PHYTOPLANKTON PATCHES FORMED ALONG THE SOUTHERN BLACK SEA COAST IN SPRING AND SUMMER 1996

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Abstract. Multivariate analysis performed on surface phytoplankton along Turkish coastal waters of Black Sea revealed presence of distinct aggregates of varying size and species composition. Much more spatial heterogeneity is observed in April than July. Five different small and large sized patchy aggregates were noticed in April 1996 via multivariate analysis (cluster and Multi-Dimensional Scaling, MDS). Based on 60% similarity level 6 different patches are observed in July 1996. Species composition and surface spatial distribution of phytoplankton showed that species differentiation between the shelf and open ocean plankton was apparent. Although, total number of species identified in July 1996 (~119) exceeded much the number of species found in April 1996 (~73), average abundance of cells/l (~$9.8x10^5$) found in April ten fold the average cells/l found in July 1996 ($9.9x10^4$).

1. Introduction

The Black Sea is known to be a region of moderate to high productivity since it is fed by a rich supply of nutrients compared with other parts of the world oceans [1]. Sorokin [2] indicated that the peaks in primary productivity of the Black Sea were known to occur twice a year, with a major bloom of mainly diatoms in early spring, followed by a secondary bloom of mainly coccolithophorids in autumn. Occasional blooms of coccoliths and dinoflagellates occurred mainly in coastal areas. Recently, additional summer blooms with predominance of dinoflagellates and coccoliths have increasingly observed in the region [3], [4], [5]. Sorokin [2] also reported the spring and summer development of red tides in the western shelf. Massive red tides have been created along the Rumanian and Bulgarian coasts by dinoflagellates [6]. There are limited observations in winter, some of which indicate massive blooms of certain plankton species along the western Anatolian coast [7] and [8]. However, information on patchy assemblages of planktonic flora at species level in the entire Turkish Black

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Sea coast other than abundance and biomass distribution at particular regions has not yet been pronounced sufficiently for the Turkish Black Sea coast.

This study was performed at 55 stations in April (Fig. 1) and at 119 stations in July 1996 (Fig. 2) for a better understanding of the scale dependent spatial pattern of the pelagic microscopic community in relation to physico-chemical properties of surface waters along the Anatolian coast of Black Sea within Turkish EEZ.

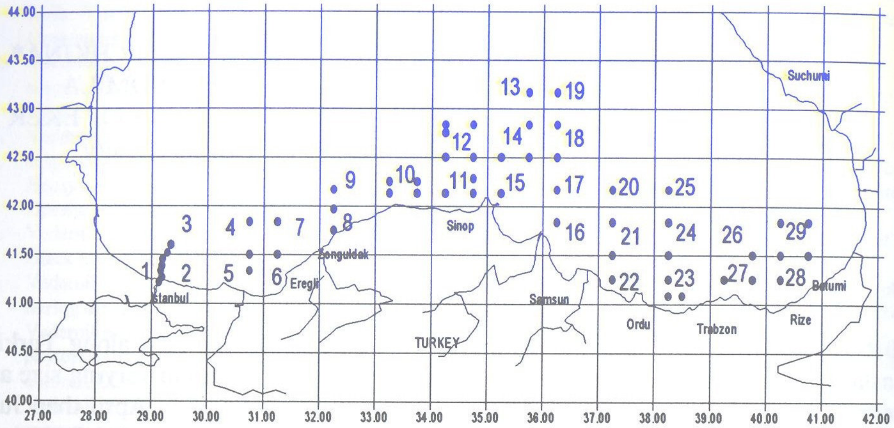

Figure 1. Sampling stations and locations of grid stations along the Turkish coast in April 996.

