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Annual Variation in the Diversity, Species Richness and Composition of the Phytoplankton Assemblages in the Izmir Bay (Eastern Aegean)

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Abstract

In this study, qualitative and quantitative characteristics of phytoplankton community structure and environmental factors which have influences on its distribution and the changes in Izmir Bay (Aegean Sea) were investigated. The water samples were collected seasonally between January 1998 and December 2001 from 3 sampling sites (from surface, -5 m, -10 m and -15 m). During the study period, a total of 115 taxa from three algal classes, Cyanophyceae, Dinophyceae and Bacillariophyceae were determined. Spatio-temporal phytoplankton community composition in the bay was often dominated by dinoflagellates but shift to diatom dominance was observed in some periods, particularly in spring and winter. The Wastewater Treatment Plant (WTP) began to treat domestic and industrial wastes since early 2000. The sampling periods of the study include both before and after the activation of treatment plant. Although WTP is sufficient for removal of nitrogen from the wastes, it is inadequate for removal of phosphate. This is also compatible with the decreasing N/P ratios observed during 2000-2001 in the middle and inner bays. Therefore, the decrease in the ratios caused by treatment plant, affects the species diversity of both dinoflagellat and diatom assemblages. The student's t-tests and the discriminant analyses outcome from different stations and years demonstrate statistically significant variances at a $P \leq 0.05$ probability level. These results indicated that the considerable improvements should be expected in the next years.

Keywords: Algal blooms, species' diversity, student's t-test, discriminant, Aegean Sea.

İzmir Körfezi'nde (Doğu Ege) Fitoplankton Topluluğunun Diversite, Tür Zenginliği ve Kompozisyonunun Yıllık Değişimi

Özet

Bu çalışmada, İzmir Körfezi (Ege Denizi) fitoplankton tür komposizyonu, türlerin kalitatif ve kantitatif dağılımları ve bu dağılımı etkileyen çevresel faktörler incelenmiştir. Su örnekleri Ocak 1998 ve Aralık 2001 tarihleri arasında 3 istasyondan mevsimsel olarak (yüzey, -5m, -10m ve -15 m) toplanmıştır. Çalışma süresince Cyanophyceae, Dinophyceae ve Bacillariophyceae olmak üzere üç alg sınıfından toplam 115 taxa saptanmıştır. Körfezde fitoplankton tür komposizyonunun bölgesel ve zamansal değişimi incelendiğinde genel yapı olarak dinoflagellatların baskınlığı göze çarpmaktadır ancak özellikle ilkbahar ve kış dönemlerinde diyatom baskınlığı gözlenmiştir. Evsel ve endüstriyel atıkların arıtılmasına, 2000 yılının başlarında atık su arıtma ünitesinin devreye girmesi ile başlanmıştır. Çalışmanın örnekleme dönemi, arıtma ünitesi aktivasyonunun öncesini ve sonrasını kapsamaktadır. Her ne kadar atık su arıtma ünitesi, azotun uzaklaştırılması için yeterli olsa da fosfatın uzaklaştırılması için yetersiz kalmaktadır. Bu durum orta ve iç körfezde 2000-2001 dönemleri arasında azalan N/P oranları ile de uymludur. Atık su arıtma ünitesinin neden olduğu bu azalma hem dinoflagellat hem de diyatom tür çeşitliliğini etkilemektedir. Student-t testi ve diskriminant analizleri ile istasyonlar ve yıllar arasında, istatistiksel olarak $p<0.05$ olasılık seviyesinde önemli farkları işaret etmektedir. Bu sonuçlar gelecek yıllar içersinde önemli gelişmelerin olabileceğini göstermektedir.

Anahtar Kelimeler: aşırı üreme, tür diversitesi, student's t-testi, diskriminant, Ege Denizi

Introduction

The Aegean Sea which is one of the Eastern Mediterranean basins displayes a complicated hydrographic and ecological structure due to its geographical position between the Black Sea and Mediterranean Seas (Siokou-Frangou *et al*., 2002; Zervakis *et al*., 2000). It is separated into two subbasins which are the North Aegean and the South Aegean, with significantly different hydrographic characteristics because of the influence of Black Sea waters and Mediterranean Sea waters, respectively.

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Izmir Bay is situated at the western coast of the Anatolian peninsula, and is connected to the Aegean Sea. It is a well known fact that the Izmir Bay is an excessively polluted focal point due to the impact of domestic and industrial wastes (Kontas *et al*., 2004; Kucuksezgin *et al*., 2006). The growing amount of industrial wastes discharged into the marine environment without being treated, the disorderly urban expansion due to rapid increase in population, and the agricultural wastes carried to the sea by the streams have all been contributed to the increasing amount of pollution in the area. Increasing eutrophication has showed adverse effects on fauna and flora resulting in a decline in the richness and diversity of species and has reached the levels of hypertrophication impairing the structure of the micro-plankton population, particularly in the Inner Bay, which is the shallowest part of the Izmir Bay. This is due to the abundance of land-based inflows and lack of sufficient circulation in this part as compared to the other parts of the bay (Colak Sabanci and Koray, 2001).

Pollution control is one of the essential aims of coastal water management. The fundamental physical, chemical and biological properties of water affect the monitoring and assessment of coastal water quality (Clark, 1996). In recent years "oligotrophy", "mesotrophy" and "eutrophy" become more common in marine literature as eutrophication has been occurred frequently (Vollenweider *et al*., 1998). Many quality indices have been used in the last years for coastal water quality. The importance of nutrient monitoring has been increased in the coastal waters of the Mediterranean, particularly in the areas affected by tourism. When descriptive univariate methods are applied, an enormous amount of nutrient data is accumulated, although it has a little effect on decision-makers (Ignatiades *et al*., 1985). Despite that, for environmental quality assessment (Moriki and Karydis, 1994; Feder *et al*., 1994; Aguilera *et al*., 2001; Shahrban and Etemad-Shahidi, 2010), phytoplankton (Ignatiades *et al*., 1985) and pollution studies (Warwick, 1988) multivariate procedures have been proved the most appropriate.

The Cigli Wastewater Treatment Plant of Izmir has been built within the framework of the so-called "Great Channel Project" in order to protect the Izmir Bay from wastewater pollution. Having been put in operation in 2000, the Cigli Wastewater Treatment Plant, with its nitrogen and phosphorus units, managed to achieve a significant upgrading in the Izmir Bay within a year.

In view of the above, this study aims at identifying phytoplankton species, their quantitative distributions and the variances in the diversity of species along a time vector of 1998 to 2001. Thereby, it would be possible to suggest a favourable statistical method to determine the fluctuations in phytoplanktic communities in the first stage of the wastewater treatment activation.

