

## DIATOM ASSEMBLAGES IN COASTAL SHALLOW WATERS AT THE WATER - SEDIMENT INTERFACE (GULF OF TRIESTE, NORTH ADRIATIC SEA)

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## ABSTRACT

The resuspended microphytobenthos, mostly consisting of benthic diatoms, plays an important role in the production of  $O_2$  as a food source for pelagic and benthic grazer at the water-sediment interface of the coastal environment. In the coastal shallow waters of the Gulf of Trieste, the possible modifications in diatom community living at the water-sediment interface have been studied in respect of disturbed conditions, such as the presence of suspended mussel cultures. Two stations were chosen, one sited below the mussel rafts (st. M), the other (reference site, st. B) in an area free of cultures. The microscopic observations have shown that both stations, where mainly epipellic species belonging to the medium size class have been recorded, are characterised by the species *Cylindrotheca closterium*, *Bacillaria paxillifera* and *Gyrosigma acuminatum*. The statistical analyses have not shown significant differences as far as biodiversity of communities is concerned. However, the diatom assemblage living under the mussel cultures has been less abundant in comparison with the reference site, presumably due to the presence of benthic grazers drawn to the greater availability of organic matter owing to biodeposition.

**Key words:** Microphytobenthos, mussels, cell density, species composition, biodiversity

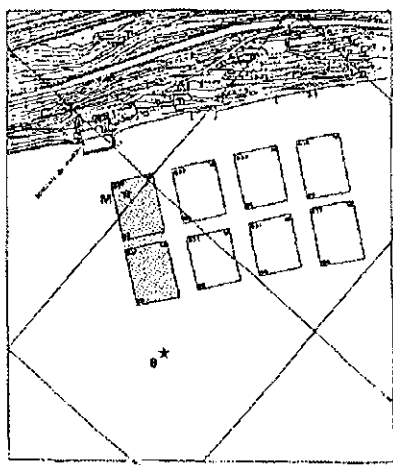
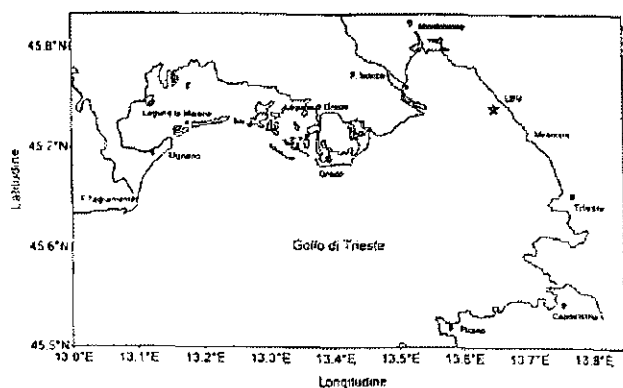
## INTRODUCTION

Microphytobenthos, mainly consisting of diatoms, plays an important role as the primary producer in the carbon cycle of nearshore marine sediment systems (Klepper, 1989; De Jong *et al.*, 1994). As producer of the new organic matter that can enter into the benthic and pelagic trophic web, microphytobenthos constitutes a substantial food source for sediment feeders (macro-meiobenthos) (Asmus, 1982; Admiraal *et al.*, 1983). Besides, it can be the main oxygen producer in coastal environments (Varela & Penas, 1985; Johnstone *et al.*, 1990), controlling also the oxygen balance at the water-sediment interface and allowing the aerobic degradation of autochthonous and sedimented organic matter in sediments (Davis & McIntire, 1983; Barranguet, 1997).

In the past, much research has been carried out into spatial and seasonal distribution patterns of microphytobenthos (Sundbäck, 1984, 1986; Miller *et al.*, 1987; Snoeijs *et al.*, 1990; Sundbäck & Snoeijs, 1991; De Jong & Colijn, 1994). Moreover, the sediment stabilisation by benthic diatoms and the microstructure of diatom films

have been widely studied (Grant *et al.*, 1986; Paterson, 1989). Although the term microphytobenthos suggests that these algae are confined to the sediments, their presence in the water column as a part of the phytoplankton has been well-documented (Humell, 1985; De Jonge & Van Beusekom, 1992). Recently, some studies have been undertaken to evidence the role of this resuspended microphytobenthos as an additional food source, in the water column, for pelagic filter-feeding community (De Jonge & Van Beusekom, 1992; De Jong *et al.*, 1994; Stachowitsch & Fuchs, 1995; De Jong & De Jonge, 1995).

It is known that benthic microalgae can be stirred up into the overlying water by hydrodynamic energy (tidal currents, waves and winds), becoming temporarily part of phytoplankton (De Jonge & Van Den Bergs, 1987; De Jonge, 1985; Delgado *et al.*, 1991). The resuspended algae are mainly species able to migrate actively up and down the sediment, or non-motile species reaching the sediment surface in relation to bioturbation features (Paterson, 1986, 1989; Haphey-Wood & Jones, 1988).



**Fig. 1: Position of the study area (★) and location of the reference (st. B) and the mussel culture site (st. M).  
Sl. 1: Slika območja raziskav ter lokacije (★) referenčne postaje (post. B) in nasadov užitnih klapavic (post. M).**

Several recent studies have investigated the environmental impacts of bivalve cultures regarding their role as suspension feeders that reduce the amount of phytoplankton (Frechette *et al.*, 1989; Asmus & Asmus, 1991). The massive biodeposition following the establishment of a mussel community also leads to a continuous organic enrichment of sediments, which increases the oxygen demand and may cause a temporary anoxia (Svane & Setyobudiandi, 1996; Barranguet, 1997). It has been demonstrated by many authors that organic input to the sediments enhances a net flux of inorganic nutrients to the water column with a high ammonium efflux (Klump & Martens, 1981; Rizzo, 1990; Hatcher *et al.*, 1994).

In order to identify any changes in diatom assemblages at the water sediment interface due to the presence of a suspended mussel farm, two stations have been investigated for this paper. Cell density, species composition, biodiversity and temporal patterns of diatom community in the mussel culture have been com-

pared to a nearby reference station, not influenced by mussels.

**MATERIAL AND METHODS**

The study sites (st. M and B) were located in the coastal area of the Gulf, in front of the Marine Biology Laboratory (Aurisina); one sampling station was situated under suspended mussel (*Mytilus galloprovincialis*) cultures (st. M), the other (control station B) in an area of similar depth and sediment type (sandy-pelitic sediment) unaffected by cultures (Fig. 1). The water depth in the sampling sites was 12 m at st. M and 13 m at st. B.

