)

Phase C1 is only carried out if the previous surveys (Phase A and B) have recorded the presence of sensitive species (bivalve mollusks, whose fishing significantly affects local economy) or sensitive habitats (such as *Posidonia oceanica* meadows, protected as per the Habitat Directive) in the coastal area offshore the beach to be nourished. The surveys performed in this phase (paragraph 3.3.3) are aimed at characterizing in detail the sensitive habitats and/or sensitive species, and to monitor (base monitoring or survey) such habitats' main characteristics, in order to be able to subsequently verify, during and after nourishment, whether or not the activities have significant effects on their health conditions. For these purposes, specific surveys must be carried out on the benthic communities during the nourishment site's characterization phase; in particular, if *P. oceanica* meadows are present in the study area, the surveys will have to be extended to the meadows' lower limit. In order to correctly plan these surveys, by this time it is necessary to be aware of the specific techniques essential for the project.

** Should the previous chemical analyses (Phase B) indicate high metal concentrations in the superficial sediments, further chemical analyses must be carried out on the superficial sediments within the area to be dredged (chemical speciation or distribution of metallic species in the various phases of the sediment).*

The monitoring study (Phases C2 and C3)

In the three areas involved, the monitoring study involves a series of surveys aimed at evaluating both the effects on the environment during operations (monitoring during activities) and the medium and long-term effects (monitoring *post operam*).

The surveys performed in the monitoring during activities phase (Phase C2) are aimed at evaluating whether the effects produced are acceptable, and therefore whether the activities may go on, or if, on the opposite, it is necessary to act on the operations, for example by suspending activities for some time, or by setting up immediate mitigation procedures. The results obtained from Phase C2 also aim at verifying the suitability of the study area identified in the characterization phase (Phase C1), extending it, if necessary, on the basis of the results obtained during the activities. It is in fact evident that, if on the one hand a correct monitoring plan implies the comparison between homologous stations, on the other, the plan must be modified on the basis of the preliminary results obtained, according to the adaptive management principle (Wilhere, 2002).

In the monitoring *post operam* phase (Phase C3), the possible medium and long-term effects of dredging and nourishment activities on the marine environment are studied in each one of the three areas involved. In particular, the study pays attention to the recovery times and procedures, i.e. the procedures with which recovery conditions similar – if not equal – to the initial ones are observed.

PHASE C2

Dredging area (chart n. 8)

The monitoring during activities study (paragraph 4.1.1) in the dredging area mainly assesses the temporal and spatial evolution of the turbidity plume; in particular, this monitoring process verifies the size and geometry of the dredged area and of the surrounding space affected by dredging, in order to set up a correct monitoring *post operam* plan. Therefore, when a relict sand dredging operation is carried out, a monitoring during activities phase must always be planned in order to monitor the turbidity plume's dispersion, to understand both the degree of disturbance induced in the short-term, and the plume's transport and diffusion modalities; the strongest effects on the environment, especially outside the dredged area, derive in fact from the re-deposition of the fine sediments put into suspension.

Finally, a benthos sampling must be planned in at least the stations sampled in Phase C1 for the dredging site's characteristics.

Transport area (chart n. 9)

Monitoring during activities (paragraph 4.1.2) in the transport area essentially addresses the need to verify whether the sensitive habitats (previously identified along the possible sand transport routes and/or in their close vicinity) are actually affected the plume's diffusion, and how strong these effects are. The spatial extension of the turbidity plume and the sensitive habitats involved will therefore be investigated.

Nourishment area (chart n. 10)

The monitoring during activities process in the nourishment area (paragraph 4.1.3) is only carried out if Phase C1 has demonstrated the actual possibility for the sensitive habitats present (for example, *Posidonia oceanica* meadows) to be negatively affected by sand replenishment. If this is not the case, this process may be skipped, and we can directly go to monitoring Phase C3.

The aim of the monitoring during activities is to assess the short-term effects of sand removal on the sensitive habitats present, with particular reference to *P. oceanica* meadows. This study must allow to evaluate whether the activities can be carried out as initially planned, or if the cumulative effects produce more significant short-term effects than initially estimated, suggesting the use of different operational methods, aimed at reducing the effects observed.

PHASE C3

Dredging area (chart n. 11)

After the cessation of dredging activities, a monitoring *post operam* activity must be carried out in the area (paragraph 4.2.1). For some parameters, such as bottom bathymetry and morphology, the monitoring's only aim is to record the bottom's physical look (morphology and bathymetry) after the dredge's action. Due to the conditions at which relict sand deposits are found along the continental shelf in the Mediterranean Sea (at very high depths, low hydrodynamics and generally low sedimentation rates), it is not reasonable to expect a complete recovery of the shapes generated by dredging, and only a general coating can be expected. For the other parameters, instead, such as benthic assemblages, monitoring's aim is to follow the evolution of communities in time, up until a new equilibrium condition is reached.

Various monitoring surveys should therefore be planned on the same study area identified in the characterization phase (Phase C1), which may possibly be extended on the basis of the results obtained in the monitoring during activities phase (Phase C2).

In order to reach the aims defined by the monitoring procedures, it will be necessary, during the various monitoring *post operam* surveys, to investigate all the parameters required, to trace the effects of dredging and the timing and procedures for recovery. The number of surveys, timing, and parameters to be investigated in each survey (not all parameters will have to necessarily be analyzed for every survey) will be decided each time, and they will depend on both local conditions and on the dredging's characteristics (monitoring is site-specific). Concerning the duration of this phase, it is generally preferable that monitoring is not interrupted before at least 2 years from the end of the operations.

Transport area (Chart n. 12)

The monitoring *post operam* phase is carried out in this area if the previous survey phase (Phase C2) has already highlighted possible effects on sensitive habitats. The aim of monitoring *post operam* is therefore to verify whether the effects last in time, and possibly, what the modalities and timing for recovery are in the environments in question.

For these purposes, it will therefore be necessary to set up experimental surveys, mainly aimed at the study of the sensitive habitats involved, as well as surveys to analyze the main hydrological parameters of the water masses and of the suspended particulate matter (paragraph 4.2.2).

Nourishment area (Chart n. 13)

In this area, the monitoring *post operam* phase (paragraph 4.2.3) is carried out with specific reference to the presence of sensitive habitats and/or sensitive species that may have been affected by beach nourishment. The aim of the monitoring process will be to evaluate the health conditions of the habitats present, and, possibly, to study their recovery times and procedures. For these purposes, various surveys must be planned in order to gather the parameters to be studied. The study area – and, especially, the sampling stations – will have to be the same ones previously sampled in the characterization phase (Phase C1), possibly extended on the basis of the results obtained from the monitoring during activities study (Phase C2). The number of surveys and their timing will have to be defined every time and for every specific case, as deciding these details in advance is very difficult.

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3 CHARACTERIZATION STUDY

As previously stated in Chapter 1, relict sand dredging and nourishment activities involve a series of physical and biological effects on the marine environment. The main physical effects are the increase in suspended particulate matter (with subsequent increase in turbidity), and the changes in the characteristics of the sea bottom, both in terms of sediment and texture, and in terms of morphology and bathymetry. Significant effects can also be observed on the area's biological resources (benthic assemblages, demersal fish assemblages and sensitive habitats present): in the dredging site, dredging activities cause the mechanical removal of benthic organisms; in the nourishment site, sand replenishment may bury the existing assemblages; in both sites, burial can also occur due to re-deposition of the sediments put into suspension during activities.

It is evident that, before engaging in such complex activities, accurate environmental surveys must be carried out in all the areas involved (dredging area, transport area, nourishment area), in order to obtain a complete set of specific information, deriving from inter-disciplinary studies, and offering a quick and integrated key to the different environmental themes that may interact with bottom removal activities; moreover, this information will must provide a basis on which the future monitoring processes can be planned and carried out, during and after activities.

The environmental characterization study aims at providing useful elements to assess whether the bottom removal activities can be carried out with tolerable effects on the environment. This study involves a series of surveys conducted in increasing detail: Phase A is a study on a regional scale, based on the collection of bibliographic data, subsequently integrated by Phase B, experimental surveys on a wide scale (macroarea), and Phase C, experimental surveys on a detail scale.

If the data collected in Phase A are recent and sufficiently representative, it is possible to directly proceed to the site characterization phase (Phase C1). If, on the opposite, the data is inadequate, and/or something with special environmental relevance may have happened after data was collected – such as exceptionally intense meteo-marine phenomena, and/or accidental spilling of polluting substances – new updated data will have to be collected through direct surveys for the characterization of macroarea (Phase B).

Based on the results obtained, it will be possible to define the survey methods, the parameters to record and the sampling plan to adopt in the subsequent phase (Phase C), aimed at the characterization of intervention sites (Phase C1), at the monitoring during activities (Phase C2), and at the monitoring *post operam* (Phase C3).

The size of the area to investigate is defined time by time, according to the known general characteristics of the specific area in question, and to the position and size of the deposit.

It is useful to highlight, once again, that the aims of this "Quaderno ICRAM" are to present and discuss the environmental aspects of relict sand dredging for beach nourishment, while the technical aspects related to sand removal and nourishment are the object of specific technical surveys carried out by project planners.

Finally, we would like to pinpoint that nourishment may only be carried out on beaches that are considered suitable, from both a chemical and a biological point of view.

3.1 CHARACTERIZATION ON A REGIONAL SCALE (PHASE A)

Bibliographic Data Collection and Analysis

Initially, the characterization study involves the collection and analysis of data available in literature, in order to characterize the continental shelf area hosting the relict sand deposits and the coastal stretch undergoing nourishment, from an environmental point of view.

Concerning the research parameters, on top of the strictly environmental parameters – which are specific for the two different areas it will be necessary to research all information regarding the legitimate uses of the sea in both areas. In this respect, particular attention must be paid to the presence of marine areas regulated by specific protection regulations, such as:

- Marine archaeological areas;
- Marine Protected Areas (MAPs);
- Protected marine natural areas, as identified in the lists provided by the Ministry for the Environment and Protection of the Territory and the Sea (WWF Blue Oases);
- Coastal territorial protected areas (parks and natural reserves, both national and regional);
- Specially Protected Areas of Mediterranean Importance (ASPIM), identified as per the Barcelona Convention* for the protection of the Mediterranean Sea;
- Submerged archaeological parks, as per Ministerial Decrees nos. 303 – 304/2/02 from 9/12/2002;
- Special areas of conservation called "Natura 2000" ** identified as per the Habitat Directive 92/43/EEC (Sites of Community Importance) and the Bird Directive 79/409/EEC (Special Protection Areas);
- Marine repopulation areas***, marine biological protection areas****.

Particular attention must also be paid to the identification of areas that are generally sensitive to bottom removal activities, such as nursery areas (i.e. concentration areas of juveniles of fish species) of the main demersal species with commercial value, and the stretch within 3 miles from the coast (or the belt within 50 m of depth, should this depth be reached before the 3 miles), and/or areas containing sensitive habitats, identified as per the Habitat Directive (e.g. the *Posidonia oceanica* meadows and the maërl *facies*) and as per the Barcelona Convention. Since the nursery areas of demersal species represent the concentration areas of juveniles of fish species, any disturbance here could jeopardize fishing activities. As far as the dredging area is concerned, considering that the offshore nursery areas found along the continental shelf are generally much wider than the ones directly undergoing sand removal activities, no significant effects are expected.

In any case, if the data available highlights the presence of sensitive elements, the latter will have to be accompanied by their specific seasonal data and information, in order to identify possible environmental windows – the periods of the year in which removal can be carried out with minimum effects on the environment – in the preliminary phase (paragraph 1.1.3.3).

Concerning the legitimate uses of the sea, the presence of the following areas must be considered:

- areas for mariculture (mollusks and fish species);
- authorized areas from harbour material dumping;
- marine artificial reefs;
- no-anchor and no-fishing zones;
- cables, pipes, oil pipes;
- offshore structures;

** The Barcelona convention (1976) for the protection of the Mediterranean Sea from polluting actions guarantees the Mediterranean's environmental quality through the protocol "Specially Protected Areas of Mediterranean Importance" (ASPIM), and engages in endangered species protection and habitat conservation. The convention was ratified by Italy through Law 25 January 1979 n. 30.*

***In particular, if the environmental compatibility study highlights the presence special areas of conservation called "Natura 2000", which may somehow be directly or indirectly affected by dredging, an evaluation of incidence will have to be activated. Regulated in Italy by art. 6 of DPR 12 March 2003 n.120, (G.U. of the Italian Republic n.124, 30 May 2003), this evaluation process will have to be drafted as per the instructions found in attachment G of D.P.R. 357/97.*

- military sites.

All the relevant elements that must be implemented in the G.I.S. (Geographic Information System) should be critically analyzed, in order to assess the quality of the data and information in general and, to evaluate the possibility of geo-referencing this data.

G.I.S. is a system of softwares, equipments, methods, and data, capable of analyzing, planning, and managing the environment and territory. The different sets of data obtained are considered to be levels of spatial information (layer), and as such, they are registered in a single database, which can be updated with new data. A G.I.S. allows to manage these levels and combine them visually (mapping), and to use them for spatial correlations, analyses and processing, enabling both an easier understanding of the complex phenomena, and the assessment of the possible future scenarios (forecast), in order to design specific *ad hoc* methods of analysis to plan and manage interventions on the territory.

This system allows to visualize the data gathered in the different fields on a series of thematic maps, and, through overlay mapping, to pinpoint the areas in which sand extraction is not acceptable, i.e. the "areas that are environmentally incompatible with sediment removal activities."

Thematic Mapping

The bibliographic data gathered in this phase, used for G.I.S. development, allows the conduction – in the areas where sand deposits were found – of a specific analysis aimed at highlighting the areas in which particular attention must be paid when carrying out sand extraction and nourishment, due to the presence of uses of the sea that are not compatible with such activities.

The data, analyzed and inserted in the G.I.S., are therefore used for the development of specific thematic maps, such as for example the map of the superficial sediment distribution (***Figure 3.1***), the map of the of benthic biocoenoses distribution (***Figure 3.2***), and the map of the legitimate uses of the sea (***Figure 3.3***).

When drafting thematic maps, it is important to consider that some of the parameters investigated, which are essential for a correct environmental compatibility analysis such as hydrology and water mass dynamics and the composition and structure of fish assemblages, are subject to seasonal variations. As a consequence, the related thematic maps will have to describe seasonal situations; ***Figure 3.4*** reports, as an example, the distribution of nursery areas in the spring period.

For the purposes of a preliminary environmental compatibility evaluation, it is possible, through a visual overlay mapping process to develop synthetic maps or overlay maps (***Figure 3.5***) containing all the relevant information related to aspects that could limit sand removal activities and/or constrain them in any way. Some of these elements constitute "strict" restrictions. Examples of this are Marine Protected Areas, dumping areas for harbour material, cables and pipes, offshore structures, no-anchor or no-fishing zones, marine artificial reefs, the belt within 3 miles from the coast, and the *Posidonia oceanica* meadows: where these restrictions are present, no bottom removal activity is possible.

In particular, where *P. oceanica* meadows are present, on top of the "strict" restriction area (areas corresponding directly to the size of the meadow itself, and in which bottom removal activities cannot be carried out), nearby "respect" areas must also be considered, in which such activities could have significant effects on the meadow, jeopardizing its health conditions.

Other elements may instead constitute "non-strict" restrictions. Their compatibility with removal activities must be evaluated each time; for example, concerning nursery areas, it is important to consider their location and size in relation to the size of the dredging site.

**** Law 17 February 1982, n. 41.*
***** D.P.R. 2 October 1968, n. 1639.*

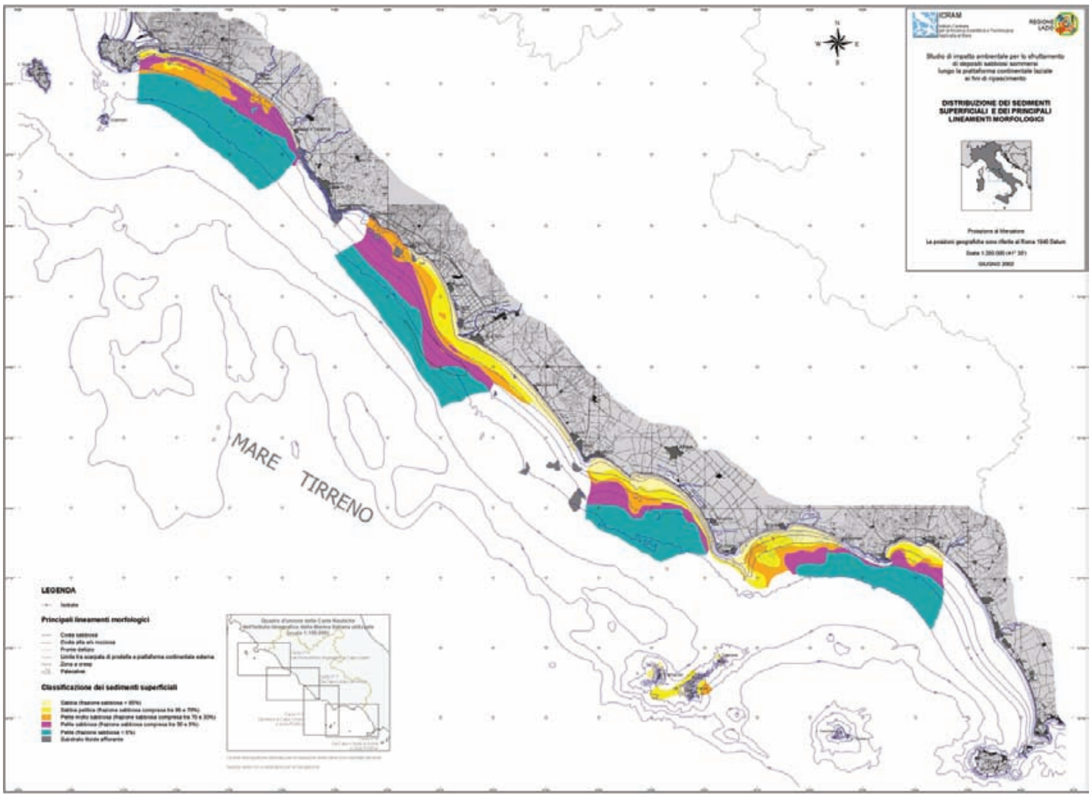


Figure 3.1 - Map of superficial sediment distribution along the Latium continental shelf (Phase A).

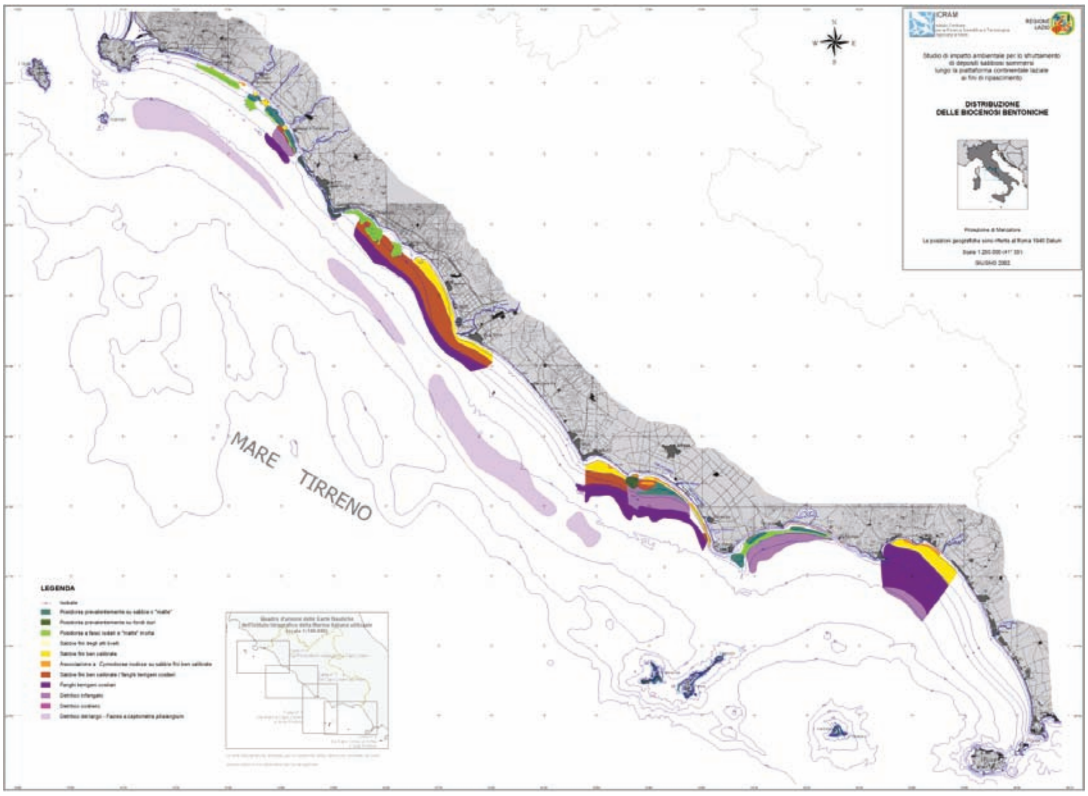


Figure 3.2 - Map of the benthic biocoenoses distribution along the Latium continental shelf (Phase A).

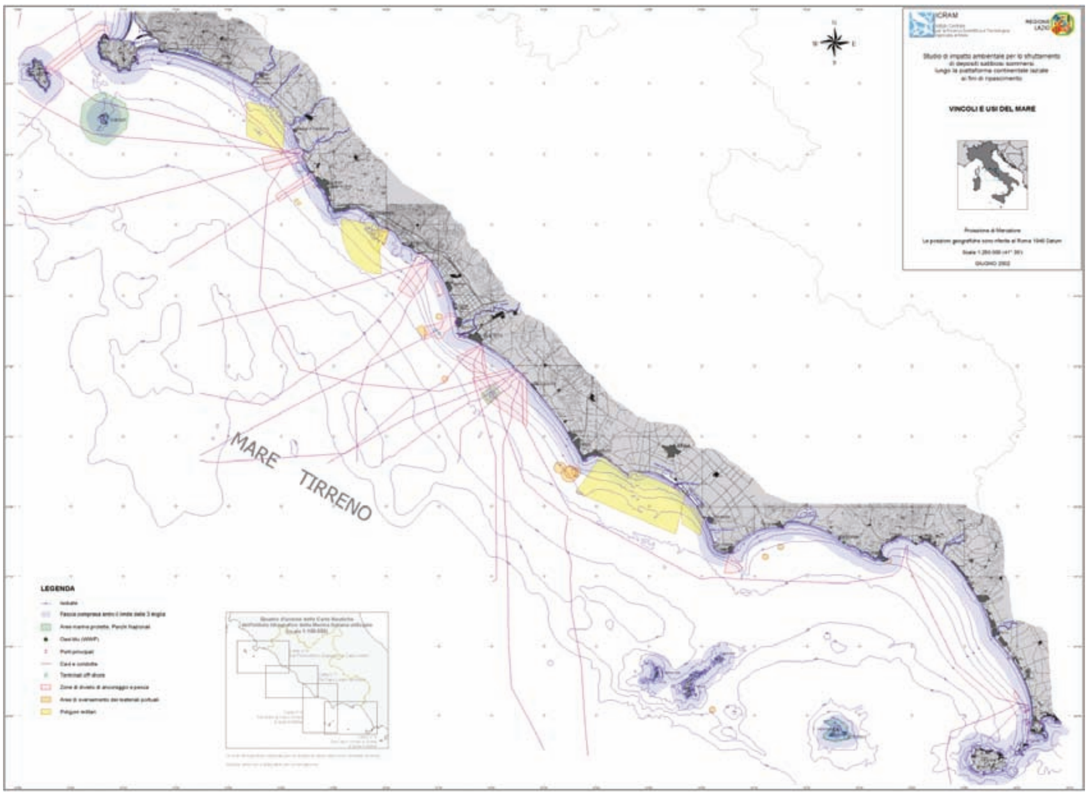


Figure 3.3 - Map of the legitimate uses of the sea along the Latium continental shelf (Phase A).

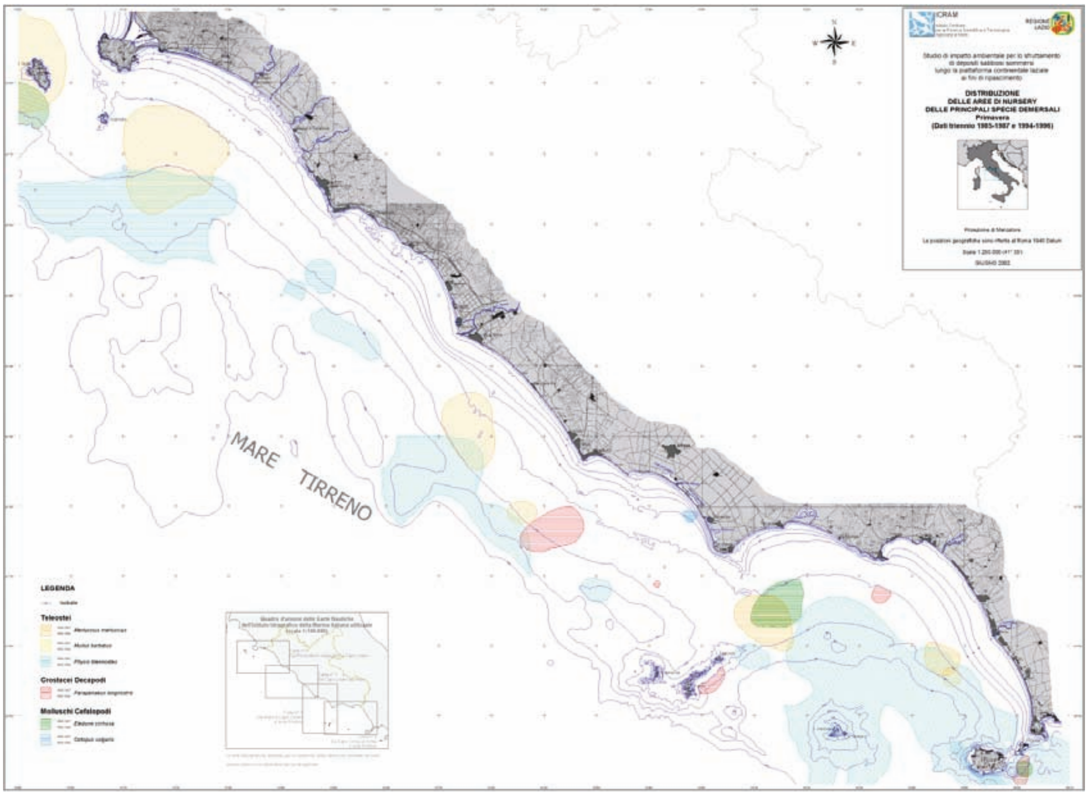


Figure 3.4 - Map of nursery area distribution along the Latium continental shelf (Phase A).

