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Research Article

Spatial Distribution of Net Diatoms Along Adjacent Water Masses of Different Origin

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Abstract: Larger diatoms (>55 µm) were sampled using closing bottles from on board the R/V Bilim along adjacent water masses of different origin in order to observe patchy assemblages of net diatoms. MDS (Multi-Dimensional Scaling) plots of diatoms in adjacent water masses inhabiting the south-western Black Sea, Bosphorus, Golden Horn, the north-eastern Sea of Marmara and İzmit Bay have shown that patchy configurations of diatom were orientated along particular dominating environmental gradients, mainly temperature and salinity. A two-way evolution takes place in the Bosphorus as the Black Sea water flows towards the Sea of Marmara near the surface and under-neath the Mediterranean inflow, below the pycnocline towards the Black Sea. Considerable changes in salinity and temperature with depth in the region affected the drifting flora considerably, especially its diatom composition. Of all the regions, the south-western Black Sea was the most species diverse and abundant.

Key Words: Bosphorus, net diatoms, patches, temperature, salinity.

Farklı Kökenli Komşu Su Kütlelerinde Net Diatomelerin Yersel Dağılımı

Özet: Farklı kökenli komşu su kütlelerinde net diatomelerin yamasal dağılımını gözlemleme amacı ile 55 mikrometre üzeri diatomeler R/V Bilim gemisinden kapama şişeleri aracılığı ile örneklendi. Güney-batı Karadeniz, İstanbul Boğazı, Haliç, kuzey-doğu Marmara ve İzmit Körfezi komşu su kütlelerinde mevcut diatomelerin Çok Boyutlu Hesaplama gösterimi, diatomelerin yamasal konfigürasyonlarının özellikle etkin çevresel değişkenlerden sıcaklık ve tuzlulukla ilişkili olduğunu göstermiştir. İstanbul Boğazı su akıntısı iki yönlü oluşmakta, yüzeyden Karadeniz suyu Marmara'ya ve tersi yönde Akdeniz suyu piknoklin tabakasının altından Karadeniz'e akmaktadır. Bölgede, derinlikle tuzluluk ve sıcaklıktaki belirgin farklılaşım bütünü ile suda pasif olarak sürüklenen florayı özellikle diatome kompozisyonunu oldukça etkilemiştir. Komşu bölgeler içerisinde güney-batı Karadeniz diğerlerine oranla en yüksek tür çeşitliliği ve yoğunluğunu göstermiştir.

Anahtar Kelimeler: İstanbul Boğazı, net-diatomeler, yamalar, sıcaklık, tuzluluk.

Introduction

In the past, a variety of environmental factors have been outlined as affecting phytoplankton growth and distribution (1). The importance of biological-physical interactions (turbulent advection, upwelling, convergence and vertical mixing) on the scale dependence, morphology and intensity of the plankton spatial pattern was clearly stated by Mackas et al. (2). Diatom species have norrow optima and tolerances for many environmental variables, which make them exceptionally useful in quantifying certain environmental characteristics to a high degree of certainty. They long have been used as indicator of short-and longterm environmental changes (3).

The Turkish Straits, constituting a transitional oceanographic system between the Aegean basin of the eastern Mediterranean and Black Sea, have been subjected to man-induced or natural environmental changes for many years. In addition the extremely transient and variable characteristics of the flow regime (especially along the Bosphorus have had a great effect on plankton communities. Information concerning the community structure of plankton in adjacent water masses projected unique features in their graphical representation of similarities between species abundances in different regions and layers. Data from the analysis of multispecies plankton and the associated physical variables (temperature, salinity, and dissolved oxygen) are reported here for the first time from this region. For a better understanding of the region, a brief summary of the physico-chemical characteristics of the adjacent water bodies is given below.

Black Sea

The excess run-off maintains a highly stable brackish surface layer, separated from deep waters by a permanent halocline at depths of 70-100m. Vertical changes, in general, and convective mixing, in particular, are seriously precluded by the presence of the permanent halocline. In the Bosphorus junction of the Black Sea, vertical profiles of salinity measured in January demonstrated that a homohaline surface layer of ~17 ppt salinity extends down to ~42m. The thickness of the surface layer increases in January as a result of wind-induced mixing.

