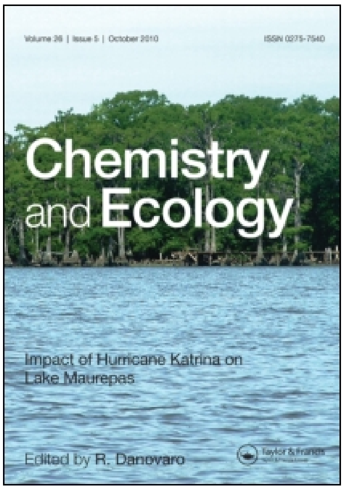

Chemistry and Ecology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455114

Seasonal Fluctuations in the Nutritional Value of Particulate Organic Matter in A Lagoon

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To cite this Article Pusceddu, Antonio , Serra, Emilio , Sanna, Ornella and Fabiano, Mauro(1996) 'Seasonal Fluctuations in the Nutritional Value of Particulate Organic Matter in A Lagoon', Chemistry and Ecology, 13: 1, 21 — 37
To link to this Article: DOI: 10.1080/02757549608039099
URL: http://dx.doi.org/10.1080/02757549608039099

Chemistry and Ecology, 1996, Vol. 13, pp. 21–37
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SEASONAL FLUCTUATIONS IN THE NUTRITIONAL VALUE OF PARTICULATE ORGANIC MATTER IN A LAGOON

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(Received 11 March 1996; in final form 14 March 1996)

Water samples were collected on a fortnightly basis in the lagoon of S. Gilla (Sardinia, Mediterranean Sea) in order to study seasonal nutritional fluctuations of particulate organic matter. The lagoon is characterized by high quantities of suspended matter throughout the year. Thermohaline conditions had no effect on particulate matter quantity and composition, but the quantity as well as quality of suspended particles was drastically affected by the wind, the major effecter of sediment resuspension. As a result of sediment resuspension, seston was always richer in inorganic fraction. However, throughout the year of investigation, most particulate organic carbon was quite appealing for filter feeding communities, although the best POM quality was available during phytoplankton blooming. The phytoplankton pool of suspended matter was just a small fraction of the bulk, accounting for only 13% on average of particulate organic carbon. In terms of energy available in the seston, the highest amount was stored in organic matter heterotrophic fraction, whilst the smallest was to be found in living phytoplankton.

Keywords: Mediterranean lagoon; particulate organic matter; nutritional value

INTRODUCTION

In aquatic environments short-term changes in physical (Millet and Cecchi, 1992, Alpine and Cloern, 1992; Kiørboe and Nielsen, 1990) and biological factors (Berg and Newell, 1986; Albertelli *et al.*, 1994; Fabiano *et al.*, 1995) may have a primary role in affecting the quantity and quality of suspended particulate matter. The main consequence of such changes is an often unpredictable high variability over time of food resources for consumers (Albertelli and Fabiano, 1990; Fegley *et al.*, 1992). Changes of food availability may be considered as the main factor affecting spatial distribution, growth rates and reproduction of suspension feeders (Fegley *et al.*, 1992). Due to energy fluxes from PAR (photosynthetically active radiation) and non-PAR sources, coastal lagoons are characterized by high primary and secondary production rates (Carrada and Fresi, 1988). In these lagoons, primary prod,uction from phytoplankton, macrophytes and saltmarsh plants exceeds consumption by herbivores. This organic matter can be directly available to other consumers but, in most cases, needs to be fragmented and processed by decomposers to become rapidly digestible (Newell, 1982; Hansen *et al.*, 1992). Thus, in coastal lagoons, detritus, more than living phytoplankton, sustains large suspension feeders biomasses. In order to estimate the amount of food available to suspension feeders, several investigations have analyzed particulate organic carbon and nitrogen content (Smaal *et al.*, 1986; Berg and Newell, 1986; Roy *et al.*, 1991; Painchaud and Therriault, 1987; Fabiano and Povero, 1992) or the size of suspended particles (Muschenheim, 1987a,b; Mayer *et al.*, 1993; Arfi and Bouvy, 1995). Recently, an increasing number of papers has examined the biochemical composition of particulate organic matter in different natural environments (Poulet *et al.*, 1986; Mayzaud *et al.*, 1989; Fichez, 1991a,b; Roy *et al.*, 1991; Fabiano *et al.*, 1993; Navarro *et al.*, 1993). However, information is lacking for Mediterranean lagoons. To study the seasonal fluctuations of seston nutritional value, its qualitative and quantitative composition is determined in a lagoon system and related to the environmental factors which may drive seasonal and unpredictable fluctuations.

MATERIALS AND METHODS

Study Site

The lagoon of S. Gilla (Southern Sardinia, Italy) with a total extent of 12.5 km2 and an average depth of 1 m is located between Mannu-

Cixerri river complex and the Gulf of Cagliari (Fig. 1). The lagoon may be divided into two different areas (Masala Tagliasacchi *et al.*, 1992) owing to the presence of fixed fishing structures: an upper region (10 km2), characterized by low water exchanges with the open sea, and a pre-lagoon (2.5 km2), characterized by tidal flows and eutrophic water inputs from the harbour of Cagliari (Serra, 1984). The lagoon is already being used for aquaculture, particularly for experimental mollusc farming (Masala Tagliasacchi *et al.*, 1992).

