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The contribution of microphytobenthos for scallop *Euvola ziczac* (Bivalvia: Pectinidae) feeding in a shallow area of the south-eastern Brazilian continental shelf

Franciane Pellizzari*[‡], Carlos Alberto Borzone*, Paulo Ricardo Pezzuto[†] and Leticia Zehnder-Alves*

*Centro de Estudos do Mar, Universidade Federal do Paraná, Avenida Beira Mar s/n°, Pontal do Sul, CEP 83255-000, Pontal do Paraná, PR, Brazil. [†]Centro de Ciências Tecnológicas, da Terra e do Mar, Universidade do Vale do Itajaí, Rua Uruguai, 458, Caixa Postal 360, CEP 88.302-202, Itajaí, SC, Brazil. [‡]Corresponding author, e-mail: francianep@yahoo.com

The general composition and abundance of microalgae in sediment, water column and stomach contents of scallops were studied at two *Euvola ziczac* beds on the south-eastern inner Brazilian continental shelf. These areas, which support an extensive demersal fishery, are hydrologically dominated by Tropical and Subantarctic Waters and exhibit a summer water intrusion of South Atlantic Central Water (SACW). The same genera of benthic diatoms, mainly $<30\,\mu$m, were found on sediment and scallop stomach samples. Despite the seasonal variation of hydrographic conditions, the composition and abundance of main benthic diatoms from sediment and stomachs did not change throughout the year. On the other hand, phytoplankton from the water samples collected above the seabed (mainly pelagic diatoms $>30\,\mu$m and dinoflagellates) was composed of distinct taxa and presented a high seasonal variation in abundance. The prevalence of microphytobenthos in the scallop diet suggests the importance of this community to the sustainability of this valuable demersal fishery resource.

INTRODUCTION

The microphytobenthos from inner shelves sandy bottoms are chiefly composed of diatoms, cyanobacteria and dinoflagellate spores. Mucilage and raphe are natural adaptations required to adhere to the sediment grains, allowing these organisms to survive in such an unstable substrate, given the resuspension as well as other physical and chemical processes affecting the seabed and water column interface. This explains why epipsammic diatoms are better adapted to adverse conditions than planktonic forms. They live under low irradiance and high grazing pressure, which enable them to occupy a wide variety of habitats (Palmisano et al., 1985).

Despite the significant number of ecological studies on the Brazilian continental shelf the importance of microphytobenthos on this ecosystem is still poorly understood. The hydrography of the south-eastern sector and its role on the local water column productivity is quite well documented (Mesquita et al., 1983; Borzone et al., 1999, among others).

Circulation in this region is complex, with very dynamic hydrographic conditions. One of its main characteristics is the onshore bottom intrusion of the South Atlantic Central Water (SACW), a cold and nutrient-rich water mass (Castro-Filho et al., 1987). The intrusion of SACW during summer impacts the local biological productivity. Several authors report subsurface chlorophyll maxima at the base of the euphotic zone, associated with this oceanic intrusion, increasing the primary production of the shelf ecosystem (Brandini, 1990; Odebrecht & Djurfeldt, 1996).

A monitoring programme of the northern continental shelf off the São Paulo State has shown that the benthic system is strongly influenced by seasonal changes in the hydrography as well as in the food supply for bottom-living organisms. The SACW intrusion during summer induces a greater amount of plankton to settle on the seabed increasing benthic production. Whereas during winter the predominant sources of food at the bottom come from the sediment and consist of detritus, available for consumers mainly when cold fronts induce resuspension events (Pires-Vanin et al., 1993). Therefore, while the actual role that phytoplankton plays on the maintenance of the benthic compartment is clear, the potential role that benthic primary producers might play in this ecosystem is still unknown.

The continental shelf of south-eastern Brazil is rich in resources of economic importance, such as the penaeid shrimps *Farfantepenaeus paulensis* and *F. brasiliensis*, the tropical scallop, *Euvola ziczac* and several demersal fish (Borzone et al., 1999). Nevertheless, the factors that account for the maintenance of these fisheries resources have not been clarified so far. Along with the pelagic production transferred to the benthic system, it is possible that in certain periods of the year, microphytobenthos might become an alternative, or even the primary source of food for those populations.