Materials and Methods

One of the largest bays in Mediterranean is Izmir Bay (38°20′ N latitude and 26°30′ E longitude, and 38°40′ N latitude and 27°10′ E longitude), which is a part of Izmir, a commercial and cultural point of Aegean Sea. The total surface area of Izmir Bay is 500 km^2, total length is 64 km providing a water capacity of 11.5 million m^3. The bay is subdivided to three parts in terms of its topographic structure: outer bay (Sta. 1), middle bay (Sta. 2) and inner bay (Sta. 3) (Figure 1). 20 km wide outer bay is located between Karaburun and Foça extending 45 km in the Northwest-Southeast direction whereas inner and middle bays lie in the east-west direction with a total

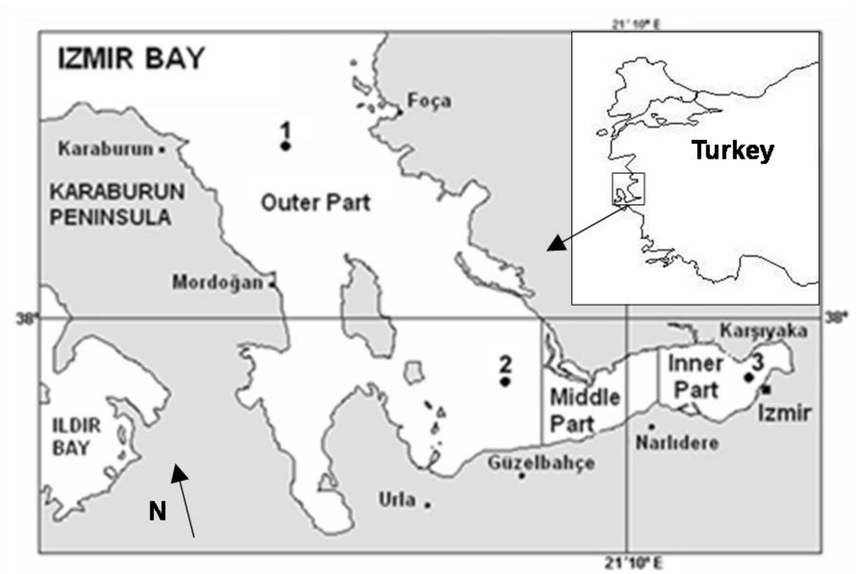

Figure 1. Location of stations in the Izmir Bay.

length of 24 km and total width of 6 km. Inner bay covering an area of 57 km^2 is relatively small and shallow reaching to a maximum depth of 15 m. Inner bay is separated from Middle bay by a 13 m deep sill. Narrow Mordoğan Strait can be seen between Uzunada and west coast with a 14 m deep sill. Outer bay presents with an approximate depth of 70 m decreasing in the direction of polluted Inner Bay (UNEP 1993).

The single-cell micro plankton group was examined at three stations from cruises of the *R/V K. Piri Reis* (Institute of Marine Sciences and Technology) within the framework of the "Izmir Bay Marine Research Project" in 1998 (January, April, September, October), 2000 (March, April, July, November) and 2001 (January, April, August, December). Water samples for phytoplanktic examination were collected with 2 L Nansen bottle from depths of 0.5 m, 5.0 m, 10.0 m and 15.0 m. The samples were fixed with Lugol's iodine solution. Then, neutral formaldehyde was added until a concentration of 4% was reached. Samples were precipitated and the upper layer was removed by siphoning and standard single drop methods were used for counting. Upon completion of the counting process, the phytoplankton count results attained from the samples with known initial volumes were transformed into "cell per litre" units by reverse calculation (Venrick, 1978; Semina, 1978). The micro plankton species were identified by means of OLYMPUS BX-50 and Nikon Labophot-2 research microscopes. The studies used for species identifications were Cupp (1977) and Tregouboff and Rose (1957).

General Oceanic Go-Flo Rosette bottles attached on Sea-Bird Model 9 CTD probe was utilized for the physical and chemical analyses of water samples. Calibration of Sea-Bird CTD sensors was performed once a year by Northwest Regional Calibration Center (operating under contract to NOAA). At the time of sampling, sample bottles (100 ml polyethylene) were rinsed twice with the sample, filled, and immediately frozen pending analysis. Seawater samples obtained (from depths of 0.5 m, 5.0 m 10.0 m and 15.0 m) by means of General Oceanic Go-Flo Rosette bottles attached to the CTD system were examined physically (temperature) and chemically [(nitrate+nitrite)-nitrogen,o.phosphate-phosphorus and silicate)] by Chemistry Department of Dokuz Eylül University Institute of Marine Sciences and Technology. A Skalar (two-channel) Autoanalyzer was used for nutrient analysis conducted within the first week following completion of the cruise. Strickland and Parsons (1972) and Grasshoff *et al*. (1983) were followed for colorimetric methods.

Intercalibration seawater samples (from QUASIMEME, Plymouth Marine Laboratory, Round 22) were used as a control for the analytical methods. The values obtained (in micromolar) for the analyses of 10 replicates of this sample were given in Table 1.

The annual variations in the diversity of species were monitored in this study by using the Shannon-Weaver diversity index of species (Shannon and Weaver, 1949). In order to determine the diversity of phytoplankton, the Shannon-Weaver diversity indexes were calculated for each station and depth based on the number of species and individuals. The lists of species for the quantitative sampling period were prepared seasonally for each station. In order for the difference in stations and years to be found, vertical counting of each station was first integrated and transformed into cell amount in water column and Student's t-test was used to test the difference. In case no difference was found, discriminant analysis was employed. Moreover, the relationship between community parameters and environmental factors were determined by Pearson's correlation analysis.

Results

Phytoplankton Composition

This study revealed 3 algae classes, namely, Cyanophyceae, Dinophyceae and Bacillariophyceae, which belong to the phytoplankton group. Among these, in genera level 1 species belongs to Cyanophyceae class, 16 genera, 61 species and 1 variety that belong to Dinophyceae class and 33 genera, 54 species that belong to the Bacillariophyceae class were identified to the genus or species level which add up to 115 phytoplankton taxa as a whole (Table 2).