Temperature and salinity were measured at the bottom layer by means of a Multiparameter Idronaut Ocean Seven mod. 401 probe simultaneously with biological sampling.

Sediment samples were collected at two stations at monthly intervals from May to October 1998. At each station, 3 sediment cores (8 cm diameter, 20 cm length) were taken by a diver and the overlying water was sampled using plastic syringes of 60 mL capacity. The overlying waters of the three cores were mixed together and fixed with a 4% hexamethylenetetramin-buffered formaldehyde solution. After manual stirring, subsamples of 10 mL were placed in a counting chamber, and then the viable cells at the time of fixing (with plasmatic content), were counted under a Leitz inverted light microscope and expressed as cells L<sup>-1</sup>, using the Utermöhl (1958) method.

Three replicates were counted and the absolute numbers of the viable cells were converted into relative abundance values (RA, %).

Cells were grouped into five size classes (a < 20, b 21-70, c 71-120, d 121-200 and e > 200 µm) expressed as frequency percentage (%). The different microalgae growth forms were also identified using the literature and experimental observations (Welker & Nichetto, 1996) and expressed as frequency value (%). The following life forms were particularly considered: epipellic (benthic species living on - or moving through - muddy sediments), epipsammic (adnate benthic species growing on sand grains) and planktonic (non-benthic species floating in the water column).

Scanning electron microscopy (SEM) was performed on a LEIKA CAMBRIDGE STEREOSCAN- 430i at the Department of Biology, Trieste University (Zingone *et al.*, 1990).

Community diversity and dominance were measured by the species richness (Margalef index), the Pielou's evenness index (J), the Shannon-Weaver index (H) and the Simpson index (L). The two quantitative indices (Shannon-Weaver index and Simpson index) were calculated from relative abundances, using the STADIV program (Ganis, 1991).

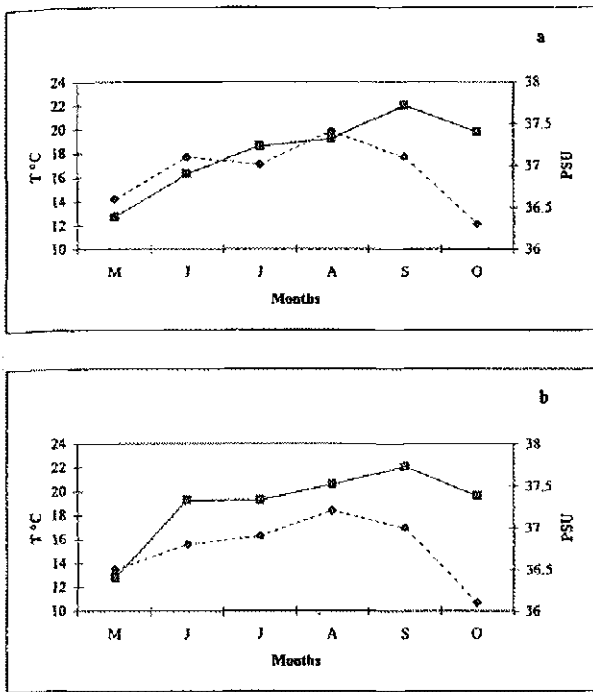


Fig. 2: Hydrological parameters recorded at the bottom layer during the sampling months at the control (a) and at the mussel cultures (b) site.

Filled squares: temperature (°C); filled rhombus: salinity (PSU).

Sl. 2: Hidrološki parametri, izmerjeni v pridnenem sloju v mesecih vzorčenja na referenčni postaji (a) in na lokaciji nasadov užitnih klapavic (b).

Črni kvadrati: temperatura (°C); črni rombi: slanost (PSU).

RESULTS

The investigated stations were characterised, at the bottom layer, by comparable salinity values between the considered months. The temperature values showed a similar increasing trend during the samplings at the two stations, with a strong increase of about 6°C from May to June (Fig. 2).

At the mussel culture station (st. M), values of temperature slightly higher than at the control station (st. B) were recorded at all times.

The temporal pattern of the cellular abundance was quite similar between the months at the stations. The average cell density values at the reference site (st. B) were generally higher than at the mussel culture site (st. M). An average absolute maximum was recorded at the stations in June, respectively with 509333 cells l<sup>-1</sup> at station M and with 1495500 cells l<sup>-1</sup> at station B. Conversely, a minimum was recorded in October with mean values of 22333 cells l<sup>-1</sup> at station M and 37500 cells l<sup>-1</sup> at station B respectively (Fig. 3).

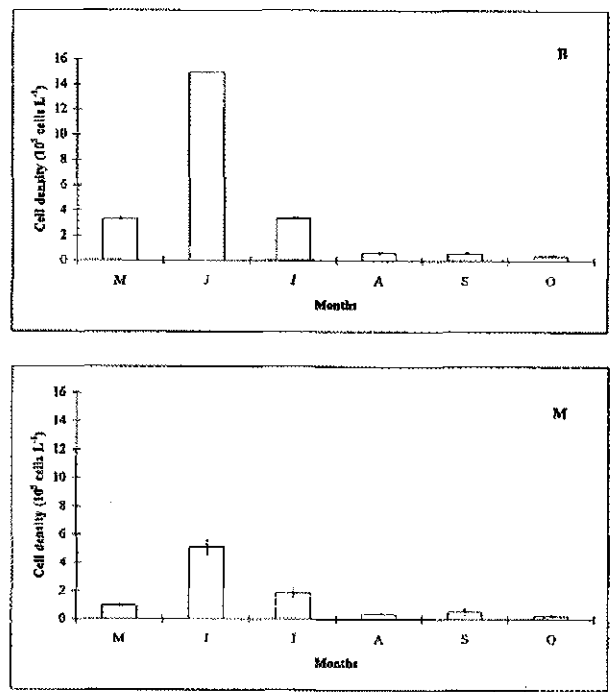


Fig. 3: Cell density at the control (B) and at the mussel culture (M) site during months of sampling. Standard deviations obtained from three replicates are indicated by error bars.