Bosphorus

A two-way evolution takes place in the Bosphorus as the Black Sea water flows towards the Sea of Marmara near the surface and underneath the Mediterranean inflow, below the pycnocline towards the Black Sea. This flow influences not only the hydrological and chemical regime of the Black Sea but also its plankton population. The Black Sea water, with 16-17 ppt salinity, exits the Bosphorus with slightly higher values of 19-21 ppt, depending on the season. This 3 to 4 ppt salinity rise results from intense vertical mixing which occurs in the Bosphorus-Marmara junction. The presence of two sills, one at the southern end (32m) and the other at northern end (~60m) of the Bosphorus, plays a significant role in the overall exchange processes. The thickness of the surface layer increases in January as a result of wind-induced mixing. Within the upper layer a homohaline layer overlays another layer with higher salinity and a thickness of ~15m, indicating entrainment from the lower layer.

Sea of Marmara

Surface flow exiting from the Bosphorus enters the Marmara Sea in the form of a shallow and narrow jet and veers to the east passing through the vicinity of the Prince Islands. The flow is then dispersed towards the south and, with its eastern extension, eventually enters the bay of İzmit. Nutrients and phytoplankters are transported by the Bosphorus outflow from the Black Sea into the Sea of Marmara via this route. In the Sea of Marmara, the existence of a permanent halocline, separating the Black Sea water from water of Mediterranean origin, is expected to play a crucial role in the distribution of nutrients. The compensation depth in the basin (corresponding to the lower limit of the euthotic zone) essentially coincides with the halocline located approximately 20m below the surface. The lower abundance of diatoms below the halocline throughout the year has been related to such stratification.

Golden Horn

The Golden Horn, a small estuary, terminates near the southern tip of the Bosphorus strait. The water column in the Golden Horn consists of two distinct layers, the upper layer, of Black Sea origin, and the bottom layer of Mediterranean origin. The characteristics of each of the layers are similar to the corresponding layers in the Bosphorus section adjacent to the entrance to the Golden Horn. The similarity of the Golden Horn properties shows that an efficient and relatively rapid exchange of the upper-layer water and the Bosphorus takes place throughout the year. A large quantity of pollutants in the upper 2-3 meters affects the temperature, salinity and dissoved-oxygen contents of the surface layer. The dissolved-oxygen content of the surface layer stayes very low, between 0 and 2 mg/l, when compared with that of the Bosphorus, ranging from 6 to 8 mg/l. The salinity of the upper layer varies between 18 and 20 ppt, while the bottom layer is 38-38.5 ppt. The two layers are separated by an interface, which varies in depth and sharpness, with its deepest position in March (25-30 meters) and shallowest in August (15 m).

İzmit Bay

One of the plankton-sampling sites in the Sea of Marmara, the Bay of İzmit terminates in a shallow (30m) and flat inner-bay area. To the west, it reaches a much deeper (180m) middle-bay area. This depression communicates with the outer bay through a narrow (3 km) transition with a sill depth of 50m. The outer bay is also relatively flat and joins the deeper waters of the Marmara via a relatively wide (5.5 km) mouth. The hydrological regime of the bay is, to a large extent, governed by the exchange of water between the Black Sea and the Mediterranean. In terms of flow and stratification characteristics, the basic nature of İzmit Bay is defined by the presence of a two-layer current system associated with the two-layer stratification defined by the presence throughout the year. The surface salinity rises to 26-28 ppt in November and reaches 30-32 ppt in March. In contrast, the surface-water temperature starts to decrease towards January (11°C) and drops to its lowest level in March (7.5°C). In winter, botton waters from the north-eastern Marmara flow into the bay and subsequently increase the surface-layer salinity (4). The halocline is located at a depth of about 20-30 m, below which the lower-layer waters reach a salinity of about 38 ppt. During winter, the lower-layer water reach a salinity of 38.5 ppt, suggesting the inflow of saline Marmara waters into the bay. This was also clearly depicted on MDS plots of the diatom composition of different layers in the regions.

Materials and Methods

Plankton samples were collected from selected stations (Figure 1) in January 1986, in relation to the studies by the Institute of Marine Sciences, Middle East Technical University (IMS-METU), concerned with the present state of health and the oceanography of the Turkish Straits formed by the Bosphorus, the Sea of Marmara and the Dardanelles, as well as the adjacent water masses. In addition, a series of physical, chemical, biological and geological parameters were evaluated.

