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Baseline

Seasonal variations of epipelic algal community in relation to environmental factors in the Istanbul Strait (the Bosphorus), Turkey

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ABSTRACT

This study was implemented to investigate the species composition, abundance, seasonal variations and diversity of epipelic algae, to determine environmental variables affecting them and to reveal the accumulation of total organic carbon in the sediment in the coastal zone of the Istanbul Strait, Turkey. Epipelic algal community consisted of 44 taxa with a low diversity. The sediment structure which is highly unstable due to the high hydrodynamism of the zone played a dominant role as the main factor in the epipelic algal flora along the coasts of Istanbul Strait. Low TOC and high carbonate values also support this result. The dominance of cyanobacteria in some periods and, as a result of this, the record of the lowest diversity index values indicated the effect of nutrient enrichment and the risk of coastal eutrophication. High dominance of cyanobacteria may also be explicated by climate changes considering its effect in the other areas.

The coastal zone is the most productive and highly dynamic marine environment (Charpy-Roubaud and Sournia, 1990; Decho, 2000) and has been regarded as an important filter and transition zone of organic material and nutrients discharged from land (Kautsky and Kautsky, 1995). Microorganisms have important and established roles which may effect large scale changes in these systems (Decho, 2000). Primary producers have an important role for the functioning of shallow coastal ecosystems and their productivity by far exceeds that of the open oceans (Charpy-Roubaud and Sournia, 1990; Aberle-Malzahn, 2004). The major primary producers are macro- and microalgae (benthic, epiphytic and pelagic) colonizing all sorts of substrates and covering vast areas within the euphotic zones of aquatic systems (Aberle-Malzahn, 2004; Nielsen et al., 2004).

Epipelic algae, defined as Cyanobacteria and eukaryotic algae that live on or in association with fine–grained and illuminated substrata (MacIntyre et al., 1996; Poulíčková et al., 2008; Špačková et al., 2009), play a key role in biodiversity and primary production in aquatic ecosystems. It may contribute up to 50% of the total primary production (Perissinotto et al., 2002; Montani et al., 2003), influence the flux of inorganic nutrients between sediment and water (Welker et al., 2002; Sundbäck et al., 2004), stabilize sediments (Yallop et al., 2000) and play an important role in the benthic and pelagic trophic web (Montagna et al., 1995; Peletier, 1996). Of the epipelic algae the species composition of which varies significantly among various habitats, especially diatoms are the most dominant group in terms of species and individual number (Round, 1981; Scipione and Mazzella, 1992; Underwood and Paterson, 1993; Snoeijs, 1994; De Stefano et al., 2000). Diatoms, important primary producers in these systems (Decho, 2000), have been the primary focus of monitoring studies due to their rapid assemblage response to stress, existing knowledge of the narrow tolerance ranges for a large number of species (Potapova et al., 2004; Bellinger et al., 2006). Many factors such as light, temperature and nutrients as well as waves and currents, sediment type and particle size, consumption by aquatic animals have effects on this flora (Round, 1981; Jesus et al., 2009).

Benthic microalgal studies are more difficult than studies on phytoplankton. Sampling as well as separation of microphytobenthos from sediment, and cleaning procedures is hampered by several methodological difficulties (Ribeiro et al., 2003). Benthic diatoms are traditionally grouped according to the substratum they colonize (Round, 1981), the free-living forms that move through muddy sediments are known as epipelic while sessile forms attached to the particles of sandy sediments are referred to as epipsammic (MacIntyre et al., 1996). In this study, traditional epipelon sampling methodology was pioneered within freshwater habitats by Round (1953) was used. However, according to some researchers, this method does not provide adequate quantitative accuracy of true epipelic biomass and leads to contamination of epipelic community by other autotrophic groups (Poulíčková et al., 2008). Due to their ecological importance, studies on microbenthic algal structure have increased in number (Peletier, 1996;

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Haubois et al., 2005; Parikh et al., 2006; Cibic et al., 2007; Facca and Sfriso, 2007). On the other hand, the number of studies carried out along the coasts of Turkey is very low (Aktan and Aykulu, 2003; Aktan and Aykulu, 2005) compared to the freshwater and planktonic studies in the same zone. The studies on algae of the Istanbul Strait are limited. While the phytoplankton community structure, which is an indicator of the changes in water quality, and its seasonal changes have been studied by Uysal (1987, 1996), Uysal and Ünsal (1996), Tüfekci and Okus (1998), Aktan et al. (1999), there is no detailed study on the epipelic algae in the coastal zone of the Istanbul Strait.

The aim of this study is to investigate the species composition, abundance and seasonal variations of epipelic algae that play an important role on the biological diversity and primer productivity, to determine environmental variables affecting them and to reveal accumulation of total organic carbon in the sediment samples in the coastal zone of the Istanbul Strait.

