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ORIGIN AND DISTRIBUTION OF SUSPENDED ORGANIC MATTER AS INFERRED FROM CARBON ISOTOPE COMPOSITION IN A MEDITERRANEAN SEMI-ENCLOSED MARINE SYSTEM

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The origin and distribution of suspended organic matter, the trophic features and the stable carbon isotopic composition of particulate organic carbon (POC) were studied monthly in a Western Mediterranean semi-enclosed basin. Sampling stations were selected as a function of wind-exposure and the degree of vegetation cover and then compared with an adjacent unvegetated site. The predominant vegetation was seagrass (*Posidonia oceanica* and *Cymodocea nodosa*) and *Caulerpa prolifera*. Water samples were analyzed for total suspended matter (inorganic and organic fractions), photosynthetic pigments (chlorophyll-a and phaeopigments), dissolved organic carbon, particulate organic carbon and their isotopic composition. Temperature and salinity were also measured at the same sampling sites within range of Mediterranean limits. The suspended organic matter concentration was $1.77 \pm 1.55\,mg\,l^{-1}$; the chlorophyll-a concentration was low ($0.35 \pm 0.24\,\mu g\,l^{-1}$); the dissolved organic carbon concentration was $2{,}140 \pm 2{,}010\,\mu g\,l^{-1}$; the particulate organic carbon concentration was $212 \pm 106\,\mu g\,l^{-1}$ and the isotopic composition was $18.77 \pm 2.51‰$. There were significant temporal differences except for phaeopigments, POC and its POC isotopic composition, and there were no spatial differences other than for $\delta^{13}C$. This picture highlighted a general seasonal trend and trophical features similar to adjacent sea.

Spatial differences in $\delta^{13}C$ showed that the source of suspended organic matter was different between stations as that between sources and wind-hydrodynamic constraints. In

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adjacent open sea, the phytoplankton component was identified as being the main isotopic signal of POC. In the Stagnone, resuspension from exposed sites and sedimentation into sheltered sites control biological dynamics, depending on wind exposition. Consequently, the dominance of the first or the second process determines the typology and the development of vegetation, allowing it to recognize different sub-systems where the origin and distribution of particulate organic carbon could be different. A first sub-system was exposed to dominant winds and affected by sediment erosion which was from wind-induced turbulence, and had a main effect on limited submersed vegetation. The POC isotopic composition ($\delta^{13}C = -18.5‰$) reflected a contemporary contribution of macrophyte and microphytobenthos. The combined effects of resuspension-sedimentation-lateral drifting permitted the autotrophic unicellular biomass marker to predominate, compared to *Cymodocea* and *Caulerpa*. The second sub-system was represented by the vitality of the waters and by unpredictability which was due to wind pulsing. As a result, a seasonal regime predominate by the trend in the seagrass leaves component (*Posidonia oceanica* and *Cymodocea nodosa*). The POC isotopic composition followed the seagrass, showing the heaviest values (spring and summer) in peaks in leaf biomass, and the lightest values in autumn and winter when the biomass was low.

Keywords: Organic matter sources; carbon isotope ratio; DOC; POC; MED

1. INTRODUCTION

In recent years, several studies have demonstrated that carbon stable isotope measurements allowed us to recognize the sources of carbon (*e.g.*, seagrass, macroalgae, microphytobenthos, phytoplankton or detritus) that affect the pool of suspended organic matter and trophic dynamics in shallow seas (Fry, 1984; Fry and Sherr, 1984; Mann, 1988; Rau *et al.*, 1991; Michener and Shell, 1994).

In these conditions, changes in the input of suspended organic matter (also by hydrodynamics, tides, internal seiches), have a primary role in affecting the quality and quantity of food sources for consumers (Albertelli and Fabiano, 1990; Fegley *et al.*, 1992; Sarà and Mazzola, 1997; Sarà *et al.*, 1998; Sarà *et al.*, in press). The main consequence is often an unpredictable spatio-temporal variability in the trophic components of these systems.

The semi-arid shallow systems of the southern Mediterranean Sea are characterized by a low or non-existent continental inflow. The main energy source is by wind-induced waves which often produces highly frequent and persistent resuspension events in exposed sites (Painchaud *et al.*, 1996; Sarà *et al.*, in press) affecting the distribution of suspended organic matter by means of lateral drifting. In wind-sheltered sites, the distribution of suspended organic matter is strongly constrained by water-dynamics.

In the Mediterranean, this picture can be important in studies dealing with physical and chemical constraints which affect the organic matter exchanges between different compartments where the primary production from phytoplankton, macroalgae and seagrass generally exceeds consumption by herbivores (Newell, 1982). Organic matter is directly available to consumers but it is highly refractory (Pirc, 1989) and needs to be fragmented and processed by means of bacterial decomposition (Pirc and Wollenweber, 1988; Hansen *et al.*, 1992).

Few studies deal with South Mediterranean environments (Giani *et al.*, 1995; Mazzola and Sarà, 1995; Sarà *et al.*, 1995; Pusceddu *et al.*, 1996; Sarà *et al.*, in press), with respect to other shallow areas (lagoons, sounds or estuaries), showing great variability of their trophic state (Painchaud *et al.*, 1990; Navarro *et al.*, 1993; Clavier *et al.*, 1995; Painchaud *et al.*, 1995; Savenkoff *et al.*, 1995; Sarà *et al.*, in press). Information about the role of the main source of suspended organic matter through carbon isotopic composition are quite scarce (Faganeli *et al.*, 1988; Dauby, 1989; Faganeli *et al.*, 1989; Posedel and Faganeli, 1991; Tufano, 1991; Jennings *et al.*, 1997).

In this paper, the spatial and temporal changes in the origin of particulate organic carbon in the Stagnone of Marsala, a semi-enclosed marine system (Western Sicily, Mediterranean Sea), will be studied. The main aims are: (1) to highlight the origin and distribution of particular organic carbon as a function of different sources; (2) to verify the existence of environmental constraints that affect the sources and spatio-temporal distribution of particular organic carbon and (3) to check how the carbon isotope measurements can improve the dynamic model of the Stagnone of Marsala.