Scallops are bivalves (Family Pectinidae) that live in a wide range of habitats, and have been cultivated in different parts of the world since natural populations began to decrease due to indiscriminate fishing (Pezzuto & Borzone, 1997; Freites et al., 1999). Experimental cultures show that food supplies are important factors in

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the development of scallop (Lodeiros & Himmelman, 2000). Some species, such as *E. ziczac*, rest partially burrowed in sandy bottoms, where they filter the interface between the seabed and the water column for food. While some studies have detected the presence of benthic diatoms in the diet of some species of Pectinidae (Shumway et al., 1987; Grant et al., 1997; Chauvaud et al., 2001) we still do not know whether the microphytobenthos is relevant to the Brazilian populations of *E. ziczac*.

Therefore, we investigated the main sources of food exploited by the scallop *Euvola ziczac* in south-eastern Brazil, analysing the composition and relative abundance of microalgae on the shelf sediments, on the stomach contents of *E. ziczac* and on the water column near the seabed.

MATERIALS AND METHODS

Samples were collected from April 1996 to May 1997 at the centre of two *Euvola ziczac* beds (V1 and V2), a bivalve of commercial importance that was intensively exploited in Brazil during the 1970s and early 1980s (Pezzuto & Borzone, 1997). The beds are located between 30 and 40 m isobaths (Figure 1). V1 is in front of the Bay of São Francisco do Sul, Santa Catarina State (26.6°S 48.6°W), and V2 in front of Bom Abrigo Island, São Paulo State (25.2°S 47.4°W).

Water column and sediment samples were collected at V1 from May to November 1996 and March and May 1997. The sampling at V2 was conducted from May to August, October and December 1996, and May 1997. Water samples were collected ≈1 m above the seabed using a Van Dorn bottle, and were preserved in Lugol's solution for counting and identification of microalgae. Sediment samples were collected using a Petit Ponar grab. After sampling and assuming that the sediment had undergone little or no perturbation, subsamples were collected on-board through an opening at the top of the grab. The top centimetre of the sediment was sampled using a corer of 30 mm in diameter. The material was preserved in 4% formaldehyde for late analysis of microphytobenthos. Vertical profiles of temperature and salinity were obtained with a mini salinity–temperature–depth probe—Sensordata™, and were used for the hydrographic description of the area (see Results in Borzone et al., 1999).

In the laboratory, the sediment was washed with 100 ml of filtered seawater. After homogenization, a 2 ml aliquot was dyed with rose Bengal and analysed in Utermöhl chambers under an inverted microscope. According to previous observations (unpublished) centric diatoms >30 μm generally indicates pelagic genera whereas pennate diatoms and cells <30 μm are associated with benthic genera. Therefore cells were counted with emphasis on sizes (>30 μm and <30 μm) and shapes (centric or pennate).

Specimens of *Euvola ziczac* were collected at V1 from April to November 1996 and February, March and May 1997. Specimens from V2 were collected in April, May, August, October and December 1996, using a beam trawl. In the laboratory, the stomachs of four adult individuals with similar sizes were separated from the rest of the organism, washed with filtered seawater and its content preserved in 4% formaldehyde. The microscopical