Located at the northern part of the Turkish Straits System, the Istanbul Strait (Turkey) is one of the narrowest straits of the world and has an average length of 31 km, a width ranging between 0.7 and 3.5 km, an average depth of 35.8 m, and its deepest point has an average depth of 110 m (Gunnerson and Özturgut, 1974). It has a two-layered current regime formed by the water exchange between the Black Sea and the Mediterranean and a special ecosystem characterized by this feature (Tuğrul and Salihoğlu, 2000). Since the Istanbul Strait is continuously fed by the surface waters flowing from the Black Sea and negatively affected by the domestic and industrial waste waters of the Istanbul city and dense sea traffic, the water quality is harmed. Observations on hydrography of the Istanbul Strait shown that the exchange flows respond dynamically to time-dependent meteorological in the area and also hydrological forcing in the adjacent basins (Özsoy et al., 2002). The current velocity of the Istanbul Strait decreases from the upper layer through the middle layer and reversibly increases from the middle layer to the surface again. The current velocity in upper layer varies between 5 and 90 cm/s but its speed can be up to 2.5 m/s under extreme weather conditions (Yüksel et al., 2003 and Yalçıner et al., 2007).

Monthly sampling was performed from June 2003 to May 2004 at five sampling stations on the coastal sediments of the Istanbul Strait which were chosen to represent the effects of different environmental conditions (Fig. 1).

Overlying water was sampled for determining some physical and chemical parameters. Temperature was measured with a thermometer, salinity by the Mohr–Knudsen method (Ivanoff, 1972) and the dissolved oxygen by the Winkler method (Winkler, 1888).

Water samples for determining nutrients were collected in 100-ml polyethylene bottles and kept in deep freeze (−20 °C) until their analysis in the laboratory. Nitrite + Nitrate-N ($NO_3 + NO_2$-N) concentrations were analyzed by the cadmium reduction method on autoanalyzer (APHA, 1999). Phosphate-P (PO_4-P), Silicate-Si (SiO_4-Si) and chlorophyll *a* (Chl *a*) analyses were carried out by the methods described by Parsons et al. (1984). Chlorophyll *a* was measured after filtering 1 liter of the sample through 0.45 μm membrane filters (Whatman GF/C). One milliliter of a 1% suspension of $MgCO_3$ was added to the sample prior to filtration. Samples were stored in a freezer, and pigments were extracted in a 90% acetone solution and measured with a spectrophotometer. Organic carbon contents of the samples were measured using a CARLO ERBA EA-1108 carbon analyzer following the removal of the inorganic carbon by acid treatment with 1 N HCl. The total carbonate contents were determined by the gasometric–volumetric method after treatment with 4 M HCl (Loring and Rantala, 1992).

Epipelic algal samples were obtained by drawing a glass tube (0.7 cm in diameter) over the sediment of one-meter deep, and depositing the sample into a petri dish (10 cm diameter) to a depth of 1 cm. Then, coverslips were placed on the mud in the Petri dishes and left for 24 h. During this time, the positively phototactic algae moved upwards through the sediments and came to rest on the undersurface of the coverslips. The latter were then removed, placed on a glass slide and transects were taken across them using a light microscope (40 × 10). The number of cells for each species was then calculated from three slides Round (1953). However, as stated above, this technique does not provide adequate to a quantitative study of epipelic community. For this reason, the abundance of epipelic diatoms and their data analyses was reported only as relative abundance. For diatom identification, an appropriate volume of each sample was boiled with H_2SO_4 and HNO_3 and washed in distilled water. The acid cleaned diatoms were mounted in Naphrax medium with a high refractive index. Hustedt (1930), (1959), (1961–1966), (1985) Cupp (1943), Hendey (1964), Patrick and Reimer (1966, 1975), Kramer and Lange-Bertalot (1986), Poulin et al. (1986), Tomas (1995), Hartley et al., (1996), Komarek and Anagnostidis (1999) were used for identifications of microalgae.

Shannon–Weaver (H′) diversity index was used to describe epipelic algal assemblage structure (Odum, 1971; Clarke and Warwick, 1994). Spatial patterns in community structure were

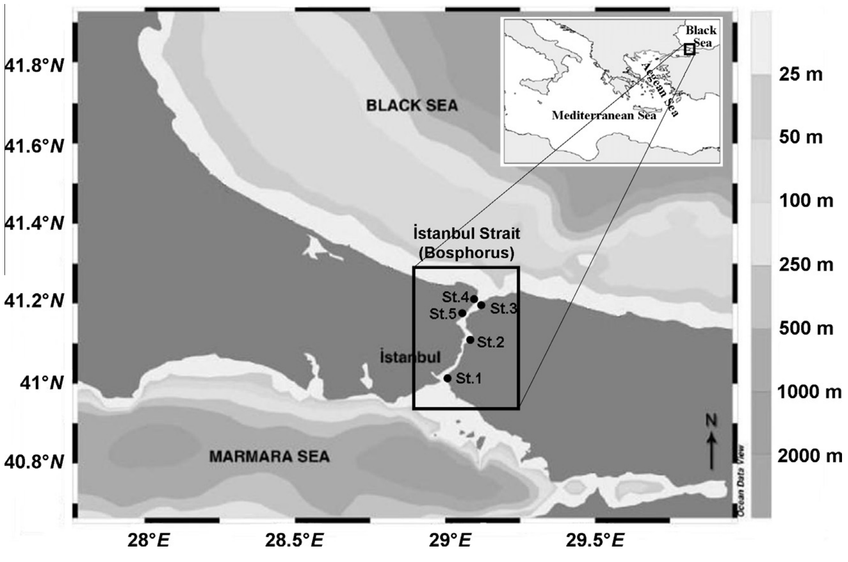

Fig. 1. Geographical map and sampling stations in the coastal zone of the Istanbul Strait.

examined by multivariate techniques using PRIMER 5 software. Species abundance data were square-root-transformed to balance the contributions from the few very abundant species with the many rare species (Clarke and Warwick, 1994). Bray–Curtis similarity was used to construct a similarity matrix using the non-metric multidimensional scaling (nMDS). Samples were grouped by season and sampling station, and differences were tested by a one-way ANOSIM test. The dominant species contributing to the spatial differences in community structure were investigated using the similarities percentage procedure according to SIMPER.

