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Sediment Analysis Evidences Two Different Depositional Phenomena Influencing Seagrass Distribution in the Gulf of Oristano (Sardinia, Western Mediterranean)

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ABSTRACT

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Sediment grain size and total organic carbon (TOC) content in sediments, coupled with image processing analysis, were investigated to assess natural *vs.* anthropogenic distribution patterns of *Posidonia oceanica* seagrass meadow, in the proximity of a river mouth and a port embankment in the Gulf of Oristano (Sardinia, Italy). Two unvegetated areas (~9 km² each) were detected by meadow mapping: (i) in front of the river mouth, and (ii) close to the port.

Both unvegetated areas were characterised by a high silt+clay content in the bottom sediments, allowing us to identify the deposition of fine sediments as a factor limiting *P. oceanica* distribution. A marked variation within the depth of sediment grain size was recorded close to the port, where a 5-cm layer with silt+clay >50% overlapped a sediment with silt+clay <20%, suggesting a recent change in depositional processes.

Grain-size fractionation was analysed using the silt : clay ratio, which indicated high-energy conditions in the area close to the port. Differently high TOC concentrations were found in front of the river mouth. These data allowed us to identify two different types of sedimentary process impacts on *P. oceanica* distribution: (i) a "natural" limitation because of the river inflow and (ii) an anthropogenic impact due to fine-sediment deposition following the dredging and building of the port.

ADDITIONAL INDEX WORDS: *Sediment, grain size, silt, clay,* Posidonia oceanica*, seagrass.*

INTRODUCTION

Seagrasses are key ecosystems of the tropical and temperate coastal seas and have been subjected to drastic reduction in recent decades (LARKUM, MCCOMB, and SHEPHERD, 1989; MARBA *et al.,* 1996; SHORT and WYLLIE-ECHEVERRIA, 1996).

Although natural disturbances, *e.g.,* geological and meteorological events, can occur, human-induced disturbance is the major cause of seagrass decline worldwide. Such disturbances include reduction of water clarity, mechanical damage, and the release of toxic compounds (SHEPHERD *et al.,* 1989; SHORT and WYLLIE-ECHEVERRIA, 1996).

Posidonia oceanica (L.) Delile is the main seagrass of the Mediterranean Sea, and generally colonises sandy and muddy-sandy soft substrata. *P. oceanica* meadows form a key ecosystem in the shallow waters of the basin. They are an important resource for fishery (MAZZELLA *et al.,* 1993), for the stabilisation of bottom sediments, and for the protection of the shoreline from erosion (DE FALCO *et al.,* 2003; JEUDY DE GRISSAC and BOUDOURESQUE, 1985).

The growing pressure of human activity in the coastal zones of the Mediterranean have caused the progressive deterioration and regression of the meadows, as documented in several studies (CAVAZZA *et al.,* 2000; MARBA *et al.,* 1996).

Siltation has been identified as a major threat to seagrass ecosystems. The increase of sediment supply may cause the reduction of light availability and the increase of silt+clay, organic matter, and nutrient concentrations in sediments, which negatively affect seagrasses (HALUN *et al.,* 2002; TERRADOS *et al.,* 1998, 1999).

High sedimentation rates may also be a cause of mortality of *P. oceanica* meadows (MANZANERA, PÉREZ, and ROMERO, 1995). The growth of the vertical axis of the plant counteracts sediment deposition up to sedimentation rates that do not exceed the maximum growth rate of the plant (*ca.* 1.5 cm year^{-1}) (BOUDOURESQUE, JEUDY DE GRISSAC, and MEINESZ, 1984; PERGENT *et al.,* 1989). Experimental evidence showed that even moderate burial levels (*ca.* 5 cm) induced significant shoot mortality (MANZANERA, PÉREZ, and ROMERO, 1995).

Mapping of the meadows is considered a useful tool in managing seagrass ecosystems and in implementing protective measures: it determines the spatial distribution of the mead-

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ows and identifies unvegetated areas caused by disturbance phenomena. For instance, the mapping of *P. oceanica* meadows in Corsica revealed that the upper growth limit was deeper at the mouth of coastal rivers and, at times, the meadow was absent near large port facilities (PASQUALINI *et al.,* 1998). However, mapping itself generally provides little information on the causes that may determine seagrass distribution. Sediment analysis can provide additional information useful in interpreting the processes that control *P. oceanica* distribution and in identifying disturbance factors. CAVAZZA *et al.* (2000) showed that the building of a large embankment at Monterosso Bay (Ligurian sea, Italy) deflected the longshore current causing beach erosion and deposition of fine sediments. The authors highlighted that those changes of sediment dynamics are related to changes of the spatial distribution of seagrasses. *P. oceanica* meadow disappeared in the deposition area of fine sediments and was subsequently substituted by the more pioneer species *Cymodocea nodosa* (CAVAZZA *et al.,* 2000). However, the deposition of fine sediments can be a natural limitation to seagrass distribution such as in proximity of river mouths.

The present study analyses the impact on meadows distribution of the deposition of fine sediments in the Gulf of Oristano (Sardinia, Italy). A previous study showed how *P. oceanica* meadow influences the sediment texture and composition in the northern sector of the Gulf of Oristano. Meadow sediments were characterised by high values of biogenic carbonate content because of the production of carbonate skeletal linked to the seagrass ecosystem (DE FALCO *et al.,* 2000).