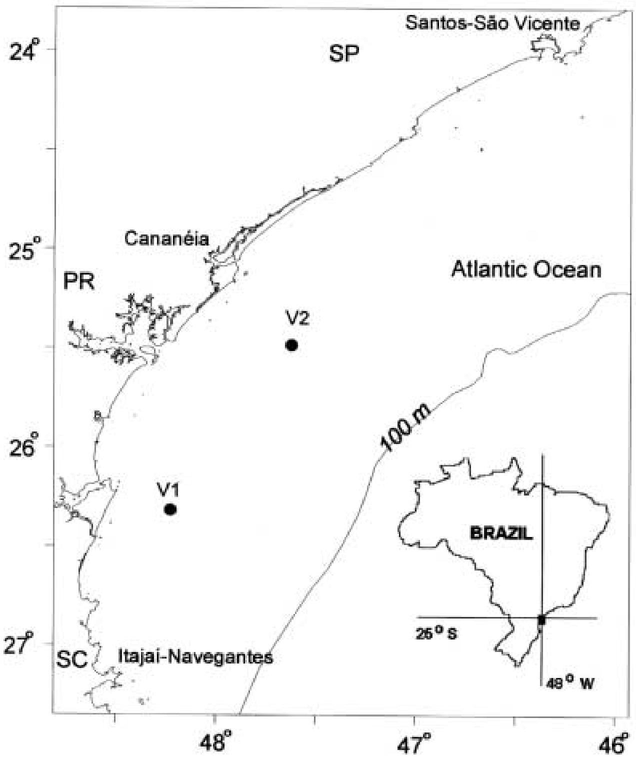

Figure 1. Sampled sites of *Euvola ziczac*. V1—São Francisco do Sul (SC) neighbourhood and V2—around Bom Abrigo Island (SP).

Table 1. *Mean values of annual abundances (%) of microalgae genera found on the sediment from V1 and V2. Pellagic diatom taxa (p) and benthic diatom taxa (b).*

>30 μm genera	V1	V2
Pleurosigma (b)	5	4
Thalassiosira (b)	1	3
Traquineis (b)	2	2
Nitzschia (b)	1	1
Coscinodiscus (p)	1	1
Navicula (b)	1	1
Actinoptychus (p)	1	1
Thalassiothrix (b)	3	0.5
Triceratium (p)	0.4	0.5
Diploneis (b)	0.5	0.5
Surirella (b)	0.5	0.5
Odontella (b)	0.1	0.2
Mastogloia (b)	0.1	0.1
Cyclotella (p)	0.1	0.2
< 30 μm genera	**V1**	**V2**
Diploneis (b)	34	32
Fallacia (b)	11	15
Navicula (b)	8	11.5
Thalassiosira (b)	14	11
Nitzschia (b)	2	7
Mastogloia (b)	0.3	3
Cyclotella (p)	10	2
Surilela (b)	3	2
Actinoptycus (p)	1	1

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counting of pelagic microalgae was carried out as described above.

In order to compare the microalgal composition of sediments, water column and stomach contents, multi-dimensional scaling analyses (MDS) were conducted using a Bray–Curtis dissimilarity matrix, considering the relative abundance and species composition identified in each compartment analysed. Analysis of similarities (ANOSIM) tests were used to determine the statistical significance of the sample group similarities (Clark & Warwick, 1994).

RESULTS

Sediment microalgae

The most abundant genera occurred in more than 90% of the samples and the same floristic composition was found in both beds. Pennate diatoms $<30\,\mu$m dominate (Table 1). On the sandy sediment of both sites, the genera of dominant viable cells $>30\,\mu$m and their mean abundances were: *Pleurosigma* (including *P. diversestriatum*, 5 and 4%), *Traquineis* (*T. aspera*, 2 and 2%) and *Thalassiothrix* (3 and 0.5%). Among Pennate $<30\,\mu$m, *Diploneis* (34 and 32%), *Thalassiosira* (14 and 11%), *Nitzschia* (2 and 7%), *Fallacia* (11 and 15%) and *Navicula* (8 and 11.5%), were relatively more abundant throughout the sampling period. These genera, including the most abundant taxa, *Diploneis* and *Fallacia*, were present throughout the year, but with an irregular pattern of fluctuation (Figure 2).

Water column microalgae

A total of 23 genera of phytoplanktonic diatoms (Table 2), five dinoflagellates and two silicoflagellates were identified, the last with an annual relative abundance lower than 1%. A bloom of the dinoflagellate *Ceratium furca* accounted for 70% of the phytoplankton composition during the summer. The diversity of the phytoplankton near the seabed was higher and very different as compared with sediment and stomach samples. Most diatom genera were found only in the water column (Table 2) except for *Coscinodiscus*, *Diploneis*, *Odontella* and *Surirela*. In addition, relative abundance fluctuations of the pelagic diatoms were higher than in sediment and stomach contents. Most taxa showed a seasonal pattern with spring and summer peaks of abundance (L. Zehnder-Alves, personal communication).