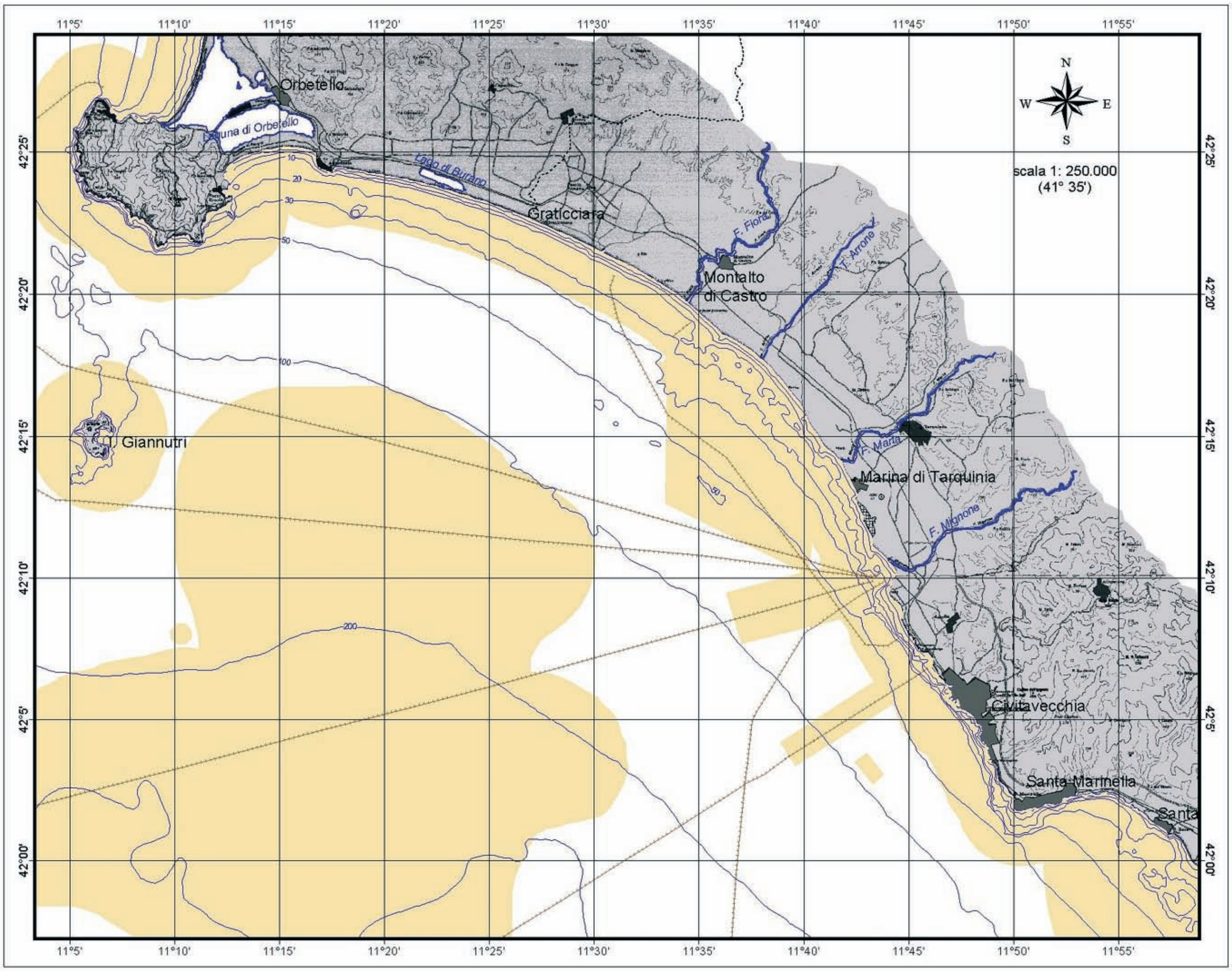


Figure 3.5 - Seasonal overlay map of the nursery areas (spring) along the Latium continental shelf (Phase A): the yellow areas represent the areas in which sand removal activities might be environmentally incompatible.

Another aspect that should not be neglected is, as mentioned, the seasonality of certain elements (restrictions), and overlay maps will have to report the different seasonal situations.

Already in this phase, therefore, the characterization study will allow the identification of appropriate environmental windows.

3.1.1 Dredging Area (*chart n.1*)

Data gathering must be carried out on a sufficiently wide area that includes the potentially exploitable sand deposits as well as the surrounding areas for a wide range, and it should possibly be extended up to the shoreline.

Concerning bibliographic research, on top of data relating to legitimate uses of the sea (paragraph 3.1), the existing data available in literature must be collected and must be subject to critical analysis, in relation to the following parameters:

- morphology and bottom bathymetry;
- textural characteristics (granulometry) of superficial sediments;

- chemical characteristics of superficial sediments:
  - organic substances or total organic carbon (TOC);
  - metals:
    Al, As, Cd, Cr_{tot}, Pb, Hg, Ni, Cu, V and Zn;
  - organic micropollutants:
    total and congeneric single PAH (polycyclic aromatic hydrocarbons): fluoranthene, naphtalene, anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, indopyrene, acenaphtene, fluorene, phenantrene, pyrene, benzo(a)anthracene, crysene, dibenzo(a,h)anthracene, indeno(1,2,3,c-d)pyrene;
    organochloride pesticides: aldrin, dieldrin, α-hexachlorocyclohexane, β-hexachlorocyclohexane, γ-hexachlorocyclohexane (lindane), DDD, DDT, DDE (for each family, sum of isomers 2,4 and 4,4);
    total and congeneric single PCB (polychlorobiphenyls): PCB28, PCB52, PCB77, PCB81, PCB101, PCB118, PCB126, PCB128, PCB138, PCB153, PCB156, PCB169, PCB180 and their sum;
    hexachlorobenzene;
    TBT (tributhyltin);
- hydrology of water masses (chemical-physical characteristics);
- suspended particulate matter (total and inorganic);
- dynamics of water masses (currentometry);
- benthic assemblages (biocenotic characterization);
- demersal fish assemblages (nursery areas).

All collected data, when analyzed and inserted in a G.I.S. system, may suggest various scenarios.

If this data is considered sufficient to environmentally characterize the area, the elements in this phase could already allow preliminary evaluation of the dredging activity's environmental compatibility, in which case we may proceed directly with the dredging site's characterization phase (Phase C1).

Should however an insufficiency of data be reported, and/or the lack of good quality data (i.e. data is too old, the survey scales are not suitable for the study, data geo-referencing is difficult), it will be necessary to start an experimental characterization phase in a wide area that contains the relict sand deposit, through the fulfillment of *ad hoc* oceanographic surveys (Phase B).

RESTRICTIONS AND LEGITIMATE USES OF THE SEA: THE CASE STUDY OF THE LATIUM CONTINENTAL SHELF

In the framework of a project aimed at exploiting relict sand deposits for beach nourishment, ICRAM, in collaboration with Regione Lazio, has carried out a study aiming at investigating the environmental compatibility of relict sand dredging (ICRAM, 2002). All the elements whose presence could significantly limit or affect sand extraction activity along the Latium continental shelf have therefore been identified and mapped (through G.I.S.).
On top of general elements, such as sea areas in which sea water depth is lower than 50 m within 3 nautical miles from the coast, and no-anchor or no-fishing areas indicated on the nautical maps, the following elements have been identified in Latium:

Marine Protected Areas

- Tor Paterno Shoals: established by Decree from the Ministry for the Environment, 29 November 2000 (G.U. 20/01/01), and includes a single general reserve zone;
- Ventotene and Santo Stefano Islands: established by Ministerial Decree, 12 December 1997 (G.U. 24/02/98), the reserve presents a 3-level zoning, with a total reserve area (zone A), an oriented reserve area (zone B), and a general reserve area (zone C).

WWF Blue Oases

- Villa di Tiberio established by C.D. 19/05/1995
- Mount Orlando: established by C.D. 04/02/1993
- Mount Gianola: established by C.D. 14/07/1992

Sites of Community Importance

- IT6000001 “Sea bottoms comprised between the mouths of Chiarone and Fiora Rivers”
- IT6000002 “Sea bottoms offshore Punta Morelle”
- IT6000003 “Sea bottoms comprised between the mouths of Arrone and Marta Rivers”
- IT6000004 “Sea bottoms comprised between Marina di Tarquinia and Punta Quaglia”
- IT6000005 “Sea bottoms comprised between Punta Sant’Agostino and Punta Mattonara”
- IT6000006 “Sea bottoms comprised between Punta del Pecoraio and Capo Linaro”
- IT6000007 “Sea bottoms offshore Santa Marinella”
- IT6000008 “Macchiatonda Shoals”
- IT6000009 “Torre Flavia Shoals”
- IT6000010 “Tor Paterno Shoals”
- IT6000011 “Sea bottoms comprised between Torre Astura and Capo Portiere”
- IT6000012 “Sea bottoms comprised between Capo Portiere and Caprolace Lake”
- IT6000013 “Sea bottoms comprised between Capo Circeo and Terracina”
- IT6000014 “Sea bottoms comprised between Terracina and Lungo Lake”
- IT6000015 “Sea bottoms surrounding Palmarola Island”
- IT6000016 “Sea bottoms surrounding Ponza Island”
- IT6000017 “Sea bottoms surrounding Zannone Island”
- IT6000018 “Sea bottoms surrounding Ventotene Island”
- IT6000019 “Sea bottoms surrounding Santo Stefano Island”

Special Protection Areas

- IT6040015 “Circeo National Park”
- IT6040019 “Ponza, Palmarola, Zannone, Ventotene, and Santo Stefano Islands”

Areas requiring protection (nursery areas for demersal assemblages)
Along the Latium coast, the presence of nursery areas of the main demersal species with commercial value has been recorded:
Teleosteans
- *Merluccius merluccius*: in spring, summer and autumn
- *Mullus barbatus*: in summer and autumn
- *Phycis blennoides*: in spring and summer

Decapod crustaceans
- *Parapenaeus longirostris*: in spring and summer

Cephalopod mollusks
- *Eledone cirrhosa*: in spring, summer and autumn
- *Octopus vulgaris*: in spring and summer

Marine artificial reefs
The Latium shelf presents 4 artificial reefs; one of these is situated offshore Fregene, and 3 are found offshore Ponza (Chiaia di Luna, Mattoni Shoal and Cala Inferno).

Dumping areas for harbour materials
18 authorized areas for dumping of harbour materials have been listed. 4 of these belong to the Civitavecchia Port Authority (Rome), 4 to the Gaeta Port Authority (Latina) and 10 to the Port Authority of Rome-Fiumicino.

Military sites
5 military sites are present along the Latium coast: 3 (Pian di Spille, Santa Severa and Furbara) belong to the Civitavecchia Port Authority (Rome) and 2 (Nettuno and Sabaudia) to the Anzio (Rome) Maritime District Office.

Cables, pipes, and oil pipes
The presence of submarine cables, discharge pipes, and oil pipes involves the prohibition of anchor and fishing activities, i.e. of any activity involving the sea bottom. In some cases, navigation is also prohibited.
- Submarine cables: numerous underwater cables are found in the area, on the sea stretch comprised between Punta S. Agostino to the North and the roadstead of Gaeta to the South.
- Submarine pipes: 5 submarine pipes are present, situated between the Pratica canal and Torre Vittoria.
- Oil pipes: the area presents a total of 5 oil pipes, situated, from North to South, along the coast between Montalto di Castro and Torre Valdaliga (with both dockings on land situated underground), in Torre Valdaliga, connecting the oil tower to land, NW of Torre Valdaliga, in Fiumicino (two submarine oil pipes converging in a single terminal) and North of the “Diga Foranea” (an outer breakwater) of the new Commercial Harbour of Gaeta, i.e. an oil pipe connected to the terminal in the roadstead bearing the same name.

Offshore structures
2 load/unload platforms and an oil tower are present in the area. The tower is situated NW of Torre Valdaliga, on the point with coordinates 42°07’27’’N and 11°43’38’’E. The two single-mooring platforms are located offshore Fiumicino.

3.1.2 Nourishment Area (*chart n. 2*)

In the nourishment area, too, the characterization study begins with the collection and analysis of data available in literature, in order to define the main environmental characteristics of the coast to be nourished.

The study area will have to be sufficiently wide, so as to include the coastal stretch or stretches that are directly involved in nourishment activities, as well as the surrounding areas. The environmental problems that may arise in this area are essentially linked to the effects that nourishment itself can cause on marine organisms: the most immediate effects are linked to burial phenomena during sand replenishment on the beach, while other problems can arise because of the modifications in the physical environment (variations in the substratum's characteristics and in water quality). It will therefore be necessary to gather and analyze data from scientific and technical literature, concerning the following environmental aspects:

- benthic assemblages;
- demersal fish assemblages.

Particular attention must be paid to the identification of high sensitivity areas, such as the nursery areas of the main demersal species, and/or the areas where sensitive habitats are present.

Nursery areas, which are concentration areas of juveniles of fish species, are particularly sensitive areas and they could suffer from the (direct and indirect) effects of nourishment, especially when their surface is limited compared to the size of the of the area involved in nourishment.

In this case too, similarly to what happens for the dredging area, the aim of the research is to identify, through detailed and accurate seasonal surveys, the periods of the year in which nourishment can be carried out with minimum effects of the environment (environmental windows), in order to concentrate nourishment activities in this time frame.

All data gathered will have to undergo a careful critical evaluation, involving both data and information quality and, in case of data input in a G.I.S. system, the possibility and need to geo-reference this data and information. The validated data will be used for the development of basic thematic maps and synthesis maps, reporting all the relevant elements that could somehow limit nourishment activities.

If the information gathered is recent and sufficiently representative of the area's environmental conditions, after Phase A we can directly go ahead and start the characterization study of the shoreline to be nourished (Phase C1). If this is the case, the characterization study carried out in Phase A may, in this phase, provide the necessary elements for a first evaluation of environmental compatibility of nourishment and for a preliminary evaluation of the possibility of adopting environmental windows. If the data gathered is not considered adequate to describe the areas' environmental characteristics, or if phenomena with particular environmental relevance have occurred (such as meteo-marine phenomena of exceptional intensity) following data gathering, an experimental characterization phase of the macroarea will have to follow, aimed at collecting updated data (Phase B).

3.2 CHARACTERIZATION OF MACROAREA (PHASE B)

This phase involves the fulfillment of wide scale experimental surveys, in order to obtain a sufficiently detailed picture, from an environmental point of view (physical, chemical, and biological), of a sufficiently wide area that includes, as far as possible, the relict sand deposit intended for dredging, and the stretch of beach awaiting nourishment for the nourishment area. This phase is required if the previous phase (Phase A) has shown insufficient data and/or the lack of good quality data (data was too old, inadequate survey scales, data is not easily geo-referenced).

3.2.1 Dredging Area (*chart n. 3*)

To carry out the characterization of the macroarea containing relict sand deposits, it is necessary to plan a specific sampling plan on a wide area containing such deposits.

The aimed experimental surveys, must involve specific, wide and homogenous sampling plans, in order to perform an in-depth characterization of the study area. The choice of the sampling stations will be decided both on the basis of the characteristics and of the gaps that may have arisen in Phase A.

An example of a sampling plan in the macroarea is shown in ***Figure 3.6***.

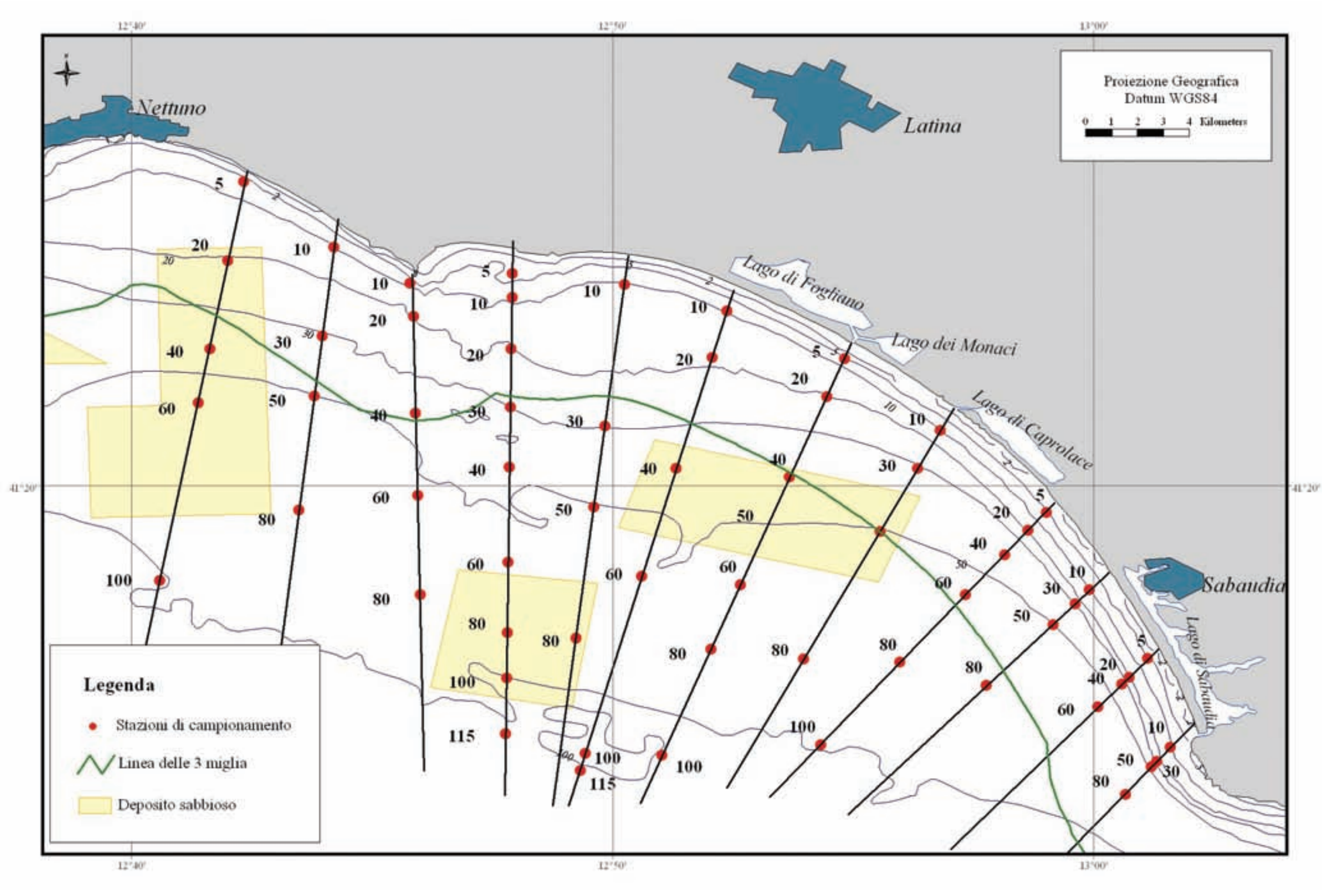


Figure 3.6 - Sampling plan for Phase B, dredging area (relict sand deposits are in yellow).

In the area defined, it will be necessary to carry out experimental surveys in relation to:

- textural characteristics (granulometry) of superficial sediments;
- chemical characteristics of superficial sediments:
  - organic substances or total organic carbon (TOC);
  - metals:
    Al, As, Cd, Cr_{tot}, Pb, Hg, Ni, Cu, V and Zn;
  - organic micropollutants:
    total and congeneric single PAH (polycyclic aromatic hydrocarbons): fluoranthene, naphtalene, anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, indopyrene, acenaphtene, fluorene, phenantrene, pyrene, benzo(a)anthracene, crysene, dibenzo(a,h)anthracene, indeno(1,2,3,c-d)pyrene;
    organochloride pesticides: aldrin, dieldrin, α-hexachlorocyclohexane, β-hexachlorocyclohexane, γ-hexachlorocyclohexane (lindane), DDD, DDT, DDE (for each family, sum of isomers 2,4 and 4,4);
    total and congeneric single PCB (polychlorobiphenyls): PCB28, PCB52, PCB77, PCB81, PCB101, PCB118, PCB126, PCB128, PCB138, PCB153, PCB156, PCB169, PCB180 and their sum;
    hexachlorobenzene;
    TBT (tributhyltin);
- hydrology of water masses (chemical-physical characteristics);
- suspended particulate matter (total and inorganic);
- dynamics of water masses (currentometry);
- benthic assemblages (biocenotic characterization);
- demersal fish assemblages (nursery areas).

In particular, in case of parameters characterized by important seasonal variations (hydrology and water mass dynamics, suspended particulate matter and demersal fish assemblages), seasonal surveys will have to be planned in order to identify the periods of the year in which removal may be carried out with the minimum possible effects on the marine environment.

The information gathered will be recorded in the G.I.S. databank, thus integrating the data collected in Phase A, summarized in thematic maps, updating the data produced in the previous phase.

On the basis of updated experimental data, this characterization phase will allow to visualize the areas that are environmentally incompatible with dredging activities (preliminary compared evaluation about the environmental compatibility of dredging activities).

The information gathered will allow to define the survey methods, the sampling design, and the parameters to use, concerning the following phase, and it will provide a basis on which to plan the future monitoring activities, during dredging and after the end of the activities.

The conclusions obtained in this phase can provide various results. If the results of the surveys are environmentally compatible, we can go on to the following phase, i.e. the dredging site characterization (Phase C1). Should the results instead indicate that the dredging activities are not environmentally compatible, it may be decided to concentrate the surveys on other deposits.

Sediment quality

A particularly important aspect in this phase concerns the sediments' chemical qualities; normally, in order to assess the chemical quality (metals and organic compounds) of sediments found on the dredging area's superficial pelitic layer, it is necessary to determine the total contents and the relative speciation of the single congeneric compounds for organic contaminants, and just the total contents for metals.

Organic contaminants

Most organic contaminants monitored for the protection of the marine environment (PAH, organochloride compounds, organostannic compounds, etc.) present a high chemical stability, and, therefore, a high environmental persistence. This unfortunately turns them into ubiquitous contaminants, which tend to accumulate in sediments and marine organisms. Their presence in the marine environment is only rarely linked to natural conditions. Therefore, should their presence be reported in the macroarea's characterization phase, the subsequent Phase C1 will have to limit the dredging area to a non-contaminated zone.

Metals

In the case of metals, instead, it can occur that the concentration anomalies found in the sediments are actually ascribable to natural phenomena (for example, geochemical anomalies); in this case, it is important to not only demonstrate the phenomenon's naturalness, but also to evaluate whether and to what extent the metal is mobile, and therefore potentially bio-available. The total abundance values alone do not allow to trace the single chemical species, nor do they allow to differentiate the natural or anthropogenic origin. In the presence of geochemical provinces, a particularly high total content in metals is not representative of a contamination situation; also, in this case, metals are generally present in a form that is hardly mobilizable by the normal variation of the chemical-physical parameters expected following sand removal. Therefore, should Phase B show concentration anomalies in the superficial pelitic sediment, the following Phase C1 will have to include more in-depth specific analyses (for example operational procedures of sequential extraction), in order to evaluate the mobility of the metallic species within the superficial sediment, and, therefore the naturalness of the concentrations observed. If the results of Phase B do not show particular enrichment in the superficial sediment, the subsequent Phase C1 will involve the determination of the total contents only (***Figure 3.7***).

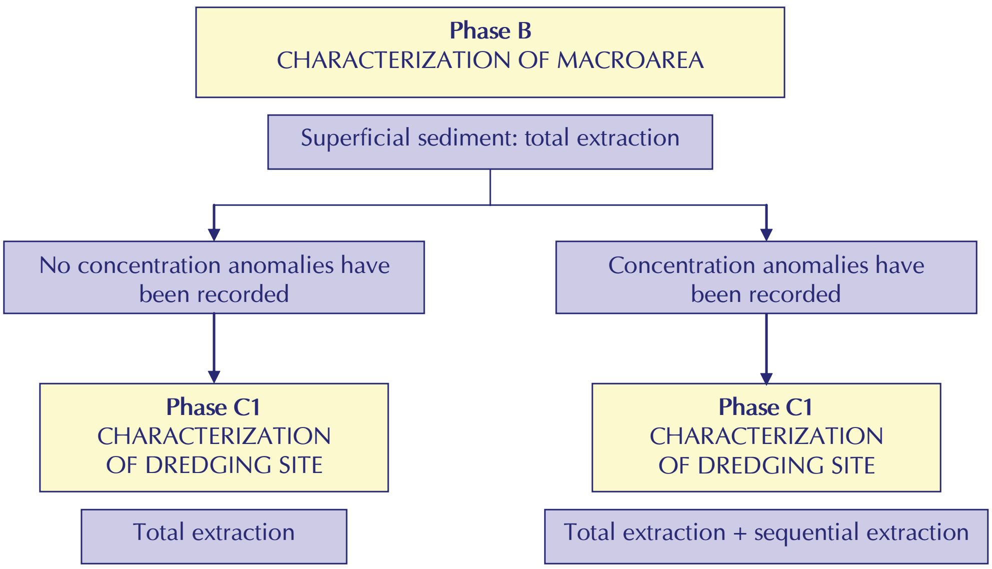
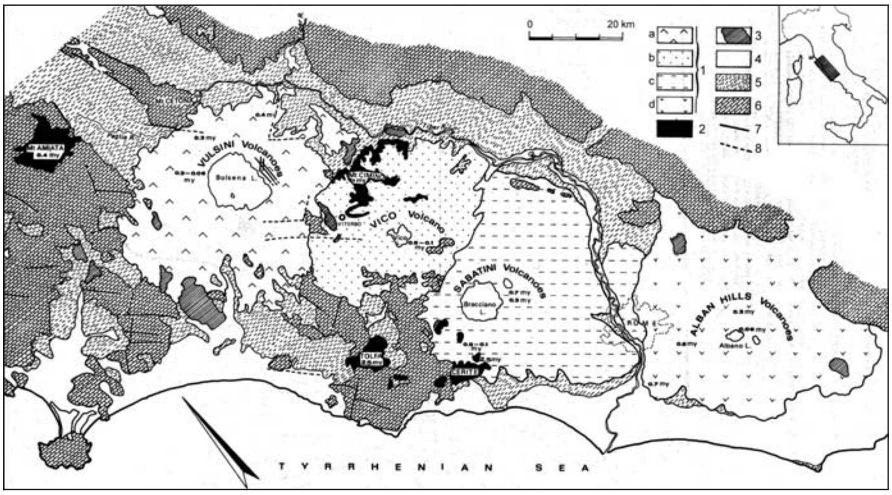


Figure 3.7 - Chemical concentration (metals) of sediments in the dredging area.

CHEMICAL CHARACTERIZATION OF SEDIMENTS: THE CASE OF METALS

The surveys mentioned below are among the first experiences carried out in Italy on environmental characterization studies related to relict sand dredging, to ever address the problem of chemical mobility of metals contained in superficial sediments in the dredging area.

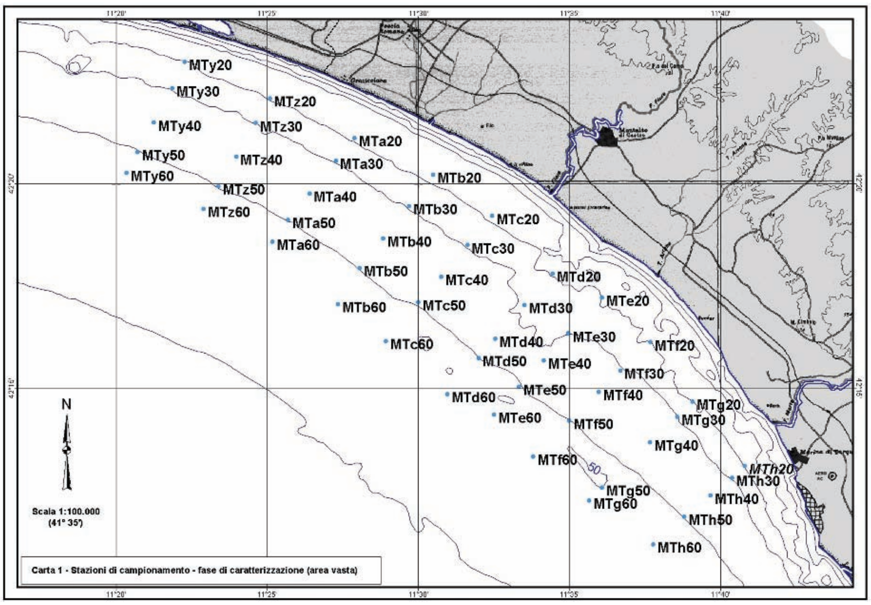
The study area is situated in a sector of the northern Latium continental shelf, offshore Montalto di Castro (Viterbo, Italy), where the presence of some anomalies in some elements, such as Hg, Pb and some elements of the Fe group has been observed, and is due both to the influence of the mercuriferous systems of Mount Amiata (Tuscany, Italy) and to the volcanic formation of K-alkaline series (Branca *et al.*, 1996).



