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Chapter 1

SEDIMENT MONITORING TO ASSESS THE ENVIRONMENTAL EFFECT OF RELICT SAND DREDGING FOR BEACH NOURISHMENT

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ABSTRACT

Beach nourishment with relict sands has been carried out for several years as a way to counter coastal erosion. Relict sands generally ensure the availability of large volumes of sediment (millions of m^3) with very similar composition to recent beaches; the use of great volumes of this material is also economically advantageous. However, relict sand dredging may have significant physical and biological effects on the marine environment, especially in highly biodiverse environments with a lot of sensitive habitats, such as the Mediterranean marine-coastal system. In these cases, specific studies are essential to assess if dredging activities can be considered environmental sustainable and the impact on marine environment negligible. Within this framework, ISPRA has carried out

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different characterization and monitoring studies related to relict sand dredging in order to assess its environmental sustainability and its impact on the marine environment. In particular, this chapter focuses on the results of the grain-size monitoring studies carried out in two dredged relict sand deposits located in the central Tyrrhenian Sea (Torvaianica and Anzio deposits). For each dredging site environmental investigations were carried out before and after the dredging activities. In both cases the results obtained reveal that observed trends are dependant on the station position and grain size changes were mainly recorded in the area directly affected by the dredging.

INTRODUCTION

The coastal environment is a dynamic system in which natural and human processes combine and interact, modifying geomorphological, physical and biological features, and in which beaches represent the most vulnerable areas. In recent decades, Italy’s coasts have undergone a noteworthy geomorphologic evolution, with most of the coastal erosion being of human origin. Over the years, numerous initiatives have been taken locally to mitigate erosion processes and to protect buildings and infrastructures (ISPRA, 2009).

In most cases, coastal defence structures have been built (as seawall, groynes, breakwaters etc.), with the goal of interfering with the shoreline dynamics underway, so as to favor sedimentation or limit the destructive force of storm surges along the coast. An alternative technique able to provide an excellent response to coastal erosion, in both environmental and economic aspects, is beach nourishment: eroded beaches are replenished by filling them with suitable sediments (in terms of both grain size and composition). For this reasons, beach nourishment has been carried out for several years as a way to counter coastal erosion. It has proven to be a successful beach protection method and currently it is considered to be one of the main tools for coastal management.

It’s well known that sediments used for beach nourishment can have different origins, coming for instance from riverbeds, quarries, coastal environments or relict sand deposits. Relict sands are non-diagenized sedimentary deposits situated at variable depths along the continental shelf (Swift, 1976). Such deposits are generally attributable to ancient beaches (paleobeaches), whose formation is traced back to the sea-level lowstand of the last glaciation or to the following sea-level rise of the Holocene (Chiocci and La Monica, 2003).

These deposits may outcrop from the seabottom or be covered by a pelitic layer of recent deposition. Their use for beach nourishment shows a number of advantages: the availability a large quantities of sediment (millions of m^3) that are similar to the current beach sediments, limited effect of dredging on the environment and moderate cost for major works.

The first dredging activities for beach nourishment date back to the first decades of the past century when submerged sands were dredged for the nourishment of Coney Island beach (NY) which took place in 1922-1923 (Dornhelm, 1995). However, such practice experienced significant developments only in the last 3 decades, spreading out in particular in Northern Europe (Holland, Belgium, Denmark, Germany etc.) and in the US. In Italy the first dredging of relict sand was carried out in 1994 for the replenishment of the Cavallino and Pellestrina beaches (Venice) (Cecconi and Ardone, 1999).

In the same period, mineral investigations were performed along wide sector of the Italian continental shelf, whose aim was to search relict sand deposits to be used for beach nourishment. Data obtained showed that the whole stretch studied contains various sedimentary deposits of minerary interest nourishment-suitable both in the central Tyrrhenian sea (Chiocci and La Monica, 1996; 1999; BEACHMED, 2003) and in the Adriatic sea (Preti, 1985; 1990; Correggiari et al., 2002, 2003). From 2003 to 2008 relict sand dredging operations have involved about 14.7 millions of m^3 of sandy sediments (ISPRA, 2009) coming from some deposits located along the continental shelf both in the Adriatic Sea (9.1 million m^3) and in the Tyrrhenian Sea (5.6 million m^3).

In the Mediterranean Sea, in general, the removal of relict sand doesn't interfere with coastal dynamics because of their position and depth. However, relict sand dredging may have significant physical and biological effects on the marine environment, especially in highly biodiverse environments and in sensitive habitats, such as the Mediterranean marine-coastal system. The main physical effects suffered by the marine environment are related to the bathymetric, morphological and sedimentological changes in the seabottom. Furthermore the seabed handling can lead the sediment suspension which may cause alteration of the chemical-physical characteristics of the water column (Gajewski and Uscinowicz, 1993; Hitchcock et al., 1999; Hitchcock and Bell, 2004; Barbanti et al., 2005); in addition, pre-existing bottom disturbances, such as extensive dredging, may amplify sediment re-suspension phenomena.

The most relevant biological effects are instead related to the benthic communities and to the demersal fish populations, both associated with the sea bottom (Desprez, 2000; ICES, 2000; Boyd, Rees, 2003; La Porta et al. 2009).

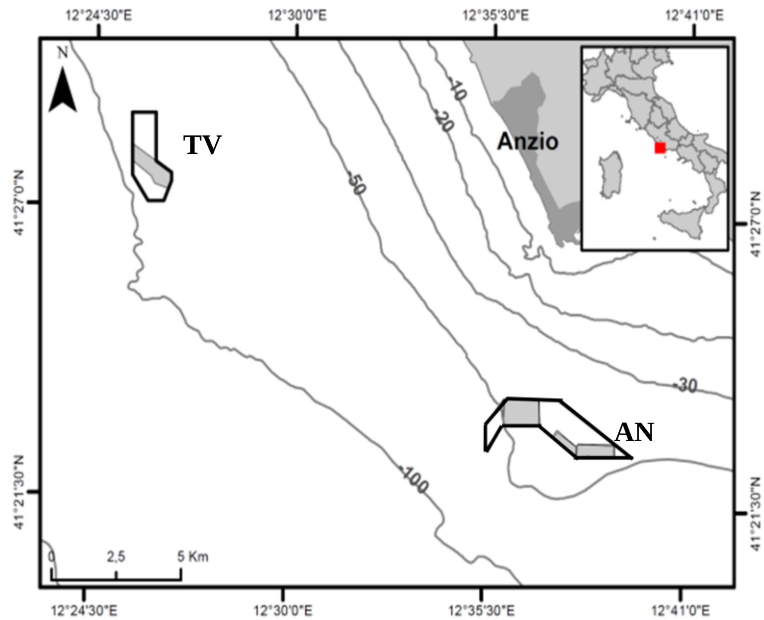
Within this framework the Regione Lazio local authority has promoted research projects to identify and characterize the relict sand deposits suitable for beach nourishment that are present along the Latium continental shelf (central Tyrrhenian sea), entrusting ISPRA to evaluate the environmental sustainability of dredging and its potential effects on marine environment. The environmental characterization and monitoring studies, conducted by ISPRA, encompassed direct and indirect investigations, such as seafloor morphology and bathymetry, surface sediments grain-size and chemistry, water column chemical-physical characteristics and particulate matter, and studies on the benthic and demersal fish communities.