Sampling

Water samples were collected from a station located in the upper region of the lagoon on a fortnightly or weekly basis, between November 1992 and October 1993, using 10-litre PVC bottles, previously washed with 0.1N HCI. Samples were carried to the laboratory within 2 hours. For total suspended matter and chlorophyll *a* analyses, 100–1000 ml were filtered from samples under gentle vacuum on to Whatman GF/F glass-fibre filters (0.45 μm nominal pore size); for protein, lipid and carbohydrate analyses, 50–1000 ml were filtered from samples on to Nuclepore filters (0.4 μm pore size).

Environmental Parameters

Temperature (accuracy ± 0.2° C) and salinity (‰ ± 0.1%) were measured using a coupled WTW LF 191 probe. Wind speed and rain data were provided by the meteorological station of Cagliari-Elmas Airport.

Total Suspended Matter

Total suspended matter (TSM) concentration was determined gravimetrically (Strickland and Parsons, 1972) after filtration through Whatman GFF glass-fibre filters (0.45 llm nominal pore size), previously treated in muffle furnace (450 C, 2h). The filters were weighed after dessication (3h, 60C) using a Mettler M3 balance (accuracy ± 1 μg). Percentage values of organic and inorganic matter were measured by ignition loss (450 C, 2h).

Phytoplankton

Water samples (500-1000ml) were collected, fixed with formalin (2% final concentration) and stored in plastic bottles in the dark. Phytoplankton analyses were carried out according to Sournia (1978).

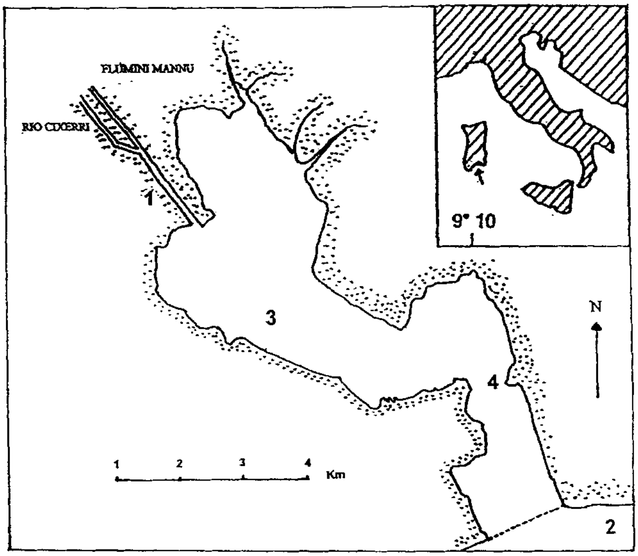

FIGURE 1 The lagoon of S. Gilla. 1) Mannu-Cixerri river complex; 2) harbour of Cagliari; 3) sampling site; 4) location of fixed fishing structures.

Photosynthetic Pigments

Chlorophyll *a* analysis was performed in 90% acetone according to Lorenzen and Jeffrey (1980). Phaeopigments were determined spectrophotometrically after acidification with 0.1 N HCI.

Elemental and Biochemical Composition of Particulate Matter

Particulate organic carbon and nitrogen were analysed using a Carlo Erba CHNSO-EA 1108 Elemental Analyzer after removal of carbonates by hydrochloric acid vapours in a dessicator (Hedges and Stern, 1983). Cyclohexanone 2-4 diphenyl hydrazone was used as a standard. Carbohydrates were determined according to Dubois *et al.* (1956), with glucose solutions used as a standard. Proteins were assessed according to Hartree (1972), with albumin solutions used as a standard. Lipids were extracted according to Bligh and Dyer (1959). Related analyses were perfomed according to Marsh and Wenstein (1966), with tripalmitine solutions used as a standard. Filters for carbohydrate, protein and lipid analysis were sonicated for two hours in 1 ml distilled water. Carbon equivalents of lipids, carbohydrates and proteins were calculated using 0.75, 0.40 and 0.49 gC g^{-1} conversion factors, respectively: Conversion factors were determined from the standard used. The labile fraction of the particulate organic carbon was determined as the sum (CPOM) of carbohydrate, protein and lipid carbon equivalents (Fichez, 1991a,b).

Nutritional Value and Food Index

The nutritional value of suspended matter was obtained by multiplying carbon equivalents by the factor of 11.4 $kcalg^{-1}$, according to Platt and Irving (1973). CPOM/POC (Fabiano *et al.*, 1993) and POM/TSM (Navarro *et al.*, 1993) ratios were used as a food index, i.e. estimates of the readily available fraction of suspended matter. Phytoplankton biomass contribution to the carbon pool was calculated taking 40 as the conversion factor for chlorophyll *a* (Nival *et al.*, 1972).

RESULTS

Temperature and salinity (Fig. 2a) showed clear seasonal patterns ranging from 9.0C (March) to 27.4 C (August) and from 0.2‰ (March 1993) to 38.8‰ (August). Other low salinity values, recorded on December 18 (13.3‰), February 10 (7.3‰) and March 3 (0.2‰) were associated with heavy rainfalls. Total suspended matter concentrations (Fig. 2b) were irregular, with ranges from 15.6 to 524.0 mgl^{-1}. All major phytoplankton groups showed wide fluctuations (Fig. 3). Diatoms had two marked peaks in February (407 × 106cell 1^{-1}) and August (61.5 × 106cell 1^{-1}). Dinoflagellates showed highest density in February (26 × 106cell 1^{-1}) and June (35.8 × 106cell 1^{-1}) while Chlorophyceae had two blooms in December (205 × 106cell 1^{-1}) and April (270 × 106 cell 1^{-1}) Seasonal changes in chlorophyll a (Chla) and phaeopigments (Phe), particulate organic carbon (POC), nitrogen (PON), protein (PRT), carbohydrate (CHO) and lipid (LIP) concentrations, are shown in Figure 4a-c. Chlorophyll ranged between 0.9 (October) and 80.1 μgl^{-1} (February); high chlorophyll a concentrations were also reported in December (19.2 $\mu g l^{-1}$ March (20.6 $\mu g l^{-1}$)

