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A Structural Analysis of Phytoplankton in the Chesapeake Bay Plume and Adjacent Shelf Waters

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A STRUCTURAL ANALYSIS OF PHYTOPLANKTON IN THE CHESAPEAKE BAY PLUME AND ADJACENT SHELF WATERS

by

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ABSTRACT

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Community structures of phytoplankton populations from the southern portion of the Chesapeake Bight were examined and associated to real and environmental spaces. The sampling design was specifically intended to examine the small scale three dimensional structure of the Chesapeake Bay plume as characterized by its phytoplankton populations. The phytoplankton were sampled at 101 stations, non-synoptically, over a five day period in mid-June, 1980.

Several multivariate numerical techniques were used to determine the relationships between the phytoplankton species distributions and the low salinity plume distribution. A pattern of distribution which approximated the salinity plume resulted from several clustering procedures. Environmental ordination demonstrated salinity most often co-varied with the phytoplankton community structure shifts. Results of the discriminant analyses revealed the variation in the phytoplankton assemblages was sufficient to classify the

stations into the plume and non-plume groups with 100% efficiency. The results suggested the plume effected the phytoplankton community structures within the Chesapeake Bight.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The Chesapeake Bay is one of the largest estuarine environments in the world. The extent of interaction between this estuarine system and the nearby continental shelf waters of the Chesapeake Bight has recently received much scientific attention (Campbell and Thomas, 1981). Of general interest during these past experiments was the temporal and spatial distributions of some biological, chemical and physical parameters as they related to the Chesapeake Bay effluent waters. As the integrity of these Bay waters are, to some extent, maintained beyond the Bay mouth onto the shelf, they form an estuarine "plume". Strong gradients of some water mass related properties have allowed a fairly complete delineation of this plume in space and time (Boicourt, 1973; Ruzecki, 1981).

One reason for the increased interest of this particular estuarine-shelf interaction zone has been the rising concern of aquatic pollution within the Chesapeake Bay and its tributaries, and its effects on the nearby coastal and continental shelf ecosystems. The drainage area of the Chesapeake Bay complex covers a major portion of the Atlantic Urban Cluster which containes approximately 45 million persons in 1970 and is expected

to support over 70 million by the year 2000 (Gross et al., 1976). It is expected with such increased population stresses, commensurate releases of domestic, urban, and industrial wastes and contaminants will ensue. Because of the transport mechanism by the Chesapeake Bay plume and the prospect of increased pollution within the Bay, serious concerns about the effects of man's activities on these ecosystems are warranted.

Acting as the primary base of most aquatic food chains, the phytoplankton component of these ecosystems is very important. Because of their small size, limited mobility and high growth rates, these organisms are sensitive to many of the aquatic pollutants mediated by man's activities (Herricks and Cairns, 1982). Owing to the passive nature of biodiffusion, which phytoplankton exhibit, they may be used to assess the effects of those factors associated with the Chesapeake Bay plume as it interacts with the shelf and coastal zone waters.

In these contexts, the objectives of this study were: 1) to identify and quantify the phytoplankton populations within the southern portion of the Chesapeake Bight with special reference to those populations associated with the Chesapeake Bay plume waters, 2) to define distinct phytoplankton assemblages which relate to plume and

non-plume waters, and 3) to identify environmental gradients which co-vary with the phytoplankton biomass distributions.

MULTIVARIATE ANALYSIS APPLICATIONS IN PHYTOPLANKTON ECOLOGY

The use of multivariate analytical procedures has only been applied to phytoplankton ecological studies within approximately the last decade. In the early seventies, multivariate analyses were becoming more widespread in all ecological applications. Following this trend, these procedures were applied to phytoplankton studies in hopes of identifying complex community structures. Phytoplankton ecological studies by their nature generally involve hundreds of species from a standard sampling base. This quantity of variables (species) renders univariate analyses relatively powerless if holistic or community level approaches are desired.

Thorrington-Smith (1971) first used classification analysis to define phytohydrographic regions and their characteristic phytoplankton associations from data collected in the Indian Ocean. Normal cluster analysis, (grouping stations, using species as attributes) using a single-linkage clustering algorithm, clustered stations into major regions which were related to different water masses. The species groups were formed from inverse

clustering of the data (clustering species, using stations as attributes). The species groups were characteristic of variability imposed by seasonality, true regional differences, tranversing currents and nutrient rich regions of instability. Multidimensional scaling was also used as a clustering aid but the technique offered little additional insight into the classification results.

Venrick (1971) used recurrent group analysis (Fager, 1957), a non-heirarchical clustering procedure, to analyze diatom associations in the epipelagic waters of the North Pacific. The analysis allowed groupings of diatom species which showed an affinity to habitate water regions. The distribution of the groups was related to the physical habitats of the North Sea region which were imposed by major currents. Species group fidelities were shown to be high (sometimes to the point of absolute exclusion). Conversion of diatom abundances to biomass (volumetric transformation) and then relating these to environmental variables was performed using multiple-linear regression. Again, physical factors within the study area were emphasized as being important in controlling the phytoplankton distributions.

Levandowsky (1972) was first to attempt an environmental ordination of phytoplankton data. Using a

similar principal vectors method, a technique differing only slightly from standard principal components analysis (PCA), he ordered sites and species from transient beach ponds and Long Island Sound. A three-dimensional ordination resulted which related, non-linearly, to salinity and temperature. The relationships between the ordination axes and the environmental variables were summarized using non-parametric correlation analysis (Kendall's tau). Levandowsky's graphical depiction of the ordinations, relative to the environmental variables, showed apparent systematic relationships between the two. The correlation analysis showed only the salinity-ordination axis association to deviate from random.

Allen and Koonce (1973) used numerical classification and principal components ordinations on 57 weekly samples of phytoplankton data from Lake Wingra, Wisconsin. Numerous transformations of the data were utilized on qualitative, quantitative and species growth rate data. Growth rate data were used according to Allen and Koonce because: "absolute values of today's standing crop have little to do with the environment; the standing crop is, in fact, yesterday's standing crop multiplied by the growth rates allowed by yesterday's environment, less a loss term."

The analysis of different data bases using various transformations revealed different and biologically meaningful aspects of the data. The new approach of using the species growth rates as ordination data did not reveal significant relationships between the environmental variables and the resultant ordination.

Legendre (1973) used several similarity coefficients and cluster analyses to analyze two years of weekly (spring - summer) phytoplankton data from the Gulf of St. Lawrence. The analysis clustered species which associated with each other. For this study area, clusters of associated phytoplankton assemblages were apparent annually. However, only one-third of the phytoplankton species recorded were involved in these successional associations.

Holland and Chaflin (1975) used a battery of multivariate techniques to investigate the horizontal distribution of planktonic diatoms in Green Bay, an embayment of Lake Michigan. Species ordinations were performed by principal components analysis using both correlation and co-variance matrices and by four factor analysis methods. The analyses generally concurred in their results. Normal and inverse cluster analyses were

performed and the results displayed geographical contiguity. Additionally, the results agreed with previous ecological studies of the Green Bay area. Multiple discriminant function analysis was used to assess the discreteness of the clusters in discriminant space. Organism-environment relationships were explored using canonical correlation analysis. The canonical correlation results showed that a majority of the species and the environmental variables did not co-vary.

Allen, Bartell and Koonce (1977) re-analyzed the 1973 phytoplankton data from Lake Wingra, Wisconsin (Allen and Koonce, 1973). The data were analyzed to address the hypothesis proposed by them after the initial analysis that the current standing crop of phytoplankton has little to do with the current environmental variables unless the phytoplanton species are in multivariate equilibrium with them. Historically speaking, as phycologists have not been able to relate species distributions to the environment, they concluded such multivariate equilibria are not generally achieved in nature. The difference of species weekly occurrences, rather than species occurrence data, were used as the data base to substantiate the above conclusion. The PCA of the new data differed greatly from the previous ordinations. Environmental variables and species first difference data clustered similarly into

six major groups. The environmental variables did not, although, systematically co-vary with the PCA axes.

Ortner, Hulburt and Wiebe (1979) investigated phytoplankton community structural differences between waters entrained by the Gulf Stream rings, the surrounding shelf waters and the northern Sargasso Sea. Correspondence Analysis (CA) was used to investigate both species and station relationships. CA is an inertia method which partitions the chi-square statistic describing a contingency table into a hierarchy of contributing variance components. The data base was species carbon per liter via Strathman's (1967) equations. The analysis revealed different communities within the rings relative to the phytoplankton communities of the other waters.

Blasco, Estrada and Jones (1980) used PCA to analyze phytoplankton distributions as they related to hydrographic variables in the northwest African upwelling region near Cabo Corbiero. As the different principal components were highly correlated to the environmental variables, interpretation of the data was made easy. The analysis revealed the stations within the upwelling region to be displaced or disjuncted within the multivariate environmental space sampled. As a similar displacement of

the phytoplankton data occurred a causality was inferred.

Harris and Piccinin (1980) used PCA and multidimensional scaling to summarize weekly sampling of phytoplankton and standard chemical and physical data from Hamilton Harbour, Lake Ontario. Species first occurrence transformations of the data were used to assess three annual cycles. Subtle changes within the environmental variables had major effects on the phytoplankton composition. The variability of phytoplankton composition was also related to a localized upwelling environment within the study area.

Maddock et al. (1981) and Holligan and Maddock (1980) used Correspondence Analysis on volumetric transformed phytoplankton data from arround the British Isles. As both stations and species are ordinated by the CA method, the British Isles program revealed four geographically distinct station groups with different phytoplankton dominants within each group. These distributions were best related to the vertical stability of the water column as calculated by a tidal energy dissipation model. Eleven years of phytoplankton data from the western English Channel showed short term community structure changes which generally co-varied with the thermo-structure of the water column. No long term trends were noticed over the

eleven year sampling period (1964 - 1974).

Carrada et al. (1981) analyzed distributions of winter surface phytoplankton in the Gulf of Naples. As previous work in the vicinity had indicated the area constituted a diversified ecosystem and the phytoplankton analysis confirmed this system. PCA and Hatheway's RQ analysis of environmental variables and species were performed to reduce the data. No mathmatical procedures were used to relate the two analyses but discrete clusters resulted from both of these analyses. This similar clustering in species and environmental space was assumed to reflect the causality between the environment and the phytoplankton organisms.

Schandelmeier and Alexander (1981) investigated phytoplankton population associations as they were influenced by ice formation in the Bering Sea. They used a group-average, agglomerative, heirarchical clustering algorithm on both untransformed and natural log transformed data (cells per liter). A fixed similarity level for interpreting the dendrograms was used, consequently up to twelve groups were sometimes formed. Within the spring data two major station groups emerged, an ice-edge group and a shelf-break group.

PHYTOPLANKTON DISTRIBUTIONS WITHIN THE LOWER CHESAPEAKE BAY AND THE VIRGINIA-NORTH CAROLINA NERETIC WATERS

Since the study of Wolfe et al. (1926) sixteen seasonal studies concerned with phytoplankton population dynamics within the Chesapeake Bay have been performed. Only two of these studies investigated the phytoplankton of the lower Chesapeake Bay region near the mouth.

Patten et al. (1963) studied the lower Bay phytoplankton bi-monthly for the year 1960. Four periods of population maxima with six diversity maxima were observed through the study. Generally, diatoms were numerically dominant during the colder periods with dinoflagellates becoming more important during the warmer months. Highest mean population densities were observed on the western side of the Bay near the York River sub-estuary. Important summer phytoplankton species included Biddulphia granulata, Chaetoceros subtilis, Coscinodiscus asteromphalus, Chilamonas sp. and Cryptomonas ssp. The variations of individual species within the total phytoplankton population were not systematically related to either the physical or chemical data. The summer period was characterized by maximum insolation, warmest water temperatures and the greatest

vertical stability.

Marshall (1980) observed a bi-modal distribution of population peaks with a fall and spring maxima. The Bay phytoplankton populations were dominated by the marine centric diatom Skeletonema costatum most of the year and other diatom species which were found in nearby neritic waters. Important summer dominant species included Coscinodiscus marginatus, Nitzschia pungens, Pleurosigma puchellum, Rhizosolenia calcar-avis, Nannochloros atomus, Gryodinium estuariale and Gymnodinium danicans. Marshall also emphasized the importance of nannoplankton to the total phytoplankton composition of the Bay throughout the seasonal study. Marshall compared the Bay sub-dominant populations to the common neritic flora found directly off the Bay mouth. It was noted that quantitative and qualitative differences were observed between the two areas.

Mulford (1963, 1964) investigated the distribution of two important phytoplankton genera within the continental shelf waters directly off the Chesapeake Bay mouth. Thirteen species from the genus Ceratium were observed during a seasonal study in the year 1960. The genus was observed to be more important proceeding offshore. Within the lower Bay the genus showed a major expression during

the period between May and August. During June, Ceratium furca was the dominant represenative with C. tripos and C. fusus also being present. Ceratium flora of the area was characterized a being a mixture of cold-water and tropical forms, suggesting the influence of the Labrador and Gulf Stream currents were involved in their distribution. The genus Chaetoceros was represented by twenty-five species during the same sampling period. This genus exhibited high numerical dominance and diversity during the fall and winter months. Of particular interest was the complete absence of any Chatoceros species during the June sampling period. Patten et al. (1963) suggested a large scale spatial model which characterized the succession of the Chaetoceros genus throughout the neritic waters of the eastern USA, yet he failed to offer any data to substantiate the model.

Marshall (1976, 1978) reported on the composition and seasonal assemblages of phytoplankton along the entire eastern coast of the United States. Six hundred and nine phytoplankton species were identified during a series of cruises. Generally the distributional patterns of these species showed highest concentrations within fifty miles from the coastline and they decreased seaward. Diatom species distributions closely followed this pattern, as did the Pyrrhophyceans, which were relatively better

represented in the pelagic environment. Dominant diatom species for the coastal-neritic waters were Skeletonema costatum, Leptocylindrus danicus, Rhizosolenia setigera, R. alata, R. calcar-avis and Thalassionema nitzschiodes. Dominant summer phytoflagellates included Ceratium macroceros, C. tripos and Prorocentrum micans. While all of these organisms were dominant relative to the summer phytoplankters, they were represented in higher concentrations during other seasons of the year.

Mulford and Norcross (1971) studied the net phytoplankton in Virginian coastal waters for a years duration. The summer months were characterized by expressions of the genus Ceratium and minor diatom represenatives. Notably, the surface sample of the closest station to the Bay mouth was characterized by phytoplankton previously reported to be associated with the lower Bay. Rhizosolenia alata, Ceratium fusus and C. tripos were the numerical dominants of the twenty-two summer species noted. The diatom to dinoflagellate ratio followed a sequence such that dinoflagellates were proportionally higher during warm months, the classical paradigm.

DESCRIPTION OF THE STUDY AREA

The sampling area was located within the southern portion of the Chesapeake Bight (Fig. 1). This area included the Chesapeake Bay mouth, plume and continental shelf area east to the shelf break and south to Oregon Inlet, North Carolina. The area approximates a rectangular shape, with dimensions of 25 by 150 km. The area was sampled along six major transects from near shore stations seaward and a small transect within the Bay mouth. The more northern transects did not fully extend to the shelf break as the plume activity was expected to preclude this area.

The Chesapeake Bay estuarine plume is an ever present but variable component of the circulation patterns within the Bay mouth area. The plume has primarily been delineated from shelf water by shipboard sampling using salinity as a marker criterion. Salinity differences as great as 12 ppt as far south as the Virginia-North Carolina state border have been recorded (Boicourt, 1973).

Boicourt showed the plume to exit the Bay mouth and turn south along the Virginia and North Carolina coasts. The southward turn is a product of the Coriolis force

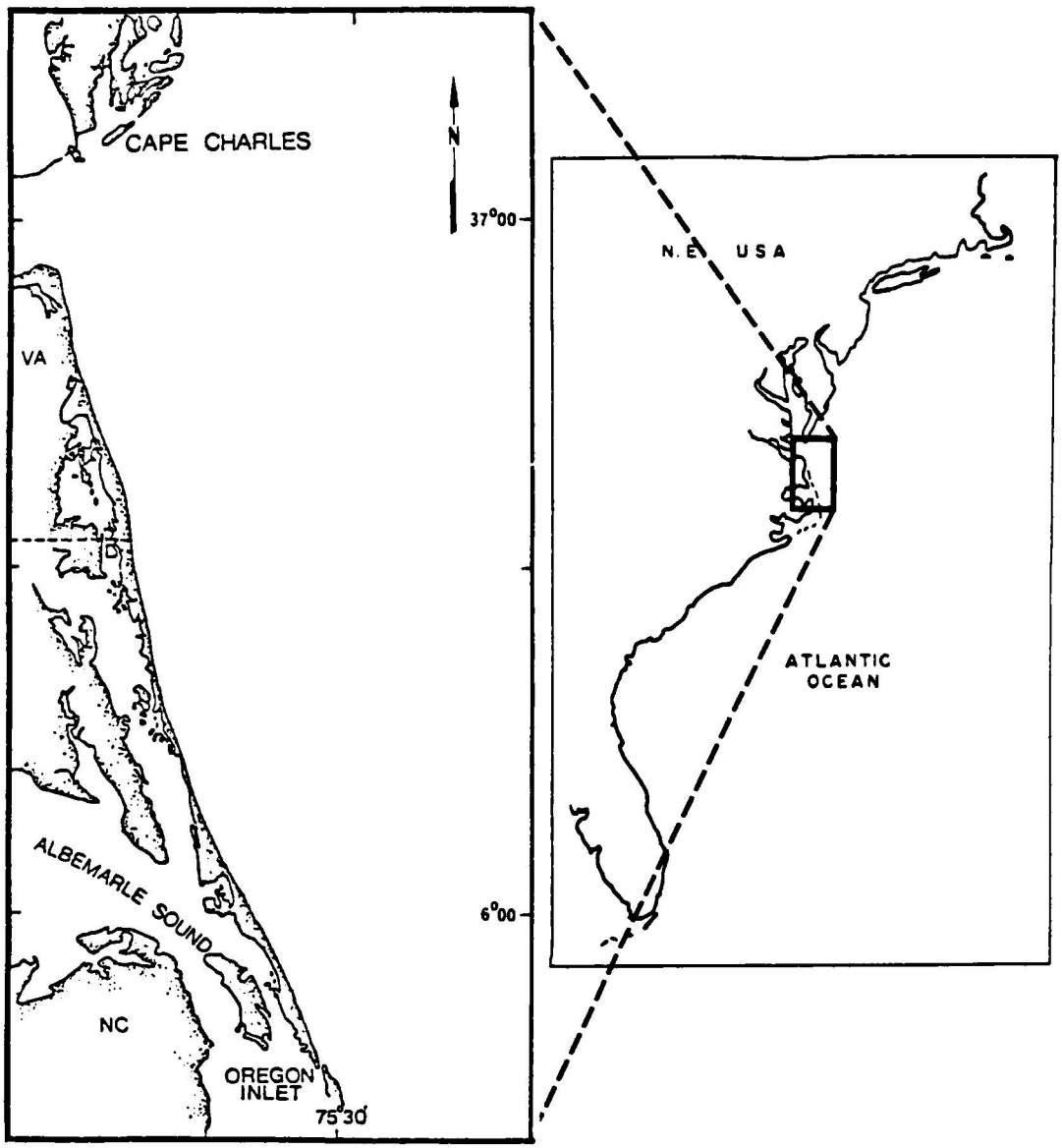


Figure 1. Map of the study area along the Virginia and North Carolina coasts.

caused by the rotation of the earth. The circulation patterns between the estuary and shelf waters were complex and in three-dimensions at the Bay mouth. Boicourt (1981) showed sections of the subsurface waters to be effluxing while others were influxing shelf and Bay waters respectively, between the Virginia Capes. Vertical sampling schemes indicated the plume to be a surface oriented phenomenon as its formation was due to density differences between the two water masses (Ruzecki, 1981).