In this chapter we present the result of grain-size investigations carried out before and after the dredging in order to identify the features and extensions of the actually-impacted areas due to excavation in two relict sand deposits located in the central Tyrrhenian Sea (named Torvaianica and Anzio deposits).

THE STUDY AREAS

The study areas are situated in the Latium continental shelf (Central Tyrrhenian Sea, Figure 1), that locally is characterized by high pelitic sedimentation with fine sediments present also at shallow depths, whereas some undernourished areas show a predominance of coarse sediments due to the presence of fluvial or coastal paleo-deposits outcropping on the seabed (ICRAM, 2002).

In the Torvaianica area, the seabed is characterized by a regular bathymetry, parallel to the coastline, with a gradual seaward increase of the fine fraction. The seabed regularity is locally interrupted by rocky outcrops, at the base of which sandy-gravelly biogenic sediment is present. In particular, historical data (Nonnis et al., 2014) show a uniform sediment distribution, with progressive grain size decrease seaward. Until 20 m depth, sand is always the prevailing fraction. Between 30 and 40 m depth we found sediments with highly variable composition (sand, silty sand, sandy silt, loam and clay), that are typical of transition zone between the sandy submerged beach and the continental shelf muds. Starting from 50 m depth, in the continental shelf environment the fine fraction is predominant; clayey silt characterizes the sea bottom between 50 and 70 m depth, while silty clay was observed starting from 80 m depth.



Authorized dredging site, dredged area.

Figure 1. The study areas of Torvaianica (TV) and Anzio (AN).

Locally clayey sands, attributable to the outcrop of the relict sand deposit, have been detected at 90 m depth, in the southern sector.

In the Anzio area morphology becomes more irregular, due to the presence, in the southern sector, of a rocky shoal. In this area the isobaths are generally oriented NW-SE and their depths vary between 40 and 70 m. In proximity to the shoal, depth decreases and the isobath’s orientation changes according to the shoal’s shape. The shoal is about 1600 m long and it houses a meadow of *Podisonia oceanica* (Chiocci et al., 2001).

In the area hosting the deposit, sedimentation appears rather heterogeneous; moving from north to south, the sediments first presented significant percentages of silt and clay, then they showed mixed granulometry (loam) and, in the southernmost sector, they were decidedly sandy, containing a significant biodetritic component associated with the rocky shoal. Sediment distribution appears to be strongly influenced by local geomorphological characteristics (De Pippo et al., 2004, Nonnis et al., 2011) and the rocky shoal played a key role in the distribution of coarse surface sediment.

The presence of biogenic substrates also seems to be able to provide a significant contribution to coarse sedimentation, even in the most distal sector, where the distribution of the sediments was compared with the distribution of benthic biocoenoses (Agnesi et al., 2012). In addition, the presence of transgressive deposits, such as relict sands, under a pelitic layer of variable thickness, can produce a more irregular distribution of the surface sediments; the recent fine sediment may contain significant percentages of the underlying sandy sediments (mixed sediments), thereby resulting in a significant alteration of the normal textural zonation.

THE DREDGING SITES

The Torvaianica relict sand deposit is one of the largest sand deposits identified on the Latium continental shelf; it has been recognised below the recent muddy sediments and interpreted as paleo-beach ridges (Chiocci and La Monica, 1999). It is characterized by a muddy layer thickness of about 1 m, a great vertical and lateral heterogeneity and a variable grain size from fine sand to gravel. Within this deposit, for the purpose of the dredging's authorization, an area of about 3km^2 has been identified. Before the dredging, the muddy layer overlying the deposit was removed and placed in a specific dumping site, previously identified (ICRAM, 2007). Sand dredging was then carried out in May 2006 with a trailer dredge, involving only a part of the authorized area; dredged sector was equal to approximately 1 km^2. The sediment extracted (1.429.000 m^3) was used for the nourishment of some beaches of southern Lazio coasts (ISPRA, 2009). The Anzio deposit was interpreted as a sedimentary wedge of sandy nature, deposited during the first phases of the sea level rise in protected-sedimentation area and later covered by fine sediment related to the shelf sedimentation process. The area potentially suitable for dredging was shaped as an irregular polygon and was situated about 1500 m from a rocky shoal. The deposit was dredged in the three different and contiguous sites (AN, AZ and AS) using trailer dredges. Specific information about the dredging activities is shown in Table 1. During the 1999 dredging, the authorized area within site AN was dredged only partially, as the most intense dredging activities were carried out southeast of the authorized area (Figure 3). Further superficial dredging activities were carried out near the AN site and 1 km northwest of the authorized site, in proximity to AS site (dredged in 2007). In sites AZ and AS, instead, the operations respected the authorized boundaries.

Table 1. Dredging activities in the Anzio deposit

Sites	Size (km^2)	Volume (m^3)	Dredging Time
AN	0.365	950.000	June - October 1999
AZ	0.590	2.039.265	April - March 2003
AS	1.244	1.658.000	February - May 2007