In this study, Dinophyceae and Bacillariophyceae were determined to be dominant in both the number of species and individuals compared to the other classes. Based on the quantitative evaluations, evident discrepancies were detected in phytoplankton densities between regions. *Ceratium furca* var. *eugrammum* (Ehrenberg) Schiller 1937**,** *Ceratium fusus* (Ehrenberg, 1834) Dujardin, 1841**,** *Ceratium kofoidii* E.G. Jørgensen, 1911**,** *Oxytoxum scolopax* Stein, 1883, *Prorocentrum micans* Ehrenberg, 1833, *Protoperidinium depressum* (Bailey, 1850) Balech, 1974**,** *Protoperidinium divergens*

Table 1. The certified values of the CTD and the obtained nutrient levels

Parameter	Certified value (standard deviation)	Measured value (standard deviation)
TNO_x-N	8.68 (0.38)	8.78 (0.04)
NO_2-N	0.50 (0.04)	0.50 (0.02)
o.PO_4-P	0.76 (0.05)	0.78 (0.01)
Si	2.55 (0.19)	2.67 (0.03)

Table 2. Microphytoplankton species observed in Izmir Bay, between 1998 and 2001

Species	1998												2000												2001											
	İst. 1				İst. 2				İst. 3				İst. 1				İst. 2				İst. 3				İst. 1				İst. 2				İst. 3			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
EUKARYOTA																																				
CHROMOPHYTA																																				
DINOPHYCEAE																																				
Ceratium carriense Gourret, 1883	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
Ceratium contortum (Gourret, 1883) Cleve, 1900	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Ceratium declinatum (Karsten, 1907) Jørgensen, 1911	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium euarcuatum Jörgensen 1920	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	1	0	0	0	0
Ceratium furca (Ehrenberg) Claparéde & Lachmann, 1859	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	0	0	1	0	0	0	0	1	0	0	1	0	0	1	0	0	0
Ceratium furca var. *eugrammum* (Ehrenberg) Schiller, 1937	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1
Ceratium fusus (Ehrenberg, 1834) Dujardin, 1841	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1	1	0	1	0	0	1	0
Ceratium horridum (Cleve) Gran, 1902	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Ceratium kofoidii E.G. Jørgensen, 1911	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	0	0	0	1	1	0	1	1	1	1	1	1	0	1	1	1
Ceratium longirostrum Gourret, 1883	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
Ceratium longissimum (Schröder, 1900) Kofoid, 1907	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Ceratium macroceros (Ehrenberg) Vanhöffen, 1897	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
Ceratium massiliense (Gourret, 1883) Jørgensen, 1911	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium pentagonum Gourret, 1883	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Ceratium ranipes Cleve, 1900	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Ceratium teres Kofoid, 1907	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0
Ceratium trichoceros (Ehrenberg, 1860) Kofoid, 1908	0	0	0	0	0	0	1	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	1	0
Ceratocorys horrida Stein, 1883	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Dinophysis acuminata Claparède & Lachmann, 1859	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Dinophysis acuta Ehrenberg, 1841	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Dinophysis caudata Saville-Kent, 1881	1	0	1	1	1	1	1	1	1	1	1	0	1	0	0	0	1	1	0	0	0	0	0	0	1	0	1	1	0	0	1	0	0	1	1	0
Dinophysis fortii Pavillard, 1923	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	0	1	1	0	0	0	1	1	0	0	0	1	0	0
Dinophysis hastata Stein, 1883	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinophysis parvula (Schütt) Balech	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Dinophysis rotundata Claparède & Lachmann, 1859	0	1	1	0	0	1	0	1	0	0	0	0	0	1	0	0	1	1	0	0	0	1	0	0	0	1	1	1	0	1	0	0	0	0	0	0
Dinophysis sacculus Stein 1883	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0
Dinophysis tripos Gourret, 1883	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diplopsalis lenticula Bergh, 1881	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	0
Exuviaella cordata Ostenfeld	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1
Gonyaulax polygramma Stein, 1883	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Lingulodinium polyedrum (F. Stein) J.D. Dodge, 1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Neoceratium arietinum (Cleve) F.Gómez, D.Moreira & P.López-Garcia 2001	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Neoceratium biceps (Claparède & Lachmann) *F.Gómez, D.Moreira & P.López-Garcia 2001*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Neoceratium candelabrum (Ehrenberg) *F.Gómez, D.Moreira & P.López-Garcia 2001*	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Neoceratium tripos (O.F.Müller) F.Gomez, D.Moreira & P.Lopez-Garcia 2001	1	1	1	1	1	0	1	1	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	1	0	1	0	0	0	1
Noctiluca scintillans (Macartney) Kofoid et Swezy 1921	1	0	0	0	1	0	0	0	1	0	1	0	1	1	1	0	1	1	1	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	1
Ornithocercus magnificus Stein, 1883	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Oxytoxum reticulatum (Stein, 1883) Schütt, 1896	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Oxytoxum scolopax Stein, 1883	1	1	0	0	1	1	1	1	1	1	1	1	1	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
Podolampas palmipes Stein 1883	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	1	0	0	1	1	1	0	0	0	0	0
Podolampas spinifera Okamura, 1912	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Prorocentrum gracile Schütt, 1895	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prorocentrum lima (Ehrenberg, 1860) Stein, 1878	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	1	0	1	1	1	1	1
Prorocentrum micans Ehrenberg, 1833	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Prorocentrum scutellum Schröder, 1900	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	1	0	0	1	1	1	0	0	1	1	0	0	1	0	1	0
Prorocentrum triestinum Schiller, 1918	0	1	1	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Protoperidinium claudicans (Paulsen) Balech 1974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1
Protoperidinium conicum (Gran, 1900) Balech, 1974	1	0	0	0	0	1	1	1	0	1	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	1	0
Protoperidinium depressum (Bailey, 1850) Balech, 1974	1	1	0	0	1	1	1	0	1	1	1	0	1	0	0	0	1	0	1	1	0	0	1	1	0	0	1	0	1	1	0	0	1	1	1	0
Protoperidinium diabolus (Karsten) Balech	0	0	0	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	1	1	0	0	1	1	1	0
Protoperidinium divergens (Ehrenberg) Balech, 1974	1	0	0	0	0	1	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	1	0	0	1	1	1	0
Protoperidinium granii (Ostenfield, 1906) Balech, 1974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Protoperidinium longipes Balech 1974	1	1	0	0	1	1	1	0	1	0	0	0	0	0	1	0	0	1	1	1	0	1	1	0	0	0	0	0	1	0	0	0	1	1	0	0
Protoperidinium mediterraneum (Kofoid, 1909) Balech, 1974	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	1	1	1	0
Protoperidinium mite (Pavillard, 1916) Balech, 1974	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Protoperidinium oceanicum (VanHöffen, 1897) Balech, 1974	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0

Table 2. (Continued)