For each parameter, differences among the means of months ($n = 12$) and sampling stations ($n = 5$) were tested using a one-way ANOVA (Tukey's HSD *post hoc* test, $P < 0.05$). The data were transformed as log-transformed values when Levene's test showed significant heterogeneity in variances. The correlation between epipelic communities and environmental variables was evaluated applying the non-parametric Spearman correlation (at $P < 0.01$).

Descriptive statistics of some physicochemical and biological parameters ($n = 12$) in the coastal waters of the Istanbul Strait was given in Table 1. Changes in water temperature were typically seasonal during the study period and changes among the stations were slight. The highest average water temperature value was 24.4 ± 1.9 °C (August 2003) and the lowest 7.1 ± 0.2 °C (March 2004). While differences among the sampling stations were not statistically significant (ANOVA, $P > 0.05$), significant differences were noted by season (ANOVA, $P < 0.01$). Dissolved oxygen concentration was generally high except for June 2003 with an average of 8.6 ± 1.9 mg l^{-1}. Significant differences were found both spatially and temporally (ANOVA, $P < 0.01$). The extremely oversaturated values of dissolved oxygen (>18–23.4 ± 5.7 mg l^{-1}) were recorded in June 2003 probably due to the exchanges with the atmosphere and micro- and macro-algal productivity. Dissolved oxygen varied from 4.6 mg l^{-1} (March 2004, Station 2) to 15.5 mg l^{-1} (October 2003, Station 3). Average salinity fluctuated between 15.7 ± 1.7 (December 2003) and 17.1 ± 0.8 ppt (July, September and November 2003) (Table 1). ANOVA revealed significant differences in salinity among the sampling stations ($P < 0.01$), but not in the annual cycle ($P > 0.05$). *Post hoc* TUKEY test indicated that Station 1 was significantly different in salinity from the other stations.

The average levels for nitrate + nitrite ranged from 1.81 ± 1.3 (November 2003) to 12.2 ± 17.1 (January 2004) μg-at N l^{-1}, for phosphate from 0.6 ± 0.4 (November 2003) to 2.45 ± 3.0 (December 2003) μg-at P l^{-1}, and for silicate from 7.28 ± 2.2 (July 2003) to 30.2 ± 36.9 (December 2003) μg-at Si l^{-1}. The seasonal trends for all nutrients were generally similar. The highest nutrient values were recorded at Station 5. While changes in the nutrient concentrations at Stations 1, 2 and 3 were not statistically significant (ANOVA, $P > 0.05$), higher nutrient values between December 2003 and May 2004 were recorded at Stations 4 and 5. *Post hoc* TUKEY test also indicated that Station 5 is significantly different in all nutrient concentrations from the other stations. Chlorophyll *a* concentrations, as an indicator of phytoplankton biomass, ranged from 1.20 ± 0.2 (October 2003) to 4.54 ± 1.3 (February 2004) μg l^{-1}. During the study period, seasonal trend of chlorophyll *a* was statistically significant (ANOVA, $P < 0.05$) but differences among the stations were not significant.

Total $CaCO_3$ contents in the surface sediments ranged from 4.3% and 44.5%. Significant differences in $CaCO_3$ were observed among the stations (ANOVA, $P < 0.05$). The highest value was recorded at Station 1 in June and the lowest at Station 5 in December. Generally, the values were considerably higher than the shale average (6.0%, Mason and Moore, 1982,). The results indicated that the sediment samples investigated consisted of coarse-grained materials and shell fragments.

In the surface sediments, TOC (%) contents ranged from 0.08% (June and August 2003) to 0.78% (October and July 2003, February 2004). TOC content was lower than the shale average at all stations (0.8%, Mason and Moore, 1982). As a result of the dynamic structure of the strait, the TOC contents in the sediment are low. The highest value was determined at Station 5 and the lowest at Stations 1 and 3 in summer. No significant difference was observed among the sampling stations (ANOVA, $P > 0.05$). The Spearman correlation displayed highly significant and negative correlation between TOC values and CaCO3 ($r = 0.55$, $P < 0.01$).

In total, 44 epipelic algae were identified in the coastal zone of the Istanbul Strait, most of them (33 taxa) belonging to Bacillariophyceae (Table 2). The following group was Cyanobacteria with eight taxa. Chlorophyceae and Dinophyceae were represented by only one and two species, respectively. The epipelic algal composition of the Istanbul Strait were mostly from marine and brackish waters, but in several occasions, typical freshwater taxa (all cyanobacterial species and *Sphaerocystis planctonica* (Korshikov) Bourr. from chlorophytes) were also found, especially at Station 5 affected by freshwater inputs.