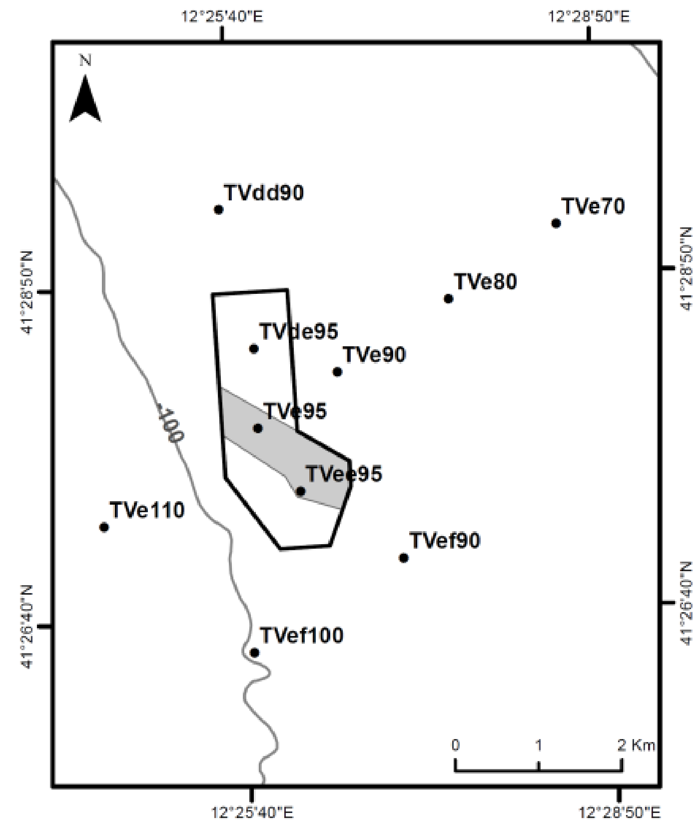
MATERIALS AND METHODS

Survey Strategy

In both studied areas, due to the lack of historical data and to the early phase of the geological surveys (the dredging sites had not yet been identified when environmental studies were started), the first environmental characterization surveys were carried out in wide areas housing the sand deposits. In the studied areas, sediment samples were collected along inshore-offshore transects (Torvaianica area) or according to a random sampling design (Anzio area). In the Torvaianica area, following the identification of the dredging site, specific surveys were carried out before and after the dredging activities (table 2). Sediment sampling was conducted using a box-corer in 10 stations, located at a depth between 70 and 110m, for a total of 40 samples analyzed; three of the selected stations were coincident with those already investigated for the wide area.In the dredging site, the sample design initially considered 3 stations inside and 7 stations outside of it according to Nicoletti et al. (2006). However, since the area actually dredged (approx 1 km^2) was smaller than that authorised, only 2 of the inner stations were actually subjected to dredging (Figure 2).

Table 2. Dredging and surveys activities in the TV site

Site	Activities	Sediment code	Sediment station	Time
TV wide area	Characterization	A	50	03/2003
TV dredging site	Characterization	B	10	04/2006
	Dredging			*05/2006*
	Monitoring	C	10	10/2006
	Monitoring	D	10	04/2007
	Monitoring	E	10	09/2007



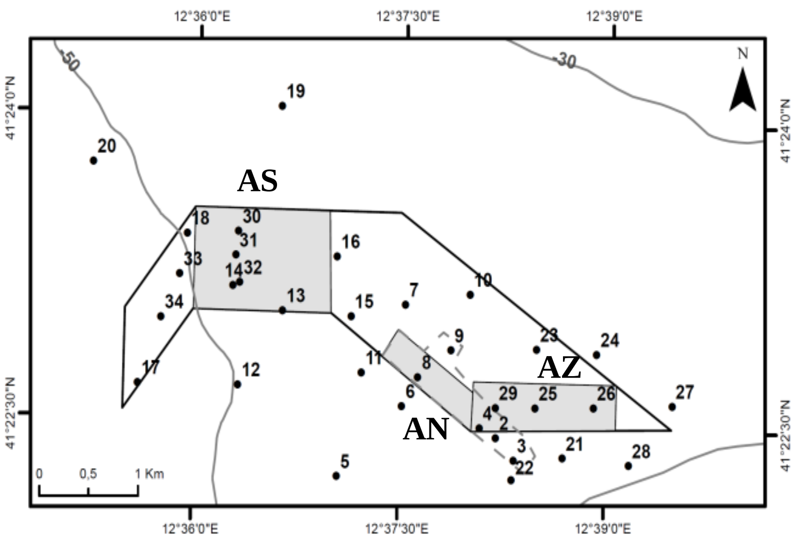
• Sampling point, —— authorized dredging site, ▭ dredged area.

Figure 2. The study area of Torvaianica (TV).

In the Anzio area the first environmental characterization survey (1999) was carried out on the whole polygonal area, which is much wider than the area authorized for the first dredging (AN site).

For sites AZ and AS, the environmental characterization surveys were instead limited to the actual dredging corridors. For each site, the monitoring surveys were carried out before, during and after the dredging activities. In the Anzio site twelve surveys were performed for the characterization and monitoring of surface sediments.

The sampling was conducted at a depth between 40 and 60m using a box-corer (Figure 3); the number of stations for each survey is shown in table 3; in total about 180 samples were analyzed.



• station, —— authorized dredging site, ▭ dredged areas (AN, AZ, AS), ⌐ ¬ most intense dredged area in 1999.

Figure 3. The study area of Anzio.

Table 3. Dredging and surveys activities in the AN, AZ, AS sites

Site	Activities	Sediment code	Sediment station	Time
Anzio wide area	Characterization	A	21	04/1999
AN	*Dredging*			*06-10/1999*
	Monitoring	B	9	03/2000
	Monitoring	C	14	11/2000
	Monitoring	D	22	04/2001
	Monitoring	E	16	07/2001
	Monitoring	F	16	01/2002
AZ	Characterization	D		04/2001
	Dredging			*03-04/2003*
	Monitoring	G	12	07/2003
	Monitoring	H	12	09/2003
	Monitoring	I	12	04/2004
	Monitoring	L	21	11/2006
AS	Characterization	L		11/2006
	Dredging			*02-05/2007*
	Monitoring	M	13	09/2007
	Monitoring	N	13	02/2008

GRAIN SIZE ANALYSIS

In the laboratory, each sediment sample was treated twice with a hydrogen peroxide (30%) and distilled water solution in proportion 1:3 for 24–48 hours at room temperature, and then washed twice with natural water. Then, samples were wet-separated into two grain size fractions (>63 μm and b63 μm) which were heat-dried and finally weighed.

In each phase, the coarser fraction (>63 μm) was dry-sieved by means of ASTM series sieves with meshes ranging from−1 to+4ϕ, and intervals of 0.5 ϕ. The weight of the whole coarse fraction was calculated through the sum of weights of the fractions retained by each sieve (Celia Magno et al., 2012). The fine fraction (<63 micron) was analysed with sedigraph (Anzio deposit and phases B and E of Torvaianica deposit) and with laser granulometer (phases C and D of Torvaianica deposit). For sedigraph analysis, the fraction <63 μm, oven dried at 40 °C, was split into sub-samples and put in suspension in a solution of distilled water and sodium hexametaphosphate (0.05%) at the rate of 2.5 g of sample for 80 ml of solution, subjected to bath of ultrasounds for 2 minutes and then analysed by means of a X-ray sedigraph (Micromeritics Sedigraph 5100®). For laser granulometer analysis, the fine fraction was oven dried at 40 °C, quartered and put in suspension in a solution of distilled water and sodium hexametaphosphate (0,05%), at a rate of 0,5 g of sample for 80 ml of solution. An amount comprised between 10 and 15 ml was extracted with a pipette from the solution, and then analysed through laser granulometer (Sympatec Helos). Prior to the analysis, the solution was subjected to ultrasounds for 10 seconds. For each sample the percentages of gravel, sand, silt and clay were recorded; the limits of sediment fractions according to Wentworth (Wentworth, 1922) were considered and sediment types were determined according to the classification of Shepard (Shepard, 1954); statistic parameter was also calculated (Folk and Ward, 1957).