Species	1998												2000												2001											
	İst. 1				İst. 2				İst. 3				İst. 1				İst. 2				İst. 3				İst. 1				İst. 2				İst. 3			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Protoperidinium pallidum (Ostenfeld, 1899) Balech, 1973	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Protoperidinium pedunculatum (Schütt, 1895) Balech, 1974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrocystis hamulus Cleve 1900	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	0
Pyrocystis robusta Kofoid, 1907	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scrippsiella trochoidea (Stein) Balech ex Loeblich III, 1965	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	1	0	1	0	0	0	1	1	0	1	1	1	0
BACILLARIOPHYCEAE																																				
Achnanthes longipes C.Agardh, 1824	1	0	1	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphiprora sp.	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Asterionellopsis glacialis (Castracane) Round, 1990	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
Asterolampra marylandica Ehrenberg 1844	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Bacteriastrum delicatulum Cleve, 1897	0	1	0	1	0	1	0	1	1	1	0	1	0	1	0	0	1	0	0	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0
Bacteriastrum elegans Pavillard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Bacteriastrum hyalinum Lauder, 1864	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0
Bacteriastrum mediterraneum Pavillard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0	1	0
Biddulphia sp.	0	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0	0	0	1	1	0	0	1	1	1	0	0	0	1	0	0	0	1	1	0	1
Cerataulina pelagica (Cleve) Hendey, 1937	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	0	0	1	1	0	1	0	0	1	1	0	0	1	1	0	0
Chaetoceros sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros affinis Lauder, 1864	1	0	0	1	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros constrictus Gran, 1897	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Chaetoceros decipiens Cleve, 1873	1	1	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	0	0	1	1	0	0	0	1
Chaetoceros didymus Ehrenberg, 1845	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros neogracile Van Land., 1968	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros peruvianus Brightwell	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Coscinodiscus sp.	1	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	0	1	0	1	1	1	0
Cylindrotheca closterium (Ehrenberg)																																				
Reiman & Lewin, 1964	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	0	1	0	0	0	1	1	1	0	1	1	1	0	1	1	1	0	0
Dactyliosolen fragilissimus (Bergon)																																				
Hasle apud G.R.Hasle & Syvertsen, 1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	1	0	1	0	1	0	0	0	0	0
Detonula pumila (Castracane) Gran, 1900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0
Ditylum brightwelli (T.West) Grunow, 1885	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	1	0	0	0	1	0	0	1
Eucampia cornuta (Cleve) Grunow	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eucampia zoodiacus Ehrenberg, 1840	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1
Grammatophora sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	1	0	1	1	1
Guinardia delicatula (Cleve) Hasle, 1997	1	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	1	0	0	0	1	0	0	0	0
Guinardia flaccida (Castracane) Peragallo, 1892	1	1	0	1	1	0	1	1	0	0	0	0	1	1	1	1	0	0	1	1	0	0	1	1	0	1	1	0	0	1	1	1	1	0	0	0
Guinardia striata (Stolterfoth) Hasle, 1997	1	0	1	1	1	0	0	1	0	0	0	0	1	1	1	1	0	0	1	1	0	0	1	1	1	1	1	1	1	0	1	1	0	0	0	0
Gyrosigma sp.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiaulus hauckii Grunow in Van Heurck, 1882	1	0	1	1	1	0	0	1	0	0	0	1	1	1	1	1	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	1
Hemiaulus sinensis Greville, 1865	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	1	1	0	1	0	1	0	1	0	0	1
Lauderia annulata Cleve, 1873	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Leptocylindrus danicus Cleve 1889	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	0	0	1
Leptocylindrus minimus Gran 1915	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	1	1	1	1	1	1	0	1	1	0	0	0
Licmophora abbreviata C.A. Agardh, 1831	1	0	0	0	0	0	1	0	1	0	0	1	1	0	1	0	1	0	0	1	1	0	0	0	0	1	0	0	0	1	0	0	1	1	0	0
Navicula sp.	1	0	0	1	1	0	0	1	1	0	0	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	0	1	1	1	0	1	1	1	1	1
Nitzschia longissima (Brébisson in Kützing) Ralfs in Pritchard, 1861	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	1	1	1	0	1	0	0	0	1	1	0
Nitzschia sigma (Kützing) W. Smith, 1853	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Pleurosigma elongatum W. Smith, 1852	1	1	0	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pleurosigma sp.	0	1	0	0	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1
Proboscia alata (Brightwell) Sundström, 1986	0	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0
Proboscia indica (Peragallo) Hernández-Becerril, 1995	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Pseudo-nitzschia delicatissima (P.T. Cleve, 1897) Heiden, 1928	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Pseudo-nitzschia pungens (Grunow ex P.T. Cleve, 1897) Hasle, 1993	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1	0	1	1	1	0	1
Pseudosolenia calcar-avis (Schultze) Sundström, 1986	0	1	1	0	0	1	1	1	0	0	0	1	1	1	1	0	1	0	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	0	1	1
Rhizosolenia imbricata Brightwell, 1858	1	1	1	1	0	1	1	1	0	0	1	0	1	0	0	0	1	0	0	1	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0
Rhizosolenia robusta G. Norman ex Ralfs in Pritchard, 1861	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Rhizosolenia setigera Brightwell, 1858	1	1	1	0	1	0	1	1	1	0	1	1	1	0	0	0	1	0	0	0	0	0	0	1	0	1	0	1	1	0	0	1	1	0	0	0
Skeletonema costatum (Greville) Cleve, 1873	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0	1	0	0	1	1	0	0	1	0	1	0	1
Striatella unipunctata (Lyngbye) C.Agardh 1832	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Thalassionema nitzschioides (Grunow, 1862) Van Heurck, 1896	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1
Thalassiosira anguste-lineata (A.Schmidt) G.Fryxell & Hasle, 1977	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassiosira rotula Meunier, 1910	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	0	0	1	1	0	0	0	1	0	0	1
Thalassiothrix mediterranea Pavillard	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0

(Ehrenberg) Balech, 1974**,** *Ditylum brightwelli* (T. West) Grunow, 1885**,** *Leptocylindrus minimus* Gran 1915**,** *Licmophora abbreviata* C.A. Agardh, 1831, *Pseudo-nitzschia pungens* (Grunow ex P.T. Cleve, 1897) Hasle, 1993, *Rhizosolenia setigera* Brightwell, 1858 were the species observed all over the sampling period. *C. furca* var. *eugrammum*, *Noctiluca scintillans* (Macartney) Kofoid et Swezy 1921, *Prorocentrum gracile* Schütt, 1895, *Prorocentrum lima* (Ehrenberg, 1860) Stein, 1878, *P. micans*, *Cylindrotheca closterium* (Ehrenberg) Reiman & Lewin, 1964, *Pleurosigma elongatum* W. Smith, 1852, *P. pungens*, *Thalassionema nitzschioides* (Grunow, 1862) Van Heurck, 1896, *Thalassiosira rotula* Meunier, 1910 were particularly recorded algal blooms in Middle-Inner Bay.