Epipelic abundance was correlated negatively with $NO_2 + NO_3$ ($r = 0.4$, $P < 0.01$) and positively with temperature ($r = 0.38$, $P < 0.01$). Diatoms and cyanobacteria were the most abundant groups. During the study period, diatoms had the highest values in early summer, autumn and late winter while Cyanobacterial abundance was very high in summer (especially in July and August) and winter (December and January). However, differences among seasons were not statistically significant (ANOVA, $P < 0.05$). Chlorophyceae was represented by only one species, *Sphaerocystis planctonica* (Korshikov) Bourr. Dinophyceae always had low abundance and did not show a remarkable seasonal variation. Fig. 2 shows relative contribution of dominant species to the epipelic algal flora.

The main findings on the epipelic algal community showed significant changes among sites (ANOVA, $P < 0.01$). Temporal variations of different epipelic algal groups were compared among five stations in Fig. 3. During the sampling period, the lowest epipelic abundance was recorded at Station 1. Since the sediments were highly mobile in June 2003 and December 2003 due to waves and the coast was covered with shell fragments, the development

Table 1

Mean ± standard deviation of some physicochemical and biological parameters in the Istanbul Strait.

	St. 1	St. 2	St. 3	St. 4	St. 5
Dis. oxygen (mg l^{-1})	8.3 ± 3.8	9.1 ± 5.8	11.4 ± 6.8	11.1 ± 3.4	9.3 ± 2.9
Salinity (psu)	18.3 ± 0.9	16.6 ± 0.3	16.5 ± 0.7	16.1 ± 0.9	15.9 ± 1.1
Temperature (°C)	13 ± 5	14 ± 6	14 ± 7	15 ± 7	15 ± 6
$NO_2 + NO_3$–N (μg-at N l^{-1})	4.18 ± 1.65	3.00 ± 1.09	1.02 ± 0.44	8.69 ± 11.39	15.26 ± 13.43
PO_4–P (μg-at P l^{-1})	0.49 ± 0.21	0.95 ± 0.82	0.29 ± 0.05	1.11 ± 1.28	3.30 ± 2.05
SiO_4–Si (μg-at Si l^{-1})	6.90 ± 3.74	5.89 ± 1.82	9.64 ± 4.12	21.10 ± 21.76	25.26 ± 17.72
$CaCO_3$ (% in sediment)	28.2 ± 7.5	18.6 ± 6.8	23.8 ± 6.9	32.7 ± 5.7	10.1 ± 2.9
TOC (% in sediment)	0.27 ± 0.13	0.61 ± 0.18	0.28 ± 0.18	2.44 ± 7.15	0.60 ± 0.14
Chl-*a* (μg l^{-1})	2.7 ± 1.5	1.7 ± 1.1	2.2 ± 1.8	2.2 ± 1.3	1.7 ± 0.8
Species number	3 ± 2	4 ± 3	14 ± 4	8 ± 5	6 ± 1

Table 2
List and frequency distribution of epipelic taxa in the Bosphorus (St. = station, V = very abundant, 81–100%; A = abundant, 61–80%; C = common, 41–60%; R = rare, 21–40%; X = present sporadically, 1–20%, – = none of the species included in this category.

Species	St. 1	St. 2	St. 3	St. 4	St. 5
Diatoms					
Amphipleura sp.	X	–	V	–	–
Achnanthes sp.	R	C	A	A	A
Amphora spp.	R	C	V	C	V
Amphora ovalis (Kütz.) Kütz.	X	X	C	C	R
Chaetoceros sp.	–	–	–	X	–
Climacosphaenia sp.	–	–	–	X	–
Cocconeis scutellum Ehrenb.	–	–	X	–	–
Cyclotella sp.	–	–	–	–	X
Cylindrotecha closterium (Ehrenb.) Lewin & Reinmann	C	X	C	C	X
Diploneis sp.	–		C	–	–
Fragilaria sp.	X	–	X	–	–
Grammatophora marina (Lyngb.) Kütz.	–	–	X	–	–
Gyrosigma fasciola (Ehrenb.) Griffith et Henfrey	–	X	–	–	–
Hantzschia amphyroxys (Ehrenb.) Grun	X	R	C	X	X
Lichmophora paradoxa (Lyngb.) Ag.	–	X	–	X	X
Melosira moniliformis (O.F. Müll.) Ag.	–	–	X	X	–
Navicula spp.	A	R	V	V	A
Navicula palpepralis Breb *ex* W. Sm.	–	–	–	X	–
Navicula placentula (Ehrenb.) Kütz.	–	–	X	–	–
Navicula pupula Kütz.	–	–	–	R	–
Navicula ramosissima var. *mucosa* (Aleem) Hendey	–	–	–	X	–
Navicula cryptocephala Kütz.	R	R	A	C	R
Navicula lyra (W.Sm.) Ralfs in Pritch.	–	–	X	X	X
Navicula tuscula (Ehrenb.) Grun	–	–	A	X	–
Nitzschia spp.	–	X	C	C	C
Nitzschia palea (Kütz.) W. Sm.	R	–	R	X	X
Pinnularia spp.	–	–	A	X	–
Petroneis humerosa (Bréb.) Stickle & Mann	–	–	C	X	X
Pleurosigma sp.	–	–	X	X	–
Skeletonema costatum Grev. in Cleve	–	X	X	–	–
Striatella unipunctata (Lyngb.) Ag.	–	–	X	–	–
Surirella spp.	–	–	–	X	–
Synedra tabulata (Kütz.) Grun	X	–	X	R	X
Cyanobacteria					
Aphanoteche sp.	–	X	–	–	–
Merismopedia glauca (Ehrenb.) Nageli	–	X	C	R	C
Oscillatoria tenuis Ag.	–	X	–	–	X
Oscillatoria limosa (C. Ag.) Gomont	–	X	–	X	X
Oscillatoria spp.	–	R	–	–	–
Phormidium sp.	–	–	X	–	–
Spirulina sp.	–	X	X	–	X
Syneococcus sp.	X	–	–	X	–
Chlorophytes					
Sphaerocystis planktonica (Korshikov) Bourr.	–	–	R	–	X
Dinophytes					
Prorocentrum scutellum Schröd.	–	X	–	–	X
Prorocentrum lima (Ehrenb.) Dodge	–	–	–	X	–