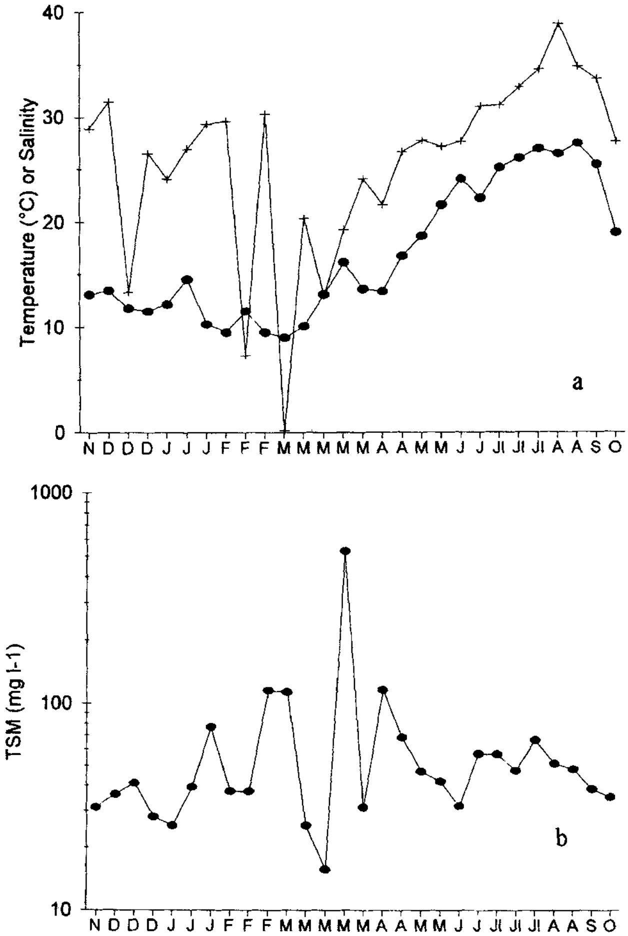

FIGURE 2 The following patterns are indicated: a) temperature (●) and salinity unit (+) and b) total suspended matter (mg l^{-1}) in the lagoon of S. Gilla.

and August (12.0 $\mu g l^{-1}$) Phaeopigment concentrations showed a similar pattern with the highest concentrations in February (11.5 $\mu g l^{-1}$) and March (23.7 and 37.4 $\mu g l^{-1}$). POC and PON concentrations ranged from 463 to 13569.3 $\mu g l^{-1}$ and from 103.9 to 2192.9 $\mu g l^{-1}$, with peaks coinciding with phytoplankton blooms. Carbohydrates (CHO), proteins (PRT) and lipids (LIP) showed a pattern similar to that of chlorophyll a ranging from 136.9 to 5687.6 $\mu g l^{-1}$ (CHO), from 68.7 to 5046 $\mu g l^{-1}$ (LIP) and from 33.8 to 6427 $\mu g l^{-1}$ (PRT). The caloric values of different biochemical components of particulate organic matter (i.e. carbohydrates, proteins and lipids), phytoplankton (i.e. chlorophyll a) and the bulk of particulate organic carbon (POC) are reported in Table I. Proteins were the biochemical component mostly (on average 45%) contributing to the energy content of labile organic carbon (i.e. the sum of protein, carbohydrate and lipid carbon, sensu Fichez, 1991a), followed by lipids (31%) and carbohydrates (24%). The energy available as phytoplankton accounted only for 13% on average of the total caloric value.

TABLE I Caloric value (cal l^{-1}) of the particulate organic carbon in the S. Gilla Lagoon. Reported are: the phytoplankton fraction (CHLa) the protein (C-PRT), carbohydrate (C-CHO) and lipid (C-LIP) fractions, the labile fraction (CPOM) and the bulk (POC).

Date	*CHLa*	*C-PRT*	*C-CHO*	*C-LIP*	*CPOM*	*POC*
24-Nov	0.4	4.1	0.8	1.3	6.2	9.4
01-Dec	0.4	3.1	0.9	0.6	4.6	5.3
18-Dec	8.7	11.7	4.0	7.1	22.8	30.6
22-Dec	7.8	6.4	2.5	3.9	12.7	17.5
14-Jan	6.1	3.8	2.4	5.1	11.4	17.1
19-Jan	1.3	5.6	1.8	1.0	8.4	9.6
27-Jan	2.0	5.8	2.0	1.5	9.3	14.8
03-Feb	1.2	3.3	2.3	3.3	8.9	14.9
10-Feb	0.5	3.8	3.2	2.8	9.8	12.9
23-Feb	36.5	35.9	12.2	15.8	63.9	154.7
03-Mar	2.0	9.4	6.6	3.1	19.1	29.3
10-Mar	0.6	3.1	1.1	2.3	6.5	8.5
16-Mar	0.6	3.7	1.6	0.9	6.2	10.0
25-Mar	9.4	2.2	25.9	43.1	71.3	114.2
31-Mar	0.7	2.7	0.9	0.8	4.4	6.7
06-Apr	1.3	2.6	2.7	3.5	8.7	14.8
20-Apr	2.7	0.7	4.1	3.7	8.5	43.9
04-May	1.1	0.2	2.7	2.5	5.4	13.2
18-May	1.1	0.3	2.1	1.8	4.2	15.2
02-Jun	1.3	5.2	1.6	4.4	11.2	13.1
15-Jun	3.2	12.3	4.5	2.8	19.6	18.9
24-Jun	0.9	7.8	2.9	1.6	12.3	21.8
15-Jul	1.0	4.9	3.2	0.9	9.0	13.0
20-Jul	1.2	9.8	2.8	2.8	15.3	18.8
03-Aug	1.1	7.7	1.9	1.4	10.9	12.8
22-Aug	5.5	9.5	2.0	5.4	16.8	16.5
21-Sep	1.9	12.2	1.1	2.6	16.0	18.0
05-Oct	0.9	7.5	2.4	2.2	12.1	15.8