Sl. 3: *Gostota celic na referenčni postaji (B) in na lokaciji nasadov užitnih klapavic (M). Označene so standardne deviacije srednjih vrednosti, izračunane iz treh ponovitev.*

The size classes that appeared with constant and significant frequency were mainly of "a", "b" and "c" classes. The smallest (< 20 µm) and 21-70 µm size groups increased from May to October, whereas the medium size diatoms (71-120 µm) indicated an evident decrease. The other size classes ("d" and "e") occurred with irregular and very low frequency during all examined period (Fig. 4).

The diatom assemblages were mostly characterised by the prevalence of epipelagic species with "raphe system"; these motile diatoms varied in mean frequency from 49.7% to 96.7% at station M and from 70.7% to 98.0% at station B (Fig. 5). The epipsammic growth forms, consisting of diatoms attached firmly to the substrate, appeared with a mean relative frequency always higher at the mussel cultures site in respect to the reference site, reaching the highest frequency (49.8%) in July. Living planktonic species were constantly present at both locations with a variation ranging from 0.5% to 3.8% at station M and from 0.2% to 14.2% at station B. Nevertheless, the highest mean frequency (14.2%) of

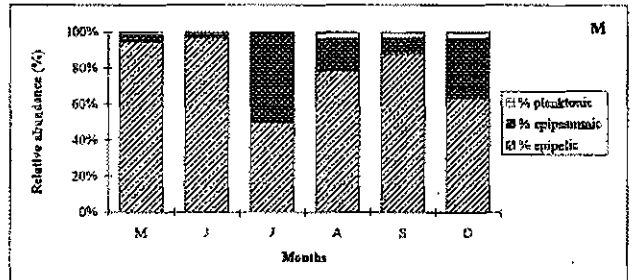
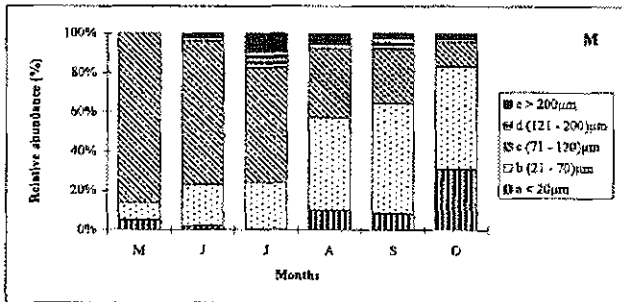
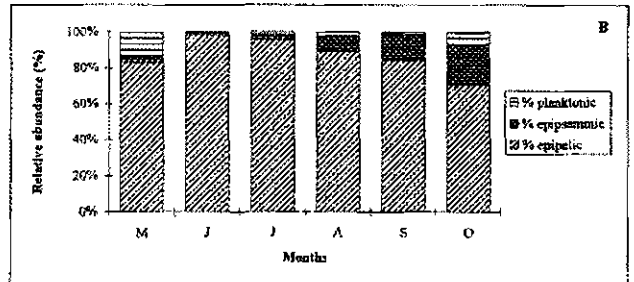
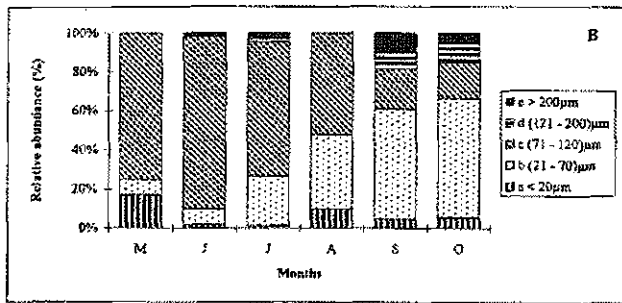


Fig. 4: Relative abundance of size groups at the control (B) and at the mussel cultures (M) site. All values are means of three replicates.

Sl. 4: Relativna abundanca velikostnih razredov na referenčni postaji (B) in na lokaciji nasadov užitnih klapavic (M). Vse vrednosti so srednje vrednosti treh ponovitev.

Fig. 5: Change in life forms frequency (%) at the control (B) and at the mussel cultures (M) site. All values are means of three replicates.

Sl. 5: Spremembe v frekvenci življenjskih oblik (%) na referenčni postaji (B) in na lokaciji nasadov užitnih klapavic (M). Vse vrednosti so srednje vrednosti treh ponovitev.

planktonic species was recorded at the control station (st. B) in May (Fig. 5).

The two sampling sites were characterised by the presence of the following epipelic species: *Cylindrotheca closterium* (EHR.) REIMANN & LEWIN, *Bacillaria paxillifera* (O. F. MÜLL.) HENDEY and *Gyrosigma acuminatum* (KUNTZ.) RABENHORST (Figs. 6 a-f).

At the control station, *C. closterium* showed the highest relative abundance in June with the mean value of 82.05%, while *B. paxillifera* and *G. acuminatum* reached the highest values in July (mean RA 16.37% and 18.16%). The relative abundance of these three species was followed by a progressive decrease during the other months (Tab. 1, Fig. 7).

At the mussel culture station, comparable relative abundances were noted. In particular *C. closterium* reached its maximum in May (mean RA 84.15%), while *B. paxillifera* and *G. acuminatum* reached it in August (mean RA 19.25%) and September (mean RA 19.88%) respectively. In spite of the constant presence of *B. paxillifera* and *G. acuminatum* at both stations during the sampling period (May-October), *C. closterium* was never found on either site (Tab. 1, Fig. 7). These species may be considered characteristic of the diatom-assemblages living at the water-sediment interface, in order to determine the features of the community, even if they

are not necessarily the most abundant species. These communities may be even defined by merely one of the characteristic species.

The epipsammic forms detached with large amounts were mainly characterised by the genera *Amphora* and *Navicula*. Particularly at station M, *Amphora* was the prevalent genus in July (mean RA 48.15%) with the highest percentage of *A. ostrearia* De BREBISSON (mean RA 46.98%; Tab. 1, Fig. 5).

The diatom communities at the water-sediment interface showed similar values in species richness (Margalef index) at both sites. The absolute maximum was recorded in September (3.4) at station B and in July (3.3) at station M, whereas the absolute minimum was noticed in August (1.5) at station B and in May (1.3) at station M.

The evenness measures ranged from 0.2 to 0.8 at the reference site, while at the mussel site they ranged from 0.3 to 0.8. Pielou's index values showed a similar temporal pattern to H-values, indicating that abundance was more evenly distributed among the species from May to October. The species abundance was unevenly distributed in June (0.2) and in May (0.3) at B and M sites respectively, as indicated by the very low Pielou's index values. A better abundance distribution among the species was evident in September at station B and in August at station M with the corresponding values near to one.