Boicourt (1981) suggested the Bay plume direction and extension were multiply controlled. He proposed the plume direction and extension to be complexly related to: a) discharge rates, b) seasonal vertical stratification, c) local and nonlocal winds within the Bay and continental shelf area and d) local subterranean topography. Ruzecki (1981) demonstrated coupling between diurnal tidal fluctuations and plume extension periodicity. Munday and Fredosh (1981) correlated Landstat imagery of the plume to local wind and tidal phenomenon. Their results showed the plume direction to systematically co-vary with local wind direction.

The above scenario depicts the Chesapeake Bay estuarine plume as it enters the continental shelf region as a highly dynamic entity. Important temporal scales of

influence range from diurnal (tidal) to seasonal periods (related to the formation of vertically stratified layers), or even longer (rare major meteorologic events). The important space scales range from tens of meters at the Bay mouth, where the plume's water mass has not had sufficient time to be dissipated by advective or diffusive processes, to maximum plume spatial scales up to hundreds of kilometers (Boicourt, 1973).

METHODS

SITE LOCATION AND SAMPLING TECHNIQUES

A total of 101 surface and sub-surface stations were established along six transects from the Chesapeake Bay mouth south to Cape Hatteras (surface stations Fig. 2). All stations were occupied within a 115 hour period, 17-21, June, 1980. The stations were sampled in order of their station number assignment as given in Table 1 which lists the location, depth, and sampling time for all stations. The locations of the stations were selected to sample the projected location of the three-dimensional structure of the Chesapeake Bay plume as it exited the Bay's mouth. The number and depths of subsurface samples at each surface station were determined according to the water column depth and its thermo-structure as assessed by deploying expendable bathythermographic probes.

The water samples were collected using a series of 20-liter Niskin sampling bottles supported from a hydrographic cable. For each phytoplankton sample a measured subsample (500 ml) of seawater was withdrawn from the Niskin sampler and transferred directly into a polyethylene bottle which contained 20 ml of buffered formalin (pH: 8.2) as a preservative. Upon returning to

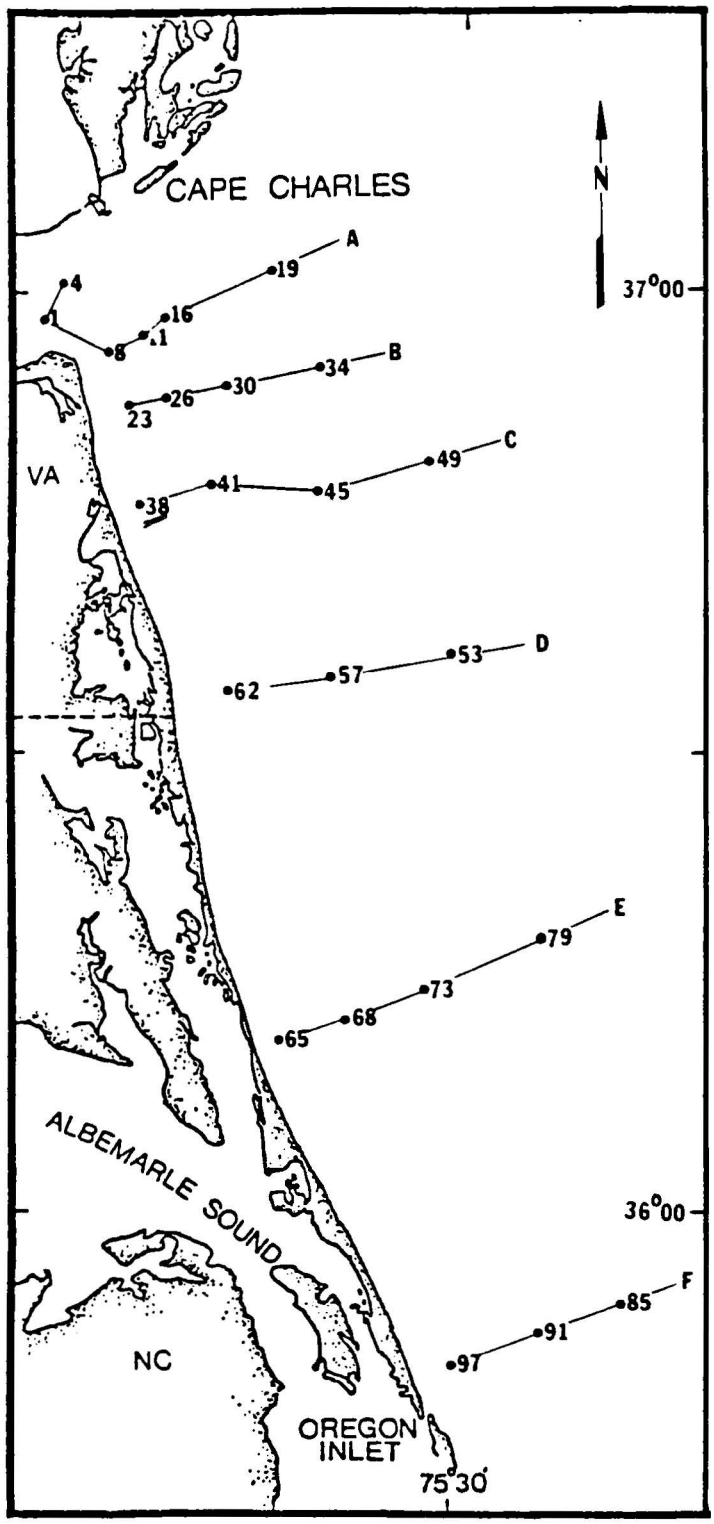


Figure 2. Map of surface stations and transects within the study area.

Table 1. Date, time, location and depth for each station.

STATION	DATE	TIME (DST)	LATITUDE (N) DEG	MIN	LONGITUDE (W) DEG	MIN	DEPTH (M)
1	6-17-80	2050	36	57.3	76	2.9	1
2	6-17-80	2050	36	57.3	76	2.9	5
3	6-17-80	2050	36	57.3	76	2.9	7
4	6-18-80	1230	36	59.2	76	0.6	1
5	6-18-80	1230	36	59.2	76	0.6	5
6	6-18-80	1230	36	59.2	76	0.6	10
7	6-18-80	1230	36	59.2	76	0.6	13
8	6-18-80	1455	36	55.0	75	58.0	1
9	6-18-80	1455	36	55.0	75	58.0	5
10	6-18-80	1455	36	55.0	75	58.0	12
11	6-18-80	1705	36	56.0	75	55.8	1
12	6-18-80	1705	36	56.0	75	55.8	5
13	6-18-80	1705	36	56.0	75	55.8	10
14	6-18-80	1705	36	56.0	75	55.8	15
15	6-18-80	1705	36	56.0	75	55.8	18
16	6-18-80	2050	36	58.0	75	51.5	1
17	6-18-80	2050	36	58.0	75	51.5	5
18	6-18-80	2050	36	58.0	75	51.5	10
19	6-18-80	2327	37	0.6	75	44.4	1
20	6-18-80	2327	37	0.6	75	44.4	5

Table 1. (Cont.)

STATION	DATE	TIME (DST)	LATITUDE (N) DEG	MIN	LONGITUDE (W) DEG	MIN	DEPTH (M)
21	6-18-80	2327	37	0.6	75	44.4	10
22	6-18-80	2327	37	0.6	75	44.4	15
23	6-19-80	1213	36	52.0	75	56.0	1
24	6-19-80	1213	36	52.0	75	56.0	5
25	6-19-80	1213	36	52.0	75	56.0	10
26	6-19-80	1730	36	52.4	75	53.5	1
27	6-19-80	1730	36	52.4	75	53.5	5
28	6-19-80	1730	36	52.4	75	53.5	10
29	6-19-80	1730	36	52.4	75	53.5	13
30	6-19-80	1949	36	53.2	75	48.6	1
31	6-19-80	1949	36	53.2	75	48.6	5
32	6-19-80	1949	36	53.2	75	48.8	10
33	6-19-80	1949	36	53.2	75	48.8	15
34	6-19-80	2200	36	54.4	75	41.8	1
35	6-19-80	2200	36	54.4	75	41.8	5
36	6-19-80	2200	36	54.4	75	41.8	10
37	6-19-80	2200	36	54.4	75	41.8	15
38	6-20-80	1758	36	45.5	75	54.7	1
39	6-20-80	1758	36	45.5	75	54.7	5
40	6-20-80	1758	36	45.5	75	54.7	10

Table 1. (Cont.)

STATION	DATE	TIME (DST)	LATITUDE (N) DEG	MIN	LONGITUDE (W) DEG	MIN	DEPTH (M)
41	6-20-80	2011	36	46.4	75	49.0	1
42	6-20-80	2011	36	46.4	75	49.0	5
43	6-20-80	2011	36	46.4	75	49.0	10
44	6-20-80	2011	36	46.4	75	49.0	15
45	6-20-80	2243	36	47.6	75	41.2	1
46	6-20-80	2243	36	47.6	75	41.2	6
47	6-20-80	2243	36	47.6	75	41.2	12
48	6-20-80	2243	36	47.6	75	41.2	18
49	6-21-80	0845	36	48.7	75	32.6	1
50	6-21-80	0845	36	48.7	75	32.6	7
51	6-21-80	0845	36	48.7	75	32.6	14
52	6-21-80	0845	36	48.7	75	32.6	21
53	6-21-80	1111	36	35.9	75	31.2	1
54	6-21-80	1111	36	35.9	75	31.2	6
55	6-21-80	1111	36	35.9	75	31.2	12
56	6-21-80	1111	36	35.9	75	31.2	18
57	6-21-80	1420	36	34.5	75	40.2	1
58	6-21-80	1420	36	34.5	75	40.2	5
59	6-21-80	1420	36	34.5	75	40.2	10
60	6-21-80	1420	36	34.5	75	40.2	15
61	6-21-80	1420	36	34.5	75	40.2	20

Table 1. (Cont.)

STATION	DATE	TIME (DST)	LATITUDE (N) DEG	MIN	LONGITUDE (W) DEG	MIN	DEPTH (M)
62	6-21-80	1802	36	33.7	75	48.1	1
63	6-21-80	1802	36	33.7	75	48.1	6
64	6-21-80	1802	36	33.7	75	48.1	12
65	6-21-80	1802	36	11.5	75	44.1	1
66	6-21-80	1802	36	11.5	75	44.1	5
67	6-21-80	1802	36	11.5	75	44.1	10
68	6-21-80	2203	36	13.1	75	38.7	1
69	6-21-80	2203	36	13.1	75	38.7	5
70	6-21-80	2203	36	13.1	75	38.7	10
71	6-21-80	2203	36	13.1	75	38.7	15
72	6-21-80	2203	36	13.1	75	38.7	20
73	6-21-80	2359	36	15.0	75	32.6	1
74	6-21-80	2359	36	15.0	75	32.6	5
75	6-21-80	2359	36	15.0	75	32.6	10
76	6-21-80	2359	36	15.0	75	32.6	15
77	6-21-80	2359	36	15.0	75	32.6	20
78	6-21-80	2359	36	15.0	75	32.6	25
79	6-22-80	0910	36	18.1	75	23.1	1
80	6-22-80	0910	36	18.1	75	23.1	5
81	6-22-80	0910	36	18.1	75	23.1	10

Table 1. (Cont.)

STATION	DATE	TIME (DST)	LATITUDE (N) DEG	MIN	LONGITUDE (W) DEG	MIN	DEPTH (M)
82	6-22-80	0910	36	18.1	75	23.1	15
83	6-22-80	0910	36	18.1	75	23.1	20
84	6-22-80	0910	36	18.1	75	23.1	25
85	6-22-80	1224	35	54.3	75	17.1	1
86	6-22-80	1224	35	54.3	75	17.1	6
87	6-22-80	1224	35	54.3	75	17.1	12
88	6-22-80	1224	35	54.3	75	17.1	18
89	6-22-80	1224	35	54.3	75	17.1	24
90	6-22-80	1224	35	54.3	75	17.1	28
91	6-22-80	1429	35	52.3	75	23.9	1
92	6-22-80	1429	35	52.3	75	23.9	5
93	6-22-80	1429	35	52.3	75	23.9	10
94	6-22-80	1429	35	52.3	75	23.9	15
95	6-22-80	1429	35	52.3	75	23.9	20
96	6-22-80	1429	35	52.3	75	23.9	24
97	6-22-80	1540	35	50.2	75	30.2	1
98	6-22-80	1540	35	50.2	75	30.2	5
99	6-22-80	1540	35	50.2	75	30.2	10
100	6-22-80	1540	35	50.2	75	30.2	15
101	6-22-80	1540	35	50.2	75	30.2	18

the laboratory, the bottles were allowed a period of at least 72 hours for the sedimentation of cells. A siphoning procedure followed which resulted in a 20 ml concentrate for each sample. For quantifying and identifying the phytoplankton cells, either aliquots or whole concentrates were placed into special settling chambers and allowed to re-settle. The cells were identified to the lowest possible taxa and counted by a random fields method using a Zeiss inverted plankton microscope. Systematic classification was according to Hendey (1974) for the diatoms and Parke and Dixon (1976) for other taxa. Random fields of the settling chamber were selected and counts were made to allow 85% confidence intervals on the total concentrations of the cells (Venrick, 1978).

Other variables measured at each station by other investigators were salinity, water temperature, dissolved oxygen, total suspended matter, nitrites, nitrates, ammonia, silicon, phosphates, chlorophyll-a and phaeopigments. Samples for all determinations were withdrawn from the same Niskin sampler at each station. Wong and Todd (1981) have reported the nutrient data, with Robertson and Thomas (1981) discussing the salinity, temperature, chlorophyll, phaeopigment and dissolved oxygen data.

DATA ANALYSES

The species and environmental data were analysed as six separate transects because of the apparent lack of structure exhibited by the entire species data matrix. Stations 1 through 7 were included in the analyses of stations 8 through 22 to reduce the number of transects. Additionally, because of the geographic proximity of these stations to each other, the combination was performed. Transects were labeled A thru F as given in Figure 2. Transect A included stations 1 through 22. For each multivariate analysis all stations were analyzed together but the results were are presented as transect A-1 for the short bay mouth series and A-2 for the rest of the stations in Transect A.

The phytoplankton abundance data were initially transformed to cellular volumes according to the formulae of Kovala and Larrance (1966). This transformation has recently been used in an attempt to facilitate successful environmental ordinations of phytoplankton data (Venrick, 1971; Ortner et al., 1979; Holligan et al., 1980; Maddock et al., 1981). The high correlation between cell carbon and cell volume (Strathman, 1967) has been the basis behind these transformations. Additionally the relationship between environment and species should prove

to be more obvious after normalizing each species abundance by cellular volume.

For all multivariate analyses the species volume data were log transformed such that:

$$Y = \log_{10} (X+1),$$

where Y is the normalized datum and X is species cubic microns per cell per liter. This has been shown to be the best transformation for phytoplankton data to be used in mathmatical methods requiring data normality (Cassie, 1967). Following the results of Austin and Greig-Smith (1968), excessively rare species were removed from each of the transect data matrices separately to reduce the problems associated with the over-definition of samples. This data parsing was performed by using the Data Screening Program for Species Importance Matrices by Gauch (1973).

CLUSTERING METHODS

To group stations, a sequential, agglomerative, non-hierarchical, non-overlapping clustering method was used. The program used was COMPCLUS by Gauch (1979). The advantages of this type of clustering method over the more

often used SAHN techniques are: a) decreased space distortion resulting from the unavoidable consequence of group unions at successively higher levels, and b) results which characterize the global optimum perspective are more likely.

The euclidian distance function was used as the association coefficient for each COMPCLUS clustering analysis because of its metric qualities. The discreteness of station clusters were examined using the multiple-discriminant function analysis program by Klecka (1975). Stepwise methods were employed as Klecka (1980) advised to eliminate weak or redundant variables. This method choose those variables (species) which in conjunction maximize the discriminating power of the analysis.

A devisive clustering method which clustered both stations and species was used to identify indicator species for the station groups (Hill et al., 1975). This was performed by the program, TWINSPAN, of Hill (1979). This program was also used to group species for calculating fidelity indices.

ENVIRONMENTAL ORDINATION

The term ordination is defined as the process of arranging or ordering stations (or species) in relation to one or more environmental gradients or abstract axes representing such gradients. Detrended Correspondence Analysis (DCA) (Hill and Gauch, 1980), was used to investigate phytoplankton species association changes inherent to the volumetric transect data. The program used was DECORANA by Hill (1979). DCA was chosen above all other available ordination algorithms because the arch effect inherent to the other methods is avoided, thus much reducing space distortion (Hill and Gauch, 1980).

Scattergram graphic depiction and non-parametric correlation methods (Spearman's Rho) were used to associate the derived ordination axes to the environmental variables.

Two studies using simulated data by Gauch and co-workers have shown DCA to be superior to all other ordination techniques available to date (Gauch et al., 1981; Hill and Gauch, 1980). To check the performance of the DCA ordination technique, data of exactly known characteristics (similar in complexity to the most complex

of the phytoplankton transect data) were generated and tested for distortion by DCA. The simulated data were generated using the Coenoplane Simulation program of Gauch (1975).