The aim of this article is to test whether the spatial variability and fractionating of sediment grain size and the variability of total organic carbon (TOC) content, coupled with meadow mapping, can allow us to distinguish natural *vs.* anthropogenic distribution patterns of *P. oceanica* in both the proximity to a river mouth and to a port embankment along the shores of the Gulf of Oristano (Sardinia, Italy).

Grain-size fractionation of siliciclastic sediments is known to be related to the physical environment and has often been used to study the source and depositional conditions of sediments in the marine environment (DAVIES and MOORE, 1970; KRANCK and MILLINGAM, 1991; MAZZULLO, LESCHAK, and PRUSAK, 1988). Silt : clay fractionation has been shown to be related to energy condition and benthonic activities (ERGIN and BODUR, 1999).

MATERIAL AND METHODS

The Study Site

The study site is located in the Gulf of Oristano, on the central-western coast of Sardinia, in the Mediterranean Sea (Figure 1). The Gulf is approximately 150 km^2 wide and is bordered to the west by two rocky capes, whereas the inner part is composed of a sandy shoreline on an alluvial plain with several marshes and lagoons. The major source of terrigenous sediments is the Tirso River, the mouth of which is located in the north-eastern part of the Gulf. The river has been subject to numerous hydraulic works in the past 70 years (building of dams and irrigation channels), which have reduced water discharge. At this time, the river occasionally has discharges linked to flood water from the dam, which is located about 20-km inland from the coastline.

A large port facility was developed in the 1970s to the south of the river mouth. The port consists of an embankment and a breakwater that protrudes 1.2 km from the natural shoreline. In addition, a channel was dredged in the seabed running approximately 3 km to the northwest and approximately 2 km to the southwest, thus lowering the seabed to a depth of 15 m.

P. oceanica Mapping

P. oceanica meadows were mapped using image analysis (PASQUALINI *et al.,* 1998) of five aerial photographs (Figure 1) collected in 1995 from an altitude of 3000 m (scale 1 : 20,000). The aerial photos were digitised with a pixel resolution of 5 m and subjected to image processing using the software MULTISCOPE (Matra Cap Systems, Villacoublay, France). To minimise distortions in the photographs, a geometrical correction was applied by overlaying the photos to a base map using 20–30 common points detected from the terrestrial part of the photos. The software readjusts the photos by fitting the points on the base map to the correspondence points on the photos using a polynomial model. In such a way, all the photo pixels were georeferenced to the coordinate system of the base map. The base map used for the geometrical correction was the Nautical Chart of the Istituto Idrografico della Marina (Italian Navy), and the geographical coordinates were used (Datum Roma 1940).

The colour analysis on the digital images was carried out by a statistical comparison of the vectors defining the level of the primary colours for each pixel by using the Principal Component Analysis method (PASQUALINI *et al.,* 1998). Colour analyses were performed separately for different sectors of the photos to analyze comparable seabed areas according to the water depth.

This method allowed the mapping of the upper bathymetric limit of the meadows down to a depth of 15 m. The image analysis was tested by direct observations of the seabed by divers.

Sediment Sampling and Analysis

Thirty-five samples of marine sediments were collected by divers from both vegetated and unvegetated sectors (Figure 1). The position of the sampling points in the field was determined using a global positioning system (GPS) device with an accuracy of *ca.* 30 m. This error was considered acceptable in comparison with the sampling grid size (1–1.5 km). Sediment samples were collected by polyvinyl chloride (PVC) pipes (10 cm length, 5 cm diameter); three replicates were made in each station.

The cores were subdivided into two parts of 5 cm to verify the variability of grain size with depth. Sediment samples were dried at room temperature. Grain-size distribution was determined by wet sieving to separate sand (>63 μm) and silt+clay fractions (<63 μm), after elimination of organic matter by oxidation in 6% hydrogen peroxide (H_2O_2) for 24 hours (CARVER, 1971); a laser method (Galai Cis 1 laser sys-

