RELATIONSHIPS BETWEEN SUSPENDED AND SEDIMENT ORGANIC MATTER IN A SEMI-ENCLOSED MARINE SYSTEM: THE STAGNONE DI MARSALA SOUND (WESTERN SICILY)

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Abstract. To gather information on the interactions between the sediment and suspended organic matter pools in the Stagnone di Marsala, water and sediment samples were collected, on a monthly basis, at 11 stations. Water temperature and salinity showed a clear seasonality whilst particulate and sediment organic matter did not show any clear seasonal pattern. Relative abundances of suspended and sediment organic matter, on the other hand, appeared to be site-dependent and controlled mainly by the dynamic balance between resuspension and sedimentation. High quantities of both suspended and sediment total organic matter were present, while very low algal biomasses (in terms of chlorophyll-a concentrations) were observed both in the suspended and sediment pools thus showing the oligotrophy of the site. The contribution of phytoplankton and microphytobenthos to the total organic content of suspended and sediment matter was negligible. The low food availability of organic matter in the Stagnone di Marsala Sound may explain the low abundance of suspension-feeding molluscs, which are substituted by limnovore and detritivore species.

Keywords: suspended matter, sediment organic matter, chloroplastic pigments, mediterranean sound, trophic relationships.

1. Introduction

It is known that in shallow coastal environments, the interactions between continental and marine energy inputs are major factors affecting primary and secondary production. Problems arising from the ecological interpretation of the functioning of a shallow water system may be partially solved through the study of its spatial homogeneity and temporal stability (Carrada and Fresi, 1988). Nevertheless, it has been demonstrated that, in such environments, the occurrence of unpredictable changes in salinity, oxygen and turbidity may foul the "classic curves" of production and consumption of the primary energy resources (Alpine and Cloern, 1992; Millet and Cecchi, 1992; Pusceddu and Fabiano, 1996; Serra *et al.*, 1995; Pusceddu *et al.* in press). The suspended and sediment pools of particulate organic matter, given their importance in the energy transfer from the primary production level to consumers, are usefull tools in understanding the quality and the quantity of trophic interactions. The functioning of an aquatic system cannot be completely assessed without the analysis of the particulate organic matter fluxes (Parsons, 1977). In addition, sediments, as a result of pelagic-benthic coupling processes, may be considered a record of the biological phenomena occurring in the overlying waters (Graf, 1992).

Shallow waters are characterized by the lack of coupling between primary and secondary production: i.e., a large part of the phytoplankton and/or macrophyte production may be trapped in the microbial-detritus chain rather becoming directly available for secondary production (Newell, 1982). Therefore it is necessary to assess the

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relative importance of detrital and living fractions of suspended and sediment organic matter, their spatial distributions and their relative abundances in lagoons, ponds and sounds.

In the present paper spatial and temporal changes in the suspended and sedimental organic matter in the Stagnone di Marsala, a semi-enclosed marine system (Western Sicily, Mediterranean Sea), are studied. The main aims are to understand which spatial and temporal patterns of variables may better describe the study site and to evaluate the potential role of resuspension processes on the distribution and food availability of suspended organic matter.

2. Material and Methods

The study was carried out in the sound Stagnone di Marsala (Figure 1) which is a shallow depression with a 7 km N-S axis. A low calcarenitic platform (Grande Island) separates the basin from the open sea. The sound is very shallow (average 1.5 m) with depth ranging from 0.2 m along eastern shore of the Isola Grande to 0.50 m in the western area and increases gradually to about 2.5 m in the southernmost area close to the open sea. The northern mouth (Bocca S. Teodoro) and the southern mouth (Bocca Grande) are 450 and 1450 m wide respectively. The latter is open to a sea water inflow with evident internal tides and the prevalence of southern winds. The northern mouth is only occasionally influenced by turbulent inputs of marine waters. The two major islands (S. Maria and S. Pantaleo), mechanical obstacles to the water flow in the middle of the basin generate turbulence. The ribbon-leaved seagrasses, particularly luxuriant in the southern basin greatly affect currents and silting. No land inputs were present during the year of investigation.