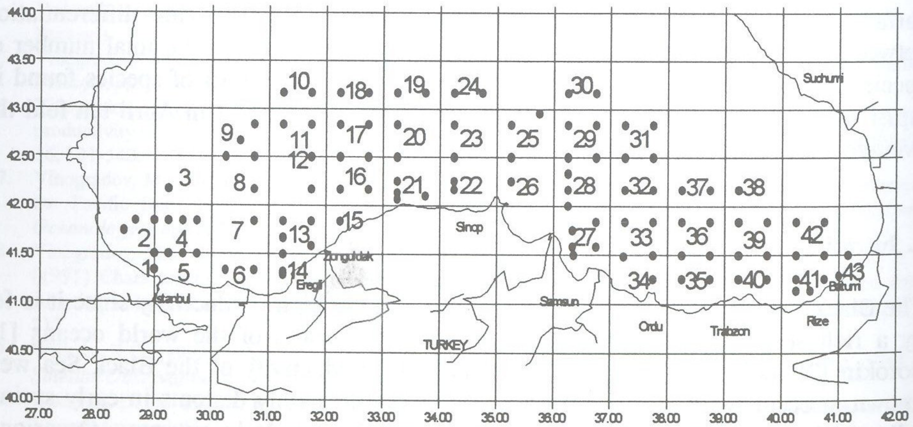

Figure 2. Sampling stations and locations of grid stations along the Turkish coast in July 1996.

2. Material and Methods

In the area extending from approximately 28xE to 41xE, near surface plankton data were collected with the aid of closing bottles of 5 liters capacity. Total volume of 1liter sea water was sampled for phytoplankton analysis and were preserved with borax-buffered 4% seawater-formalin solution. Total number of 55 stations in April and 119 stations in July 1996 have been surveyed with the Turkish research vessel R/V Bilim of the Institute of Marine Sciences - Middle East Technical University (IMS-METU), and these stations were then grouped further into grids for multivariate analysis (see Fig.s 1 and 2).

2.1. ANALYTICAL METHODS

Analysis of multispecies data was done utilizing both STATGRAPHICS (Univariate Statistics Package) and PRIMER (Multivariate Analyses Package - Plymouth Routines in Multivariate Ecological Research), a number of PC programs written at the Plymouth Marine Laboratory.

Data set required root-root transformation to adjust the weight of abundant species. Bray-Curtis Coefficient, one of the most used method in ecological studies, was used to assess similarity. Then the similarity matrix is formed between every pair of samples in a lower triangular array for further clustering and ordination.

For a graphic representation of relations among sites dendograms showing clustered groups at an arbitrary cut-off level of 50% (for April) and of 60% (for July) were constructed. Among the various hierarchical sorting strategies the group-average sorting is preferred to produce a dendogram from the similarity matrix. This joins 2 groups of samples together at the average level of similarity between all members of one group and all members of the other. In order to visualize sample (site) relationships, ordination was done by delineating dendogram classes on the corresponding ordination via Multi-Dimensional Scaling (MDS).

The contribution to average dissimilarity ($\overline{\delta}$) or similarity ($\overline{S}$) from ith species is calculated to determine the discriminating species responsible for groupings among the community. Simply $\delta = 100 - S$, and the contribution to δ_{jk} from ith species is:

$$\delta_{jk}(i) = 100|y_{ij} - y_{ik}|/\Sigma_i\ (y_{ij} + y_{ik})$$

δ_{jk} then averaged over all pairs (with j in 1st and k in 2nd group) to give average contribution $\overline{\delta}_i$ from ith species. Its standard deviation is given as SD(δ_j) in the context. High $\overline{\delta}_i$ and a high ratio of $\overline{\delta}_i$ /SD(δ_i) determined the discriminating species. Further, the contribution of the ith species ($\overline{S_i}$) to the average similarity within a group ($\overline{S}$) was similarly computed. This indicates that the species concerned is consistently prominent in that group [9].

3. Results and Discussion

Total number of phytoplankton species encountered in July 1996 (119 species) exceeded much the number of species found in April 1996 (73 species). Dinoflagellates comprised about 45 % of all the species encountered in April and more than 60 % of all species encountered in July. This is followed by diatom species with much lower contributions being 36 % in April and 20 % in July. Although, total number of species identified in July 1996 (~119) exceeded much the number of species found in April 1996 (~73), average abundance of cells/l (~9.8x10^5) found in April ten fold the average cells/l found in July 1996 (~9.9x10^4).