In the sampling conducted in 1998, *C. furca* var. *eugrammum*, *P. micans* and *P. gracile* of the class Dinophyceae and *C. closterium*, *P. elongatum* and *P. pungens* of the class Bacillariophyceae were the species that revealed the highest cell numbers. All the species except *P. pungens* were found to reach their highest densities in all depths of the station 3, representing the Inner Bay. *C. furca* var. *eugrammum* reached its highest concentration in spring as $6.06x10^4$ - $9.10x10^4$ cell L^{-1} at 0.5 m and 5.0 m, respectively. *P. micans* reached a maximum in spring at 0.5 m ($1.46x10^5$ cell L^{-1}) and 5.0 m ($7.28x10^4$ cell L^{-1}) and in autumn at 5.0 m ($4.00x10^4$ cell L^{-1}) and at 10.0 m ($3.46x10^4$ cell L^{-1}). *P. gracile* was recorded at all depths in autumn, reached to a maximum cell density of $1.02x10^5$ cell L^{-1} at 10.0 m. *C. closterium* of Bacillariophyceae showed an excessive growth exclusively in summer at all the three depths and revealed a maximum cell density ($5.02x10^5$ cell L^{-1}) at 10.0 m. *P. elongatum* was observed in winter at all depths and presented with the highest density at 5.0 m ($2.25x10^4$ cell L^{-1}). The same species reached to its maximum in spring only at 5.0 m ($6.06x10^4$ cell L^{-1}). *Chaetoceros neogracile* Van Land., 1968 was only observed in spring and found to achieve its highest density at 0.5 m with a number of $1.40x10^5$ cell L^{-1} while no individuals were encountered in other depths. As for *P. pungens* which was detected at 0.5, 10.0 and 15.0 m in the Middle Bay (station 2) was observed to reach its highest number of cells at 0.5 m ($1.21x10^4$ cell L^{-1}).

In 2000, during the period following the activation of the wastewater treatment plant, *N. scintillans* and *P. micans* of the class Dinophyceae and *P. pungens* of the class Bacillariophyceae were the species that demonstrated higher cell densities. *N. scintillans* of Dinophyceae demonstrated an excessive growth in winter and spring at 0.5 and 5.0 m reaching to its maximum at 0.5 m of station 3 ($1.10x10^5$ cell L^{-1}). Also, *P. micans* revealed an excessive growth in autumn at all depths and reached to the highest cell density of $1.64x10^5$ cell L^{-1} at 5.0 m of the same station. *P. pungens* was found at all depths of station 1 and 2 in winter and spring. It reached to the highest cell density at 0.5 m of station 1 in winter and showed a decline in cell number parallel to the depth increase ($3.58x10^4$-$1.63x10^4$ cell L^{-1}). Also in the same period it made a peak at 5.0 and 10.0 m of station 2 ($2.15x10^5$ cell L^{-1}). In spring, an excessive growth was observed in all the three depths of station 1, however the maximum cell density ($4.63x10^4$ cell L^{-1}) was determined at 15 m of the station 2.

In 2001, *P. lima* and *P. micans* of the class Dinophyceae in addition to *T. nitzschoides* and *T. rotula* of the class Bacillariophyceae exhibited algal blooms. *Prorocentrum* sp. of Dinophyceae reached the highest cell numbers at all the depths of the station 3 in spring while a decrease was observed in cell numbers parallel to the depth increase. *P. lima* and *P. micans* achieved their highest densities at 0.5 m with the numbers of $7.78x10^5$ and $6.90x10^5$ cell L^{-1}, respectively. No bloomings were detected in Dinophyceae during the other seasons. A similar trend was observed in the winter period for Bacillariophyceae with *T. nitzschioides* ($1.16x10^4$ cell L^{-1}) and *T. rotula* ($2.59x10^4$ cell L^{-1}) which were represented with their highest cell numbers at 5.0 m of the station 3.

Physical and Chemical Parameters

In general, the minimum and the maximum water temperature of the Izmir Bay found between 9.74-28.47ºC in winter and summer 2001, respectively. Izmir bay showed temperature stratification during the summer as a result of radiant heating of the surface. In winter, there was no stratification in view of temperature due to surface cooling and vertical mixing induced by winds. The salinity ranges between 21.43 psu in winter 2000 and 39.98 in spring 2000, and minimum salinities were observed in areas which were just near to freshwater inputs (Kontas *et al*., 2004). Table 3 presents the average values (0-15 m) and standard error of the seasonal variations of TNO_x-N, o.PO_4-P, [Si(OH_4)-Si] and N/P concentrations in the Izmir Bay. Throughout the year, maximum amounts of (nitrate+nitrite)-nitrogen (TNO_x-N), o. phosphate-phosphorus (o.PO_4-P), and silicate [Si$(OH)_4$-Si] were 10.33 μM (autumn 2000, sta. 3), 2.43 μM (summer 2000, sta. 3) and 11.67 μM (spring 1998, sta. 3) respectively. The lowest N/P ratios occurred in the winter 2001 in the outer bay, while the highest ratios occured in the spring 1998 in the inner bay. In general, N/P ratios were decreased from inner bay to outer bay.

Statistical Analyses

The results of the diversity index of Shannon-Weaver, which was created by the annual changes of species and cell numbers at chosen depths were given in Figure 2 and 3. Shannon-Weaver diversity (H′) were found between 0.01 (1998) and 3.78 (2001). The inrease in the diversity of diatom species on an annual

Table 3. Descriptive statistics of chemical parameters in the upper (0-15 m) layers of Izmir Bay