Diversity indices of Hurlbert (1971) were used to summarize up to thirty-dimension species data into single statistics. Hurlbert's diversity indices are conceptually superior to standard diversity indices in that they are: a) not sample density dependent and b) are probabilities so they are inter-comparable.

All programs were executed on the Digital Equipment Corporation, Model 10 computer of the Old Dominion University Computer Center. Computer graphics were performed on a Varian Statos III electrostatic plotter linked to the computer.

RESULTS

PLUME DELINEATION

A tongue of relatively low salinity water was evidenced exiting the Chesapeake Bay mouth and then turned south and ran parallel to the Virginia-North Carolina coasts (Fig. 3). The plume of low salinity Bay water was positioned within the near coastal upper water column stations. At the southernmost transect it deviated from the coastal orientation and was observed within the offshore surface stations. Figure 3 depicts those stations with at least ca. 31.3% Bay water. This low salinity tongue will be referred to as the salinity plume and will be used as a comparison criterion. The 31.3% cutoff level was chosen as it was the maximum value possible which delineated the salinity plume across all of the transects. The maximum differences in salinity between the identified plume and the non-plume stations ranged from 12.4 ppt (100% Bay water) to 3.7 ppt (31.3% Bay water).

Averaged proportions of Bay water within the defined salinity plume stations for the 6 major transects are shown in Figure 4. The percentage of Bay water within the plume shows a systematic decrease as the plume progresses

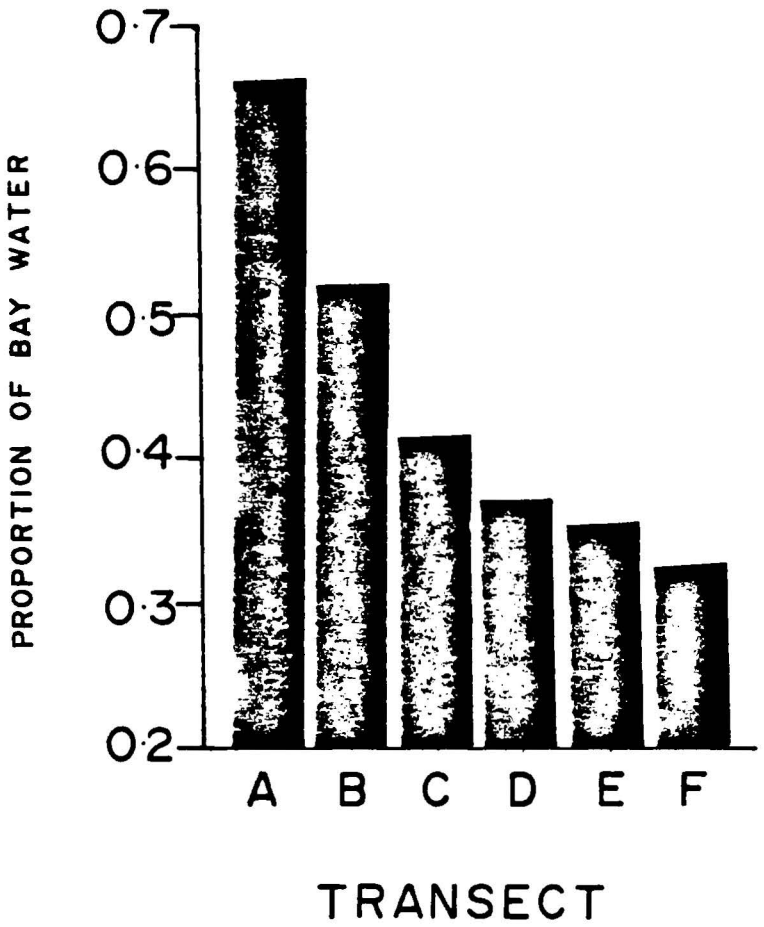
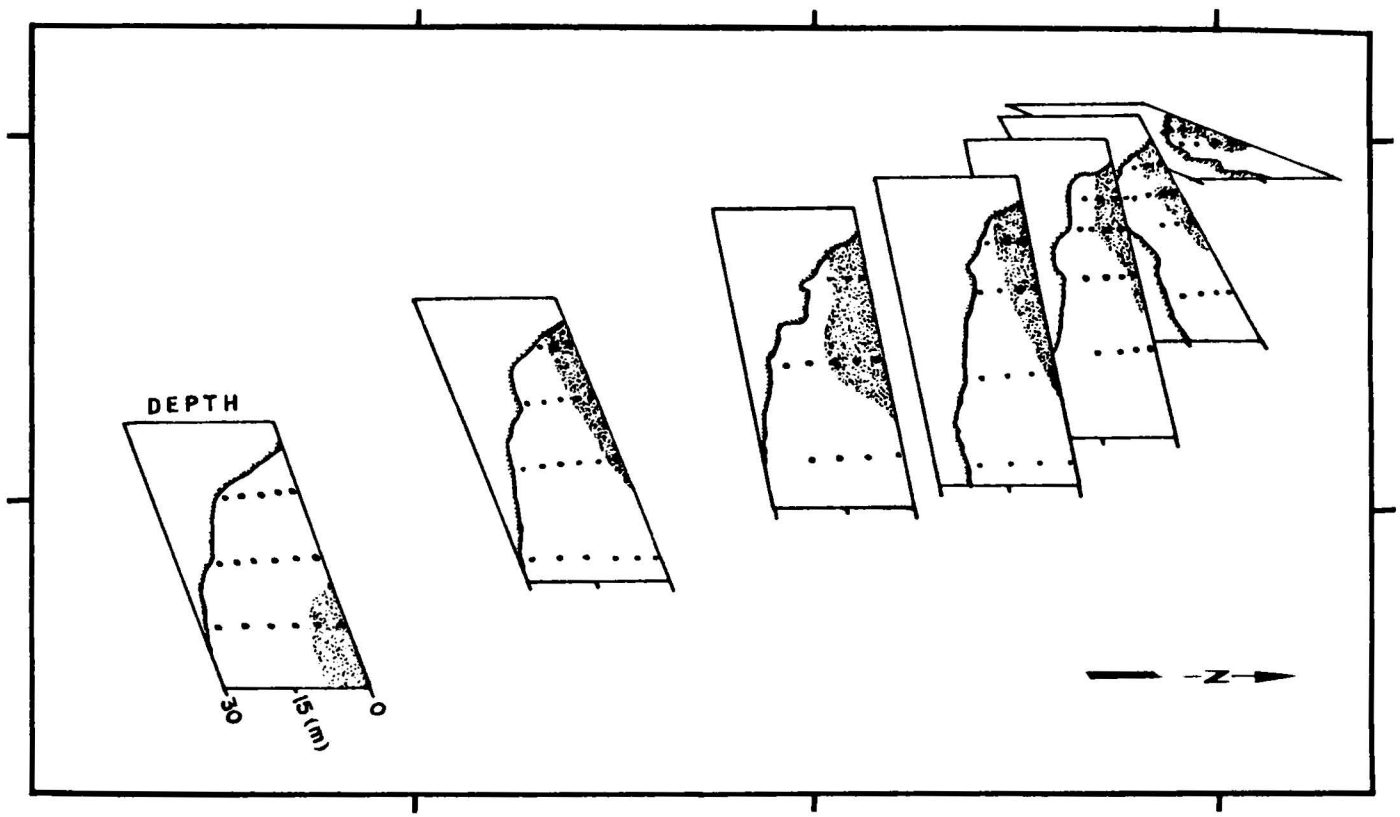


Figure 4. Histogram of the mean proportions of Bay water for those stations within the low salinity plume for each transect.

Figure 3. Diagram of the salinity plume distribution during the study period. Shaded areas indicate regions having less than or equal to 31.3% Bay water.



southward. This decrease is considered the result of both diffussive and advective processes causing the salt concentrations to change (Boicourt, 1973).

TOTAL PHYTOPLANKTON BIOMASS DISTRIBUTIONS

One-hundred and sixty-seven phytoplankton organisms from 9 taxonomic groups were identified from the 101 stations (Table 2). Diatoms accounted for 58.7% (98) of the species, dinoflagellates 29.3% (49), coccolithophores 5.4% (9) and six other taxonomic groups 6.6% (11). The volumes of the individual species ranged from 8 cubic microns for Cryptomonas sp. to 19,815,596 cubic microns for Coscinodiscus wailseii.

A visual comparison of standard cell counts and estimated cell volumes for taxonomic groups are presented in Figure 5. The histogram displays data from a represenative station (# 11) within the Bay plume where numerous unidentified green coccoid cells (diameters ranged: 1 - 10 microns) were the numerical dominants. Because of the relatively small volume of these unidentified cells to the other species observed, their contribution to the total was small.

Table 2. List of the 167 phytoplankton organisms found during the cruise.

BACILLARIOPHYCEAE

Actinoptychus sp.
Actinoptychus senarius Ehrenberg
Amphora sp.
Amphora cuneata Cleve
Asterionella glacialis Castracane
Bacillaria paxillifer (Muller) Hendey
Bellochea horologicalis von Stosch
Biddulphia alternans (Bailey) Van Heurck
Biddulphia aurita (Lyngbye) Brebisson
Biddulphia mobiliensis (Bailey) Grunow
Biddulphia rhombus form trigona Hustedt
Biddulphia sinensis Greville
Campylosira cymbelliformis (Schmidt) Grunow
Cerataulina pelagica (Cleve) Hendey
Chaetoceros sp.
Chaetoceros atlanticum Cleve
Chaetoceros compressum Lauder
Chaetoceros costatum Pavillard
Chaetoceros curvisetum Cleve
Chaetoceros danicum Cleve
Chaetoceros decipiens Cleve
Chaetoceros gracile Schutt
Chaetoceros pendulum Karsten
Chaetoceros peruvianum Brightwell
Chaetoceros sociale Lauder
Cocconeis sp.
Coscinodiscus sp.
Coscinodiscus gigas Ehrenberg
Coscinodiscus grani Gough
Coscinodiscus granulosus Grunow
Coscinodiscus lineatus Ehrenberg
Coscinodiscus marginatus Ehrenberg
Coscinodiscus nitidus Gregory
Coscinodiscus oculus iridis Ehrenberg
Coscinodiscus wailesii Gran and Angst
Coscinosira polychorda (Gran) Gran
Cyclotella sp.
Cylindrotheca closterium (Ehrenberg) Reimann and Lewin
Dactyliosolen mediterraneus Peragallo
Ditylum brightwelli (West) Grunow
Eucampia zoodiacus Ehrenberg
Grammatophora sp.
Guinardia flaccida (Castracane) Peragallo
Gyrosigma sp.
Hemiaulus hauckii Grunow
Leptocylindrus danicus Cleve
Leptocylindrus minimus Gran

Table 2. (Cont.)

Navicula sp.
Navicula cancellata Donkin
Navicula lyra Ehrenberg
Navicula transitans asymmetrica (Cleve) Cleve
Nitzschia sp.
Nitzschia delicatissima Cleve
Nitzschia gracillima Heiden and Kolbe
Nitzschia insignis Gregory
Nitzschia longissima (Brebisson) Ralfs
Nitzschia pungens Grunow
Nitzschia spathulata Brebisson
Paralia sulcata (Ehrenberg) Cleve
Plagiogramma sp.
Plagiogramma staurophorum (Gregory) Heilberg
Plagiogramma vanheurckii Grunow
Pleurosigma sp.
Pleurosigma angulatum (Quekett) W. Smith
Pleurosigma normanii Ralfs
Rhaphoneis sp.
Rhaphoneis amphiceros Ehrenberg
Rhaphoneis surirella (Ehrenberg) Grunow
Rhizosolenia alata Brightwell
Rhizosolenia alata gracillima (Cleve) Grunow
Rhizosolenia alata indica (Peragallo) Gran
Rhizosolenia bergonii Peragallo
Rhizosolenia calcar-avis Schultze
Rhizosolenia delicatula Cleve
Rhizosolenia fragilissima Bergon
Rhizosolenia imbricata Brightwell
Rhizosolenia robusta Norman
Rhizosolenia setigera Brightwell
Rhizosolenia stolterfothii Peragallo
Rhizosolenia styliformis Brightwell
Skeletonema costatum (Greville) Cleve
Stephanopyxis palmeriana (Greville) Grunow
Tabellaria fenestrata asterionelloides Grunow
Tabellaria fenestrata (Lyngbye) Kutzing
Thalassionema nitzschiodes Hustedt
Thalassiosira sp.
Thalassiosira eccentrica (Ehrenberg) Cleve
Thalassiosira gravida Cleve
Thalassiosira nordenskioldii Cleve
Thalassiosira pseudonana (Hustedt) Hasle and Heimdal
Thalassiosira rotula Meunier
Thalassiothrix frauenfeldii Grunow
Triceratium acutum Ehrenberg
Unidentified centric diatoms (diameter less than 20)
Unidentified centric diatoms (diameter between 20 & 100 microns)

Table 2. (Cont.)

Unidentified pennate diatoms (apical axis less than 20 microns)
Unidentified pennate diatoms (apical axis greater than 20 microns)

DINOPHYCEAE

Amphidinium sp.
Amphidinium acutum Lachmann
Ceratium arcticum (Ehrenberg) Cleve
Ceratium buceros (Zacharias) Schiller
Ceratium extensum (Gourret) Cleve
Ceratium furca (Ehrenberg) Claparade and Lachmann
Ceratium fusus (Ehrenberg) Dujardin
Ceratium lineatum (Ehrenberg) Cleve
Ceratium macroceros (Ehrenberg) Vanhoffen
Ceratium massiliense (Gourret) Jorgensen
Ceratium minutum Jorgensen
Ceratium pentagonium Gourret
Ceratium trichoceros (Ehrenberg) Kofoid
Ceratium tripos (Muller) Nitzsch
Dinophysis sp.
Dinophysis acuminata Claparade and Lachmann
Dinophysis acuta Ehrenberg
Dinophysis caudata Kent
Dinophysis fortii Pavillard
Dinophysis hastata Stein
Dinophysis norvegica Claparade and Lachmann
Dinophysis ovum Schutt
Dinophysis punctata Jorgensen
Dinophysis rotunda Claparade and Lachmann
Dinophysis tripos Gourret
Goniaulax sp.
Goniaulax diegensis Kofoid
Goniaulax spinifera (Claparade and Lachmann) Diesing
Gymnodinium sp.
Gymnodinium arcticum Wulff
Gymnodinium breve Davis
Gyrodinium sp.
Prorocentrum sp.
Prorocentrum aporum (Schiller) Dodge
Prorocentrum balticum (Lohmann) Loeblich III
Prorocentrum compressum (Bailey) Abe
Prorocentrum micans Ehrenberg
Prorocentrum minimum (Pavillard) Schiller
Protoperidinium sp.
Protoperidinium cerasus (Paulsen) Balech
Protoperidinium depressum (Bailey) Balech

Table 2. (Cont.)

Protoperidinium minutum (Kofoid) Loeblich III
Protoperidinium oceanicum (Vanhoffen) Balech
Protoperidinium punctulatum (Paulsen) Balech
Protoperidinium steinii (jorgensen) Balech
Pyrophacus sp.
Pyrophacus horologium Stein
Unidentified dinoflagellate cysts
Unidentified dinoflagellates

HAPTOPHYCEAE

Acanthoica quattrospina Lohmann
Emiliana huxleyi (Lohmann) Hay and Mohler
Michaelsarsia elegans Gran
Ophiaster hydroides (Lohmann) Lohmann
Pontosphaera sp.
Pontosphaera syracusana Lohmann
Rhabdosphaera stylifer Lohmann
Syracosphaera pulchra Lohmann
Unidentified coccolithophores

CHRYSOPHYCEAE

Dictyocha fibula Ehrenberg
Distephanus speculum (Ehrenberg) Haekel
Ebria tripartita (Schumann) Lemmermann

CYANOPHYCEAE

Johannesbaptistia pellucida (Dickie) Taylor and Drouet

EUGLENOPHYCEAE

Eutreptia sp.

CHLOROPHYCEAE

Pediastrum simplex (Meyen) Lemmermann

Table 2. (Cont.)

CRYPTOPHYCEAE

Chroomonas sp.
Cryptomonas sp.

UNIDENTIFIED FORMS

Green spherical cells less than 3 microns in diameter.
Green spherical cells between 3 and 5 microns in diameter.
Green spherical cells between 5 and 10 microns in diamter.

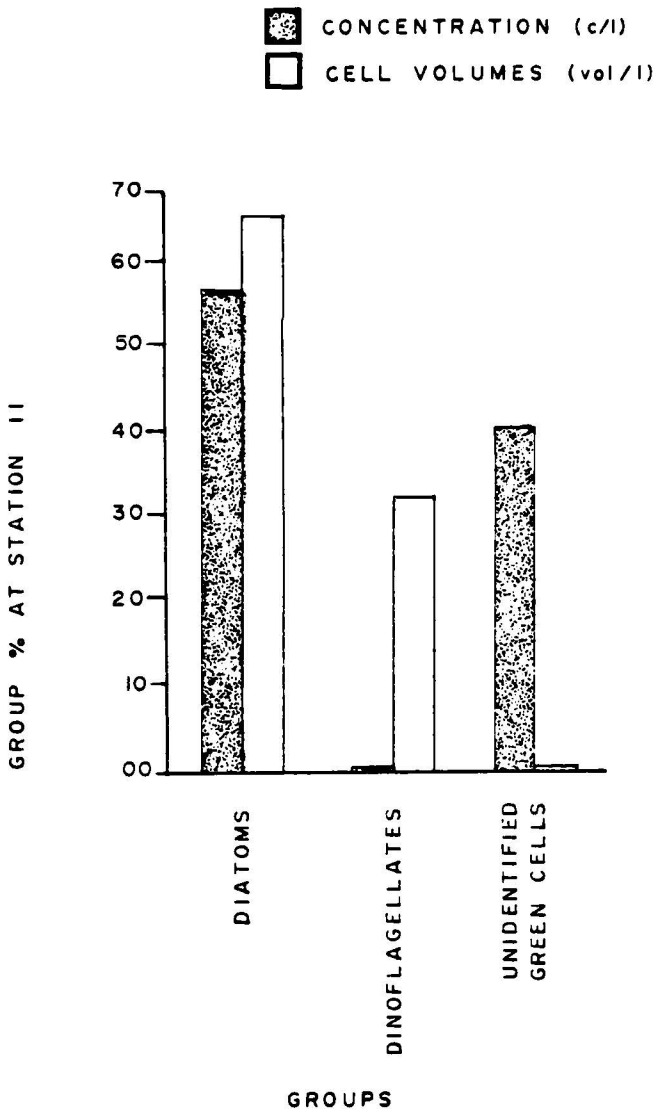


Figure 5. Histogram of taxonomic proportions at station 11 relative to abundance of cells and cell volumes.