Cells and chains $>30\,\mu$m dominate in water column samples. Among these, the main diatoms and their annual mean abundances at beds V1 and V2 respectively were *Coscinodiscus* sp. (14% for both sites), *Thalassiothrix* sp.2 (4 and 10%), *Chaetoceros* (3 and 1%), and *Fragillariopsis* (1 and 10%). The dominant genera $<30\,\mu$m were *Chaetoceros* (11 and 2%), *Paralia* (8 and 6%), *Coscinodiscus* sp.2 (3 and 5%), and *Navicula* (1 and 5%).

Stomach content

Stomach contents of *Euvola ziczac* showed 18 genera of diatoms and one genus of cyanobacteria (Table 3). The same diatoms from the sediment were found in the

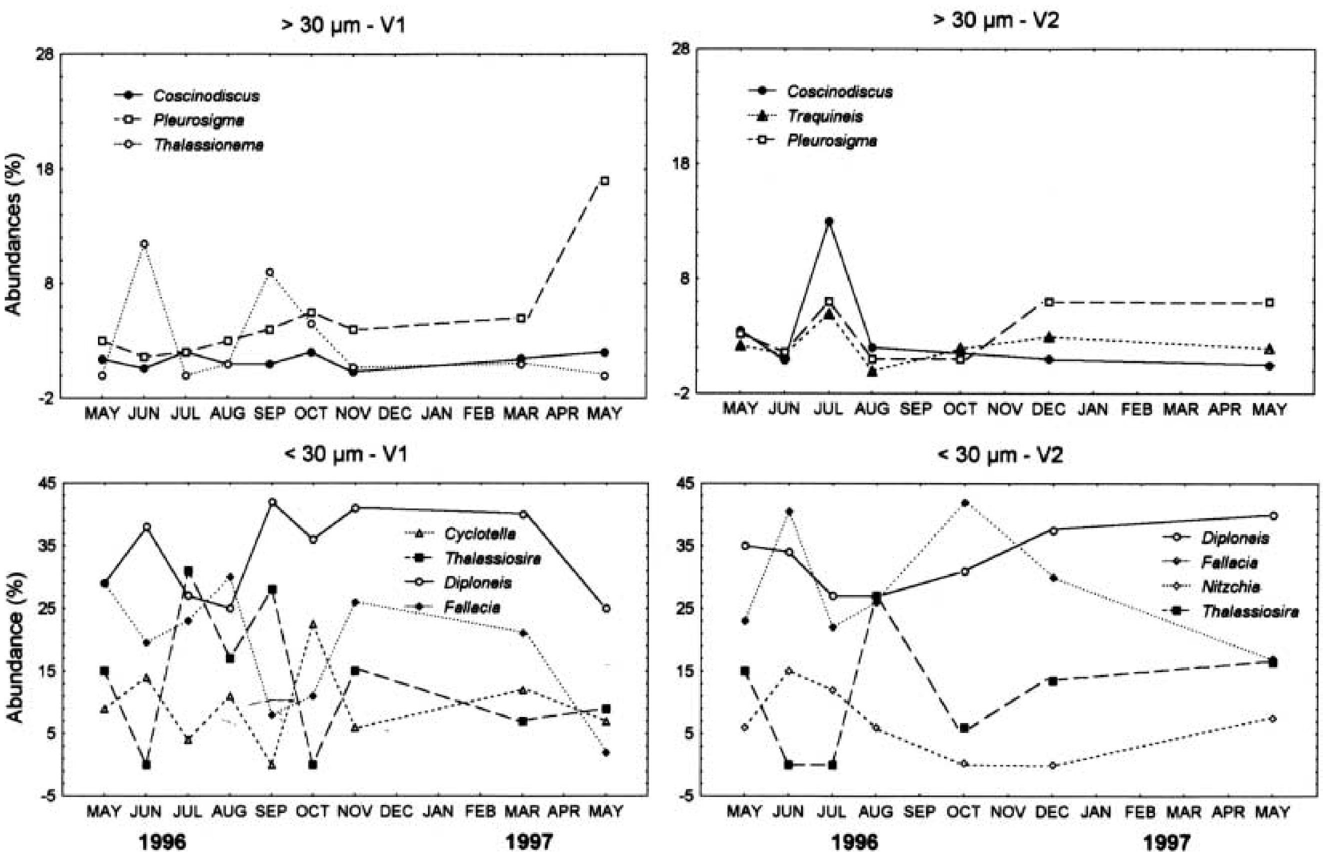

Figure 2. Microalgae genera found on the sandy sediment from V1 and V2. The cell counting was distinct to the sizes $>30\,\mu$m and $<30\,\mu$m.

Table 2. *Mean values of annual abundances (%) of microalgae genera found on the stomach contents of the scallops captured in V1 and V2. Pellagic diatom taxa (p) and benthic diatom taxa (b).*

>30 μm genera	V1	V2
Pleurosigma (b)	5	3.2
Thalassiothrix (b)	3	0.5
Traquineis (b)	2	2
Thalassiosira (b)	1	1
Navicula (b)	1	1
Coscinodiscus (p)	1	3
Nitzschia (b)	1	1
Surirella (b)	1	0.2
Actinoptychus (p)	0.5	0.5
Triceratium (p)	0.3	0.3
Odontella (b)	0.1	0.2
Cyclotella (p)	0.1	0.1
<30 μm genera	V1	V2
Diploneis (b)	34	33
Fallacia (b)	21	22
Thalassiosira (b)	13	11
Anabaena (cyanobacteria b)	2	11
Cyclotella (p)	9	2
Nitzschia (b)	3	7
Cocconeis (b)	1	0
Actinoptychus (p)	1	1

stomach contents throughout the year, but in different relative abundances. The only exception was *Anabaena* sp., which was present only in the stomachs. Pelagic dinoflagellates and silicoflagellates, were also found, but with relative abundances lower than 1%.