2. MATERIAL AND METHODS

2.1. Study Site

The Stagnone of Marsala (15 km^2, 37° 52′ N, 12° 28′ E) (Fig. 1) is a semi-enclosed basin and is separated from the open sea by a low calcareous ooze (Grande Island). The northern mouth has a muddy bottom, and is 450 m wide, and allows turbulent inputs of marine waters. The southern mouth is 1450 m wide and is open to the sea

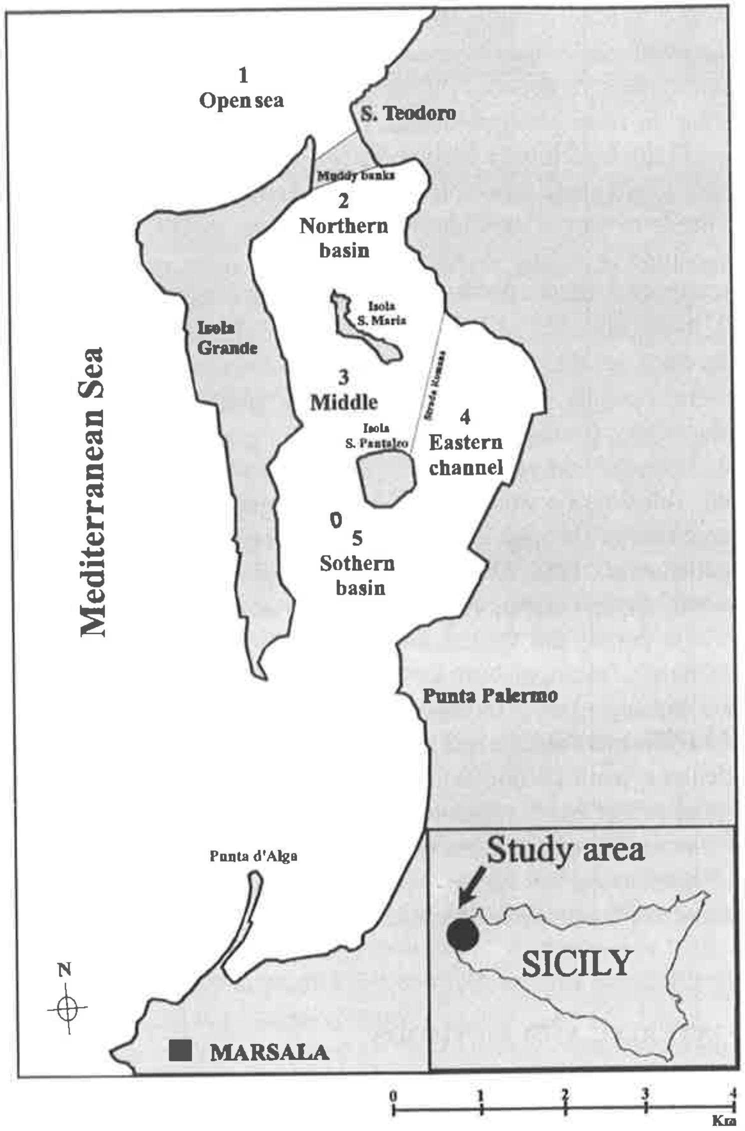

FIGURE 1 The study site.

water inflow. Three islands (S. Maria, S. Pantaleo and La Scuola) and Strada Romana (Roman Road) act as mechanical obstacles to the water flow in the middle of the basin and generate turbulence. The

dominant seagrasses are *Cymodocea nodosa* and *Posidonia oceanica,* the former luxuriant in the southern and central area. Macroalgae, principally *Caulerpa prolifera*, occurred, often coupled with *Cymodocea* at the station mostly exposed to the wind (Sarà *et al.*, submitted). No land inputs are present. Water exchange is ensured by currents with speeds ranging from 5.10 ± 1.54 cm s^{-1}in the southern mouth and from 2.21 ± 0.87 cm s^{-1} in the northern area.

2.2. Sampling and Environmental Variables

Superficial water samples (0.5 m depth) were collected monthly from March 1996 to February 1997, using 10 l Niskin bottles, at 5 stations located along a north–south transect (Fig. 1). They were characterized by having a different vegetal cover (Tab. I) (as degree of coverage) proposed by Scilipoti (1997) and Scilipoti *et al.* (1997) and confirmed by remote sensing (Calvo *et al.*, 1996). To obtain isotopic data of the particular organic carbon ($\delta^{13}C_{(POC)}$), total suspended matter (TSM), suspended pigments and particular organic carbon (POC) in 2000–4000 ml of water was filtered in a gentle vacuum using Whatman GF/F glass-fibre filters. The filtered water was analyzed for dissolved organic carbon (DOC). On each sampling date, water temperature and salinity were measured *in situ* using a Hydrolab multiprobe, and salinity values from the probe were tested monthly using silver nitrate titration.

TABLE I Features of sampling sectors at Stagnone of Marsala

Site	*Substrate*	*Depth (m)*	*Cover density*	*Exposure*	*Vegetation*
Station 1 Open-sea	Sand-muddy	5	Absence	Exposed	Unvegetated
Station 2 Northern basin	Muddy-sand	1.05	Average	Exposed	*Cymodocea nodosa* *Caulerpa prolifera*
Station 3 Middle basin	Sandy	1.20	High	Sheltered	*Cymodocea nodosa* *Posidonia oceanica*
Station 4 East Channel	Muddy-sand	1.10	Low	Partially Exposed	*Cymodocea nodosa* *Caulerpa prolifera* Other macroalgae
Station 5 Southern basin	Sandy	1.00	High	Sheltered	*Cymodocea nodosa* *Posidonia oceanica*

2.3. Suspended Matter Features

To determine TSM, Whatman GF/F filters (0.45 μm nominal pore size) were weighed after desiccation (60°C, 24 h) using a Sartorius A200 balance (accuracy ± 1 μg). Suspended organic matter (OSM) concentrations were determined after loss on ignition (450°C, 4 h; Strickland and Parsons, 1969). Chlorophyll-a (CHL-a) analyses were carried out according to Lorenzen and Jeffrey's (1980) method by using a spectrophotometer Jasco (Mod. V-530). Phaeopigments (PHAEO) were determined after acidification with 0.1N hydrochloric acid. The sum of chlorophyll-a and phaeopigment was reported as chloroplastic pigments equivalents (CPE; Pfannkuche, 1993). Particular organic carbon was determined with a CHN Elemental Analyzer (Perkin-Elmer Mod. 2400), using acetanilide at 925°C as a standard, after the removal of inorganic carbon (Iseki *et al.*, 1987). DOC measures were carried out with Shimadzu TOC (Mod. 5000) (Sugimura and Suzuki, 1988).