Among the grids grid number 13 yielded the least counts (~5000 cells/l) and grid number 22 the highest counts (3.08x10^6 cells/l) in terms of cell abundance where the diatom species *Nitschia delicatissima* made the major contribution for both grids. Areas of high interest and significance in terms of cell abundance appeared to be the coastal region between 29 and 38° E in April. Phytoplankton bloomings mainly took place between Bosphorus and Sakarya River in the west, near Sinop and Yeşilýrmak and Kýzýlýrmak Rivers in the east and offshore Rize in the far east (Fig. 3). The region between Bosphorus and Sakarya river has also been found significantly productive in the past [10]. Offshore regions in the east, characterised by high temperature (Fig. 4) and high salinity (Fig. 5) remained at relatively low levels in terms of cell abundance.

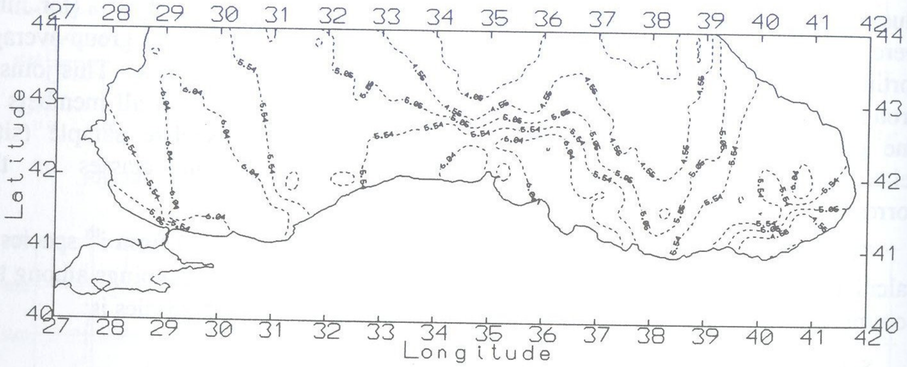

Figure 3. Surface spatial distribution of phytoplankton abundance (log transformed), in April 1996.

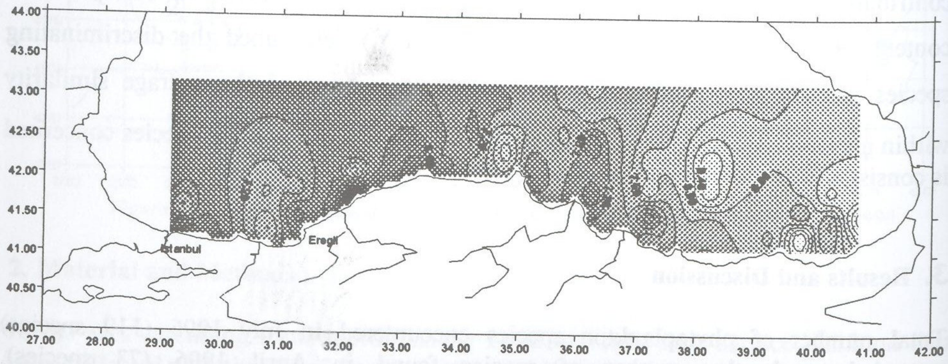

Figure 4. Surface temperature distribution along Turkish coastal waters of Black Sea in April 1996.

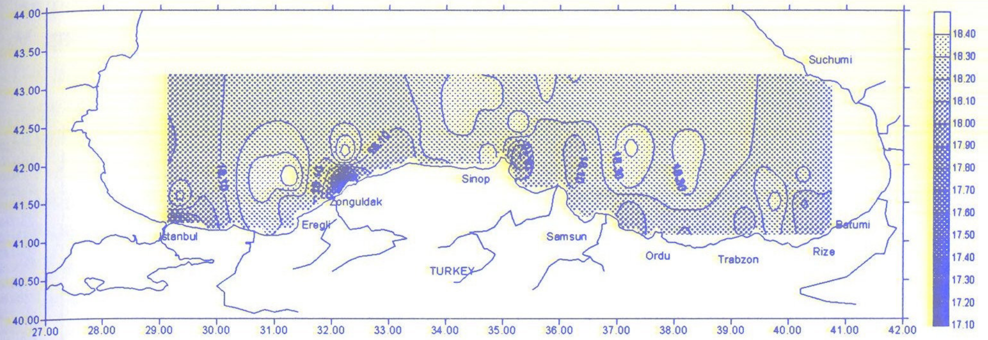

Figure 5. Surface salinity distribution along Turkish coastal waters of Black Sea in April 1996.