Phytoplankton samples were collected from the surface and depths of 10 and 30m. In the Golden Horn, samples were taken from depths of 10, 20 and 30m, due to the dense accumulation of wastes of different origin at and near the surface. Quantitative samples were collected with closing bottles of 5 l capacity, and filtered on board through a net with a 55-micron mesh size. Filtrates were then preserved in borax-buffered 4% seawater-formalin solution. Washing of the specimens with acid in a separate collection for full coverage was performed prior to identification under the microscope (5).

Analytical methods

Plankton surveys yield complex bodies of biotic and environmental data, from which patterns and relationships need to be extracted. In this study, the aim was to search for patterns amongst the biological variables with an attempt to interpret these in terms of the environmental data, as pointed out by Field et al in 1982 (6). For the analysis of multispecies data and associated environmental variables, PRIMER (Multivariate Analyses Package-Plymouth Routines in Multivariate Ecological Research) and a number of PC programs written at the Plymouth Marine Laboratory, UK were used (7).

The raw biological data consisted primarily of diatom species. Such a data set required root-root transformation in order to adjust the weight of abundant species. In order to assess similarity, the Bray-Curtis Coefficient, one of the most commonly used methods in ecological studies, was used. Then the similarity matrix was formed between every pair of samples in a lower-triangular array for further clustering and ordination. Group-average sorting was preferred in producing a dendogram from the similarity matrix. In order to visualize individual (sample) relationships, ordination was determined by delineating dendogram classes in the corresponding ordination. Here, the preferred method of ordination was multi-dimensional scaling (MDS).

Finally, to determine the discriminating species responsible for groupings within the community, the contribution to the average Bray-Curtis dissimilarity (δ) or similarity (S) from the i'th species was calculated. From this, the contribution to δ_{jk} from the *i* th species is calculated as:

$$\delta_{jk}(i) = 100 \mid y_{ij} - y_{ik} \mid / \sum_{i=1}^{p} (y_{ij} + y_{ik})$$

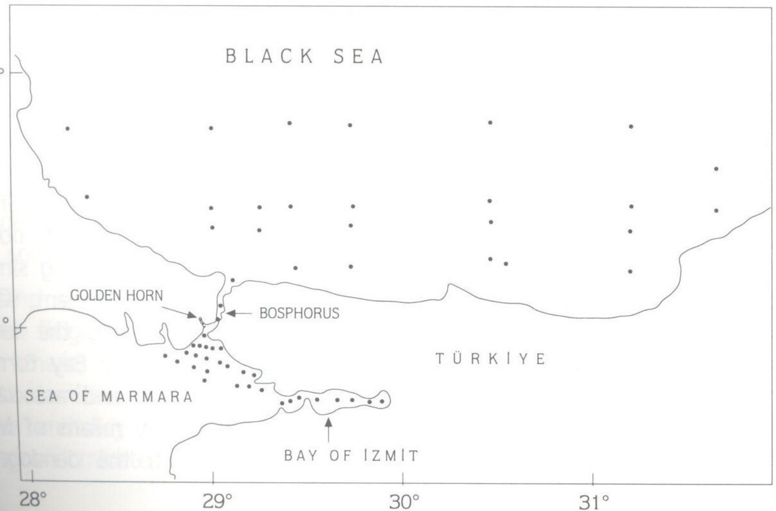

Figure 1. Net diatom sampling stations along adjacent water masses formed by the south-western Black Sea, Bosphorus, Golden Horn, north-eastern Marmara Sea and Izmit Bay.

δ_{jk} (i) is then averaged over all pairs (with j in the 1st and k in the 2nd group), to give the average contribution δ_i from the i th species. The standard deviation is given as SD (δ_i) in the context. Higher δ_i and a high ratio of δ_i/SD (δ_i) indicate the discriminating species. Furthermore, from the similarity equation, the contribution of the its species ($\bar{S}_i$) to the average similarity within a group ($\bar{S}$) can be computed similarly. This indicates that the species concerned is consistently prominent in that group.