Water samples for determining the composition of isotopic carbon were treated with 1N hydrochloric acid, then rinsed and dried (60°C; 24 h). Plankton, macroalgae, seagrass isotopic analyses were performed as above (2N hydrochloric acid); macroalgae and seagrass were scraped for vegetal epiphytes. The organic carbon was converted to carbon dioxide by combustion over cupric oxide (550°C, overnight) in a Pyrex tube. Purified carbon dioxide was analyzed by a mass spectrometer (Delta S, Finnigan MAT) and the results, expressed in the usual δ‰ units, were reported against the PDB international standard. The reproducibility of the δ^{13}C determination was ± 0.2‰.

A Spearman-Rank correlation was performed to test correlation degree between measured variables (Sokal and Rohlf, 1981). Data were ordered by means of a principal components analyses (PCA; Flury, 1988) using station by month environmental matrixes. Statistica (Statsoft Inc.; rel. 5.1) was used to perform statistical analysis.

3. RESULTS

Table II summarizes main statistics of measured hydrological parameters. Temperature and salinity (Fig. 2) showed seasonal trends with a significant peak in summer and lower values between November and March. No significant differences occurred between open sea and inner sectors but a qualitative positive gradient was observed along a north – south transect.

Organic (OSM) and inorganic (ISM) fractions of total suspended matter (TSM) were significantly correlated ($n = 60$; $r_s = 0.74$; $p < 0.05$) and showed a peak in July (Fig. 3a). Maximum values were reached in middle and eastern stations whilst the lowest values occurred in the southern basin (Fig. 3b), although no significant spatial differences were observed.

TABLE II Statistics of the measured variables. See the text for acronyms

Variables	*Mean*	*±s.d.*	*Min*	*Max*
T(°C)	18.8	5.5	11.2	29.1
S (psu)	38.6	3.2	32.8	47.1
OSM (mg l^{-1})	1.8	1.6	0.1	10.1
ISM (mg l^{-1})	4.3	5.5	0.7	28.4
CHL-a (μg l^{-1})	0.4	0.2	0.0	1.3
PHAEO (μg l^{-1})	0.2	0.1	0.0	1.7
DOC (mg l^{-1})	2.1	2.0	0.0	8.5
POC (μg l^{-1})	211.6	106.0	22.5	1,344
δ^{13}C (‰)	– 18.8	2.5	– 25.1	– 13.7

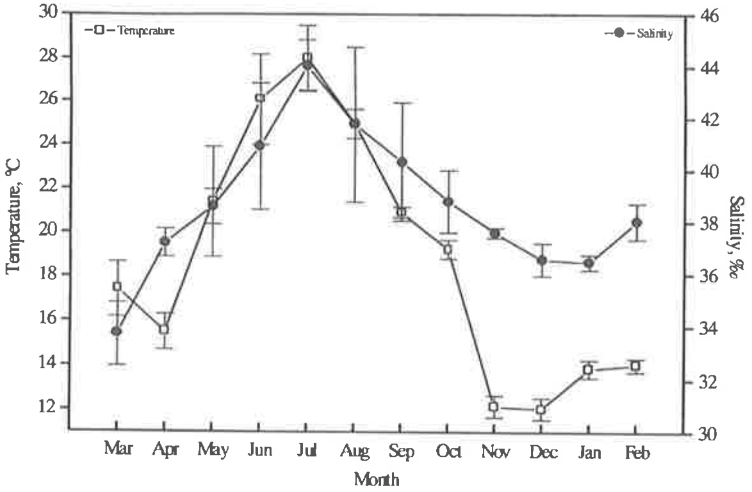

FIGURE 2 Monthly trend of temperature (°C) and Salinity (psu) in the Stagnone. Standard deviations are reported.

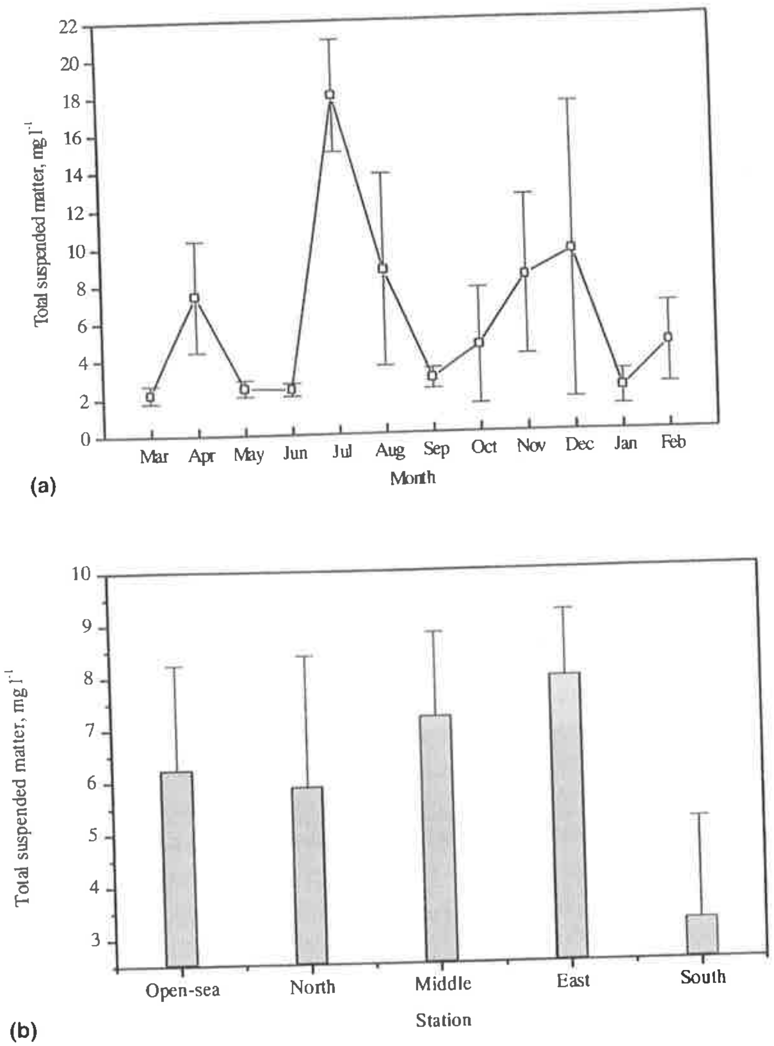

FIGURE 3 Monthly trend (a) and spatial pattern (b) of total suspended matter (TSM; mg l^{-1}) in the Stagnone. Standard deviations are reported.