DISCUSSION

Torvaianica Deposit

The TV area (dredged in 2006) before dredging (phase A) presented homogeneous sediments characterized by the prevalence of fine fraction (silty clay); in particular, between 70 and 110 m depth we observed a gradual increase of clayey fraction. Locally clayey sands, attributable to the outcrop of the relict sand deposit, have been detected at 90 m depth, in the southern sector.

Five months after dredging (phase B), externally to the dredged area, the results indicate the presence of sediments mainly classified as clayey silt (Figure 4). Within the dredged area, sediments show unimodal distributions, with significant contents of coarse fractions (TVe95: 95% sand; TVee95: 18% gravel and 54% sand) (Figure 5).

Eleven months after dredging (phase C), externally to the dredged area, sediments classifiable as clayey silt and silty clay are recorded, whereas inside the area the sediments still show significant contents of coarse fractions (TVe95: 90% sand; TVee95: 11% gravel, 53% sand).

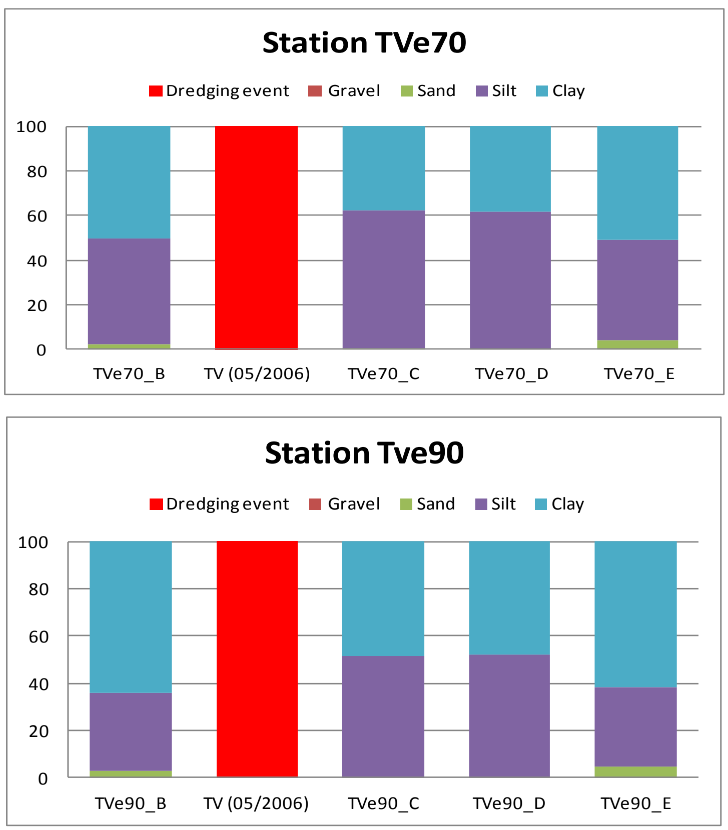


Figure 4. TV site: external to dredged area. The results indicate the presence of fine sediments, which remain reasonably undisturbed by dredging.

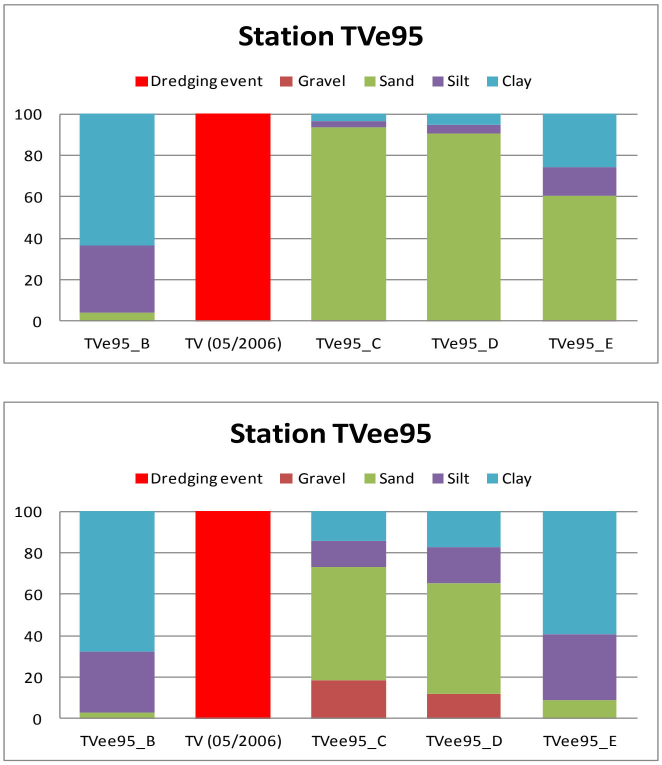


Figure 5. TV site: more intensely dredged area. As early as five months after dredging, sediments show unimodal distributions, with significant contents of coarse fractions (samples TVe95C and TVee95C).

The monitoring carried out sixteen months after dredging (phase D) confirms for the external samples grain size distributions very similar to those existing before the dredging. Inside the dredged area, the sediment sampled in the TVe95 station, although having a unimodal distribution, is characterized by a sandy percentage of only 60% (clayey sand), while sediment sampled in TVee95 station has coarse fractions less than 10% (silty clay).

In general, the data related to the four phases of the investigation (B, C, D and E) show a significant change in grain size for the inner stations of the dredged area (TVe95 and TVee95). In fact, before the dredging, seabed sediments were homogeneous, mainly characterised by silty and clayey fractions (sand fraction lower than 5%).

In the same stations, after the dredging (phases C and D), sandy and gravelly-sandy sediments were detected; this marked change was caused by the removal of the muddy layer and by subsequent outcrop of the underlying sands.

However, 11 months after dredging, in the internal stations, sediments with a substantial increase of the fine fraction were recorded (Figure 5). This phenomenon is similar to that observed in the Anzio deposit, where it was interpreted as a partially recovery of the shelf's sedimentation processes (Nonnis et al., 2011). A filling of fine sediment can be also ascribable to the collapsing of the cavity's wall as effect of small-scale instability phenomena of the disturbed sediment (Desprez, 2000).