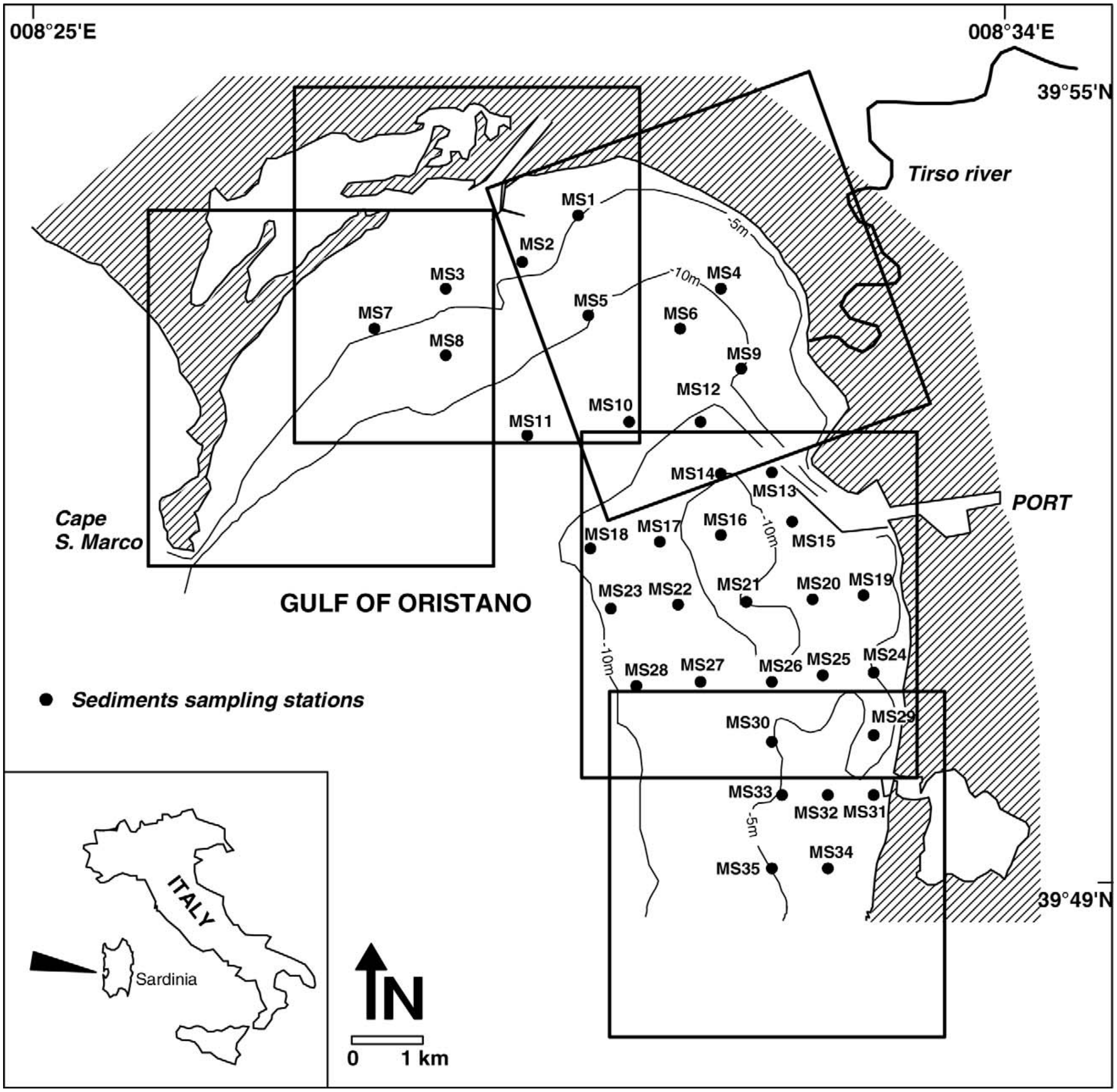

Figure 1. Map of the study site with the location of sediment sampling stations. The quadrates indicate the boundaries of the five aerial photos used for the image-processing analyses.

tem, magnetic cell mode; Galai Productions, Migdal-Haemek, Israel) was used to analyze the silt+clay fraction after the addition of a dispersant—0.6% sodium-hexametaphosphate $(NaPO_3)_6$—for 24 hours (MOLINAROLI *et al.,* 2000). The boundary between silt and clay fractions was adopted at 4 μm.

Total organic carbon analyses were performed by chemical oxidation of organic C and titration with a ferrous sulphate solution until the colour change of the ferroin indicator (WALKLEY and BLACK, 1934). Three analyses were performed for each replicate. The variability of the replicates was ±6.5%.

Maps of sediment grain-size parameters and TOC content distribution were made by using contour lines calculated by spatial interpolation of sediment data, using the kriging method by means of the software Surfer 7.0 (Golden Software, Golden, Colorado). Vegetation maps and sediment composition maps were compared using the software Mapinfo 6.5 (MapInfo, Troy, New York).