The trend of phytoplankton biomass (as chlorophyll-a concentration) (Fig. 4a) was marked by two primary peaks (May and October) and by a secondary peak (December), lowest values being reached in February. Chlorophyll-a concentration reached maximum values in

the open-sea and in the northern and middle basin (Fig. 4b). Phaeopigments showed a primary peak in correspondence to chlorophyll-a in May; secondary peaks were observed in November and

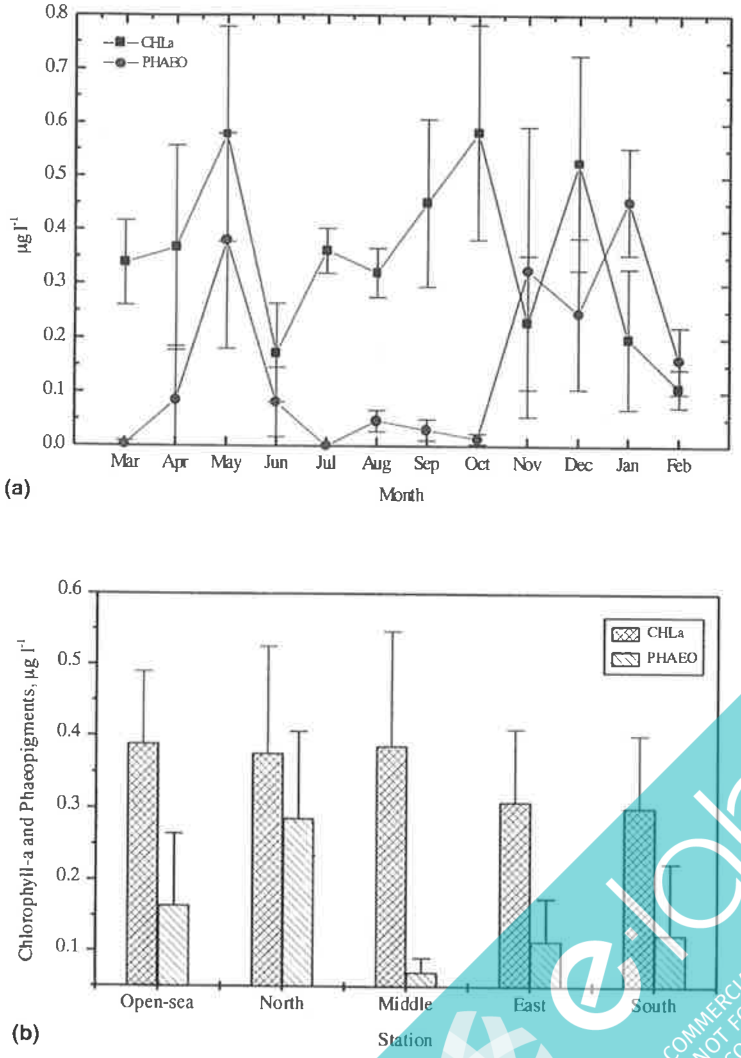

FIGURE 4 Monthly trend (a) and spatial pattern (b) of chlorophyll-a and phaeopigments (CHL-a and Phaeo; µg l^{-1}) in the Stagnone. Standard deviations are reported.

January with some time-delay respective to chlorophyll-a (Fig. 4a). Spatial pattern was different to chlorophyll-a, reaching a maximum value in the northern basin and a minimum value in the middle sector (Fig. 4b).

Dissolved organic carbon showed two marked loading periods in spring and summer (Fig. 5a), both of which preceded the chlorophyll-a peaks. DOC maximum values were reached in the middle and southern sectors, whilst they were minimum in the open sea and in northern sectors (Fig. 5b).

Particulate organic carbon showed maximum values in late spring and in winter (Fig. 6) and minimum values in summer and autumn. The POC pattern was different to the DOC in the other stations, except for the highest values in middle sector. The $\delta^{13}C_{(POC)}$ values ranged between $-25.1‰$ to $-13.7‰$ (Tab. II) with the highest in summer (Fig. 6). Significant differences in $\delta^{13}C_{(POC)}$ were found between the open sea and sites within the Stagnone with higher values in the middle station, corresponding to a maximum in POC concentration (Fig. 7).

Isotopic analyses were carried out on some organic carbon sources: seagrass (*Posidonia* and *Cymodocea*; $\delta^{13}C = -7‰$), macroalgae

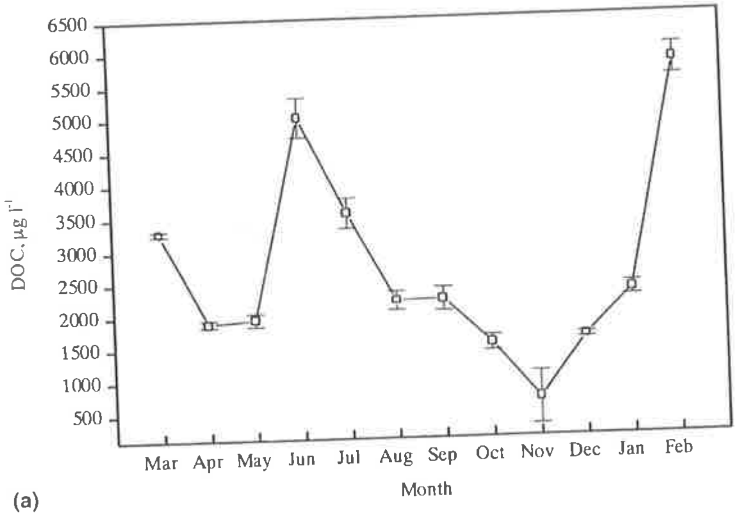

FIGURE 5 Monthly trend (a) and spatial pattern (b) of dissolved organic carbon (DOC; $\mu g\, l^{-1}$) in the Stagnone. Standard deviations are reported.