Geological scheme of the peri-Tyrrhenian Latium domain. Legend: 1) Alkaline potassic volcanites (Quaternary) (a. Vulsini Mountains Volcanic District; b. Vicani Mountains Volcanic District; c. Sabatini Mountains Volcanic District; d. Albani Hills Volcanic District); 2) Acid volcanites (Pliocene-Pleistocene); 3) Travertine; 4) Continental and coastal sediments (Quaternary); 5) Clayey and sandy sediments (Higher Miocene-Pliocene-Lower Pleistocene); 6) Mainly sedimentary successions (Carboniferous-Lower Miocene); 7) Faults; 8) Buried faults (from Locardi *et al.*, 1976)

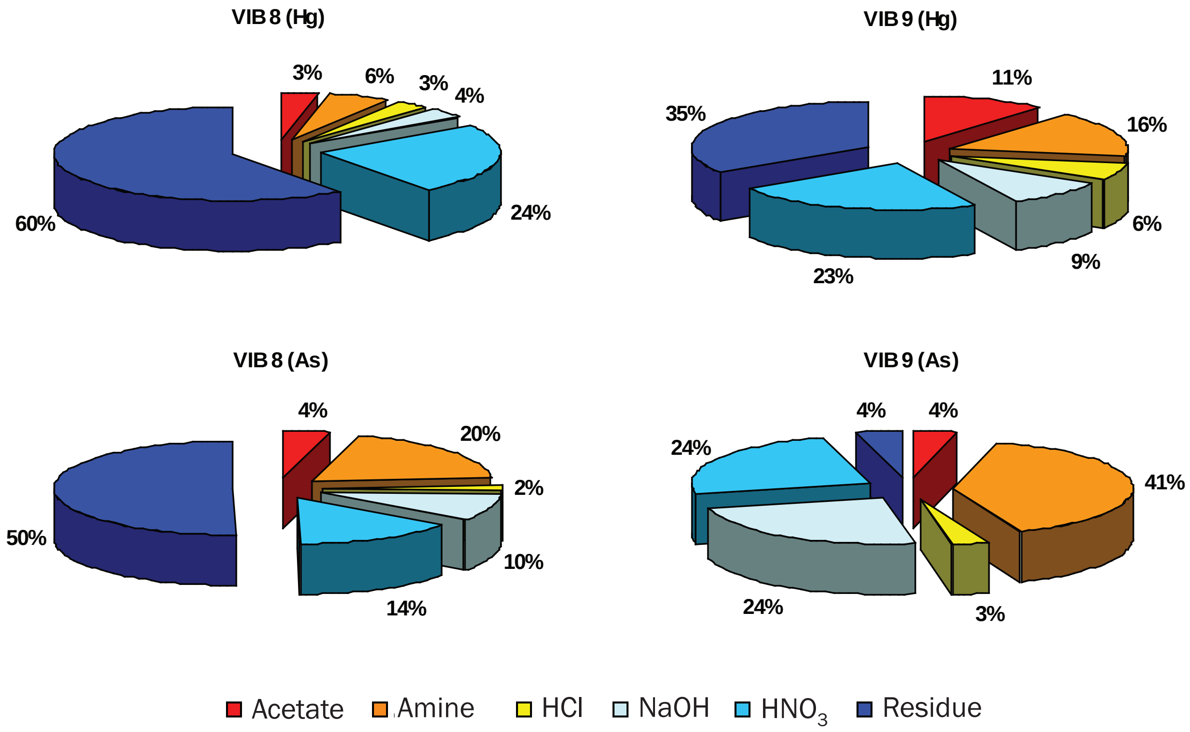
Here, following the identification of relict sand deposits that can be used for nourishment, ICRAM, in collaboration with Regione Lazio, carried out a characterization study of the dredging area, performing, in particular, chemical analyses of the superficial sediments.

The environmental study began with the chemical characterization of the superficial sediments in a wide area (Phase B) that contained the relict sand deposits. This was done by gathering 36 samples of superficial sediment, according to the sampling scheme illustrated in the following figure.



Sampling scheme for the chemical characterization of superficial sediments (Characterization of macroarea)

In this phase, analyses were carried out on the organic micropollutants and on metals. Metals (As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn) dissolution was conducted using microwave assisted digestion with the mixture of strong acids (method US EPA 3052) and analytical determination carried out by atomic absorption spectrometry.
The results obtained showed the absence of contamination as far as organic micropollutants are concerned, while, concerning metals, they recorded the presence of some abnormal values, probably ascribable to the geochemical characteristics of the hydrographic basins.
Afterwards, after Regione Lazio provided the exact coordinates of the dredging area, a detail analysis of the intervention site was initiated (Phase C1). It is important to keep in mind that the results related to this phase will be used to obtain the sand removal authorization, according to D.M. 24 January 1996 and D.lgs 152/1999. Chemical analyses were therefore carried out to determine the total metal content, according to the aforementioned methodology, on the superficial sediments in 4 stations situated within the dredging area. The results obtained have not shown particular concentration anomalies, if not for some relatively higher values of As and Hg. A comparison with the values reported on D.M. 367/2003, related to the quality standards for marine coastal sediments (which are not specific to evaluate the conformity of shelf sediments, but as of now the only national reference regulation available), revealed that As and Hg had higher values than those established by the decree. The need arose therefore to verify that these concentrations actually represented the natural concentration (as provided by the decree). Furthermore, given the toxicity of the elements present in higher concentrations, it was decided to proceed with further in-depth chemical analyses, integrating the methodology protocol used up to this point (Paganelli *et al.*, 2005).
Further samples of superficial sediment were collected in 2 stations, called VIB8 and VIB9. On these samples, in addition to determining the total metal content, chemical analyses were carried out to determine the distribution of the metallic species in the different fractions. The metal's mobility in the different fractions was therefore evaluated through an operational procedure of sequential extraction with solvents with growing extraction power (Maggi *et al.*, 2006).
Similarly to what was observed in the previous survey phases, the results obtained for the total abundances indicate that the concentrations of Cu, Fe, Mn, Ni, Pb, Hg, Cd, As and Zn are consistent with values reported in literature for the central Tyrrhenian shelf (Leoni *et al.*, 1991, 1993; Niccolai *et al.*, 1993; Cosma *et al.*, 1994; Barghigiani *et al.*, 1996; Branca *et al.*, 1996), with higher average contents in VIB8, wherein the pelitic fraction is sensibly higher than that present in VIB9. In particular, concerning Hg and As, in one of the two samples (VIB8) the content in Hg proved higher than the environmental quality standard stated in the D.M. 367/2003, while As proved higher in both samples.
The sequential extractions have however highlighted that in sample VIB8, which presented higher Hg concentration values (total contents 0.499 mg/kg s.s.), more than 50% of the total content is present in the residual fraction, and is insoluble, and the fraction extracted with nitric acid, which represents chemical forms with very low mobility, constitutes 23%. Concerning As, it was also verified that the metal percentage present in the form of insoluble residue ranges between 50% and 35% in VIB8 (total contents 58.300 mg/kg s.s.) and VIB9 (total contents 34.111 mg/kg s.s.), respectively; the aliquot extracted with nitric acid reaches 14% in VIB8 and 23% in VIB9.
The percent distribution of the different fractions extracted for Hg and As is shown in the following page.



Percent distribution of the single phases for Hg (top) and As (bottom) in the superficial sediment

The sequential extractions have also highlighted other situations. For example, metals Cd and Pb, – whose mobile fraction (represented by the first two fractions extracted) reaches higher percentages compared to what was recorded in case of Hg and As – did not generate any concern among researchers, as these percentages are referred to very low total metal contents (0.114 and 0.059 mg/kg s.s. for Cd and 23.909 and 11.304 mg/kg s.s. for Pb, respectively).
At the end of these specific surveys, it was possible to observe that, although some metals showed concentration anomalies, in the two samples of superficial sediment undergoing sequential analysis, the conditions recorded in accordance to the sediment's granulometric characteristics did not cause any concern because over 50% of the metal's total content was "blocked" in a non-mobile form.
The results obtained in the frame of the environmental characterization study carried out offshore Montalto di Castro (Viterbo, Italy) brought to the implementation of the monitoring protocol, showing that the use of sequential extraction procedures is an efficient survey to assess the naturalness of the metals present in the sediment. For these reasons, it is appropriate to plan this kind of survey in the dredging site's characterization phase, if the previous phase (characterization of macroarea) provided high total concentration values.

3.2.2 Nourishment Area (*chart n. 4*)

This phase involves the collection of all the necessary data to evaluate whether the variations induced on the physical environment (such as variations in the granulometry of superficial sediments and increase in turbidity) may significantly affect the existing benthic organisms and sensitive habitats, such as *Posidonia oceanica* meadows.

For the characterization of macroarea, on the basis of the first data obtained from Phase A, a specific sampling plan must be designed on a wide area that contains the coastal stretch to be nourished. In this area, it will be necessary to carry out direct surveys in relation to:

- granulometry of superficial sediments;
- benthic assemblages (biocenotic characterization);
- demersal fish assemblages (nursery areas).

In particular, the study of the benthic component will have to investigate the possible presence of sensitive habitats, such as for example *P. oceanica* meadows – which are the object of specific protection regulations (paragraph 3.1), and/or sensitive species. Direct surveys will also have to be carried out seasonally, in order to identify the main characteristics of the area's demersal assemblage, with particular reference to the identification of nursery areas.

Particular attention must be paid to the identification of benthic species with commercial value, such as the bivalve mollusk *Chamelea gallina*. A negative effect on these species could in fact have important economic repercussions. For these purposes, it will be useful to be aware of these species' life cycles, in order to identify the periods of the year in which nourishment activities can be conducted with minimum effects.

All the information obtained from the surveys will be registered in the G.I.S. databank, and used for the creation of thematic maps.

The information gathered, integrated with the data relating to Phase A through G.I.S., will provide information on the possible impacts that may arise following sand replenishment on the beach, thus allowing to assess the environmental compatibility of the interventions planned.

The information collected in this phase will also provide a basis for the future characterization and monitoring (during activities and *post operam*) of the nourishment site.

The results obtained in this phase can define various scenarios. If the surveys indicate that nourishment activities are environmentally compatible, the following survey phase – i.e. characterization of nourishment site (Phase C1) – can begin.

3.3 CHARACTERIZATION OF INTERVENTION SITES (PHASE C1)

Phase C1 involves detail environmental analyses in an area that is smaller than the one object of the previous surveys (Phase A and B).

Phase C1 is carried out in all 3 areas involved: dredging area, transport area and nourishment area. The specific survey areas will have to contain the dredging site, the route chosen for relict sand transport up to the beach to be nourished, and the nourishment site, respectively.

This site characterization phase begins once the executive project is known. The executive project indicates: the area chosen for dredging, i.e. the sand deposit's sector actually meant for dredging (dredging corridor), the beach of destination for the sand, and the technical specifications of the activity (dredging method, duration and period of the year, quantity and quality of the sand, etc.)

The aim of the phase is to obtain the necessary results in order to carry out a compared evaluation of environmental compatibility, and to acquire data that will provide an environmental picture of the area in undisturbed conditions. This data will be used in the subsequent monitoring phases (Phase C2 and C3), as comparison data to evaluate both the possible effects induced by such activity, and the recovery times of the marine environment.

3.3.1 Dredging Area (*chart n. 5*)

The sampling plan that must be adopted in this phase must allow a significant characterization of the whole surface and volume of the material that will be removed.

The sampling plan will be set up on the basis of the impact hypotheses generated in Phases A and B; in any case, the stations will be placed both within the site expected for dredging and outside of it, at increasing distances, according to the hydrodynamic characteristics of the area and of the possible presence of sensitive areas in the surroundings (***Figure 3.8***).

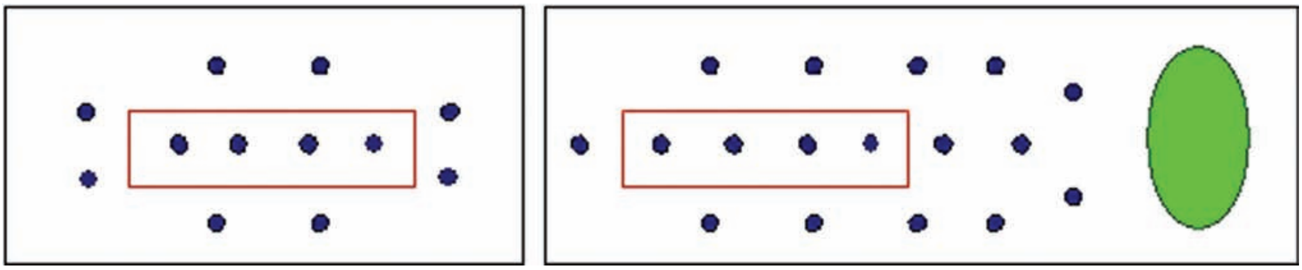


Figure 3.8 - Hypothesis of sampling station distribution in the absence (left) and in the presence (right) of sensitive habitats. The red area indicates the dredging corridor, while the green zone represents a sensitive habitat.

In particular, the sampling stations will have to placed as follows:

- area within the deposit: 4 stations per km^2; for sites smaller than 1 km^2, the number of stations cannot be lower than 3;
- area outside the deposit: 8 stations for sites of up to 1 km^2 in size; the number will have to increase proportionally according to the area's increase in size.

Marine sediments

Concerning the characterization of the marine sediments intended for nourishment (relict sand), the deposit sands' characteristics will have to be compared with the parameters (metals and organic micropollutants) listed in Decree 367/2003, which indicate the quality standards for marine coastal sediments, with particular reference to the concentration of priority substances and dangerous and priority substances, identified as per decision n. 2455/2001/CE of the European Parliament and of the Council, 20 November 2001. It is though necessary to observe that, as stated in the same decree, attachment A, general section, art. 3, *"the concentrations found in the sediments situated in geochemical regions presenting higher background levels than those stated in table 2, can be substituted by the natural bottom concentrations"*, which means that the concentration values stated in the table for metals can be exceeded, provided that their natural origin is demonstrated.

Concerning the chemical characterization of relict sand deposits, in at least 3 stations inside the dredging area, it is necessary to remove some sediment cores in order to perform the chemical and granulometric analyses. The cores will have to be dissected in different levels of the sediment, chosen so that the results are representative of the deposits' whole thickness, in order to verify the congruity with the quality standards indicated in the aforementioned decree (D.M. 367/2003).

During the planning phase, it will also be necessary to evaluate the effects that may derive from the possible chemical and/or mineralogical compositional differences between the relict sands and the original sands from the beach to be nourished, which may cause significant physical effects during sand replenishment on the beach and during the subsequent remixing action of waves and currents (for example, an increase in turbidity by means of the friction of grains with different hardness). For these purposes, as soon as the relict sand deposit intended for nourishment of a certain coastal stretch is identified with certainty, specific studies will have to be carried out through the use of mathematical and/or physical models. The compositional difference between the original sand and the sand used for nourishment can also generate an aesthetic impact due to the different macroscopic characteristics of the sediment, such as color, shape and size. These aspects will have to be evaluated during the planning stage. The physical and mechanical characteristics of the relict sands to be used, which are strongly linked to the operation's feasibility, are not the object of the environmental study, but they are an essential part of the technical project for nourishment.

In the case of deposits with a pelitic layer, the sampling and characterization of the superficial sediments (for a thickness of 5 cm) will have the only aim of evaluating the effects on the environment following a possible mobilization of contaminants. In fact, should the chemical analyses carried out on the superficial pelitic cover suggest a condition of contamination (in progress or past), sand extraction will not be possible, because of the possible release of pollutants generated by the mobilization of superficial sediments.

In all sampling stations, it will be necessary to gather data pertaining to the following:

- textural characteristics (granulometry) of superficial sediments;
- hydrology of water masses (chemical-physical characteristics);
- suspended particulate matter (total and inorganic);
- benthic assemblages.

Concerning just the stations situated within the dredging site, the following surveys must be carried out on the superficial sediments:

- chemical characteristics of superficial sediments:
  - organic substances or total organic carbon (TOC);
  - metals:

Al, As, Cd, Cr_{tot}, Pb, Hg, Ni, Cu, V and Zn;
- organic micropollutants:
  total and congeneric single PAH (polycyclic aromatic hydrocarbons): fluoranthene, naphtalene, anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, indopyrene, acenaphtene, fluorene, phenantrene, pyrene, benzo(a)anthracene, crysene, dibenzo(a,h)anthracene, indeno(1,2,3,c-d)pyrene;
  organochloride pesticides: aldrin, dieldrin, α-hexachlorocyclohexane, β-hexachlorocyclohexane, γ-hexachlorocyclohexane (lindane), DDD, DDT, DDE (for each family, sum of isomers 2,4 and 4,4);
  total and congeneric single PCB (polychlorobiphenyls): PCB28, PCB52, PCB77, PCB81, PCB101, PCB118, PCB126, PCB128, PCB138, PCB153, PCB156, PCB169, PCB180 and their sum;
  hexachlorobenzene;
  TBT (tributhyltin).

The bottom's morphology and bathymetry in the dredging site are analyzed through Side Scan Sonar (S.S.S.) and Multibeam analyses.

In order to characterize the sandy sediment to be dredged, at least 3 cores must be removed within the dredging site and, for each core, the following analyses must be carried out:
- textural characteristics (granulometry) of the deep sediment;
- chemical features of the deep sediment (organic substance or total organic carbon (TOC), metals: Al, As, Cd, Cr_{tot}, Pb, Hg, Ni, Cu, V and Zn).

Should the relict sand deposit for beach nourishment lack of a pelitic coating (therefore outcropping), the superficial sediments must undergo microbiological analyses to test its contents in:
- Coliforms (*Escherichia coli*);
- Enterococcus (fecal);
- Salmonella;
- Clostrids (spores of sulphite-reducing clostrids);
- Staphylococcus;
- Mycets.

The results obtained in this phase (dredging site's characterization), integrated with the ones obtained in the previous phases and with information on the dredging modalities and techniques, will allow the formulation of hypotheses on the possible impacts on the environment, and to consequently define the procedures for both the monitoring during activities and monitoring *post operam* phases.

The study conducted during the dredging site's characterization phase (Phase C1) can have the following results:
- sand dredging is environmentally compatible and significant effects on the surrounding marine environment are not expected;
- sand dredging is environmentally compatible, but only with the appropriate technical precautions;
- sand dredging is environmentally incompatible.

3.3.2 Transport Area (*chart n. 6*)

The transport area corresponds to the area containing the dredge's navigation route from the dredging site to the nourishment site.

In the transport area, the site's characterization (Phase C1) is only conducted if sensitive habitats are present inside of it or in its surroundings.

The main environmental effects that may be induced by sand transport involve the water column, and are due to the plume generated by the dredge's overflow (paragraph 1.2.1), with possible effects on the sensitive habitats that are possibly present nearby (paragraph 1.3.3.2). Direct surveys aimed at the characterization of these habitats must therefore be carried out.

The data gathered in this phase must be processed in function of the hypothetical route, of the area's hydrodynamics, of the sand's composition, of the presence of a pelitic layer on the deposit, of the technical characteristics of the dredging and transport processes, of the activities' expected duration and of the period in which they take place.

This way, it will be possible to conduct a compared evaluation of the environmental compatibility of sand transport activities from the dredging to the nourishment site, thus confirming the initially hypothesized route, and suggesting different paths and/or operational modalities so as to reduce the effects on the environment to a minimum, or in some cases, verifying the environmental non-compatibility of these activities in this area.

3.3.3 Nourishment Area (*chart n. 7*)

The nourishment site's characterization phase (Phase C1) is carried out through environmental surveys performed in the area facing of the beach to be nourished and, possibly, in the nearby areas. The size of the area to be investigated will essentially depend on the characteristics of the sensitive habitats identified, but it is generally advisable to extend the survey area down to a depth of 10 m, and, in the presence of *Posidonia oceanica* meadows, at least down to the plant's lower limit, which need to be accurately measured.

In particular, the surveys will concern:

- textural characteristics (granulometry) of the superficial sediments;
- sensitive habitats and/or species.

The data collected in this phase, integrated with data relating to the environmental surveys carried out in the previous phases (Phase A and Phase B), will also have to be analyzed in function of the technical characteristics of the nourishment, such as:

- geographic position and size of the coast to be nourished;
- textural and mineralogical characteristics (granulometry) of the sand intended for nourishment;
- project's characteristics: estimated progradation of the shoreline, expected sand volume required for nourishment, setup of the new equilibrium profile, closure depth of the active beach, method planned for sand spilling, estimated duration of the operations, and period of the year of the timing of nourishment activities.

The estimation of the closure depth (the depth at which the sediment is still affected by the action of wave motion) is important in the presence of sensitive habitats such as *P. oceanica* meadows; if the closure depth is situated at a depth higher than that of the meadow's upper margin, burying episodes of the meadows themselves could occur (***Figure 3.9***).

Furthermore, knowing the technical characteristics of nourishment is important, because one of the most environmentally important aspects is the momentary increase in turbidity, whose relevance is significantly influenced by the phenomenon's duration, by the sediment's granulometric characteristics, and by the season in which the operations are taking place.

Concerning the compositional compatibility between the sands from the dredging area and the original sands of the beach to be nourished, effects on the environment may derive from

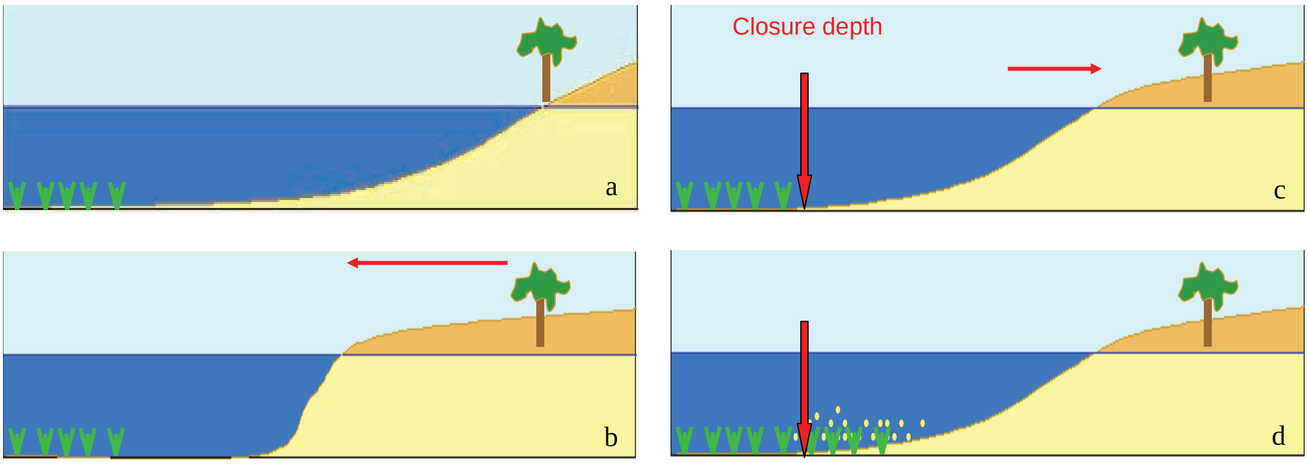


Figure 3.9 - Closure depth of the active beach in a nourishment intervention: a) beach profile on an eroding littoral with *Posidonia oceanica*, b) beach profile right after the new sediment's placement. New beach profile after remodeling of the new sediment by wave motion: c) a case in which the closure depth is lower than that of the meadow's upper limit and d) a case in which the closure depth is higher than that of the meadow's upper limit.

possible compositional differences, as in the case of an increase in turbidity, generated by the friction of grains with different hardness. Such effects will have to be the object of specific studies during the planning phase (paragraph 3.3.1).

The compared evaluation of all these aspects allows to assess the environmental compatibility of the nourishment activities (identifying, where necessary, the technical precautions that must be followed in order to minimize the effects on the environment) and to define the specific monitoring procedures.

The study performed during the nourishment site's characterization phase (Phase C1) may therefore have one of the following outcomes:

- nourishment is environmentally compatible:
  - no sensitive habitats are present in proximity to the nourishment area;
  - sensitive habitats are present in proximity to the nourishment area.

  In the first case, monitoring *post operam* (Phase C3) will be the only process to be carried out, while in the second case a monitoring during activities study must be performed (Phase C2).
- nourishment is environmentally incompatible.

Chapter 4

t r t

4 MONITORING STUDY

The monitoring study must be performed for each of the three areas (dredging area, transport area, nourishment area) involved. The study is articulated in two phases: the Monitoring during activities (Phase C2) and the Monitoring *post operam* (Phase C3) phases.

The monitoring during activities phase can vary in duration, depending on the expected duration of the sediment removal activity. The monitoring *post operam* phase should not, however, last less than two years. Should *Posidonia oceanica* meadows be present in the environments involved, the monitoring *post operam* phase will need to last longer, in order to correctly evaluate the effects on the meadows, considering to these phanerogams' very slow growth.

4.1 MONITORING DURING ACTIVITIES (PHASE C2)

4.1.1 Dredging Area (*chart n. 8*)

The objective of this phase is to assess, during dredging activities, the possible variations in the environmental parameters that could negatively affect the area's natural set up and its future recovery. In particular, both the disturbances induced on the water column (turbidity increase) and on the benthic assemblages will need to be investigated. It is necessary to assess whether major phenomena of overflow are associated with the dredge; also, it is important to find out whether these phenomena can affect the sensitive habitats that might be present. For these purposes, specific surveys on the water masses (chemical-physical characteristics, suspended particulate matter, current intensity and direction) will be conducted in order to follow the spatial and temporal evolution of the turbidity plume. If, during this phase, a distribution of the suspended sediment affecting the sensible surrounding habitats is reported, such habitats will need to undergo a further, more in depth detailed monitoring.

The frequency of the activities and the number of surveys to be carried during this investigation phase are established each single time, taking into account both the impact hypotheses emerged from the previous phases of environmental characterization and the dredging's project specifications among which the expected duration for removal activity has a great importance.

More in detail, in the monitoring during activities phase, experimental surveys should be carried out in relation to:

- spatial and temporal evolution of the turbidity plume;
- benthic assemblages.

The surveys on benthic assemblages shall be carried out in each of the stations chosen during the previous characterization phase (Phase C1). The results obtained during the monitoring *post operam* phase, integrated with those obtained in the study on the environmental characterizations (Phase A, B and C1), will be used to operationally define the protocols to be followed during the upcoming monitoring *post operam* (Phase C3). If, in the monitoring during activities, some of the results show effects on the environment – such as effects on the sensitive habitats – the possible immediate suspension of the dredging activities will need to be evaluated. In any case, whether or not the dredging is interrupted (possibly by means of the appropriate technical/procedural precautions), it will be necessary to go ahead to the monitoring *post operam* phase (Phase C3).

4.1.2 Transport Area (*chart n. 9*)

The monitoring during activities assessment of the effects induced on the environment by relict sand transport (Phase C2) must be carried out on the same study area that was already defined beforehand (Phase C1). This phase's environmental studies aim at understanding whether the physical consequences (turbidity increase) induced on the water column can affect the existing surrounding sensitive habitats.

Similarly to what we suggested in the case of the dredging area, during this phase too, it is of major importance to understand if the plume's diffusion can really affect the nearby sensitive habitats. In particular, some specific surveys on water column must be planned, to characterize the turbidity plume in space and time.

In order to establish the frequency of activities (several monitoring surveys may be planned) the following different aspect shall be taken into account:

- the results obtained in the characterization study;
- the dredging characteristics (in particular, the pelitic percentage present in the sand transported, and the volumes of sediment mobilized);
- the presence of sensitive habitats and/or of habitats needing protection along the sand transfer routes or in their closest vicinity.

The study of the monitoring during activities phase might bring the following results:

- the overflow does not interfere with the sensitive habitats;
- the overflow interferes with the sensitive habitats, and transport can go on only after use of the appropriate precautions (such as alternative routes);
- the overflow interferes with the sensitive habitats and the transport cannot go on.

In the two latter cases, the studies show some sediment distribution patterns that affect the sensitive habitats. Therefore, such habitats will need to undergo specific monitoring *post operam* (Phase C3), whose modality will be defined based on the results obtained in this phase.

4.1.3 Nourishment Area (*chart n. 10*)

The monitoring during activities phase (Phase C2) is carried out in the nourishment area only when the previous phase (Phase C1) has indicated a real possibility for the sensitive habitats to be directly affected by the sand replenishment. More in general, we deem important to underline that the objective pursued in this phase is not to evaluate the variations of the environmental parameters induced by nourishment activities – the short-term effects on the environment and on existing marine organisms being evident – but rather to asses the possible direct effects (burying and consequent suffocation) induced on sensitive habitats, such as the *Posidonia oceanica* meadows, which are by the way protected by *ad hoc* legislation (paragraph 3.1).