The genera $<30\,\mu$m were numerically predominant (Table 3), as they were in the sediment. Relative mean abundances of the most frequent genera $>30\,\mu$m found in the stomach contents were: *Coscinodiscus* (1 and 3%), *Thalassiothrix* sp.1 (3 and 0.5%), *Thalassiosira* (1% for both sites), *Pleurosigma* (5 and 39%) and *Traquineis* (2% for both sites). Among cells $<30\,\mu$m, the predominant genera were *Diploneis* (34 and 33%), *Fallacia* (21 and 22%), *Thalassiosira* (13 and 11%) and *Anabaena* (2 and 11%) (Figure 3). The cyanobacterias were counted per chains (30 μm) and not per cells in order to facilitate the analysis.

Table 3. *Mean values of annual abundances (%) of microalgae genera found in the water column from V1 and V2. Benthic diatom taxa (b).*

>30 μm genera	V1	V2
Coscinosdiscus	14.2	14.9
Diatom. Penadas n.i. (b)	18.6	30.5
Dinoflagellate	7	0.3
Lauderia	4.5	0
Thalassiothrix	3.8	10.3
Chaetoceros	3.1	1.2
Eucampia	1.8	0
Guinardia	1.5	2.3
Coscinosira	1.2	0
Rhizosolenia	1.2	0.3
Fragillariopsis	0.9	10.2
Hemiaulus	0.7	0.2
Leptocylindrus	0.5	0
Ditylum	0.3	0
Navicula (b)	0.2	0.6
Silicoflagellate	0.2	0.2
Odontella(b)	0.2	0.07
Stephanophysis	0.2	0.04
Climacodium	0.2	0.07
Surirella	0.12	0.4
Meuniera	0.12	0
Paralia	0	0.8
Bacteriastrum	0	0.2
Corethron	0.01	0.1
Hemidiscus	0.01	0.1
<30 μm genera	V1	V2
Chaetoceros	10.6	2.1
Paralia	8.3	6
Diploneis (b)	4.3	2.6
Coscinosdiscus	3.5	4.6
Hemiaulus	3.4	0
Diploneis (b)	1.9	2.6
Navícula (b)	1.3	4.9
Diatom. Penadas n.i. (b)	2.6	2.3
Dinoflagellate	0.7	0.9
Silicoflagellate	0.7	0.6
Bacteriastrum	0.4	0.2
Lauderia	0.4	0
Coscinosira	0.36	0
Meuniera	0	0.6