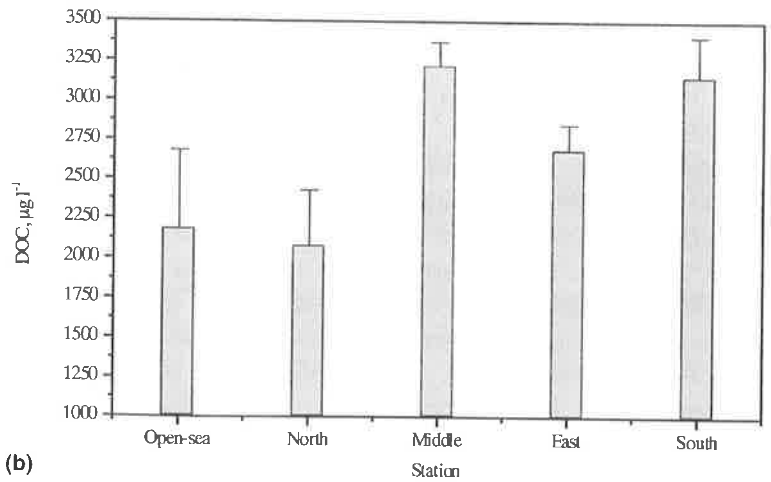

FIGURE 5 (Continued).

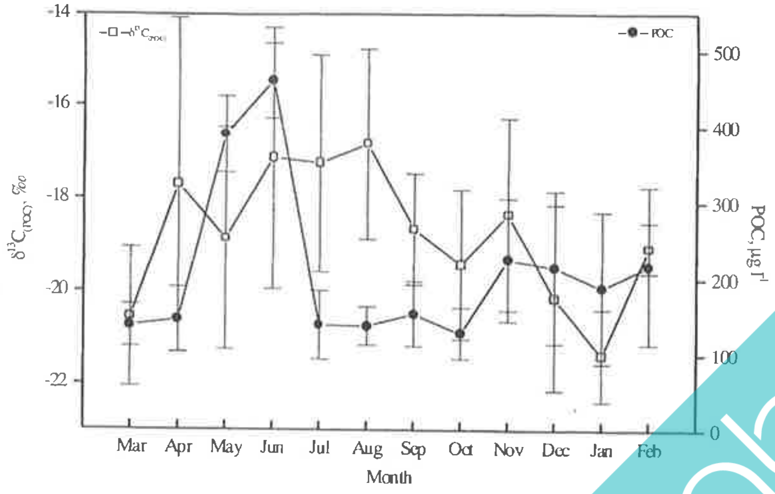

FIGURE 6 Monthly trend of particulate organic carbon (POC; $\mu g\, l^{-1}$) and $\delta^{13}C_{POC}$ (‰) in the Stagnone. Standard deviations are reported.

(*Caulerpa*, *Ritiphlea*, *Rodophicaee*, *Laurencia*, *Halimeda* and *Cystoseira* sp; $\delta^{13}C = -13.5‰$) and plankton (phytoplankton and zooplankton; $\delta^{13}C = -21/-22$ ‰).

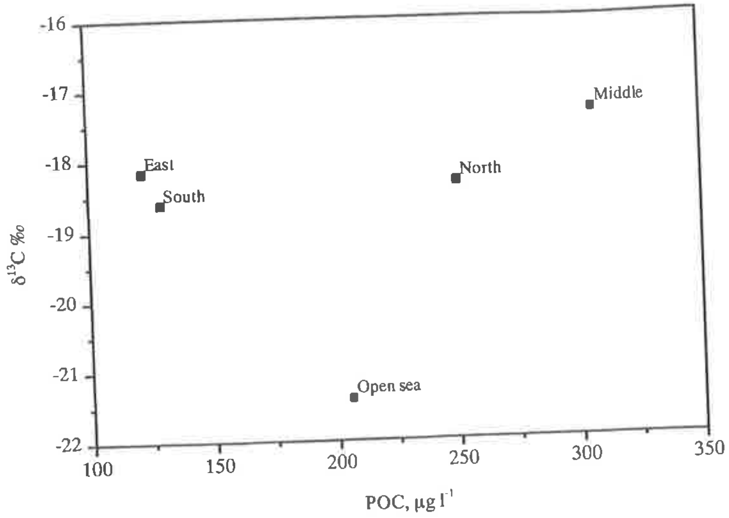

FIGURE 7 Spatial pattern of carbon stable isotope ratio of particulate organic carbon ($\delta^{13}C_{POC}$, ‰) *vs.* concentration of particulate organic carbon (POC, µg l^{-1}) in the Stagnone.

4. DISCUSSION

The Stagnone of Marsala is a Mediterranean semi-enclosed marine system, characterized by the absence of chemical–physical gradients (*i.e.*, temperature and salinity). The low chlorophyll-a concentrations (*i.e.*, CHL-a < 1.0 µg l^{-1}) were similar to these found in the adjacent sea. DOC mean concentration (2.14 mg l^{-1}) was lower than that of Egadi Islands (4.54 mg l^{-1}; Sarà, in perparation), but higher in other Mediterranean values (1.5 mg l^{-1}; Copin-Montegut and Avril, 1993) or in other oceanic or coastal values (Mantoura and Woodward, 1983; Sugimura and Suzuki, 1988; Guo *et al.*, 1995). The absence of any differences in DOC concentrations between the sea and the sound may show that the trophic background similar and consequently each local escape is probably due to physical constraints and/or to *in situ* production and decomposition processes.

Unlike "true" lagoons (Pusceddu *et al.*, 1996; Friligos *et al.*, 1989; Chassany de Casabianca *et al.*, 1995) or estuaries (Painchaud *et al.*, 1995; Savenkof *et al.*, 1995; Clavier *et al.*, 1995), where chlorophyll-a and DOC concentrations are higher than in the adjacent sea, and where often in the whole of the year, the living fraction (mostly labile) represents most of the particular organic carbon, in the Stagnone, the carbon content of the living biomass rarely exceeds 10% of a non-living fraction. Relatively high DOC concentration, high photosynthetic rates (2 mg C m^{-3} h^{-1}; Magazzù, 1977) and a significant correlation between chlorophyll-a and POM concentrations (Sarà *et al.*, 1995) could show that suspended pigments could be derived from a living planktonic component with a role in the POC pool (Pusceddu *et al.*, 1997; Sarà *et al.*, in press). Nevertheless, Maimone *et al.* (1997) have documented dominance of tycoplanktonic cells (especially benthic diatoms) in the water column. The remaining part of POC is probably of detritic or heterotrophic nature (Sarà *et al.*, in press).