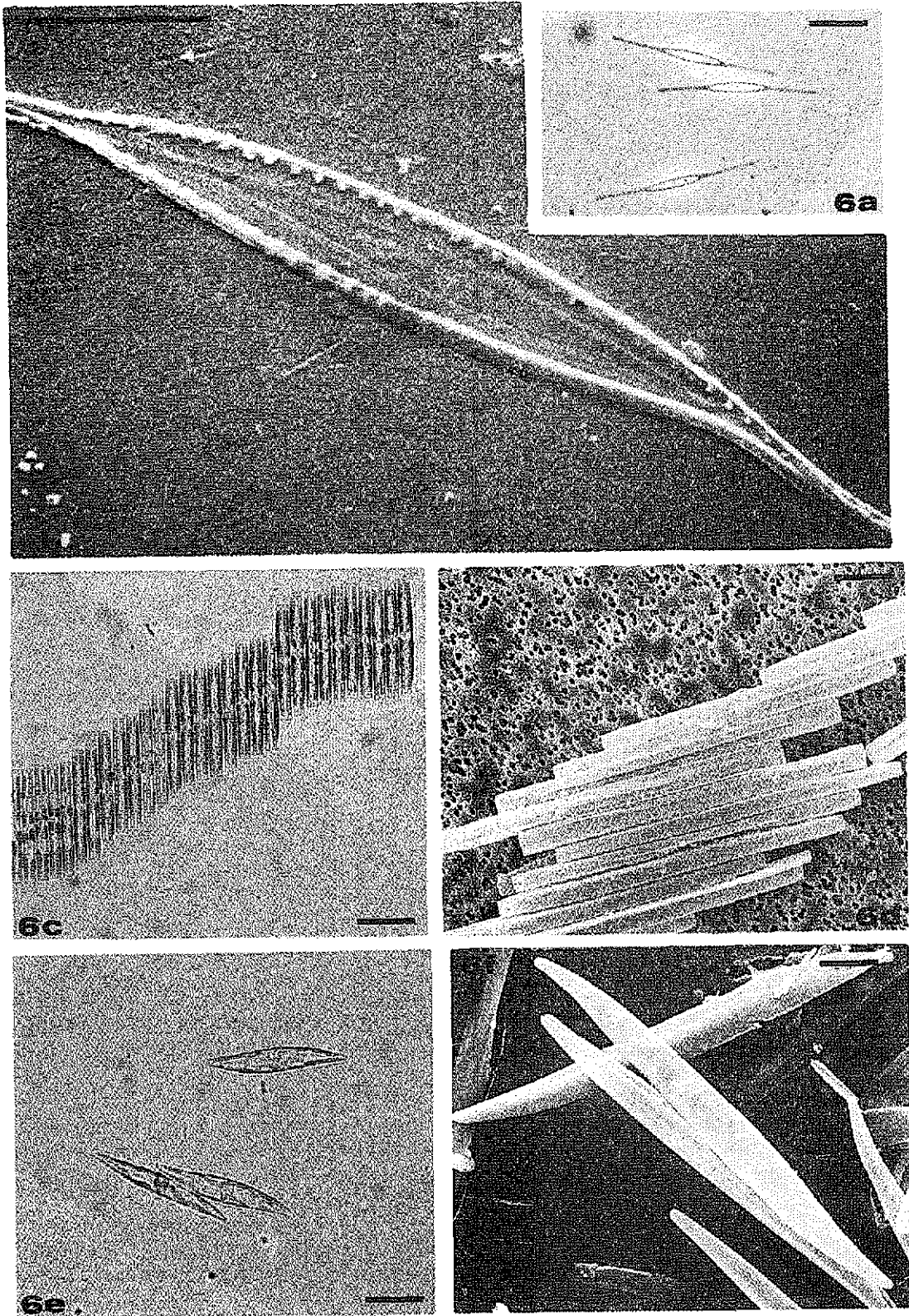


Fig. 6: Micrographs by inverted light and scanning electron microscope of following characteristic species: *Cylindrotheca closterium* (a-b), *Bacillaria paxillifera* (c-d) and *Gyrosigma acuminatum* (e-f). Scale bar (a, c and e) = 33  $\mu\text{m}$ ; (b, d and f) = 10  $\mu\text{m}$ .

Sl. 6: Posnetki invertnega svetlobnega mikroskopa in elektronskega mikroskopa značilnih vrst: *Cylindrotheca closterium* (a-b), *Bacillaria paxillifera* (c-d) in *Gyrosigma acuminatum* (e-f). Merilo (a, c in e) = 33  $\mu\text{m}$ ; (b, d in f) = 10  $\mu\text{m}$ .

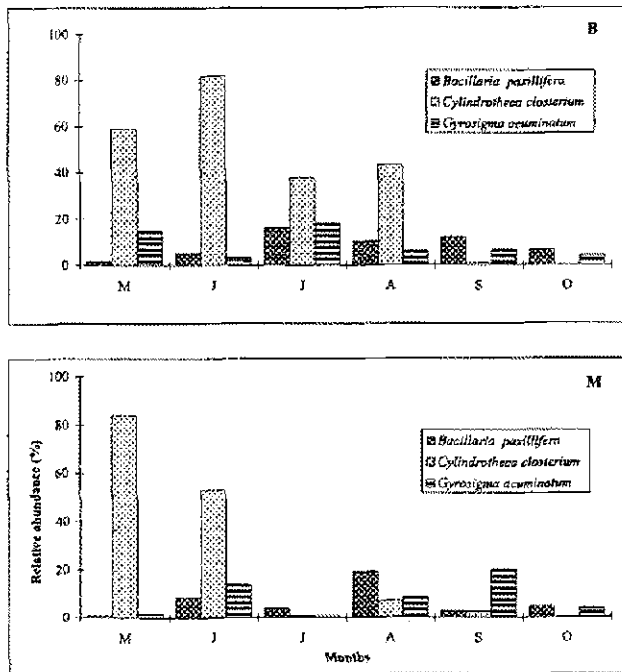


Fig. 7: Relative abundance of characteristic species at the control (B) and at the mussel cultures (M) site. All frequency values are means of three replicates.