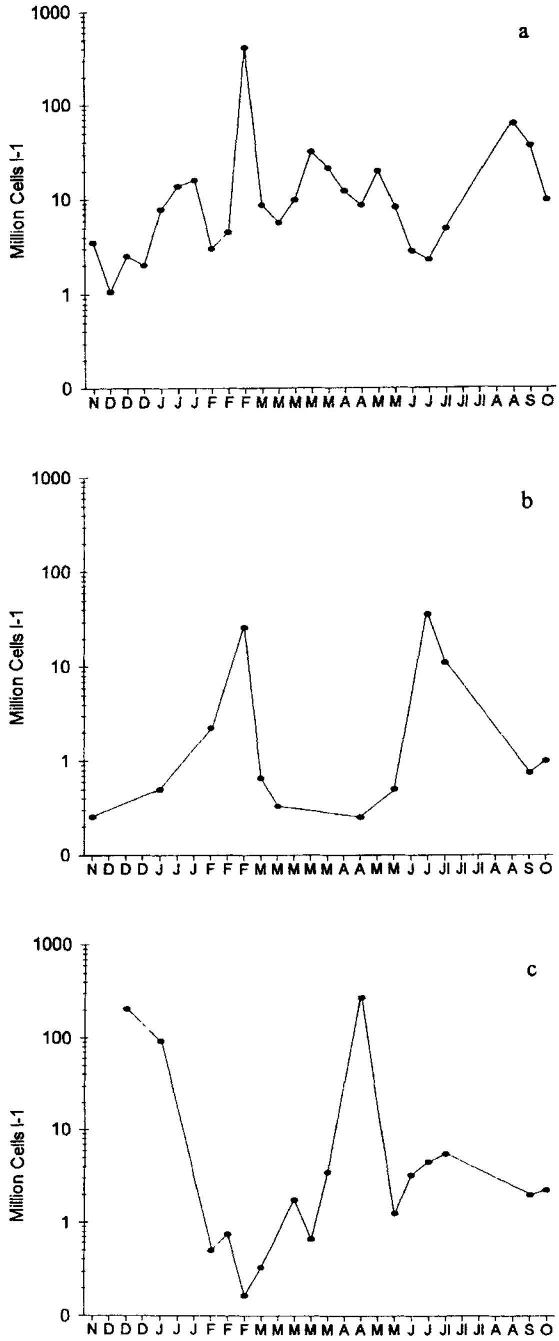

FIGURE 3 The seasonal changes in: a) Diatoms, b) Dinoflagellates and c) Chlorophyceae abundance during sampling period.

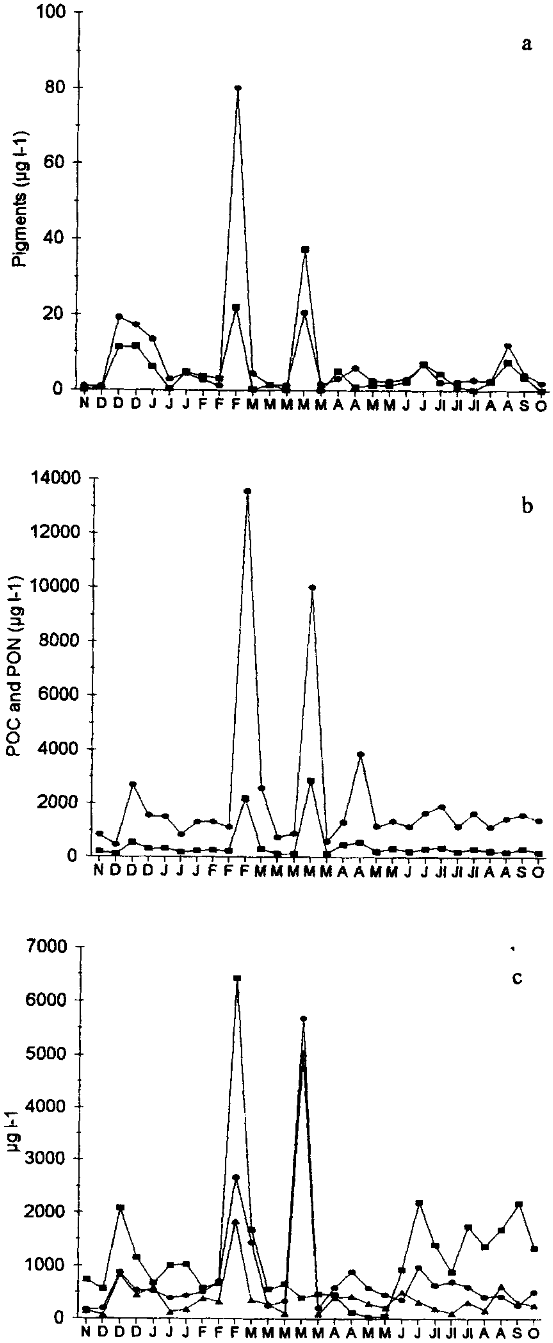

FIGURE 4 The seasonal changes in: a) Chlorophyll a; (●) and Phaeopigments ((■); b) particulate organic carbon (●, POC) and nitrogen ((■), PON); c) particulate carbohydrate (●), protein ((■) and lipid (Δ) concentrations in the S. Gilla lagoon.