Stable carbon isotopes may discriminate among the main carbon sources affecting the POC pool. The isotopic signature of macroalgae and plankton was quite similar to that documented in other marine areas, whilst *Posidonia oceanica* and *Cymodocea nodosa* appear to be slightly enriched (~ 1.5‰ to −7.5‰) compared to the literature data (Dauby, 1989; Jennings *et al.*, 1997). Such enrichment could be determined by higher temperature and sun irradiance (Hemmings and Mateo, 1996) due to the shallowness of the studied area compared to other investigated areas (Tufano, 1991; Dauby, 1989; Jennings *et al.*, 1997). Seagrass values were higher (Tab. III), although within in the bibliographic range (Fry, 1984; Mann, 1988; McMillan, 1980). Different isotopic values occurred as a function of different trophy processes prevailing in the different sites.

Principal component analysis summarizes the trophic picture of the Stagnone (Fig. 8).

The open sea site was characterized by values and a seasonal fluctuation in POC concentration similar to those reported by Fabiano *et al.* (1996) for various sites in the south-western Mediterranean. It showed phytoplanktonic production periods in spring and autumn and more negative $\delta^{13}C_{(POC)}$ values (−21‰/−22‰) which were similar to those reported in other areas or similar to that of batch-cultured phytoplankton (Gearing *et al.*, 1984; Faganeli *et al.*, 1989; Lee Van Dover *et al.*, 1992). It may be possible to identify the planktonic component as the major source of POC due to a greater depth and unvegetated bottom (Figs. 8, 9). Conversely, Campolmi *et al.* (1997, 1998) and Maimone *et al.* (1997) have documented the

TABLE III Comparison of $\delta^{13}C$ values of different carbon sources in different environments

Source	*Values*	*Environment*	*References*
Phytoplankton	– 18/– 24	Open sea	Fry, 1984
Phytoplankton	– 22	Shallow	Tufano, 1991
Benthic unicellular algae	– 10/– 20	Estuary	Haines and Montague, 1979
Benthic diatoms	– 15/– 16	Estuary	Riera and Richard, 1996
Phytoplankton and diatoms	– 20/23	Estuary	Gearing *et al.*, 1984
Cymodocea nodosa	– 7.20	Shallow	This paper
Cymodocea nodosa	– 9.30	Shallow	Hemmings and Mateo, 1996
Posidonia oceanica	– 7.80	Shallow	This paper
Phanerogames detritus	– 4.50	Shallow	This paper
Posidonia detritus	– 11.20	Shallow	Tufano, 1991
Posidonia oceanica	– 11.80	Shallow	Tufano, 1991
Posidonia oceanica	– 11.90	Shallow	Hemmings and Mateo, 1996
Macroalgae	– 17/– 20	Estuary	Riera and Richard, 1996
Macroalgae	– 13.5	Shallow	This paper
Sediment – open sea – Stagnone	– 17.50	Shallow	Mazzola *et al.*, submitted
Sediment – exposed site – Stagnone	– 15.00	Shallow	Mazzola *et al.*, submitted
Sediment – sheltered site – Stagnone	– 11.00	Shallow	Mazzola *et al.*, submitted

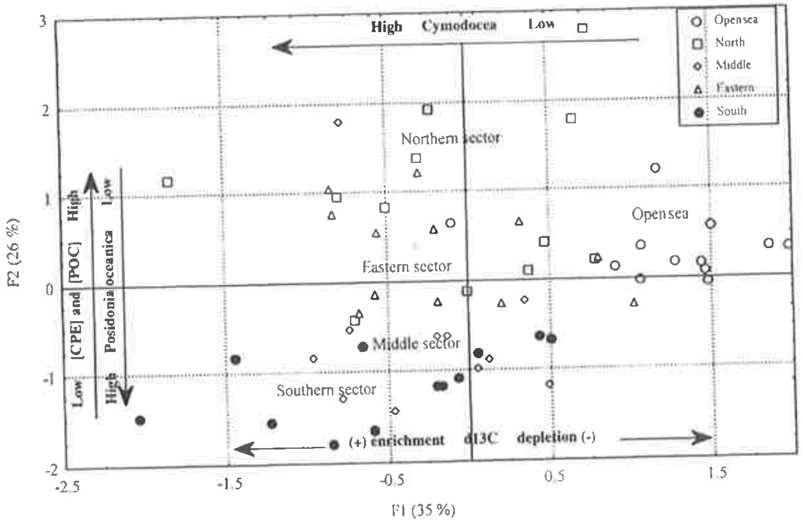

FIGURE 8 Principal components analysis: point-sector by point-month qualitative two-dimensional ordination as a function of correlation with F1 axis (contributing to F1 axis [35%] = $\delta^{13}C_{POC}$ –86%; *Cymodocea nodosa* –85%; *Caulerpa prolifera* –45%) and F2 axis (contributing to F2 axis [26%] = [CPE] 62%; [POC] 50%; *Posidonia* –73%).

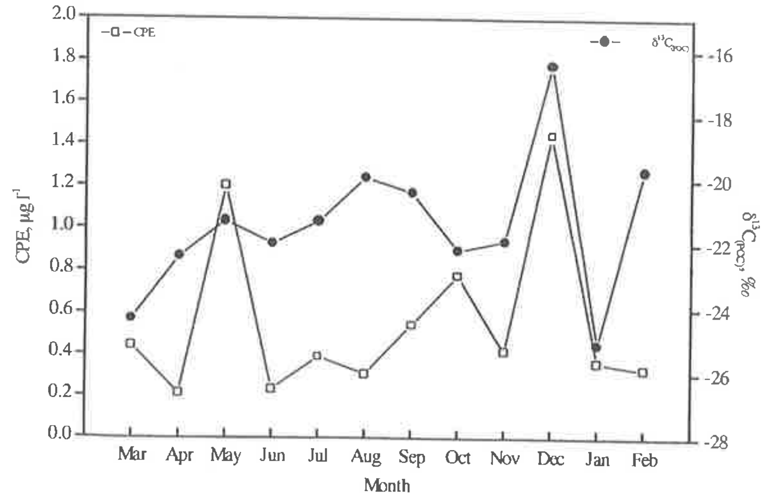

FIGURE 9 Open-sea – monthly trend of carbon stable isotope ratio in comparison to CPE concentration ($\mu g\,l^{-1}$).

dominance of planktonic (phyto and zooplankton) species which are typical of the Mediterranean open-sea, even if Campolmi (1998) had found a tycoplanktonic peak (MacIntyre *et al.*, 1996) which might produce the evident enrichment in isotopic composition in December, whilst the depletion found in January could be produced by a terrestrial contribution. The prevalence of planktonic organic carbon could indicate a greater availability of more labile organic matter in the water column (Mann, 1988; Fichez, 1991).