Sl. 7: Relativna abundanca značilnih vrst na referenčni postaji (B) in na lokaciji nasadov užitnih klapavic (M). Vse vrednosti so srednje vrednosti treh ponovitev.

The Shannon-Weaver's diversity (H) index varied between 0.9 and 3.0 at site B, whereas at site M the same index varied between 0.8 and 2.7. The H-values showed an increasing trend from May to October at both sites. At the two stations the highest diatoms community biodiversity (H) was reached at different times. In particular at station B, the Shannon-Weaver index was equal to 3.0 in September, while at the other station the highest value was recorded in August (H = 2.7). Inversely, the lowest H-index values were recorded in June (H = 0.9) and in May (H = 0.8) at sites B and M respectively.

The Simpson index values showed an evident opposite temporal trend in view of the trend observed for the Shannon-Weaver index. The lowest Simpson index values were reached in September at st. B (L = 0.07) and in August at st. M (L = 0.09), the months in which the highest H-values were revealed. As these quantitative indices are inversely correlated, this corresponds with the absence of any dominant species. In addition, the highest L-index values (0.67 at st. B in June and 0.71 at st. M in May) together with the lowest H-index values were registered in the same months, indicating a clear dominance of some species (Tab. 2).

## DISCUSSION

The between-site differences in total cell density indicated that the diatoms community at the water-sediment interface, affected by the mussel cultivations, was always less abundant than the one observed at the reference site. The diatom assemblage under the suspended mussel cultures seemed to be limited in growth, in spite of the enhanced sedimentation of organic material and furthermore active nutrients regeneration at the water-sediment interface (Klump & Martens, 1981; Rizzo, 1990; Hatcher et al., 1994; Svane & Setyobudiandi, 1996). On the other hand, the sediments are usually considered an inexhaustible source of inorganic nutrients for benthic algae so that nutrient limitation should not arise (Sundbäck, 1986; Sundbäck & Snoeijs, 1991). The lower diatom abundance, at the mussel site, could be explained by considering the presence of the other limiting factors. As already seen by several authors (Sundbäck, 1986; Paterson, 1986; De Jonge & Colijn, 1994), light intensities may be considered a limiting factor for microphytobenthos, which can survive shading for long periods and recover rapidly when light conditions improve. The mussel site, although placed at a lower depth than the other one (st. B) and also conditioned by higher bottom temperature, might be unfavourable to photosynthetic activity, presumably for a diminished light irradiance at the bottom layer. This limitation might be due to the shading effect of the floating mussel systems and the continuous release and biodeposition of organic matter (faeces and pseudofaeces) from the water column to the bottom layer. As far as the incident light intensity reaching the water sediment interface is concerned, Barranguet (1997) highlighted, in a recent study on microphytobenthic primary production in a mussel culture, that the incident light percentages lower at a mussel station than at a reference station are a limiting factor for microphytobenthos production. Besides, enriched sediments by biodeposition are usually inhabited by a quantitatively rich associated fauna consisting of both infauna in the sediment and attached epifauna on the shells (Svane & Setyobudiandi, 1996).

In addition, direct underwater observations showed that the soft-bottom under the investigated mussel cultures was covered by living mussels and shells that had fallen down from the rafts. This modified substrate was an optimal support of adhesion for the settling of epibenthic communities. This community, known as O-R-M (*Ophiothrix*, *Reniera* and *Microcosmus* genus) community (Stachowitsch & Fuchs, 1995), was largely made of mobile and sessile filter or suspension feeders that had aggregated in the form of the so-called multi-species clumps (F. Aleffi, pers. comm.). Therefore, the diatom community living at the water-sediment interface below the mussel site might be subject to a major selec-