Multivariate analysis

The MDS analysis of microalgae assemblage from sediment and stomach contents showed that the latter are more correlated among themselves than with the sediment samples, forming three significant groups of samples (Global R=0.819, $P<0.001$) (Figure 4). In addition, there was a significant separation among the stomach samples from beds V1 and V2 (R(1/2)=0.776, $P<0.001$) due to differences in relative abundance of cells ingested by scallops from each bed. Sediment samples did not show these differences and samples were heterogeneously distributed without a defined pattern. This indicates that their relative abundance oscillates throughout the year without qualitative changes in the flora composition.

The configuration of sediment samples (1) together with phytoplankton (2) and stomach samples (3), without bed discrimination, formed three significant groups (Global R=0.804, $P<0.001$). Despite the presence in stomachs of some components also found in the water column, the phytoplankton samples were clustered apart from the sediment and stomach samples, suggesting a major difference in cell composition between the water and bottom compartments (R(1/2)=0.985, $P<0.001$; R(3/2)=0.947, $P<0.001$) (Figure 5).

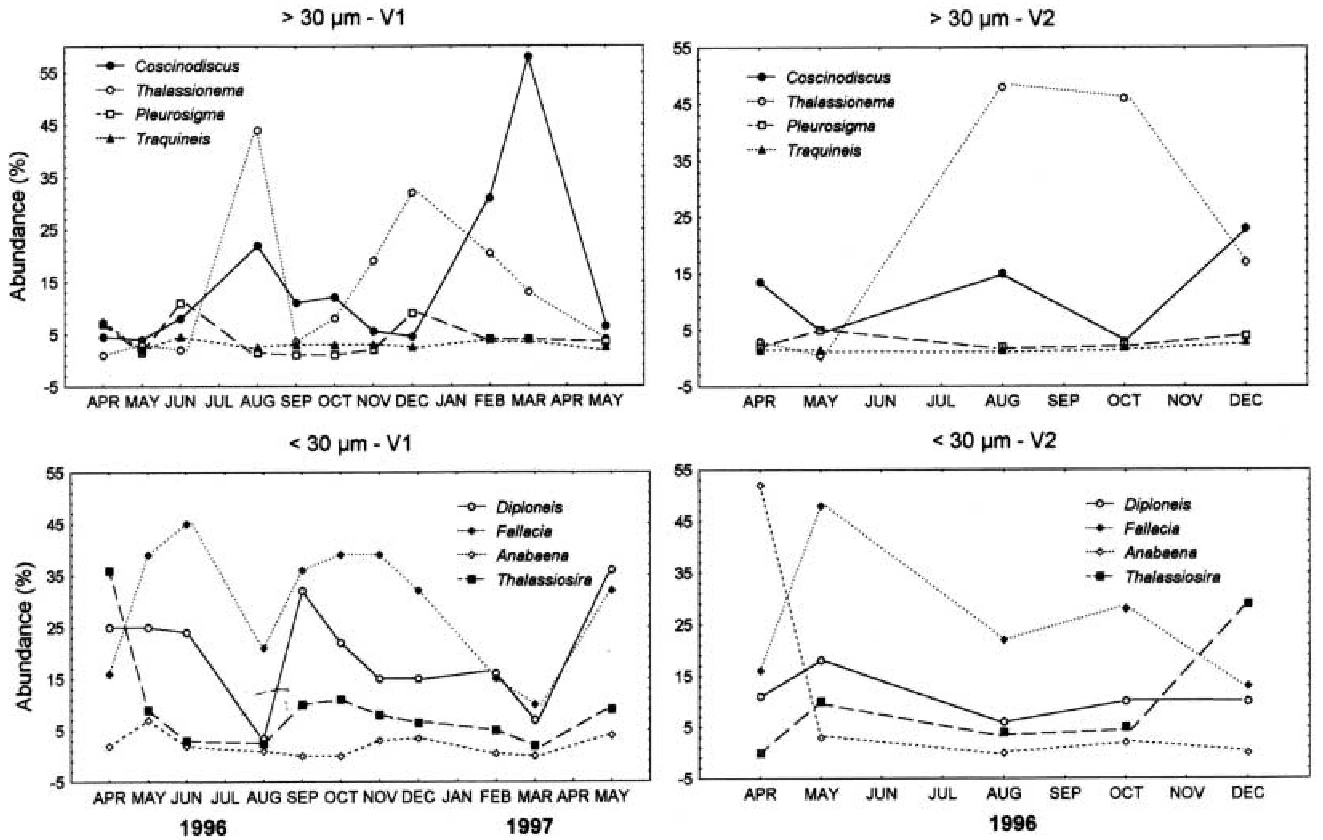

Figure 3. Microalgae genera found in the stomach contents from V1 and V2. The cell counting was distinct to the sizes $>30\,\mu$m and $<30\,\mu$m.

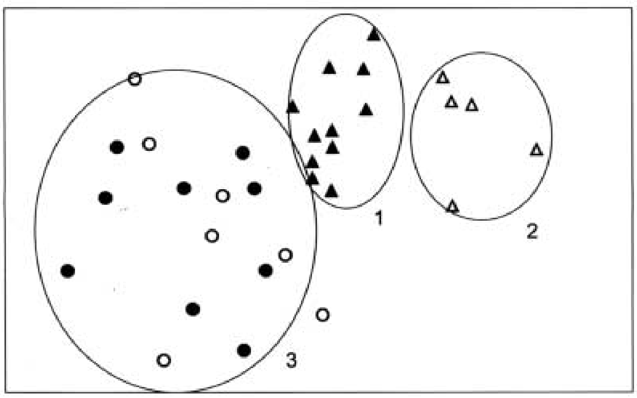