Unlike the open sea, shallowness and presence of submersed vegetation may affect the POC isotopic composition inside the Stagnone. The distribution of suspended organic matter was determined by hydrodynamic constraints (wind-waves energy and small tides) (Sarà *et al.*, submitted). Resuspension from exposed sites and sedimentation into sheltered sites controlled the biological dynamics present in the Stagnone (Pusceddu *et al.*, 1997; Pusceddu *et al.*, in press), depending on the wind direction and intensity. The dominance of the first or the second process determined the vegetation typology and the degree of cover, allowing us to divide the Stagnone ecosystem into different sub-systems (Sarà *et al.*, in press) where origin and distribution of particulate organic carbon can differ (Fig. 8).

The northern basin and eastern channel could represent the first sub-system which being exposed to dominant winds (Sarà *et al.*, in press), and is characterized by the pulsing fluctuations of the pool of organic matter. These sites could produce as an effect, a limited vegetation (Scilipoti *et al.*, 1997) as affected by a frequently alternating of resuspension and sedimentation events (Kullenberg, 1972, 1976; Levasseur *et al.*, 1983; Millet and Cecchi, 1992). The POC isotopic composition ($\delta^{13}C = -18.5‰$) might reflect a contemporary contribution of *Cymodocea nodosa*, *Caulerpa prolifera* and probably microphytobenthos (MacIntyre *et al.*, 1996) as carbon sources. In the northern basin, higher wind exposure could justify chlorophyll-a and phaeopigments peaks, but these peaks correspond to a different vegetal cover degree (high in May and low in January; Fig. 10a; see also Fig. 8), the lightest isotopic ratios (about $-21‰$) could reflect the signature of planktonic and microbenthic components. In this situation, lateral drifting can be a further factor that could remove *Cymodocea* and *Caulerpa* detritus for storing it. Furthermore, Pusceddu *et al.* (1997, 1998) have documented a positive gradient of sedimentary organic matter along the N-S axis of the Stagnone. The total effect of resuspension-sedimentation-lateral drifting could permit the autotrophic uni-

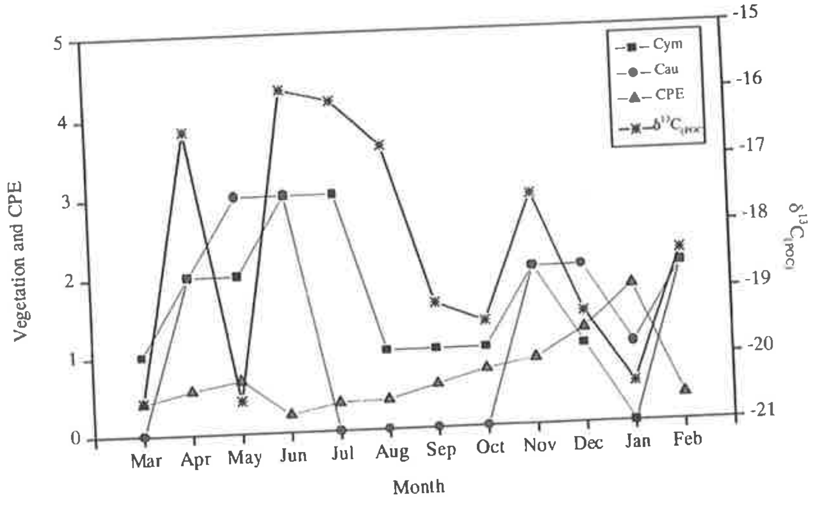

FIGURE 10a Northern basin – monthly trend of carbon stable isotope ratio in comparison to vegetation type (cover class; Cym = *Cymodocea nodosa*; Cau = *Caulerpa prolifera*) and CPE ($\mu g\,l^{-1}$).

cellular biomass marker to become predominant with respect to *Cymodocea* and *Caulerpa*.

This dynamic frame well fits with the eastern channel situation, even if it is characterized by less dominant-wind exposure. A weakening of the resuspension frequency could produce an increase in the sedimentation rate of fine material (Sarà *et al.*, in press). Lower intensity of lateral drifting could explain the greater quantity of suspended material. According to Peres and Picard (1964), the prevalence of a muddy bottom can support *Caulerpa prolifera* which, being more abundant, can affect the composition of isotopic POC. Even if chlorophyll-a concentrations were high (Fig. 10b; see also Fig. 8), $\delta^{13}C_{(POC)}$ values are always heavier. Confirming the weakening in resuspension frequency, more positive values resulted shifted with respect to peaks in *C. prolifera* (March and June) meaning that this alga probably affected the composition of isotopic POC, especially when it is successively resuspended after its storage in the sedimentary detritus pool.

In this context and even if Gambi and Di Meglio (1996) have documented high toughness of *Caulerpa prolifera*, the identification

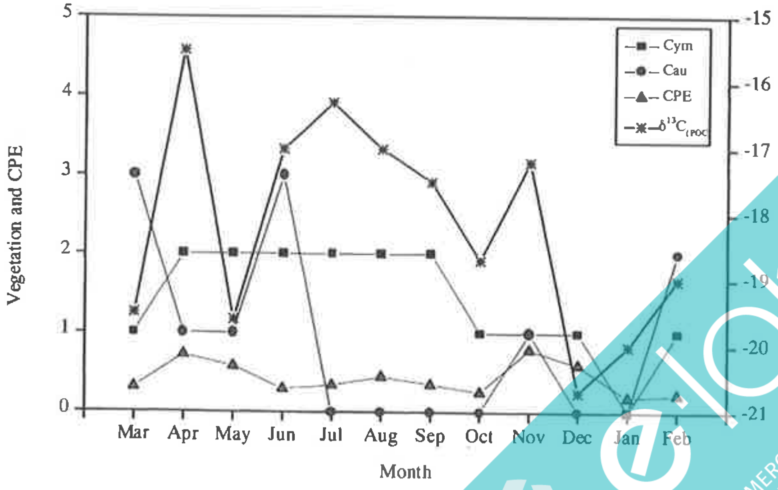

FIGURE 10b Eastern channel – monthly trend of carbon stable isotope ratio in comparison to vegetation type (cover class; Cym = *Cymodocea nodosa*; Cau = *Caulerpa prolifera*) and CPE ($\mu g\,l^{-1}$).

of components which are more easily degradable (plankton and macroalgae) as carbon sources could support a hypothesis that the organic matter available is mostly labile (Mann, 1988).