Diatom taxon	Control station (st. B)						Mussel culture station (st. M)					
	M	J	J	A	S	O	M	J	J	A	S	O
<i>Amphora coffeaeformis</i> (Agardh) Kützing	0,2	0,2	-	0,3	0,9	1,3	1,4	0,9	0,9	2,3	0,6	3,7
<i>Amphora ostrearia</i> de Brébisson	-	-	0,2	-	2,9	0,4	-	-	47,0	11,7	1,2	0,7
<i>Amphora ovalis</i> (Kützing) Kützing	0,1	-	0,1	0,3	2,6	2,2	0,2	0,4	0,3	-	1,2	0,7
<i>Amphiprora alata</i> Kützing	-	-	-	-	-	-	-	-	0,2	-	-	-
<i>Amphiprora paludosa</i> W. Smith	-	-	0,0	-	-	-	-	-	0,1	-	-	-
<i>Bacillariapaxillifera</i> (O. F. Müller) Hendey	1,6	5,2	16,4	10,2	12,0	6,7	0,7	8,6	3,8	19,2	2,8	4,5
<i>Campylodiscus</i> sp.	-	0,0	1,2	0,3	-	2,7	-	0,5	-	-	-	2,2
<i>Cocconeis placentula</i> Ehrenberg	-	-	-	-	-	-	-	-	0,3	-	-	-
<i>Cocconeis</i> sp.	-	-	-	-	0,3	0,4	-	-	-	-	-	1,5
<i>Cyclotella</i> sp.	-	-	0,1	-	-	-	-	-	-	-	-	-
<i>Cylindrotheca closterium</i> (Ehrenberg) Reimann et Lewin	59,0	82,1	37,9	43,3	0,9	-	84,2	53,0	0,5	7,0	2,4	-
<i>Cymbella</i> cf. <i>cistula</i> (Hemprich) Grunow	-	-	0,3	-	-	-	-	-	-	-	-	-
<i>Cymbella</i> sp.	-	-	-	0,8	1,4	0,9	-	0,1	0,2	-	0,3	-
<i>Diploneis bombus</i> Ehrenberg	-	0,0	-	0,3	-	0,9	-	-	-	-	0,3	-
<i>Diploneis crabro</i> Ehrenberg	-	-	-	-	-	-	-	0,2	-	-	-	-
<i>Diploneis ovalis</i> (Hilse) Cleve	0,3	0,0	0,9	1,9	2,0	-	0,5	0,6	0,3	-	0,6	6,0
<i>Diploneis smithii</i> (de Brébisson) Cleve	0,2	0,0	0,2	-	1,4	0,9	0,4	-	0,3	1,9	0,6	-
<i>Diploneis</i> sp.	-	0,0	-	-	0,3	-	-	-	-	-	-	-
<i>Eunotia</i> sp.	-	-	-	-	-	9,8	-	-	-	-	-	-
<i>Grammatophora</i> sp.	-	0,0	-	-	-	-	-	-	0,3	-	-	-
<i>Gyrosigma acuminatum</i> (Kützing) Rabenhorst	14,8	3,3	18,2	6,2	6,9	4,0	1,6	13,9	0,8	8,5	19,9	3,7
<i>Gyrosigmafasciola</i> (Ehrenberg) Griffith et Henfrey	0,1	-	0,8	-	0,6	-	0,2	4,6	-	-	-	-
<i>Gyrosigma macrum</i> W. Smith	-	0,0	0,4	-	0,6	1,3	-	0,4	4,5	1,4	2,4	1,5
<i>Gyrosigma obliquum</i> (Grunow) Boyer	-	-	-	-	-	-	-	-	0,4	-	-	-
<i>Licmophora gracilis</i> Grunow	-	0,0	-	-	-	-	-	-	-	-	-	-
<i>Licmophora</i> sp.	-	-	-	-	-	0,4	-	-	-	-	-	0,7
<i>Melosira moniliformis</i> (O. F. Müller) Agardh	-	0,1	0,3	-	14,6	7,1	1,8	3,5	1,1	-	3,1	3,0
<i>Navicula cancellata</i> Donkin	-	-	-	-	0,3	-	-	-	-	-	-	-
<i>Navicula</i> cf. <i>directa</i> (W. Smith) Ralfs	1,3	1,0	2,3	4,8	8,9	5,3	0,7	2,5	2,7	4,7	3,1	-
<i>Navicula simulans</i> Donkin	0,1	0,1	0,8	-	2,6	4,0	-	0,4	0,3	-	-	-
<i>Navicula</i> sp. 1	2,6	1,5	0,8	7,3	2,3	4,0	3,2	1,6	0,3	5,2	4,6	29,1
<i>Navicula</i> sp. 2	2,0	0,3	1,5	16,4	5,4	21,3	1,9	1,1	5,0	12,2	35,5	15,7
<i>Navicula</i> sp. 4	-	-	-	-	-	-	-	-	-	0,9	-	-
<i>Navicula</i> sp. (tubo)	-	0,0	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia angularia</i> (A. Schmidt) W. Smith	-	0,1	0,9	-	2,6	-	-	-	1,1	-	1,2	-
<i>Nitzschia gracilis</i> Hantzsch	-	0,3	0,8	-	-	0,4	-	0,5	0,4	0,5	-	-
<i>Nitzschia irresoluta</i> Hustedt	0,3	0,5	0,2	-	1,4	0,9	-	-	2,0	1,4	1,5	2,2
<i>Nitzschia lanceola</i> Grunow	-	0,1	0,3	-	-	0,4	-	0,1	-	-	-	-
<i>Nitzschia longissima</i> (de Brébisson) Ralfs	-	0,1	0,2	-	0,6	0,9	-	0,3	0,1	-	-	-
<i>Nitzschia lorenziana</i> Grunow	0,3	0,9	0,8	0,3	1,4	0,4	0,2	0,2	2,7	3,8	1,2	-
<i>Nitzschia obtusa</i> (A. Schmidt) W. Smith	-	0,1	0,6	-	0,6	-	-	-	-	-	-	-
<i>Nitzschia</i> cf. <i>palea</i> (Kützing) W. Smith	-	-	-	-	1,1	-	-	-	-	-	-	-
<i>Nitzschia panduri</i> Jormis Gregory	0,2	-	0,1	-	-	-	-	0,1	0,2	-	-	2,2
<i>Nitzschia recta</i> Hantzsch	0,3	0,8	1,0	0,8	0,3	2,7	0,5	1,8	2,4	1,9	1,8	2,2
<i>Nitzschia sigma</i> (Kützing) W. Smith	0,4	1,1	8,6	1,3	5,1	4,0	-	2,4	2,5	4,7	1,8	4,5
<i>Nitzschiasigma</i> var. <i>intercedens</i> Grunow	-	-	-	-	-	-	-	0,1	1,6	-	0,3	-
<i>Nitzschiasigma</i> var. <i>sigmatella</i> Grunow	-	-	-	-	-	-	-	0,5	1,4	-	-	-
<i>Nitzschia sigmoidea</i> (Ehrenberg) W. Smith	0,1	0,1	0,5	-	6,6	-	-	1,1	1,4	1,4	1,2	-
<i>Nitzschia tryblionella</i> Hantzsch	1,1	0,8	0,9	3,0	3,7	7,6	0,5	1,5	3,1	4,2	5,5	8,2
<i>Nitzschia vermicularis</i> (Kützing) Grunow	-	0,7	0,5	-	4,6	-	-	1,4	1,4	0,9	1,2	-
<i>Pinnularia</i> cf. <i>leptosoma</i> Grunow	0,2	-	-	-	0,3	-	-	0,3	-	-	-	-
<i>Pinnularia viridis</i> (Nitzsch) Ehrenberg	-	0,0	-	-	-	-	-	0,3	-	0,5	-	-
<i>Pinnularia</i> sp.	-	-	0,3	-	-	-	-	-	-	-	-	-
<i>Pleurosigma aestuarii</i> (de Brébisson) W. Smith	-	-	-	-	-	0,9	-	0,3	-	-	-	0,7
<i>Pleurosigma angulatum</i> (Quekett) W. Smith	-	-	-	-	0,3	-	-	-	-	-	-	-
<i>Pleurosigma formosum</i> W. Smith	-	-	0,4	-	-	-	-	0,1	0,5	0,5	-	-
<i>Pleurosigma minutum</i> Grunow	-	-	-	-	-	-	-	-	0,3	-	-	-

<i>Proboscia alata</i> (Brightwell) Sundström	-	0,0	-	-	-	-	-	-	-	-	-	-
<i>Rhopalodia gibba</i> (Ehrenberg) O. Müller	0,1	0,0	-	-	0,3	1,3	-	0,2	-	-	0,6	-
<i>Surirella</i> sp.	-	-	0,7	-	-	-	-	0,3	0,1	-	-	-
<i>Synedra</i> sp.	-	-	-	-	-	3,1	-	-	-	-	-	-
<i>Thalassiosira eccentrica</i> (Ehrenberg) Cleve	0,2	0,0	-	-	0,3	0,9	0,7	-	0,4	0,9	0,3	2,2
<i>Thalassiosira</i> sp.	14,2	0,1	0,3	2,4	1,1	1,3	1,6	0,3	0,5	3,8	3,7	1,5
<i>Triceratium</i> sp.	-	-	-	-	0,3	-	-	-	-	-	-	-
<i>Tropidoneis lepidoptera</i> (Gregory) Cleve	-	-	0,3	-	-	-	-	-	-	-	0,3	3,0
<i>Tropidoneis longa</i> Cleve	-	-	0,3	-	-	-	-	-	-	-	-	-
<i>Tropidoneis</i> cf. <i>longa</i> Cleve	-	-	-	-	2,0	-	-	-	2,2	-	-	-
<i>Tropidoneis</i> sp.	0,2	0,0	-	0,3	0,9	1,3	-	0,3	2,0	0,5	0,6	-

Tab. 1: List of diatom taxa with mean relative abundance value (%).