		1998				2000				2001			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Station 1	$TN0_x$-N	0,26 ± 0,01	0,24 ± 0,01	-	0,23 ± 0,01	0,20 ± 0,00	0,22 ± 0,04	0,25 ± 0,07	0,26 ± 0,04	0,23 ± 0,02	0,26 ± 0,03	0,19 ± 0,01	0,29 ± 0,01
	o.PO_4-P	0,02 ± 0,00	0,03 ± 0,00	0,02 ± 0,00	0,02 ± 0,00	0,02 ± 0,00	0,02 ± 0,00	0,02 ± 0,01	0,02 ± 0,00	0,03 ± 0,00	0,02 ± 0,00	0,02 ± 0,00	0,02 ± 0,00
	Si	1,27 ± 0,07	1,50 ± 0,15	0,95 ± 0,10	0,93 ± 0,01	1,29 ± 0,21	1,04 ± 0,14	1,27 ± 0,12	0,51 ± 0,03	0,49 ± 0,01	0,58 ± 0,04	1,07 ± 0,03	1,17 ± 0,03
	N/P	13,00 ± 0,50	9,07 ± 0,74	-	11,67 ± 0,44	9,83 ± 0,17	9,23 ± 0,23	11,50 ± 1,04	11,33 ± 0,88	8,90 ± 0,59	13,00 ± 1,53	9,50 ± 0,29	14,67 ± 0,44
Station 2	$TN0_x$-N	0,34 ± 0,02	0,41 ± 0,05	0,36 ± 0,08	0,28 ± 0,01	0,36 ± 0,04	0,37 ± 0,07	0,26 ± 0,03	1,70 ± 0,21	0,40 ± 0,05	0,34 ± 0,02	0,28 ± 0,04	0,61 ± 0,02
	o.PO_4-P	0,05 ± 0,00	0,05 ± 0,00	0,03 ± 0,00	0,03 ± 0,00	0,05 ± 0,01	0,06 ± 0,01	0,15 ± 0,01	0,41 ± 0,04	0,05 ± 0,01	0,04 ± 0,00	0,05 ± 0,01	0,04 ± 0,00
	Si	1,33 ± 0,18	2,17 ± 0,22	1,03 ± 0,14	1,53 ± 0,19	0,83 ± 0,23	0,96 ± 0,03	1,05 ± 0,07	0,76 ± 0,04	0,81 ± 0,08	1,17 ± 0,03	1,07 ± 0,08	1,27 ± 0,07
	N/P	7,20 ± 0,11	7,70 ± 0,65	13,17 ± 1,59	9,33 ± 0,20	7,67 ± 0,27	6,53 ± 0,24	1,73 ± 0,18	4,17 ± 0,12	8,83 ± 0,45	9,33 ± 0,44	5,93 ± 0,07	15,27 ± 0,39
Station 3	$TN0_x$-N	1,93 ± 1,02	0,90 ± 0,45	3,10 ± 1,59	5,50 ± 2,75	1,97 ± 1,02	1,30 ± 0,66	1,13 ± 0,70	10,33 ± 5,36	2,20 ± 1,15	4,07 ± 2,56	0,24 ± 0,13	8,37 ± 4,63
	o.PO_4-P	0,77 ± 0,39	1,10 ± 0,55	-	1,30 ± 0,65	0,73 ± 0,37	0,83 ± 0,42	2,43 ± 1,22	2,23 ± 1,12	0,48 ± 0,24	0,79 ± 0,41	1,83 ± 0,92	1,40 ± 0,74
	Si	5,63 ± 2,83	11,67± 5,90	2,30 ± 1,23	6,50 ± 3,33	2,33 ± 1,20	7,43 ± 3,87	5,33 ± 3,18	4,57 ± 2,29	2,57 ± 1,31	3,83 ± 1,93	3,87 ± 1,99	9,67 ± 5,24
	N/P	1,67 ± 0,84	0,54 ± 0,27	-	2,80 ± 1,40	1,77 ± 0,89	1,03 ± 0,52	0,31 ± 0,18	3,10 ± 1,64	3,03 ± 1,56	3,27 ± 1,82	0,09 ± 0,05	3,93 ± 1,99

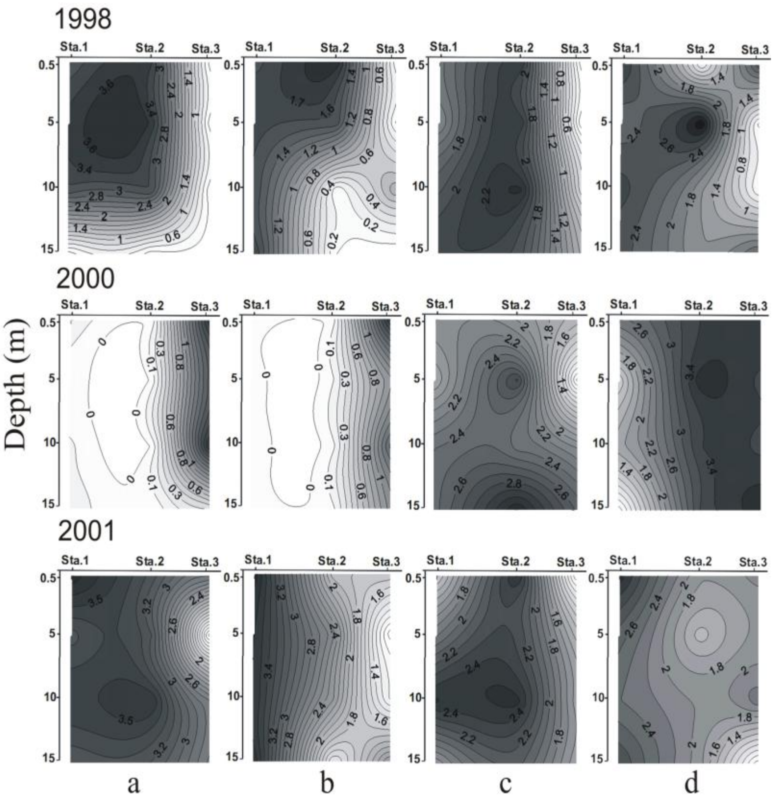

Figure 2. The annual changes of species diversity (H') in Bacillariophyceae class (a: winter, b: spring, c: summer, d: autumn).

basis were found to be higher than those in the diversity of dinoflagellate species. The lowest diversity index was observed before 2000 in winter, summer and autumn periods due to the high cell densities of *P. micans*, *C. closterium* and *P. pungens*. After 2000, the increase in the diversity index values were explained by the decrease in the abundance of both diatom and dinoflagellate species.

Correlation analysis was performed in order to determine the correlations between community parameters (number of species, number of individuals and diversity index) and environmental factors (TNO_x-N, o.PO_4-P, $[Si(OH)_4$-Si] and N/P). Table 4 summarised the result of the correlation analysis. The species number of both dinoflagellats and diatoms revealed a poor and negative correlation with all enviromental parameters (except for N/P) in 1998 (before WTP). Dinoflagellat cell densities demonstrated a positive correlation with nitrogen (r=0.60), phosphorus (r=0.71) and silica (r=0.62) concentrations. Diatom cell densities showed a positive correlation with phosphorus (r=0.48) and silica (r=0.56). After the activation wastewater treatment in 2000, a positive correlation was found

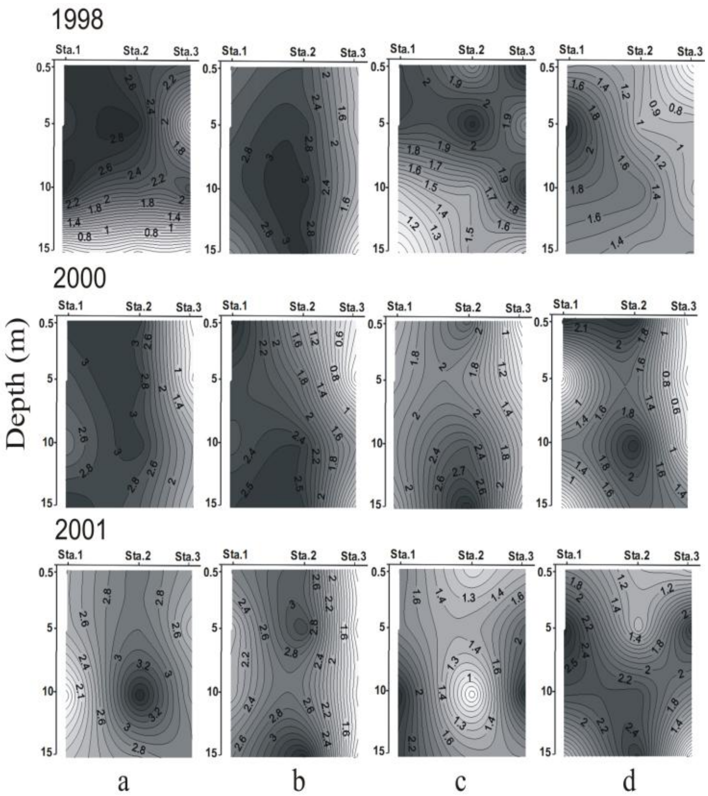

Figure 3. The annual changes of species diversity (H') in Dinophyceae class (a: winter, b: spring, c: summer, d: autumn).