Middle area and southern basin represent the second sub-system which are constrained by different hydrodynamic processes controlling the POC origin. These sites are characterized by a vitality of waters (Sarà *et al.*, in press) permiting a wide presence of seagrass (*Posidonia oceanica* and *Cymodocea nodosa*). In the absence of "unpredictability" due to wind pulsing, seasonal regimes predominate and are correlated to the trend in seagrass leaf component. The main source of organic material in the POC compartment is the detritus from phanerogames. In particular, the middle site represents the area where the sedimentation-resuspension process has been inverted. This sheltered site was probably affected by hydrodynamics, which was produced by currents coming from both the northern and southern areas. Apart from two phytoplankton production periods (May and October), when $\delta^{13}C_{(POC)}$ values decreased (Fig. 10c; see also Fig. 8), POC isotopic composition followed the seasonality of seagrass, showing heaviest values (spring and summer) in correspondence to peaks in leaf biomass and lightest values in autumn and winter when the biomass is low (Mazzella and Ott, 1984; Velimirov, 1987).

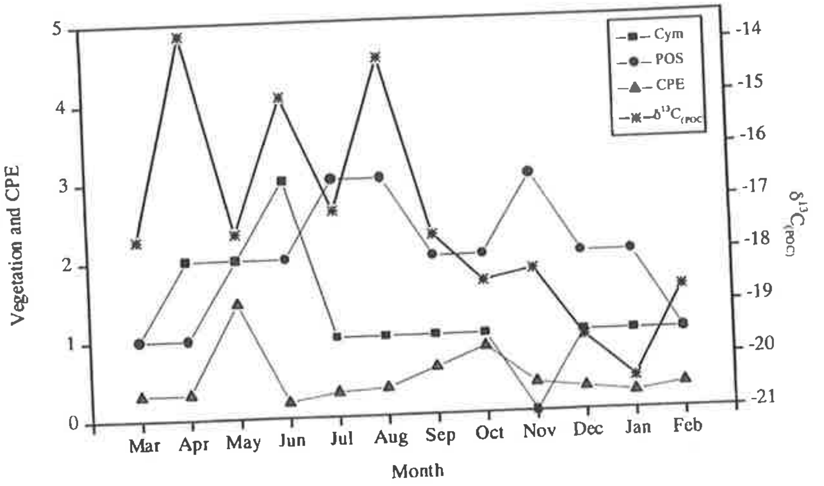

FIGURE 10c Middle basin – monthly trend of carbon stable isotope ratio in comparison to vegetation type (cover class; Cym = *Cymodocea nodosa*; POS = *Posidonia oceanica*) and CPE ($\mu g\, l^{-1}$).

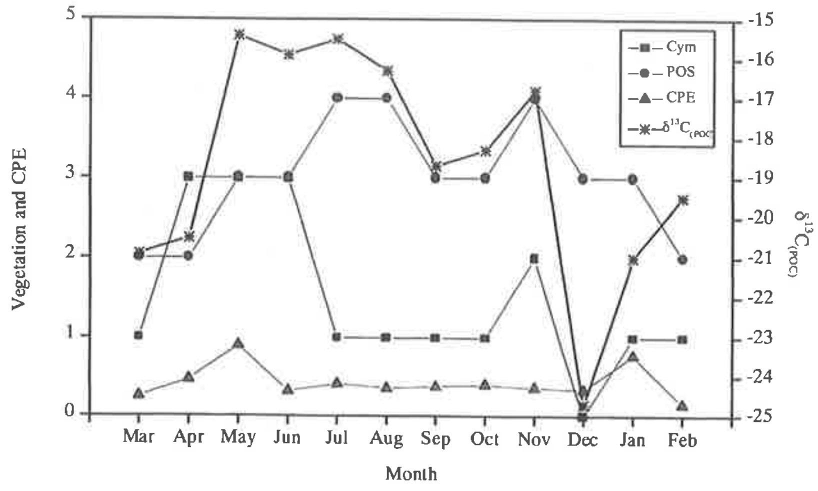

FIGURE 10d Southern basin – monthly trend of carbon stable isotope ratio in comparison to vegetation type (cover class; Cym = *Cymodocea nodosa*; POS = *Posidonia oceanica*) and CPE ($\mu g\, l^{-1}$).

The southern area was also affected by inputs of sea water with tidal periodicity coming from the southern mouth (P. Palermo) (Sarà *et al.*, 1995; Campolmi *et al.*, 1997, 1998). The reduced phenomena of resuspension (being the sheltered site) and tidal periodicity of water movements caused the dominance of *Posidonia* with respect to *Cymodocea*. Seasonal dynamics of *Posidonia* strongly affected the composition of isotopic POC except in winter and spring when plankton contribution can predominate. In December (Fig. 10d; see also Fig. 8), the POC composition is probably affected by input of terrigenous material (Fry, 1984) which can lower the composition of isotopic POC. On the other hand, the density of zooplankton community is very scanty (Campolmi, 1998).

Thus, the prevalence of organic carbon which is more resistant to processes of degradation as that derived from seagrass (Pirc and Wollemweber, 1988), and could support the hypothesis of the low availability of organic matter is mostly refractory (Mann, 1988).

5. CONCLUDING REMARKS

The quality and quantity of organic matter and the carbon isotopic composition permit the discrimination between the main carbon sources and the main physical processes, which regulate their distribution. In this shallow environment, relationships among the main hydrodynamic processes (resuspension-sedimentation-lateral drifting) and carbon sources could define the main factors determining the quality of suspended organic matter. Resuspension events seems to increase the level of lability (and consequently the availability for consumers; cfr. Newell, 1982) of organic matter which is characterized by the lightest isotopic values according to Hopkinson (1985) who said that resuspension appears to control the relative amounts of organic carbon as well as the sites and rates of organic matter degradation in the benthos and water column. By contrast, the predominance of sedimentation processes could produce organic matter, which is mostly refractory (thereby lowering the availability for consumers), with heavier values.

Nevertheless, further information about other factors, including nitrogen and sulphur isotope ratios, is necessary for a more complete analysis of the relationships between biotic and abiotic components in this Mediterranean area.

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