One-way analysis of variance (ANOVA) was used to test

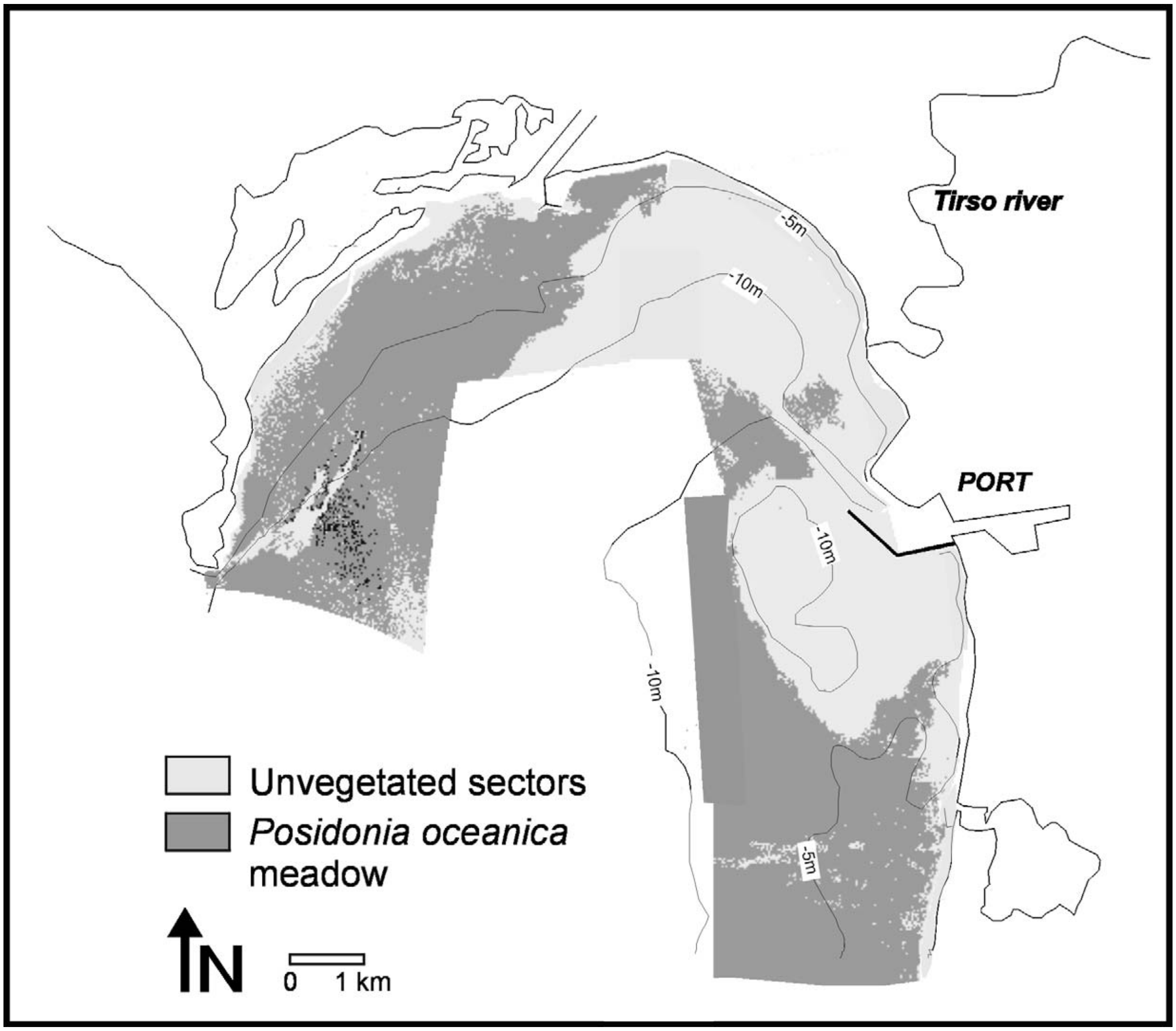

Figure 2. Distribution of the seagrass *Posidonia oceanica* in the Gulf of Oristano as a result of image-processing analyses.

whether the differences in sediment grain size and composition between the depositional environments were significant. The pairwise differences between depositional environments were tested using the Tukey HSD test.

RESULTS

The image analysis revealed that the upper bathymetric limit of *P. oceanica* meadow is generally adjacent and parallel to the coastline of the Gulf of Oristano except for two large unvegetated areas. The unvegetated sectors ($\sim$9 km^2 each) are located (i) in front of the river mouth and (ii) close to the commercial port to the south of the breakwater (Figure 2).

To the west of the river mouth, the upper limit of the meadow is $\sim$4 km from the shoreline. To the north of the commercial port, the meadow has been partly removed following the dredging of a channel to allow for the passage of ships. To the south of the port, the upper limit is $\sim$2.5 km from the breakwater.

The spatial variability of silt+clay content, silt : clay ratio, and TOC content in sediments are shown in Figures 3, 4, and 5.

The contour map in Figure 3 highlights two sectors characterised by sediments with a silt+clay content higher than $>$50%. The northern sector corresponds to the unvegetated area in front of the river mouth whereas the southern sector corresponds to the unvegetated area located in the proximity of the port's breakwater (Figure 2).

The cores did not show variations in depth of grain size in the northern unvegetated sector. A marked variation was recorded in the samples of the southern unvegetated sector (samples MS14, MS13, MS15, and MS20) where the upper 5-cm sediment layer showed significantly higher silt+clay content in comparison with the deeper layer 5–10 cm (83 $\pm$ 13% *vs.* 16 $\pm$ 4%, $p = 0.0006$).

The grain-size partitioning of the silt+clay fraction was analyzed using the silt : clay ratio. The values of the ratio range