Table 4. Results of the correlation analysis conducted to determine the annual differences in Dinophyceae (A) and Bacillariophyceae (B) community

Dinophyceae-A		N	P	Si	N/P
	Species number	-0.02	-0.10	-0.13	0.03
1998	Individual number	**0.60**	**0.71**	**0.62**	**-0.51**
	SHD	**-0.49**	**-0.50**	**-0.41**	0.19
	Species number	-0.02	-0.29	-0.25	0.13
2000	Individual number	**0.68**	**0.39**	0.21	-0.16
	SHD	**-0.60**	**-0.72**	**-0.60**	0.33
	Species number	-0.10	0.17	-0.03	**-0.45**
2001	Individual number	0.20	0.17	0.18	-0.26
	SHD	-0.28	-0.22	-0.27	0.12
Bacillariophyceae-B		N	P	Si	N/P
	Species number	0.12	-0.16	-0.35	0.15
1998	Individual number	0.16	**0.48**	**0.56**	**-0.49**
	SHD	-0.27	**-0.46**	**-0.49**	**0.57**
	Species number	**0.40**	0.13	-0.09	0.14
2000	Individual number	-0.18	-0.26	-0.24	0.20
	SHD	**0.46**	**0.41**	0.24	**-0.38**
	Species number	-0.29	**-0.64**	**-0.49**	**0.54**
2001	Individual number	**0.36**	0.15	0.16	-0.18
	SHD	-0.25	**-0.49**	**-0.37**	**0.36**

between dinoflagellat cell densities and nitrogen (r=0.68) and phosphate (r=0.39) concentrations ($P<0.05$). Diatom cell densities revealed a positive correlation only with nitrogen (r=0.36) concentration.

Table 5 summarizes the results of the Student's t-test conducted to clarify the annual differences. Based on this table, for diatom assemblages, station 1 and station 3 showed an inter-year variation. The structure of the station 1 in 1998 was found to be different from that in 2001 and station 3 in 1998 from that of 2000 and 2001 ($P \leq 0.05$). However, dinoflagellat assemblages did not reveal a difference among years and therefore discriminant analysis was used. The eiqenvalue of the diatom and dinoflagellate populations associated with the first function contributed to the varience of the orginal data were 99.45% and 99.67% respectively. In addition to this, the second function contributed 0.55% and 0.33%. Diatom populations were different from each other on an annual basis at a level of P≤0.01. Dinoflagellate populations, in contrast to diatom populations, did not display a net statistical difference (P=0.06). It is interesting that the p significance level value was close to the critical value of P≤0.05. The distribution diagram of the first two components is shown in Figure 4. Although there were overlapping areas in dinoflagellate population, between the group sentroids, it can be said that a slightly distinction did exist (Figure 4A). As can be seen on the diagram, an increasingly evident distinction exists in diatom population, moving from 1998 towards 2001 (Figure 4B). 2001 was clearly separated from the others, and there was a change in species composition.

Discussion

This study was made to determine a number of phytoplanktic members of algae from three classes, namely, Cyanophyceae, Dinophyceae and Bacillariophyceae. A total of 115 taxa were identified to the genus or species level. Diatoms presented their maximum contributions to density in summer 1998 period during the *C. closterium* develop. In addition to this, other minor contributions were observed in spring 1998 especially during *C. neogracile* develop and both in spring 1998 and winter 2000 during the *P. pungens* develop. In the study period, *C. closterium* was encountered at all the stations particularly in the inner bay. Hopkins (1964) and Underwood (1994) reported that *C. closterium* was exclusively dense in a lagoon of England in summer. On the contrary, in a study conducted by Ribeiro *et al*. (2003), the same species was noted to be abundant every month during the sampling period. The only explanation concluded is that, seasonal impact is greater at higher latitutudes where annual light and temperature variations are more commonly observed but these variations at temperate areas are not much effective. An excessive growth of *P. pungens* was observed at Northeastern Mediterranean that in August and October in coastal waters rich in nutrient (Polat *et al*., 2000). *P. pungens* were observed all throughout the study period, and this species demonstrated an excessive growth in autumn 1998. The same species reached to its highest

Table 5. Results of Student's t-test conducted to determine the annual differences for the years 1998, 2000 and 2001. The upper part of each group summarizes the probability values and below the matrices diagonal are calculated t-values (dino; dinoflagellate, baci; diatom)

Dino	Sta.1			Sta.2			Sta.3		
	1998	2000	2001	1998	2000	2001	1998	2000	2001
1998		0.62	0.24		0.34	0.40		0.79	0.64
2000			0.69			0.22			0.44
Baci	Sta.1			Sta.2			Sta.3		
	1998	2000	2001	1998	2000	2001	1998	2000	2001
1998		0.08	0.02*		0.26	0.58		0.00*	0.03*
2000			0.34			0.13			0.52

Significant data are shown in (*) (P≤0.05)

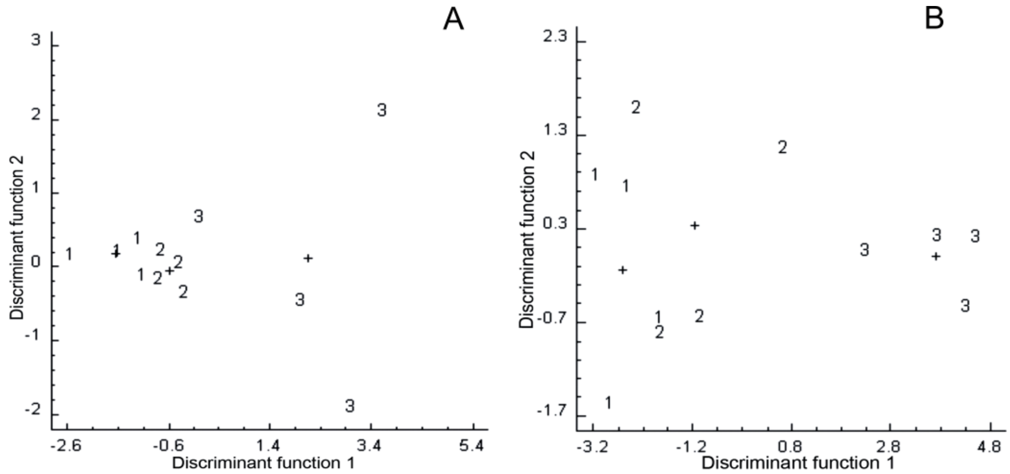

Figure 4. Distribution diagram of the first two components in the Dinophyceae (A) and Bacillariophyceae (B) discriminant analysis (1- 1998, 2- 2000, 3- 2001). Center of group centroids are shown in (+)

cell density in winter 2000 when the Wastewater Treatment Plant became operative.