of epipelic algae on the sediments was limited and a notable seasonal change was not recorded. At this station, diatoms were dominant in terms of species and individual number and the highest abundance was recorded in March 2004.

At Station 2, the highest values in epipelic flora were recorded in summer and early autumn, and the contribution of cyanobacteria (especially *Aphanothece* sp., *M. glauca* (Ehrenb.) Nageli and *Oscillatoria* spp.) to total epipelic algal abundance reached 89%. Following a gradual decrease in total organism number in autumn, the lowest values were recorded in winter and spring.

Compared to the other stations, high abundances were recorded at Station 3. Based on the abundance values of epipelic algae, the nMDS analyses confirmed a clear separation of Station 3 from the others (Fig. 4). Multiple *post hoc* comparisons (Tukey's HSD, $P < 0.05$) showed that the epipelic algal community structure at Station 3 had significantly higher values than the other groups.

When investigated in terms of species number, diatoms are generally dominant but in June–September 2003 period *M. glauca* (Ehrenb.) Nageli of Cyanobacteria and *S. planctonica* (Korshikov) Bourr. of Chlorophyceae were recorded to show a remarkable development. Due to the negative environmental conditions in winter (decrease in water temperature, wind and wave and mobility of sediments), the development of benthic algae was limited and the lowest epipelic algal abundance was recorded.

At Station 4, diatoms, particularly *Achnanthes* spp., *Amphora* spp., *C. closterium* (Ehrenb.) Lewin & Reinmann, *N. cryptocephala* Kütz., dominated in terms of species number and abundance by comprising up to 97% of the epipelic algal community in all sampling periods except for June, August 2003 and May 2004. The contribution of Cyanobacteria to total epipelic community at this station increased in June 2003 (65%), August 2003 (96%) and May 2004 (95%) due to the intense development of *M. glauca* (Ehrenb.) Nageli.

Epipelic algal community at Station 5 was dominated by diatoms (approximately 100% of total abundance) in early summer. Cyanobacteria were recorded to have (52% of total epipelic algae) in July 2003. In the following samples, whilst epipelic Cyanobacteria reached the highest values all through autumn and winter

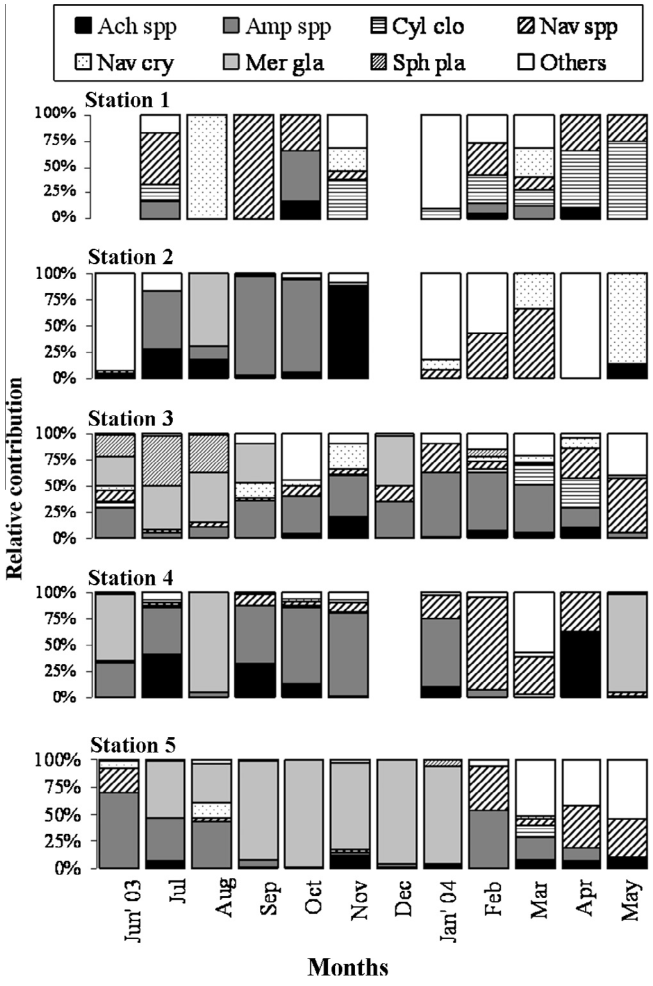

Fig. 2. Relative contribution of the dominant species to the epipelic algal flora (Ach spp: *Achnanthes* spp., Amp spp: *Amphora* spp., Cyl clo: *Cylindrotecha closterium*; Nav spp: Navicula spp., Nav cry: *Navicula cryptocephala*; Mer gla: *Merismopedia glauca*; Sph pla: *Sphaerocytis planctonica*).