Superficial water samples (0.5 m) were collected monthly from January to December 1994, using 10 l Niskin bottles, at 11 stations located along a North-South transect (Figure 1). At the same time duplicate samples of superficial sediment were collected using manual corers. Water temperature, salinity and dissolved oxygen were measured *in situ* using a Hydrolab Inc. multiprobe. Water samples were screened through a 200 µm mesh net in order to remove larger zooplankton and debris, then aliquots (100 to 500 ml) were filtered onto prewashed, precombusted (450°, 4 h) and preweighed Whatman GF/F filters (0.45 µm nominal pore size) for the analyses of total suspended matter (TSM) and photosynthetic pigments.

For the determination of TSM, Whatman GF/F filters (0.45 µm nominal pore size) were weighed after desiccation (60°C, 24h) using a Mettler M3 balance (accuracy ± 1µg). Organic suspended matter (OSM) content was determined by loss on ignition (450°C, 4h; Strickland and Parsons, 1968). Sediment organic matter relative to the top (0-2 cm) was determined by loss on ignition (550°C, 4h; Parker, 1983).

Chlorophyll-a and phaeopigments concentrations (90% acetone extraction) were calculated according to Lorenzen and Jeffrey (1980) for suspended material and according to Danovaro and Fabiano (1992) for sedimentary material.

3. Results

3.1 WATER TEMPERATURE, SALINITY AND DISSOLVED OXYGEN

Temperature patterns were quite similar at all the stations showing a clear seasonal trend (Figure 2). The minimum temperature was observed in December at station 6 (11.8° C), while the maximum was measured in August at station 7 (28.6°C). Salinity also showed a clear seasonal trend (Figure 3), the minimum being recorded at station 5 in February (33.1‰), the maximum measured at station 1 in September (45.5‰). Dissolved oxygen reached highest values (up to 13.6 ppm) at station 10 in January and was relatively low only in July (minimum 4.4 ppm at station 4).

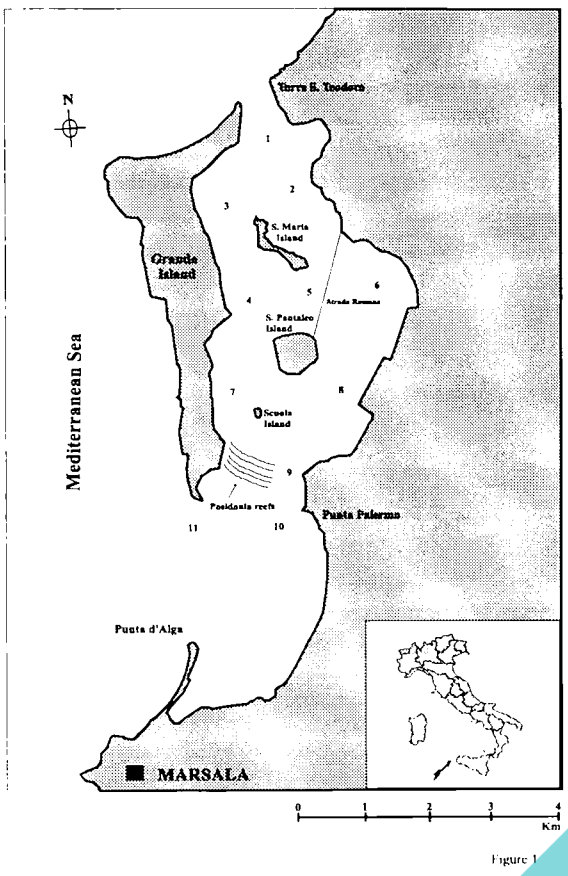

Figure 1

Figure 1. The Stagnone di Marsala Sound (Western Sicily) showing the 11 sampling stations, representing a transect from N to S.

The data were analysed by Principal Component Analysis (PCA) (Flury, 1988) using monthly environmental rank (Spearman rank transformation) transformed matrixes. For each set of variables it was possible to obtain two results; PCA organized by variable (Q-type analysis) and PCA organized by station (R-type analysis).