Tab. 1: Seznam diatomejskih vrst in njihove relativne vrednosti abundance (%).

Site B:

Date	Mean cell densities (cells L <sup>-1</sup> )	Number of species	Species richness evenness	Pielou's index (J)	Shannon-Weaver index (H)	Simpson index (L)
M	331000	24	1,8	0,4	1,4	0,39
J	1496000	36	2,5	0,2	0,9	0,67
J	334000	36	2,8	0,6	2,1	0,21
A	62000	18	1,5	0,7	1,9	0,24
S	58340	38	3,4	0,8	3,0	0,07
O	37500	32	2,9	0,8	2,9	0,08

Site M:

Date	Mean cell densities (cells L <sup>-1</sup> )	Number of species	Species richness evenness	Pielou's index (J)	Shannon-Weaver index (H)	Simpson index (L)
M	94670	16	1,3	0,3	0,8	0,71
J	509300	36	2,7	0,5	1,9	0,31
J	185200	41	3,3	0,6	2,4	0,24
A	35500	24	2,2	0,8	2,7	0,09
S	54500	29	2,6	0,7	2,4	0,18
O	22330	22	2,1	0,8	2,5	0,13

Tab. 2: Summary tables of statistic indices calculated from relative abundance, using the STADIV program.

Tab. 2: Pregled statističnih indeksov, izračunanih iz relativne abundance z uporabo STADIV programa.

tive pressure by benthic invertebrates (Asmus, 1982; Admiraal *et al.*, 1983, De Jong *et al.*, 1994).

The highest total abundances showed by the diatom assemblage at the water-sediment interface in June were probably due to the sudden increase in temperature in the study area. As already demonstrated, changes in temperature seem to be correlated with the increase of microphytobenthic density, until blooming begins at the water-sediment interface (De Jong & Admiraal, 1984; Dellavalle *et al.*, 1993; De Jong & De Jonge, 1995; Welker & Nichetto, 1996).

The relative minimum in diatoms abundance according to our results in October might be related to physical variations, such as light attenuation and vertical instability of the overlying water due to the active mixing of the winds, cooling and mechanical stirring. In fact, water column stratification that was established in May

was not recorded from September on; the overlying water appeared homogeneous and remained constantly unstratified during the ensuing months. In addition, few days before October sampling, an aggravation of the meteorological conditions (characterised by low barometric pressure, increasing precipitation and wind intensity) was recorded (M. Celio, *pers. comm.*). Therefore all these physical variations could act as a disturbance phenomenon in diatom community monitored, as already seen by Dellavalle *et al.* (1993) for a fouling community of the Gulf of Trieste.

Besides, due to some previous studies (Hudon & Bourget, 1983; Dellavalle *et al.*, 1993) we also know that physical disturbance, in diatom assemblage, leads usually to a fall in highly motile and chain forming species in diatom community. This observation would be in agreement with our results concerning growth of life



forms. In fact, in fall, the epipelagic species reached their minimum frequency favouring the epipsammic growth forms development, presumably better adapted to existence under unfavourable conditions (such as low light intensity or very fast current) and continual disturbance (Miller *et al.*, 1987; Paterson, 1989).

However, the presence of epipelagic species at the water-sediment interface is probably linked to the vertical active migrations towards the sediment surface that take place whenever the sediment is disturbed, finding a way out into the overlying water. Besides, a highly stimulated photosynthetic activity at the sediment surface may in itself function as a selective pressure on the microalgal community by selectively transporting away easily suspendible species (Sundbäck & Snoeijs, 1991). Conversely, when the conditions at the water-sediment interface are not yet favourable, owing to chemical and physical variations, these motile diatoms are able to take cover in the sediment. On the other hand, De Jonge (1985) highlights how the capacity of epipelagic diatoms to migrate could be interpreted as a survival strategy to prevent populations from being resuspended. These considerations, which were eventually confirmed by other authors (Paterson, 1986; De Jonge & Van Den Bergs, 1987; Happey-Wood & Jones, 1988; Delgado *et al.*, 1991; De Jong & De Jonge, 1995), would explain the decrement in epipelagic species frequency, proceeding from the summer stability to the fall unfavourable situation. Adversely, the epipsammic species, firmly bound to the substrate with persistent mucilaginous attachment structures, would be found at the water-sediment interface only after stirred up by hydrodynamic forces. This would explain their higher abundance at the end of summer and early autumn, periods characterised by an increasing instability at the bottom layer (M. Celio, *pers. comm.*). Besides, the epipsammic percentage values, greater at the mussel culture station than at the reference station, might be a result of the changed substrate conditions which, for the presence of the mussel shells and their harvesting remains, could act as an additional adhesion support. Similar results were already obtained in the recent work by Barranguet (1997), in which he highlighted how under the mussel culture area the microphytobenthos is composed mainly of diatoms, with a high abundance of epiphytic forms.

The planktonic species, which can be found at the water-sediment interface, are usually the consequence of the sinking phenomena involving either the vegetative cells at the end of the blooming period or the resting cells (non-growing diatom cells) (Smayda, 1971; Smetacek, 1985). During our investigation, these diatoms appeared to be slightly more abundant at the reference site than at the mussel culture site, suggesting that phytoplankton biomass is probably influenced by the presence of these filter feeders (Frénchette *et al.*, 1989; Asmus & Asmus, 1991). Large amounts of planktonic

diatoms were particularly evident in May, at the reference site, following the spring diatom bloom at the subsurface layer (S. Cok, *pers. comm.*).