DISCUSSION

The Role of Environmental Factors

Temperature and salinity showed seasonal fluctuations and few differences were observed in comparison with earlier investigations conducted on the same lagoon (Serra, 1984; Serra and Roni, 1984; Masala Tagliasacchi *et al.*, 1992). Salinity was significantly affected by rainfall ($r = -0.65$; $p < 0.01$), but no significant correlations were found between thermohaline conditions and particulate matter quantity and quality.

Wind speed was positively correlated with total suspended matter (TSM) concentration ($r = -0.68$, $p < 0.01$) (Fig. 5), suggesting that sediment resuspension induced by wind is the main cause of lagoon water turbidity. Sediment resuspension was also due to the shallow sampling site (average depth, 1 m). Owing to sediment resuspension, the particulate matter, on a yearly average, was mainly composed of inorganic particles (up to 97%) as was observed in several other estuarine ecosystems (Widdows *et al.*, 1979; Berg and Newell, 1986; Navarro *et al.*, 1993). The wind also has a remarkable effect on particulate organic matter quality, with a significant correlation ($r = -0.50$, $p < 0.01$) (Fig. 6) found between protein concentration and wind speed. Proteins are generally considered as the organic matter pool on which consumers preferably feed (Buchsbaum *et al.*, 1991; Fichez, 1991a,b; Tenore, 1983; Tenore *et al.*, 1984). In our study, owing to sediment resuspension, suspended particles rich in appealing food (i.e., protein fraction) were available to consumers. This was due to the addition of sedimented material which directly enriched the suspended protein pool. Also, planktonic microbial growth is stimulated by resuspended sediments in a few hours (Wainwright, 1987, 1990). In this lagoon, the pattern in resuspended sediment nutritional value is different from that observed in several coastal ecosystems where sediment resuspension generally causes less favourable conditions to suspension feeders, due to a greater fraction of less digestible organic mat,ter (i.e., older detritus) for consumers (Albertelli and Fabiano, 1990; Fabiano *et al.*, 1995).

Phytoplankton Biomass Role

The high short-term variability (hours to days) of phytoplankton biomass is typical of coastal lagoons and estuaries, where several sour-

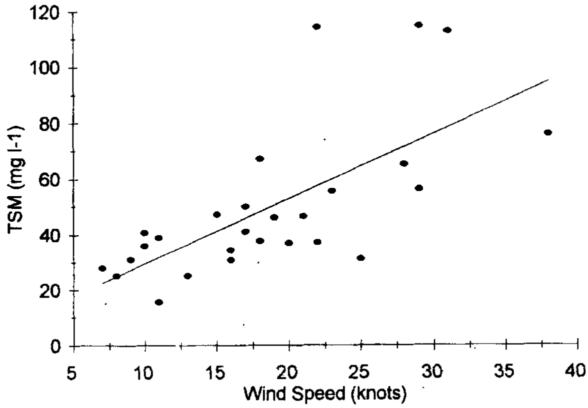

FIGURE 5 Relationship between wind speed (knots) and total suspended matter concentration (mg l^{-1}) in the lagoon of S. Gilla.

ces of 'environmental noise', like wind or rainfall, may drastically change the seasonal pattern of phytoplankton standing stocks (Alpine and Cloern, 1992; Millet and Cecchi, 1992; Serra *et al.*, 1995). In our study, chlorophyll a was characterized by four major peaks: in December (19.2 μg l^{-1}) as the result of a Chlorophyceae bloom; in February (80.1 μg l^{-1}) due to a diatom bloom; in March (20.6 μg l^{-1}) and

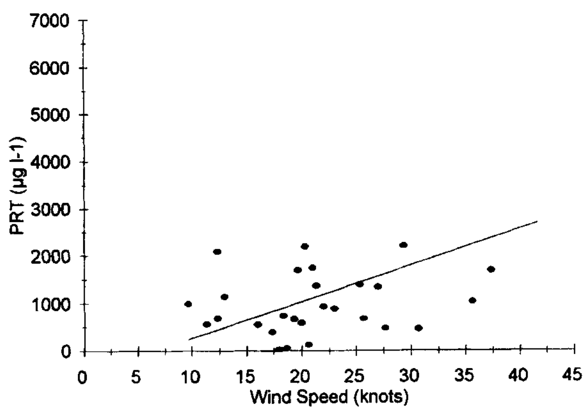

FIGURE 6 Relationship between wind speed (knots) and particulate protein concentration (,ug l^{-1}) in the lagoon of S. Gilla.

August 12.0 μg l^{-1}), when there was no evidence of a phytoplanktonic origin of pigments. Phytoplankton biomass pattern was characterized by several pulses in chlorophyll a concentration, which allowed no clear distinction of any seasonal pattern. This was due to the interference of pigments deriving from microphytobenthos resuspension, particularly during late winter, when high speed winds occurred (Serra *et al.*, 1995): this 'noise' drastically contributed to fouling up the usual seasonal curve of phytoplankton biomass.