On the opposite, the stations situated around the dredged site did not present any substantial grain size variations, as evidenced by the comparison of phases B and E. As reported in the "materials and methods", while the coarse fraction was analysed using the same analytical techiniques for each phases, the fine fraction was detected by sedygraph (B and E phases) and by laser granulometer (C and D phases).

The different techniques used for the fine fraction analyses showed differences in the subdivision of silty and clay fractions. Therefore, the effects of the dredging were assessed focusing the attention principally on the variations occurred in the coarse fraction (always analysed by sieving).

Some considerations were made by examining the results obtained in the samples collected outside the dredged area, not influenced by dredging.

So, comparing data obtained by sedigraph and by laser granulometer, we observed that the different methods affect the classification of sediments, moving the resulting class towards a higher clay or silt content.

In fact, we obtained mainly silty clay class in case of samples analysed by sedigraph, and clayey silt class, in case of samples analysed by granulometer (Figure 6). Moreover, the use of different analytical methodologies is also highlighted by the different values of the statistical parameters: mean, median and sorting show higher values in the samples analysed by sedigraph (Figure 7). Only Skewness and Kurtosis do not show any influences related to the different analytical method.

The differences between sedigraph and laser granulometer results can be explained taking into account that the first is able to detect more particles in grain-size extreme intervals (De Falco et al., 1999), namely for diameters higher than 5 phi or lower or equal to 11 phi.

In contrast, the laser granulometer detects more particles in grain-size range between 5 and 10.5 phi.

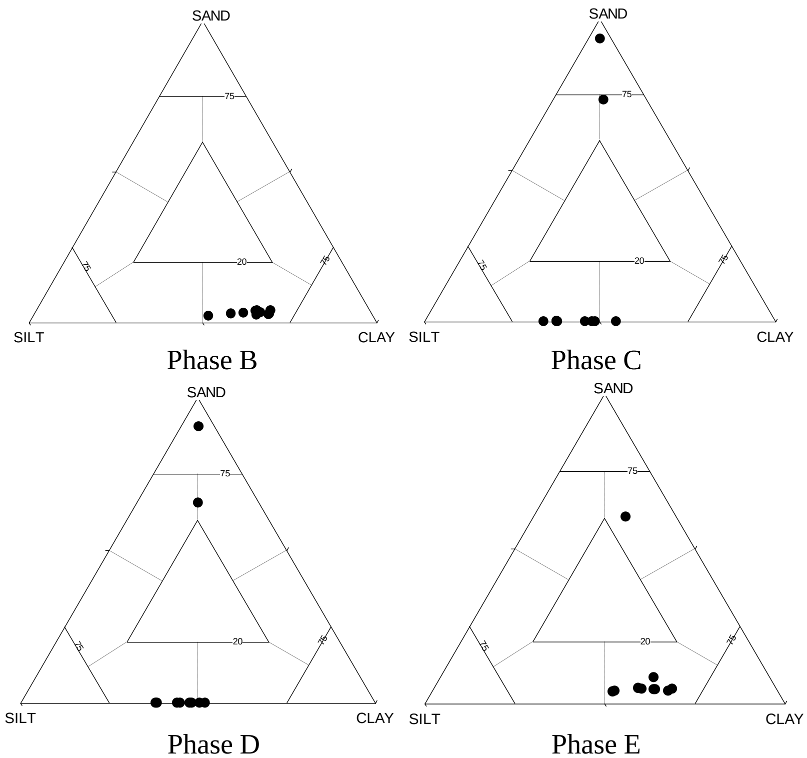
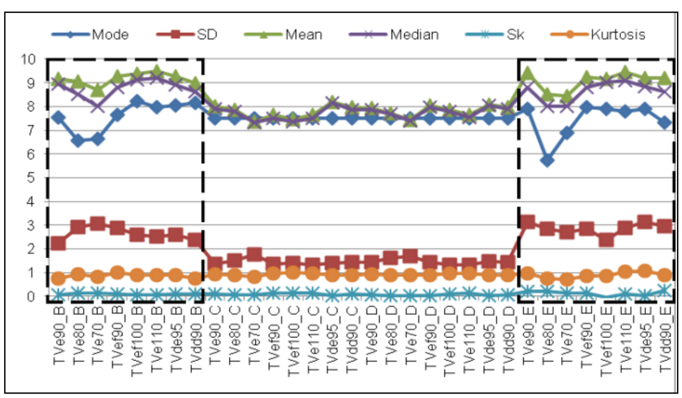


Figure 6. Sample distributions on Shepard diagram related to different monitoring survey and to different techniques used for the fine fraction analyses.



– – samples analysed by sedigraph.

Figure 7. Main statistical parameters behavior in all monitoring phases of the dredging site.

Anzio Deposit

The relict sand deposit was dredged in three different and contiguous sites (AN, AZ and AS).

In AN site (dredged in 1999), the pre-dredging analyses showed, moving from north to south, sediments with significant percentages of silt and clay, mixed sediment (loam) and, in the southernmost sector, sandy sediment, containing a significant biodetritic component.

Starting from the fourth month after dredging, within the more intensely dredged area (stations 2 and 3), sediments were found to be generally pelitic (fine fraction >95%) (Figure 8). More generally, among all the samples analyzed, only two had significant and variable percentages of sand (30% and 90%).