In July, bloomings are observed both at coastal and offshore regions (Fig. 6). Despite the picture in April, coastal regions remained relatively at low levels in terms of cell abundance. Highest counts are recorded offshore Bosphorus, Eregli, Sinop and near Batumi. Among the grids cell abundance ranged between ~15150 cells and ~213800 cells/l. Minimum count is attained at grid number 8 far offshore Sakarya river and to a maximum is reached at grid number 24 (see Fig. 2). The near Bosphorus region to the east defined as grid number 5 remained at relatively low levels (~48000 cells/l). The Bosphorus exit to Black Sea defined as grid number 1 yielded relatively higher counts than the surrounding grids 2 and 5. It is noteworthy to note here that grid number 1 almost tripled the cell counts of adjacent grid number 5. In general, much warmer (Fig. 7) and saline (Fig. 8) offshore regions in the east yielded less counts.

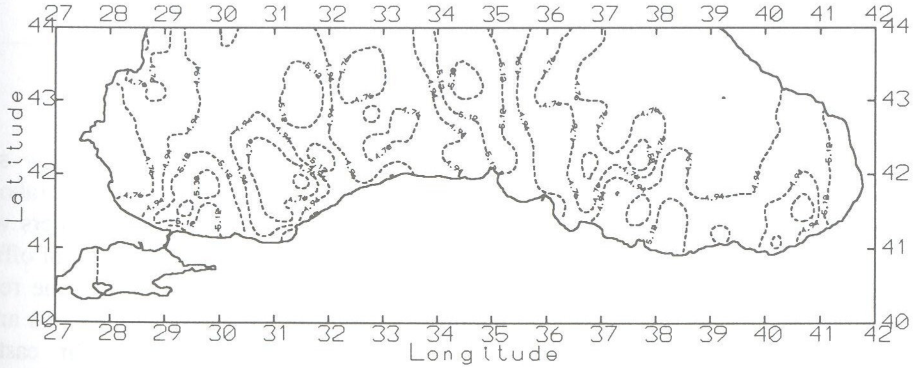

Figure 6. Surface spatial distribution of phytoplankton abundance (log transformed), in July 1996.

Figure 9 shows two-dimensional non-metric MDS plots of gridded surface stations having 5 distinct groups at an arbitrary similarity level of 50%. Group I is composed of grid 1 which corresponds to Bosphorus exit to Black Sea, group II of grid 5 located offsore Sakarya River, group III of grids 13, 19, 20, 24 and 25 all located offshore in the east, group IV of coastal grids 23, 27 and 28 around Trabzon. Finally group V forming the largest group includes the rest of the grids.

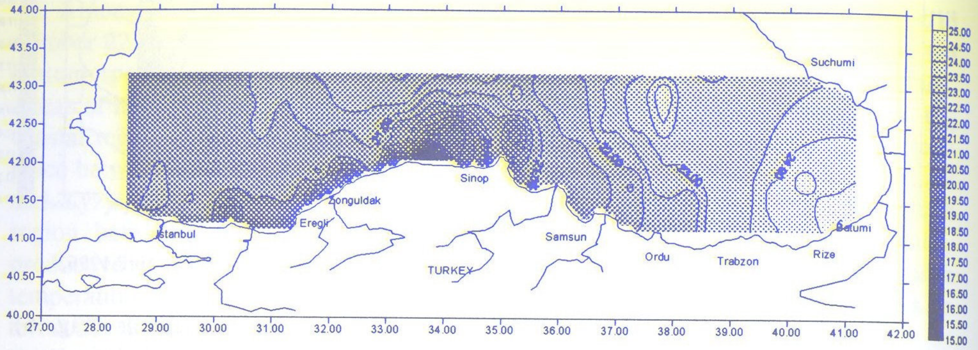

Figure 7. Surface temperature distribution along Turkish coastal waters of Black Sea in July 1996.

