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BEACHMED-e
Regional Framework Operation

# Strategic management of beach protection for sustainable development of Mediterranean coastal zones

## 3rd Technical Report Phase C

may 2008

# BEACHMED-e
## Regional Framework Operation

Strategic management of beach protection measures for the soustainable development of Mediterranean coastal areas

3rd Phase "C" Technical Report

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## Preface

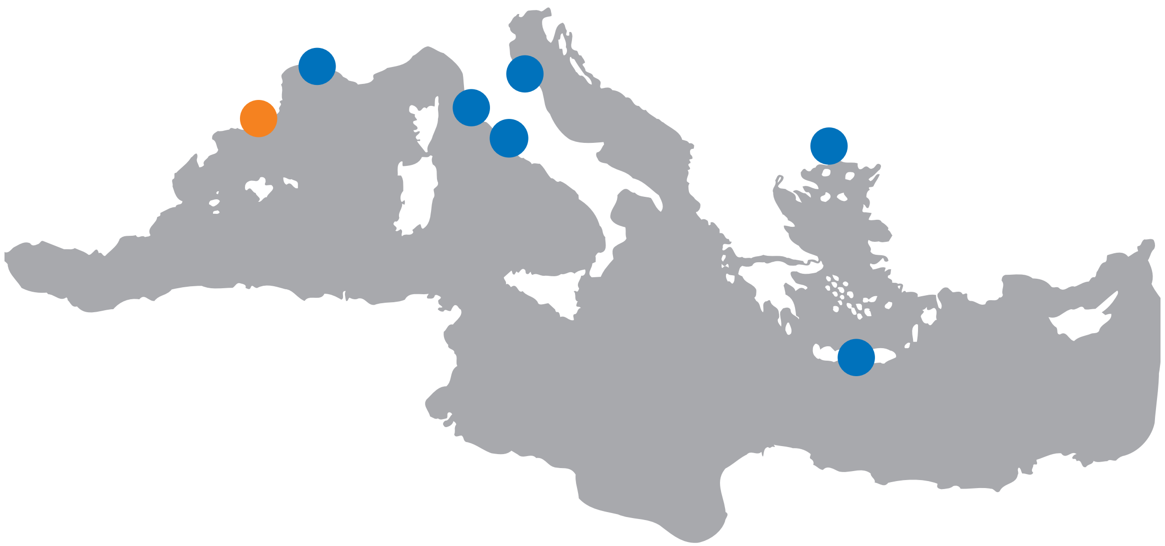
The third Technical Book for the BEACHMED-e Regional Framework Operation is the last task of Subproject Phase C. It summarizes all the methodologies and the results achieved by the carried out pilot projects and practical applications. The third book is a technical document compiled by 36 participants, including Universities, Research Organizations and European and Mediterranean Local
Authorities, clustered into nine transnational partner groups. Over and above the technical and scientific value of this project, must be pointed out the outstanding level of team work, which has been promoted and coordinated by European Regions, and carried out by a wide network of very qualified participants.
Nine Coastal and Mediterranean Administrations , from four different countries, have found themselves sharing many coastal erosion related problems and working together to overcome geographical, technological, regulatory and cultural obstacles. The BEACHMED-e Operation represents one of the most important European initiatives of its kind, also in relation with the substantial funding received (about 7,6 million euro). It has focused on specific areas which were high on the Lisbon and Gothenburg agendas (sustainable development, eco-innovation, risk mitigation, etc.). BEACHMED-e subproject deliverables, i.e. the development of methodological protocols, perfectly match the "best practices" philosophy at the heart of new projects planned for 2007-2013 which are based on a structured and cooperative regional approach.
The BEACHMED-e Operation has defined and implemented nine highly scientific sector specific studies whose wide range of practical results will be significant indefining future strategies from the regional to European level. The outcomes have included environment evaluation protocols, coastal planning and monitoring ,marine geology practices, etc..

As we have already had the opportunity to appreciate in the previous BEACHMED project (2002-20004, INTERREG IIIB – Medocc), practical results will be also useful for new research studies. This will surely happen, for example, about the new locations of marine sand deposits discovered by Beachmed-e activities and it's well known how these ones are indispensible and strategic for the sustainable coastal defense against climate change effects and erosion attack (EUROSION 2004). BEACHMED-e's structured approach has provided results as well in the search for regulatory measures which can upgrade existing legislation to match new requirements in the coastal zone protection sector and take advantage of new opportunities offered by modern technology.
Finally the "Bologna Charter", signed during the Beachmed-e work, deserves a specific mention as a very concrete result in Mediterranean coastal policy. In this document 9 Public and Mediterranean Administrations, seconded by "Arco Latino" organization as well, have clearly stated the political willing to implement cooperation amongst coastal Regions and Departments for new actions in the field of climate change adaptation and for the achievement of a Mediterranean Observatory on this matter.
The third Technical Book opens with a brief presentation of the BEACHMED-e Framework Operation and the involved partners.
Then it moves on to include short versions of the contributions from nine European groups on as many coastal management and defense related topics. The full versions of these documents can be found on the official web site of the Beachmed-e Operation (www.beachmed.eu) available in French and, partially, English and Italian.

*The Operation coordinator*
*Mr. Paolo Lupino*

# GESA

MANAGEMENT OF SAND DEPOSITS COLLECTED BY COASTAL AND RIVER INFRASTRUCTURE: RECOVERY OF SEDIMENT TRANSPORT



| Responsible of measure: Miriam Moyes Generalitat de Catalunya |
| --- |
| **3.3. Sedimentary Cycle: management of sand deposits collected by infrastructure along the coast and recovery of sediment transport flowing from riverbeds**<br><br>Estimate of affected volumes, options and methodologies for the reuse of partially contaminated material, management of deposits found in artificial reserves, protection of compatible soil, monitoring and control methods for the sedimentary cycle |

| RFO Partner | Budget |
| --- | --- |
| Generalitat de Catalunya | €232.000,00 |
| Regione Emilia-Romagna | €55.500,00 |
| Regione Toscana | €75.600,00 |
| Département de Hérault | €133.000,00 |
| East Macedonia-Thrace Region | €96.760,00 |
| Regione Lazio | €73.000,00 |
| Crete Region | €85.000,00 |
| TOTAL | €750.860,00 |

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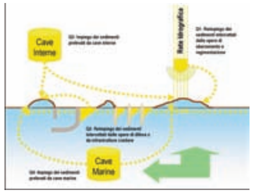


## MEASURE 3.3

### Sedimentary Cycle: Management of sand deposits collected by infrastructure along the coast and recovery of sediment transport flowing from riverbeds

*Harbour defense infrastructure (dams) act as barriers for longitudinal sedimentary movements intercepting sand that would otherwise be naturally moving along the coast. This effect is particularly noticeable in those areas where there is a predominant direction for these movements causing high levels of erosion as sand cannot get to its destination as it is intercepted and accumulates upstream. In order to improve sand deposit management it is necessary to evaluate the volumetric size of sand reserves along the coast, the sedimentary processes that are responsible for the deposits and the average annual exchange rate between contiguous sedimentary cells. These volumes can be estimated by assessing sedimentary thickness recorded by seismic surveys. Sedimentary Cycle analysis has to be extended to the river system, reaching the river mouths from which sand longitudinal movements originate. Sand drifts along the coastlines are a result of the sedimentary balance between river contribution and their distribution towards the areas that are farthest from the delta, activated by the coastline currents generated by wave movements. Several factors influence the quantity of sedimentary river contributions, which are of vital importance to the equilibrium of sedimentary balance along the coast. The coastline retreats or advances over time in proportion to the size of these contributions.*

*General Objectives*

- *Identify sand, sedimentary deposits and geographical units along the coast in order to effectively manage sand reserves along the coast using controlled beach nourishment processes.*
- *Quantify the volumes of sediments which can be retrieved from the sedimentary cycle and define the recovery timescales and implementation costs as well as best intervention methods.*