Diversity Indices

For a better understanding of the diversity indices of the diatom-community structure. Margalef's Index d and the Shannon-Wiener Index H' were calculated. To measure the proportional representation (Equitability), Pielou's Evenness Index was used (8).

Results and Discussion

In terms of the density and number of species among adjacent water masses, the remarkable input from the Black Sea to the Sea of Marmara via the Bosphorus surface flow has persisted. This flow regime has also considerably influenced the diatom flora of the Golden Horn. Significant differences in the abundance distribution of diatoms according to depth were recorded in each region (Table 1). Except for the higher cell counts obtained at 30m in the south-western Black Sea, the lowest figures in the lower layers were peculiar to the rest of the regions.

Table 1. Variation in species diversity at different depths and locations along the coast in January 1986.

Site *	Total cell number	Total # species	Richness d	Shannon H'	Evenness J'
BS1	28221	14	1.03	0.65	0.24
BS2	360233	15	1.09	0.55	0.20
BS3	555290	15	1.06	0.46	0.17
B01	376728	9	0.62	1.02	0.47
B02	441053	8	0.54	1.03	0.50
B03	138448	13	1.01	1.19	0.46
GH1	250111	10	0.72	0.52	0.23
GH2	78159	10	0.80	0.90	0.39
GH3	26055	11	0.98	1.12	0.47
MS1	102377	6	0.43	1.18	0.66
MS2	155522	11	0.84	1.41	0.59
MS3	8327	11	1.11	1.28	0.53
IB1	124180	16	1.28	0.99	0.36
IB2	101883	12	0.95	1.19	0.48
IB3	5084	11	1.17	1.28	0.53

* Abbreviations: BS = Black Sea, BO = Bosphorus, GH = Golden Horn, MS= Marmara Sea and IB = İzmit Bay. Numbers 1,2 and 3 define sampling depths (1= Surface, 2 = 10 m, 3 = 30m) except

Diatom flowering in the Black Sea sector could possibly emerge from the rich nutrient inputs drifting from the Romanian and Bulgarian coasts via the "Devil's Stream" towards the Bosphorus exit to the Black Sea (9). The cyclonic boundary current flowing to the south along the west coast of the Black Sea takes up considerable water masses from some large rivers, namely, the Dnieper, Bug, Dniester, and the Danube. Caspers (9) has also reported that in a limited area off the Bosphorus exit to the Black Sea was more species diverse and abundant than the rest of the regions (recent studies have also confirmed this). The diversity figures given in Table 1 clearly indicate that the proportional representation of diatom species in the south-western Black Sea was very poor due to a massive outburst of the pennate diatom *Nitzschia delicatissima* Cleve in the region. In contrast, the species richnes was higher at all depths. In the case of the Bosphorus, although the diversity was higher, the species richness was much lower in the upper layer in comparison with other regions. Increasing levels of environmental stress are generally considered to produce a decrease in species richness (d), diversity (H') and in proportional representation (J'). In the Golden Horn the bulk was at a depth of about 10m.

Figure 2 is a dendogram showing site affinities according to depth based on the root-root-transformed abundance of a total of 36 net diatom species identified, using the Bray-Curtis measure of similarity. The solid line drawn at the arbitrary similarity level of 50% delineated 4 major groups. Considering the highly dynamic water exchange within the system, this level was taken much higher than those applied for benthic faunal studies. Group I comprised colder, brackish and well-oxygenated water layers of the Black Sea and Bosphorus. The Golden Horn itself formed the second group, having slightly higher temperature and salinity levels at 10 and 20m depths. At 30 m the temperature almost doubles and the salinity reaches ~38 ppt, reflecting its Mediterranean origin. Group III comprised the upper 20 m layer of the north-eastern Sea of Marmara and İzmit Bay, having similar properties. Finally, the warmer, oxygen-deficient, saline water of Mediterranean origin occupying the lower layers of the Sea of Marmara and İzmir Bay formed the fourth group. All the groupings and associated physical parameters were ordinated by means of MDS to conform groupings defined from the dendogram (Figure 3 a, b, c and d).