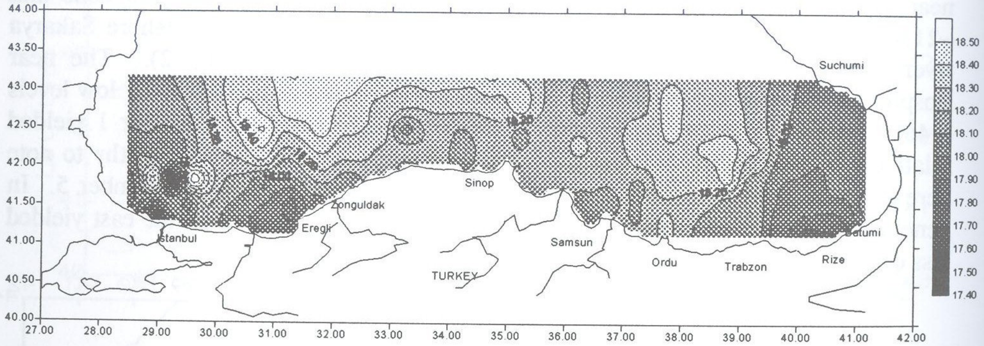

Figure 8. Surface salinity distribution along Turkish coastal waters of Black Sea in July 1996.

It is clearly seen that plankton sampled from much colder and less saline Bosphorus junction (grid 1) differed much from the rest where few species (about 6) found to exist. Similarly grid 5 near Sakarya River fall apart from the others where relatively saline and warmer waters occupy the region. Group III composed of offshore grids in the east where relatively much warmer and saline waters occupy the region. Species of *Nitzschia delicatissima, Hillea fusiformis* and *Peridinium triquetrum* are the major contributing species to the planktonic flora (Table 1). In far east the neighbouring coastal grids 23, 27 and 28 under group IV (see Fig. 8) formed another patch. Dominant phytoplankton species encountered in this region are *Nitzschia delicatissima, Emiliana huxleyi, Striatella delicatula* and *Peridinium triquetrum*. Group V occupied the largest area dominated by *Nitzschia delicatissima, Peridinium triquetrum, Hillea fusiformis, Peridinium pellucidum* and *Glenodinium sp.*

Species discriminating groups are given in Table 2. Group I (Bosphorus junction) fall apart from group III lacking species of *Hillea fusiformis, Emiliana huxleyi* and

Glenodinium sp. Only species of *Nitzschia delicatissima* and *Peridinium triquetrum* are found to coexist in both groups. Major contribution (almost 93%) to group I is made by the pennate diatom *Nitzschia delicatissima.* Group II (grid number 5) is dominated mainly by diatom species of *Nitzschia delicatissima* ($6.0x10^5$ cells/l), *Skeletonema costatum* ($4.4x10^5$ cells/l), and *Chaetoceros simplex* ($8.8x10^4$ cells/l).

In July 1996, six different groups are observed (Figure 10) based on 60 % similarity level. Group I is composed of grid 8 located far offshore Sakarya River, group II of grid 30 located in the eastern gyre, group III of grid 5 near Bosphorus exit to the east, group IV of western grids 3 and 7, Group V of grid 1 corresponding to the Bosphorus exit to Black Sea and finally the largest of all, group VI included the rest of the grids.

It is interesting to note here that, small scale patches mostly took part in the west indicating a much more dynamic region. Scattered positioning of adjacent grids in the east implies the intensity of stress, in other words, complexity of mixing in the region. Despite this fact, high similarity level between all stations denotes more homogeneity within phytoplankton in the whole region. As observed in April, the Bosphorus junction, shown as grid 1, fall apart from the others. Major contribution to the largest group VI was made by coccolithophorid *Emiliana huxleyi* and by dinoflagellates *Gyrodinium sp*, *Gymnodinium sp* and *Glenodinium paululum* (Table 3).

Group I (grid 8) found as the least abundant in terms of cell counts. Dinoflagellate species of *Gymnodinium* sp and *Gyrodinium* sp contributed significantly to the total abundance in this group. Group V (grid 1) is dominated mainly by *Oscillatoria planctonica* and by the coccolith *Emiliana huxleyi*.