*Specific Objectives*

- *Collect basic information from existing studies concerning technology for the treatment of sedimentary material and management and implementation costs.*
- *Regional inventory and 2D1/2 model of coastal sedimentary prism with HR and THR seismic systems.*
- *Specific study of coastal sedimentary prism using THR seismic system.*
- *Methodology for the definition of areas of interest and quantification of existing volumes and volumes achievable on a yearly basis, of sand granulometry, chemistry, mineralogy, microbiology and toxicology.*
- *Methodology for the selection of areas needing beach nourishment, as per requirements, textural characteristics, color of deposits and cost-benefit analysis of intervention.*
- *Methodology for dredging and beach nourishment activities (analysis of best methods and feasibility study of innovative technology aimed at improving effectiveness).*
- *Guidelines for managers Illustrating the various beach nourishment activities (including along the coast beach nourishment).*
- *Creation of numeric models for along the coast beach nourishment activities at chosen sites.*
- *Assessment of possible impact connected to sand withdrawal from nearby coasts.*
- *Assessment of results, effect of methodologies used and volumes of sand movements, especially when the areas providing the sand and the areas requiring beach nourishment require the need for a port bypass.*
- *Circulation of results by involving the various parties involved (at various levels) and creation of an interface which is easy to use for the end user also enabling managers to take advantage of the models.*
- *Simulation of along the coast beach nourishment using a physical model.*
- *Implementation and monitoring of an along the coast pilot beach nourishment intervention at a natural site, including additional treatments chosen among those identified as "Best Demonstrable Available Technique".*
- *Estimate sedimentary volumes required for the recovery of the sedimentary cycle equilibrium.*
- *Study possible local short and medium term interventions (for example material entrainment, exploitation of deposits which have become unusable, interventions on existing barrage infrastructure etc..).*
- *Study of possible long-term interventions, which can be carried out across the whole system (for example interventions on morphology and or land use, implementation of hydrogeological plans etc.).*
- *Estimate quantity of recoverable sediments as a result of new interventions.*
- *Estimate timescales and costs for the partial recovery of sedimentary transport aimed at stabilizing the sedimentary cycle.*
- *Guidelines for the recovery and stabilization of the sedimentary cycle.*

## GESA Subproject

# Management of sand deposits collected by coastal and river infrastructure: Recovery of sediment transport

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Keywords: Dredging, Nourishment, Sedimentary dynamics, Littoral sandy deposit, River sandy deposit, Sedimentary cycle.

## Introduction

As part of the drive towards achieving integrated management of coastal zones the Gesa subproject has focused on sand deposits which have been intercepted by coastal and river infrastructure as well as the recovery of river sediment material. The Gesa subproject is part of "Measure 3.3" of the sedimentary cycle and it is therefore important to fully understand the variables and parameters which may cause changes to the sedimentary cycle. The Gesa subproject therefore aims to examine two sedimentary environments: a) Hydrographic basins (fluvial and dams) in order to understand how shoreline cells have responded to manmade, natural or climatic changes and b) Coastal zones, in order to understand what effect coastal infrastructures have on accumulation/erosion and the morphological evolution of the coastline (fig. 3.3.1). In order to fully understand the changes that affect the coastline it is important to take into account its geographical subdivision into coastal sedimentary cells. The Gesa subproject divided areas into cells according to specific variables and criteria, such as: i) Sand sources (such as rivers, tributaries, currents etc.) which bring sand to the shore, ii) Sand deposits (such as sand deposits intercepted by port infrastructures and deposits found in dams and river basins), iii) Longitudinal transport caused by coastal and transversal shifting and iv) nourishment of shoreline and dredged locations (fig. 3.3.1).
During phases A and B partners analysed current scenarios, specific problem areas for each pilot site and the research strategies published in the *Technical Logs* by Alonso *et al.* (2007). Phase C consists in establishing availability of sedimentary deposits, nourishment of shoreface and emerged beaches and dredging activities in sites where the presence of sand is undesirable. We also intend to supply information on any discoveries, equipment and suggestions that interested parties may wish to use as part of their integrated coastal zone management strategies. The following chapters contain a summary of criteria used in the Gesa subproject. More detailed information on survey results can be found in Gesa's complete report at the www.beachmed.eu website.

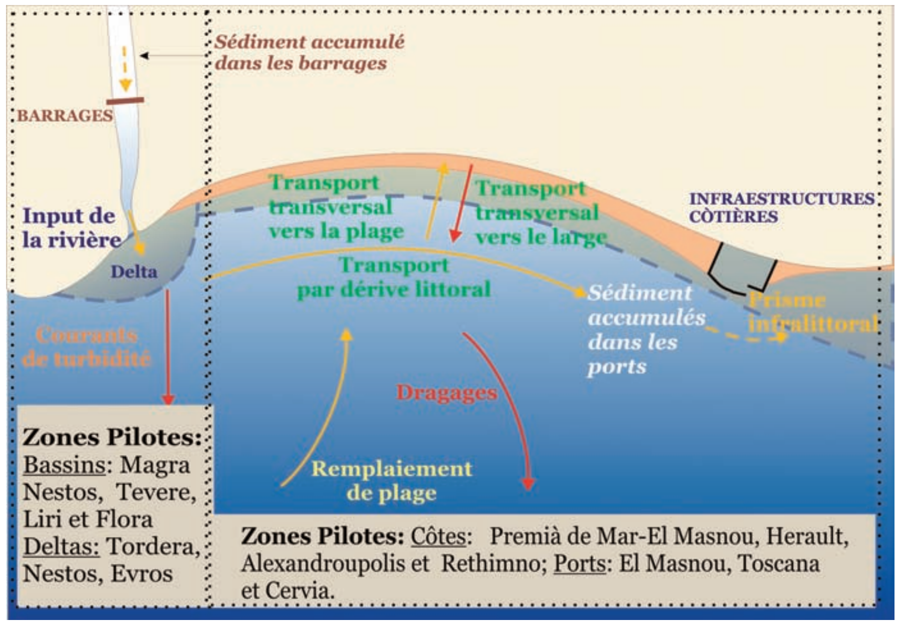


Fig. 3.3.1 – Conceptual model of a sedimentary cell showing the variables and parameters examined by the Gesa subproject in seven pilot sites located in different regions: Catalogne, Languedoc-Roussillon, Toscana, Emilia Romagna, Lazio, Macedonia and Thrace and Crete.

## Searching hydrographic basins as a strategic solution for integrated coastal zone management

Table 3.3.1- Evaluation of sand deposits available in the hydrographic basins examined as part of the Gesa subproject.

| Hydrographic basins | Volumes |
|---|---|
| Magra basin | 17.800 $m^3$ |
| Lazio/Umbria reservoirs | 60.000 $m^3$/year |
| Nestos dam | 800.000 $m^3$/year |

A full understanding of hydrographic basins is required as they are representative of coastal sediment surveys and the morphodynamic system. Knowledge of volumes and quantities of sand deposits, how they are created and evolve over time is a key component of any lasting management scheme which extends to all basins. Contributions to the Gesa subproject shown in this section have therefore taken the following aspects into consideration: Sediment quantification, dynamics of how fine sediment from rivers or tributaries is dispersed and the formation of sedimentary deltas. Six pilot sites have been selected for this research project: The Magra, Nestos and Tiber river basins and the Tordera, Evros and Nestos deltas. Table 3.3.1 summarises data obtained on sand deposits

### *Quantification of sediments which can be dredged within the hydrographic basins*

*The Toscana Region* has analysed the Magra basin in order to quantify sediments available for dredging and analyse the potential environmental impacts of dredging projects in the basin of the River Magra. Problems associated with this type of work are linked to the effects that sediment extraction can have on the river and the quality of seawater. Geomorphologic surveys of nine sites (Phase A) have reinforced the need for an evaluation which can quantify coarse and arenaceous sediments which can be transferred to other areas. An estimated total of 17.800 $m^3$ of sedimentary material suitable for dredging has been identified (Table 3.3.1). In order to characterise the flow of gravel bars downstream and forecast the effects of sediment transferral activities we need to look at how these sediments are produced and are transported and how this affects the river bed. With this information we can deduce what the future geomorphologic effects on the river bed will be. Most of the material found in the tributary river we analysed had been dragged there. The following work has been analysed: papers issued by the Interregional Authority for the Magra river basin, maps 1:10.000 and 1:5.000, geological and geotechnical reports and other publications (Rinaldi and Simoncini 2007).