3.2 SUSPENDED MATTER

The annual mean concentration of TSM was quite high in 1994; varying between 2.4 ± 0.4 mg l^{-1} (August) and 12.0 ± 10 mg l^{-1} (February). The highest concentration was observed in January (49.0 mg l^{-1}) at Sta. 1, whilst the lowest was measured in April (1.6 mg l^{-1}) at Sta. 8. Suspended organic matter concentrations appeared quite constant at all sampled stations throughout the year (Figure 4). The maximum concentration (13.0 mg l^{-1}) occurred in February at Sta. 3, the minimum (0.20 mg l^{-1}) in October at Sta. 9. The Chlorophyll-a concentrations (Figure 5) ranged between 0.02 µg l^{-1} (Sta. 1, January) and 2.0 µg l^{-1} (Sta. 1, July). The highest values were measured in January and February (on average 0.55 ± 0.38 µg l^{-1}) whilst the lowest were recorded in June (0.19 ± 0.11 µg l^{-1}). Chlorophyll-a concentrations in the northern stations were on average significantly higher than those measured in the southern one. Phaeopigments were significantly correlated with chlorophyll-a ($r=0.98$; $p<0.001$) and showed the same temporal patterns (Figure 5). Highest concentrations were recorded in January (0.20 ± 0.19 µg l^{-1}) and March (0.20 ± 0.12 µg l^{-1}).

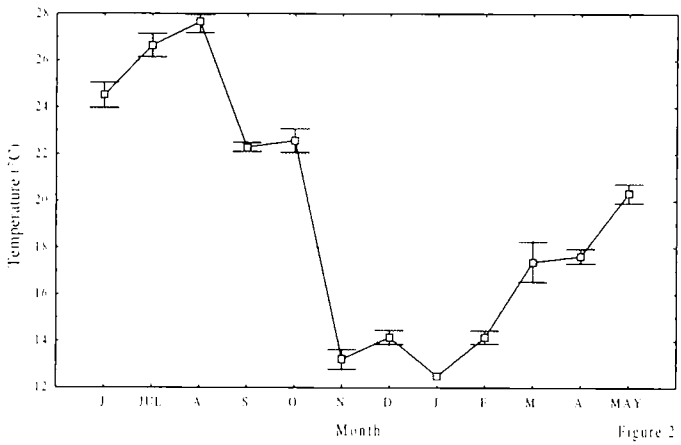

Figure 2. Seasonal pattern of water temperature (°C) in the Stagnone di Marsala Sound during 1994. Standard deviations from mean values of all 11 stations are reported.

3.3 SEDIMENTARY PARAMETERS

Total organic matter content of the sediments did not show evident seasonal changes (Figure 6a). Only in autumn, especially in November were sediments extremely rich in organic matter (305.5 ± 255.5 mg g^{-1}). The maximum organic matter content was recorded at Sta. 2 in November (972.2 mg g-1), the minimum at Sta. 1 in January (17.0 mg g^{-1}). Chlorophyll-a content of the sediments varied from 1.30 µg g^{-1} (January) to 5.28 µg g^{-1} (April). Concentrations of sedimental chloroplastic pigments (i.e. the sum of chlorophyll-a and phaeopigments, CPE, Figure 6b) showed an evident N-S gradient (Figure 7). The contribution of phytodetritus (as CPE concentrations) to the total

sediment organic matter content, was very low (less than 0.2 ‰) but higher, however, in the mid stations (4-6) rather than in proximity to the open sea.

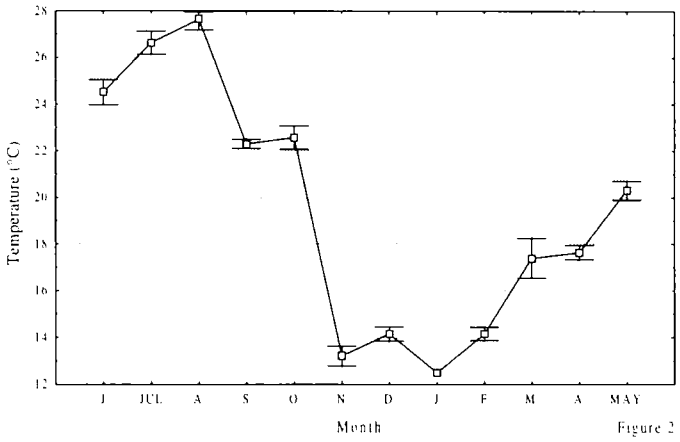

Figure 3. Seasonal pattern of salinity (‰) in the Stagnone di Marsala Sound. Standard deviations from mean values of all 11 stations are reported.