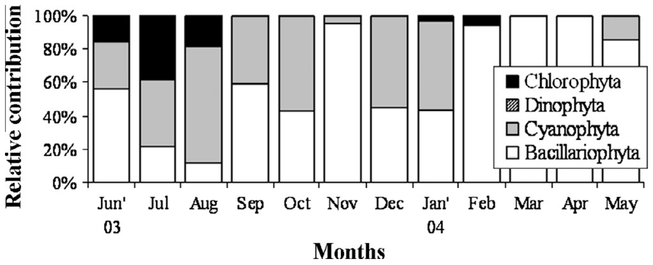

Fig. 3. Temporal variations of relative contribution of the different groups to epipelic algal abundance.

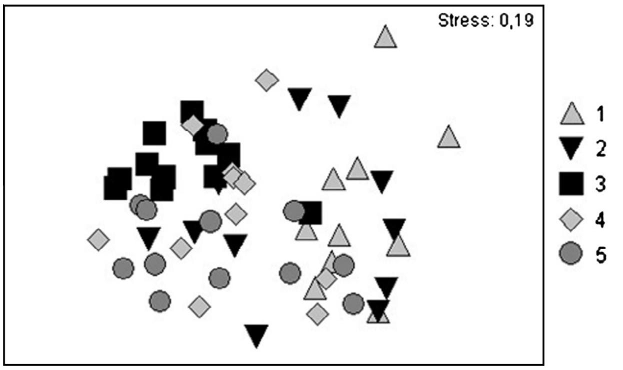

Fig. 4. Multi-dimensional scaling ordination of the five stations based on Bray Curtis similarity matrix derived from abundance data.

periods (from September 2003 to January 2004 until February 2004), it was the dominant group in abundance by comprising up to 98% of the total epipelic algae.

The highest diversity index (H') was obtained in October 2003 (3.32, Station 3), and the lowest in winter (0.00, Station 1, 2 and 4). The average epipelic algal diversity (H') during the sampling period was low with an average of $H' = 1.50 \pm 0.48$. As seen in Fig. 5, diversity was recorded more than 3 only at Station 3 in October 2003. Species diversity was positively correlated with epipelic algal species number ($r = 0.73$, $P < 0.01$). *Post hoc* TUKEY test noted that Station 3 is significantly different in species richness and diversity from the other stations. Both species richness ($S = 14 \pm 4$) and diversity ($H' = 2.50 \pm 0.52$) were always higher at Station 3 throughout the year. The Spearman correlation displayed significant, but negative correlations of Shannon Index with the $NO_2 + NO_3$ and PO_4 ($r = 0.46$ and 0.34 respectively, $P < 0.01$).

Significant locational differences were confirmed in the results of ANOSIM analyses ($P < 0.01$). The similarity within station groups was low, with less than 40% similarity. There was relatively more similarity (36%) at species level at Station 3 due to *Amphora* and *Navicula* species. Based on the abundance values of epipelic algae, the nMDS analyses confirmed a clear separation of Station 3 from the others (Fig. 4). Multiple *post hoc* comparisons (Tukey's HSD, $P < 0.05$) showed that the epipelic algal community structure at Station 3 had significantly higher values than the other groups. Species contributing to main spatial differences were explored with SIMPER analyses (Table 3). According to SIMPER analyses, the largest contributors to the dissimilarity between pairs of station groups were *Amphora* spp. and *M. glauca* (Ehrenb.) Nageli.

The Istanbul Strait is a dynamic system located between two large marine and terrestrial masses and highly influenced by both anthropogenic activities (urban and industrial wastewaters, nutrient inputs from small rivers and agricultural activities, heavy marine traffic) and inflow of nutrients due to water exchange between the Black Sea and the Marmara Sea.

The present study describes the epipelic algal assemblages with regard to some major physical and chemical variables and accumulation of TOC and $CaCO_3$ in sediment samples in the coastal zone of the Istanbul Strait.

The diversity and functional role of epipelic communities have become a major topic in benthic research recently. Despite their importance in coastal zones, microphytobenthos is relatively little studied in marine ecosystems. Marine ecosystems are sensitive to a variety of external forcings whereby often physical controls, such as hydrodynamics, solar energy input or temperature are often

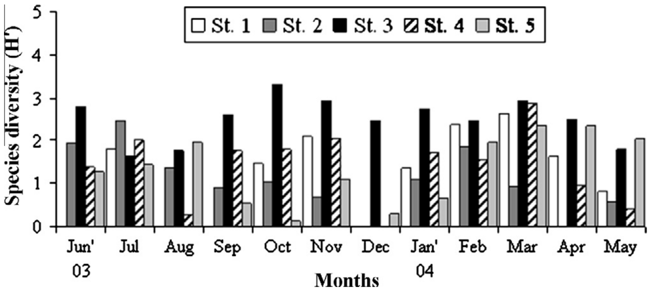

Fig. 5. Seasonal variation of species diversity at sampling stations in the Istanbul Strait.