The dominant volumetric species throughout the study varied. Two general patterns of dominance were expressed by both: a) very numerous small to medium sized chained diatioms, e.g. Skeletonema costatum, Rhizosolenia fragilissima, Leptocylindrus danicus and Thalassiosira gravida, or b) lower numbers of very large cells (volumetrically), e.g. Ceratium tripos, Guinardia flaccida and Rhizosolenia styliformis. The dinoflagellate Ceratium tripos was the most abundant species throughout the study, being volumetrically dominant in 5 of the 6 transects.

The average total cell volume from the 35 low salinity plume stations was 6.48 cubic mm per liter. The average for the non-plume stations was 4.24 cubic mm per liter, yet, the two means were not statistically different because the variability of the two groups was large.

Vertically, chlorophyll-a distributions were quite distinct within two regions of the sampling area. Within the vicinity of the Bay mouth (stations: 1 thru 29), chlorophyll-a (MEAN: 2.6 ug/l) was homogenously mixed throughout the water column. In the stations away from the Bay mouth (stations: 30 through 101), vertical stratification of chlorophyll was observed with maximum values being in the lower depths. The chlorophyll-a

values were generally higher within the southern stations, but were highly variable (MEAN: 1.07 ug chl-a/l; SD: 0.88 ug chl-a/l).

The correlation between chlorophyll-a and total cell volume per liter was low but statistically significant ($r=0.39$, $\alpha \leq 0.05$) for all 101 stations. Correlation values of 0.283 and 0.497 were determined for the salinity plume and non-plume associations respectively. These correlation values were statistically homogeneous ($\alpha \leq 0.05$). Chlorophyll-a values for the plume and non-plume areas were 1.77 ± 1.78 ug chla/l and 1.47 ± 1.05 ug chla/l (MEAN $\pm$ 1SD) respectively.

Diversity indices (Table 3) were not strongly related to either stratification phenomenon within the water coulmn nor to spatial distributions relative to the salinity plume.

Table 3. Listing of calculated diversity parameters and number of species for each station.

STATION	HURLBERT'S PIE	EVENESS	NUMBER OF SPECIES
1	0.283	0.303	15
2	0.476	0.508	16
3	0.454	0.481	18
4	0.575	0.606	20
5	0.554	0.575	28
6	0.619	0.638	33
7	0.634	0.656	29
8	0.182	0.190	26
9	0.224	0.234	24
10	0.342	0.364	17
11	0.685	0.714	24
12	0.625	0.656	21
13	0.823	0.852	29
14	0.328	0.355	13
15	0.524	0.544	27
16	0.629	0.664	19
17	0.585	0.618	19
18	0.764	0.799	23
19	0.364	0.380	24
20	0.594	0.620	24
21	0.776	0.815	21
22	0.849	0.906	16
23	0.310	0.323	24
24	0.284	0.297	23
25	0.583	0.618	18
26	0.192	0.202	20
27	0.239	0.255	16
28	0.627	0.651	27
29	0.791	0.823	25
30	0.534	0.562	20
31	0.525	0.563	15
32	0.701	0.742	18
33	0.710	0.747	20
34	0.407	0.429	20
35	0.348	0.368	18
36	0.732	0.778	17
37	0.558	0.586	21
38	0.737	0.778	19
39	0.702	0.745	17
40	0.717	0.748	24
41	0.607	0.640	19

Table 3. (Cont.)

STATION	HURLBERT'S PIE	EVENESS	NUMBER OF SPECIES
42	0.543	0.568	22
43	0.627	0.651	27
44	0.769	0.795	30
45	0.026	0.028	19
46	0.677	0.707	23
47	0.788	0.829	20
48	0.206	0.215	24
49	0.464	0.486	22
50	0.589	0.618	21
51	0.253	0.263	25
52	0.312	0.328	21
53	0.780	0.815	23
54	0.408	0.424	25
55	0.672	0.701	24
56	0.401	0.418	24
57	0.412	0.433	21
58	0.776	0.809	24
59	0.566	0.587	28
60	0.671	0.701	23
61	0.694	0.716	33
62	0.761	0.801	20
63	0.702	0.739	20
64	0.729	0.775	17
65	0.739	0.770	25
66	0.432	0.450	24
67	0.722	0.753	24
68	0.319	0.333	25
69	0.215	0.223	27
70	0.492	0.508	31
71	0.450	0.466	29
72	0.471	0.486	32
73	0.695	0.728	22
74	0.820	0.863	20
75	0.630	0.657	24
76	0.776	0.817	20
77	0.768	0.799	25
78	0.854	0.883	31
79	0.652	0.696	16
80	0.700	0.746	16
81	0.704	0.744	19
82	0.512	0.549	15
83	0.507	0.533	21
84	0.227	0.241	17

Table 3. (Cont.)

STATION	HURLBERT'S PIE	EVENESS	NUMBER OF SPECIES
85	0.382	0.402	20
86	0.440	0.467	17
87	0.708	0.741	22
88	0.806	0.830	35
89	0.709	0.731	33
90	0.600	0.617	37
91	0.463	0.488	20
92	0.533	0.561	20
93	0.211	0.221	22
94	0.471	0.490	26
95	0.818	0.839	41
96	0.517	0.530	41
97	0.501	0.530	18
98	0.749	0.783	23
99	0.808	0.841	26
100	0.853	0.881	31
101	0.475	0.491	30

DATA REDUCTION FOR MULTIVARIATE ANALYSES

The transect data were reduced from their initial complexity, N-dimensional (N representing the initial number of species present), to a lesser dimension as imposed by the minimum-keep criterion within the data screening program. By setting the minimum-keep criterion equal to 2, each species occuring only once within a transect was eliminated. Table 4 displays some of the data reduction statistics generated during the data reduction steps. The percentage of total variance retained is presented but this quantity does not take on its usual meaning. Specifically, this quantity reflects the proportion of cumulative univariate variances retained to the total of the univariate variances. The percentage of variance retained ranged from 82 to 89 for the data reduction steps.

COMPCLUS CLUSTERING

Figure 6 (A-F) displays the station groups formed from the normal clustering by the COMPCLUS program. The groupings were derived from both the results of the cluster analysis and the discriminant analysis. Small aggregates of stations formed during the cluster analyses were assigned to the larger groups within each transect according to the discriminant functions produced. The groups displayed were considered discrete clusters as assessed by discriminant analysis. In all transects 100% correct classification was obtained. The stepwise discriminant proceedure invaribly used only a portion of the species for the analysis and these species were not the same for the different transects (Table 5).

Transect A segregated into 4 station groups. Station group 1 included surface stations within the bay mouth and 11 seaward stations. The remaining 3 groups divided the subsurface bay mouth stations and the shoreward stations of the larger transect.

Transect B formed two geographically discrete evenly sized station clusters. Group 1 constituted all but 2 of

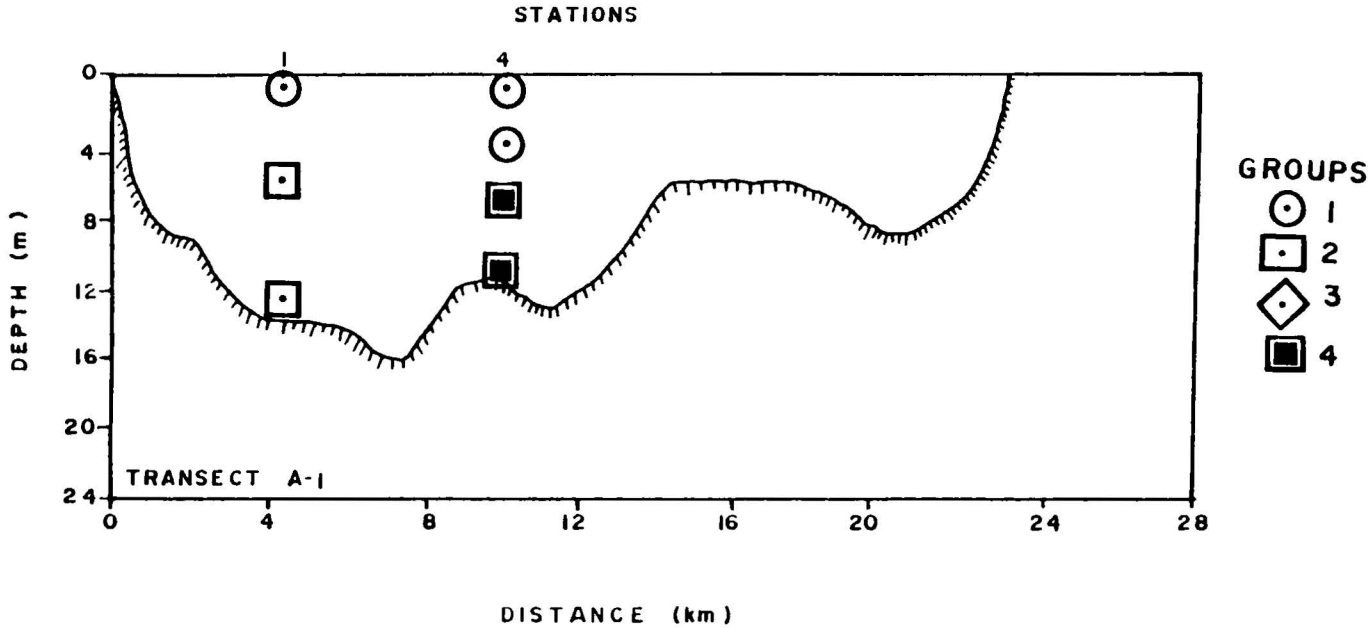


Figure 6-A1. Diagram of the station groups of transect A1 as clustered by the COMPCLUS procedure.

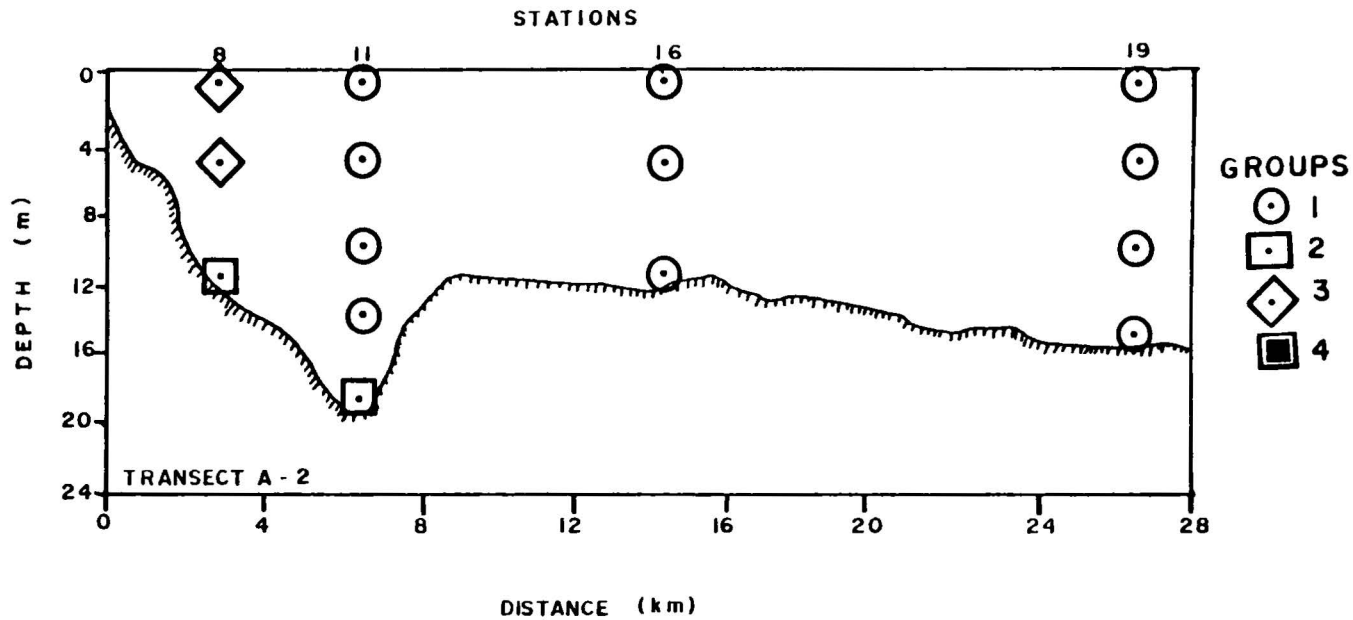


Figure 6-A2. Diagram of the station groups of transect A2 as clustered by the COMCLUS procedure.

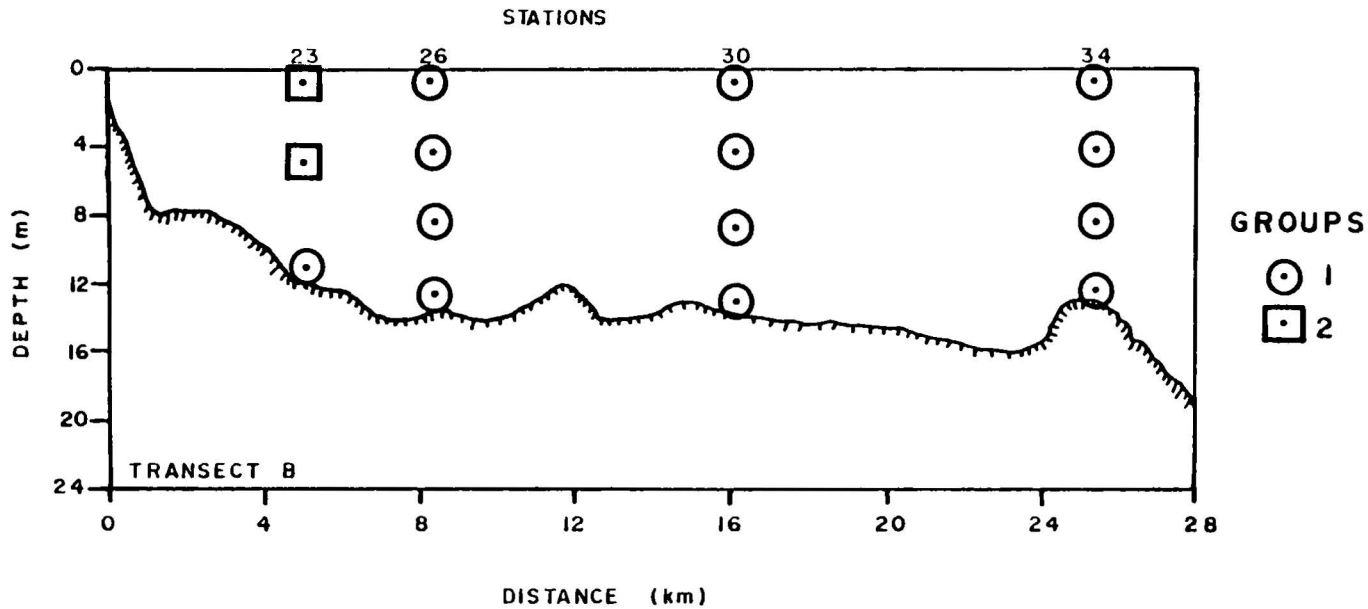


Figure 6-B. Diagram of the station groups of transect B as clustered by the COMCLUS procedure.

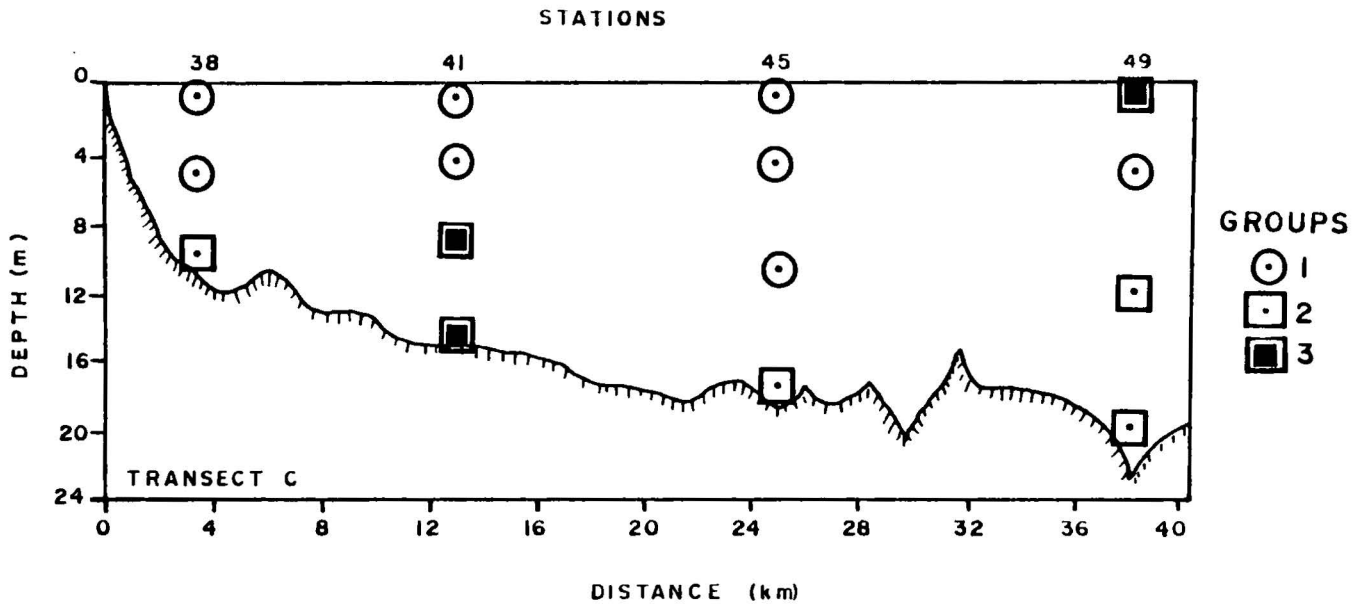


Figure 6-C. Diagram of the station groups of transect C as clustered by the COMCLUS procedure.