In particular, when a *Posidonia oceanica* meadow is present along the shallow bottoms facing the beach to be nourished, and if its upper limit is relatively close to the area involved in the nourishment, a specific monitoring plan will have to be organized in order to make sure that the sand is not spilled directly over the meadow. A conspicuous, direct sand spilling over the meadow would in fact cause immediate effects; and since *Posidonia oceanica* grows extremely slowly (between 1 and 6 cm/y, Badalamenti *et al.*, 2006), the effect might even be irreversible. One should also take into account that the accumulation of the effects may cause short-term impacts that are more significant than those expected, thus suggesting different operational modalities in order to minimize the effects observed.

The study area on which the monitoring during activities phase should be carried out must correspond to the one in Phase C1, and direct surveys must be carried out in relation to sensitive habitats identified in the previous phases.

The data assembled must be analyzed in order to highlight whether nourishment activities may have significant effects on sensitive habitats, therefore evaluating the environmental impact of nourishment, and providing information on the possible continuation of activities with the possible adoption of technical precautions. Furthermore, these data, integrated with data obtained from the environmental characterization study (Phases A, B and C1) will have to allow the definition of specific monitoring *post operam* plans.

4.2 MONITORING *POST OPERAM* (PHASE C3)

At the end of the activities, a monitoring study will need to be carried out in order to follow the evolution over time of the effects induced by relict sand dredging and nourishment, up until the complete recovery of the original environmental conditions, or until new equilibrium conditions are reached.

Such surveys deal with different parameters, and are articulated in different time cycles to be decided based on the characteristics of the environment in which the activities take place.

Furthermore, the monitoring study results will need to provide the relevant authorities with the technical information in order to understand:

- whether the indications resulting from the previous phases have been followed;
- the timing and the modalities for the recovery of the study area;
- if further similar interventions should be taken into consideration, once the possible effects induced by relict sand dredging and nourishment have been defined, and after the recovery times have been established.

4.2.1 Dredging Area *(chart n. 11)*

The aim of the surveys conducted at the end of the dredging operations is to provide data on the variation of the parameters investigated following bottom removal activities, and to evaluate the times for recovery. Such surveys regard several parameters, and are articulated in different time cycles, identified according to the characteristics of the dredging site's environment.

The monitoring process needs to able to evaluate the recovery time for the environments involved, and must cover a minimum time period of 2 years; it is imaginable that the surveys will initially be more frequent, and that they will become scarcer as time goes by.

It is important that at least some of the monitoring surveys are conducted in the same season in which the site characterization phase had been conducted (Phase C1). The latter phase, with regard to dredging activities, constitutes in fact the original situation (blank), on which comparisons should be based.

In particular, concerning the monitoring of demersal fish assemblages, the experimental trawl fishing activities must be carried out, for each cycle, both in proximity to the dredged areas and in the adjacent areas, in order to highlight the possible effects of dredging.

The activities in this phase concern:

- bottom morphology and bathymetry;
- textural characteristics (granulometry) of superficial sediments;
- hydrology of water masses (chemical-physical characteristics);
- suspended particulate matter (total and inorganic);
- benthic assemblages;
- demersal fish assemblages.

If a possible effect on the sensitive surrounding habitats emerged in the monitoring during activities phase (Phase C2), such habitats will need to undergo *ad hoc* monitoring.

4.2.2 Transport area *(chart n. 12)*

In the transport area, the monitoring *post operam* phase is only carried out if, during the previous phase (Phase C2), the plume's spatial distribution might affect the sensitive habitats along the sand transfer routes (or in their immediate surroundings).

The area in which the study will be conducted is the one identified in Phase C2. In order to define the number of monitoring studies and their frequency, the area's environmental characteristics and the dredging's technical features must be considered, after the due integration of data with the results obtained from the previous phases.

During the monitoring phases, some direct studies will have to be carried out on:

- hydrology of water masses (chemical-physical characteristics);
- suspended particulate matter (total and inorganic);
- sensitive habitats.

The monitoring of the transport area must be conducted until the recovery of environmental conditions that are comparable with those *ante operam*, and must allow the assessment of recovery time for the sensitive habitats affected by sand transport.

4.2.3 Nourishment Area *(chart n. 13)*

The monitoring activity in this area has the specific aim of assessing the short-term and long-term effects of nourishment on the benthic communities present on the submerged beaches, with particular attention to sensitive habitats – if present – such as *Posidonia oceanica* meadows.

The sampling scheme for the monitoring *post operam* phase will need to be based on the same study areas and the same stations that were already identified during Phase C1 – and Phase C2, if it was carried out. The frequency of activities and the number of the experimental surveys will be defined each time, and will be decided based on the area's environmental features and on the nourishment project's specifications, integrated with the results emerged during Phase C1 (and during Phase C2, if conducted). In all cases, the overall duration of the monitoring process must allow to record the possible effects induced and, possibly, to re-establish the equilibrium conditions.

For each experimental survey, direct tests will need to be carried out on:

- granulometry of superficial sediments;
- sensitive habitats and/or species.

Granulometric studies of superficial sediments are carried out with the only aim of supporting the studies conducted on sensitive habitats and/or species.

Chapter 5

Bar charts

5 SUMMARY CHARTS

This chapter presents the summary charts and flow charts related to the survey protocol proposed by ICRAM for environmental studies linked to relict sand dredging and their use for the purposes of beach nourishment.

chart 1

Environmental Characterization Study

PHASE A
DREDGING AREA
PRELIMINARY CHARACTERIZATION ON A REGIONAL SCALE

Study area

A sufficiently wide area including the potential existing sand deposits and the surroundings areas with a wide range up to the shoreline, possibly extended to the whole physiographic unit.

Technical-scientific information available in literature, related to:

The area's environmental characteristics:

- Bottom morphology and bathymetry;
- Textural characteristics (granulometry) of superficial sediments;
- Chemical characteristics of superficial sediments:
    - ORGANIC SUBSTANCE OR TOTAL ORGANIC CARBON (TOC);
    - METALS
      Al, As, Cd, Cr_{tot}, Pb, Hg, Ni, Cu, V and Zn;
    - ORGANIC MICROPOLLUTANTS
      total and congeneric single PAH (polycyclic aromatic hydrocarbons): fluoranthene, naphtalene, anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, indopyrene, acenaphtene, fluorene, phenantrene, pyrene, benzo(a)anthracene, crysene, dibenzo(a,h)anthracene, indeno(1,2,3,c-d)pyrene;
      organochloride pesticides: aldrin, dieldrin, α-hexachlorocyclohexane, β-hexachlorocyclohexane, γ-hexachlorocyclohexane (lindane), DDD, DDT, DDE (for each family, sum of isomers 2,4 and 4,4);
      total and congeneric single PCB (polychlorobiphenyls): PCB28, PCB52, PCB77, PCB81, PCB101, PCB118, PCB126, PCB128, PCB138, PCB153, PCB156, PCB169, PCB180 and their sum;
      hexachlorobenzene;
      TBT (tributhyltin);
- Hydrology of water masses (chemical-physical characteristics);
- Suspended particulate matter (total and inorganic);
- Dynamics of water masses (currentometry);
- Benthic assemblages (biocenotic characterization);
- Demersal fish assemblages (nursery areas).

Legitimate uses of the sea:

- Areas subject to specific protection legislation:
  Marine archaeological areas;
  Marine Protected Areas (MAPs);
  Natural marine protected areas (WWF Blue Oases);
  Coastal territorial protected areas (parks and natural reserves);
  Specially Protected Areas of Mediterranean Importance (ASPIM);
  Submerged archaeological parks;
  Special areas of conservation called "Natura 2000" (SIC and ZPS);
  Marine repopulation areas and marine biological protection areas.

- Areas needing protection:
  - Nursery areas of the main demersal species;
  - *Posidonia oceanica* meadows and/or other sensitive biocoenoses;
  - The zone within 3 nautical miles from the coast or the belt within 50 m of depth, should this depth be reached before the 3 miles.
- Other legitimate uses of the sea:
  - Areas for mariculture (mollusks and fish species);
  - Authorized areas from harbour material dumping;
  - Marine artificial reefs;
  - No-anchor and no-fishing zones;
  - Cables, pipes, oil pipes;
  - Offshore structures;
  - Military sites.

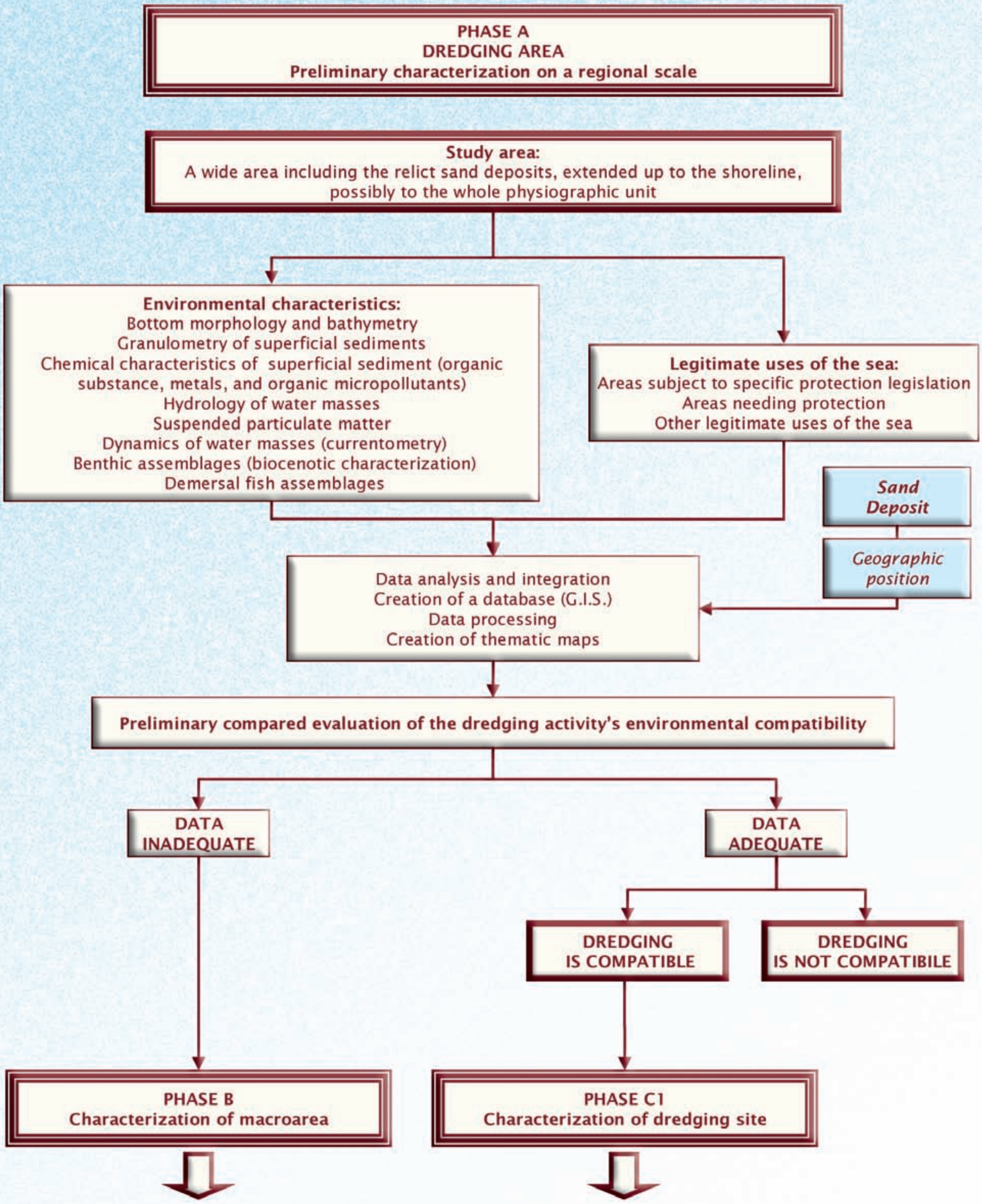
Data processing
- Critical analyses of the data gathered;
- Creation of an *ad hoc* database (preferably based on the G.I.S. system);
- Data processing based on the first, general indications on the sand deposit's characteristics (geographical localization);
- Creation of thematic maps.

Results
Preliminary compared evaluation of dredging activities' environmental compatibility.

Conclusions
- Data in literature are not adequate →Phase B (characterization of dredging area);
- Data in literature are adequate and:
  - dredging is compatible →Phase C1 (characterization of dredging site);
  - dredging is not compatible.

Surveys planned for Phase A in the dredging area are illustrated in flow chart n. 1.

ENVIRONMENTAL CHARACTERIZATION STUDY 1



Flow chart n. 1 - Environmental characterization study, Phase A – dredging area.

chart 2

Environmental Characterization Study

PHASE A
NOURISHMENT AREA
PRELIMINARY CHARACTERIZATION ON A REGIONAL SCALE

Study area

A sufficiently wide area including the beaches directly involved in nourishment activities, possibly extended to the whole physiografic unit.

Technical-scientific information available in literature, related to:

The area's environmental characteristics:
- Benthic assemblages (biocenotic characterization);
- Demersal fish assemblages (nursery areas)

Legitimate uses of the sea:
- Areas subject to specific protection legislation:
  - Marine archaeological areas;
  - Marine Protected Areas (MAPs);
  - Natural marine protected areas (WWF Blue Oases);
  - Coastal territorial protected areas (parks and natural reserves);
  - Specially Protected Areas of Mediterranean Importance (ASPIM);
  - Submerged archaeological parks;
  - Special areas of conservation called "Natura 2000" (SIC and ZPS);
  - Marine repopulation areas and marine biological protection areas.
- Areas needing protection:
  - Nursery areas of the main demersal species;
  - *Posidonia oceanica* meadows and/or other sensitive biocoenoses.
- Other legitimate uses of the sea:
  - Areas for mariculture (mollusks and fish species);
  - Marine artificial reefs;
  - No-anchor and no-fishing zones;
  - Cables, pipes, oil pipes;
  - Offshore structures;
  - Military sites.

Data processing
- Critical analyses of the gathered data;
- Creation of an *ad hoc* database (preferably based on the G.I.S. system);
- Data processing based on the first, general indications on the nourishment characteristics (geographical localization of coastal area involved);
- Creation of thematic maps.

Results

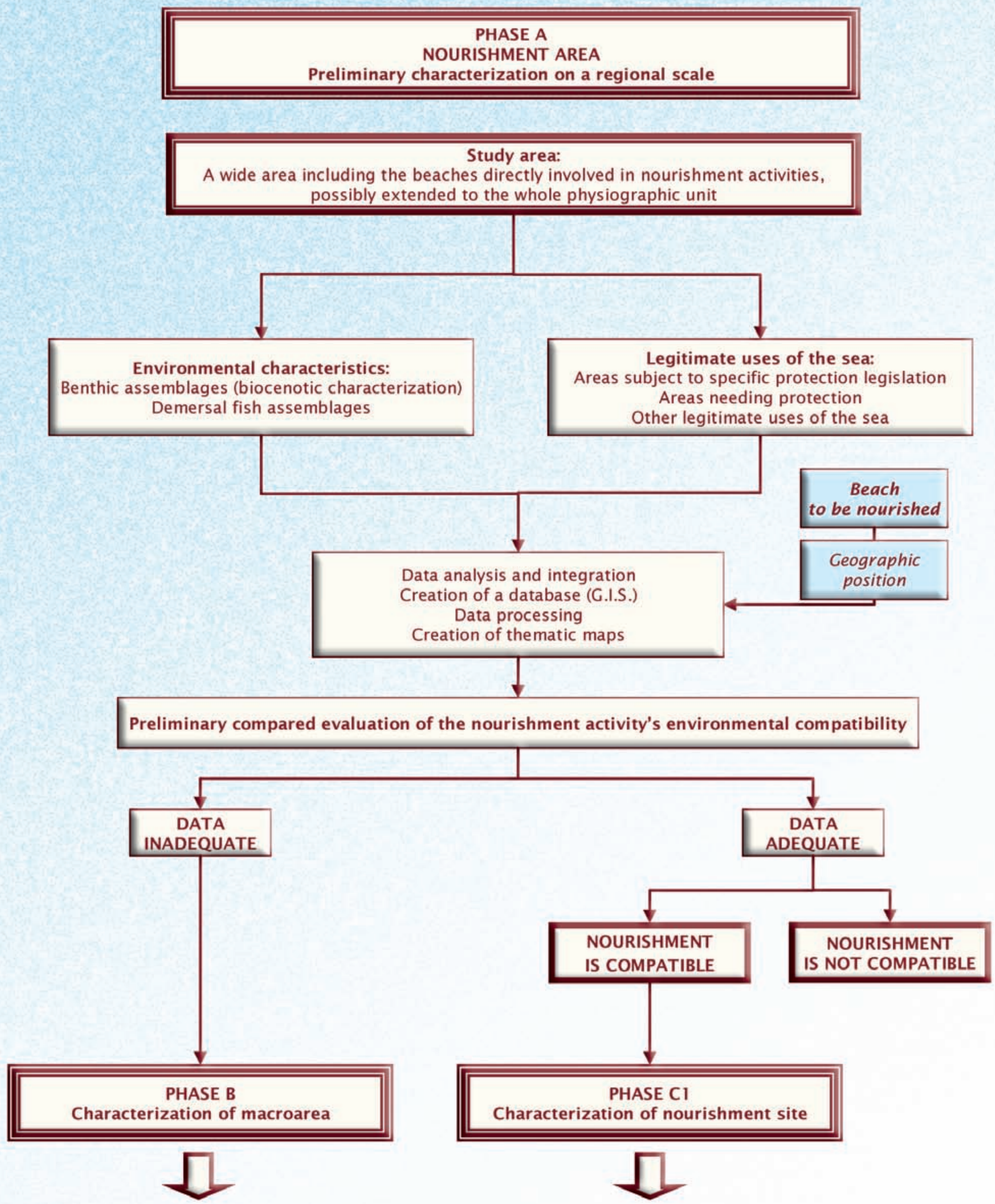
Preliminary compared evaluation of nourishment activities' environmental compatibility.

Conclusions

- Data in literature are not adequate →Phase B (characterization of nourishment area);
- Data in literature are adequate and:
  - nourishment is compatible →Phase C1 (characterization of nourishment site);
  - nourishment is not compatible.

Surveys planned for Phase A in the nourishment area are illustrated in flow chart n. 2.

2 ENVIRONMENTAL CHARACTERIZATION STUDY



Flow chart n. 2 - Environmental characterization study, Phase A – nourishment area.

chart 3

Environmental Characterization Study

PHASE B
DREDGING AREA
CHARACTERIZATION OF MACROAREA

Study area
The specific sampling plan on a wide area including the relict sand deposits, possibly extended to the whole physiografic unit.

Surveys related to:
- Textural characteristics (granulometry) of superficial sediments;
- Chemical characteristics of superficial sediments:
  - ORGANIC SUBSTANCE OR TOTAL ORGANIC CARBON (TOC);
  - METALS
    Al, As, Cd, Cr_{tot}, Pb, Hg, Ni, Cu, V and Zn;
  - ORGANIC MICROPOLLUTANTS
    total and congeneric single PAH (polycyclic aromatic hydrocarbons): fluoranthene, naphtalene, anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, indopyrene, acenaphtene, fluorene, phenantrene, pyrene, benzo(a)anthracene, crysene, dibenzo(a,h)anthracene, indeno(1,2,3,c-d)pyrene;
    organochloride pesticides: aldrin, dieldrin, α-hexachlorocyclohexane, β-hexachlorocyclohexane, γ-hexachlorocyclohexane (lindane), DDD, DDT, DDE (for each family, sum of isomers 2,4 and 4,4);
    total and congeneric single PCB (polychlorobiphenyls): PCB28, PCB52, PCB77, PCB81, PCB101, PCB118, PCB126, PCB128, PCB138, PCB153, PCB156, PCB169, PCB180 and their sum;
    hexachlorobenzene;
    TBT (tributhyltin);
- Hydrology of water masses (chemical-physical characteristics, seasonal sampling surveys);
- Suspended particulate matter (total and inorganic, seasonal sampling surveys);
- Dynamics of water masses (currentometry, seasonal surveys);
- Benthic assemblages (biocenotic characterization);
- Demersal fish assemblages (nursery areas, seasonal surveys).

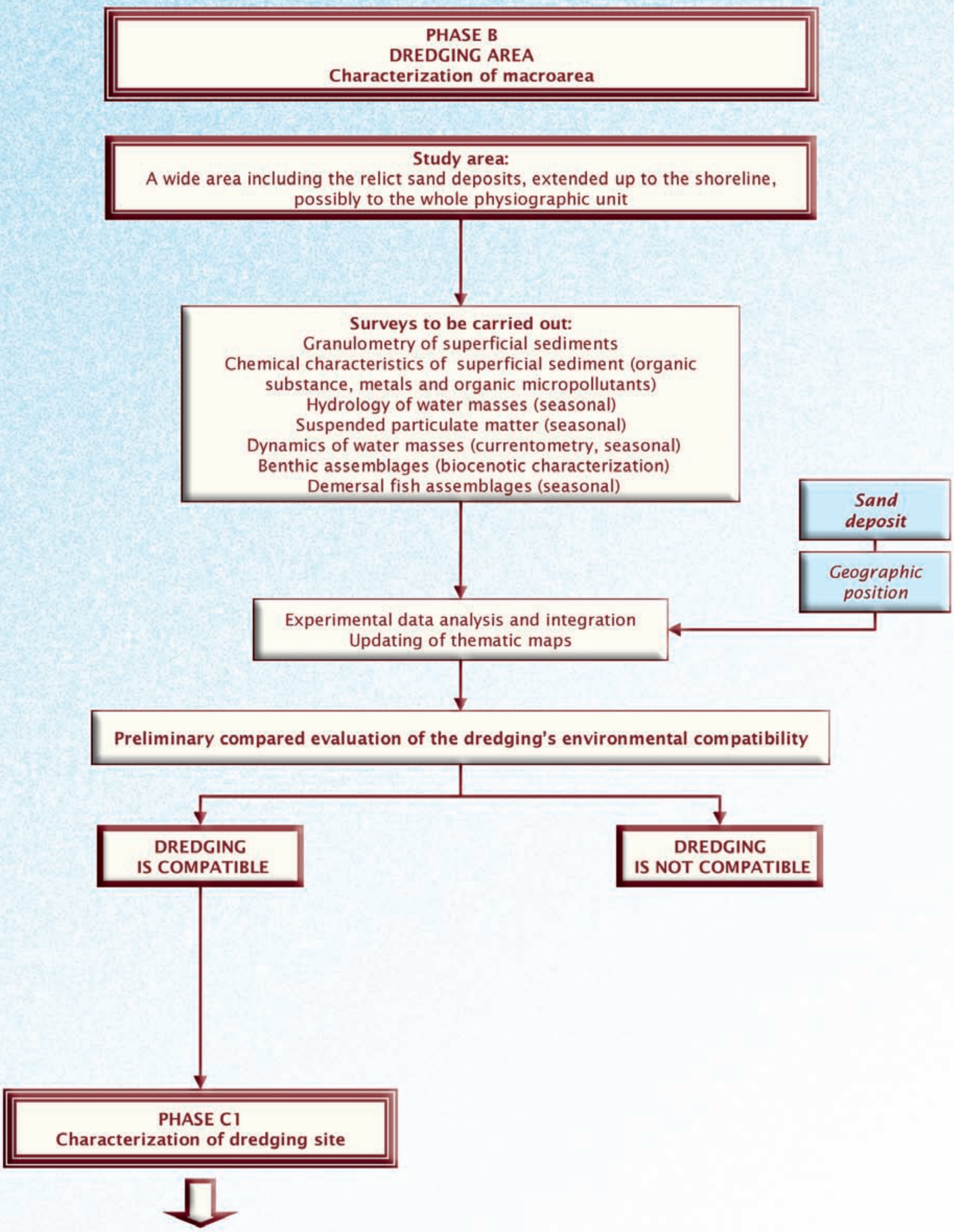
Data processing
- Elaboration and integration of the obtained data with the data gathered in Phase A;
- Creation of updated thematic maps.

Results
Preliminary compared evaluation of the dredging activities' environmental compatibility.

Conclusions
- Dredging is compatible →Phase C1 (characterization of dredging site);
- Dredging is not compatible.

Surveys planned for Phase B in the dredging area are illustrated in flow chart n. 3

3 ENVIRONMENTAL CHARACTERIZATION STUDY



Flow chart n. 3 - Environmental characterization study, Phase B – dredging area.

chart 4

Environmental Characterization Study

PHASE B
NOURISHMENT AREA
CHARACTERIZATION OF MACROAREA

Study area

A specific sampling plan in a wide area including the beaches to be nourished, possibly extended to the whole physiografic unit.

Surveys related to:

- Textural characteristics (granulometry) of superficial sediments;
- Benthic assemblages (biocenotic characterization);
- Demersal fish assemblages (nursery areas, seasonal surveys).

Data processing

- Elaboration and integration of the obtained data with the data gathered in Phase A;
- Creation of updated thematic maps.

Results

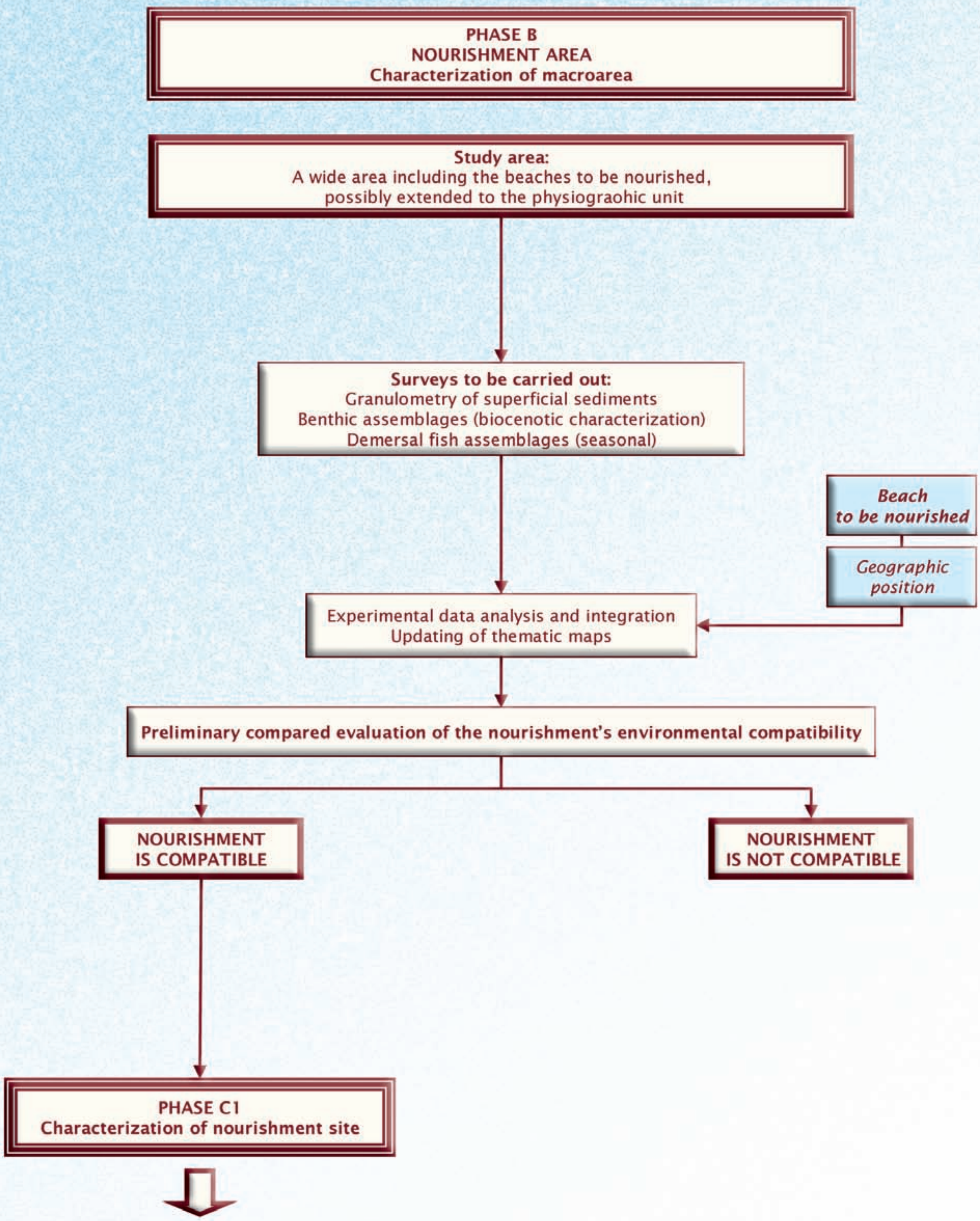
Preliminary compared evaluation of the nourishment activities' environmental compatibility.