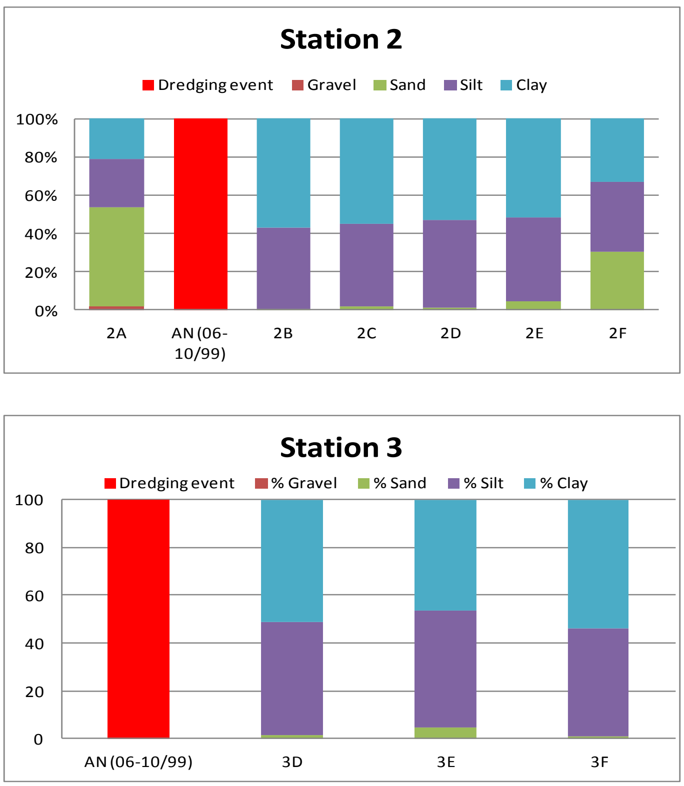
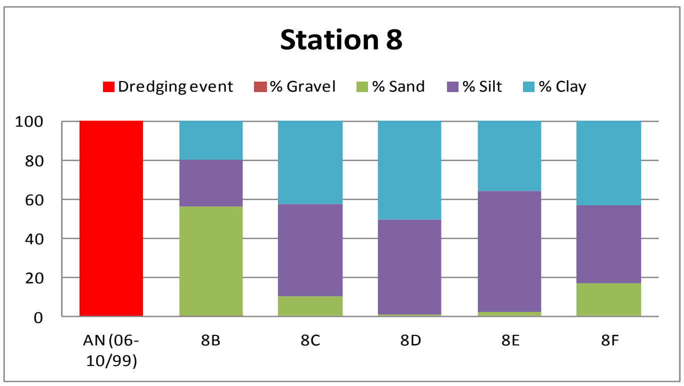


Figure 8. AN site: more intensely dredged area. Until 2 years after dredging (samples 2B and 3D) sediments were generally pelitic (fine fraction >95%).

These results could be ascribed to the technical methods used, involving a deep-digging dredging head that reached the sandy layer and emptied out the deeper sandy sectors, thus causing the collapse of the overlying pelitic levels. Slumping of the walls may also have occurred and this may have been intensified by the significant depth of the holes caused by intensive dredging. It is well-known that the technical-operational methods are among the main parameters used to define the intensity and characteristics of dredging-linked disturbances (Nicoletti et al., 2006). Concerning the more superficially dredged sectors (stations 8, 9, 13), surveys carried out four months after dredging revealed the presence of sediments with a 40–50% of sand in stations 8 and 9 and percentages higher than 90% in station 13 (Figure 9).



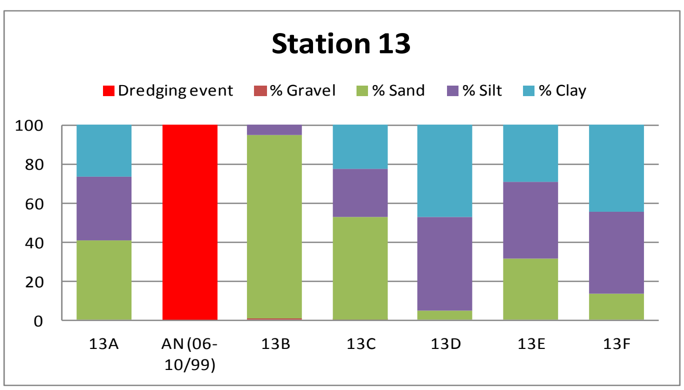


Figure 9. AN site: superficially dredged area. Four months after dredging, sediments with a 40–50 sand percentage (sample 8B) and percentages higher than 90% (sample 13B) were observed.

In all three stations a considerable increase in the fine fraction (40%) was recorded 9 months after dredging.

In the stations close to the dredged areas, and in those placed at a certain distance, 9 months after dredging the granulometric characteristics of the sediments were considerably heterogeneous and showed no significant trends.

In various stations, however, it was observed a decrease in the pelitic fraction.

Finally, in the control stations (stations 1 and 5), the sediment samples collected after dredging showed substantially unaltered distributions in station 1 (Figure 10), and a non-negligible increase in the pelitic fraction (12÷19%) in station 5 (Figure 11).

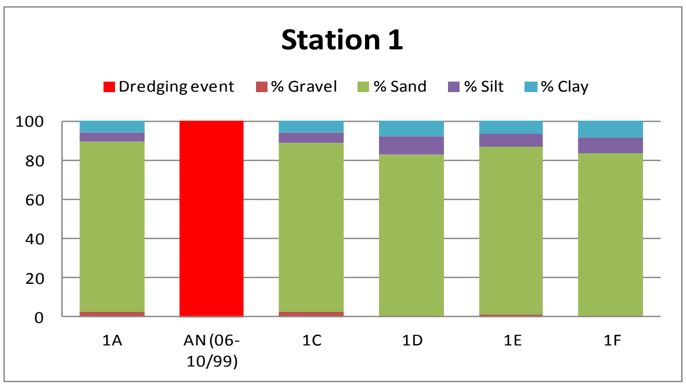


Figure 10. Site AN. In control station 1, sediments showed a substantially unaltered distributions.

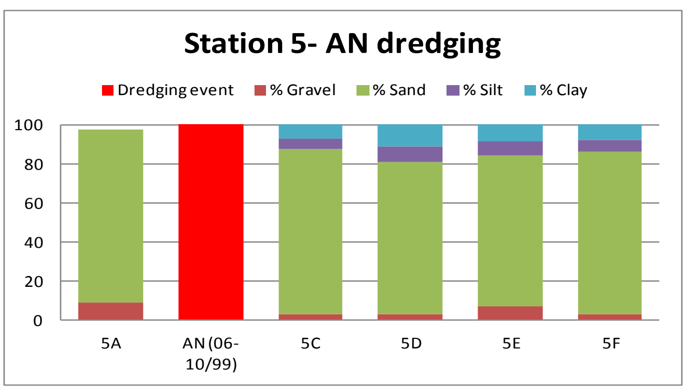


Figure 11. Site AN. In control station 5, sediments showed a non-negligible increase in the pelitic fraction.

In AZ site (dredged in 2003 and adjacent to AN site), the surveys carried out before dredging indicated the presence of loam and silty-clayey sediments in the easternmost portion of the area (not involved in 1999 dredging) and of heterogeneous sediments of variable grain sizes – ranging from silty clay to clayey silt and sand – in the western part of the investigated area, which partially corresponds to the zone dredged in 1999.

Four months after dredging, the stations situated within the dredged area (25, 26 and 29) contained very high percentages of sand (always >95%) (Figure 12). Modest quantities of fine fraction (ca. 10%) were sometimes observed 6 months after dredging. This increase of fine fraction can be ascribed to the shelf's sedimentation process; after 6 months from the end of the dredging activities, this process's contribution to sediment characterization was fully restored and significantly active.