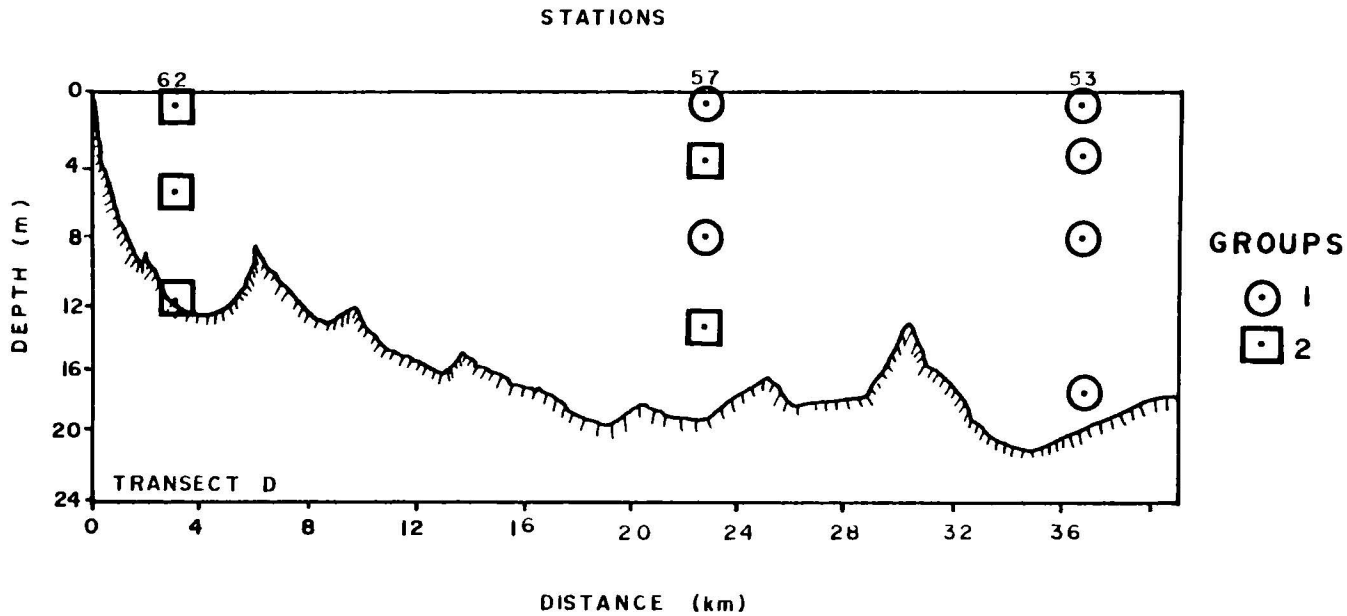


Figure 6-D. Diagram of the station groups of transect D as clustered by the COMCLUS procedure.

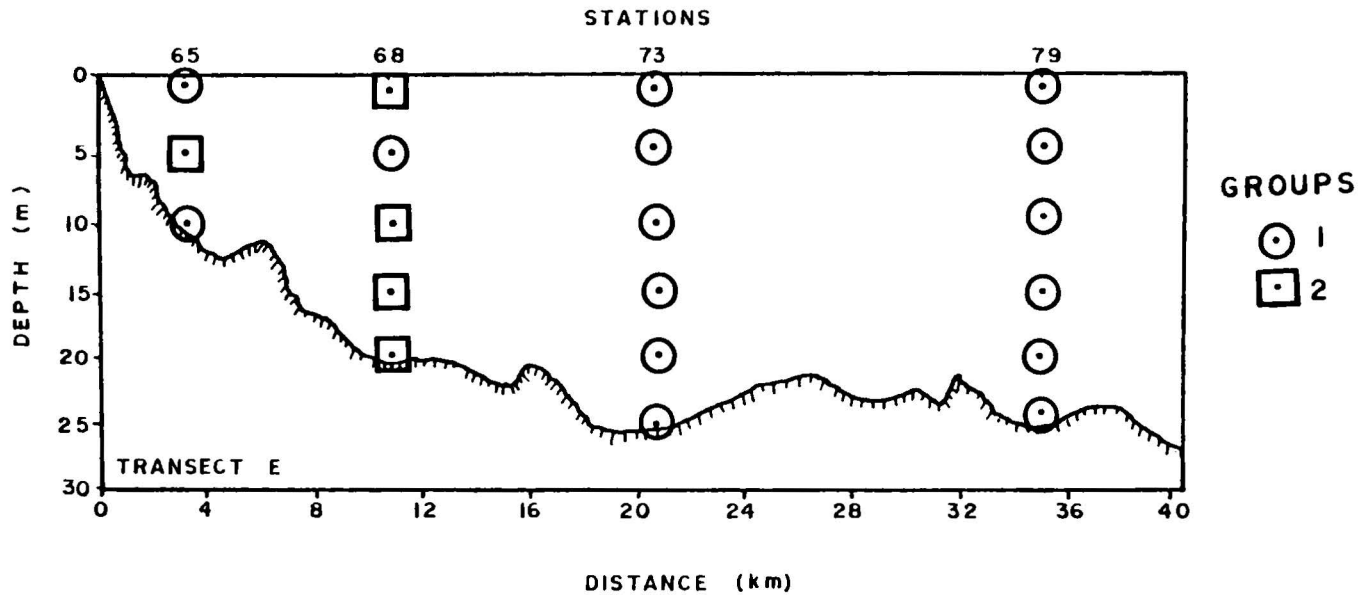


Figure 6-E. Diagram of the station groups of transect E as clustered by the COMCLUS procedure.

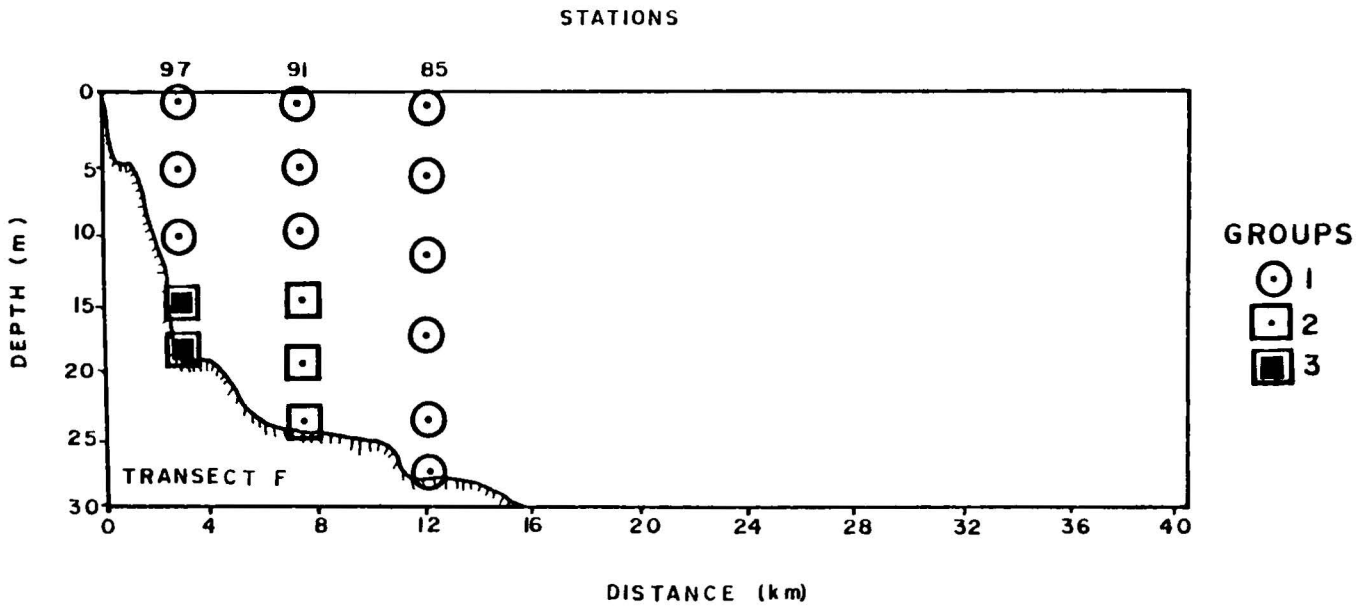


Figure 6-F. Diagram of the station groups of transect F as clustered by the COMCLUS procedure.

Table 5. List of species which were assessed to have sufficient discriminating power to sucessfully separate COMPCLUS station clusters for each transect.

TRANSECT A

Species	Between groups
Actinopytchicus senarius	1 - 3
Biddulphia alternans	1 - 3
Bidduphia rhombus	1 - 4
Chaetoceros pendulum	1 - 3
Dinophysis rotula	1 - 3
Paralia sulcata	1 - 3
Pennates < 20 microns	1 - 3
Prorocentrum balticum	1 - 3
Protoperidinium depressum	1 - 3
Rhizosolenia calcar-avis	1 - 3
Small green spheres (3-5 microns dia.)	1 - 2

TRANSECT B

Species	Between groups
Cyclotella sp.	1 - 2
Cylindrotheca closterium	1 - 2
Dinophysis fortii	1 - 2
Prorocentrum minimum	1 - 2
Skeletonema costatum	1 - 2
Small green spheres (3-5 microns dia.)	1 - 2

TRANSECT C

Species	Between groups
Ceratium massiliensis	1 - 3
Ceratium minutum	2 - 3
Dinoflagellate cysts	2 - 3
Distephanus speculum	2 - 3
Gyrosigma sp.	1 - 3
Nitzschia pungens	2 - 3
Paralia sulcata	2 - 3
Rhizosolenia calcar-avis	2 - 3
Rhizosolenia delicatula	2 - 3

Table 5. (cont.)

TRANSECT D

Species	Between groups
Ceratium lineatum	1 - 2
Ceratium macroceros	1 - 2
Rhizosolenia styliformis	1 - 2
Small green spheres (5-10 microns dia.)	1 - 2
Thalassionema nitzschiodes	1 - 2

TRANSECT E

Species	Between groups
Centrics < 20 microns dia.	1 - 2
Leptocylindrus minimus	1 - 2
Prorocentrum compressum	1 - 2
Thalassiosira nordenskioldii	1 - 2

TRANSECT F

Species	Between groups
Bacillaria paxilifer	1 - 2
Ceratium minutum	2 - 3
Coscinodiscus sp.	2 - 3
Guinardia flaccida	2 - 3
Leptocylindrus danicus	2 - 3
Pleurosigma sp.	2 - 3
Protoperidinium sp.	2 - 3
Protoperidinium steinii	2 - 3
Rhizosolenia calcar-avis	1 - 2
Thalassiosira gravida	1 - 2

the transects 15 stations. Group 2 was formed by station 23 and 24, coastal surface and sub-surface stations.

Transect C segregated into 3 station groups. Group 1 encompassed all the salinity plume stations of transect C plus two subsurface seaward stations. The remaining two groups included stations which were not geographically coherent.

Two station groups were formed from the clustering of the stations of transect D. Generally the demarcation separating the two regions was seaward versus shoreward. The middle vertical sampling series of stations included represenatives of both groups.

Transect E again generally formed an on-shore versus off-shore dichotomy to characterize the station groups. Group 1 consisted of 5 stations from the two most coastal oriented station series. The twelve seaward most stations clustered together.

Transect F stations clustered into 3 major groups. The large cluster (12 stations) comprised the surface to mid-depth stations of the inshore series and all stations of the seaward-most stations. The remaining 5 stations formed two groups that were aligned according to depth in

the water column and distance from shore.

TWO-WAY INDICATOR SPECIES ANALYSES

STATION CLUSTERS

Figure 7 (A - F) depicts the results of the dichotomous level clustering by the two-way Indicator Species Analysis (ISA). Table 6 lists the proportions of the inter-group station changes required for conformity between the two clustering method and a comparison of the clustering results to the salinity plume.

The comparison between the two clustering methods (COMPCLUS AND TWINSPAN) suggested the two methods grouped the data similarly. Changes in 27% of the COMPCLUS groups were required to attain groupings identical to the TWINSPAN cluster results. Conversly, this demonstrates 73% of the stations were grouped similar by the two methods. Due to the non-probabilistic nature of these clustering methods, this similarity in results of the two methods significantly strengthens the results of the entire analysis.

Relationships between the two clustering results and the defined salinity plume show the average transect

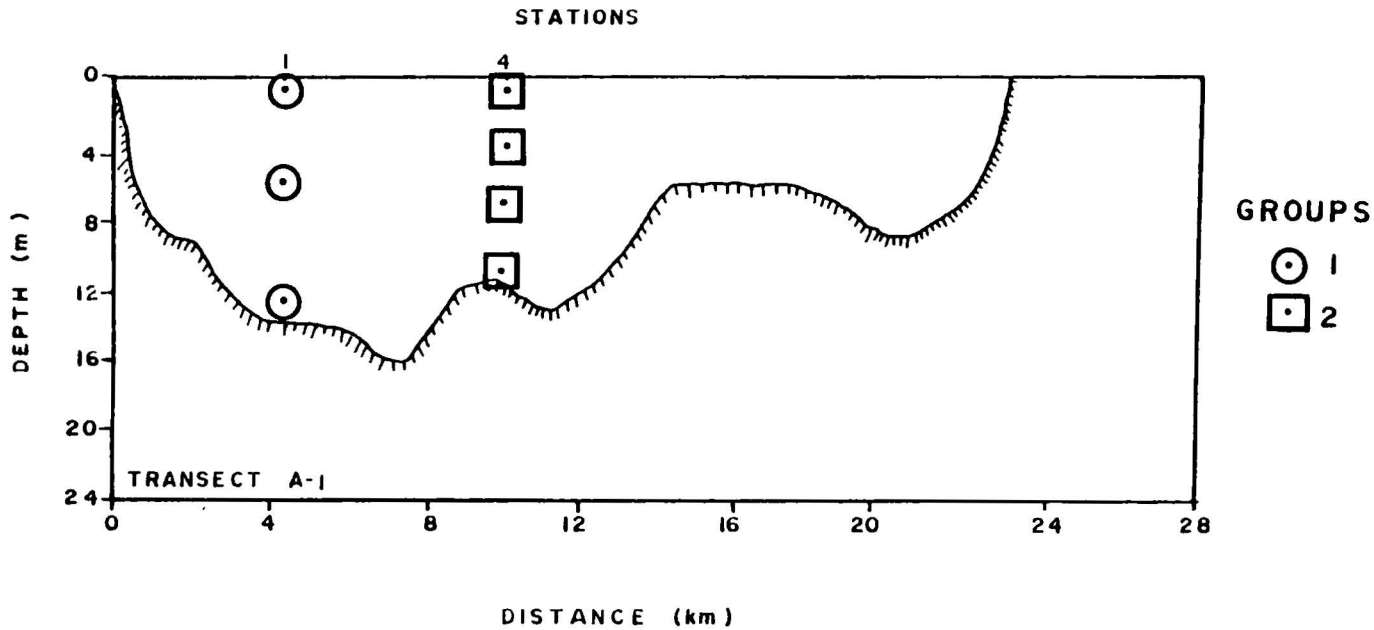


Figure 7-A1. Diagram of the station groups of transect A1 as clustered by the ISA procedure.

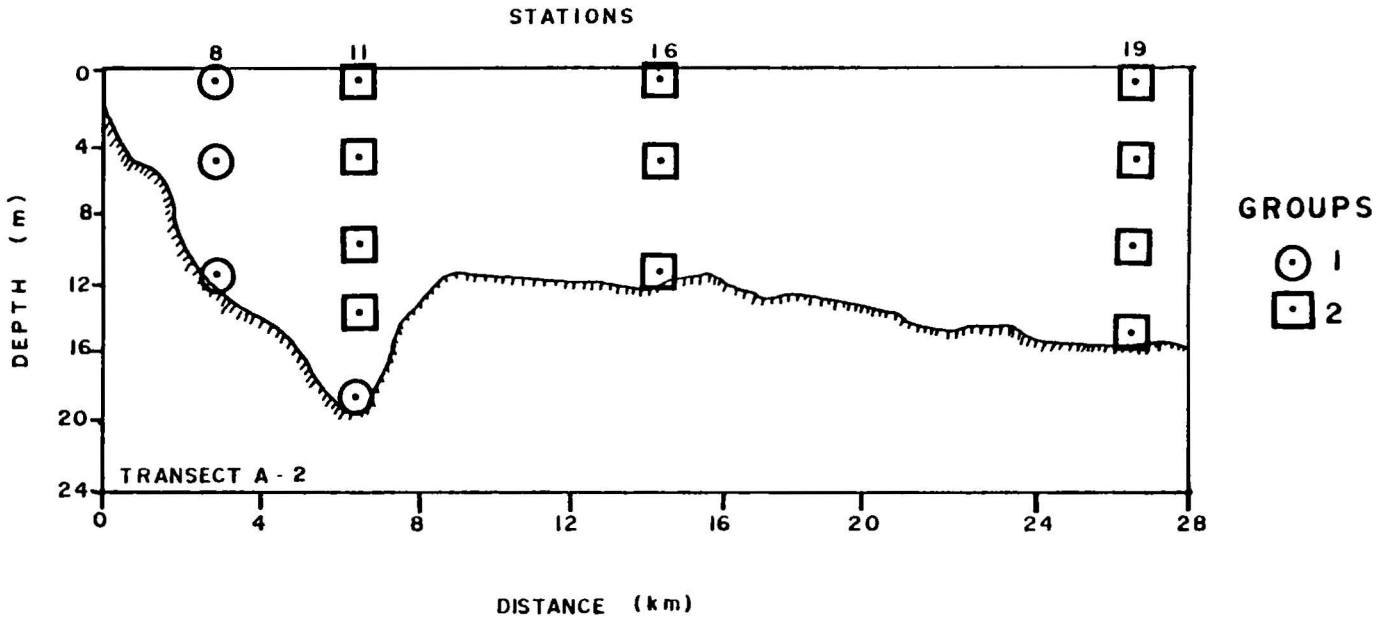


Figure 7-A2. Diagram of the station groups for transect A2 as clustered by the ISA procedure.