Conclusions

- Nourishment is compatible →Phase C1 (characterization of nourishment site);
- Nourishment is not compatible.

Surveys planned for Phase B in the nourishment area are illustrated in flow chart n. 4.

4 ENVIRONMENTAL CHARACTERIZATION STUDY



Flow chart n. 4 - Environmental characterization study, Phase B – nourishment area.

chart 5

Environmental Characterization Study

PHASE C1
DREDGING AREA
CHARACTERIZATION OF DREDGING SITE

Study area

The area including the expected dredging site.

The sampling stations are positioned within the expected dredging site and outside of it, at increasing distances, according to the hydrodynamic characteristics of the area and to the possible presence of sensitive areas in its surroundings. The position and number of sampling stations are as follows:

- within the dredging site, 4 stations per km^2, at least 3 stations for smaller sites;
- outside of the dredging area, 8 stations for sites with size equal or lower than 1 km^2. The number will have to proportionally increase as the site's extension.

Surveys related to:

- Bottom morphology and bathymetry[1];
- Textural characteristics (granulometry) of superficial sediments;
- Chemical characteristics of superficial sediments:
  - ORGANIC SUBSTANCE OR TOTAL ORGANIC CARBON (TOC);
  - METALS

    Al, As, Cd, Cr_{tot}, Pb, Hg, Ni, Cu, V and Zn;
  - ORGANIC MICROPOLLUTANTS:

    total and congeneric single PAH (polycyclic aromatic hydrocarbons): fluoranthene, naphtalene, anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, indopyrene, acenaphtene, fluorene, phenantrene, pyrene, benzo(a)anthracene, crysene, dibenzo(a,h)anthracene, indeno(1,2,3,c-d)pyrene;

    organochloride pesticides: aldrin, dieldrin, α-hexachlorocyclohexane, β-hexachlorocyclohexane, γ-hexachlorocyclohexane (lindane), DDD, DDT, DDE (for each family, sum of isomers 2,4 and 4,4);

    total and congeneric single PCB (polychlorobiphenyls): PCB28, PCB52, PCB77, PCB81, PCB101, PCB118, PCB126, PCB128, PCB138, PCB153, PCB156, PCB169, PCB180 and their sum;

    hexachlorobenzene;

    TBT (tributhyltin);
- Microbiology of superficial sediments[2]:

  Coliforms (*Escherichia coli*);

  Enterococcus (fecal);

  Salmonella;

  Clostrids (spores of sulphite-reducing clostrids);

  Staphylococcus;

  Mycets;
- Textural characteristics (granulometry) of deep sediments[3];
- Chemical characteristics of deep sediments (organic substance or total organic carbon (TOC); metals: Al, As, Cd, Cr_{tot}, Pb, Hg, Ni, Cu, V and Zn);
- Hydrology of water masses (chemical-physical characteristics);

- Suspended particulate matter (total and inorganic);
- Benthic assemblages.

Data processing

Critical analysis of gathered data, integrated with the data obtained in Phases A and B, based on:

- geological and sedimentological characteristics of the sandy sediment: position, extension, volume, average thickness, composition, presence of a pelitic layer;
- dredging method;
- timing and modalities expected for dredging operations.

Results

- Compared evaluation concerning the environmental compatibility of the dredging activities.
- Definition of the dredging's conditions in order to minimize the effects on the environment.
- Definition of the procedures (timing and modalities) for monitoring during activities (Phase C2).

Conclusions

- Dredging is compatible →Phase C2 (monitoring during activities of dredging site);
- Dredging is compatible only with the due technical precautions →Phase C2 (monitoring during activities of dredging site);
- Dredging is not compatible.

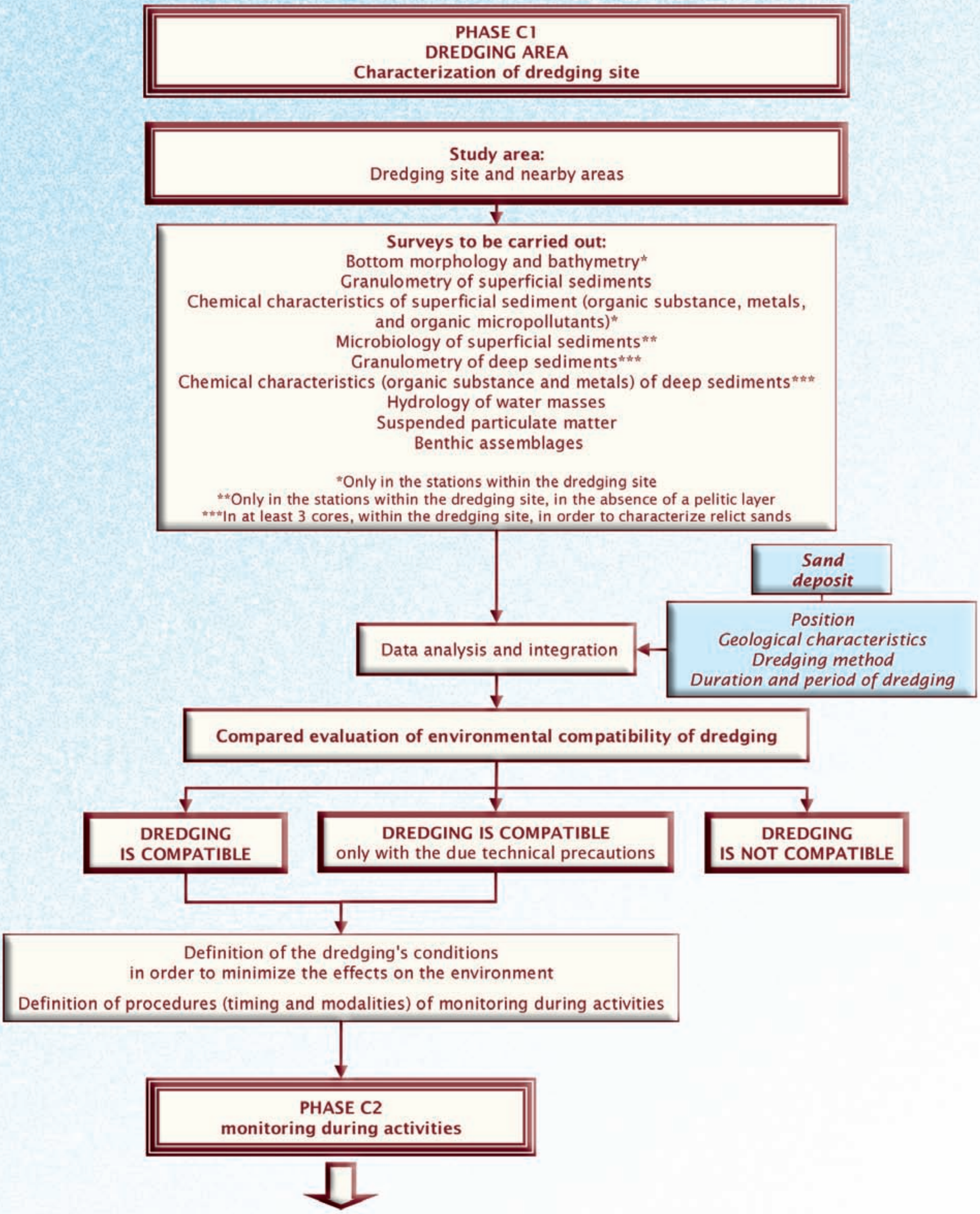
Surveys planned for Phase C1 in the dredging area are illustrated in flow chart n. 5.

1 *Only in the stations located within the dredging site.*

2 *Only in the stations located within the dredging site, should the sand intended for nourishment outcrop and lack of a pelitic layer.*

3 *In at least 3 cores, at significant depths in order to characterize the sandy sediment to be dredged.*

ENVIRONMENTAL CHARACTERIZATION STUDY 5



Flow chart n. 5 - Environmental characterization study, Phase C1 – dredging area.

chart 6

Environmental Characterization Study

PHASE C1
TRANSPORT AREA
CHARACTERIZATION OF TRANSPORT AREA

This phase is conducted only in case sensitive habitats are present along and/or in proximity to routes for sand transport from the dredging site to the nourishment site.

Study area

Area including the dredge navigation routes for sand transfer from the dredging site to the nourishment site.

Surveys related to:

- Sensitive habitats (the main benthic biocoenoses).

Data processing

Critical analysis of data gathered, according to:

- Hypothetic route;
- Local hydrodynamics;
- Sand composition;
- Presence of a pelitic layer on the deposit;
- Technical characteristics of dredging and overflow phenomena;
- Expected duration and period for dredging activities.

Results

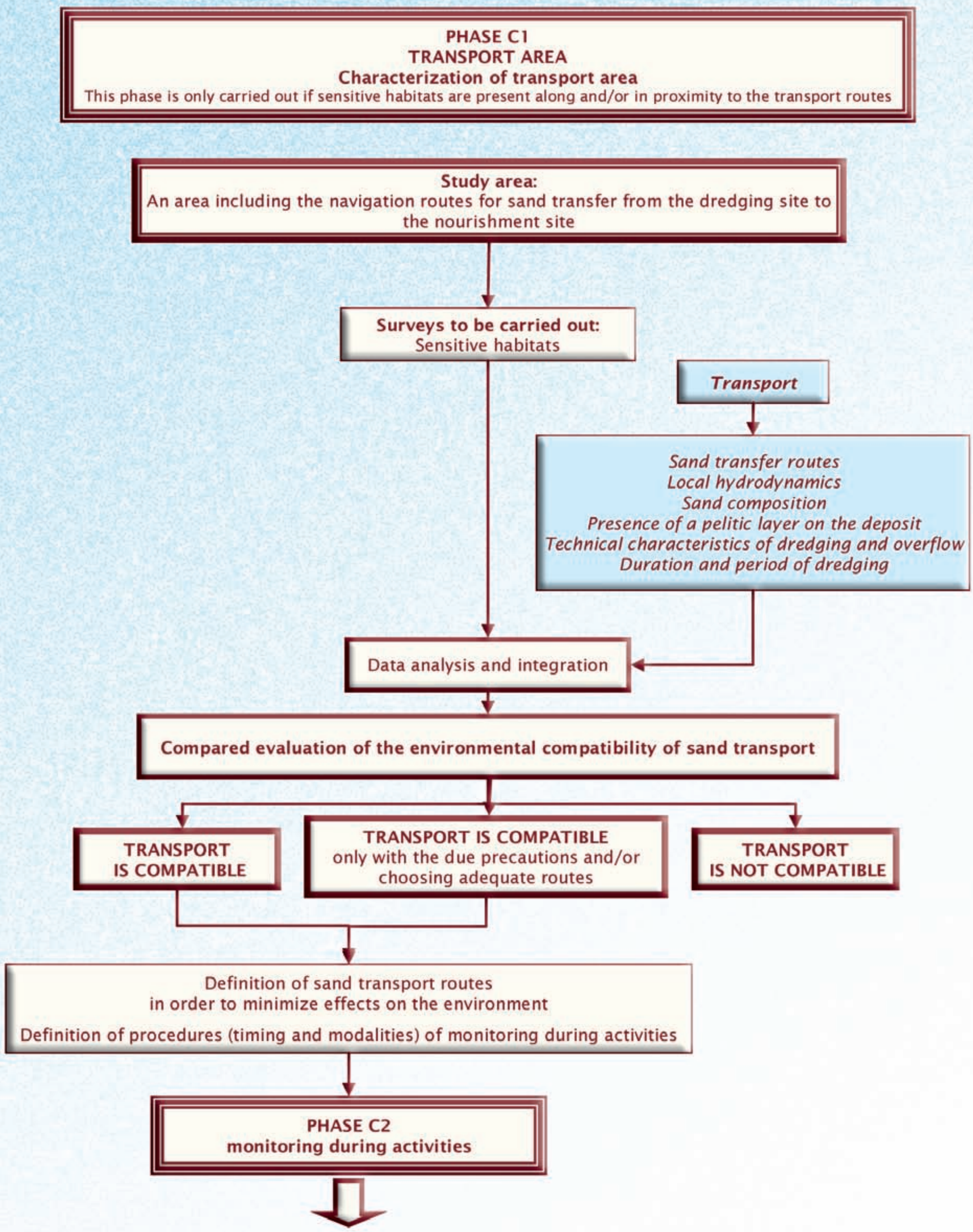
- Compared evaluation concerning the environmental compatibility of sand transport activities from the dredging site to the nourishment site;
- Definition of sand transport routes in order to minimize effects on the environment;
- Definition of procedures (timing and modalities) for monitoring during activities (Phase C2).

Conclusions

- Transport is compatible →Phase C2 (monitoring during activities of transport site);
- Transport is compatible only with the due technical precautions and/or by choosing adequate transport routes →Phase C2 (monitoring during activities of transport site);
- Transport along the hypothesized routes is not compatible.

Surveys planned for Phase C1 in the transport area are illustrated in flow chart n. 6.

ENVIRONMENTAL CHARACTERIZATION STUDY 6



Flow chart n. 6 - Environmental characterization study, Phase C1 – transport area.

chart 7

Environmental Characterization Study

PHASE C1
NOURISHMENT AREA
CHARACTERIZATION OF NOURISHMENT SITE

Study area
The area involved in the nourishment activity.

Surveys related to:
- Textural characteristics (granulometry) of superficial sediments;
- Sensitive habitats and/or species.

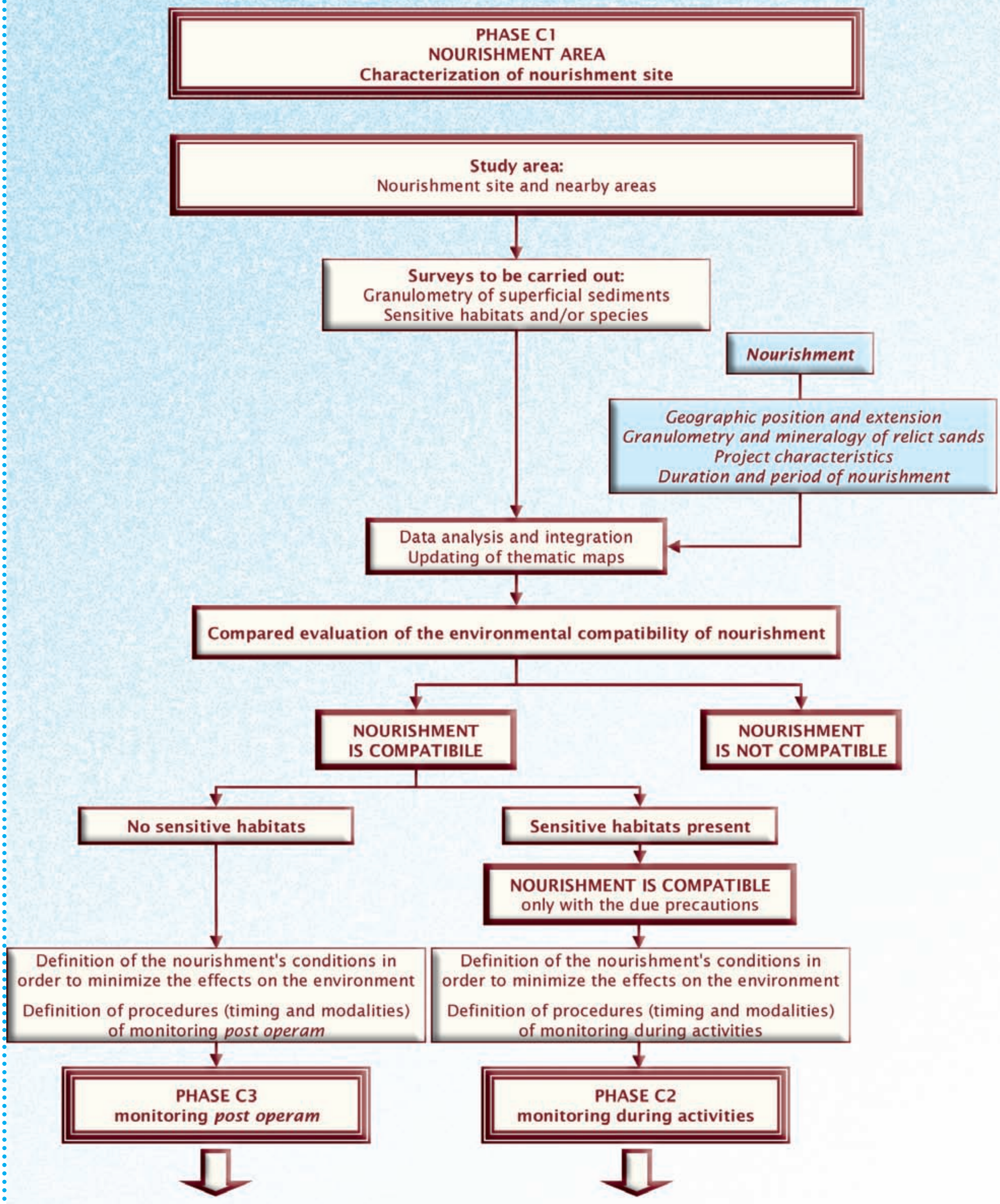
Data processing
Critical analysis of gathered data, integrated with the data obtained in Phases A and B, based on the nourishment technical characteristics such as:
- geographic position and extension of the coastal area to be nourished;
- textural (granulometry) and mineralogical characteristics of the sand to be used for the nourishment;
- project's characteristics: estimated shoreline progradation, expected volume of sand for the nourishment, design of the new equilibrium profile and of estimated closure depth, method planned for sand replenishment;
- expected duration of the nourishment activities;
- expected period for the execution of the nourishment activities.

Results
- Compared evaluation concerning the environmental compatibility of the dredging activities;
- Definition of the nourishment's conditions in order to minimize the effects on the environment;
- Definition of the procedures (timing and modalities) for the monitoring during activities (Phase C2).

Conclusions
- Nourishment is compatible:
  - absence of sensitive habitats in the surroundings of nourishment site →Phase C3 (monitoring *post operam* of nourishment site);
  - presence of sensitive habitats in the surroundings of nourishment site →Phase C2 (monitoring during activities of nourishment site);
- Nourishment is not compatible.

Surveys planned for Phase C1 in the nourishment site are illustrated in flow chart n. 7.

ENVIRONMENTAL CHARACTERIZATION STUDY 7



Flow chart n.7 - Environmental characterization study, Phase C1 – nourishment area.

chart 8

Environmental Monitoring Study

PHASE C2
DREDGING AREA
MONITORING DURING ACTIVITIES

Study area
The same area and stations as those identified in Phase C1.

Surveys related to:
- Spatial and temporal characterization of the turbidity plume;
- Benthic assemblages.

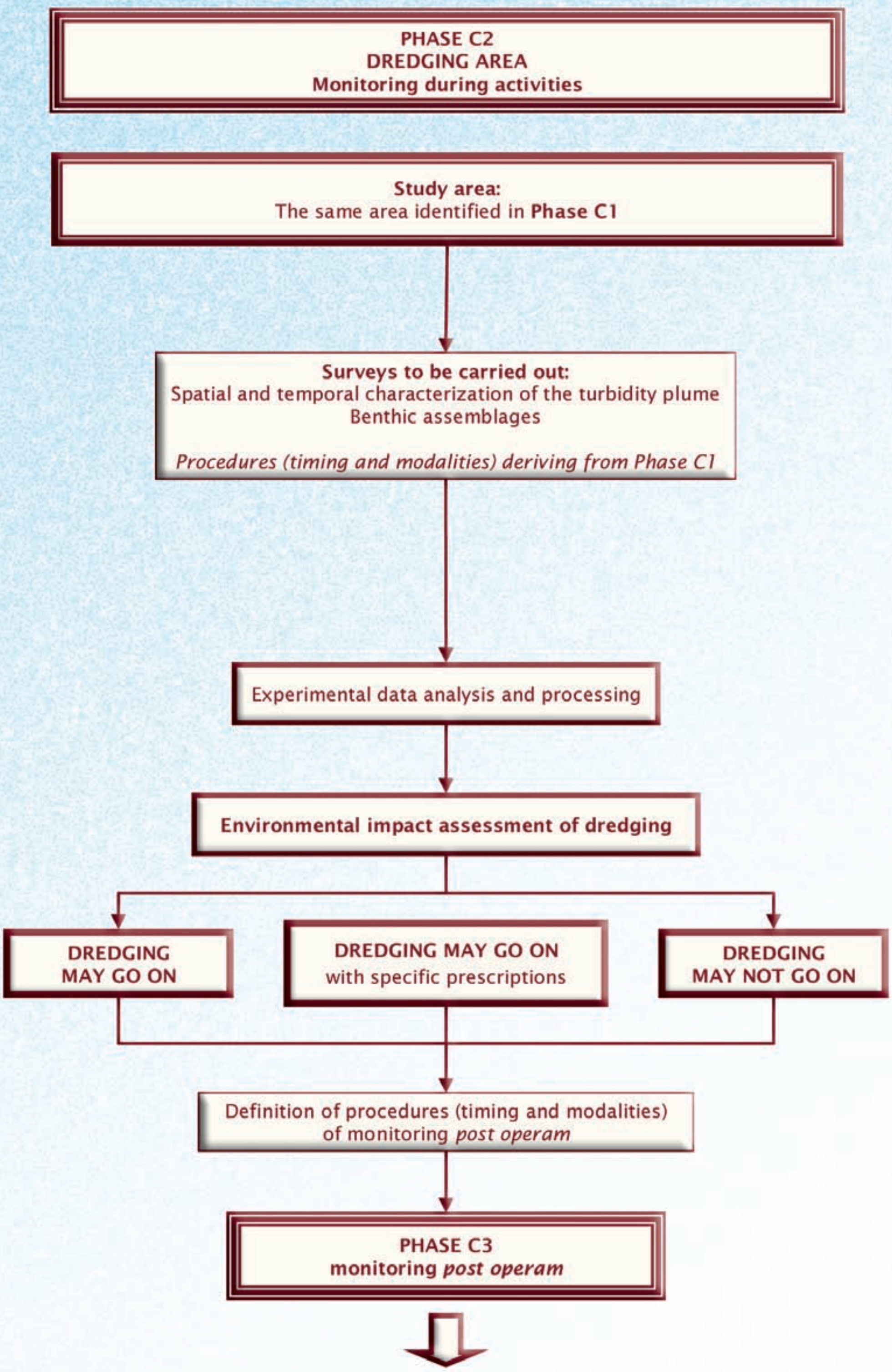
Data processing
Critical analysis of gathered data.

Results
- Environmental impact assessment of dredging activities;
- Definition of timing and modalities for the monitoring *post operam* (Phase C3).

Conclusions
- Dredging may go on →Phase C3 (monitoring *post operam* of dredging site);
- Dredging may go on after the definition of *ad hoc* technical precautions →Phase C3 (monitoring *post operam* of dredging site);
- Dredging may not go on: immediate, subsequent interruption of activities →Phase C3 (monitoring *post operam* of dredging site).

Surveys planned for Phase C2 in the dredging area are illustrated in flow chart n. 8.

ENVIRONMENTAL MONITORING STUDY 8



Flow chart n. 8 - Environmental monitoring study, Phase C2 – dredging area.

chart 9

Environmental Monitoring Study

PHASE C2
TRANSPORT AREA
MONITORING DURING ACTIVITIES

Study area

The same area as that identified in Phase C1. In this phase, several monitoring surveys may be conducted: the activities' frequency is decided based both on the characteristics of the area and dredging techniques used, and on the results already obtained in the previous phases.

Surveys related to:

- Spatial and temporal characterization of the turbidity plume;
- Sensitive habitats.

Data processing

Critical analysis of gathered data, in order to assess whether the dredge is associated to overflow phenomena during transport, and if these phenomena may affect the sensitive habitats present.

Results

- Environmental impact assessment of the sand transport activities from the dredging site to the nourishment site;
- Definition of timing and modalities for the monitoring *post operam* process (Phase C3), to be conducted if the distribution patterns of the sediment put into suspension may affect the sensitive areas.

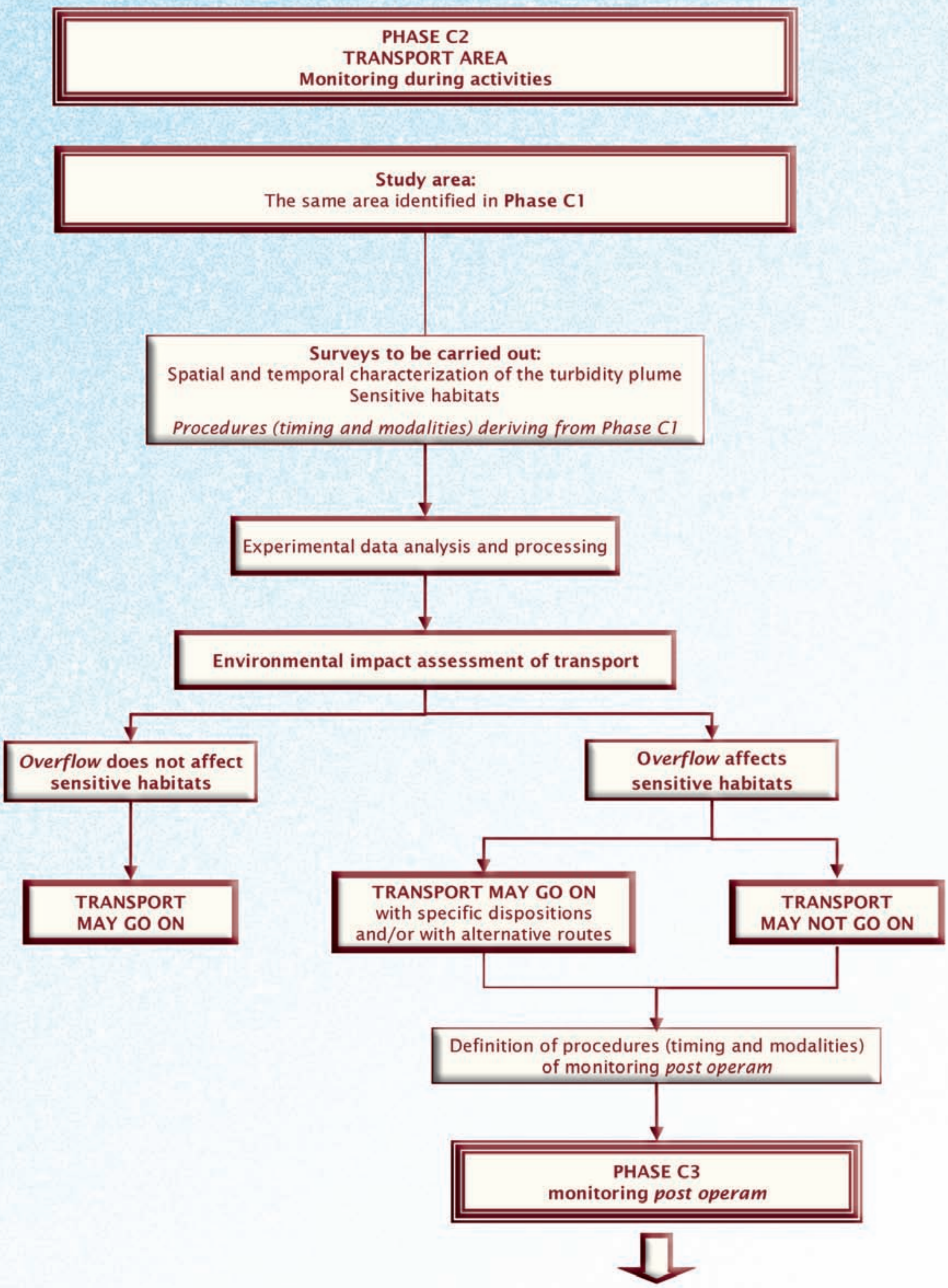
Conclusions

- Overflow does not interfere with sensitive habitats, transport may go on;
- Overflow interferes with sensitive habitats:
  - transport may go on only with the due technical precautions and/or by choosing adequate alternative transport routes →Phase C3 (monitoring *post operam* of transport site);
  - transport may not go on →Phase C3 (monitoring *post operam* of transport site).