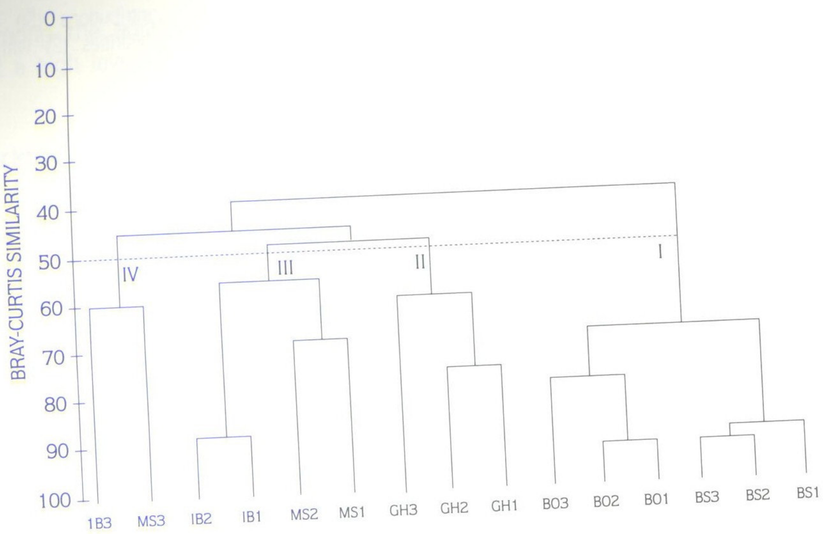

Figure 2. Dendogram showing classification of 15 stations (5 different regions and 3 depths) based on the Bray-Curtis measure. Four main site groups (I-IV) were distinguished at an arbitrary similarity level of 50%.

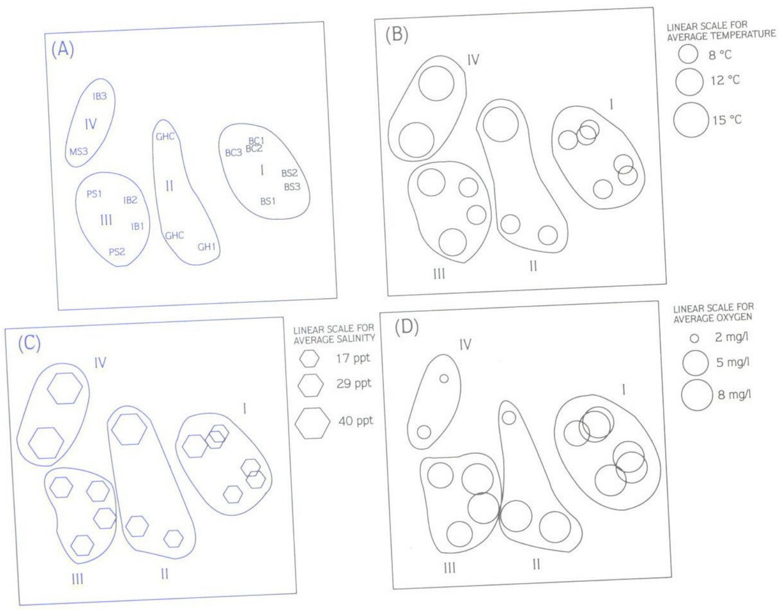

Figure 3. MDS ordination of 15 stations in 2 dimensions based on the dendogram given in Figure 2 and relation of station groups to environmental factors. MDS plots of superimposed values of (b) temperature, (c) salinity and (d) oxygen for 15 stations.

Apart from the physical parameters distinguishing the sites, the diatom-species characteristics of each group were determined (Table 2). It is apparent that the neritic pennate diatoms *Nitzschia seriata* Cleve and *N. delicatissima* have contributed much to the flora of the south-western Black Sea and Bosphorus.

The species *N. delicatissima* and *Rhizosolenia setigera* Brightwell made the Golden Horn distinct from the others. Towards the south, *R. setigera* and *N. seriata* dominated the flora in the north-eastern Marmara and Bay of Izmit. In fact, no single common species dominated all the regions. However, a closer look at the high level of similarity among the groups on the dendogram indicates that most of the species were present in the system with varying frequency of occurrence due to mixing.

The species displaying a major role in discriminating between groups are shown in Table 3. From the list, it can be seen that *N. seriata* has played a significant role in differentiating the water bodies. Besides this, the presence of *Chaetoceros subsecundus* (Grunow) Hustedt only in the brackish waters of the Black Sea and along the Bosphorus strait (Group I in Figure 3) has greatly contributed to such a distinction from the rest of the regions. This species

Table 2. Species contributions ($\bar{S}_i$) to average similarities ($\bar{S}$) within site groups.