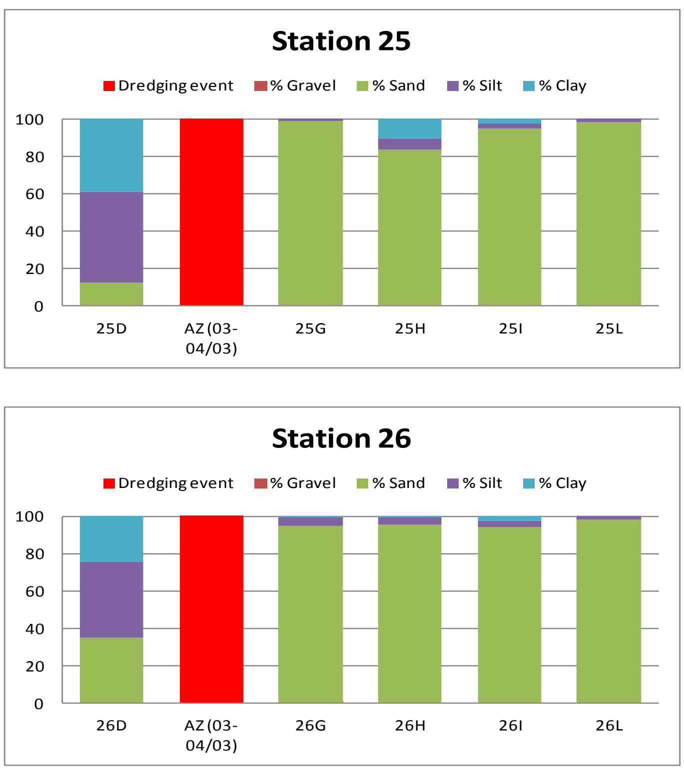
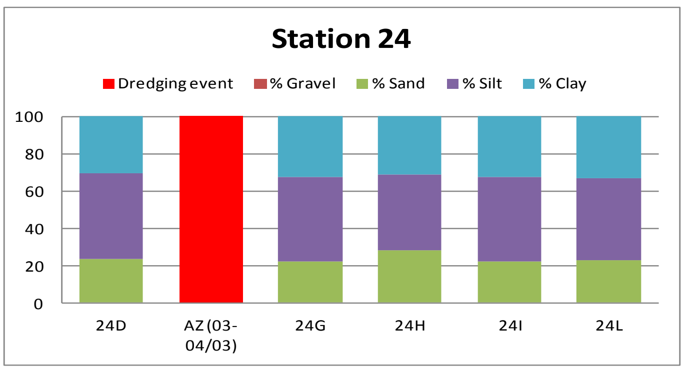


Figure 12. AZ site: inside the dredged area. Four months after dredging, high sand percentages were found (see stations 25G and 26G). Modest quantities of fine fraction were observed 6 months after dredging (see sample 25H).

In the stations located in the northern (23 and 24) (Figure 13), eastern (27) and southern (21) sections of the dredged area (not affected by the 1999 dredging), sediments did not show any substantial granulometric variations. In station 28, situated southeast of the dredged area (and also not affected by the 1999 dredging), sediments initially showed an increase in sandy fraction (ca. 15% after 4 months) and, subsequently, an increase in the fine fractions (ca. 10% after 6 months) (Figure 13). In station 2, which also underwent heavy dredging in 1999, an important increase in the sandy fraction (ca. 40%) was observed following the 2003 dredging operations.

Different results were recorded in stations 8 and 9, yet superficially dredged in 1999: station 8 did not show any significant granulometric variations, while station 9 presented an important increase in the sandy fraction, equal to ca. 50-60%.



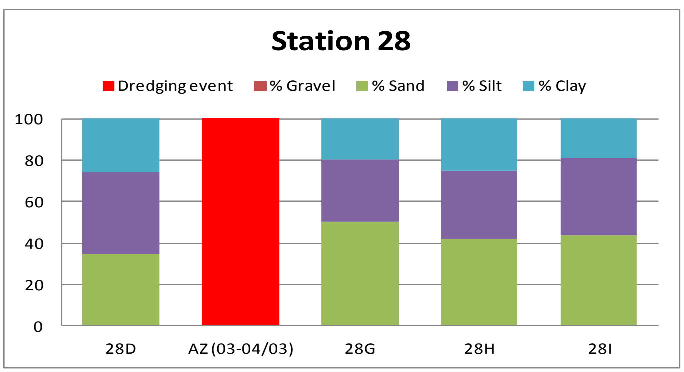


Figure 13. AZ site: outside the dredged area. Sediments showed no substantial changes (station 24). In station 28 sediments initially showed an increase in sandy fraction (sample 28G) and subsequently, an increase in the fine fractions.

As far as the control station (station 5) is concerned, the granulometric distributions after dredging showed a further increase in the pelitic fraction, with peaks of 19–24% (a less significant increase in the pelitic fraction had already been observed in this station after the 1999 dredging, see figure 14).

The AS site (dredged in 2007), before dredging presented mixed sediments (loam), showing a characteristic bimodal distribution. Moving landwards, these sediments turned pelitic (clay silt), while moving seawards and towards the shoals, a transition toward coarse sediments (clay sands) could be observed.

A common characteristic of all samples was a prevailing bioclastic composition in the sandy fraction, probably ascribable to the breakdown of the bioconstructions associated with the rocky shoal. In the internal stations of the dredged area (30, 31 and 32), the sediments found four months after dredging were decidedly sandy, and their fine fraction was lower than 5%; the fine fraction percentage increased to about 10% in the samples collected ca. 9 months after dredging (Figure 15). This increase can be related to the shelf sedimentation phenomena, as already recorded in the AZ site.

On the opposite, the stations situated around the dredged site did not present any substantial granulometric variations after removal (Figure 16, station 12). Station 18, however, situated in close proximity to the westernmost border of the authorized area, showed a 20% increase in its sandy fraction (Figure 16).