### *Quantification of sediments found in the river before and after dam construction*

*The Lazio Region* has developed an evaluation method for calculating sediment quantities trapped in the reservoirs. The method uses rainfall data collected by the Hydrographic Office over about 70 years. The model has been created using two different methods: The *SCS Runoff Curve Number Method* for surface runoff and sound detection models for runoff below the surface. Results confirm there is a good match between calculated and measured values. The next step is the evaluation of solid river material transported as a result of rainfall, for which we have taken Fleming's report into consideration (mononominal expression with two independent parameters). Finally, three well known empirical methods have been adopted to evaluate reservoir trap efficiency (Brown, Brune and Churchill). This method has been applied to twelve reservoirs in the Lazio Region and central Italy (fig. 3.3.2).

*The Macedonia and Thrace Region* has calculated the sedimentation rate of the River Nestos before and after the large dams were built along the river. A numerical simulation using mathematical model RUNERSET (Andredaki 2008) shows that the yearly sedimentation rate at the mouth of the River Nestos before the dams were built was an average of about 1,8 million tons, with a peak of 3,3 million tons, a minimum value of 0,5 million tons and a standard inflection of 0,7 million tons. After the dams were built the yearly sedimentation rate at the mouth of the river decreased to only 0,32 million tons. This means that there has been a significant reduction (about 82%) in sedimentary material transported directly to the mouth of the river and, therefore, indirectly to the surrounding coast. This event has obviously affected the sedimentary equilibrium of the river and the erosion of the shoreline close to the mouth of the River Nestos. The results of this analysis clearly show that there is a need to ensure that "environmentally friendly" practices are followed when building dams, taking into account the sedimentary equilibrium before and after the construction work. The dam of Thissavros is 180 metres high and has an upstream reservoir which covers an area of about 50 kilometres. This means that conditions do not favour the transfer of sedimentary material by emptying or

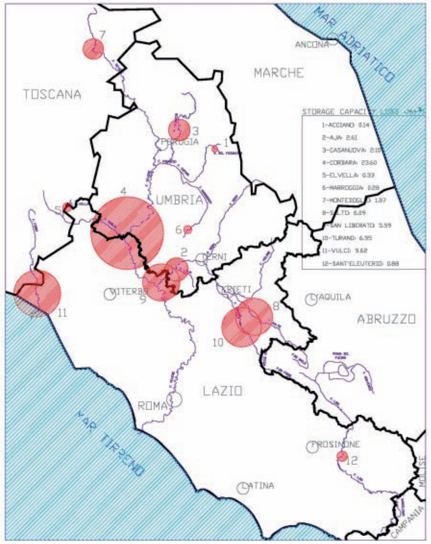


Fig. 3.3.2 - Results of a model used to evaluate quantities of sedimentary material trapped in twelve reservoirs in central Italy.

washing out the reservoir. There are many regulations in place which govern water management practices and require dam owners to release minimum volumes of water into the river in order to preserve the natural habitat. Unfortunately, however, there are no regulations which also prescribe the release of minimum quantities of sedimentary material from artificial reservoirs.

### *Dynamics of fine sediment transport from a river to surrounding seabed: evolution of turbidity currents*

*The Macedonia and Thrace Region* has explored the behaviour of fine sediments transported by a river. The aim of this task is to gain an understanding of the dynamics and characteristics of erosion and turbidity current deposits which are formed at the mouth of the river. The evolution of turbidity currents during inundations in the River Evros have been studied in the north Aegean Sea. A 3D numerical model (FLUENT) (Georgoulas 2008) has also been developed. This model has been used to study the transport of sedimentary material from the River Evros into the north Aegean Sea, focusing on specific large-scale inundations where the concentration of suspended sedimentary material in the river reached its highest values. Figure 3.3.3 shows profiles of volume fractions for suspended sediments in the north Aegean Sea after 536 seconds and 2.566 seconds and profiles for water rich in sedimentary material flowing along the river. Sediment rich water from the River Evros has transported sediments a long way from the mouth of the river. At 3,5 Km from the river's flow path the

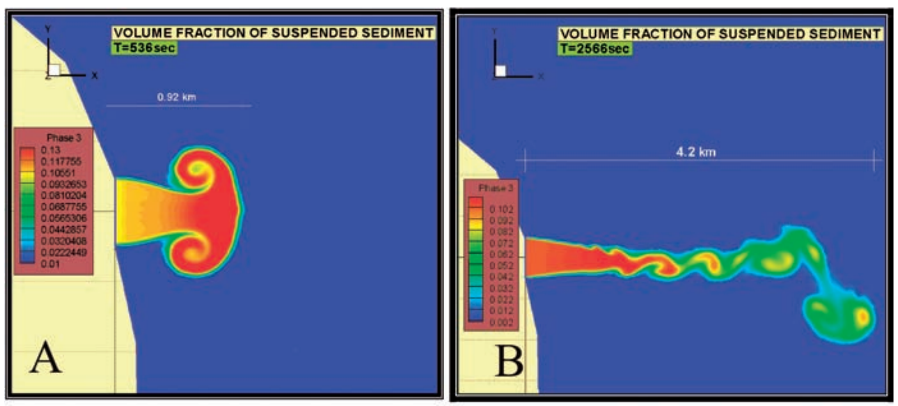


Fig. 3.3.3 – Numerical simulation of the sediment rich flow of water from the River Evros, which flows into the Northern Aegean Sea. Contours of suspended sediment fractions are evaluated (A) after 536 seconds and (B) after 2,566 seconds (Section Z is free-flow).

turbidity current shifted to the right due to the Coriolis effect. This created some small whirlpools which, as it dragged the sea water along, caused the water to decrease in intensity as it lost and deposited its sediments.

### *Sedimentary contribution of the river to delta systems*

*The Catalogna Region* has analysed the reasons behind the negative sedimentary balance and why the Maresme shoreline sedimentary cells are no longer being nourished. The procedure needs to look at information available on morphodynamic and physical processes, the structure and chronological data of the River Tordera's delta system and analyse any changes that have occurred. Results of the sediment distribution study and bathymetric and seismic studies show that there are three old delta lobes which, during the last phases, have generated an increase in the level of the sea. The current delta front is affected by a number of gravitational processes, due to the sand front facing the delta and the steep sloping of the delta itself (fig. 3.3.4). The study of the chronological