Surveys planned for Phase C2 in the transport area are illustrated in flow chart n. 9.

ENVIRONMENTAL MONITORING STUDY

9



Flow chart n. 9 - Environmental monitoring study , Phase C2 – transport area.

chart 10

Environmental Monitoring Study

PHASE C2
NOURISHMENT AREA
MONITORING DURING ACTIVITIES

This phase is conducted only in case Phase C1 indicates a real possibility that the existing sensitive habitats may be directly affected by sand replenishment (for instance, *Posidonia oceanica* meadows). If this is not the case, we should proceed directly to the subsequent monitoring *post operam* (Phase C3).

Study area
The same area identified in Phase C1.

Surveys related to:
- Sensitive habitats.

Data processing
Critical analysis of gathered data in order to assess whether the nourishment activities may negatively affect the existing sensitive habitats.

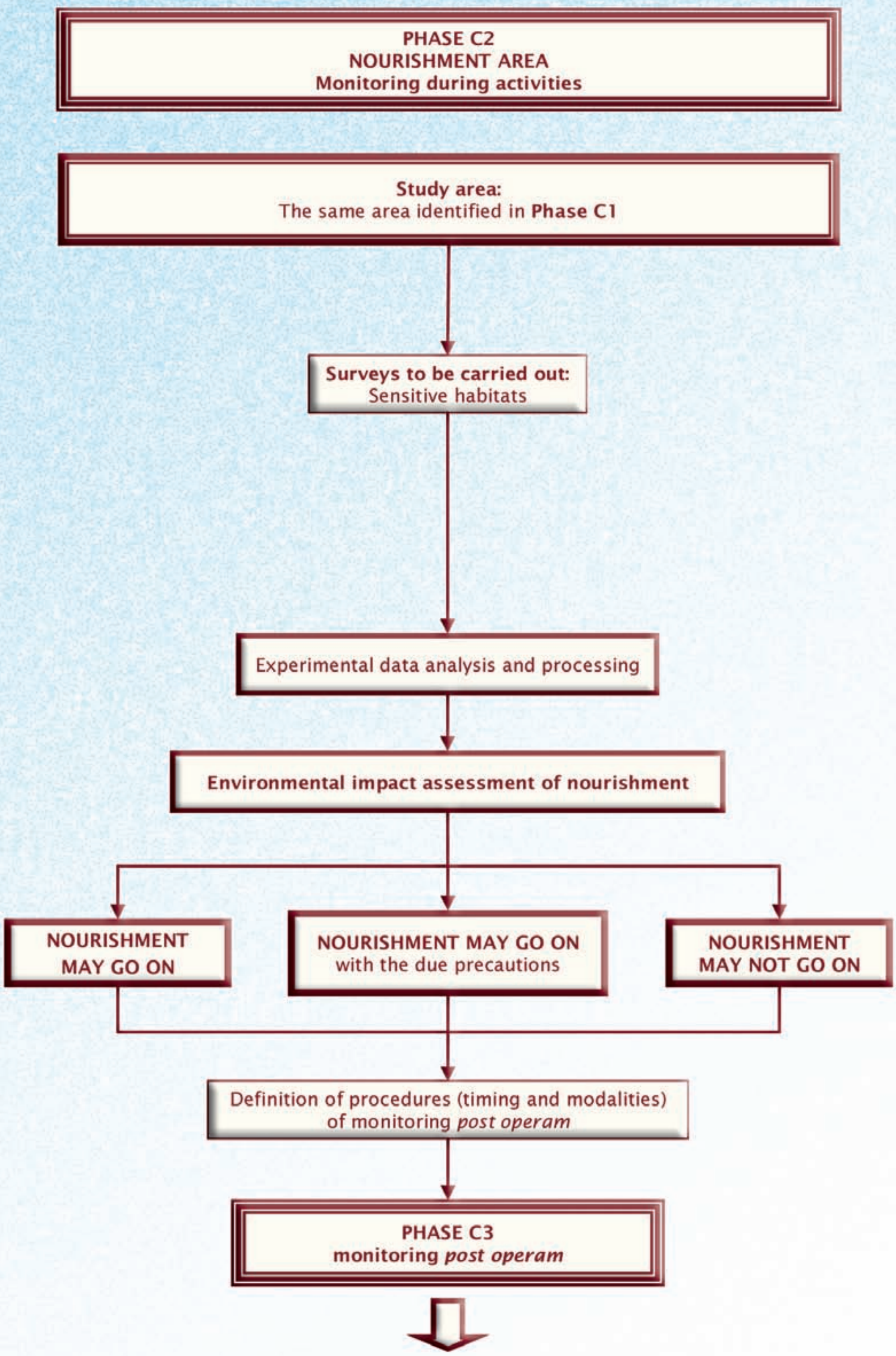
Results
- Environmental impact assessment of the nourishment activities;
- Definition of timing and modalities for monitoring *post operam* (Phase C3).

Conclusions
- Transport may go on →Phase C3 (monitoring *post operam* of nourishment site);
- Transport may go on only with the due technical precautions →Phase C3 (monitoring *post operam* of nourishment site);
- Transport may not go on, which results in the subsequent, immediate interruption of activities →Phase C3 (monitoring *post operam* of nourishment site);

Surveys planned for Phase C2 in the nourishment area are illustrated in flow chart n. 10.

ENVIRONMENTAL MONITORING STUDY

10



Flow chart n. 10 - Environmental monitoring study, Phase C2 – nourishment area.

chart 11

Environmental Monitoring Study

PHASE C3
DREDGING AREA
MONITORING *POST OPERAM*

Study area
The same area and same stations as those identified in Phase C1, and times deriving from Phases C1 and C2.

Surveys related to:
- Bottom morphology and bathymetry;
- Textural characteristics (granulometry) of superficial sediments;
- Hydrology of water masses (chemical-physical characteristics);
- Suspended particulate matter (total and inorganic);
- Benthic assemblages;
- Demersal fish assemblages (nursery areas, seasonal surveys).

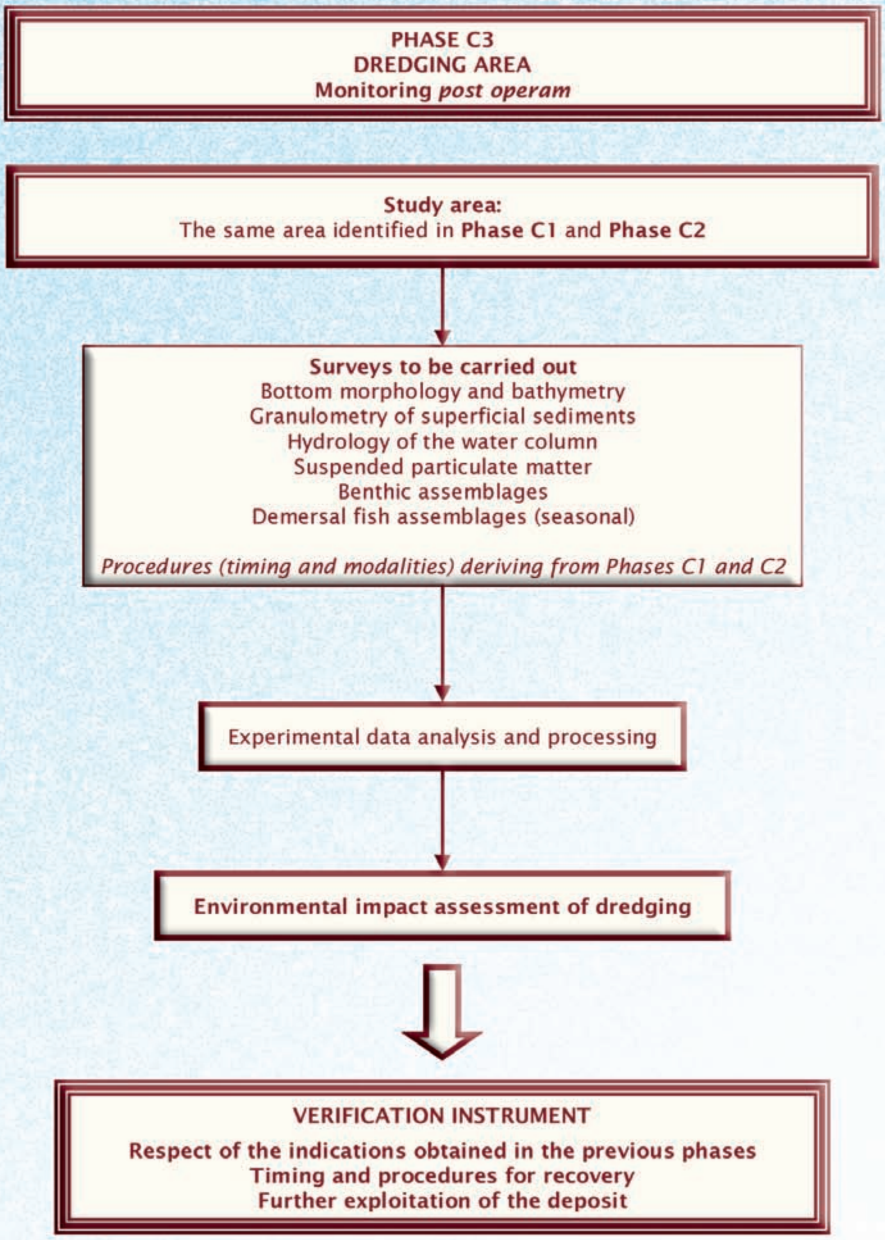
Data processing
Critical analysis of gathered data.

Results
Environmental impact assessment of the dredging activities. Assessment of timing and modalities for the area's recovery.

Conclusions
The results of the monitoring provide the relevant authorities with the information needed to state:
- whether the indications provided – in order to prevent possible negative effects on the environment of sand dredging, and deriving from the previous phases – have been respected;
- timing and modalities for the dredged area's recovery;
- if – following the definition of the possible effects induced by sand removal, and of the environmental recovery times – further exploitation of the deposit may be hypothesized.

Surveys planned for Phase C3 in the dredging area are illustrated in flow chart n. 11.

ENVIRONMENTAL MONITORING STUDY 11



Flow chart n. 11 - Environmental monitoring study, Phase C3 – dredging area.

chart 12

Environmental Monitoring Study

PHASE C3
TRANSPORT AREA
MONITORING *POST OPERAM*

This phase is conducted only in case Phase C2 showed that the distribution patterns of the sediment put into suspension during transport may affect sensitive habitats.

Study area
The same area as that identified in Phase C2. The activities' frequency is decided based on the characteristics of the area as well as based on the results obtained in the previous phases.

Surveys related to:
- Hydrology of water masses (chemical-physical characteristics);
- Suspended particulate matter (total and inorganic);
- Sensitive habitats.

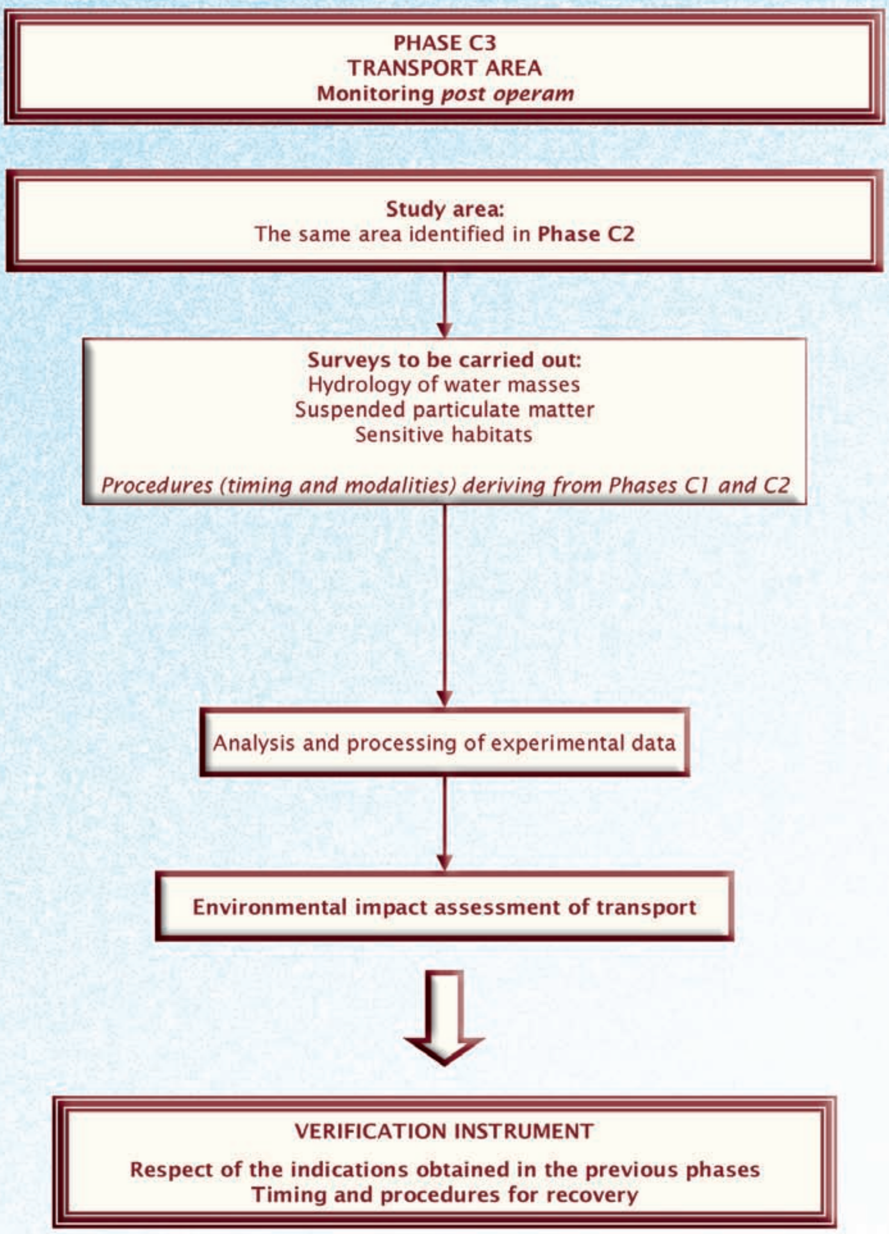
Data processing
Critical analysis of gathered data.

Results
Environmental impact assessment on sensitive habitats involved in overflow phenomena occurred during transport. Assessment of timing and modalities for the area's recovery.

Conclusions
The results of the monitoring provide the relevant authorities with the information needed to state:
- whether the indications provided – in order to prevent possible negative effects on the environment of sand dredging, and deriving from the previous phases – have been respected;
- timings and modalities for the dredged area's recovery;
- if – following the definition of the possible effects induced by sand transport, and of the environmental recovery times – further utilization of the same routes may be hypothesized.

Surveys planned for Phase C3 in the transport area are illustrated in flow chart n. 12.

ENVIRONMENTAL MONITORING STUDY 12



Flow chart n. 12 - Environmental monitoring study, Phase C3 – transport area.

chart 13

Environmental Monitoring Study

PHASE C3
NOURISHMENT AREA
MONITORING *POST OPERAM*

Study area
The same area and same stations as those identified in Phase C1 and Phase C2.

Surveys related to:
- Textural characteristics (granulometry) of superficial sediments;
- Sensitive habitats and/or species.

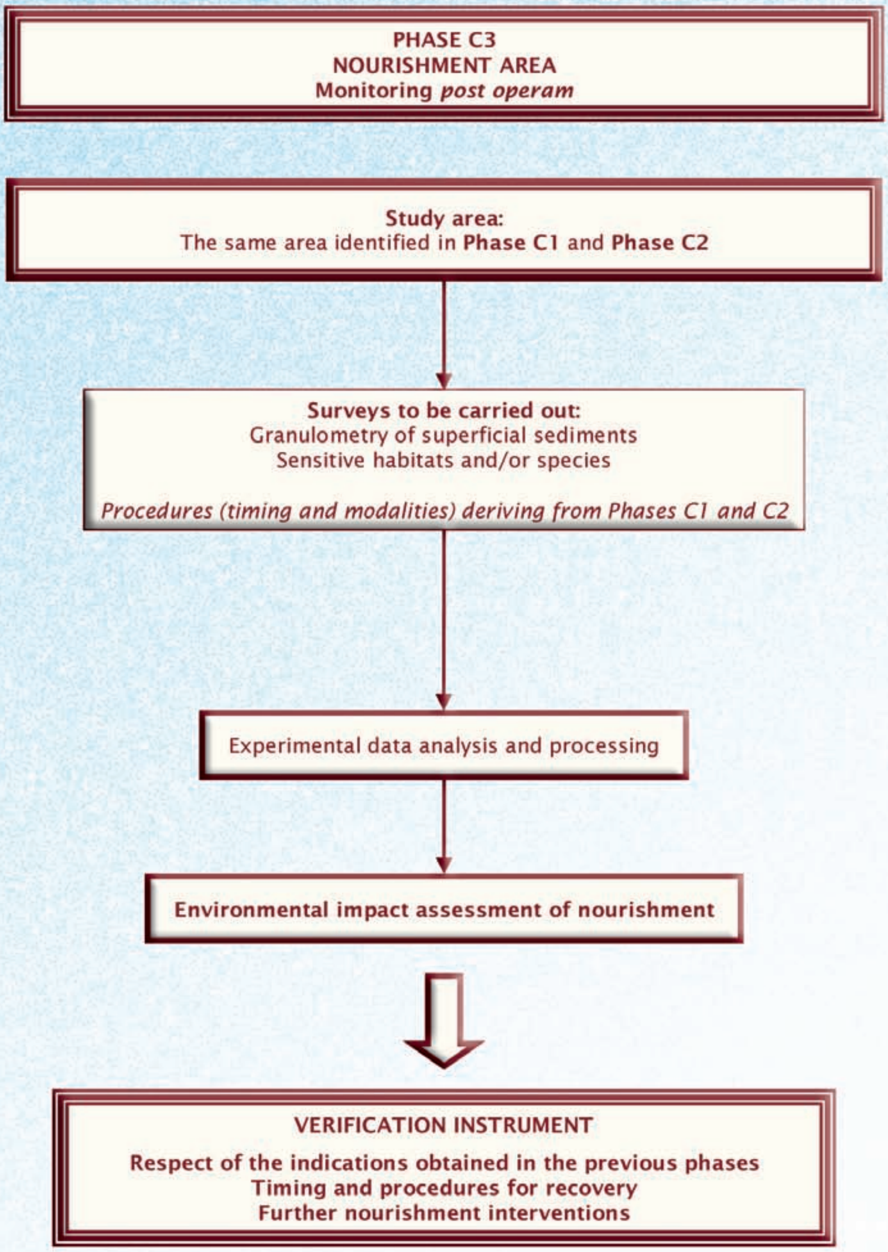
Data processing
Critical analysis of gathered data.

Results
Environmental impact assessment of nourishment activities. Assessment of timing and modalities for the area’s recovery.

Conclusions
The results of the monitoring provide the relevant authorities with the information needed to state:
- whether the indications provided – in order to prevent possible negative effects on the environment of sand replenishment, and deriving from the previous phases – have been respected;
- timing and modalities for the dredged area’s recovery;
- if – following the definition of the possible effects induced by sand replenishment, and of the environmental recovery times – further future nourishment activities may be hypothesized.

Surveys planned for Phase C3 in the nourishment area are illustrated in flow chart n. 13.

ENVIRONMENTAL MONITORING STUDY 13



Flow chart n. 13 - Environmental monitoring study, Phase C3 – nourishment area.

[illegible][illegible]ar[illegible]

Acoustic Doppler Current Profiler (ADCP)

An instrument that senses the direction and intensity of sea currents on a given point along the whole water column, from the surface to the sea bottom.

Anchor dredging

A dredge that stays steady, sometimes anchored; it dredges in a point and then is moved to another point nearby.

Background

The concentration values of the chemical elements present in an area where no anthropogenic activity was recorded. The presence of these elements must be ascribed to the natural (both geochemical and mineralogical) characteristics of the sediments.

Backscatter

A commonly used term to indicate the return energy from the sea bottom. The acoustic waves emitted by a Side Scan Sonar reach the bottom and energize it. Part of the energy, diffracted from the sea bottom, returns to the towfish (see Side Scan Sonar) and is immediately transmitted to the acquisition system through a connection cable. The intensity of the return energy, or backscatter, is expressed by the different shades of gray on the final sonogram.

Beach

Beaches are most of the transition's areas from the emerged land to the sea. A beach is comprised between the highest level reached by waves during storms and the submerged area interested by wave action; beyond that depth the sediment transport due to wave motion becomes negligible.

Benthic plume

The turbidity that can be observed near the sea bottom, caused by the re-suspension of fine sediment generated by the mechanic and hydrodynamic interaction between the dredging head and the bottom.

Benthos

A group of organisms (plants or animals) living in close contact with the sea bottom. Benthos can be subdivided in phytobenthos (plants organisms) and zoobenthos (animal organisms). Organisms that are larger in size than 1 mm are defined macrobenthos, those smaller than 100 micron are called microbenthos.

Bioaccumulation

An organism's ability to concentrate chemical substances in its tissues, starting from the medium that carries these chemicals. It is possible to establish a relationship between the concentrations measured, the organism's life time and the exposition levels.

Biocoenosis or community

A group of individuals belonging to different species with bearing common environmental needs, that coexist and reproduce in a common space characterized by homogenous environmental parameters.

Biomass

The quantity of living organisms (plants or animals) per surface or volume unit expressed in weight units.

Box-corer

An instrument that allows to obtain a large sediment volume, which in its central part can be considered undisturbed. A box-corer is a box with a square or rectangular ballasted base that is able to penetrate the bottom by about 30 cm; the sediment's retrieval is obtained by closing down the box's base. Box-corers allow sampling and an accurate description of the sediment along the whole section retrieved.

Breakwater

A coastal protection system consisting of hard structures placed parallel to the coastline.

Chemical speciation

The identification of the specific chemical form in which a substance is found in the environment in question.

Community

See *Biocoenosis*

Contaminant

Any substance that is able to have a toxic action on the environment or on an organism. A substance's toxicity is both a qualitative characteristic – because the toxic action depends on the interaction of the molecular structure with biological molecules – and a quantitative feature – as the toxic action only takes place when threshold concentration levels are reached in the environment or in certain tissues of the organism. Two main parameters are exposition – i.e. the quantity of substance that can enter the organism – and dose – the quantity of substance that actually enters the organism.

Continental shelf

The submerged portion of a continent, characterized by shallow sea bottoms and weak slopes (0,1° - 1°), associated, at medium latitudes, with silt-clay sedimentation. The continental shelf is delimited landwards by the submerged beach limit, and seawards by an external edge (shelf-break), situated at an average depth of 130-140 m, and identified by an abrupt increase in bottom slope.

Crustaceans

Arthropods, mainly belonging to the marine environment, provided with branchial respiration, usually bearing forked appendages and two pairs of antennae on the head. The segmented body is covered with a resistant external calcified cuticole.

CTD (Conductivity, Temperature, Depth)

A multi-parameter probe that is able to measure some continuous physical-chemical parameters (such as temperature, salinity, chlorophyll, pH, etc.) of the water column. The probe is lowered through a windlass vertically from the surface to the bottom; the data gathered are transmitted via cable to a computer situated on the boat.

Current meter (or currentometer)

An instrument that measures the direction and intensity of sea currents. Currently, current meters are used for punctual measurements at a given depth (single-point current meters) or for vertical profiles (Doppler Current meters, or ADCP). A single-point current meter measures the two-dimensional direction and velocity of a current in a single point of the water column, while a doppler profiler carries out three-dimensional measurements at many levels (cells) in the water column.

Demersal, assemblage

A group of species that are able to carry out movements independently from the water masses (nekton), having a more or less constant relationship with the sea bottom.

Differential Global Positioning System (DGPS)

A positioning system based on a network of satellites transmitting synchronized signals. By interpolating the information from three or more satellites, integrated with that coming from a fixed station situated in a known point, these systems are able to calculate the coordinates of their position in relation to the earth surface, with great preciseness (1-2 m).

Dredge (nautical vehicle)

An especially equipped boat, used to draw materials from the sea bottom, or more generally, from the bottom of a water body. The material-gathering method can be mechanic or hydraulic. Dredges can be stationary (anchor dredging) or self-moving (trailer dredging).

Dredging

Extraction of bottom sediment within a water body (lake, canal, river, and sea) through the use of a dredge.

Dredging area

An area of the continental shelf, containing one or more deposits of relict sands intended for dredging.

Dredging corridor

The area inside a relict sand deposit in which the dredging operation will be carried out.

Dredging head

The terminal portion of the pipe situated on the dredge, through which the sediment is pumped.

Environmental window

The time of the year in which all dredging activities should be concentrated as the effects expected on the environment are minimal. The concept of environmental window, born as a management option for dredging and dumping activities in harbours and bays (Dickerson *et al.*, 1998), derives directly from the concept of seasonal restriction (the period in which dredging is not allowed) by Schubel *et al.* (1978).

Fecal pellets

Organic matter (fecal globules) present in the sediment in the form of organic amorphous degraded, rounded material, generally characterized by high density. Fecal pellets are mainly produced by organisms such as polychaetes, mollusks, crustaceans, and fish.

Flocculation

A phenomenon according to which suspended particles in a colloidal solution aggregate in floccules giving rise to a bottom body.

G.I.S (Geographic Information System)

A computer system designed to allow users to collect, manage and analyze large volumes of spatially referenced and associated attribute data. The major components of a GIS are: a user interface system; data base management capabilities; data base creation/data entry capacity; spatial data manipulation and analysis packages; and display/product generation functions.

Grab

An instrument used to sample benthic organisms on a soft bottom. This instrument allows to draw a well-defined quantity of sediment, and to therefore obtain the sample's reproducibility. The grab area usually ranges between 0.03 and 0.55 m^2. The most common grabs are the Van Veen grab, the Smith-McIntyre grab, and the Day grab.

Groin (or groyne)

A coastal protection system composed of hard structures positioned perpendicular to the coastline.

Habitat

An environment defined by specific abiotic and biotic factors, in which a group of species lives.

Load vehicle

A support nautical vehicle used to transport the dredged material from the dredging area to the nourishment one.

Marine phanerogams

Superior plants (organized in rhizomes, leaves, and roots) that live submerged in the sea. The main species present in the Italian seas are: *Posidonia oceanica, Cymodocea nodosa, Zostera marina, Nanozostera noltii,* and *Halophila stipulacea*.

Microbial film

An organic matrix formed by biopolymers with low water solubility, in which a microscopic fauna that is a source of food for many organisms lives and reproduces. The microbial film, which covers every surface submerged in the sea, represents the first phase of the biological colonization.

Mollusks

Bilateral-symmetry organisms with a soft body, typically consisting of an anterior head, a ventral foot and a dorsal visceral mass. The body is generally covered by a mantle and it can be protected with an calcium carbonate external shell.

Monitoring

Gathering and analysis of observations or measurements repeated in time in order to describe the temporal evolution of physical, chemical and biological phenomena within a given area.

Multibeam

Also called multibeam echo-sounder, this instrument is used for high resolution bathymetric surveys. The instrument simultaneously sends various signals and allows to cover the sea bottom along a stretch whose size may vary according to the instrument's characteristics and to the depth of the analyzed area. For a correct use the instrument must be interfaced with a DGPS, a movement sensor, a gyrocompass and a CTD probe.

Multiparameter probe

See CTD

Natural concentration

Concentration of a chemical substance in a matrix before the occurrence of a certain phenomenon, natural or anthropogenic, that can change the chemical composition of the matrix and the concentration of the substance.