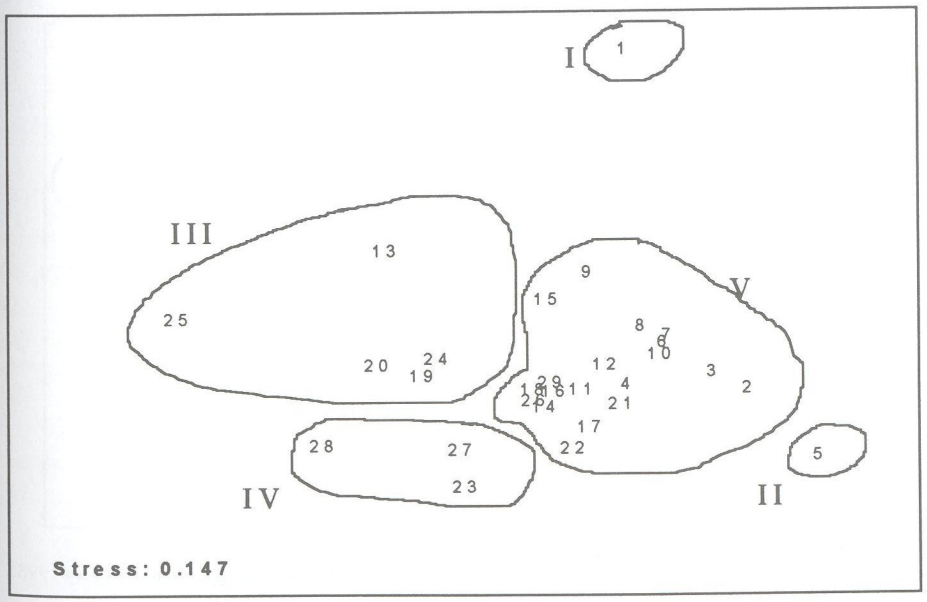

Figure 9. Two-dimensional non-metric Multi-Dimensional Scaling ordination of all grid stations, April 1996.

TABLE 1. Species contribution ($\overline{S_i}$) to average similarities ($\overline{S}$) within groups in April 1996.

Group	Species	$\overline{S_i}$	SD(S_i)	$\overline{S_i}$ /SD(S_i)	$\Sigma\ \overline{S_i}$ %
*59.16	*Nitzschia delicatissima*	10.4	3.4	3.0	17.5
	Hillea fusiformis	9.0	2.1	4.3	32.8
III	*Peridinium triquetrum*	8.3	2.8	3.0	46.9
	Glenodinium sp	7.1	2.5	2.8	58.9
	Emiliana huxleyi	6.8	5.9	1.1	70.3
*65.18	*Nitzschia delicatissima*	17.2	7.3	2.4	26.4
	Emiliana huxleyi	10.2	0.1	145.1	41.9
IV	*Striatella delicatula*	6.2	1.1	5.5	51.5
	Peridinium triquetrum	4.4	0.6	7.1	58.2
	Poropilla dubia	3.5	0.5	6.5	63.6
*63.16	*Nitzschia delicatissima*	25.2	4.4	5.7	39.9
	Peridinium triquetrum	5.1	1.0	5.2	47.9
V	*Hillea fusiformis*	4.4	1.3	3.4	54.9
	Peridinium pellucidum	2.8	0.5	5.6	59.4
	Glenodinium sp	2.4	1.8	1.3	63.1

* Average similarity ($\overline{S}$) within the group.