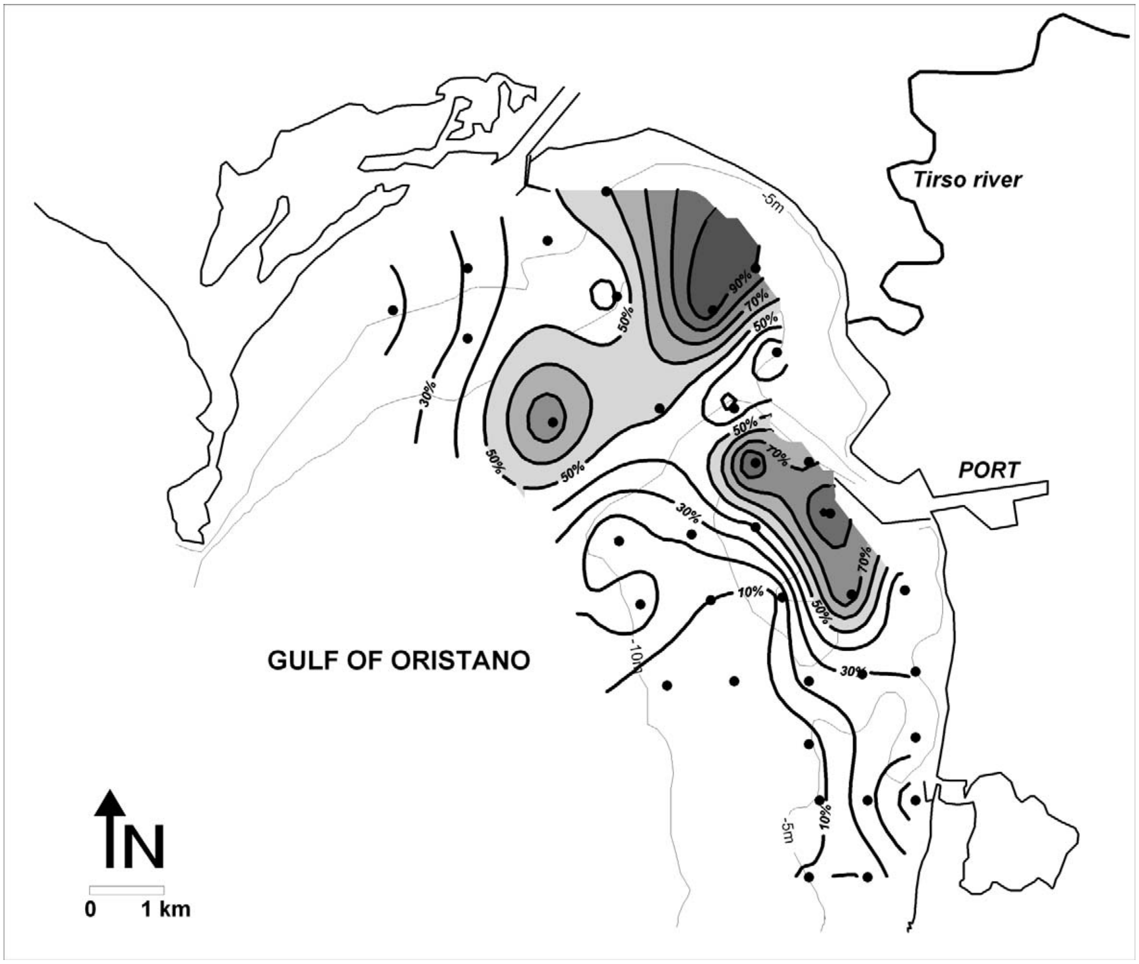

Figure 3. Contour map of the silt+clay content in sediments. The areas with silt+clay content >50% are shaded.

from 1.4 to 25.5. In Figure 4, the sector with the silt : clay ratio >9 is shaded: the highest values were found in the unvegetated area south of the breakwater. The silt : clay ratio values decrease in the vegetated sites and in the unvegetated northern sector (<6).

The spatial distribution of TOC content showed a maximum (~2%) in the northern sector (Figure 5). TOC values decreased toward the west (~0.6%) as well as close to the port (~0.6%).

A comparison between silt+clay content, silt : clay ratio, and TOC content was performed between three depositional environments identified by the mapping: the *P. oceanica* meadow (a), the northern unvegetated area in front of the river mouth (b), and the southern unvegetated area adjacent to the port (c).

Table 1 shows the mean values of the considered variables for each of the depositional environments, whereas Table 2 shows the summary results of the one-way ANOVA.

Silt+clay content is significantly lower (Tukey HSD test) in sediments of *P. oceanica* (a) compared with sediments of both unvegetated areas (b and c) (Table 2).

Sediments of the southern unvegetated sector (c) show significantly higher silt : clay ratios, whereas sediments of the northern unvegetated sector (b) show higher TOC content.

DISCUSSION

The distribution of *P. oceanica* meadow in the Gulf of Oristano revealed two unvegetated sectors related to the presence of the river mouth and the port embankment.

Both unvegetated sectors were characterised by high percentages of silt+clay content in the sediments allowing us to identify the deposition of finer sediments as an important factor limiting *P. oceanica* distribution in the studied site. By contrast, the two unvegetated sectors differed in terms of the spatial trend of the limit of the meadow, the silt : clay ratio, and the thickness of the silt+clay layer in the sediments.

In the northern area, the limit of the meadow is approximately perpendicular to the coastline, and the meadow is absent up to the river mouth.

The solid load of the river probably constitutes a natural limitation for *P. oceanica* meadow. The presence of the mead-