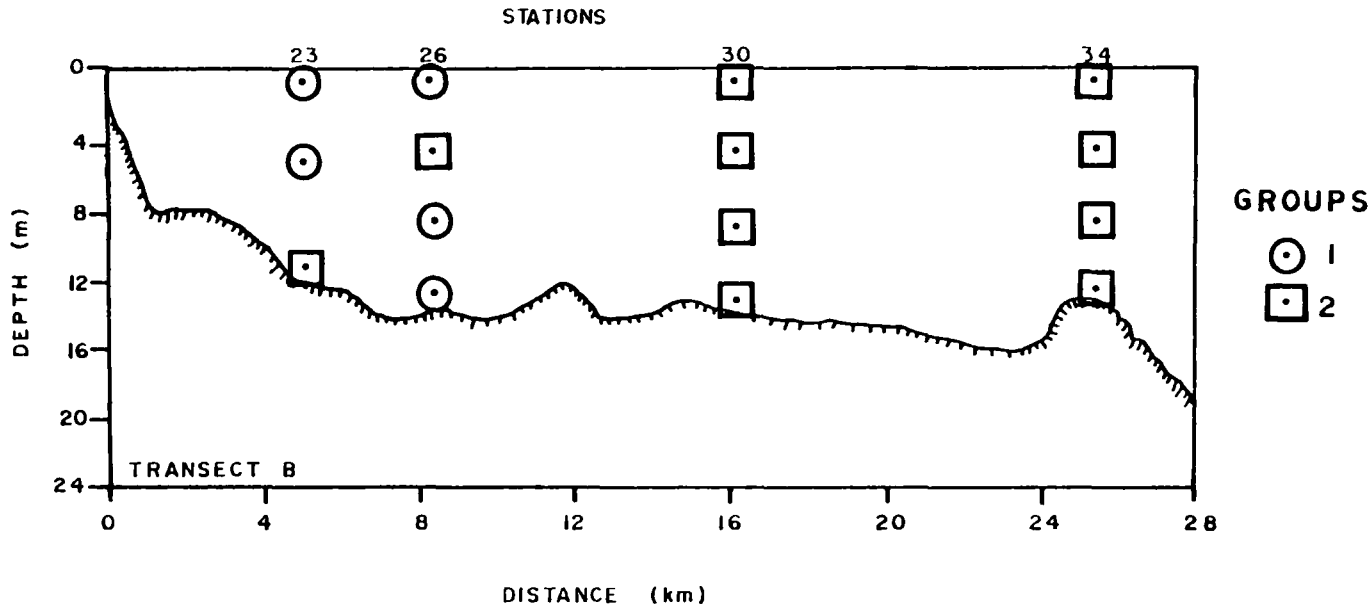


Figure 7-B. Diagram of the station groups for transect B as clustered by the ISA procedure.

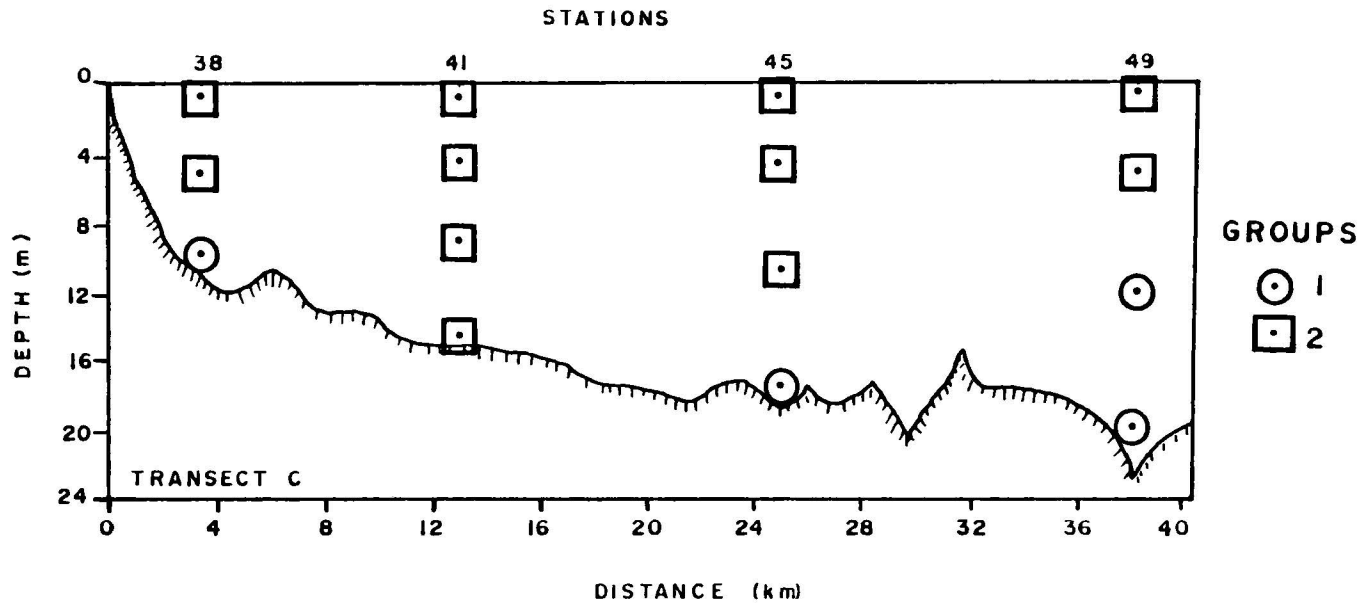


Figure 7-C. Diagram of the station groups for transect C as clustered by the ISA procedure.

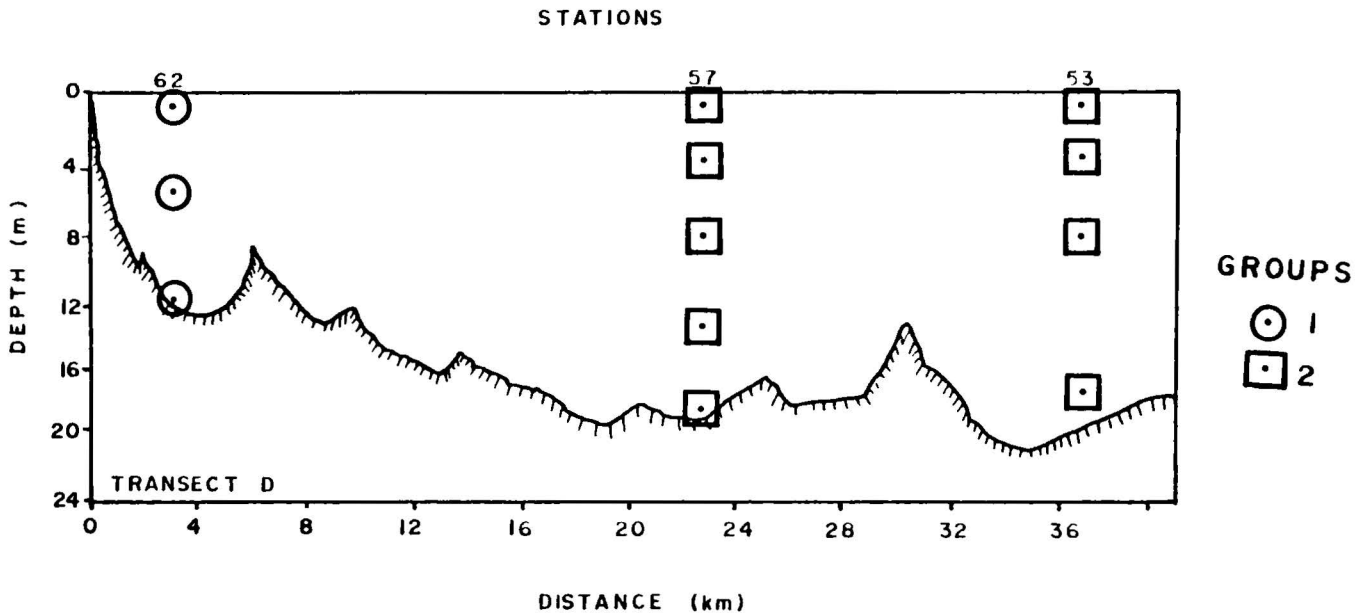


Figure 7-D. Diagram of the station groups for transect D as clustered by the ISA procedure.

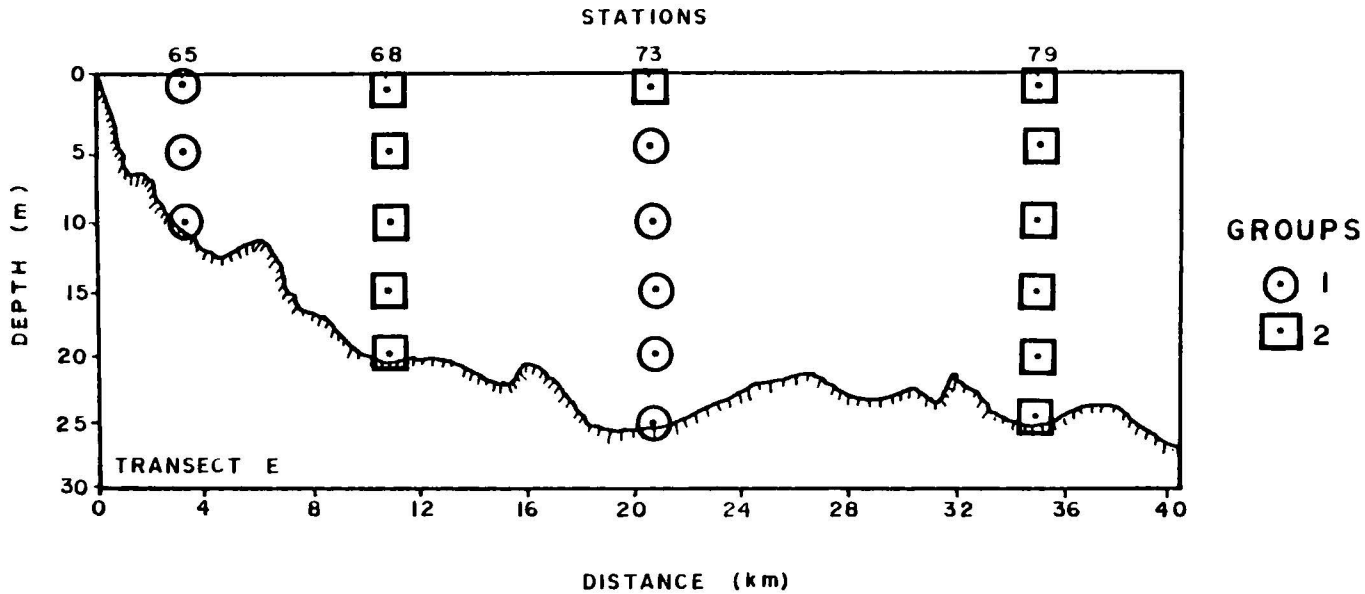


Figure 7-E. Diagram of the station groups for transect E as clustered by the ISA procedure.

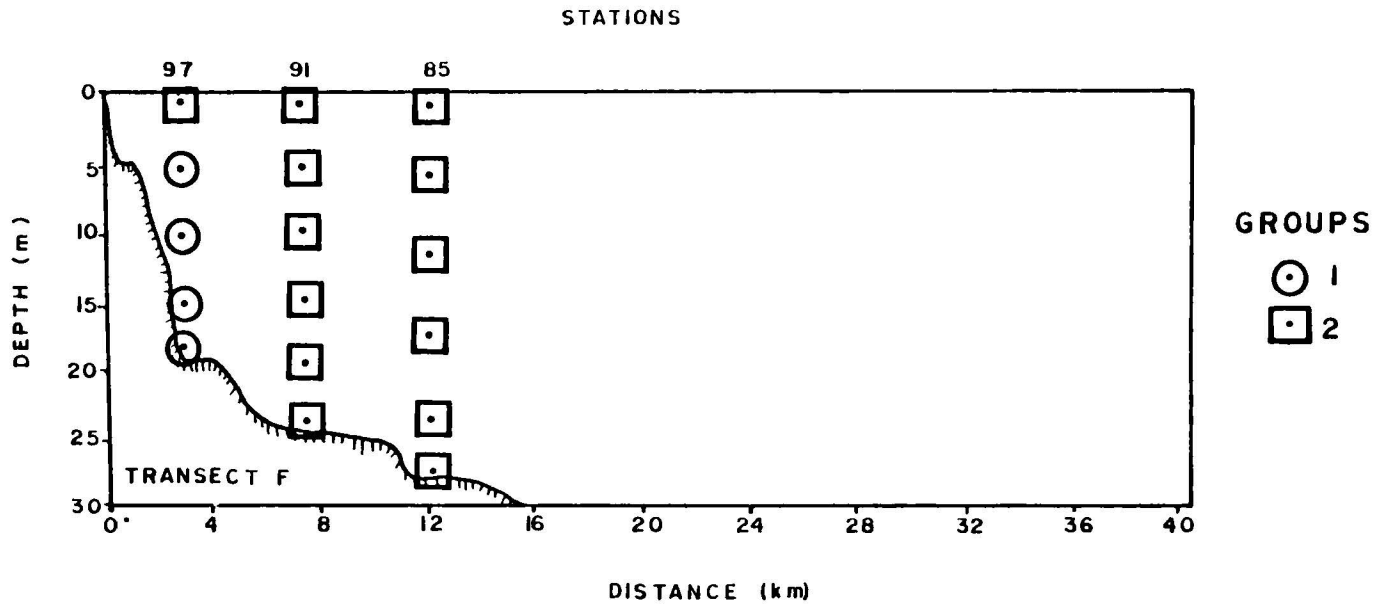


Figure 7-F. Diagram of the station groups for transect F as clustered by the ISA procedure.

deviation from conformity with the salinity plume was 31.5% and 34.5% for the two clustering methods.

Boesch's (1978) quantitative fidelity index, concentration of abundance was calculated according to the results of the Indicator Species analyses. Species groups from TWINSPAN clustering were determined using cluster levels 8 thru 15 from each transect. A combined species list from all transects for those groups having fidelities higher than 0.80 are also listed in Table 7. Each transect has groups of species having very high fidelity (greater than or equal to 0.80) for the station groups. Generally, the species groups do not form assemblages which are found at each transect. Rhizosolenia imbricata and the unidentified coccoid green cells (diameter = 3-5 microns) were the only taxa which repeat as high fidelity species for the station groups (transects A, B, and E).

Table 7. List of species having high fidelity to the coastal and off-shore station groups.

COASTAL SPECIES GROUP	OFF-SHORE SPECIES GROUP
Actinoptychus senarius	Biddulphia sinensis
Asterionella glacialis	Cerataulina pelagica
Bacillaria paxillifer	Chaetoceros pendulum
Biddulphia aurita	Coscinodiscus oculus-iridis
Chaetoceros gracile	Coscinosira polychorda
Chaetoceros peruvianum	Cylindrotheca closterium
Coscinodiscus lineatus	Eucampia zoodiacus
Guinardia flaccida	Navicula transitans
Hemiaulus hauckii	Rhizosolenia alata
Leptocylindrus danicus	Rhizosolenia fragilissima
Nitzschia gracillima	Rhizosolenia setigera
Nitzschia insignus	Rhizosolenia styliformis
Nitzschia pungens	Tabellaria fenestrata
Plagiogramma staurophorum	
Pleurosigma angulatum	Ceratium massiliense
Rhaphoneis amphiceros	Dinoflagellate cysts
Rhizosolenia alata gracillima	Dinophysis norvegica
Rhizosolenia delicatula	Dinophysis ovum
Skeletonema costatum	Dinophysis punctata
Thalassiothrix frauenfeldii	Prorocentrum minimum
Unknown centrics LT 20 microns	Protoperidinium steinii
Unknown pennates LT 20 microns	
	Ophiaster hydroides
Ceratium fusus	
Ceratium minutum	
Ceratium tripos	
Dinophysis rotundata	
Prorocentrum balticum	
Prorocentrum micans	
Protoperidinium depressum	
Ebria tripartita	
Green spherical cells LT 3 microns	
Green spherical cells between 3 and 5 microns	

ENVIRONMENTAL ORDINATION

Results of the Detrended Correspondence Analyses are presented in Table 8 and Figure 8 (A-F). In all analyses the stations were ordinated in a way similar to the Indicator Species Analyses results. Well defined groups were not evident yet minor disjunctions in the DCA axes coincided to the TWINSPAN clustering.

The average ammount of variation accounted for by the first two DCA axes was 80.23 $\pm$ 5.32%. Numerous significant ($\alpha \leq .05$) correlations between the environmental variables and the extracted DCA axes emerged from the data, but many of the correlation values were low and consequently not easily interpreted. Figure 9 displays the values of various environmental variables which were ($\alpha \leq 0.005$) strongly correlated to the DCA ordination axes. Salinity and the DCA axes from the various transects most often covaried (Rho = -0.68, Transect A; Rho = 0.865, Transect B; Rho = -0.802, Transect D). Ammonia and silicates within transect D also were highly correlated (Rho = -0.739 and Rho = -0.727 respectively) with the first and second DCA axes.

Appendix 1 contains the results of a data simulation

Table 8-A. Ranked results of DCA ordinations for transect A. Eigenvalues for each axis are also included.

	AXIS 1		AXIS 2		AXIS 3	
EIGENVALUE	0.269		0.169		0.081	
	STA	SCORE	STA	SCORE	STA	SCORE
	9	207	10	221	9	135
	8	202	7	160	18	104
	1	151	6	147	20	104
	2	146	18	137	7	89
	3	143	5	126	5	80
	10	138	22	109	11	78
	15	128	8	95	17	77
	4	86	21	90	14	71
	11	82	17	86	6	67
	7	78	12	84	15	65
	5	77	16	79	19	57
	6	72	14	78	22	55
	13	57	19	76	21	51
	12	53	20	75	16	42
	20	51	15	73	3	41
	18	49	13	70	4	41
	19	43	9	67	1	40
	16	39	4	65	10	37
	17	24	3	52	2	17
	22	16	11	29	12	11
	14	4	2	14	13	8
	21	0	1	0	8	0

Table 8 -C. Ranked results of DCA ordinations for transect C.

	AXIS 1		AXIS 2		AXIS 3	
EIGENVALUE	0.172		0.109		0.026	
	STA	SCORE	STA	SCORE	STA	SCORE
	48	157	45	141	39	112
	52	127	47	102	49	76
	51	111	50	75	40	60
	40	94	46	70	50	60
	45	93	42	60	45	52
	43	71	41	56	47	44
	50	70	48	51	41	38
	49	57	38	48	51	38
	44	53	49	44	46	33
	47	44	51	42	42	29
	46	35	52	32	43	29
	39	28	43	26	52	28
	41	27	44	10	48	21
	38	0	40	7	44	13
	42	0	39	0	38	0

Table 8 -D. Ranked results of DCA ordinations for transect D.