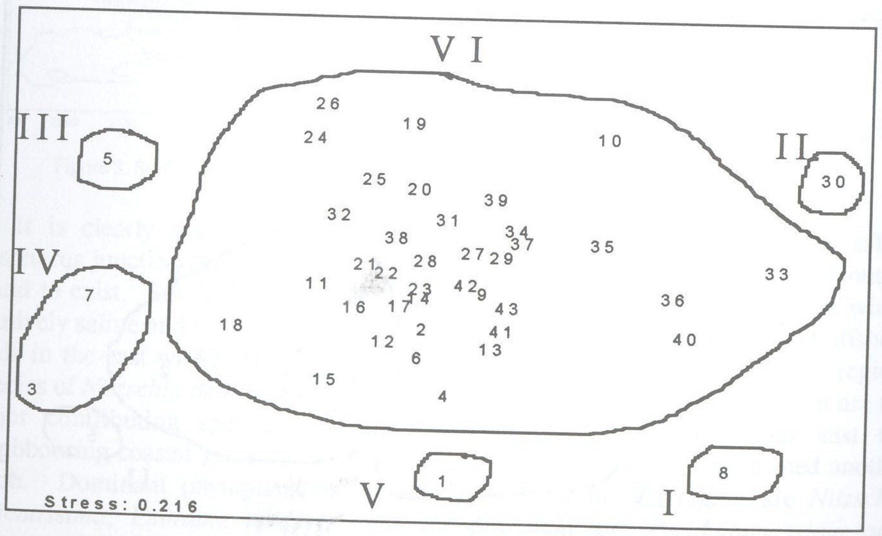

Figure 10. Two-dimensional non-metric Multi-Dimensional Scaling ordination of all grid stations in July 1996.

TABLE 2. Species contribution ($\overline{\delta_i}$) to total average dissimilarity ($\overline{\delta} = \Sigma\ \overline{\delta_i}$) between groups in April 1996.

Group	Species	$\overline{\delta_i}$	SD($\overline{\delta_i}$)	$\overline{\delta_i}$ /SD($\overline{\delta_i}$)	$\Sigma\ \overline{\delta_i}$ %
*75.86	*Hillea fusiformis*	7.9	2.1	3.7	10.4
	Emiliana huxleyi	7.8	4.9	1.6	20.7
III&I	*Glenodinium sp*	6.6	2.3	2.9	29.4
	Peridinium triquetrum	4.8	2.0	2.5	35.8
*72.52	*Skeletonema costatum*	11.4	1.4	8.4	15.7
	Nitzschia delicatissima	8.6	2.5	3.4	27.6
III&II	*Chaetoceros simplex*	7.7	0.9	8.4	38.1
	Chaetoceros spp	5.0	0.6	8.4	45.1
*74.64	*Nitzschia delicatissima*	9.2	6.4	1.4	12.3
	Emiliana huxleyi	8.1	0.03	254.7	23.2
IV&I	*Striatella delicatula*	5.7	1.3	4.5	30.9
	Poropilla dubia	3.4	1.1	3.3	35.5
*67.97	*Skeletonema costatum*	10.3	0.1	110.9	15.2
	Chaetoceros simplex	6.9	0.1	110.9	25.3
IV&II	*Chaetoceros* sp	4.6	0.04	110.9	32.0
	Chaetoceros wighamii	4.4	0.04	110.9	38.5
*54.32	*Nitzschia delicatissima*	7.4	5.4	1.4	13.6
	Striatella delicatula	4.2	1.1	3.9	21.4
IV&III	*Hillea fusiformis*	3.2	1.2	2.8	27.4
	Glenodinium sp	2.9	1.7	1.8	32.7
*73.33	*Nitzschia delicatissima*	16.9	4.1	4.1	23.1
	Hillea fusiformis	4.5	1.3	3.5	29.2
V&I	*Peridinium triquetrum*	3.3	1.0	3.3	33.7
	Glenodinium sp	3.2	1.9	1.7	38.0
*54.16	*Skeletonema costatum*	8.2	1.8	4.5	15.2
	Chaetoceros simplex	5.6	1.1	5.1	25.5
V&II	*Chaetoceros* sp	4.0	0.6	6.8	32.9
	Chaetoceros wighamii	4.0	0.3	14.2	40.1
*53.96	*Nitzschia delicatissima*	13.6	4.8	2.8	25.3
	Emiliana huxleyi	3.0	2.3	1.3	30.8
V&III	*Dinobryon* sp	2.3	2.1	1.1	35.0
	Peridinium pellucidum	1.7	0.9	1.9	38.2
*52.28	*Nitzschia delicatissima*	6.8	3.7	1.8	13.0
	Striatella delicatula	3.1	0.6	4.9	18.9
V&IV	*Emiliana huxleyi*	3.0	2.0	1.5	24.6
	Hillea fusiformis	2.2	1.0	2.2	28.8

TABLE 3. Species contribution ($\overline{S_i}$) to average similarities ($\overline{S}$) within groups in July 1996.