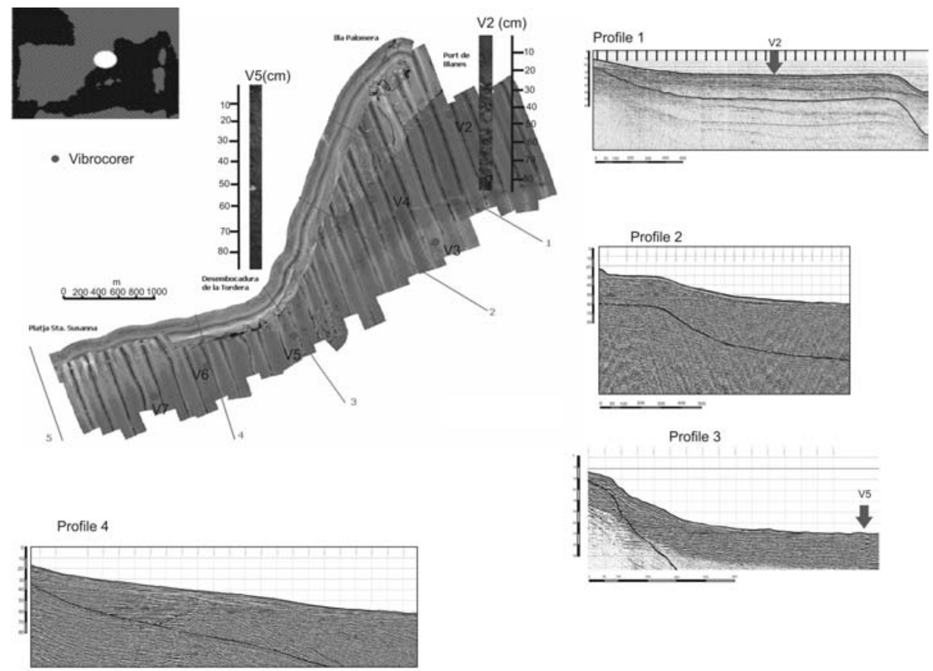


Fig. 3.3.4 – Mosaic ("Side Scan Sonar") and seismic profiles of the River Tordera's prodelta obtained using "vibracoring".

history of the delta lobe remains show that Deltas I, II and III, located respectively at a depth of 50, 35 and 15 metres developed between 11,9 and 7,5 thousands years ago. This chronological analysis helps us to evaluate sedimentary deposit rates and associated structures. This data can then be compared with existing processes, which supply the documentation needed to manage sedimentary resources, define indicators and pursue policies which can guarantee the integrated and lasting management of coastal zones (ICZM).

### Shoreline searches as part of sand deposit management schemes

In order to identify new coastal management strategies the Gesa subproject has analysed a number of aspects which are included in this chapter. These aspects consist in establishing availability of sedimentary deposits, nourishment of shoreface and emerged beaches, and to what degree this could provide a quick and useful solution when managing sand deposits, and dredging activities carried out at sites where the presence of sand is undesirable. Six pilot sites have been selected for this research project: The River Nestos, the delta of the River Tordera, the Premià de Mar-El Masnou and Herault coasts, and the El Masnou, Toscana and Cervia ports.

*Availability of sand deposits*

Shoreline managers' growing demand for sedimentary material and the issue of Mediterranean coast erosion have driven the scientific community and authorities to search for new sedimentary sources. One of Gesa's objectives has therefore been to evaluate available sediments in three main scenarios (deltas, ports and lower plateaus/infralittoral zones). Research work has been based on bathymetric data, seismic profiles, core drillings, surface samples and the use of the MIKE21 software application.

*Sand deposits in the delta zone*

The Catalogna Region has estimated sand deposit volumes in the delta zone by taking into account new bathymetric data, seismic profiles and sedimentation data. About 38 x $10^6$ $m^3$ of sedimentary material has accumulated in the delta zone of the River Tordera, distributed along a strip of land located at 8 m below sea surface level (10 x $10^6$ $m^3$) as well as among what remains of the delta of the River Tordera (D-I and D-II), respectively at a depth of 35 and 50 metres below sea surface level (28 x $10^6$ $m^3$). The largest quantity of sediment in the Tordera delta is inside this strip of land, which is what has enabled sand to be deposited in this area. As things currently stand the size of this material is similar to that of accumulated natural sand and is therefore a candidate for nourishment activities.

*Sand deposits intercepted by the ports*

Quantification of sand deposits intercepted by the ports has been carried out: (i) based on periodic bathymetric multi beam and sedimentation (core drilling) data for the Catalogna Region, (ii) based on periodic single beam bathymetric data (old/new) for the Toscana Region, (iii) based on the MIKE21 software used in the Emilia Romagna Region.

-*The Catalogna Region* has been able to identify a good quantity of sand deposits in the port of Masnou (fig. 3.3.5). Sediments have accumulated upstream and along the infrastructure at a rate of about 70.510 $m^3$/year (from June 2006 to May 2007) and contain sedimentary material from the Premià de Mar-El Masnou coastal cell intercepted by the port. Accumulated sand is coarse (average size of grains: between 0,66 and 0,83 millimetres) and contains scarce quantities of mica (< 15 %), it is also similar to the sand collected on the beach.
- Results obtained in the *Toscana Region* port show that the only exploitable sediment deposits which should not be overlooked are found south of the port of Viareggio. It is estimated that this accumulation grows at a rate of about 20.000 $m^3$/year. In Marina di Carrara we can see that it is currently losing sediments, especially along the shoreface, while Livorno's bathymetric data is fundamentally stable due to the fact that accumulation and erosion cancel each other out, even though trends for recent years show that the shoreface is being affected by erosion. Therefore we have only proceeded to analyse other possible uses for accumulated sediments in the port of Viareggio. From these results we can

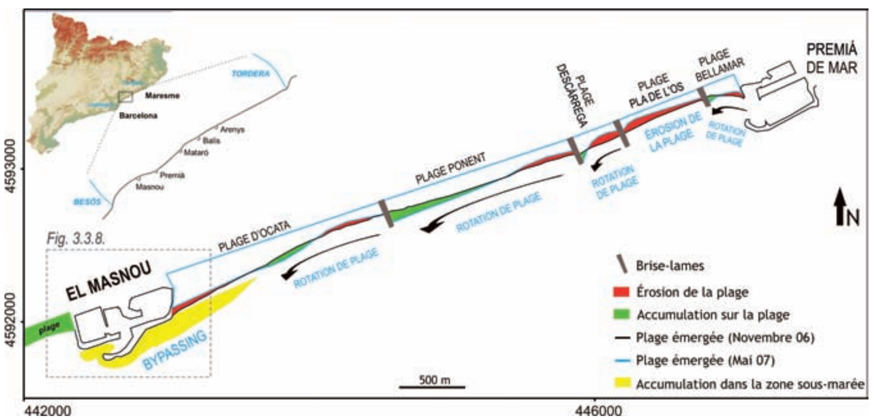


Fig. 3.3.5 - Morphological evolution model for the Premià de Mar-El Masnou coastal cell.

therefore conclude that although sediment deposits accumulated around the ports in the Catalogna and Toscana Regions (70.511 m³ for El Masnou, and 17.000 m³/year for Viareggio) have not received much focus they actually contain excellent sources of local sedimentary material.

- In the *Emilia Romagna Region* the MIKE21 software has enabled us to analyse the hydro-morphological characteristics of a 7 Km long beach which starts in Via Cupa and ends at the port of Cervia. The short pier in the port of Cervia routes the flow of sediments drifting along the coast from the beach in Milano Marittima towards the inbound channel. The flow of sediments amounts to about 20.000 m³/year and covers a 1 Km strip of coastline.

Sand deposits in the internal plateau and infralittoral zone

Evaluation of sand deposits in the internal plateau and infralittoral zone has been based on a high and very high resolution seismic approach, one which is not generally used along modern parts of the shallow shoreline (Certain *et al.*, 2005. This method has been adopted by the Languedoc-Roussillon and Catalogne Regions (Table 3.3.2).