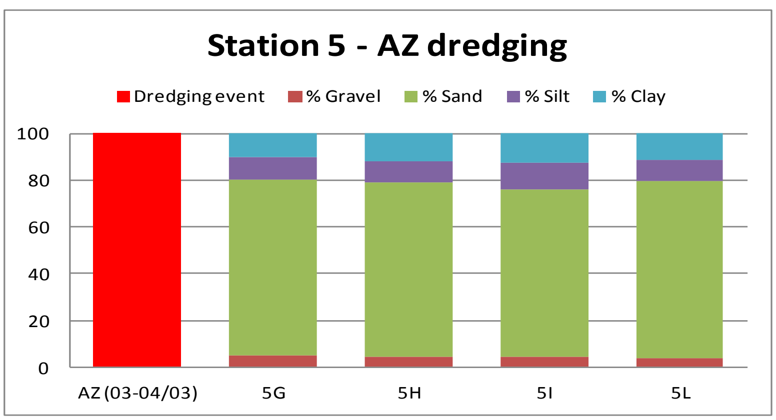
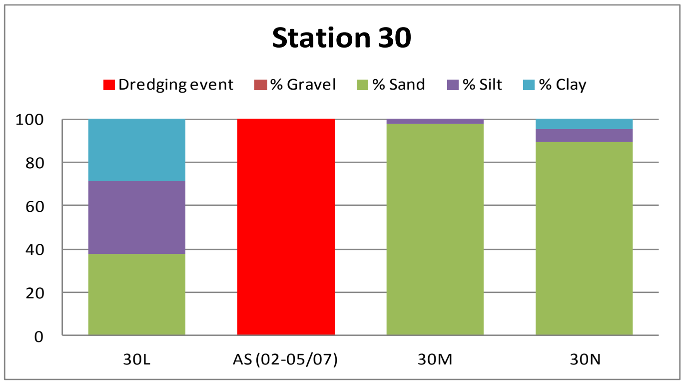


Figure 14. AZ site: control station. A further increase in the pelitic fraction was recorded (see sample 5F in figure 10).



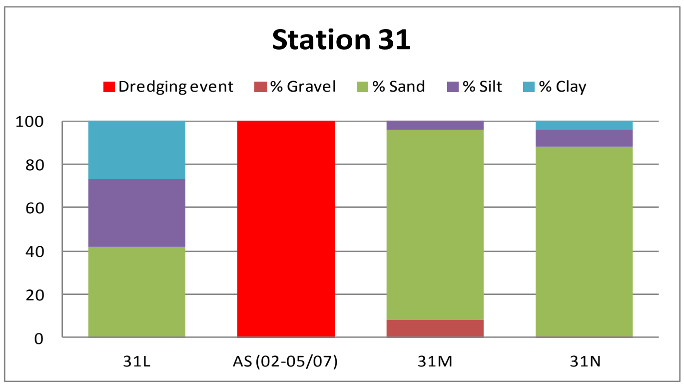
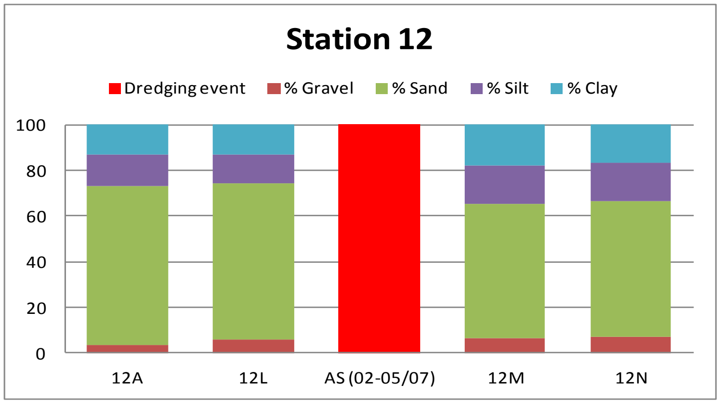


Figure 15. AS site: inside the dredged area. High percentages of sand were found (see stations 30 and 31).

The variations recorded in station 18 can be ascribed to the light dredging activities carried out on a small sector, west of the authorized area. This is clearly shown by the results of the multibeam surveys, which reveal that in this area the bottom is much more articulated than in the surrounding, undisturbed areas (Nonnis et al., 2011).

Another notable result observed outside of the dredged area is related to station 12, presenting a 20% increase in fine fraction.

This station is also characterized by relevant and characteristic variations in the benthic assemblages (ICRAM, 2008). The sediment's hydration characteristics, recorded hastily during sampling, do not seem to support a clear involvement of the station in the re-deposition of the sediment removed during dredging.



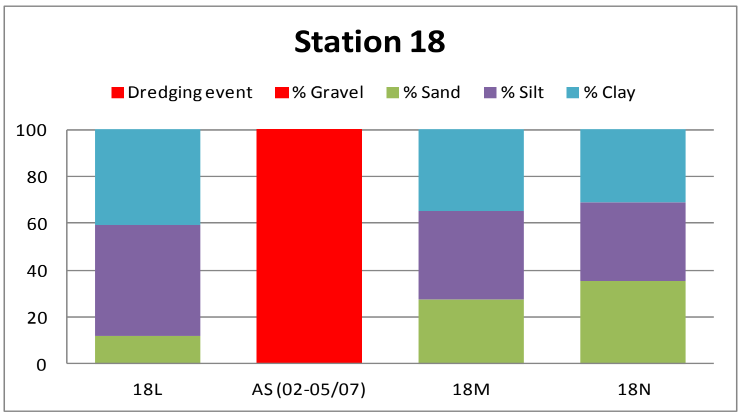


Figure 16. AS site: around the dredged site. An increase both of fine fraction sediment (see station 18) and of sandy fractions (see station 12) were found.

CONCLUSION

The environmental monitoring carried out in the Torvaianica and Anzio relict sand deposits allowed to evaluate the effects on surface sediments as a result of seabed dredging.

The two sites have been subjected to dredging for the exploitation of a relict sand deposit for nourishment; in particular three different dredging phases were performed in the Anzio site, while only a single dredging activity took place in the Torvaianica site.

In both cases, as far as the dredged areas are concerned, a clear surface sediment grain-size variation was observed inside the site just after the dredging, mainly due to the relict sands outcropping.

In general, in all dredged stations a non-negligible increase in the pelitic sedimentation was recorded as soon as few months after dredging. This could be ascribed to both the re-deposition of the turbidity cloud generated by these activities, and the shelf's pelitic sedimentation. But seabed instability can reduce the grain-size changes, hence favouring a shorter recovery time of grain size distribution, as it seems to have happened especially in the Anzio deposit. In this case, due to the technical methods used, the collaps of the overlying pelitic levels may have occurred, thus favouring the presence of fine sediments even immediately after the dredging. In fact, it is well known that one of the most important factors in determining intensity and characteristics of dredging-linked disturbances, in addition to site's characteristics (as surface sediment grain size), seems to be associated to the dredging operational methods (Hitchcock and Bell, 2004).

We could affirm that in the case of sandy deposits covered by fine sediments and dredged only once, the particle size analysis allows to differentiate areas dredged from those not dredged, as in the case of AS Anzio site and the site Torvaianica. It is also evident that in intensely dredged areas granulometric analyses alone did not always suffice to define the dredged area. In this case it can be useful to integrate the gran size investigation with geophysical analyses (sidescan sonar and multibeam echosounder) in order to better define the limits of the dredged area, and the entity of the dredging itself.

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