Figure 4. Multidimensional scaling analyses ordination (Stress 0.11) between sediment (●) and stomachs (▲) samples from V1 (bold) and V2 (not bold).

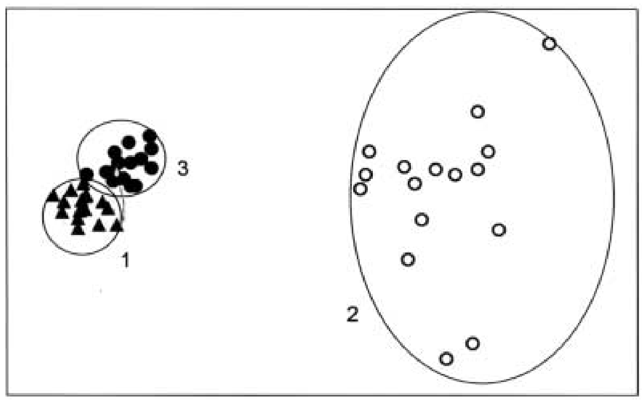

Figure 5. Multidimensional scaling analyses ordination (Stress 0.09) between sediment (●), scallop stomach contents (▲) and water column samples (○).

DISCUSSION

Although previous studies have described sandy sediments as being poor and relatively unproductive, this contribution revealed a well developed microphytobenthics assemblage living at 40 m depth on the Brazilian south-eastern inner continental shelf. The bottom intrusion of SACW during the summer months determined higher nutrient concentrations between 30 and 40 m depth that promote the development of microphytobenthos on the sediment and phytoplankton in the water column near the seabed (Pezzuto et al., 1998).

During stable climatic conditions, phytoplanktonic cells seem to dominate the water column over the bottom with low cell settlement rates. In this condition, the nutrient input through the water masses is essential for the development of these organisms. Thus, seasonal differences observed in the phytoplanktonic composition were related

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to seasonal differences in nutrient input. On the other hand, the benthic flora that live attached to the sediment grains did not vary seasonally, showing that the assemblage probably has a stable input of nutrient from the bottom throughout the year, as found in other continental shelf studies (Sundback et al., 1996).