Table 3.3.2 - Sand deposits available in infralittoral prisms of L´Hérault (a) and Maresme (b). Key: U, seismic unit, SS, seismic sequence.

| | ***Area(m²)*** | ***Volume ( m³)*** |
|---|---|---|
| Box 1-Carnon[a] | 431.000 | 353.459 (USU) |
| | | 1.585.051 (U2 +U3) |
| Box 2-Grand Travers[a] | 728.000 | 2.187.289 (U3) |
| Box 3-Grande Motte[a] | 595.000 | 2.059.871 (U3) |
| Box 4-El Masnou-Premià de Mar[b] | 26.000.000 | 137.070.000 (SS2) |

Two different approaches have been adopted in the *Languedoc Region*, one using a large grid on the Hérault coast and one using a short one at a specific site. It has been proven that the Superficial Sand Unit (SSU) along the Hérault coast, which corresponds to the volume of sand which covers the first hard substratum layer, is of a type which is suitable for use on the beach and/or surrounding cells. This unit can be identified by pinpointing where non sandy sediments start by analysing the base of the unit. With the Carnon-La Grande Motte infralittoral prism we can differentiate between units of upper mobile sand and deposits of grit deeper down. With regards to sand deposit volumes we can see that these generally increase as we get closer to the coast (fig. 3.3.6).

The *Catalogne Region* believes that the best type of material in the Premià de Mar-El Masnou infralittoral prism consist of an upper seismic unit with sediments deposited during the last period of high seawater levels (Ercilla *et al.*, 2008). In other words these sediments are composed of river material from the last 6.500 years. The average sediment volume we have calculated is 137,07 x 10⁶ m³ distributed in three depocentres (around 20 metres thick) located in the infralittoral zone of Premià de Mar-El Masnou (fig. 3.3.7). The core drillings (< 3 m in length) obtained from the infralittoral prism show that sediments are mainly composed of coarse, medium sized quartz sand.

*Nourishment of shorelines and emerged beaches as a strategic solution for integrated coastal zone management*

The search for new coastal management strategies drives us to implement procedures which can effectively exploit sand deposits as well as help us understand coastal sediment dynamics. It is critically important to understand how infrastructures affect the coasts by analysing the causes – often specific to the site – and develop appropriate and effective defence strategies. With this in mind the Gesa sub-project has proposed two specific objectives: (i) understand the morphological evolution of the Mediterranean pilot site shorelines using physical data and numerical simulation and (ii) understand how beaches react to nourishment procedures using ad hoc laboratory tests. The approach to this research project is based on using numerical models and laboratory tests.

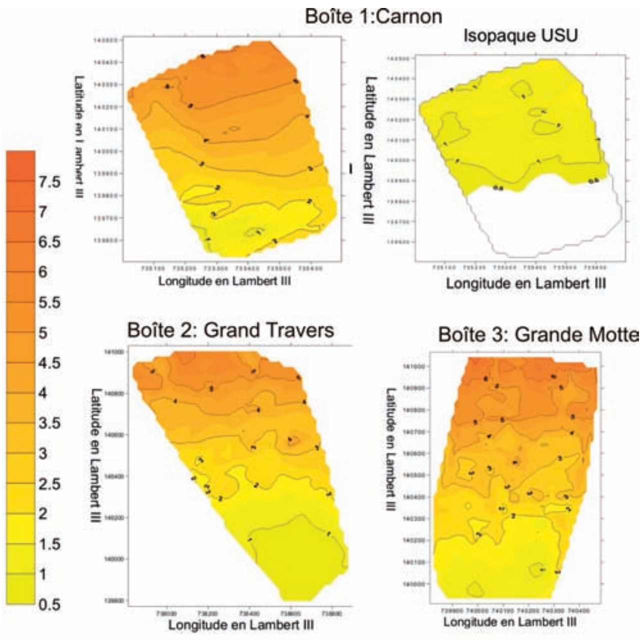


Fig. 3.3.6 - Thickness of prism for the Herault coast represented in metres by map curve for sand with equal thickness, relating to unit U3 of boxes 2 and 3 and unit 2 (and SSU) of box 1.

Applying numerical models to pilot sites: Definition of sand deposit management strategies

We have studied the displacement of sediment caused by littoral drift and transversal sediment transport by selecting a number of different numerical models and focusing on two main scenarios (shores and shorefaces).

• *Coastline evolution*

Coastline evolution has been calculated using and, where possible, compared with actual onsite survey data. Numerical simulation was carried out in the *Catalogne Region* using the SMC software application, covering the area between the port of Premià de Mar and the port of El Masnou. Results provide final bathymetry and erosion zone/accumulation data which match that obtained by monitoring the actual site. Site survey data has shown erosion in the northern supralittoral, foreshore and infralittoral zones and an accumulation of sediments in the southern tidal zone (fig. 3.3.5). A similar scenario can be seen in the port of Viareggio in the *Toscana Region* where coastal evolution over time (20 years) is simulated using the GEDAS model. Two scenarios have been simulated, one without any dredging and the other using dredged material amounting to about 180.000 m³ in volume. In both instances erosion is greater to the north of the port, while to the south we can clearly see evidence of accumulation, which matches actual site survey data. More specifically we can say that dredging increases erosion and accumulation rates. Studies have been carried out on

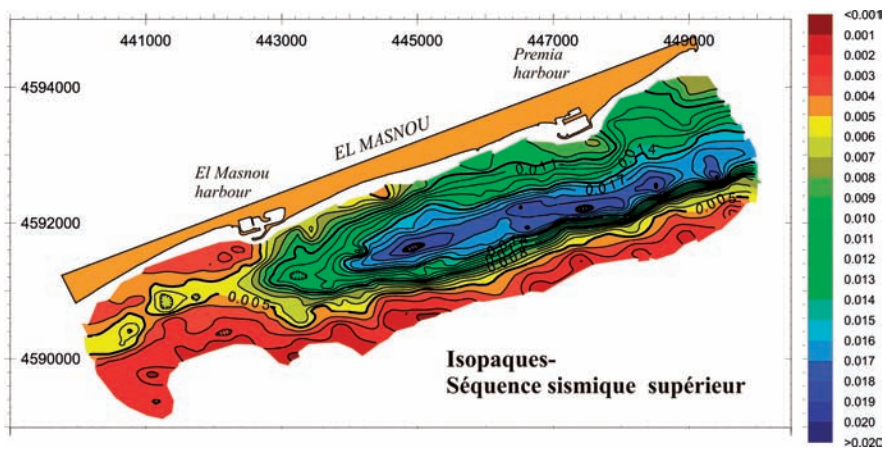


Fig. 3.3.7 – Thickness of infralittoral prism for the Premià di Mar-El Masnou coast represented by the equal thickness map curve for the upper seismic sequence. Vertical scale is in seconds.

evolution trends for the Rethimnon coast in the *Crete Region*, using the Als model. These results have been used to define various scenarios, including nourishment of beaches and underwater breakwaters, as well as testing effectiveness and application methods. After the arrival of strong wave motions coming from the north-west and north-east we observed accumulations at port entrance and erosion about 1km east from the leeward pier. We have used the CEDAS model in the *Macedonia and Thrace Region* to analyse the evolution trend for the River Nestos, specifically focusing on how the coast has changed due to wave motions, coastal structures and construction work (decrease in sedimentary rates due to the building of dams). Condition of the coast at the beginning of test period compared to status after 10, 20 and 40 years of simulations clearly show evidence of erosion in the delta of the River Nestos. Sediment deposit rates calculated using this model show a yearly average loss of sedimentary material of 1.000.000 m³.

• *Shoreface dynamics*

*The Languedoc-Roussillon Region* has focused on calculating transverse transport figures and numerical simulations using models Modhys, Télémac and S-Beach. These simulations have been compared with each other in order to evaluate the effectiveness and lasting effect of two beach nourishment procedures used along the shoreface; these are nourishing external sedimentary sandbars and creating a deep sandbar (Gulf of Lion). Results show that the first nourishment procedure is more effective than the second one. The three selected models generate results which on the whole differ from each other but are consistent. This is especially the case when they correctly simulate erosion levels and identify areas of uncertainty for areas affected by accretion as well as emerged beaches. The selected numerical method is extremely sensitive to the shoreface's initial profile although still not strong enough to describe the characteristics of the emerged beaches. Numerical models need to be constantly adjusted using experimental data and, where applicable, with measurements taken of the site before and after a storm.