The temporal increasing pattern of the smallest and medium-small diatoms could be related to the corresponding increase in temperature at the bottom layer. The specific growth rate,  $\mu$ , is a convenient parameter for characterising the growth potential of a species as a function of environmental variables and it provides a means of comparing one species with another. Among the environmental factors, temperature is the main variable that can affect the growth rate of diatoms. Each species show a maximum specific growth rate, probably genetically determined, at its temperature optimum. Changes in temperature affect the specific microalgal growth rate, inducing slight shift within both the planktonic and benthic communities. In addition, larger cells grow at a slower rate than small-celled species of both pennate and centric diatoms. Therefore, small size diatoms respond more quickly to a sudden rise in temperature with respect to the larger ones. A benthic diatom community can modify its composition, especially within size classes, when changes in temperature occur (Eppley, 1977). In natural environment, small size diatoms can have precedence over the larger ones and can characterise the whole community (Malone *et al.*, 1993).

As regards species composition, the diatom communities described in this study did not show substantial differences, as confirmed by similar richness values. These diatom assemblages are typical of muddy sediment in the Gulf of Trieste, and comparable to those found by Welker & Nichetto (1996) in deeper offshore waters in the same area.

Since variation in diatom species composition is a good indicator of the environmental condition (Snoeijs *et al.*, 1990), the large amounts of epipsammic species *A. ostrearia* (only at the mussel culture site) suggest that this species seems to prefer enriched sediments with higher organic content. On the other hand, *A. ostrearia* was often found, in large quantities, in oyster-bed culture (Maestrini & Robert, 1987), perhaps favoured by photoheterotrophic growth at low light intensities (Admiraal *et al.*, 1984; Sundbäck, 1986).

Although the density of benthic diatoms is apparently not correlated with nutrient availability at the bottom layer, it seems to be influenced to a certain extent by the changes in temperature (De Jong & Admiraal, 1984; Sundbäck, 1986; Sundbäck & Snoeijs, 1991; Dellavalle *et al.*, 1993; De Jong & De Jonge, 1995; Welker & Nichetto, 1996). However, the species *C. closterium* seems positively affected by nutrient availability. In fact, it reached the maximum abundance value in early summer, period characterised by highest ammonium and phosphate concentration at the bottom layer (S. Predonzani, *pers. comm.*). This is in agreement

with previous observations, in which highly motile *C. closterium* cells were able to benefit from the inorganic nutrient enrichment and laboratory experiments that also showed their capability to increase its growth rate with higher salinity and temperature (Jong & Admiraal, 1984; Sundbäck & Snoeijs, 1991).

The between-site variation of diversity was small, but slightly lower diversity at the mussel culture site might have been caused by a combination of several factors, such as the occurrence of intense mechanical disturbance by grazing, shading effect, high organic content, etc. The slight decrease in diversity that according to some previous studies occurred near the shore could perhaps be interpreted as an indicator of stress, such as from organic pollution (Pielou, 1975). Decrease in diversity has also been observed in benthic diatom communities under eutrophic conditions (Sundbäck, 1984). Although there are few studies that overlook diatom communities diversity of mud substrates, the Shannon-Weaver's index values obtained during our investigations were comparable to those reported for diatom communities of sandy substrates (Sundbäck & Snoeijs, 1991). The Simpson index values also confirmed the net dominance of *C. closterium*, above all in early summer, at both sites.

### CONCLUSIONS

The assemblages of diatoms at the water-sediment interface were at both investigated stations composed mainly of epipelagic species belonging to the medium size group, represented by the following characteristic spe-

cies: *C. closterium*, *B. paxillifera* and *G. acuminatum*.

Regarding the possible effects of the presence of the suspended mussel cultures on the two diatom communities, no evident variations were noted during the study regarding the species composition as underlined by Margalef index, and temporal pattern. The only disturbing effect due to the presence of mussel rafts, which also causes a between-site dissimilarity, was noted in algal cell density. In spite of a rather similar biodiversity index value (Shannon-Weaver index) within both stations, the lower diatom abundance observed at the mussel site might be due indirectly to their presence. Among all the disturbance factors, such as shading effect, biodeposition and grazing by benthic animals, the latter is the only one that does not affect the species composition of the diatom assemblages. A light attenuation at the bottom layer, generally, can favour some shading-adapted species. On the other hand, the continuous deposition of organic matter (faeces and pseudofaeces) may select some species characterised by a photoheterotrophic metabolism. Suspension and filter feeders invertebrates are not able to select the desirable diatom species, as food source, so the grazing effect on the community at the water-sediment interface is relevant only for the cell abundance.

Therefore it can be assumed that the diatom community under the suspended mussel cultures is limited in cell density due to a larger grazing activity by the rich associated fauna, drawn to higher availability of organic matter, and by filter-feeders of epibenthic O-R-M community.

## KOPIČENJE DIATOMEJ NA VMESNI PLASTI VODNIH USEDLIN V OBALNIH VODAH TRŽAŠKEGA ZALIVA (SEVERNI JADRAN)

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### POVZETEK

Resuspendirani mikrofitobentos, ki sestoji predvsem iz bentoških diatomej, igra pomembno vlogo v proizvodnji  $O_2$  kot hrane za pelagične in bentoške prehranjevalce na vmesni plasti vodnih usedlin v morskem obrežnem okolju. Da bi preverili morebitne spremembe v kopičenju diatomej na vmesni plasti vodnih usedlin zaradi tam domujočih suspendiranih kultur užitnih klapavic, je bilo opravljenih več raziskav na dveh izbranih postajah v Tržaškem zalivu. Mikroskopske analize so pokazale, da so za obe postaji, kjer so bile zabeležene predvsem epipelagične vrste srednje velikosti, značilne vrste *Cylindrotheca closterium*, *Bacillaria paxillifera* in *Gyrosigma acuminatum*. Statistične analize niso pokazale kakih večjih razlik glede biotske pestrosti teh združb. Pa vendar so bile diatomeje, živeče pod kulturami užitnih klapavic, manj številne, če jih primerjamo s tistimi na referenčnih postajah, nemara zaradi pojavljanja bentoških prehranjevalcev, ki jih je privabila večja razpoložljivoist organskih snovi zaradi biodepozicije.

**Ključne besede:** mikrofitobentos, školjke, gostota celic, vrstna sestava, biodiverzitet

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