Group	Species	$\overline{S_i}$	SD(S_i)	$\overline{S_i}$ /SD(S_i)	$\Sigma \overline{S_i}$ %
*66.33	*Emiliana huxleyi*	10.0	1.5	6.5	15.0
	Gyrodinium sp	4.5	0.7	5.9	21.8
VI	*Gymnodinium* sp	4.1	1.4	2.9	28.0
	Glenodinium paululum	3.7	1.5	2.6	33.6
	Gyrodinium fusiforme	3.6	0.6	6.4	39.0

* Average similarity ($\overline{S}$) within the group.

Species discriminating groups are given in Table 4. Group V separated from the largest group VI lacking species of *Gymnodinium* sp, *Hillea fusiformis* and *Prorocentrum micans* and having *Oscillatoria planctonica* predominantly.

TABLE 4. Species contribution ($\overline{\delta}_i$) to total average dissimilarity ($\overline{\delta} = \Sigma\ \overline{\delta}_i$) between groups in July 1996.

Group	Species	$\overline{\delta}_i$	SD($\overline{\delta}_i$)	$\overline{\delta}_i$ /SD($\overline{\delta}_i$)	$\Sigma\ \overline{\delta}_i$%
*60.0	*Emiliana huxleyi*	7.0	0.2	38.8	11.7
	Nitschia delicatula	3.6	0.3	13.4	17.7
IV&I	*Glenodinium lenticola*	3.0	1.4	2.2	22.7
	Nitzschia tenuirostris	3.0	0.3	10.3	27.6
*60.2	*Hillea fusiformis*	3.3	0.3	12.2	5.4
	Nitzschia delicatula	3.0	0.2	16.7	10.5
IV&II	*Spirulina* sp	3.0	0.3	12.2	15.5
	Glenodinium sp	2.7	0.2	12.2	20.0
*43.4	*Gyrodinium spirale*	4.9	0.4	11.4	11.2
	Syracosphaera sp	3.1	1.4	2.3	18.4
IV&III	*Glenodinium lenticola*	2.7	1.2	2.2	24.6
	Rhizosolenia fragilissima	2.5	3.5	0.7	30.3
*49.8	*Oscillatoria planctonica*	6.0	0.5	13.4	12.1
	Glenodinium paululum	4.2	0.3	13.4	20.6
V&IV	*Gymnodinium* sp	2.9	0.6	4.6	26.3
	Glenodinium sp	2.9	0.2	13.4	32.1
*45.7	*Emiliana huxleyi*	6.8	1.2	5.9	14.9
	Nitzschia delicatula	2.4	1.3	1.9	20.2
VI&I	*Gymnodinium splendens*	2.1	1.2	1.8	24.9
	Nitzschia tenuirostris	2.0	0.8	2.6	29.3

TABLE 4. Continued

Group	Species	$\overline{\delta}_i$	SD($\overline{\delta}_i$)	$\overline{\delta}_i$ /SD($\overline{\delta}_i$)	$\Sigma\ \overline{\delta}_i$%
*44.69	*Spirulina* sp	2.4	0.5	5.2	5.5
	Carteria sp	2.2	0.2	12.3	10.3
VI&II	*Nitzschia delicatula*	2.1	1.1	1.9	15.0
	Gymnodinium splendens	1.9	1.0	1.9	19.1
*43.67	*Gyrodinium spirale*	4.2	0.5	8.6	9.6
	Syracosphaera sp	2.4	1.1	2.2	15.0
VI&III	*Hillea fusiformis*	2.3	1.7	1.4	20.4
	Glenodinium sp	1.7	1.1	1.5	24.1
*44.9	*Glenodinium paululum*	2.6	0.9	2.8	5.8
	Hillea fusiformis	2.3	1.6	1.4	11.0
VI&IV	*Rhizosolenia fragilissima*	2.2	1.7	1.3	15.8
	Glenodinium sp	1.6	1.1	1.5	19.5
*42.27	*Oscillatoria planctonica*	5.2	0.9	5.5	12.2
	Gymnodinium sp	2.4	0.7	3.6	17.9
VI&V	*Hillea fusiformis*	2.0	1.5	1.4	22.7
	Prorocentrum micans	1.7	0.3	5.6	26.8

4. Acknowledgements

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