Nekton

A group of animal species able to propel themselves independently of the currents in their surrounding water mass, having wide horizontal and vertical movements. These group of organism can resist and/or oppose to currents and water movements. The group of nektonic species that have a more or less constant relationship with the sea bottom are known as demersal species.

Nourishment

A coastal protection intervention consisting in reconstructing the eroded beach through the replenishment with appropriate material of sea or land provenance.

Nourishment area

A part of the submerged or emerged beach where appropriate sedimentary material is replenished; in this case the materials are relict sands used for the beach restoration.

Nursery area

A concentration area of juveniles of fish species. Nursery areas are situated where fish growth is related to particular oceanographic water characteristics and favored by the availability of trophic resources.

Overflow

A phenomenon linked to the offshore discharge of a water-fine sediment mixture; overflow occurs mainly during the dredge-loading phases, due to discharge of excess water pumped together with the sediment.

Overlay mapping

The process of combining spatial information from two or more maps to derive a map consisting of new spatial boundaries.

Paleo offshore bars

Transgressive depositional bodies formed in a coastal environment parallel to the shoreline for many-kilometers long. Their internal geometry show a seaward-progradating reflectors and an acoustic *facies* with low transparency, a flat bottom and a top surface ranging from wavy to flat.

Paleobeach

A beach developed in the geological past during periods of low sea level stationing.

Pipe

The dredge's pipes through which sediments are pumped from the sea bottom.

Photosynthesis

The process that uses sunlight energy to transform carbon dioxide into carbohydrates, with oxygen liberation. Photosynthesis is carried out by autotrophic organisms.

Pioneer species

Organisms that settle more or less rapidly on every non-colonized substratum (which can be new or defaunated). These cosmopolitan and opportunist species are able to rapidly colonize a substratum thanks to their high reproductive rate, exploiting a transitional situation favored by the absence of competitors.

Plankton

Drifting organisms (zooplankton: small protozoans and metazoans; phytoplankton: small algae) that are unable to resist ocean waves and currents. Eggs, larval stages or juveniles of animals that are benthic or nektonic as adults, may also belong to the plankton (meroplankton).

Plume

Also called turbidity plume, this is a temporary phenomenon caused by the introduction in a certain area of suspended solid material as an effect of dredging, determining a localized increase in turbidity. The size and duration of a plume depend on the nature and volume of the moved sediment, on the characteristics of the dredging activities, and on the local hydrodynamic conditions.

Pollutant

Any substance (or energy), directly or indirectly introduced in the environment and able to cause an alteration in the ecosystem that will produce negative effects on biological resources on human health and on water quality (GESAMP, Group of Experts on the Scientific Aspects of Marine Environmental Protection). According to this definition, all substances are potentially pollutants.

Polychaetes

Polychaetes are one of the benthos's most important systematic groups. Their body is subdivided in a large number of rings or segments. They are divided in errant polychaetes or sedentary polychaetes. Errant polychaetes are benthic organisms moving on the bottom thanks to outwards protruding fleshy appendages called parapods. Sedentary polychaetes live in fissures or inside burrows and tunnels they have built for themselves.

Polychlorobiphenyls (PCB)

A family of organic compounds in which the biphenyl group is linked to the chlorine. These substances are very stable and persistent, they are used as isolating materials in electric transformers and in condensers, and as lubricants in gas pipelines.

Polycyclic Aromatic Hydrocarbon (PAH)

A large class of aromatic compounds, all structurally characterized by the presence of two or more aromatic rings condensed together. Along with their use in the oil industry, PAHs are used in the production of coloring agents, plastic materials, pesticides and medicines.

Posidonia oceanica

A marine phanerogam, analogous to superior plants, and therefore bearing rhizomes, leaves and roots. *Posidonia oceanica* grows in the euphotic zone down to a depth of 40 m and it can form meadows. Its importance lies in the fact that it traps sediment with the rhizomes, thus helping prevent coastal erosion, and it serves as a "nursery" for a large variety of marine organisms.

Primary production

The primary production is the weight of a new organic substance produced in a given period of time, following photosynthetic or chemosynthetic processes, plus losses (respiration, excretion, damaging, natural death, and withdrawal by herbivore organisms).

Recruitment

A term used in the study of assemblages dynamics to indicate the arrival of a new generation in an assemblage following a reproductive event.

Relict sands

Non-diagenised sedimentary deposits, present along the continental shelf, which formed during periods of low-sea level stationing or during the following rising phase that characterized the Holocene. These deposits, which are generally associated to ancient beaches (paleobeaches), can outcrop on the sea bottom or they can be covered with recently deposited fine sediments.

Reproduction area

A concentration area of adult breeding fish species. The reproduction areas of the different assemblages in the temperate seas are often well-defined and regularly used by each species during each reproductive period.

River paleobed

River-created incisions of the continental shelf, formed during periods of low sea-level stationing. These are a continuation of still active water streams, or they are situated in front of ridges that, in the past, nourished the fluvial networks that carved the continental shelf.

Shear resistance

The resistance to rupture that soils or rocks can oppose when they are interested by shear stress (i.e. tangential stress). It depends on cohesion and normal stress multiplied by the friction angle.

Side Scan Sonar (S.S.S.)

An instrument used to import images of the sea bottom (sonograms), whose interpretation allows to define the bottom's morphological setup. The system consists of a "towfish" towed by a surface vessel from a controlled distance from the sea bottom and connected to the onboard registration system through a cable. The morpho-acoustic image of the bottom expresses the backscatter's intensity variations as shades of gray, associated to morphological variations, changes in the texture/composition of sediments and to the presence of rocky outcroppings.

Siltation
The effects generated by the deposition and accumulation of the solid suspended in the water column.

Soft bottom
A term used to indicate incoherent sea floors in which the constituting particles can be easily moved away one from the other. These elements can have varying sizes, from a few centimeters (pebbles) to a few microns (clays).

Thermocline
The water column layer in which the maximum value of the vertical thermal gradient is observed.

Trace metals
Chemical elements that are present in the investigated matrix, with a concentration of 1 part to a million, or lower. These elements generally belong to the class of transition metals, with the addition of some elements such as arsenic and mercury that have no metallic characteristics.

Trailer dredging
A dredge that slowly moves along predefined routes during dredging activities.

Transport area
The sea stretch coinciding with the navigation routes chosen for the relict sand transport from the dredging area to the nourishment one.

Turbidity
The expression of a liquid's optical characteristic that causes the absorption and reflection of rays of light, limiting their diffusion in a straight line within the liquid itself. The measure of a water body's turbidity is based on the measure of the loss of light intensity registered when light impulses run along a certain path through a solution. The attenuation of the impulse depends both on the water body's physical characteristics and on the suspended particulate substance, as well as on the dissolved substance's nature. Finally, turbidity is often measured as the concentration of solid in suspension in a given water volume (mg/l).

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ADRIAANSE L.A., COOSEN J. (1991) - Beach and dune nourishment and environmental aspects. *Coastal Engineering*, **16**: 129-146.

ALDRIDGE A., GOTTSCHALK W. (1988) – *In situ* settling behaviour of marine snow. *Limnology and Oceanography*, **33**: 339-351.

ALIANI S., BIANCHI C.N., DE BIASI A.M. (1994) – Modificazioni del benthos in un'area marina soggetta a discarica di materiale portuale. *Biologia Marina Mediterranea,* **1** (1): 265-269.

ARDIZZONE G.D., PELUSI P. (1983) - Regression of a tyrrhenian *Posidonia oceanica* prairie exposed to nearshore trawling. *Rapport et Procès-verbaux de Réunion CIESM*, Monaco, **28** (3): 175-177.

ASCHAN M. (1988) - Soft bottom macrobenthos in a Baltic archipelago: Spatial variation and optimal sampling strategy. *Annales Zoologici Fennici*, **25**: 153-164.

ASPER V. (1987) - Measuring the flux and sinking speed of marine snow aggregates. *Deep Sea Research*, **34**: 1-17.

AUCELLI P. *et al.* (2006) - Lo stato dei litorali italiani. Gruppo Nazionale per la Ricerca sull'Ambiente Costiero. *Studi Costieri*, **10**: 5-112.

AUGIER H., GILLES G., RAMONDA, G. (1984) - L'herbier de *Posidonia oceanica* et la pollution par le mercure sur le littoral des Bouches-du-Rhone et du Var (France). In: "International Workshop on *Posidonia oceanica* Beds", Boudouresque C.F., Jeudy de Grissac A., Olivier J. (eds.), GIS Posidonie publ., Fr., **1**: 399-406.

AULD A.H., SCHUBEL J.R. (1978) - Effects of suspended sediment on fish eggs and larvae: a laboratory assessment. *Estuarine and Coastal Marine Science*, **6**: 153-164.

BADALAMENTI F., DI CARLO G., D'ANNA G., GRISTINA M., TOCCACELI M. (2006) - Effects of dredging activities on population dynamics of *Posidonia oceanica* (L.) Delile in the Mediterranean sea: the case study of Capo Feto (SW Sicily, Italy). *Hydrobiologia*, **555**: 253-261.

BALLESTA L., PERGENT G., PASQUALINI V., PERGENT-MARTINI C. (2000) – Distribution and dynamics of *Posidonia oceanica* beds along the Alberéres coastline. *Life Sciences*, **323**: 407-414.

BARBANTI A., CHIARLO R., FORNASIERO P., GABELLINI M., LA VALLE P., NICOLETTI L. (2005) - Innovative Monitoring of Turbidity due to Dredging Activities. In: "MEDCOAST '05 - Proceedings of the Seventh International Conference on the Mediterranean Coastal Environment", Özhan E. (ed.), 25-29 October 2005, Kusadasi, Turkey: 803-814.

BARGHIGIANI C., RISTORI T., LOPEZ ARENAS J. (1996) - Mercury in marine sediment from a contaminated area of the northern Tyrrhenian Sea: <20 mm grain-size fraction and total sample analysis. *The Science of the Total Environment*, **192**: 63-73.

BEACHMED (2003) - IL PROGETTO BEACHMED: Recupero ambientale e mantenimento dei litorali in erosione con l'utilizzo di depositi sabbiosi marini (Convenzione 2002-01-4.3-i-028). PROGRAMMA OPERAZIONALE INTERREG III B. Protezione e valorizzazione del patrimonio naturale e culturale, gestione della biodiversità, dei territori e dei paesaggi. SPAZIO DEL MEDITERRANEO OCCIDENTALE. 1° Quaderno tecnico (Fase "A"), Roma, ottobre 2003: 236 pp.

BEACHMED (2004) - IL PROGETTO BEACHMED: Recupero ambientale e mantenimento dei litorali in erosione con l'utilizzo di depositi sabbiosi marini (Convenzione 2002-01-4.3-i-028). PROGRAMMA OPERAZIONALE INTERREG III B. Protezione e valorizzazione del patrimonio naturale e culturale, gestione della biodiversità, dei territori e dei paesaggi. SPAZIO DEL MEDITERRANEO OCCIDENTALE. 3° Quaderno Tecnico (Fase "C"), Roma, dicembre 2004: 275 pp.

BELLAN G. (1984) - Indicateurs et indices biologiques dans le domaine marine. *Bulletin d'Écologie*, **15** (1): 13-20.

BELLAN G., BOURCIER M., PICARD J., SALEN-PICARD C., STORA G. (1985) – Conséquences structurelles dues aux perturbations affectant les biocénoses benthiques méditerranéennes de substrat meuble. *Rapport Commission International Mer Méditerranée,* **29** (5): 215-221.

BENASSAI E., GENTILOMO M., RAGONE A., SETARO F., TOMASICCHIO U. (1997) - Littoral restoration by means of protected beach nourishment: recent italian works (Venetian and Tyrrhenian-Calabrian coasts). *Bulletin of the Permanent International Association of Navigation Congresses*, CIP 1997, **94** (28 ref.): 43-55.

BIANCHI C.N., MORRI C. (1985) - Policheti come descrittori della struttura trofica degli ecosistemi marini. *Oebalia*, **XI**: 203-214.

BIRKLUND J.W.M., WIJSMAN J. (2005) – Aggregate extraction: a review on the effect on ecological functions. Report Z3279.10, WL Delfet Hydraulics, Delft, The Netherlands. In: "SANDPIT Sand Transport and Morphology of offshore sand mining pits. Process knowledge and guidelines for coastal management", Van Rijn L.C., Solusby R.L., Hoekstra P., Davies A.G. (eds.), EC Framework V Project N. EVK3-2001-00056: J1- J11.

BLAKE N.J., DOYLE L.J., CULTER J.J. (1996) - Impacts and direct effects of sand dredging for beach renourishment on the benthic organisms and geology of the west Florida shelf. Contract 14-35- 0001-30644. US Dept. of Interior, MMS, Office of International Activities and Marine Minerals: 109 pp.

BLANC J.J., JEUDY de GRISSAC A. (1984) – Erosions sous-marines des herbiers à *Posidonia oceanica* (Méditerranée). In: "International Workshop on *Posidonia oceanica* Beds", Boudouresque C.F., Jeudy de Grissac A., Olivier J. (eds.), GIS Posidonie publ., Fr., **1**: 23-28.

B.N.P. (1995) - Beach Nourishment and Protection. http://www.nap.edu/books/0309052904/html/index.html

BOESCH D.F. (1982) - Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences, and Options. U.S. Fish and Wildlife Service FWS/OBS-82/59: 256 pp.

BONSDORFF E. (1980) - Macrozoobenthic recolonization of a dredged brackish water bay in SW Finland. *Ophelia*, suppl. **1**: 145-155.

BONVICINI PAGLIAI A.M., COGNETTI VARRIALE A.M., CREMA R., CURINI GALLETTI M., VANDINI ZUNARELLI R. (1985) – Environmental impact of extensive dredging in a coastal marine area. *Marine Pollution Bulletin*, **16**: 483-488.

BOTTCHER M.E., RINNA J., WARMING B., WEHAUSEN R., HOWELL M.W., SCHNETGER B., STEIN R., BRUMSACK H.J., RULLKOTTER J. (2003) – Geochemistry of sediments from the connection between the western and eastern Mediterranean Sea. *Paleogeography*, *Paleoclimatology*, *Paleoecology*, **190**: 165-194.

BOURCIER M. (1989) - Régression des herbiers à *Posidonia oceanica* (L.) Delile, à l'Est de Marseille, sous l'action conjuguée des activités humaines et des modifications climatiques. In: "International Workshop on *Posidonia oceainca* beds", Boudouresque C.F., Meinesz A., Fresi E., Gravez V. (eds.), GIS Posidonie publ., Fr., **2**: 287-299.

BOYD S.E., REES H.L. (2003) – An examination of the spatial scale of impact on the marine benthos arising from marine aggregate extraction in the central English Channel. *Estuarine, Coastal and Shelf Science*, **57**: 1-16.

BRAMBATI A., FONTOLAN G. (1990) - Sediment resuspension induced by clam fishing with hydraulic dredges in the Gulf of Venice (Adriatic Sea). A preliminary experimental approach. *Bollettino di Oceanologia Teorica e Applicata*, **VIII** (2): 113-121.

BRAMBATI A., VENZO G.A. (1967) - Recent sedimentation in the Northern Adriatic Sea between Venice and Trieste. *Studi Trentini di Scienze Natutali,* Sez. A, **XLIV**: 202-274.

BRAMBATI A., BREGANT D., LEONARDI G., STOLFA D. (1973) - Transport and sedimentation in the Adriatic sea. Museo friulano di Storia naturale, Udine, pubblicazione n. **20**: 1-60.

BRANCA M.E., CALDERONI G., PETRONE V. (1996) - Geochimica dei sedimenti. In: "Il Mare del Lazio", Università degli Studi di Roma "La Sapienza" - Regione Lazio, Assessorato Opere e Reti di Servizi e Mobilità: 109-135.

BRESSAN G., BABBINI L., GHIRARDELLI L., BASSO D. (2001) – Biocostruzione e biodistruzione di Corallinales nel Mar Mediterraneo. *Biologia Marina Mediterranea*, **8** (1): 131-174.

BROWN K.M., SWEARINGEN D.C. (1998) - Effects of seasonality, length of immersion, locality and predation on an intertidal fouling assemblage in the Northern Gulf of Mexico. *Journal of Experimental Marine Biology and Ecology*, **225** (1): 107-121.

C-CORE (1996) - Proposed marine mining technologies and mitigation techniques: A detailed analysis with respect to the mining of specific offshore mineral commodities. C-CORE Publication 96-C15, Contract Report for U.S. Dept. of the Interior, Minerals Management Service: 400 pp.

CAPOBIANCO M., STIVE M.J.F. (1997) - Soft Protection Technologies as a Tool for Integrated Coastal Zone Management. In: "MEDCOAST '97 - Proceedings of the Third International Conference on the Mediterranean Coastal Environment", Özhan E. (ed.), 11–14 November 1997, Valletta, Malta: 469-484.

CAPOBIANCO M., HAMM L., SILVA P. (1999) - Interventi di ripascimento nelle coste europee: ricadute a livello italiano. *Studi costieri. Dinamica e difesa dei litorali - Gestione integrata della fascia costiera*, **1**: 3-12.

CARTER R.W.G., WOODROFFE C.D. (1994) - Coastal Evolution: an introduction. In: "Coastal Evolution. Late Quaternary shoreline morphodynamics", R.W.G. Carter and C.D. Woodroffe (eds.), Cambridge University Press: 1-32.

CECCONI G., ARDONE G. (1999) - La protezione delle spiagge della laguna di Venezia. In: "Riqualificazione e salvaguardia dei litorali: idee, proposte e confronti tra esperienze mediterranee". A. Tervisani e V. Petrocelli (eds.), ACLI Anni Verdi – Pro Loco Bernalda (MT). Patrocinio: Regione Basilicata, Amministrazione Provinciale di Matera: 58-65.

CHIMENZ GUSSO C., TARAMELLI E., GRAVINA M.F. (1996) – I popolamenti bentonici litorali. In: "Il Mare del Lazio", Università degli Studi di Roma "La Sapienza" – Regione Lazio, Assessorato Opere e Reti di Servizi e Mobilità: 147-193.

CHIOCCI F.L., LA MONICA G.B. (1999) - Individuazione e caratterizzazione dei depositi sabbiosi presenti sulla piattaforma continentale della Regione Lazio e valutazione di un loro utilizzo ai fini del ripascimento dei litorali in erosione. Rapporto della prima fase. Università degli Studi di Roma "La Sapienza", Dipartimento di Scienze della Terra – Regione Lazio, Dipartimento OO.PP. e Servizi per il Territorio – ROMA, settembre 1999: 100 pp.

CIUCCI P. (2004) - Il monitoraggio della biodiversità. Dispense del Master di II livello. In: "Conservazione della biodiversità animale: aree protette e reti ecologiche"; Università degli Studi di Roma "La Sapienza", Facoltà di Scienze Matematiche Fisiche e Naturali, Dipartimento di Biologia Animale e dell'Uomo: 47 pp.

C.N.R. (1978) - Ricerche sulla piattaforma continentale dell'Alto Adriatico. Risultati delle crociere 1976 e 1977 (da Ancona alla foce del Reno). In: "CNR Prog. Fin. Oceanografia e Fondi Marini", Colantoni P., Gallignani P. (eds.), Subprogetto 4, Quad. **1**, Bologna: 113 pp.

COLANTONI P., GALLIGNANI P. (1980) - Ricerche sulla piattaforma continentale dell'alto adriatico: considerazioni conclusive. In: "CNR Prog. Fin. Oceanografia e Fondi Marini", Colantoni P., Gallignani P. (eds.), Subprogetto 4, Quad. **2**, Bologna: 81-87.

COLANTONI P., GALLIGNANI P., LENAZ R. (1979) - Late Pleistocene and Holocene evolution of the North Adriatic continental shelf (Italy). *Marine Geology*, **33**: 41-50.

COLTELLACCI M.M. (1980) – Distribuzione dei sedimenti sulla piattaforma continentale tra Ravenna e Chioggia. In: "CNR Prog. Fin. Oceanografia e Fondi Marini", Colantoni P., Gallignani P. (eds.), Subprogetto 4, Quad. **2**, Bologna: 29-36.

CORREGGIARI A., FRASCARI F., MISEROCCHI S., FONTANA D. (1992) - Breakwaters and eutrophication along the Emilia-Romagna Coast. In: "Marine coastal eutrophication. The response of marine transitional systems to human impact: Problems and perspectives for restoration", Vollenweider R.A., Marchetti R., Viviani R. (eds.), Amsterdam, Elsevier: 277-290.

CORREGGIARI A., CATTANEO A., CARRÀ D., PENITENTI D., PRETI M., TRINCARDI F. (2002) - Offshore sand for beach restoration: North Adriatic shelf examples. *CIESM* Workshop n. 18 "Erosion littorale en Méditerranée: dynamique, diagnostic et remèdes" - Tanger, Maroc, 18-21 septembre 2002: 79-82.

CORREGGIARI A., CARRÀ D., LANDUZZI V., PENITENTI D., VIGLIONE M., PALTRINIERI D., ANTONELLI U. (2003) - Research and identification of sand deposit in the central Adriatic sea. Convegno: "Le sabbie sottomarine dell'Adriatico centrale. Proteggere ed ampliare l'orizzonte delle spiagge" - Sirolo, 4-5 maggio 2003.

COSMA B., DRAGO M., PICCAZZO M., TUCCI S. (1994) - Heavy metal in high Tyrrhenian Sea sediments: distribution of Cr, Cu, Ni, and Mn in superficial sediments. *Atti della Società Toscana di Scienze Naturali*, **87**: 145-161.

CREMA R. (1989) – Aspetti della successione in comunità macrozoobentoniche marine di fondi mobili. *Atti della Scienza Italiana di Ecologia* (1989), **7**: 315-320.

CREMA R., VALENTINI A. (1998) – Ricostituzione della comunità zoobentonica in fondali defaunati da operazioni di dragaggio. *Biologia Marina Mediterranea*, **5** (1): 144-153.

CREMA R., CASTELLI A., PREVEDELLI D. (1991) – Long term eutrophication effects on macrofaunal communities in northern Adriatic Sea. *Marine Pollution Bulletin*, **22** (10): 111-122.

CURZI P.V., GALLIGNANI P. (1982) - Evoluzione sedimentaria recente della piattaforma continentale centro e nord adriatica. Atti Conferenza Nazionale per una politica ambientale di salvaguardia dei litorali. *Cronache Adriatiche*, **1-2**: 64-66.

CURZI P.V., MARABINI E., TOMADIN L. (1987) - Provenienza e dispersione dei sedimenti attuali sulla piattaforma abruzzese. *Memorie della Società Geologica Italiana*, **37**: 437-451.

CURINI GALLETTI M.C. (1987) – Recovery a soft bottom community after extensive dredging. I. Mollusca. *FAO Fisheries Report*, **352** (suppl.): 54-56.

DE GRAVE S., WHITAKER A. (1999) – Benthic community re-adjustment following dredging of a muddy-maërl matrix. *Marine Pollution Bulletin*, **38** (2): 102-108.

DE GROOT S.J. (1979) – An assessment of the potential environmental impact of large-scale sand-dredging for the building of artificial islands in the North Sea. *Ocean Management*, **5**: 211-232.

DELLA CROCE N., CATTANEO VIETTI R., DANOVARO R. (1997) – Ecologia e protezione dell'ambiente marino costiero. Utet, Torino: 420 pp.

DESPREZ M. (2000) – Physical and biological impact of marine aggregate extraction along the French coast of the Eastern English Channel: short- and long-term post-dredging restoration. *ICES Journal of Marine Science*, **57**: 1428-1438.

DIAZ R.J., CUTTER G.R. Jr., HOBBS H. III (2004) – Potential impacts of sand mining offshore of Maryland and Delaware: Part 2 – Biological considerations. *Journal of Coastal Research*, **20** (1): 61-69.

DICKERSON D.D., REINE J.J., CLARKE D.G. (1998) - Economic impacts of environmental windows associated with dredging operations, DOER Technical Notes Collection (TN DOER-E3), US Army Engineer Research and Development Center, Vicksburg, MS: 18 pp.

DOMURAT G.W. (1987) - Beach nourishment: a working solution. *Shore and Beach*, **55** (3-4): 92-95.

DORNHELM R.B. (1995) - The Coney Island public beach and boardwalk improvement of 1923. *Shore and Beach*, **63** (1): 7-11.

ELLIS D.V., HOOVER P.M. (1990) - Benthos in Tailings Beds from an Abandoned Coastal Mine. *Marine Pollution Bulletin,* **21** (10): 477-480.

ELZINGA C.L., SALZER D.W., WILLOUGHBY J.W., GIBBS. J.P. (2001) - Monitoring plant and animal populations. Blackwell Science, Inc.: 360 pp.

EVANS N.C. (1994) – Effects of Dredging and Dumping on the Marine Environment of Hong Kong. *Terra et Aqua*, **57**: 15-25.

FABI G., MANOUKIAN S., TEDESCHI R. (2003) – Monitoraggio dell'area destinata al prelievo di sabbie al largo di Ravenna. Rapporto per ARPA Emilia Romagna: 10 pp.

FABI G., MANOUKIAN S., TEDESCHI R. (2004) – Monitoraggio dell'area destinata al prelievo di sabbie al largo di Ravenna. Rapporto per ARPA Emilia Romagna: 17 pp.

FANELLI E., NICOLETTI L., FRANCESCHINI G., GIOVANARDI O., GABELLINI M., PRETI M. (2003) - Environmental Impact Assessment after Sand Extraction for Beach Nourishment: a Methodological Approach. In: "MEDCOAST '03 - Proceedings of the Sixth International Conference on the Mediterranean Coastal Environment", Özhan E. (ed.), 7-11 October 2003, Ravenna, Italy: 951-958.

FRANCOUR P. (1997) - Fish assemblages of *Posidonia oceanica* beds at Port-Cros (France, NW Mediterranean): Assessment of composition and long-term fluctuations by visual census. *Marine Ecology*, **18** (2): 157-173.

GAJEWSKI L.S., USCINOWICZ S. (1993) - Hydrologic and sedimentologic aspects of mining aggregate from the Slupsk Bank (Baltic Sea). *Marine Georesources and Geotechnology*, **11**: 229-244.

GAMBI M.C., GIANGRANDE A. (1985) – Caratterizzazione e distribuzione delle categorie trofiche dei policheti nei fondi mobili del Golfo di Salerno. *Oebalia*, **IX**: 241-252.

GAMBI M.C., FRESI E., GIANGRANDE A. (1982) - Descrittori efficaci di comunità bentoniche. *Naturalista Siciliano*, S. IV, VI (suppl.), **3**: 489-497.

GAMBI M.C., DAPPIANO M., LORENTI M., IACONO B., FLAGELLA S., BUIA M.C. (2005) – Chronicle of a Death Foretold - Features of a *Posidonia Oceanica* Bed Impacted by Sand Extraction. In: "MEDCOAST '05 - Proceedings of the Seventh International Conference on the Mediterranean Coastal Environment", Özhan E. (ed.), 25-29 October 2005, Kusadasi, Turkey: 441-450.

GHIRARDELLI E. (1981) – La vita nelle acque. UTET, Torino: 609 pp.

GOLDBERG W.M. (1988) - Biological effects of beach nourishment in south Florida: the good, the bad, and the ugly. In: "Proceedings of Beach Preservation Technology", 1988. Tallahassee: Florida Shore and Beach Preservation Association.

GRAY J.S., CLARKE K.R., WARWICK R.M., HOBBS G. (1990) – Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea. *Marine Ecology Progress Series*, **66**: 285-299.

GREEN K. (2002) - Beach nourishment: a review of the biological and physical impacts. ASMFC (Atlantic States Marine Fisheries Commission), Habitat Management Series, **7**: 174 pp.

GUIDETTI P., BUSSOTTI S. (1998) - Juveniles of littoral fish species in shallow seagrass beds: preliminary quali-quantitative data. *Biologia Marina Mediterranea*, **5**: 347-350.

GUIDETTI P., FABIANO M. (2000) – The use of lepidochronology to assess the impact of terrigenous discharge on the primary leaf production of the Mediterranean seagrass *Posidonia oceanica*. *Marine Pollution Bulletin,* **40** (5): 449-453.