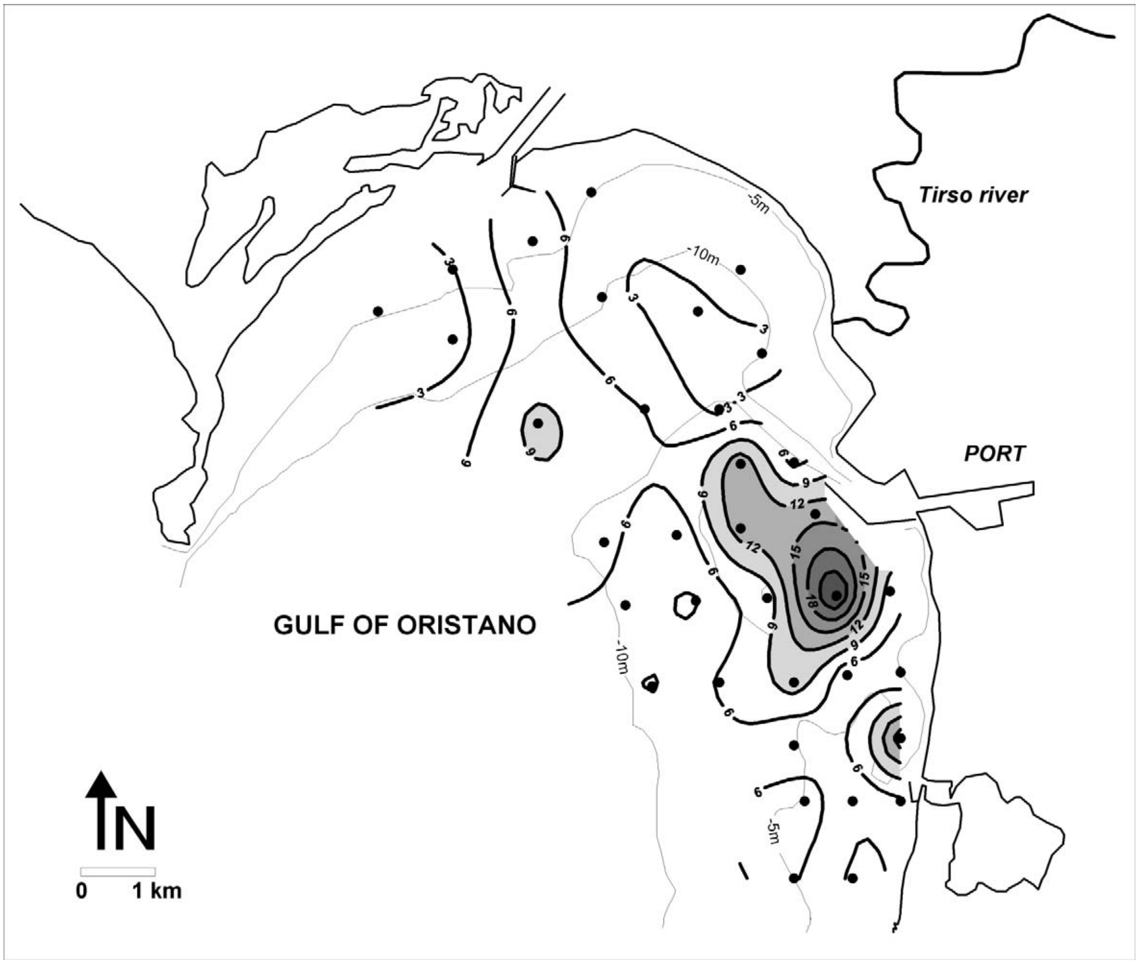

Figure 4. Contour map of the silt : clay ratio variability in the sediments. The areas with silt : clay ratio >9 are shaded.

ow in front of the port entrance (Figure 2) indicates that fine-sediment deposition, caused by river inflow, is mainly in the northern direction and toward the deepest area of the Gulf. Low values of silt : clay ratio (<6) indicate low-energy conditions that favour the accumulation of fine particulates. It is known that the development of seagrass meadows in deltaic areas may be limited by turbid water, which decreases light availability, as well as by the siltation due to the high sedimentation rate of fine-grained sediments (TERRADOS *et al.,* 1998).

The trend of the upper limit of the *P. oceanica* meadow in front of the port clearly indicate a regression due to the building of the embankment. The meadow limit moves away from the embankment that protrudes from the coastline for *ca.* 1.5 km and gets closer to the shoreline toward the south. Large amounts of silt+clay sediment were removed following the building of the port and the dredging of the channel in the 1970s. The dredged sediments should be dumped outside the Gulf of Oristano. It can be supposed that during the dredging, the finer fraction of the bottom sediments were resuspended, transported by currents outside the dredging area, and partly deposited in the southern area, which corresponds to the unvegetated sector close to the port. The silt fraction settled in this sector. Meanwhile, the clay fraction was dispersed in a wider area. This process seems confirmed by the presence of a thin layer (*ca.* 5 cm) of fine sediments (silt+clay >50%) with a low clay fraction content (silt : clay ratio >9), which overlapped sand sediments.

Sediment removal, dispersal, and deposition are probably the main factors determining the absence of the *P. oceanica* beds in this sector due to increased sedimentation following dredging, which triggered *P. oceanica* regression as result of siltation (CAVAZZA *et al.,* 2000; MANZANERA, PÉREZ, and ROMERO, 1995).

The spatial distribution of organic matter content in sediments confirms the differences between the two depositional environments of fine-grained sediments. Spatial distribution of TOC in sediments indicated that the northern unvegetated sector, with higher TOC values, is influenced by river inflow, unlike the southern unvegetated sector, which has lower TOC values. This pattern could be explained by the deposition in