Quality and Nutritional Value of the Diet Availablefor Filter Feeders

The phytoplankton biomass, in terms of chlorophyll a concentration, was relatively lower than the data reported for other Sardinian lagoons (Cottiglia, 1984) and, on average, accounted for only 13.0% of the particulate organic carbon, giving a significant contribution only during blooms (up to 45%). Cottiglia *et al.*, (1983a, b) and Serra and Roni (1984) found that, in the lagoon of S. Gilla, a considerable phytoplankton biomass is rapidly intercepted by filter feeders like sedentary polychaetes, which may outcompete for suspended food and limit the energy flux to the molluscan communities. The latter are more likely to meet their nutritional needs with organic detritus rather than with living phytoplankton. Similar results were reported by Masala Tagliasacchi *et al.* (1992) in the same environment. Studying mussel growth rates, they found that the particulate organic matter pool may account for over 90% of all mussel nutritional needs. In this study, high amounts of suspended matter were found. Although the inorganic fraction was generally higher than the organic one, the latter appeared to be very appealing as food. POM/TSM ratio, used to measure the quality of the diet available to filter feeding organisms (Navarro *et al.*, 1993), decreased sharply only when the highest wind speed was recorded and showed the highest values during phytoplankton blooms (Fig. 7). CPOM/POC ratio (Fig. 8), used as a measure of readily available organic carbon fraction (Fabiano *et al.*, 1995), was widely fluctuating, ranging between 19% and 100%, more than 65% (average). Unlike POM/TSM ratio, CPOM/POC ratio had apparently no relation with phytoplankton biomass patterns, due to the lower impact of detritus on particulate organic matter quality. For a quantitative estimate of phytoplankton, nonphytoplankton (i.e., hetero-

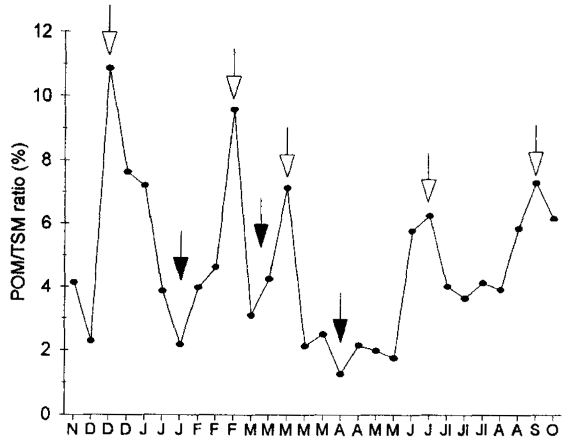

FIGURE 7 POM/TSM ratio patterns in the lagoon of S. Gilla. The black arrows indicate the highest wind speed, while white arrows correspond to major phytoplankton blooms.

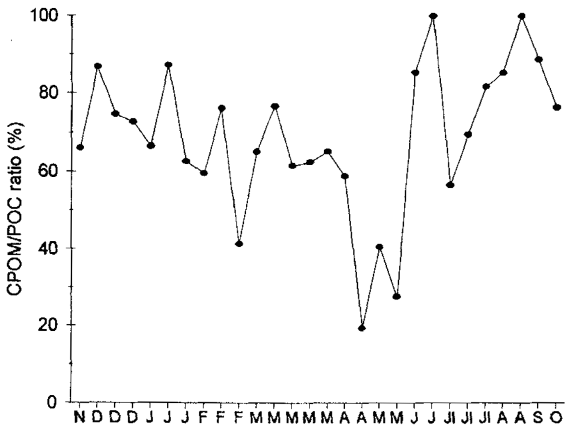

FIGURE 8 CPOM!POC ratio pattern (%) in the lagoon of S. Gilla during the period of investigation

trophic) labile material and refractory detritus contribution to the energy available in lagoon waters, we chose the following formulae:

cal l^{-1} phytoplankton = (CChla)* 0.0114 cal μg^{-1}
cal l^{-1} non-phytoplankton material = (CPOM-CChla)* 0.0114 calμg^{-1}
cal l^{-1} refractory material = (POC-CPOM-CChla)* 0.0114 cal μg^{-1}

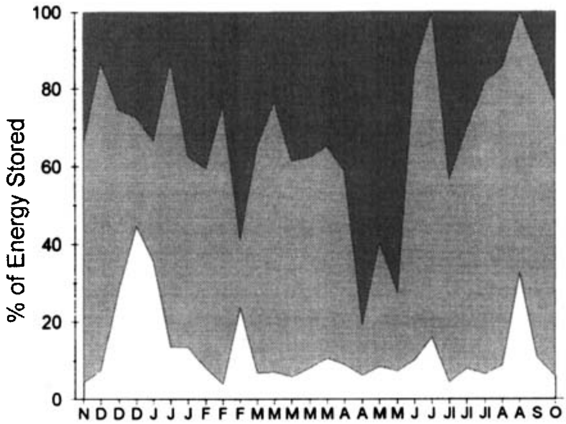

FIGURE 9 Phytoplankton (white), non-phytoplankton (grey) and refractory material (black) contribution to the energy stored in the particulate organic carbon available in lagoon waters.

As shown in Figure 9, non-phytoplankton material contribution to the bulk of available energy was constantly higher than other fractions, accounting for more than 50% on average.

Finally, although phytoplankton contribution to the bulk of organic carbon was relatively low, suspended food occurring naturally in the lagoon was of high quality. This confirms that, in the lagoon of S. Gilla, filter feeding communities take up heterotrophic material rather than living phytoplankton.