Laboratory tests on a nourished beach: Understanding processes and defining an alternative to numerical models

The study focuses on two types of nourishment procedures (sand beaches and gravel beaches). In the event of numerical models yielding insufficient results laboratory tests provide a good alternative.

• *Nourishment of sand beaches*

Some small scale physical tests have been carried out inside an abandoned canal in the *Languedoc-Roussillon Region* in order to understand behaviour of shorefaces undergoing nourishment procedures, especially when numerical models did not provide the desired results. Tests have been used to study accretion processes – inadequately represented by available models – and understand the mechanisms behind them. The second nourishment process has been tested "in the external sandbar trench" and has shown to be sufficiently effective, especially with regards to the decreasing phase, during which the beach covers sedimentary material lost at the height of the storm. Differences between numerical simulations and physical tests are basically due to the way in which storms are analysed by numerical models. Finally, shoreface nourishment seems to provide a valid alternative to the more traditional option of nourishing emerged beaches.

• *Nourishment of gravel beaches*

*The Toscana Region* has analysed behavioural trends of gravel beaches, especially when these beaches are protected by other coastal structures, although this variable is not sufficiently accounted for by models which we currently have available. A series of lab tests were carried out on gravel beaches, analysing two types of gravel (average of 4 and 8 mm in diameter), characterised by a curve with limited angle and two different beach profiles (natural and protected by underwater structures). Influence of the structures on the final profile were clearly seen in all tests. Both accretion and erosion profiles linked to the effects of wave motions were analysed.

### Sandbank removal from locations where the presence of sand is undesirable: Sand dredging

Coastal infrastructures need to be frequently dredged due to large quantities of sand accumulations that are formed in these areas. Sand accumulations can grow large enough to obstruct access through the channel and require the urgent application of dredging activities. There is also the additional and more general need to remove sand from areas where these deposits may cause problems and move the sand to areas in need. This document therefore analyses two types of dredging activities: the one in the port of Cervia and the one in the port of El Masnou.

*Cervia-Milano Marittima port monitoring*

Average wave motion data provided by Phase A has been confirmed in the *Emilia Romagna Region*, although previous year's measurements were for a scenario with an orientation which was slightly more to the south. Dredged material matches the quality required by nourishment procedures. Although material is slightly too fine it was all placed along the coast during the work carried out in May 2007. The coarse sand which obstructs the port is of the right quality and does not need to be treated in any way, while finer sand should only be used after being treated mechanically. At one point, while nourishing the beach, losses due to temporary deposits were measured and then simulated numerically, showing that: (i) methods used are effective and do not produce significant levels of turbidity and (ii) leaf stacks need to have more strength and this can be achieved using a cantilever beam which connects the stacks together.

*El Masnou port monitoring*

In the Catalogne Region sediments accumulated at the El Masnou site in a year (from June 2006 to June 2007) reached a volume of 70.510 $m^3$. Their distribution over time is a consequence of the marine climate. An insignificant amount of sediments accumulated at the El Masnou site between June 2006 and November 2006, due to frequency of wave motions along the east-south-east sector. Wave motions between November 2006 and May 2007 mainly moved in the east-north-east and south-east direction, with storms coming in from the east. In these conditions sand intercepted by the port represents 71% (49.810 $m^3$) of the total. A year after dredging was carried out morphological structures caused by dredging (drainage ditches and sandy trenches) were partly or entirely covered and the accretion zone spread to the southwest at a rate of 130 m/year (fig. 3.3.8) Sedimentary material accumulated upstream and along the infrastructure at a maximum depth of 8-9 metres below the water surface. These sediment deposits have different characteristics to those of native sand, both in terms of size and grain composition. Native sand is of average size (0,22 mm) and contains high levels of mica (up to 68%). Sediments trapped by the infrastructure on the other hand contain coarse sand (between 0,66 and 0,83 mm) and contain 15% less mica.

### Conclusions

Main outputs of the Gesa subprojects have therefore led us to make three conclusions for the six hydrographic basin and Mediterranean coast pilot sites:

***(1) Efficiency and effectiveness of data acquisition methods.*** It is important to look at different aspects (such as cost, compatibility, duration of intervention) as well as potential of existing sources of data. High and very high resolution seismic technology is a good tool to use in coastal management strategies as it is easy to apply and can be run by just a few operators. The use of old and recent bathymetric data (*multibeam* or *single beam*) provides us with information on volumes of sedimentary deposits.

***(2) Definition of useful sedimentary deposits.*** Knowledge of sand deposit location and how they are formed as well as of morpho-sedimentary characteristics for the various scenarios (hydrographic basins and coastal zones) is a fundamental part of any sustainable management policy. This project has defined a number of "useful sedimentary deposits". Volumes and grain characteristics of river sediments examined have shown that this material is a valid source for small beach nourishment projects. Certain quantities of dislocated river sediment can reduce inundation levels and slow down the bed deterioration process which can lead to landslides as well as shore erosion due to an increase in height of the coast. The use of local sand deposits in the ports can provide an excellent way of recreating the sedimentary balance of the shoreline and guaranteeing that access routes to the ports are kept clear.

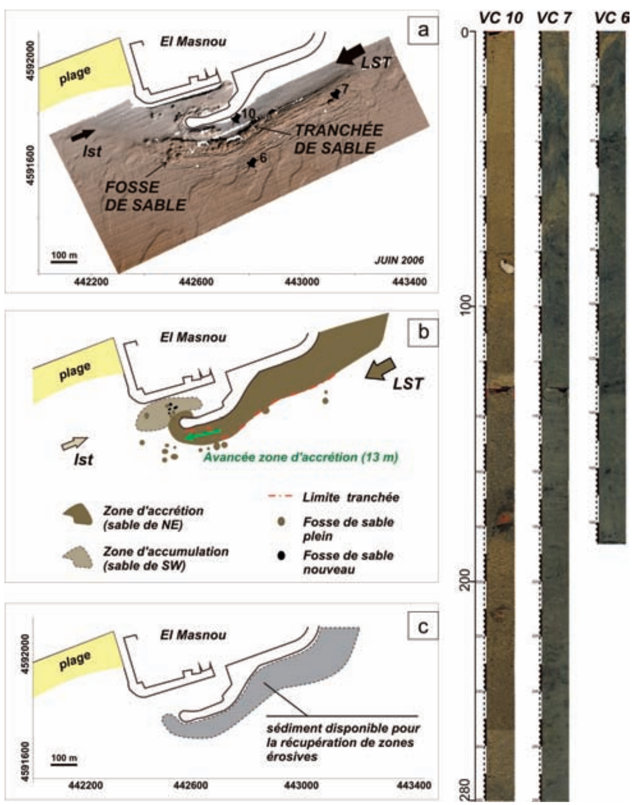


Fig. 3.3.8 – Maps of the El Masnou site: (a) Multi beam bathymetry at the end of dredging work (June 2006). (b) Interpretation of main sediment accumulation processes (sediment transport due to littoral drift in north-easterly and south-easterly directions, LST). The picture shows the main morphological structures of the seabed (drainage ditches and sandy trenches) and core drilling scenario, length of drills is in centimetres. (c) Availability of sediment deposits.

*(3) Port dredging.* Due to a general decrease in tributary deposits, subsidence etc. sand has become an important resource which we cannot afford to waste. Dredging interventions inside the ports therefore need to be carefully planned so that they can be linked to beach nourishment projects. Dredging of sand intercepted by the infrastructure should enable the sedimentary balance to be recreated. During this project phase it is therefore necessary to take by-pass methods into consideration, whether in direction of the current or counter current.