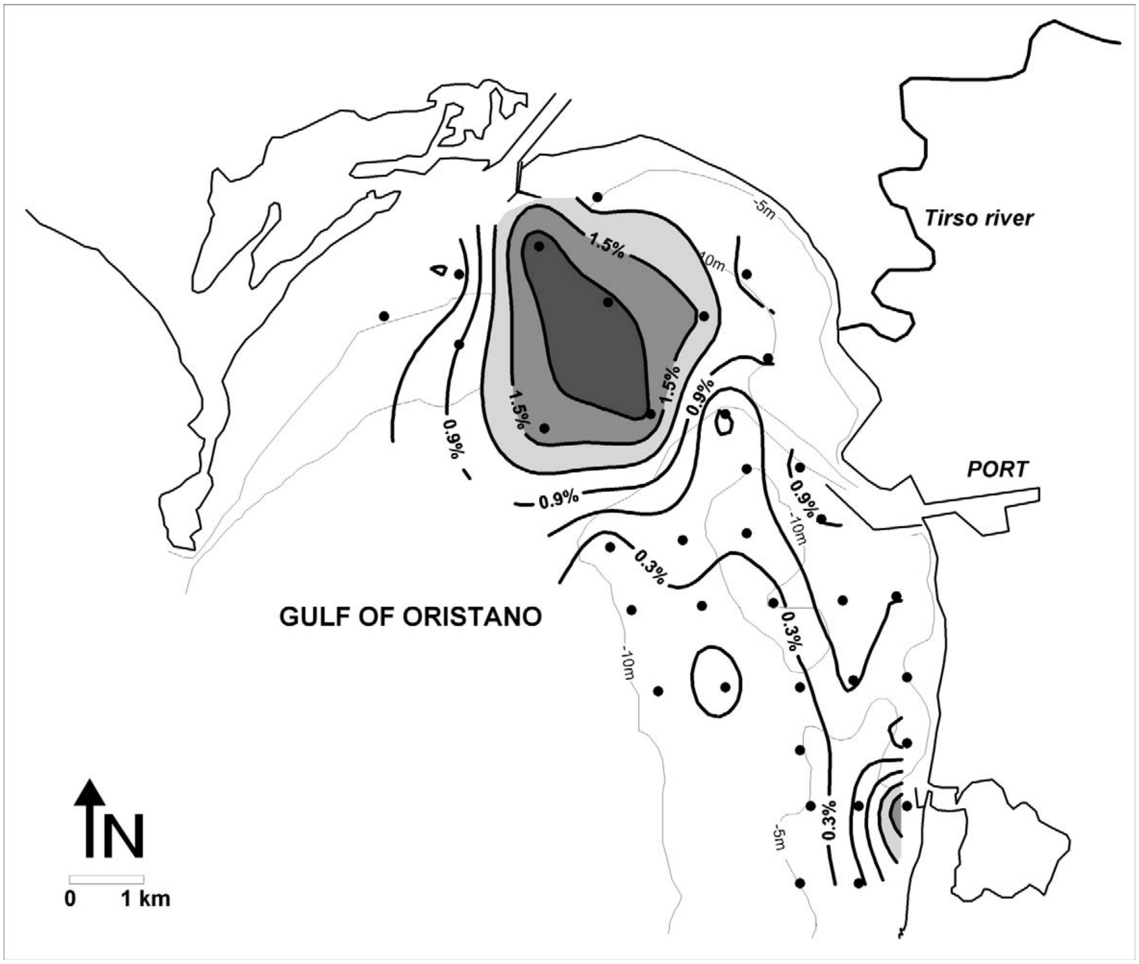

Figure 5. Contour map of the total organic carbon (TOC) content in the sediments. The areas with TOC content >1.2% are shaded.

Table 1. *Mean values of silt+clay content, silt : clay ratio and total organic carbon (TOC) content in the three depositional environments identified by aerial photo image processing.*

		Silt+Clay (%)		Silt : Clay Ratio		TOC (%)	
Depositional Environments	*n*	Mean	SD	Mean	SD	Mean	SD
Posidonia oceanica meadow (a)	20	21	16	4.1	2.3	0.5	0.6
Unv. Northern sector (b)	5	73	28	5.5	3.1	1.6	0.4
Unv. Southern sector (c)	10	48	32	11.8	6.7	0.5	0.3

Table 2. *Summary of one-way ANOVA results. Depositional environments are* Posidonia oceanica *meadow (a), river delta (b), and unvegetated area close to the port (c). Nonsignificant pairwise differences are underlined.*

	% Variability				
Dependent Variable	Among Depositional Environments	Within Depositional Environments	*F*	*p*	Pairwise Differences
Silt+clay	92	8	11.6	0.00016	abc
Silt : clay ratio	92	8	11.9	0.00013	abc
Total organic carbon	90	10	9.5	0.0059	abc

the southern sector of deeper sediments generally characterised by lower organic matter content.

Pasqualini *et al.* (1998), analyzing *P. oceanica* mapping along Corsica island (France), observed that the upper limit of *P. oceanica* meadows tends to move away from the coastline in the proximity of urban centres, port facilities, and coastal river mouths. The authors suggested that this phenomena can be caused by human activity or drops in salinity (Pasqualini *et al.,* 1998), but they did not support these hypotheses with other data that could explain the causes of meadow regression.

The findings of this study, with results of the comparison of sediment and vegetation data, seem to indicate the deposition of fine sediments as a limitation to *P. oceanica* meadow in the Gulf of Oristano. Following these results, further sediment analysis, using a more detailed grid sampling size, can contribute to a better inference of the origin and sediment transport pathway in the studied area.

In conclusion, sediment analysis evidenced two different depositional phenomena influencing *P. oceanica* distribution identified by photo aerial image analysis in the northern part of the Gulf of Oristano: (i) a "natural" limitation because of fine-sediment deposition in front of river mouth and (ii) an anthropogenic impact due to fine-sediment deposition related to dredging and port building.

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LITERATURE CITED

Boudouresque C.F.; Jeudy De Grissac, A., and Meinesz, A., 1984. Relations entre la sédimentation et l'allongement des rhizomes orthotropes de *Posidonia oceanica* dans la Baie d'Elbu. *In:* Boudouresque C.F.; Jeudy De Grissac, A., and Olivier, O. (eds.), *International Workshop on* Posidonia oceanica *Beds.* Marseille, France: GIS Posidonie Publishing 1, 185–191.

Carver, R.E., 1971. Procedures in sedimentary petrology. New York: John Wiley & Sons Inc., 653p.

Cavazza, W.; Immordino, F.; Moretti, L.; Peirano, A.; Pironi, A., and Ruggiero, F., 2000. Sedimentological parameters and seagrass distributions as indicators of anthropogenic coastal degradation at Monterosso Bay (Ligurian Sea, NW Italy). *Journal of Coastal Research,* 16(2), 295–305.