Acknowledgements

This work was supported by the Ministero Universita Ricerca Scientifica Tecnologica of the Italian Government (60% and 40%). Dr. Antonio Pusceddu was financially supported by a grant from Credito Industriale Sardo (Italy). We are grateful to Prof. M. Cottiglia and M. L. Masala Tagliasacchi (University of Cagliari) for laboratory facilities. We would also like to thank Dr. C. Misic (University of Genoa) for POC analyses.

References

Albertelli, G. and Fabiano, M. (1990) Caratteristiche trofiche di una stazione costiera in Mar Ligure. *Atti VII Congresso A. I. O. L (Italian Association of Limnology and Oceanography)*, Pallanza (Italy), 1-3 June, 1988, 59–66.

Albertelli, G., Chiantore, M. and Fraschetti, S. (1994) A one-year study of a sandy bottom community: seasonal fluctuations compared to a previous sampling period. *Atti X Conqresso A. I. O. L (Italian Association of Limnology and Oceanography)*, Alassio (Italy), 4-6 November, 1992, 529–542.

Alpine, A. E. and Cloern, J. E. (1992) Trophic interactions and direct physical effects control phytoplankton biomass and production in a estuary. *Limnology and Oceanography*, **37**, 946–955.

Arfi, A. and Bouvy, M. (1995) Size, composition and distribution of particles related to wind-induced resuspension in a shallow tropical lagoon. *Journal of Plankton Research*, **17**, 557–574.

Berg, J. A. and Newell, R. I. E. (1986) Temporal and spatial variations in the composition of seston available to the suspension feeder *Crassostrea virginica. Estuarine Coastal and Shelf Science*, **23**, 375–386.

Bligh, E. G. and Dyer, W. (1959) A rapid method for total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, **37** 911–917.

Buchsbaum, R., Valiela, I., Swain, T., Dzierzeski, M. and Allen, S. (1991) Available and refractory nitrogen in detritus of coastal vascular plants and macroalgae. *Marine Ecology Progress Series*, **72**, 131–143.

Carrada G. C. and Fresi E. (1988) Le lagune salmastre costiere. Alcune riflessioni sui problemi e sui metodi. In G. C. Carrada, F. Cicogna and E. Fresi (Eds.), *Coastal lagoons: Research and Management*. CLEM, Massa Lubrense (Napoli), 35–56.

Cottiglia, M. (1984) Gli 'stagni' salsi sardi, situazione attuale e possibilita future. *Quaderni del Laboratorio di Tecnologia della Pesca*, **3**, 185–200.

Cottiglia, M., Masala Tagliasacchi, M. L. and Serra, E. (1983a) Relations trophiques dans une laune littorale tyrrhenienne. 1. Reseaux bases sur le phytoplancton, le tripton et les depouilles animales. *Rapport Commission Internationale Mer Mediterranee* **28**, 147–149.

Cottiglia, M., Masala Tagliasacchi, M. L. and Serra, E. (1983b) Relations trophiques dans une lagune littorale tyrrhenienne. 2. Reseaux bases sur le phytobenthos et le detritus. *Rapport Commission Internationale Mer Mediterranee*, **28**, 151–153.

Dubois, M., Gilles, K., Mamilton, J. K., Rebers P. A. and Smith, F. (1956) Colorimetric method for determination of sugars and related substances. *Analytical Chemistry*, **28**, 350–356.

Fabiano, M. and Povero, P. (1992) Particulate carbon and nitrogen in Ligurian coastal waters (October, 1985) *Bollettino Oceanologia Teorica ed Applicata*, **10**, 65–71.

Fabiano, M., Povero, P. and Danovaro, R. (1993) Distribution and composition of particulate organic matter in the Ross Sea (Antarctica). *Polar Biology*, **13**, 525–533.

Fabiano, M., Danovaro, R. and Fraschetti, S. (1995) Temporal trends in the elemental and biochemical composition of organic matter in subtidal sandy sediments of the Ligurian Sea (north-western Mediterranean): a three year study. *Continental Shelf Research*, **15**, 1453–1469.

Fegley, S. R., MacDonald, B. A. and Jacobsen, T. R. (1992) Short-term variation in the quantity and quality of seston available to benthic suspension feeders. *Estuarine, Coastal and Shelf Science*, **34**, 393–412.

Fichez, R. (1991a) Composition and fate of organic matter in submarine cave sediments; implications for the biogeochemical cycle of organic carbon. *Oceanologica Acta*, **14**, 369–377.

Fichez, R. (1991b) Suspended pariculate organic matter in a submarine cave. *Marine Biology*, **108**, 1 67–174.

Hansen, J. A., Klumpp, D .W., Alongi, D. M., Dayton, P. K. and Riddle, M. J. (1992) Detrital pathways in a coral reef lagoon. 11. Detritus deposition, benthic microbial biomass and production. *Marine Biology*, **113**, 363–372.

Hartree, E. F. (1972) Determination of proteins: a modification of the Lowry method that gives a linear photometric response. *Analytical Biochemistry*, **48**, 422–427.

Hedges, J. I. and Stern, J. H. (1983) Carbon and nitrogen determination of carbonate containing solids. *Limnology and Oceanography*, **29**, 568–663.

Kiorboe, T. and Nielsen, T. G. (1990) Effect of wind stress on vertical water column structure, phytoplankton growth and productivity of planktonic copepods. In Barnes M. and Gibson R.N. (eds) *Trophic Interactions in the Marine Environment. Proceedings of the 24th EMBS*. Aberdeen. 28–40.

Lorenzen, C. J. and Jeflfrey, S. W. (1980) Determination of chlorophyll and phaeopigments spectrophotometric equations. *Limnology and Oceanography*, **12**, 343–346.