*(4) Simulation using numerical and physical models.* Numerical models applied to the pilot sites can generally accurately forecast evolution trends of the coastline and beach profile, even though, in some circumstances there may be some discrepancies due to model formulation and assumptions. The numerical models for transversal transport of sediments and beach profiles provide a useful tool when available models supply us with uncertain results; however these models still need to be modified with regards to formulation and adjustments using lab tests (on both a small and large scale). The effects that a submerged structure can have on the profile of a gravel beach depend on the extent to which storm waves transport sediments picked up from the shoreface onto the beach.

## Equipment and solutions required to improve management of coastal areas

A series of measures have been identified by the Gesa subproject which can, through integrated management strategies, help recreate a balanced, resilient and dynamic coastal system. These measures can be divided into three groups: (1) Detailed analysis of evaluations carried out on sedimentary deposits suitable for dredging activities. (2) Validate effectiveness of dredging and transferral activities. (3) Application of models (numerical and physical) which can provide information on mechanisms behind erosion and how these can be contained. At a regional level this would allow us to increase our understanding of shoreline sedimentary dynamics and evaluate available sand deposits which can help implement integrated coast management strategies.

### *Evaluation of sedimentary material available for the nourishment of eroded zones*

*Scenario 1 – Sedimentary material accumulated in hydrographic basins*

Results relating to quantities accumulated in hydrographic basins (Table 3.3.1) have shown that proposed methodologies (a, using direct measurements and through the analysis of satellite images, b, by applying the RUNERSET mathematical model etc. and applying Fleming's report) provide effective tools with which to forecast sediment quantities which flow in hydrographic basins and reservoirs. These methodologies also enable us to evaluate long term capacity of reservoirs to store sand, which therefore encourages us to carry on perfecting this method and apply it to other scenarios. Methods used to evaluate sediment quantities need to be transferable and applied elsewhere in order to assess sediment deficiencies in coastal areas caused by dams or the construction of other obstructions. This is why we believe that these procedures can be successfully applied to establish which reservoirs may cause the most problems in terms of loss of storage capacity and sedimentation. On the other hand any sand exploitation and utilisation strategy must be sufficiently debated in order to establish how the local habitat may respond to the artificial addition of sand, sustainability of intervention and social and financial costs involved.

*Scenario 2 – Sediments accumulated in the delta area*

Deltas provide good sources of sedimentary material, as sand basically deposits itself near the front and close to the delta, and can therefore be used as part of coastal zone management strategies. In the Catalogne Region sediments from the River tributary are trapped along the arrow shaped coastal sandbar and relict delta formations (total volume of 38 million $m^3$). The sandbar system, which is not as deep, provides a simpler source of resources than those contained in the delta lobes. Before carrying out any exploitation of these resources in the future it would be advisable to carry out environmental feasibility studies.

*Scenario 3 – Sand trapped by ports*

Evaluation of sand quantities trapped in port harbours is an important part of coastal zone management strategies as these areas provide "reservoirs of local sediment". Sand trapped in coastal structures has very similar characteristics to sand found locally and can be used to nourish the coast. The exploitation of these sand deposits together with other coastal management strategies ("derivation" and beach nourishment) can ensure that the sedimentary balance is reinstated.

The port of El Masnou studied by the *Catalogne Region* shows that sand volumes accumulated in a year (70.510 $m^3$) are similar to sand quantities deposited along the Northern beach during the same period (73.500 $m^3$). Additionally this sand has similar characteristics to sand found on the beach. Sand extraction can reinstate longitudinal sediments, guarantee access to the port and rebuild eroded zones. In the *Toscana Region* we have only been able to select the port of Viareggio as a case study for dredging activities, Simulations carried out with CEDAS software provide the position of the coast over time and provide accurate results, both with and without dredging work. The effect of dredging on the adjacent coast shows an increase in erosive and accretion trends for the port of Viareggio it is possible to dredge sediments (at a maximum dredging depth of 5m) from the submerged sandbar and the external part of the port's breakwater (180.000 $m^3$), both of which provide good matches for the beaches located in front. This last scenario is therefore a possible approach to managing sand deposits. The *Emilia Romagna Region* has shown what needs to be done to ensure that access to the port of Cervia is kept free for longer periods of time. A possible strategy could be to extend the southern dam by 100 m, another solution could consist in applying changes to dredging methods by dredging wider channels and, more specifically, dredging the internal sandbar of the Milano Marittima beach. This would need to be done at a distance of 150 m, close to the southern dam. The abovementioned dredging method would seem to also fit into a global strategy for the nourishment of Milano Marittima. The method used for beach nourishment activities would mean that techniques used during the work could be applied without delay, including temporary deposits located deep under water and protected by piles of foliage. This method would need to be integrated in order to treat sand in batches using a pump, so that the few polluted sections can be removed and disposed of.

*Scenario 4 – Internal plateaus and infralittoral prism*

Quantification of sand deposits plays a critical part in the development of coastal management strategies. Identification of dislocated sand deposits using only bathymetric profiles does not provide an accurate analysis of coastal vulnerability. It is also now necessary to take into consideration global sand volumes available along the entire coast, especially in submerged areas which is where most of the deposits are located. This type of survey needs to be implemented by using an innovative method, in order to provide geophysical imagery which allows us to visualise and quantify these deposits. The seismic approach applied through the use of boxes is a valid and undemanding technique which can also be applied to other beaches. Results from the *Languedoc-Roussillon* and *Catalogne Regions* show that the infralittoral prism (Table 3.3.2) contains potential sand deposits and could provide suitable nourishment material for the coast.

*Validation of effectiveness of dredging and transferral activities and analysis of sand treatment systems*

One of the objectives of the Gesa subproject is to recommend suitable coastal management strategies by inspecting work that has already been carried out. Rather than provide general guidelines we intend to highlight a lesson learnt from monitoring activities carried out in real case scenarios. We will therefore analyse two types of dredging activities: one in the port of El Masnou and the other in the port of Cervia. The evaluation of various dredging projects using "derivation" can provide an excellent way of resetting the sedimentary balance of the coasts and guaranteeing that access routes to the ports are kept clear. On the one hand the analysis of sand treatment methods has highlighted the fact that combined dredging and nourishment activities using coarse sand do not generally require any

treatment. If, on the other hand, material being dredged contains silt then treatment may well be required. The best method to adopt varies from case to case.
The port of El Masnou, in the *Catalogne Region*, is heavily affected by the accumulation of sedimentary material. With the aim of finding a solution the regional authorities (Catalogne area) decided to launch a "derivation" project. Sand trapped in the port has been transferred from the accretion zone to an area affected by erosion which is downstream and transversal to the port. The development of planned surveys within the port of El Masnou has enabled us to validate the effectiveness of dredging activities used to transfer deposits intercepted by coastal infrastructure in order to reinstate the longitudinal transport of sediments. The dredging study has basically concluded that the yearly volume of sand that can be dredged in the port of El Masnou in order to guarantee access to the port amounts to about 70.500 $m^3$/year. Of this quantity at least 87% is composed of sand intercepted by the port and corresponds to the annual volume of sand placed back into circulation inside the El Masnou port in order to reinstate the longitudinal transport of sediments. These dredging activities must not go any deeper than 8-9 m below surface water level as sediments are only trapped up to this depth. Any deeper dredging would include finer native sand and would not correspond to that intercepted by the port. The remaining accretion zone has grown 130 m towards the south east over a period of one year. If trapped sand is not transferred the accretion zone would rise to the south of the breakwater and inside the entrance to the port. In order to avoid this we suggest removing the sand accumulated against the external dam before carrying out any dredging activities. The morphological evolution model proposed for the Premià de Mar - El Masnou coast has been defined using studies on beach and coastline profile studies carried out after completion of recovery activities (Nuez *et al.*, 2008). The effect of beach rotation has also been identified (Short and Masselink, 1999). A circling mechanism is generated affecting the natural sand (part of the sedimentary material from Ocata beach moves towards the marina of El Masnou) when beach rotation is greater than limits imposed by the infrastructure. This sand displacement results in a visible accumulation below the surface of the water, along the coast and upstream from the marina. Due to this rotation effect sand replenishment activities should only be carried out at the northern tip of the beaches, along the coast of Premià de Mar - El Masnou.
In the *Emilia Romagna Region* access to the port of Cervia is often blocked. Regional authorities aim to ensure that the port can be accessed at all times by applying a global approach which looks at the requirements of the whole coast and transfers dredged materials to the areas that need it the most. Dredging practices consist in dredging channels a bit deeper than requested by the marketplace. By comparing old bathymetric data (Phase A of complete report) and more recent data (Phase C of complete report) we can see that the port access channel is not full of sediments but tends to veer towards the direction of the storm, basically southwards. Dredging activities have not been very effective as a simple storm has managed to block access to the port. The dredging study has basically concluded that the yearly volume of sand that can be repositioned from Cervia to Milano Marittima amounts to about 10,000 $m^3$/year.