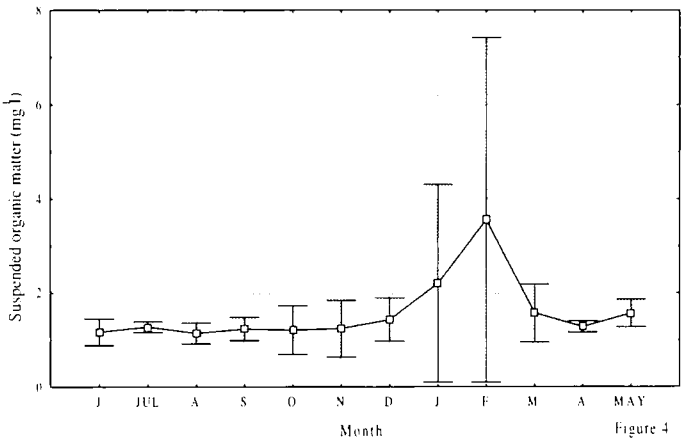

Figure 4. Concentrations of suspended organic matter (mg l^{-1}) in the Stagnone di Marsala Sound. Standard deviations from mean values of all 11 stations are reported.

4. Discussion

Sarà *et al.* (1995) highlighted the role of water exchange between the open sea and the interior sites of the Stagnone di Marsala Sound in determining short-term quantity and biochemical composition of particulate organic matter. They showed that the southern

area of the Stagnone Sound is generally characterized generally by sea vivification and by allochtonous (marine) particulate organic matter. In contrast the northern area is

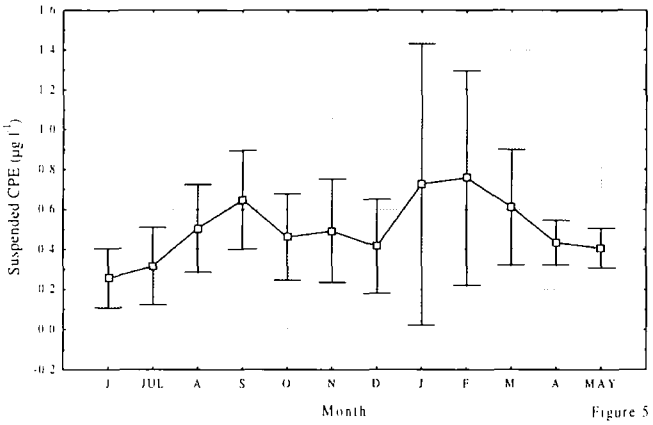

Figure 5. Concentrations of suspended chloroplastic pigments equivalents (µg l^{-1}) in the Stagnone di Marsala Sound. Standard deviations from mean values of all 11 stations are reported.

scarcely influenced by the open sea and is characterized by particulate organic matter deriving mostly from resuspension.

Results from the present study suggest that processes of resuspension and sedimentation, influence to different degrees both the suspended and sediment pools of organic matter in the whole study area. Total suspended matter and the concentrations of its autotrophic component (i.e. chlorophyll-a) decrease from the northern to the southern sampling sites (Figure 8). Although no measure of water currents or downward fluxes of particulate matter are available for the study area, we hypothesize that this pattern results from the attenuation of resuspension processes along a N-S transect according to the depth profile of the sound. The sediment organic matter (in terms of total organic matter and its autotrophic component expressed as CPE) reached the highest concentrations in the central stations (Figure 7), suggesting that sedimentation processes increase along the same N-S transect, becoming still greater as the *Posidonia oceanica* bed (Figure 1) is approached. This large seagrass bed acts as a mechanical barrier to the lateral drifting of suspended matter, giving rise to an increase in the sinking velocities of suspended particles.

Results of the principal component analysis (Table 1; Figure 9) only partially confirm our hypotheses about the role of resuspension and sedimentation processes in affecting the spatial distribution of organic matter in the Stagnone di Marsala Sound. Sta.1 (northern area) and Sta. 5 (mid-lagoon) clearly represented the spatial segregation of, respectively, resuspension and sedimentation processes, the latter being influenced by the *Posidonia oceanica* bed (Figure 1). All other stations showed no clear segregation or pattern.