Table 3
Species contributing to the similarity of stations in clusters that were identified with the Bray–Curtis similarity measure, defined with SIMPER (Average abundance, A; average within-group similarity, Av. SIM; standard deviation of similarity SIM/SD; the percentage contribution to the similarity, Cont.%; the accumulated similarity, Cum.%).

Sites	Species	Av. A.	Av. SIM	SIM/SD	Cont.%	Cum.%
Station 1	*Navicula* spp.	16.7	14.10	1.03	47.34	47.34
Š = 29.78	*Cylindrotecha closterium*	19.8	10.04	0.85	33.71	81.05
	Achnanthes sp.	95.1	4.81	0.64	27.89	27.89
Station 2	*Navicula* spp.	7.8	4.72	0.36	27.39	55.28
Š = 17.25	*Amphora* spp.	198.8	3.99	0.38	23.12	78.41
	Navicula cryptocephala	9.6	1.98	0.33	11.48	89.89
Station 3	*Amphora* spp.	1969.7	14.14	2.26	38.61	38.61
Š = 36.63	*Navicula* spp.	844.9	4.30	1.08	11.74	50.34
Station 4	*Amphora* spp.	950.8	8.41	0.70	31.30	31.30
Š = 26.86	*Navicula* spp.	120.9	8.22	1.29	30.62	61.93
	Achnanthes sp.	415.6	3.51	0.72	13.07	75.00
Station 5	*Merismopedia glauca*	1900.1	11.52	0.62	40.68	40.68
Š = 28.32	*Amphora* spp.	550.8	6.87	0.94	24.26	64.95
	Navicula spp.	88.5	4.43	0.64	15.66	80.61
	Achnanthes sp.	60.5	3.55	0.93	12.53	93.13

most prevailing (Wirtz and Wiltshire, 2005). Benthic algae rather than phytoplankton rapidly responding to environmental disturbance due to high growth rate are more appropriate for determination of site-specific conditions (Sand-Jensen and Borum, 1991).

The community structures, species compositions and species dominance of the benthic marine algae which are important in terms of biodiversity and production are the indicators of environmental factors and water quality (Hickman and Clarer, 1975; Leskinen and Hällfors, 1988). There are several factors that affect the composition and biomass of coastal algae negatively or positively. The composition of epipelic flora is determined by a complex of factor, of which the chemical composition of the overlying water is the dominant one, interacting with the chemical and physical nature of the sediment and with the degree of water movement (Round, 1981). While nutrients, light and temperature cause biomass increases to a certain extent, environmental dynamism, currents and wave intensity, suspended solid and consumption by aquatic animals are the factors that affect biomass increase negatively (Aktan and Aykulu, 2005). During the study, water temperature values in the Istanbul Strait showed changes in line with seasonal normals and were affective on the seasonal development of the epipelic algal flora. Salinity values which are important for the composition of benthic algal flora changed parallel to precipitation. While this change is not very notable in open seas, in coastal zones salinity values decrease due to precipitation and increases in fresh water inputs especially after winter. Dissolved oxygen concentration is not limiting for the development of benthic algae, which are photosynthetic organisms. In this study, intense development of macrobenthic algae and phytoplanktons as well as hydrodynamism caused by waves and winds affected the seasonal changes in dissolved oxygen. Especially, the value >18 mg l^{-1} recorded in June can be explained with phytoplankton and microalgae development as a result of coastal eutrophication.

Although nutrients are known to be the main limiting factor for algae development, it is assumed in general that the development of benthic microalgae is not limited by nutrients since nutrient concentrations in the pore water are generally high (Cadée and Hegemann, 1974; Admiraal, 1984). However, in the thin layer of diatoms at the sediment surface biomass may be highly concentrated, and thus nutrients may temporarily become depleted (Admiraal, 1977; Aberle-Malzahn, 2004). In this study, the seasonal trends of all nutrients were generally similar. Maximum values were recorded in winter. In December, there was a strong increase in all nutrient concentrations at Station 4 and 5. The highest values were probably due to an uncontrolled input of waste water into these stations. Nitrogen is the most common element limiting phytoplankton growth in most marine ecosystems (Stefanson and Richards, 1963) and in this study the results indicated that $NO_2 + NO_3$-N concentrations were low and N/P ratios (5.9 ± 2.3) were smaller than the Redfield ratio which suggested potential N limitation. On the other hand, according to Justic et al. (1995), criteria for stoichiometric nutrient limitation were developed based on nutrient requirements of diatoms and it was hypothesized that silicon deficiency may be exacerbating eutrophication by reducing the role of diatoms in coastal food-webs especially in sewage effluent waters. But in this study, no Si limitation was recorded during the whole sampling period. A total of 44 taxa belonging to four classes (Bacillariophyceae, Cyanobacteria, Dinophyceae and Chlorophyceae) were recorded from the benthic microalgae communities living on the coastal sediments in the Istanbul Strait. During the study period, pennate diatoms were dominant in terms species number at all stations. With their specific sliding motion, many pennate diatoms with raphe are the dominant species of the epipelic flora (Wetherbee et al., 1998). In many studies it was stated that of all algal groups pennate diatoms have a higher density and species richness in the epipelic algal flora of both freshwater (Happey-Wood and Priddle, 1984; Aktan and Aykulu, 2001; Špačková et al., 2009) and the coastal zones of seas (Ribeiro et al., 2003; Aktan and Aykulu, 2005; Haubois et al., 2005; Facca and Sfriso, 2007). In this study, excessive growths of the single genera from diatoms (like *Navicula cryptocephala* Kütz. and *Navicula* spp. that can adapt to high hydrodynamic structure of the strait with their specific movement capabilities) were recorded during the August and September at Station 1. On the other hand, it should be noted that non-motile species, which are known to exist in the sediments, could be ignored and not examined because of the method used.