	AXIS 1		AXIS 2		AXIS 3	
EIGENVALUE	0.265		0.169		0.050	
	STA	SCORE	STA	SCORE	STA	SCORE
	62	168	59	167	61	110
	63	166	58	153	64	70
	64	106	57	120	63	67
	60	99	63	96	55	56
	55	53	60	79	56	49
	61	18	64	79	60	48
	57	15	62	78	59	28
	58	14	61	71	57	18
	56	10	54	66	53	8
	59	10	55	64	62	7
	53	1	53	50	58	2
	54	0	56	0	54	0

Table 8-E. Ranked results of DCA ordinations for transect E.

	AXIS 1		AXIS 2		AXIS 3	
EIGENVALUE	0.232		0.132		0.086	
	STA	SCORE	STA	SCORE	STA	SCORE
	76	162	79	205	73	162
	75	159	80	185	74	139
	65	151	74	148	68	108
	78	146	81	141	78	105
	77	125	82	118	70	84
	74	119	70	115	75	81
	67	107	78	106	76	77
	66	88	75	99	71	72
	83	86	69	94	72	64
	79	59	76	84	66	61
	80	54	77	82	77	61
	84	54	72	74	79	59
	73	53	66	70	67	51
	81	52	67	68	80	50
	82	46	68	68	84	39
	68	27	71	52	83	32
	69	20	65	48	69	30
	70	15	73	45	82	20
	71	10	83	25	65	11
	72	0	84	0	81	0

Table 8-F. Ranked results of DCA ordinations for transect F.

	AXIS 1		AXIS 2		AXIS 3	
EIGENVALUE	0.318		0.132		0.092	
	STA	SCORE	STA	SCORE	STA	SCORE
	101	200	88	147	90	165
	100	186	89	134	101	129
	99	181	85	103	96	122
	98	128	87	93	89	115
	95	79	100	83	97	100
	92	60	101	77	87	94
	97	59	93	76	100	89
	88	54	94	62	88	88
	96	54	90	58	99	88
	89	49	99	49	91	85
	94	37	95	48	85	81
	90	35	91	33	95	79
	85	28	98	31	98	70
	86	26	86	30	93	63
	87	10	97	23	86	38
	93	10	92	10	94	33
	91	0	96	0	92	0

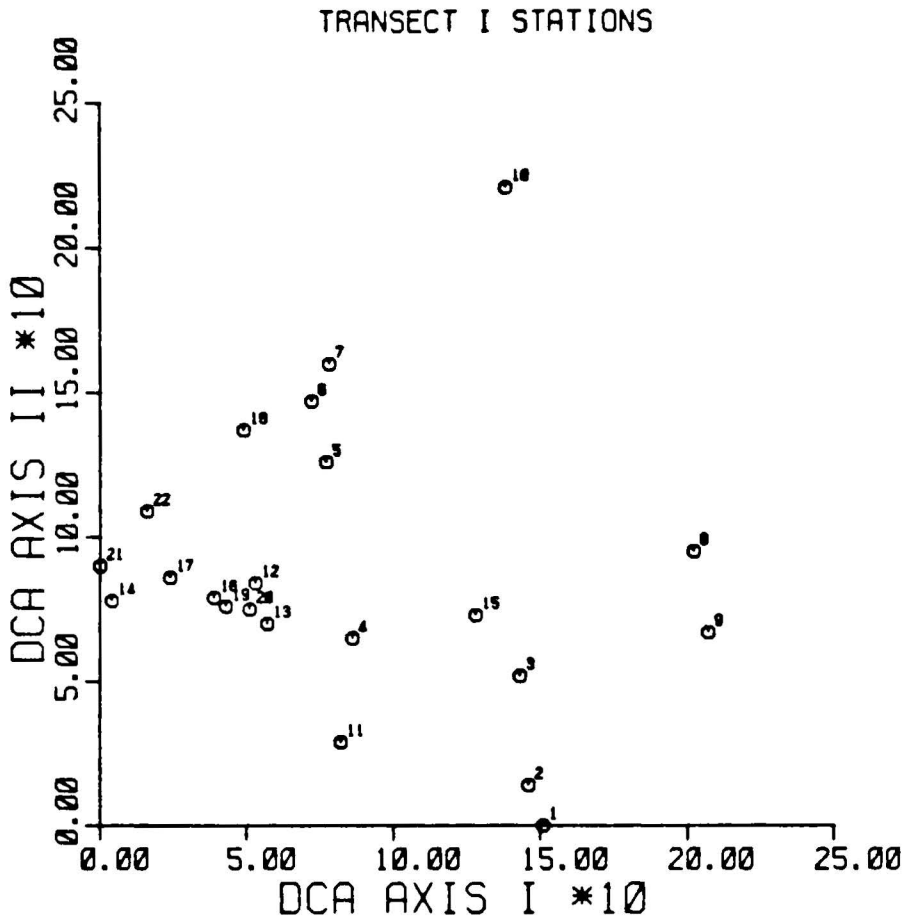


Figure 8A. Scattergram of the two dimensional results of the DCA for transect A.

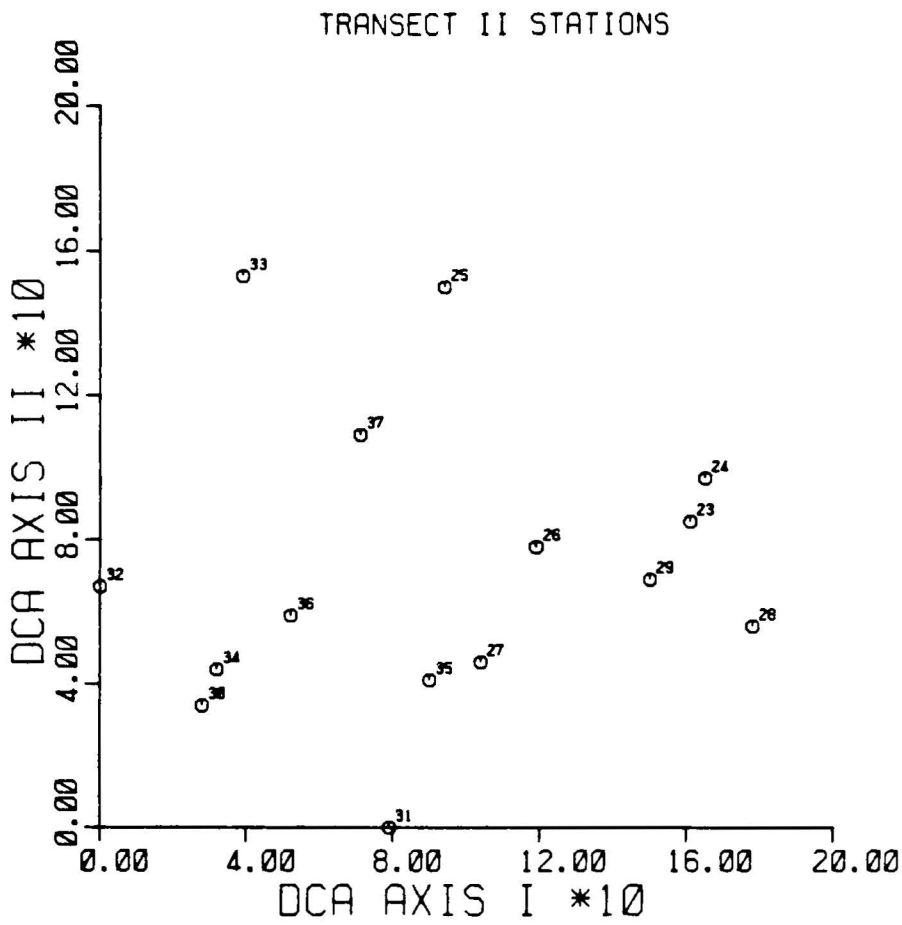


Figure 8B. Scattergram of the two dimensional results of the DCA for transect B.

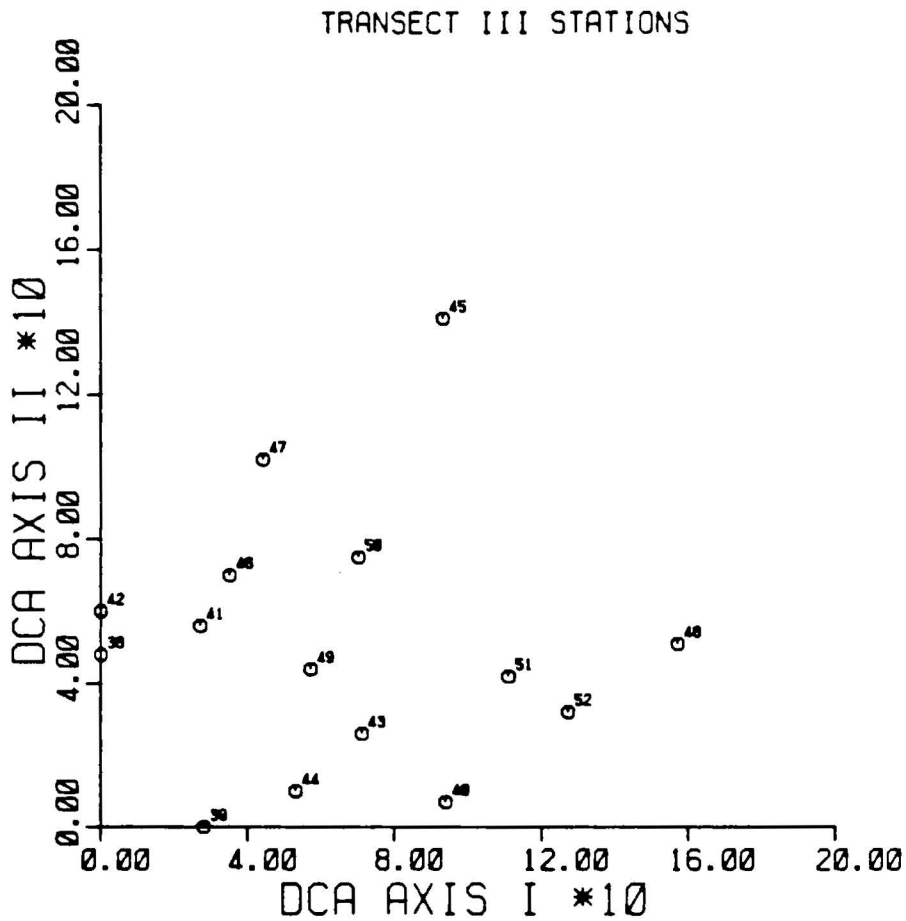


Figure 8C. Scattergram of the two dimensional results of the DCA for transect C.

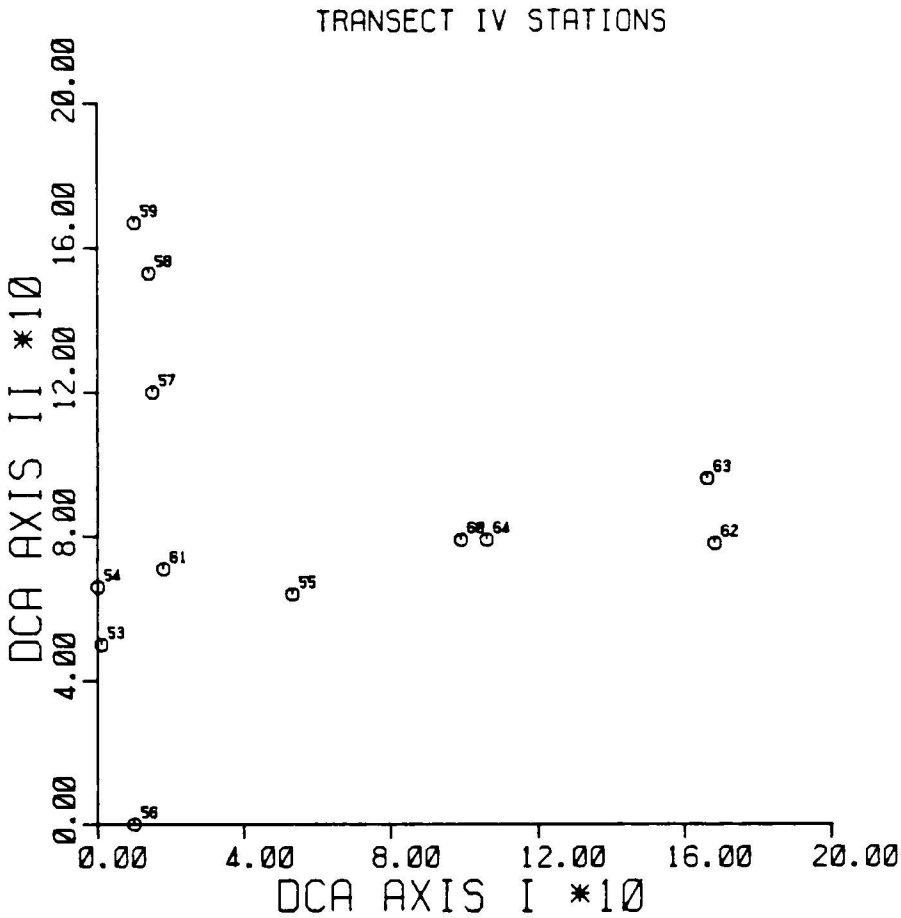


Figure 8D. Scattergram of the two dimensional results of the DCA for transect D.

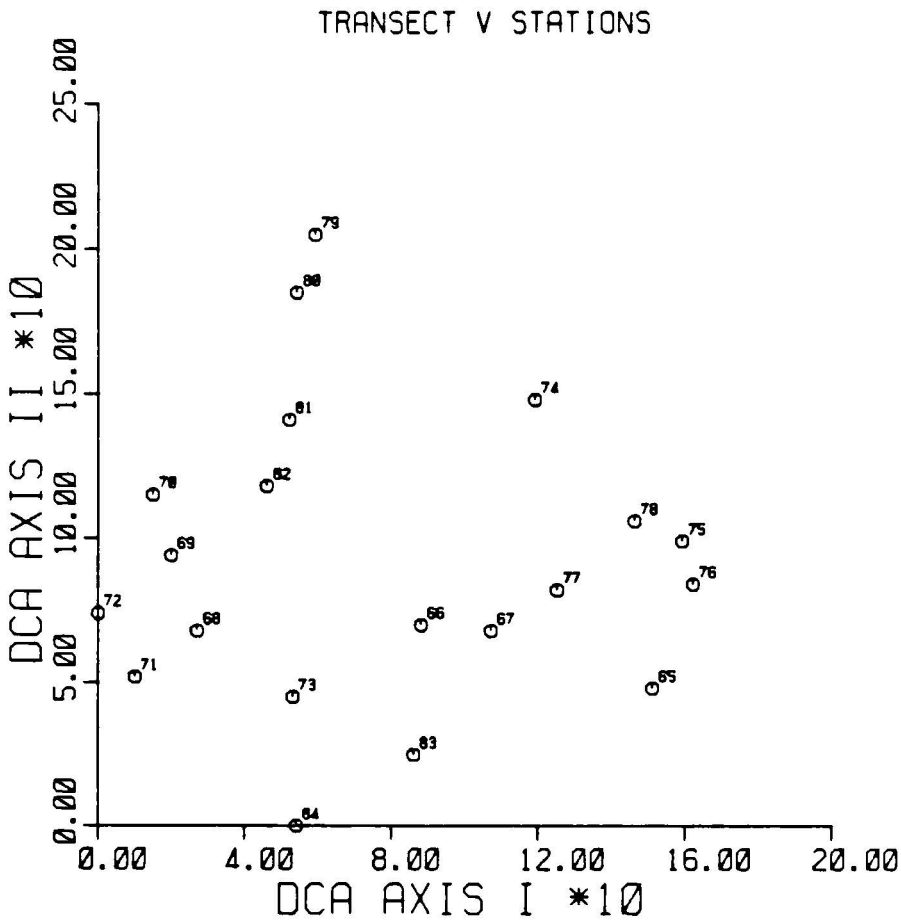


Figure 8E. Scattergram of the two dimensional results of the DCA for transect E.

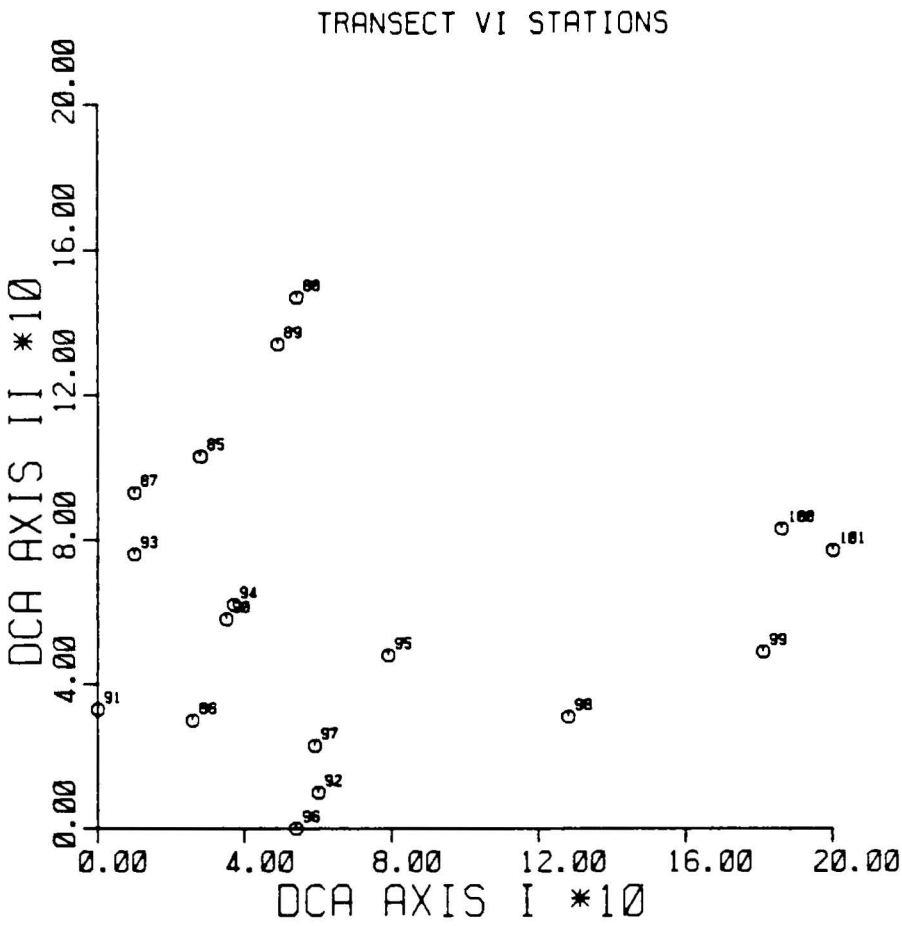


Figure 8F. Scattergram of the two dimensional results of the DCA for transect F.