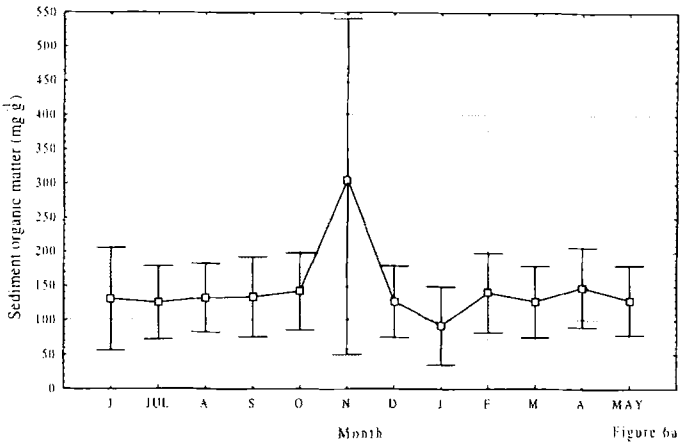

Figure 6a

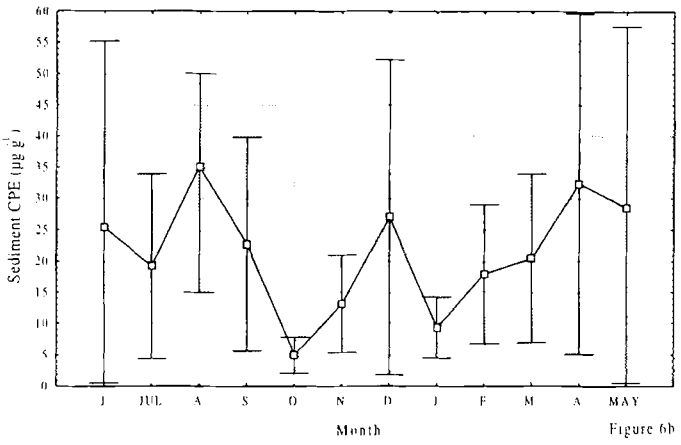

Figure 6b

Figure 6. Total organic matter (a, mg g^{-1}) and chloroplastic pigments equivalents (b, µg g^{-1}) in the sediments (top 0-2 cm) of the Stagnone di Marsala Sound. Standard deviations from mean values of all 11 stations are reported.

Although further investigation of the sedimentation rates and the biochemical composition of organic matter should strengthen our hypothesis, we suggest that resuspension may be utilized profitably to explain some trophic interactions. Indeed, Hopkinson, (1985) suggested that resuspension determines the relative amounts of organic carbon as well as the sites and rates of organic matter degradation in the benthos and water column. Moreover, Wainright (1987; 1990) performing feeding experiments by means of heterotrophic microorganisms as consumers of resuspended organic matter, demonstrated that microbial growth was stimulated by resuspension of sediment. Thus, resuspension could significantly enhance microbial degradation of suspended organic matter and appear to influence POM cycling, persisting much longer than resuspension even itself.

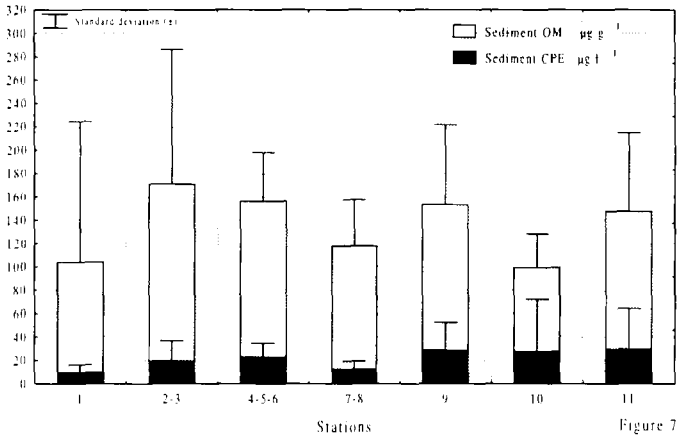

Fig. 7 - Spatial distribution (annual average) of chloroplastic pigments equivalents and total organic matter in the sediments (top 0-2 cm) of the Stagnone di Marsala Sound. Stations 2-3, 4-5-6 and 7-8 were averaged to obtain a N-S transect representation.

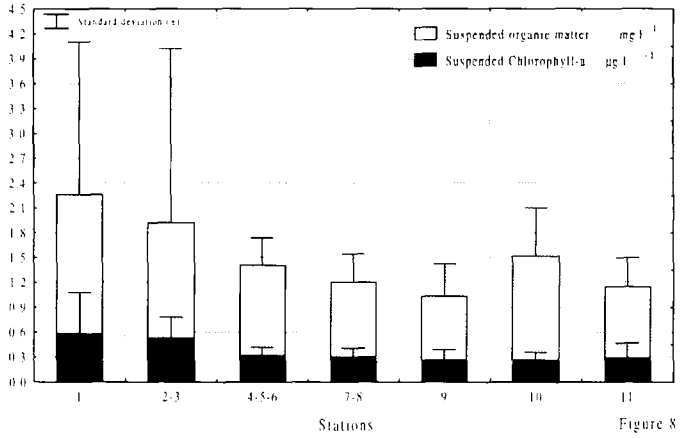

Figure 8. Spatial distribution (annual average) of suspended chlorophyll-a and total suspended matter in the Stagnone di Marsala Sound. Stations 2-3, 4-5-6 and 7-8 were averaged to obtain a N-S transect representation.