Spatial and annual changes in algal productivity mainly responded to temperature, nutrients and light intensity (MacIntyre et al., 1996; Karosiene and Paskauskas, 2011; Paerl and Paul, 2012). Sediment type is an other important variables affected on the microbenthic algal assemblages. According to Jesus et al. (2009), assemblages diversity mostly controlled by sediment type and sandy sediments are more stable environments responding to seasonality changes while muddy sediments more exposed to unpredictable disturbance events. But, in the present study, in the coasts of the strait the difference in epipelic flora among stations was not very notable due to high hydrodynamism. Only at Station 3, relatively high intra-group similarity (36.6%) was recorded. The epipelic flora is more affected by mechanical stress (changes in grain size due to waves and currents) in terms of annual changes. The fact that the studied sediment samples mainly consisted of coarse-grained materials (sand + gravel) also supports limited development of epipelic algae.

At the stations with convenient fine sediment structure due to calm weather period, cyanobacteria were recorded as dominant in summer, late spring and even in winter periods probably due to increased light penetration. The low N/P ratios observed in these periods also support cyanobacterial dominance. Cyanobacterial increase (especially the increase in *Oscillatoria* and *Lyngbya* species) in waters with a high level of nutrients was studied many researchers. These studies have shown that benthic filamentous and coccoid genera can also undergo explosive growth and their blooms are indicative of eutrophication (Parikh et al., 2006 and references therein; Paerl and Fulton, 2006). In previous studies, similar results indicating the development of *Merismopedia* species were recorded (Aktan and Aykulu, 2003) in the epipelic flora of İzmit Bay, which was regarded as one of the most polluted zones of the Marmara Sea (Aktan and Aykulu, 2005). However, cyanobacterial growth sould be evaluated not only as an indicators of eutrophic status but also in respect to other global factors. Cyanobacteria are well adapted to environmental stress including exposure to UV, high solar radiation, nutrient enrichment and climatic changes (Pittman and Pittman, 2005) and blooms often occur in shallow and sheltered inshore waters as a responses of cyanobacteria to changing environmental patterns associated with global climate change (Paul, 2008). Studies in recent years indicate that climating change can act synergistically with antropogenic nutrient enrichment to promote global expansion of cyanobacteria (Paul, 2008; Paerl and Paul, 2012).

In order to explain the structure of communities, species diversity analyses are carried out. Species diversity is higher in the communities with a stable balance than those affected by humans. Communities with high species diversity generally consist of a high number of species and there is no considerable difference observed among the individual number of species (Odum, 1971). Habitat heterogeneity is related with the changes in species diversity (Watanabe et al., 2000). Shannon–weaver diversity index is one of the indices used in determining the pollution status of aquatic environments. In this study, the average species diversity in the coastal zone of the Istanbul Strait was determined as $H' = 1.50 \pm 0.48$. This value was regarded as "moderately polluted" according to the scales of Islam (2008) and references therein. Low species diversity is mainly due to both high sediment mobility and high cyanobacterial development in parallel with temperature increase in some periods. Relatively higher values were recorded in autumn and spring. During the study period, the highest species diversity was observed at Station 3 where macroalgae and macrophyte of the sheltered coastal zone keep sediments and form a more stable and balanced zone.

In this study, the sediment structure which is highly unstable due to high hydrodynamism of the zone played a deciding role as the main factor in the seasonal and spatial changes of the epipelic algal flora along the coasts of the Istanbul Strait. Low TOC values recorded to be lower than the shale average and high carbonate values in the study area also support this result. On the other hand, increased anthropogenic loading of nutrients into the coastal zone is now a worldwide phenomenon (Sundbäck and McGlathery, 2005). The dominance of cyanobacteria, which may show a good development in aquatic systems with high trophic status (Moncheva et al., 2001; Parikh et al., 2006; Paul, 2008), in the study area in certain periods and very low diversity index values recorded as a result of the dominance may be regarded as the indicators of coastal eutrophication. As a conclusion, it may be suggested that the Istanbul Strait which is known to be affected by the upper layer currents from the Black Sea which is fed by many rivers has a dynamic structure with intense flows. However, its trophic structure is affected negatively by the stress from Istanbul which is a huge metropolitan. On the other hand, long term monitoring studies are also needed to assess the impact of global warming and associated hydrological changes on coastal ecosystem.

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