Marsh, J. B. and Wenstein, W. J. (1966) A simple charring method for determination of lipids. *Journal of Lipids Research*, **7**, 574–576.

Masala Tagliasacchi, M. L., Fabiano, M. and Cottiglia, C. (1992) Seston ed accrescimento di mitili in ambiente lagunare. *Oebalia*, **17**, 187–194.

Mayer, L. M., Jumars, P. A., Taghon, G. L., Macko, S. A. and Trumbore, S. (1993) Low-density particles as potential nitrogenous foods for benthos. *Journal of Marine Research*, **51**, 373–389.

Mayzaud, P., Chanut, J. P. and Ackman, R. G. (1989) Seasonal changes of the biochemical composition of marine particulate matter with special reference to fatty acids and sterols. *Marine Ecology Progress Series*, **56**, 189–204.

Millet, B. and Cecchi, P. (1992) Wind-induced hydrodynamic control of the phytoplankton biomass in a lagoon ecosystem. *Limnology and Oceanography*, **37**, 140–146.

Muschenheim, D. K. (1987a) The dynamics of near-bed seston flux and suspension-feeding benthos. *Journal of Marine Research*, **45**, 473–496.

Muschenheim, D. K. (1987b) The role of hydrodynamic sorting of seston in the nutrition of a benthic suspension feeder, *Spio setosa* (Polychaeta: Spionidae). *Biological Oceanography*, **4**, 265–288.

Navarro, J. M., Clasing, E., Urrutia, G., Asencio, G., Stead, R. and Herrera, C. (1993) Biochemical composition and nutritive value of suspended particulate matter over a tidal flat of Southern Chile. *Estuarine Coastal and Shelf Science*, **37**, 59–73.

Newell, R. C. (1982) The energetics of detritus utilization in coastal lagoons and nearshore waters. *Oceanologica Acta, Proceedings International Symposium on Coastal Lagoons*, SCOR/IABO/UNESCO, Bourdeaux, France, 8-14 September 1981, 347–355.

Nival P., Charra, R., Malara, G. and Boucher, D. (1972) La matiere organique particulaire de la Mediterranee occidentale en mars 1970. Mission Mediprod du 'Jean Charchot'. *Annales Istitute Oceanographiyue*, Paris, **48**, 141–156.

Painchaud, J. and Therriault, J-C. (1989) Relationships between bacteria, phytoplankton and particulate organic carbon in the Upper St. Lawrence Estuary. *Marine Ecology Progress Series*, **56**, 301–311.

Platt, H. M. and Irving, B. (1973) Caloric content of phytoplankton. *Limnology and Oceanography*, **18**, 306–309.

Poulet, S. A., Cossa, D. and Marty J-C. (1986) Combined analyses of size spectra and biochemical compositin of particles in St. Lawrence Estuary. *Marine Ecology Progress Series*, **30**, 205–214.

Roy, S., Mayzaud, P. and Souchu P. (1991) Environement physico-chimique et trophique d'un site mytilicole, fles-de-la-Madeleine (Quebec): 11. Matiere particulaire, composition biochimique et productivite primaire. In Therriault J-C. (Ed), *The Gulf of St. Lawrence: Small Ocean or Big Estuary*, Canadian Special Publication of Fisheries and Aquatic sciences **113**, 219–230.

Serra, E. (1984) Nutrienti e biomasse fitoplanctoniche nello «stagno» di S. Gilla. *Rendiconti Seminario Facolta Science Universita di Cagliari*, **54**, 29–39.

Serra, E. and Roni, C. (1984) Produzione e consumo di fitoplancton in una laguna sarda (S. Gilla). *Rendiconti Seminario Facolta Scienze Universita di Carliari, Atti VII Convegno Gruppo 'G. Gadio' per l'ecoligia di base*, Cagliari 27 29 Aprile 1984, **54**, 29–39.

Serra, E., Pusceddu, A. and Serra, A. (1994) Blooms fitoplanctonici ed agenti atmosferici un ambiente lagunare. *Biologia Marina Mediterranea*, in press.

Smaal, A. C., Verhagen, J. H. G., Coosen, J. and Haas, H. A. (1986) Interaction between seston quantity and quality and benthic suspension feeders in the Oosterschelde, The Netherlands, *Ophelia*, **26**, 385–399.

Sournia, A. (1978) *Phytoplankton Manual.* UNESCO Monography on Oceanographic Methodology, 337 pp.

Strickland, J. D. H. and Parsons, T. R. (1992) A practical handbook of seawater analysis. *Bulletin Fisheries Research Board of Canada*, **167**, 310 pp.

Tenore, K. (1983) What controls the availability to animals of detritus derived from vascular plants: organic nitrogen enrichment or caloric availability? *Marine Ecology Progress Series*, **10**, 307–309.

Tenore, K., Hanson, R. B., McClain, J., Maccubbin, A. E. and Hodson, R. E. (1984) Changes in the composition and nutritional value to a benthic deposit feeder of decomposition detritus pools. *Bulletin of Marine Science*, **35**, 299–311.

Wainright, S. C. (1987) Stimulation of heterotrophic microplankton production resuspended marine sediments. *Science*, **238**, 1710–1712.

Wainwright, S. C. (1990) Sediment to water fluxes of particulate material and microbes by resuspension and their contribution to the planktonic food web. *Marine Ecology Progress Series*, **62**, 271–281.

Widdows, J., Fieth, P. and Worrall, C. M. (1979) Relationships bwteeen seston, available food and feeding activity in the common mussel *Mytilus edulis*. *Marine Biology*, **50**, 195–207.