This appears even more probable in shallow water systems, where unpredictable changes in the major environmental variables affect sediment resuspension (Pusceddu and Fabiano, 1996; Pusceddu *et al.*, in press) and, consequently, plankton ecology (Alpine and Cloern, 1992; Millet and Cecchi, 1992). In oligotrophic sites, such as the Ligurian Sea (Albertelli and Fabiano, 1990) resuspended particles are principally composed of

refractory matter and only contribute in a limited way to the nutritional needs of the suspension feeder community. In these areas benthic filter feeders meet their nutritional needs mainly from bacteria bound to suspended particles (Danovaro and Fabiano, 1995). In contrast, in eutrophic areas, such as Mediterranean coastal lagoons (Pusceddu and Fabiano, 1996) suspension feeders reach their food requirements by filtering particles which mainly originate from the resuspension of nitrogen enriched phyto-detritus rather than directly from living phytoplankton.

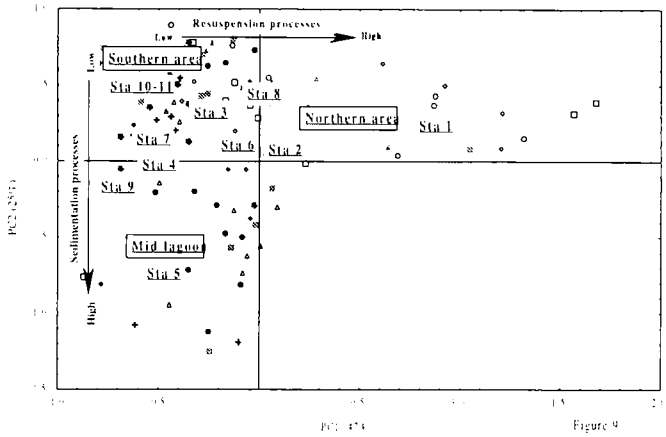

Figure 9. Results of the Principal Component Analysis organized by station.

Table I

Principal Components Analysis: variance explained by the system and relative contribution of each variable on the two factorial axis (PC1, PC2)

Variable	PC1	PC2
Suspended Organic Matter	0.80	-0.11
Suspended Inorganic Matter	0.87	-0.08
Suspended Chlorophyll-a	0.94	-0.08
Suspended Phaeopigments	0.95	-0.08
Sedimental Chlorophyll-a	-0.20	-0.88
Sedimental Phaeopigments	-0.15	-0.90
Sedimental Organic Matter	-0.03	-0.04
Total variance (%)	**47**	**25**

In this study phytoplankton and microphytobenthos biomasses, in terms of chlorophyll-a concentrations, were very low (on average less than 0.3 $\mu g\ l^{-1}$ and 2.9 $\mu g\ g^{-1}$ respectively), confirming the oligotrophy of the site, and contributing little to the suspended and sediment organic matter pools (on average less than 0.1 and 0.2 ‰ respectively). Thus, we may assume that most of the organic matter in the Stagnone di Marsala Sound is of

detrital (non-living) and heterotrophic origin. Moreover, owing to the presence of the large *Posidonia oceanica* bed in the southern area of the sound, it is expected that a large fraction of the organic matter pool is refractory and, thus, unappetizing to consumers.

This hypothesis has been confirmed by the analysis of the biochemical composition of particulate organic matter performed in the study by Sarà *et al.* (1995). They found that the contribution of the labile fraction to the bulk particulate organic matter, used as a food index (Navarro *et al.*, 1993), was quite low (on average about 20%; range 2-30 %) when compared with values found in Mediterranean shallow coastal lagoons (on average 50%; range 30-100%, Pusceddu *et al.*, in press). The low food availability of organic particles may explain partially the low abundance of suspension-feeding molluscs, which are substituted by limnovore and detritivore species (Chemello, pers. comm.).

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