*Model application*

<u>*Numerical models as indicators of erosion mechanisms and how to reduce these mechanisms*</u>

• *Scenario 1 – Delta erosion zone*

In the Macedonia and Thrace Region the construction of large dams along the River Nestos has seriously impacted the morphological structure of the mouth of the river and adjacent beaches. The numerical model applied can assess these impacts by forecasting yearly average erosion rates at the mouth of the Nestos. The large deposits adjacent to the mouth of the tributary currently help ease the problems which, over the next two decades, will be caused by erosion.

• *Scenario 2 – Beach dynamics*

In the Catalogne Region results using numerical models are of the same quality of those obtained from on-site monitoring activities. Even though it overestimates accumulation zones this tool can be useful in forecasting erosion and accumulation zones and in providing data which can be used in future nourishment projects. In the *Languedoc-Roussillon Region* selected numerical models are very sensitive to initial profile of submerged areas but cannot adequately describe emerged beaches. Numerical models always need to be adjusted using experimental data and, if required, on-site measurements carried out before and after a storm. The *Crete Region* has proposed a coastal defence strategy which can combat erosion of the port of Rethimnon as well as provide nourishment of beaches with submerged structures (4300 m long breakwaters parallel to the coast with an empty stretch of about 125 m between them). Sand used to nourish the beach is taken from accumulation zones in the western coast, outside the port, where material is of the right quality to be used in nourishment procedures

• *Scenario 3 – Sand trapped by ports*

In the *Toscana Region* detailed analysis of available sediments provide us with some possible dredging sources inside the port and along the coast of Viareggio.

In actual fact the port of Viareggio is the only site along the coast of Toscana which could be selected as a possible case study for dredging activities. Simulations provide good quality results, both with and without dredging activities. Dredging of submerged sandbar along adjacent coasts provides a good source for beaches facing those areas where sand is being dredged from.

*Application of physical models: New nourishment options*

Laboratory tests provide a good alternative to numerical models yielding negative results.

• *Scenario 1 – Nourishment of sandy beaches*

The *Languedoc-Roussillon Region* believes that the differences between numerical simulations and physical tests are basically due to the way in which storms are analysed by numerical models. In general numerical models provide a critical tool in the decision making process, even though they would need to be optimised – especially with regards to accretion – in order to solve more difficult cases. The channel itself has roused a certain amount of interest even though, up until now, it has hardly been used. Actually creating a third underwater sandbar offshore does not produce any effects unless it is either large enough, fairly close to the edge or in a bathymetric position which is high enough compared to the profile to cause the waves to break. This option has not yet been analysed or simulated. This critical information will need to be taken into account for future activities as any morphological structure that is created will need to be of a substantial size. Finally, shoreface nourishment seems to provide a valid alternative to the more traditional option of nourishing emerged beaches.

• *Scenario 2 - Nourishment of gravel beaches*

The *Toscana Region* believes that the effectiveness of a submerged structure on the evolution of a gravel beach cannot always be seen in outlines of wave motions and tested beaches. With waves which cause accretion due to *transversal transport towards the beach* from the submerged zone the submerged structure may reduce beach accretion immediately after the storm, while if beaches are affected by erosion the submerged structure reduces coastal erosion. Laboratory tests provide a useful tool for the validation of these effects, especially when available models produce uncertain results.

### Gesa's recommendations

In order to successfully manage sand deposits Gesa recommends only taking into consideration the most effective ways of exploiting sediment deposits (potential sources) in addition to nourishment or dredging activities. After having evaluated results and methods it will be possible to share this information with other members of the community. Three useful practices have been taken into consideration.

***(1) Improving knowledge of hydrographic basin and coastal variables in order to carry out medium and long term forecasts.*** Sand deposits (natural and manmade) are the result of deposit processes. Plans for the exploitation and use of these sand resources represent a critical step towards gaining a balanced sedimentary environment. Therefore the exploitation and use of these sand deposits needs to be based on and managed according to their historical environmental limitations. From this point of view, methods used to evaluate sediments accumulated in hydrographic basins provide an interesting and effective alternative. Evaluation of sand deposits should be carried out by analysing specific and detailed bathymetric data as well as high and very high resolution seismic profiles, which can then be applied to other scenarios.

***(2) Applying traditional measures aimed at creating a balanced sedimentary environment through the use of strategic and combined sediment deposits.*** Although quantities of sediments originating from rivers and deposits located outside the ports are much less than those found in the infralittoral prism these sediments can be dredged and used to nourish small beaches. The use of fresh water sediments (course grains) could be optimised to reduce hydraulic risk and could, furthermore, mitigate negative effects on natural habitat and tributary infrastructure. This type of sediment, composed of coarse grains, could be covered with sand while natural coating occurs and only be exposed to the effects of storms. The use of sand deposits intercepted by the port "derivation" projects has resulted in many advantages: removing obstructions from port entrance, costs reductions, ease of sourcing and a renewed balance to the sedimentary environment. Stabilisation using submerged breakwaters could provide a good solution when sand deposits are insufficient. In this way it is possible to have better control over erosion processes and coastal protection in general. We must also consider that temporary deposits at sea provide a financially viable alternative and have minimum impact on local habitat: this method is therefore of general interest and can be applied to other scenarios.

*(3) Application of new nourishment options* The suggestion here is to not only nourish beaches, as is usually the case, but also submerged areas, that is the part of the beach that is under water. At a first look this method has a number of advantages, such as reducing the need for sediment transportation, cost

reduction, the use of finer sand than what would be needed for shorefaces, as well as requiring less rigid procedures. Although this solution always needs to be accompanied by beach nourishment activities, monitoring of post-nourishment beach will provide additional input into nourishment plans. It is recommended that these be carried out at yearly intervals, by integrating monitoring data with numerical simulations on coastal evolution. Numerical models continue to provide a critical tool, especially when there is the need to decide how to combat erosion and implement dredging activities. However just monitoring the coast is not enough as this does not provide information on possible zones where sand can be sourced from. The effects of dredging on adjacent coasts should and can be evaluated using numerical simulations. We therefore recommend comparing any results with on-site measurements as this comparison can help understand the erosion processes.

### Gesa's outputs

Gesa's outputs are as follows: (i) Reports for local authorities (as well as Beachmed-e reports). (ii) An available database on the Gesa website. (iii) Some guidelines to incorporate procedure provided by the Languedoc-Roussillon region: this document supplies information on advantages and disadvantages of nourishment procedures, French law, environmental impacts, nourishment site selection and financial costs. (iv) The Toscana Region's guidelines on managing sediments in hydrographic basins and assessing any possible negative impact linked to their removal. (v) Some guidelines from the Emilia Romagna Region on sediment treatment methods and sediment boundaries. (vi) The development of a 3D model (FLUENT) by the Macedonia and Thrace Region which can effectively simulate the path and deposit behaviour models of fine sediments transported by the Evros along the seabed adjacent to the receiving basin of the Aegean Sea.

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