Group	Species	$\bar{S}_i$	SD (S_i)	$\bar{S}_i$/SD (S_i)	$\Sigma\bar{S}_i$ %
*74.3	*Nitzschia delicatissima*	21.3	2.4	9.0	28.7
	Nitzschia seriata	14.4	1.3	11.1	48.1
I	*Chaetoceros subsecundus*	8.3	0.4	23.6	59.3
	Chaetoceros curvisetus Cleve	7.3	0.8	8.9	69.1
* 64.6	*Nitzschia delicatissima*	19.1	2.5	7.5	29.5
	Rhizosolenia setigera	10.8	0.9	11.6	46.2
II	*Chaetoceros decipiens* Cleve	9.8	3.2	3.1	61.4
	Nitzschia lngissima (Breb.)	7.6	0.5	16.6	73.2
* 62.9	*Rhizosolenia setigera*	17.4	1.0	17.3	27.6
	Nitzschia seriata	14.2	3.1	4.6	50.2
III	*Chaetoceros decipiens*	11.2	0.5	24.4	68.0
	Nitzschia longissima	6.7	1.0	6.8	78.7

* Average similarity (S) within the group.

Table 3. Species contribution (δ_i) to total average dissimilarity ($\delta = \Sigma\delta_i$) between all four site groups.

Group	Species	δ_i	SD (δ_i)	S_i/SD (δ_i)	$\Sigma\delta_i$ %
*55.6	*Nitzschia seriata*	9.5	1.7	5.8	17.2
	Chaetoceros subsecundus	5.3	0.7	7.2	26.7
I&II	*Chaetoceros decipiens*	5.1	1.3	4.0	35.9
	Chaetoceros curvisetus	4.7	0.7	6.4	44.4
* 61.4	*Nitzschia delicatissima*	11.1	2.6	4.2	18.0
	Rhizosolenia setigera	5.9	2.7	2.2	27.7
I&III	*Chaetoceros decipiens*	5.5	0.2	25.8	36.6
	Chaetoceros subsecundus	4.8	0.8	6.2	44.4
* 68.4	*Nitzschia delicatissima*	16.2	1.8	9.2	23.7
	Nitzschia seriata	6.5	2.2	3.0	33.2
I&IV	*Chaetoceros subsecundus*	6.3	0.8	7.5	42.4
	Chaetoceros curvisetus	5.6	0.8	6.5	50.6
* 52.3	*Nitzschia delicatissima*	9.1	3.6	2.6	17.5
	Nitzschia seriata	9.1	2.3	3.9	34.8
II&III	*Rhizosolenia setigera*	5.1	0.8	6.7	44.6
	Chaetoceros lauderi Ralfs	3.1	2.8	1.1	50.5
* 55.8	*Nitzschia delicatissima*	14.9	3.2	4.7	26.7
	Nitzschia seriata	6.1	1.3	4.7	37.7
II&IV	*Chaetoceros lauderi*	4.8	3.1	1.5	46.3
	Chaetoceros decipiens	3.5	2.3	1.5	52.7
* 54.2	*Rhizosolenia setigera*	6.5	0.6	10.8	12.0
	Nitzschia seriata	5.7	2.7	2.1	22.4
III&IV	*Chaetoceros decipiens*	4.3	0.5	8.0	30.4
	Chaetoceros lauderi	3.9	3.1	1.2	37.7

* Average similarity (δ) within the group.

was defined as a neritic, boreal-arctic species and recorded by Gran (1912) as a northern temperature species (10).

Conclusions

Net diatom assemblages along the Bosphorus and neighbouring water masses were found to be strongly regulated by and spatially correlated with physical parameters (temperature and salinity). In such a dynamic region the dispersion of diatom flora to regional water bodies of different origin is inevitable. Higher levels of similarity among all five sites mainly emerged from such active transport prevailing in the Bosphorus flow system. MDS ordination of net diatom samples has clearly identified the existence of definite boundaries among the adjacent water masses of different origin at a high level of similarity (50%).

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