However, environmental energy (currents and internal waves), meteorological fronts and sediment composition are important factors controlling the resuspension of sediments and bottom-dwelling organisms. According to Borzone et al. (1999), the sediments of the studied area are relatively homogeneous on the bathymetric gradient. Fine to very fine quartz sands predominate, the silt–clay fraction increases with depth and kurtosis values are high to the south of the studied area and between 30 and 40 m. Tanner (1995) suggested that these kurtosis values are typical of environments where waves and currents act. This might indicate the occurrence of cycles of deposition and resuspension resulting from local current dynamics. Thus, resuspension and sedimentation in shallow shelf areas enrich the phytoplankton with benthic diatom cells during short periods of resuspension increasing food availability for suspension feeders.

The diatom genera *Diploneis*, *Traquineis*, *Thalassiosira*, *Pleurosigma*, *Coscinosdiscus*, *Thalassionema* and *Navicula*, found in the present study, have been cited in several studies at shelf areas around the world (Shumway et al., 1987; Pilditch & Grant, 1999). The microphytobenthic flora is very specialized and has a low specific diversity. As already observed in previous studies, the development of these organisms is related more to the type of substratum and local dynamics than to seasonal changes of physical and chemical factors such as temperature and salinity (Pilditch & Grant, 1999).

The phytoplanktonic genus *Coscinodiscus* was also identified in the microphytobenthos. Probably, the cells sampled on the sediment and in the water column represent different species, considering that the planktonic specimens were significantly larger (200 μm) than the benthic ones (60 μm). On the other hand, *Diploneis*, *Navicula* and *Odontella*, included in the same benthic family, are characteristically small sized and, therefore, could be easily deposited and resuspended from the sediment. The remaining phytoplanktonic genera were different from the ones identified in sediment and stomach samples.

Microphytobenthic assemblage seems to be fundamental to the development of *Euvola ziczac*. Stomach contents showed the prevalence of the benthic diatom genera $<30\,\mu$m in the scallop diet. The small differences in relative abundances of these genera in stomachs and sediment can result from the higher availability of smaller material during resuspension. The bivalve *E. ziczac* lives half-buried in the sandy sediment upon its convex shell. As with many other pectinids, it has developed some swimming capacity ejecting water from the interior of the shell through repeated contractions of the adductor muscle. However, the muscle contractions of large animals generally produce only a rotational movement of the animal on the bottom (C.A. Borzone, unpublished data), resuspending the sediment in its surroundings. This behaviour has been considered as a strategy to increase the food availability by resuspending particles from the sediment (Bricelj & Shumway, 1991).

The strong relationship of *E. ziczac* and sediment was well documented by Freites et al. (1999) and Lodeiros & Himmelman (2000) in experiments with suspended cultures in Venezuela. These authors considered food supply the most important factor for the development of these bivalves, because in suspended cultures the scallops did not reach the size and growth rates observed in natural bottom populations (70–90 mm). In another study, Vélez et al. (1995) found higher survival rates of *E. ziczac* specimens cultured in bottom cages installed on the natural substrata as compared with the specimens maintained in suspended cages. The authors have attributed these results to the better access of the organisms to the organic matter of the sediment.

Mean organic matter content in the sediment of the two beds was low (Borzone et al., 1999), this suggests that the limiting factor in the suspended culture may not only be the amount of organic matter *per se* but rather the presence of living microflora in the diet, which should contain small benthic diatoms that only grow in the sediment.

Microphytobenthos represents an important and, perhaps, an alternative source of food for some microphytophagous invertebrates, such *E. ziczac*. Therefore, future studies in the region should focus on the determination of the absolute abundance of benthic diatoms, sediment chlorophyll contents, productivity and hydrodynamics for a better understanding of the filter-feeder dynamics of this important fishing ground off the Brazilian coast.

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