Davies, D.K. and Moore, W.R., 1970. Dispersal of Mississippi sediment in the Gulf of Mexico. *Journal of Sedimentary Petrology,* 40, 205–212.

De Falco, G.; Ferrari, S.; Cancemi, G., and Baroli, M., 2000. Relationships between sediment distribution and *Posidonia oceanica* seagrass. *Geo-Marine Letters,* 20, 50–57.

De Falco, G.; Molinaroli, E.; Baroli, M., and Bellacicco, S., 2003. Grain size and compositional trends of sediments from *Posidonia oceanica* meadows to beach shore, Sardinia, Western Mediterranean. *Estuarine Coastal and Shelf Science,* 58(2), 299–309.

Ergin, M. and Bodur, M.N., 1999. Silt/clay fractionation in surficial Marmara sediments: implication for water movement and sediment transport paths in a semi-enclosed and two-layered flow system (north-eastern Mediterranean Sea). *Geo-Marine Letters,* 18, 225–233.

Halun, Z.; Terrados, J.; Borum, J.; Kamp-Nielsen, L.; Duarte, C.M., and Fortes, M.D., 2002. Experimental evaluation of the effects of siltation-derived changes in sediment conditions on the Philippine seagrass *Cymodocea rotundata. Journal of Experimental Marine Biology and Ecology,* 279, 73–87.

Jeudy De Grissac, A. and Boudouresque C.F., 1985. Roles des herbiers de phanerogames marines dans les mouvements des sediments cotiers: les herbiers a Posidonia oceanica. *Colloque Franco-Japonais Oceanographie.* (Marseille, France, September 16–21, 1985), 1, 143–151.

Kranck, K. and Milligan, T.G., 1991. Grain size in oceanography. *In:* Syvitsky, J.P.M. (ed.), *Principles, Methods, and Application of Particle Size Analysis,* New York: Cambridge University Press, 332–345.

Larkum, A.W.D.; McComb, A.J., and Shepherd, S.A., 1989. Biology of Seagrasses. Amsterdam, The Netherlands: Elsevier, 841p.

Manzanera, M.; Pérez, M., and Romero, J., 1995. Seagrass mortalità due to oversedimenation: an experimental approach. Proceedings of the Second International Conference on the Mediterranean Coastal Environment MEDCOAST 95 (Terragona, Spain, October 24–27, 1995).

Marba, N.; Duarte, C.M.; Cebrian, J.; Gallegos, M.E.; Olensen, B., and Sand-Jensen, K., 1996. Growth and population dynamics of *Posidonia oceanica* on the Spanish Mediterranean coast: elucidating seagrass decline. *Marine Ecology Progress Series,* 137, 203–213.

Mazzella, L.; Scipione, M.B.; Gambi, M.C.; Buia, M.C.; Lorenti, M.; Zupo, V., and Cancemi, G., 1993. The Mediterranean seagrass *Posidonia oceanica* and *Cymodocea nodosa*: a comparative overview. First International Conference on Mediterranean Coastal Environment. MEDCOAST 93, (Antalya, Turkey, November 2–5, 1993), pp. 103–116.

Mazzullo, J.; Leschak, P., and Prusak, D., 1988. Sources and distribution of late Quaternary silt in the surficial sediment of the northeastern continental shelf of the United States. *Marine Geology,* 78, 241–254.

Molinaroli, E.; De Falco, G.; Rabitti, S., and Portaro, R.A., 2000. Stream-scanning laser system, electric sensing counter and settling grain size analysis: a comparison using reference materials and marine sediments. *Sedimentary Geology,* 130, 269–281.

Pasqualini, V.; Pergent-Martini, C.; Clabaut, P., and Pergent, G., 1998. Mapping of *Posidonia oceanica* using aerial photographs and side scan sonar: application off the island of Corsica. *Estuarine, Coastal and Shelf Science,* 47(3), 359–368.

Pergent, G.; Boudouresque, C.F.; Crouzet, A., and Meinesz, A., 1989. Cyclic changes along *Posidonia oceanica* rhizomes (lepidochronology): present state and perspective. *Marine Ecology,* 10, 221–230.

Shepherd, S.A.; McComb, A.J.; Bulthuis, D.A.; Neverauskas, V.; Steffensen, D.A., and West, R., 1989. Decline of seagrasses. *In:* Larkum, A.W.D.; McComb A.J., and Shepherd, S.A. (eds.), *Biology of Seagrasses.* Amsterdam, The Netherlands: Elsevier, 346–359.

Short, F.T. and Wyllie-Echeverria, S., 1996. Natural and human-induced disturbances of seagrasses. *Environmental Conservation,* 23(1), 17–27.

Terrados, J.; Duarte, C.M.; Fortes, M.D.; Borum, J.; Agawin, N.S.R.; Bach, S.; Thampanya, U.; Kamp-Nielsen, L.; Kenworthy, W.J., Geertz-Hansen, O., and Vermaat, J., 1998. Changes in community structure and biomass of seagrass communities along a gradient of siltation in SE Asia. *Estuarine, Coastal and Shelf Science,* 46, 757–768.

Terrados, J.; Duarte, C.M.; Kamp-Nielsen, L.; Agawin, N.S.R.; Gacia, E.; Lacap, D.; Fortes, M.D.; Borum, J.; Lubanski, M., and Greve, T., 1999. Are seagrass growth and survival constrained by the reducing conditions of the sediment? *Aquatic Botany,* 65, 175–197.

Walkley, A. and Black, I.A., 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science,* 37, 29–38.