HAMMER R.M., BALCOM B.J., CRUICKSHANK M.J., MORGAN C.L. (1993) - Synthesis and Analysis of Existing Information Regarding Environmental Effects of Marine Mining. Final Report by Continental Shelf Associates, Inc. for the U.S. Department of the Interior, Minerals Management Service, Office of International Activities and Marine Minerals, Herndon, VA, OCS Study MMS 93-0006: 392 pp.

HARDAWAY C.S. Jr., MILLIGAN D.A., THOMAS G.R., HOBBS C.H. (1998) – Environmental studies relative to potential sand mining in the vicinity of the City of Virginia Beach, Virginia. Part 2: Preliminary shoreline adjustments to dame Neck Beach nourishment project southeast Virginia coast – Final Report: MMS Cooperative Agreement 14-35-0001-30807 trough Virginia Institute of Marine Science of the College of William & Mary: 82 pp.

HARVEY M., GAUTHIER D., MUNRO J. (1998) – Temporal Changes in the Composition and Abundance of the Macro-benthic Invertebrate Communities at Dredged Material Disposal Sites in the Anse à Beaufils, Baie des Chaleurs, Eastern Canada. *Marine Pollution Bulletin*, **36** (1): 41-55.

HAY B.J., HONJO S., KEMPE S., ITTEKKOT V.A., DEGENS E.T., KONUK T., IZDAR E. (1990) - Interannual particle flux in the southwestern Black Sea. *Deep Sea Research,* **37**: 911-928.

HERBICH J.B. (1990) - Handbook of Coastal and Ocean Engineering. Vol. **1**: Wave Phenomena and Coastal Structures. Gulf Publishing Company, Houston: 1200 pp.

HERBICH J.B. (1992a) - Handbook of Coastal and Ocean Engineering. Vol. **3**: Harbours, Navigation Channels, Estuaries and Environmental Effects. Gulf Publishing Company, Houston: 864 pp.

HERBICH J.B. (1992b) - Handbook of Dredging Engineering. McGraw-Hill, New York: 600 pp.

HERBICH J.B. (2000) - Handbook of Dredging Engineering. Second Edition McGraw-Hill, New York: 992 pp.

HILL A.S., VEALE L.O., PENNINGTON D., WHYTE S.G., BRAND A.R., HARTNOLL R.G. (1999) - Changes in Irish Sea benthos: possible effects of 40 years of dredging. *Estuarine, Coastal and Shelf Science*, **48**: 739-750.

HITCHCOCK D.R., BELL S. (2004) – Physical impacts of marine aggregate dredging on seabed resources in coastal deposits. *Journal of Coastal Research*, **20** (1): 101-114.

HITCHCOCK D.R., DRUCKER B.R. (1996) – Investigation of benthic and surface plumes associated with marine aggregates mining in the United Kingdom. In: "The Global Ocean towards

Operational Oceanography", Proceedings of the Oceanology International Conference, ISBN 0-900254-12-2: 221-234.

HITCHCOCK D.R., NEWELL R.C., SEIDERER L.J. (1999) - Investigation of benthic and surface plumes associated with marine aggregate mining in the United Kingdom. Final Report. Contract Report for the U.S. Department of the Interior, Minerals Management Service. Contract Number 14-35-0001-30763. Coastline Surveys Ltd Ref. 98-555-03 (Final): 168 pp.

ICES (1992) - Report of the ICES Working Group on the effects of extraction of marine sediments on fisheries. ICES co-operative research report n. **182**. ICES, Copenhagen, Denmark: 78 pp.

ICES (1996) – Report of the working group on the effects of extraction of marine sediments on the marine ecosystems. ICES CM 1996/E:7 MEQC, Stromness, Scotland, 23-26 April 1996: 111 pp.

ICES (2000) - Report of the working group on the effects of extraction of marine sediments on the marine ecosystems, Gdansk, Poland: 172 pp.

ICES (2001) – Effects of extraction of marine sediments on the marine ecosystem. Cooperative research report n. **247**: 80 pp.

ICES (2003) – Working group on the Effects of extraction of marine sediments on the marine ecosystem. ICES CM 2003/E:07, Ostend, Belgium, 1-5 April 2003: 104 pp.

ICRAM (2001) - Studio pilota per l'impatto ambientale connesso allo sfruttamento di depositi sabbiosi sommersi ai fini di ripascimento: il caso Anzio (Roma). Relazione Finale Terza Campagna Monitoraggio - Fase III/t. Rapporto Tecnico per la Regione Lazio: 83 pp.

ICRAM (2002) - Studio per l'impatto ambientale connesso allo sfruttamento di depositi sabbiosi sommersi lungo la piattaforma continentale laziale ai fini di ripascimento: Fase A - Caratterizzazione della piattaforma continentale laziale (Sintesi dei dati di letteratura scientifica e tecnica esistenti). Rapporto Tecnico per la Regione Lazio: 140 pp.

ICRAM (2004) - Studio per l'impatto ambientale connesso allo sfruttamento di depositi sabbiosi sommersi ai fini di ripascimento lungo la piattaforma continentale laziale: area di Tor Vaianica. Fase C1 – Caratterizzazione del sito C2. Rapporto Tecnico per la Regione Lazio: 87 pp.

ICRAM (2005a) - Studio in corso d'opera e monitoraggio per l'impatto ambientale connesso allo sfruttamento del deposito sabbioso sommerso ai fini di ripascimento, Cava A2 – Montalto di Castro. Fase C3 - Monitoraggio. Rapporto Tecnico per la Regione Lazio: 97 pp.

ICRAM (2005b) - Studio per l'impatto ambientale connesso allo sfruttamento di depositi sabbiosi sommersi ai fini di ripascimento lungo la piattaforma continentale laziale: Sito Anzio (AZ). Fasi di Monitoraggio (C3): luglio 2003, settembre 2003 e aprile 2004. Rapporto Tecnico per la Regione Lazio: 240 pp.

ICRAM (2005c) - Programma pluriennale di monitoraggio dell'area a mare da cui sono state prelevate sabbie utilizzate per il ripascimento delle spiagge emiliano-romagnole. Fase di Monitoraggio (Anno III) - Rapporto Tecnico per l'ARPA Emilia Romagna: 122 pp.

ICRAM (2006) - Studio per l'impatto ambientale connesso allo sfruttamento di depositi sabbiosi sommersi ai fini di ripascimento lungo la piattaforma continentale laziale: Cava A2 - Montalto di Castro - Fase C1 - caratterizzazione del sito (Settembre 2005). Rapporto Tecnico per la Regione Lazio: 51pp.

JEUDY DE GRISSAC A., BOUDOURESQUE C.F. (1985) - Rôles des herbiers de phanérogames marines dans les mouvements des sédiments côtiers: les herbiers à *Posidonia oceanica*. In: "Les aménagements côtiers et la gestion du littoral", Ceccaldi H.J., Champalbert G. (eds.), Coll. Pluridisciplinaire franco-Japonais océanographie: 143-151.

KENNY A.J., REES H.L. (1994) – The effects of marine gravel extraction on the macrobenthos: early post-dredging recolonization. *Marine Pollution Bulletin*, **28**: 442-447.

KENNY A.J., REES H.L. (1996) - The effects of marine gravel extraction on the macrobenthos: results of 2 years post-dredging. *Marine Pollution Bulletin*, **32**: 615-622.

KENNY A.J., REES H.L., GREENING J., CAMPBELL S. (1998) - The effects of marine gravel extraction on the macrobenthos at an experimental dredge site off North Norfolk, U.K. (results 3 years post-dredging). ICES, Theme Session on Recovery and Protection of Marine Habitats and Ecosystems from Natural and Anthropogenic Impacts, report N. CM 1998/V, 14: 1-8.

KIM E.H., MASON R.P., PORTER E.T., SOULEN H.L. (2004) - The effect of resuspension on the fate of total mercury and methyl mercury in a shallow estuarine ecosystem: a mesocosm study. *Marine Chemistry*, **86**: 121-131.

LEE G.F., JONES R.A. (1992) - Water quality aspects of dredging and dredged sediment disposal. In: "Handbook of Dredging Engineering", Herbich J.B. (ed.): 923-959.

LEONI L., SARTORI F., DAMIANI V., FERRETTI O., VIEL D. (1991) - Trace element distributions in superficial sediments of the Northern Tyrrhenian Sea: contribution to heavy-metal pollution assessment. *Environmental Geology Water Science*, **17**: 103-116.

LEONI L., SARTORI F., NICOLAI I. (1993) - Metalli pesanti nei sedimenti attuali della piattaforma costiera toscana. *Atti della Società Toscana di Scienze Naturali*, **CII**: 23-60.

LIN H.J., SHAO K.T. (2002) - The development of subtidal fouling assemblages on artificial structures in Keelung harbour, northern Taiwan. *Zoological Studies*, **41** (2): 170-182.

LOCARDI E., FUNICIELLO R., LOMBARDI G., PAROTTO M. (1976) - The main volcanic groups of Latium (Italy): relations between structural evolution and petrogenesis. In: “International Colloquium of Planetary Geology”, Roma, September 22-30, 1975. Proceedings. *Geologica Romana*, **15**: 279-300.

LOUIS BERGER GROUP Inc. (1999) - Use of federal offshore sand resources for beach and coastal restoration in New Jersey, Maryland, Delaware, and Virginia. Contract N. 1435-01-98-RC-30820. Department of the Interior, Minerals Management Service, Office of International Activities and Marine Minerals, Herndon, VA: 244 pp.

MAGGI C., BIANCHI J., DATTOLO M., MARIOTTI S., COZZOLINO A., GABELLINI M. (2006) - Fractionation studies and bioaccumulation of cadmium, mercury and lead in two harbour areas. *Chemical Speciation and Bioavailability*, **18** (3): 95-103.

MANZANERA M., PÉREZ M., ROMERO J. (1998) – Seagrass mortality due to oversedimentation: an experimental approach*. Journal of Coastal Conservation*, **4**: 67-70.

MARGOLUIS R., SALAFSKY N. (1998) - Measures of success: designing, managing and monitoring conservation and development projects. Island Press, Washington, D.C., USA: 382 pp.

MARZIALETTI S., GABELLINI M., LA PORTA B., LATTANZI L., LA VALLE P., PAGANELLI D., PANFILI M., TARGUSI M., NICOLETTI L. (2006) - Attività di dragaggio ai fini di ripascimento al largo di Montalto di Castro (VT): effetti sul popolamento a policheti. *Biologia Marina Mediterranea*, **13** (1): 601-605.

MAURER D., KECK R.T., TINSMAN J.C., LEATHEM W.A. (1981a) – Vertical migration and mortality of benthos in dredged material. I. Mollusca. *Marine Environmental Research*, **4**: 299-319.

MAURER D., KECK R.T., TINSMAN J.C., LEATHEM W.A. (1981b) – Vertical migration and mortality of benthos in dredged material. II. Crustacea. *Marine Environmental Research*, **5**: 301-317.

MAURER D., KECK R.T., TINSMAN J.C., LEATHEM W.A. (1982) – Vertical migration and mortality of benthos in dredged material. III. Crustacea. *Marine Environmental Research*, **6**: 49-68.

MAURER D., KECK R.T., TINSMAN J.C., LEATHEM W.A., WETHE C.A., LORD C., CHURH T.M. (1986) – Vertical migration and mortality of benthos in dredged material: a synthesis. *International Revue der gesamten Hydrobiologie*, **71**(1): 49-63.

MAZZELLA L., SCIPIONE M.C., BUIA M.C. (1989) - Spatio-temporal distribution of algal and animal communities in a *Posidonia oceanica* (L.) Delile meadow. *P.S.Z.N.I. Marine Ecolology*, **10**: 107-131.

McCAULEY S.E., PARR R.A., HANCOCK D.R. (1977) – Benthic infauna and maintenance dredging: a case study. *Water Research,* **11**: 133-242.

MMS (2001) - Development and design of biological and physical monitoring protocols to evaluate the long-term impacts of offshore dredging operations on the marine environment. U.S. Department of the Interior Minerals Management Service. Final Report. OCS Study, MMS 2001-89: 116 pp.

MORRISON M.L. (2002) - Wildlife restoration: techniques for habitat analysis and animal monitoring. Island Press Washington, USA: 209 pp.

MORTON B. (1996) – The subsidiary impacts of dredging (and trawling) on a subtidal benthic molluscan community in the southern waters of Hong Kong. *Marine Pollution Bulletin*, **32** (10): 701-710.

NELSON W.G., COLLINS G.W. (1987) - Effects of Beach Nourishment on the benthic macrofauna and fishes of the nearshore zone of Sebastian inlet state recreation area. Unpublished report to Jacksonville District, U.S. Army Corps of Engineers from the Department of Oceanology and Ocean Engineering, Florida Institute of Technology.

NELSON D.A., DICKERSON D.D. (1988) - Hardness of nourished and natural sea turtle nesting beaches on the East Coast of Florida. USACE Waterways Experiment Station Vicksburg, Mississippi: 27 pp.

NEWELL R.C., HITCHCOCK D.R., SEIDERER L.J. (1999) – Organic enrichment associated with outwash from marine aggregates dredging: a probable explanation for surface sheens and enhanced benthic production in the vicinity of dredging operations. *Marine Pollution Bulletin*, **38** (9): 809-818.

NEWELL R.C., SEIDERER L.J., HITCHCOCK D.R. (1998) - The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. *Oceanography and Marine Biology: an Annual Review,* **36**: 127-178.

NEWELL R.C., SEIDERER L.J., SIMPSON N.M., ROBINSON J.E. (2004) – Impacts of marine aggregate dredging on benthic macrofauna off the South coast of the United Kingdom. *Journal of Coastal Research*, **20** (1): 115-125.

NICCOLAI I., FERRETTI O., MANFREDI FRATTARELLI F.M. (1993) - Distribuzione degli elementi traccia nei sedimenti superficiali tra l'Isola d'Elba e l'Argentario. In: "Arcipelago Toscano, Studio oceanografico, sedimentologico, geochimico e biologico", Enea Area Energia Ambiente e Salute, S. Teresa (La Spezia): 185-195.

NICOLETTI L., LA VALLE P., CHIMENZ GUSSO C. (2004b) – Specie indicatrici: il caso *Corbula gibba* (Olivi, 1792). *Biologia Marina Mediterranea,* **11** (2): 273-277.

NICOLETTI L., BELLUSCIO A., LA VALLE P., ARDIZZONE G.D. (2005) – Monitoring of *Posidonia Oceanica* Meadow after Beach Nourishment. In: "MEDCOAST '05 - Proceedings of the Seventh International Conference on the Mediterranean Coastal Environment", Özhan E. (ed.), 25-29 October 2005, Kusadasi, Turkey: 451-460.

NICOLETTI L., LA VALLE P., PAGANELLI D., GABELLINI M. (2002) - Il ripascimento mediante sabbie relitte: studi di compatibilità ambientale nell'esperienza laziale. Atti del congresso "Processi erosivi delle coste. Fenomeni di sedimentazione e trasporto: prevenzione e risanamento". Vieste, 30 novembre 2002: 48-53.

NICOLETTI L., LA VALLE P., PAGANELLI D., GABELLINI M. (2004a) – Environmental impact study of marine sand extraction for beach nourishment. IGCP-464 "Continental Shelves during Last Glacial Cycle" 4th Annual Conference, 28 August - 3 September 2004 Rome and Ponza Island: 67-68.

NICOLETTI L., FANELLI E., LATTANZI L., LA VALLE P., GABELLINI M., CHIMENZ GUSSO C. (2003) - Contribution to the knowledge of coastal detritic bottoms off Anzio (central Tyrrhenian sea). *Biologia Marina Mediterranea,* **10** (2): 589-592.

NONNIS O., NICOLETTI L., LA VALLE P., CELIA MAGNO M., GABELLINI M. (2002) - Environmental impact after sand extraction for beach nourishment in an area off Latium coast (Tyrrhenian sea, Italy). Littoral 2002, The changing coast. EUROCOAST/EUCC, Porto – Portugal, EUROCOAST – Portugal (Ed.), **3**: 81-84.

NORDEN-ANDERSEN O.G., NIELSEN P.E., LETH J. (1992) – Effects on sea bed, benthic fauna and hydrography of sand dredging in Koge Bay, Denmark. In: "Proceedings of the 12th Baltic Marine Biologists Symposium", Helsingor, Denmark 25-30 August 1991: 1-6.

OAKWOOD ENVIRONMENTAL Ltd. (1998) - Strategic cumulative effects of marine aggregates dredging (SCEMAD). U.S. DOI. Final report to the Minerals Management Service, Washington, D.C., under contract N. 1435-01-98-CT-30894.

OCCHIPINTI AMBROGI A., FORNI G. (2003) – Gli indici biotici. In: "Manuale di metodologie di campionamento e studio del benthos marino mediterraneo", Gambi M.C. e Dappiano M. (eds.), *Biologia Marina Mediterranea*, **10** (suppl): 577-604.

OMOE (ONTARIO MINISTRY OF ENVIRONMENT) (1994) - Evaluating Construction Activities Impacting on Water Resources. PART III B, Handbook for Dredging and Dredged Material Disposal in Ontario - Dredging Transport and Monitoring. Queen's Printer for Ontario: 26 pp.

OTT J. (1980) - Growth and production in *Posidonia oceanica* (L.) Delile. *P.S.Z.N.I. Marine Ecology,* Germ., **1**: 47-64.

PAGANELLI D., LA VALLE P., MAGGI C., NICOLETTI L., NONNIS O., GABELLINI M. (2005) – Il ripascimento della spiaggia di Roma (Ostia): Studio di compatibilità ambientale per lo sfruttamento dei depositi sabbiosi sommersi. Atti dei Convegni Lincei "Ecosistema Roma", Roma 14-16 Aprile 2004, Bardi Editore, **218**: 359-365.

PEIRANO A., BIANCHI C.N. (1995) - Decline of the seagrass *Posidonia oceanica* in response to environmental disturbance: a simulation-like approach off Liguria (NW Mediterranean Sea). In: "Proceedings of the 30th E.M.B.S.", Southampton, UK, September 1995: 87-95.

PELLEGRINI D., ONORATI F., VIRNO LAMBERTI C., MERICO G., GABELLINI M., AUSILI A. (2002) - Aspetti tecnico-scientifici per la salvaguardia ambientale nelle attività di movimentazione dei fondali marini. Dragaggi Portuali. Quaderno ICRAM n. **1**: 201 pp.

PÉRÈS J.M., PICARD J. (1964) – Nouveau manuel de bionomie bénthique de la Mer Méditerranée. *Recueil des Travaux de la Station Marine d'Endoume*, **31**: 5-137.

PERGENT G. (1991) - Les indicateurs écologiques de la qualité du milieu marin en Méditerranée. *Océanis,* **17** (4): 341-350.

PERGENT G., PERGENT-MARTINI C., BOUDOURESQUE C.F. (1995) – Utilisation de l'herbier à *Posidonia oceanica* comme indicateur biologique de la qualité du milieu littoral en Méditerranée: état des connaissances. *Mésogée*, **54**: 3-29.

POINER I.R., KENNEDY R. (1984) – Complex patterns of change in the macrobenthos of a large sandbank following dredging. *Marine Biology*, **78**: 335-352.

PORCHER M. (1984) - Impact des mouillages forains sur les herbier a *Posidonia oceanica*. In: "International Workshop on *Posidonia oceanica* Beds", Boudouresque C.F., Jeudy de Grissac A., Olivier J. (eds.), GIS Posidonie publ., Fr., **1**: 63-72.

PRETI M. (1985) - Ricerca di depositi sabbiosi sul fondo del mare Adriatico da utilizzare per il ripascimento delle spiagge in erosione. IDROSER, Bologna: 176 pp.

PRETI M. (1990) - Ricerca di depositi sabbiosi sul fondo del mare Adriatico da utilizzare per il ripascimento delle spiagge in erosione, 2ª campagna. IDROSER, Bologna: 115 pp.

PRETI M. (2002) - Ripascimento di spiagge con sabbie sottomarine in Emilia-Romagna. *Studi costieri,* **5**: 107-134.

PRETI M., ALBERTAZZI C. (2003) - Complex Sand Nourishment in Emilia-Romagna Region. In: "MEDCOAST '03 - Proceedings of the Sixth International Conference on the Mediterranean Coastal Environment", Özhan E. (ed.), 7-11 October 2003, Ravenna, Italy: 1639-1648.

PUIG P., PALANQUES A., SANCHEZ-CABEZA J.A., MASQUÈ P. (1999) – Heavy metals in particulate matter and sediments in the southern Barcelona sedimentation system (North-Western Mediterranean). *Marine Chemistry*, **63**: 311-329.

PULCINI M., NICOLETTI L., LA VALLE P., PAGANELLI D., GABELLINI M. (2002) – Il GIS applicato ad un'analisi di compatibilità ambientale per lo sfruttamento di depositi sabbiosi sommersi lungo la piattaforma continentale laziale ai fini di ripascimento. *Atti 6° conferenza A.S.I.T.A.*, Perugia, novembre 2002, **2**: 1179-1183.

RAKOCINSKI C.F., HEARD R.W., LECROY S.E., McLELLAND J.A., SIMONS T. (1996) - Responses by macrobenthic assemblages to extensive beach restoration at Perdido Key, Florida, USA. *Journal of Coastal Research,* **12** (1): 326- 353.

REES H.L., DARE P.J. (1993) – Sources of mortality and associated life-cycle traits of selected benthic species: a review. Ministry of Agriculture, Fisheries and Food Directorate of Fisheries Research. Fisheries Research Data Report, n. **83,** Lowestoft, 1993: 36 pp.

ROBERTS R.D., GREGORY M.R., FOSTER B.A. (1998) – Developing an efficient macrofauna monitoring index from an impact study – a dredge spoil example. *Marine Pollution Bulletin*, **36** (3): 231-235.

RUIZ J.M., ROMERO J. (2003) – Effects of disturbances caused by coastal constructions on spatial structure, growth dynamics and photosynthesis of the seagrass *Posidonia oceanica*. *Marine Pollution Bulletin*, **46**: 1523-1533.

RUIZ J.M., MARIN A., CALVO J.F., RAMIREZ-DIAZ L. (1993) – Interactions between floodway and coastal constructions in Aguilas Bay (southeastern Spain). *Ocean and Coastal Management*, **19**: 241-262.

SALEN-PICARD C., BELLAN G., BELLAN-SANTINI D., ARLAHAC D., MARQUET R. (1997) – Changements à long terme dans une communauté benthique d'un golfe méditerranéen (golfe de Fos). *Oceanologica Acta*, **20** (1): 299-310.

SANDPIT (2005) – Sand transport and morphology of offshore sand mining pits. Process knowledge and guidelines for coastal management. van Rijn L.C., Soulsby R.L., Hoekstra P., Davies A.G. (eds.). EC Framework V Project No. EVK3-2001-00056: 816 pp.

SARDÀ R., PINEDO S., GREMARE A., TABOADA S. (2000) – Changes in the dynamic of shallow-bottom assemblages due to sand extraction in the Catalan Western Mediterranean Sea. *ICES Journal of Marine Science*, **57**: 1446-1453.

SCHUBEL J.R., CARTER H.H., WILSON R.E., WISE W.W., HEATON M.G., GROSS M.G. (1978) - Field investigations of the nature, degree, and extent of turbidity generated by open-water pipeline disposal operations. Technical Report D-78-30. Marine Sciences Research Centre, State University of New York, Stony Brook, NY: 245 pp.

SCIPIONE M.B. (1989) – Comportamento trofico dei Crostacei Anfipodi in alcuni sistemi bentonici costieri. *Oebalia*, **XV**-1NS: 249-260.

SCIPIONE M.B., FRESI E. (1984) - Distribution of amphipod crustaceans in *Posidonia oceanica* (L.) Delile foliar stratum. In: "International Workshop on *Posidonia oceanica* Beds", Boudouresque C.F., Jeudy de Grissac A., Olivier J. (eds.), GIS Posidonie publ., Fr., **1**: 319-329.

SEIDERER L.J., NEWELL R.C. (1999) – Analysis of the relationship between sediment composition and benthic community structure in coastal deposits: implications for marine aggregate dredging. *ICES Journal of Marine Science*, **56**: 757-765.

SNYDER G.R. (1976) - Effects of dredging on aquatic organisms with special application to areas adjacent to the northeastern Pacific Ocean. *Marine Fisheries Review*, **38**: 34-38.

STICKENEY R.R., PERLMUTTER D. (1975) – Impact of intracoastal maintenance dredging on a mud-bottom benthos community. *Biological Conservation*, **7**: 211-225.

TAYLOR P.D., WILSON M. A. (2003) - Paleoecology and evolution of marine hard substrate communities. *Earth-Science Reviews*, **62**: 1-103.

TOUMAZIS A.D. (1995) – Environmental impact associated with the dumping of dredged material at sea. A study for the limassol port extension works. *Water Science and Technology*, **32** (9-10): 151-158.

TUNESI L., BOUDOURESQUE C.F. (2006) – Les causes de la régression des herbiers à *Posidonia oceanica*. In: "Préservation et conservation des herbiers à *Posidonia oceanica*". Ramoge publ: 32-47.

TURNER S.J., TODD C.D. (1991) – The effects of *Gibbula cineraria* (L.), *Nucella lapillus* (L.) and *Asterias rubens* L. on developing epifaunal assemblages. *Journal of Experimental Marine Biology and Ecology*, **154**: 191-213.

VAN DALFSEN J.A., ESSINK K., TOXVIG MADSEN H., BIRKLUND J., ROMERO J., MANZANERA M. (2000) – Differential response of macrozoobenthos to marine sand extraction in the North Sea and the Western Mediterranean. *ICES Journal of Marine Science*, **57**: 1439-1445.

VAN DER VEER H.W., BERGMAN M.J.N., BEUKEMA J.J. (1985) – Dredging activities in the Dutch Wadden Sea: effects on macrobenthic infauna. *Netherlands Journal of Sea Research*, **19**: 183-190.

VAN DOLAH R.F., CALDER D.R., KNOTT D.M. (1984) – Effects of dredging and open-water disposal on benthic macroinvertebrates in a South Carolina Estuary. *Estuaries*, **7** (1): 28-37.

VAN MOORSEL G.W.N.M. (1993) - Long-term recovery of geomorphology and population development of large molluscs after gravel extraction at the Klaverbank (North Sea). Bureau Waardenburg bv, Culemborg, The Netherlands: 5-54.

VAN MOORSEL G.W.N.M. (1994) - The Klaverbank (North Sea), geomorphology, macrobenthic ecology and the effect of gravel extraction. Bureau Waardenburg bv. Culemborg. The Netherlands: 65 pp.

VAN MOORSEL G.W.N.M., WAARDENBURG H.W. (1990) - Impact of gravel extraction on geomorphology and the macrobenthic community of the Klaverbank (North Sea) in 1989. Bureau Waardenburg bv. Culemborg. The Netherlands.

VAN MOORSEL G.W.N.M, WAARDENBURG H.W. (1991) - Short-term recovery of geomorphology and macrobenthos of the Klaverbank (North Sea) after gravel extraction. Bureau Waardenburg bv. Culemborg. The Netherlands: 26 pp.

WHITESIDE P.G.D., OOMS K., POSTMA G.M. (1995) – Generation and decay of sediment plumes from sand dredging overflow. In: "Proceedings of the 14^{th} World Dredging Congress", **14**: 877-892.

WILBER P., STERN M. (1992) - A re-examination of infaunal studies that accompany beach nourishment projects. In: "New directions in beach management". Proceedings of the 5th annual national conference on beach preservation technology, Tait L. (ed.), St. Petersburg, Florida, February 12-14, 1992: 242-257.

WILBER D.H., CLARKE D.G., RAY G.L., BURLAS M. (2003) – Response of surf zone fish to beach nourishment operations on the northern coast of New Jersey, USA. *Marine Ecology Progress Series*, **250**: 231-246.

WILHERE G.F. (2002) - Adaptive management in habitat conservation plans. *Conservation Biology*, **16** (1): 20-29.

WRIGHT S. (1977) - Evolution and the genetics of populations. Vol. 3 - Experimental results and evolutionary deductions. University of Chicago Press, Chicago: 614 pp.

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