Dinoflagellate density reached its highest level during the spring 2001 corresponding with the dominance of *P. micans* and *P. lima*. In addition to this, minor contributions to the densities of the dinoflagellate were carried out by *C. furca* var. *eugrammum* in spring 1998. Although the maximum cell density of *C. furca* var. *eugrammum* was quite low compared to the others, it was seen that the colour of sea water changed to light orange at the sea surface due to the relatively large cell volumes of the species. During summer in semi enclosed areas phytoplankton community is dominated by diatoms as reported by Caroppo and Cardellicchio (1995). Spatio-temporal phytoplankton community composition in the bay was often dominated by dinoflagellates but shift to diatom dominance was observed in some periods, particularly in winter and spring. The activation of the Wastewater Treatment Plant gave rise to increases in species diversity of both dinoflagellat and diatom assemblages, in addition to this there were decrease in the number of species which present with an excessive growth.

During the study period, 15 harmful and toxic species (*C. furca* var. *eugrammum*, *Dinophysis acuminata* Claparède & Lachmann, 1859, *Dinophysis acuta* Ehrenberg, 1841, *Dinophysis caudata* Saville-Kent, 1881, *Dinophysis rotundata* Claparède & Lachmann, 1859, *Dinophysis sacculus* Stein 1883, *Lingulodinium polyedrum* (F. Stein) J.D. Dodge, 1989, *N. scintillans*, *P. lima*, *P. micans*, *Scrippsiella trochoidea* (Stein) Balech ex Loeblich III, 1965 from Dinophyceae; *C. neogracile*, *C. closterium*, *Pseudo-nitzschia delicatissima* (P.T. Cleve, 1897) Heiden, 1928, *P. pungens* from Bacillariophyceae) were recorded in Izmir Bay. The cell concentrations of these species, however, were not at a level to cause any harm or toxicity. The over reproduced *Prorocentrum* species determined in this research causes red tide during specific periods in Izmir Bay. Same situation also observed in Izmit Bay (Aktan *et al*., 2005), but it was stated that other noxious algal blooms were not recorded during the research period.

The main reason for determining diversity indexes for a particular area is to examine the variations in the population structure of that area and to establish a relation between the degree of the pollution and the variations in the structure of the living populations in case of any pollution. Koray (1987a, 1987b), in his studies on the Izmir Bay, reports that the use of diatoms as an indicator of contamination level produce more accurate results than the use of dinoflagellate or total phytoplankton. Based on the results of this study, the diversity index values were higher in outer and middle bays compared to inner bay. The station at outer bay represents Aegean Sea and middle bay is a transition area between outer bay and inner bay. The clear water masses transported to these stations by means of currents have an important impact on species' diversity resulting in increase of diversity index values. However the inner bay is not influenced by these water masses at all and there are increase in cell densities due to inputs with terrestrial origin resulting in decreasing of diversity index values.

It is known that key important of several environmental parameters arise from significance in assessing the phytoplanktic community succession and diversity by supporting or restricting the development of different phytoplankton groups as well known from previous researches (Lohrenz *et al*., 2003; Song *et al*., 2004). The middle and inner parts of the bay showed higher nutrient concentrations in comparison with the outer part of the bay. As a result of bacterial degradation in inner bay, maximum levels of TNO_x-N, o.PO_4-P, [$Si(OH_4)$-Si] were observed during autumn and summer, respectively. It is known (Kucuksezgin *et al*., 2006) that the Gediz River is polluted by industrial, domestic and agricultural wastes. It annually discharges total 295 000 tons of solid material and 4900 tons of nitrogen to the Izmir Bay and this is more than the total amount carried by all the other rivers to the bay (UNEP 1993). Gediz River flow into the middle and inner bay, but because of the low water circulation, between inner and outer part of the bay, there were maximum nutrient concentrations in the inner part of the bay during summer and autumn. The concentrations of TNO_x-N was reduced after the activation of treatment plant, while increases were recorded for the mean levels of o.PO_4-P in the middle and inner parts of the bay (Kucuksezgin *et al*., 2006). The capacity of wastewater plant was not enough to purify to the phosphate. Phytoplankton nutrient limitation in aquatic ecosystems has long been predicted via N/P ratio of Redfield. Mutual dissolved inorganic nitrogen and dissolved inorganic phosphorus availability was shown to cause a seasonal change in N/P ratio (high in winter and low in summer) by Fiocca *et al*. (1996). Aktan *et al*. (2005) found that diatoms and dinoflagellates present with a maximum growth rate in late spring, summer and autumn, when the total nitrogen and total phosphorus availability give rise to minimal N/P ratios under the theoretical assimilation ratio of 16:1 for the world's oceans. As the seasonal N/P changes in Izmir Bay is examined, it was found to be always at constant ratio of 16:1 causing observation of over-production of diatoms and dinoflagellates throughout the study period. In the present study, minimum values for all the periods were especially observed during summer. Nitrogen is indicated to be the limiting element in the bay. Kontas *et al*. (2004) established that the quality of marine environment in middle and inner parts has not yet considerably improved. In the present study, environmental parameters (TNO_x-N, o.PO_4-P, [$Si(OH_4)$-Si] and N/P) which have impact on phytoplankton growth and composition were found to reveal a statistically significant difference. Both the individual numbers of dinoflagellate and diatom showed an increase due to the rise of nitrogen, phosphorus and silica concentrations before the Wastewater Treatment Plant has became operative. Following the activation of the treatment plant, the individual numbers of dinoflagellates still showed a positive correlation with nitrogen, phosphorus while diatoms presented a weak negative correlation with nutrients. In 2001, the individual numbers of dinoflagellates were observed to have a positive but not statistically significant relationship with nutrients. For diatoms, only the nitrogen concentration and the number of individuals were observed to possess a positive correlation.

In this study, the phytoplankton data pertaining to pre- and post-treatment facility periods in the Izmir Bay were, for the first time, successfully discriminated from each other by using discriminant analyses. According to the result of the analyses, before the activation of treatment plant, it was appeared that all stations were different from each other in terms of both dinoflagellat and diatom populations. As a result of the reduction of pollution after the activation, these differences faded away in 2000 and 2001, and all the stations began to demonstrate a homogeneous population structure. The results of the discriminant analyses revealed that the improvements in the phytoplankton structure in the post-treatment facility period where the facility used only 60-100% of its capacity were more speedy than expected. Therefore, the Izmir Bay may, with a high probability, re-establish itself in the first decade of the 21^{st} century.

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