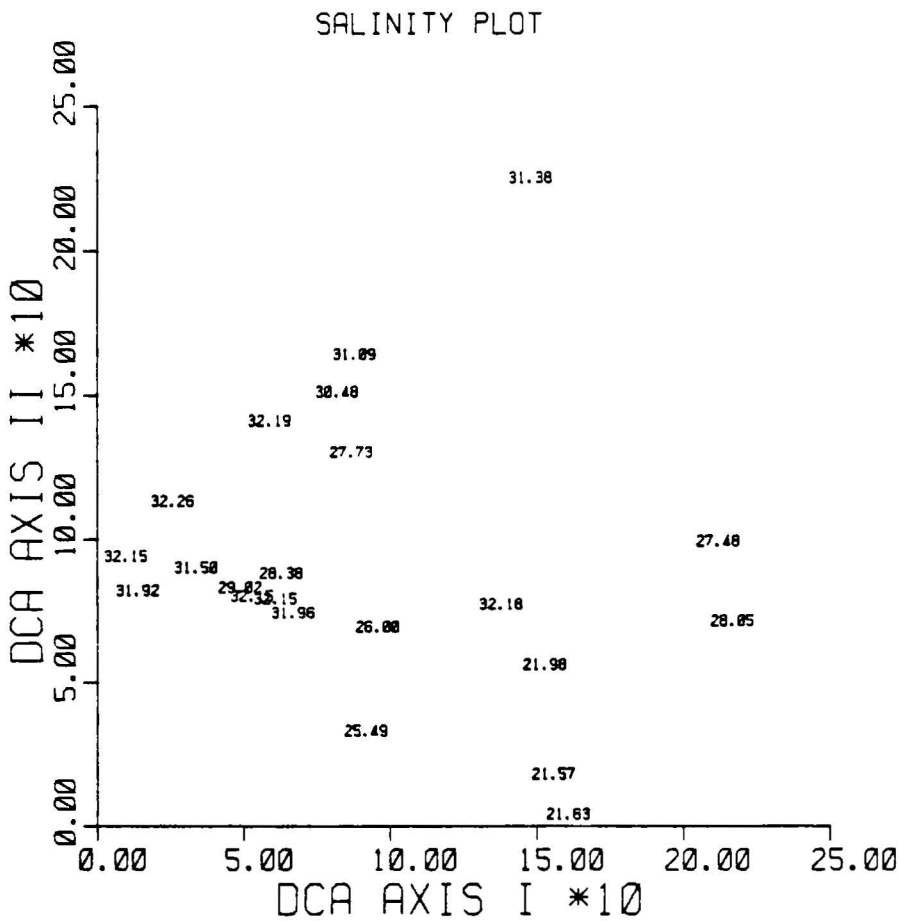


Figure 9A. Scattergram of the two dimensional results of the DCA with salinity (ppt) displayed for transect A.

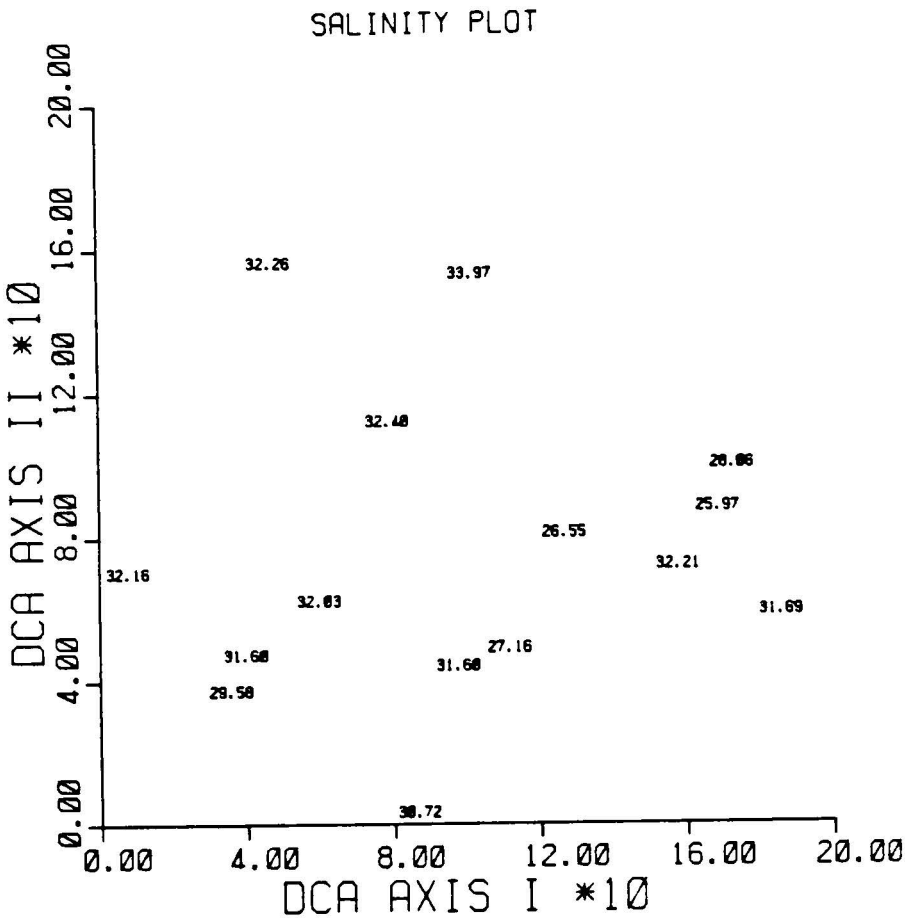


Figure 9B. Scattergram of the two dimensional results of the DCA with salinity (ppt) displayed for transect B.

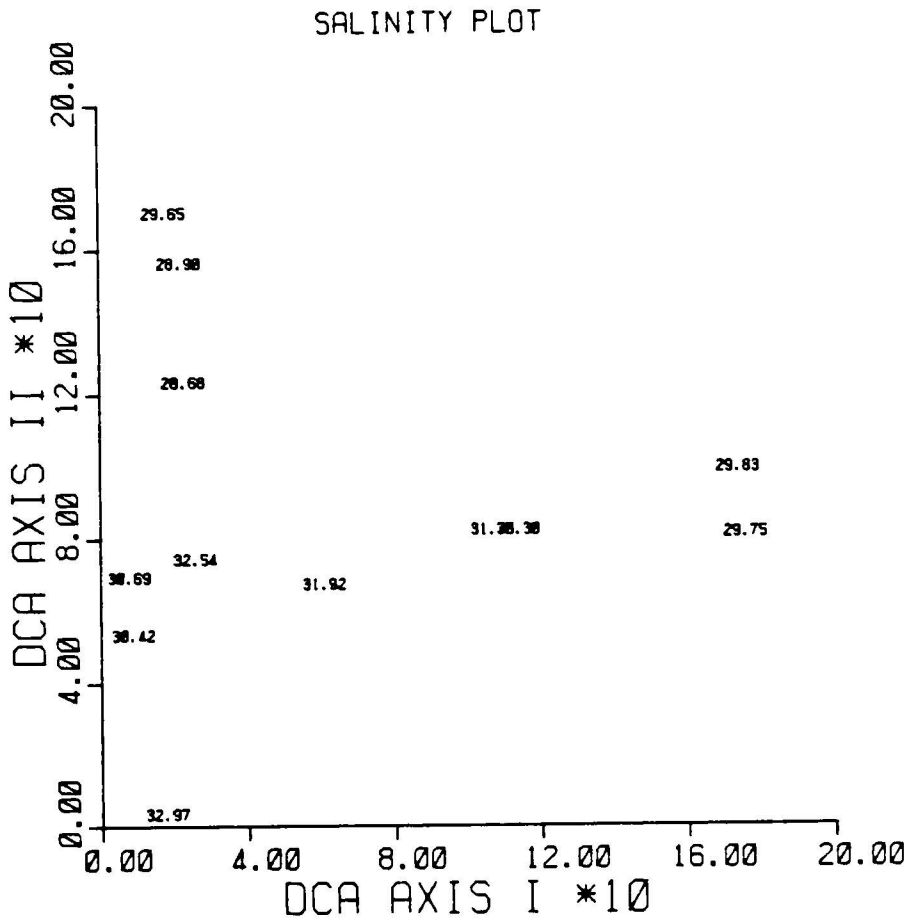


Figure 9C. Scattergram of the two dimensional results of the DCA with salinity (ppt) displayed for transect D.

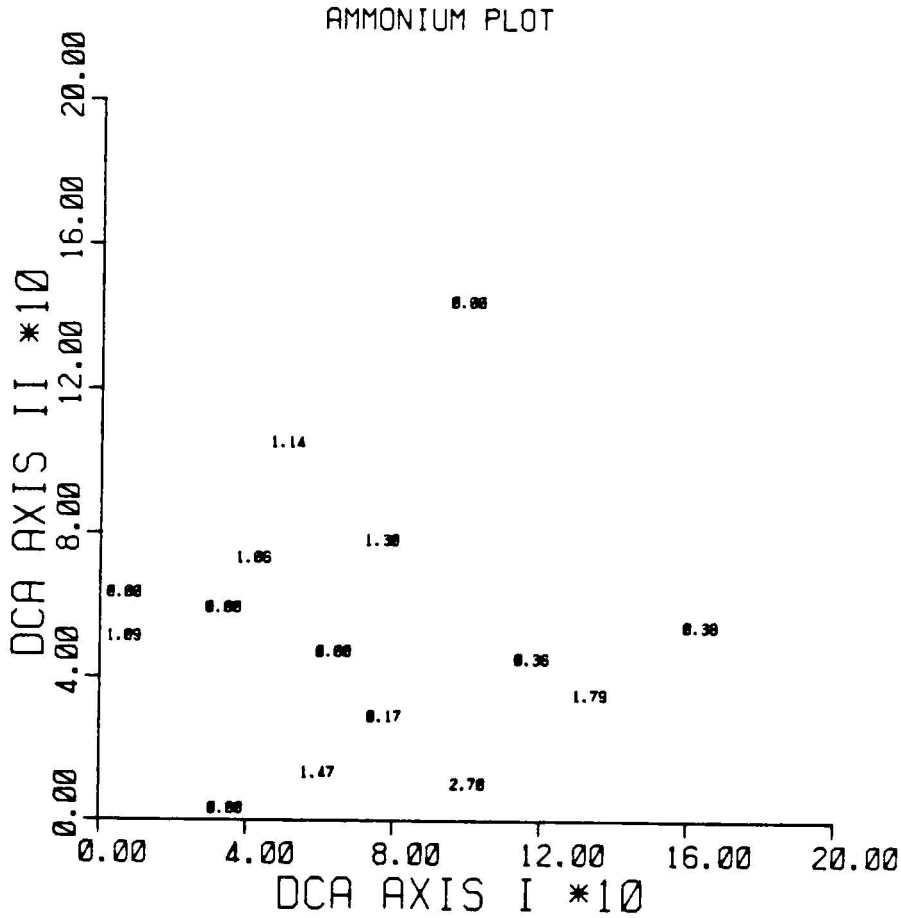


Figure 9D. Scattergram of the two dimensional results of the DCA with ammonium (mmoles/l) displayed for transect C.

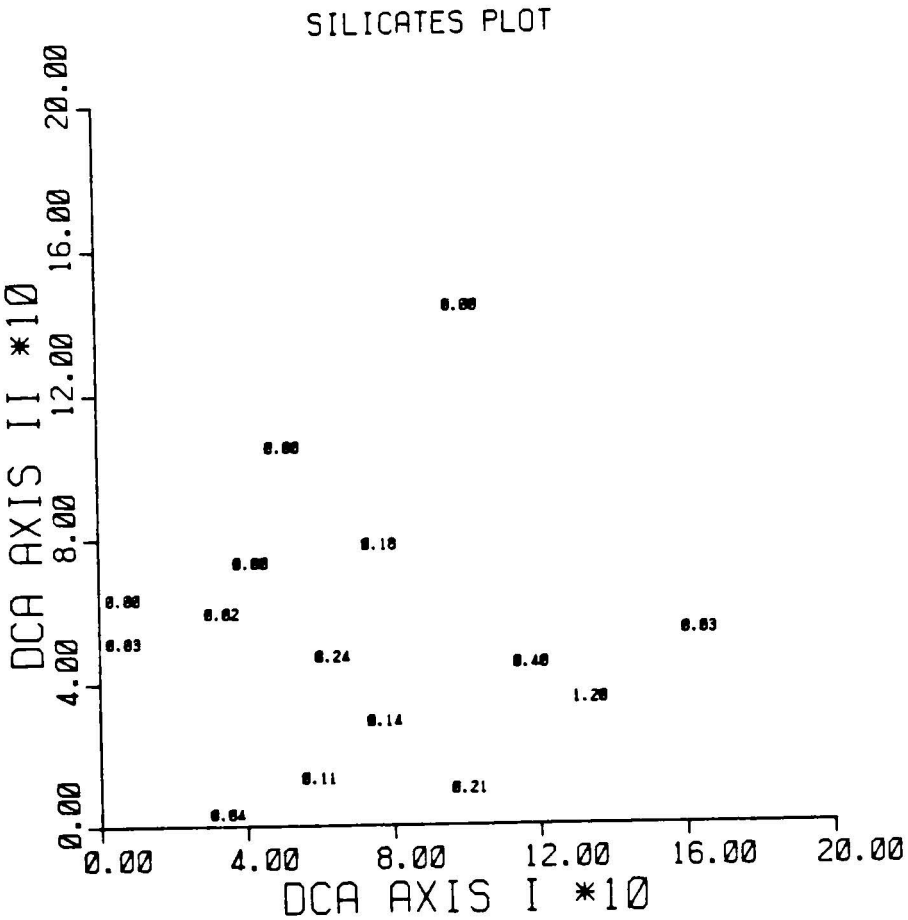


Figure 9E. Scattergram of the two dimensional results of the DCA with silicates (mmoles/l) displayed for transect C.

experiment designed to test the validity of the ordination techniques used. The results of the simulation experiments showed the DCA ordination method to be quite sensitive to the noise content of the data matrices.

DISCRIMINANT ANALYSES

Table 9 lists those species which contributed to the discriminant functions which were designed to differentiate between the plume and non-plume stations. Four of the transects (A,C,D,E) had sufficient variation by their represenative species to result in 100% correct classification into the low salinity plume and non-plume stations. Several species were discriminating species at more than one transect. A group of three diatoms (Pleurosigma sp., Nitzschia pungens and Thalassiosira gravida) were shown to be discriminating species at adjacent transects (C,D).

Transects B and F were characterized as having phytoplankton species assemblages which did not relate to the low salinity plume distribution. This was suggested by the failure of the discriminant analyses because the individual species within these transects did not vary in their distributions in a systematic manner which related

to the plume and non-plume areas.

Table 9. List of species which were assessed to have sufficient discriminating power to sucessfully separate the low-salinity plume and non-plume stations for each transect.

TRANSECT A

Species

Asterionella glacialis
Cerataulina pelagicus
Ceratium macroceros
Ceratium minimum
Chaetoceros gracilis
Chaetoceros pendulum
Coscinodiscus lineatum
Dinophysis punctata
Dinophysis rotundatum
Distephanus speculum
Gymnodinium brevis
Protoperidinium sp.
Rhizosolenia delicatula
Skeletonema costatum

TRANSECT B

Analysis Failed

TRANSECT C

Species

Ceratium fusus
Ceratium minutum
Chaetoceros atlanticum
Cylindrotheca closterium
Dinophysis fortii
Guinardia flaccida
Nitzschia pungens
Pleurosigma sp.
Skeletonema costatum
Small green spheres (5-10 microns dia.)
Thalassiosira gravida

Table 9. (cont.)

TRANSECT D

Species

Cryptomonas sp.
Dinophysis norvegica
Distephanus speculum
Nitzschia pungens
Pleurosigma sp.
Thalassionema nitzschiodes
Thalassiosira gravida

TRANSECT E

Species

Ceratium massiliensis
Chaetoceros gracilis
Chroomonas sp.
Dinophysis fortii
Nitzschia sp.
Nitzschia spathulata
Rhizosolenia calcar-avis

TRANSECT F

Analysis Falied

DISCUSSION

CHESAPEAKE BAY PLUME

During the 1980 mid-June sampling period the Chesapeake Bay plume was evident within the southern portion of the Chesapeake Bight. The distribution of the plume followed closely the theoretical distribution based on density differences suggested by Ruzecki (1981). This existence offers evidence to the near permanent nature of the plume as the sampling period coincided with extremely low freshwater discharges into the Chesapeake Bay. Specifically, the month of June, 1980, represented a 39% decrease in the monthly average of freshwater discharge into the Bay as compared to June monthly averages from 1929 to 1966 (Ruzecki, 1981).

The plume, emerging from a nutrient rich and undoubtedly polluted estuary, offers a transport mechanism for many materials. By tracing the distribution of the materials, the plume may be delineated relative to the surrounding aquatic environment in space and time. All materials moved out of the Bay may be classified, according to their constancy within the environment, as either conservative or non-conservative materials. Of the variables measured during the study, only temperature and

salinity are classified as conservative. The other variables (both biotic and abiotic) are dynamic in that they may react chemically, and grow (increase) or degrade and die (decrease) within the dynamics of the plume. The classification of the materials relates to the ability to use them effectively as tracers of the plume phenomonon.

PHYTOPLANKTON ECOLOGY

The total phytoplankton biomass was measured using two methods (total cell volumes and chlorophyll-a). While the two measures were not highly correlated, the dual measurement was believed to give a more accurate assessment of the phytoplankton distributions. Both phytoplankton biomass measurements proved not to be significantly different relative to the salinity plume and the non-plume waters.

The four multivariate methods used to define the phytoplankton species shifts generally concurred in their results. The ordination and classification methods showed consistently that the species distributions along the transects were not homogeneous. The station groups defined within each transect should not, however, be

considered distinct holistic entities in species multidimensional space. The discriminant analyses, which consistently failed when considering all species in the analysis, suggested that the community concept for these station groups not be supported. Invariably, to discriminate the station groups within the transects only a portion of the species were used. These species were not similar from transect to transect so any real space coherence evidenced in the station groupings was not related to coherence in phytoplankton species distributions in real space. This change in discriminating species along the plume may reflect the complexity of environmental changes which are ongoing.

The station groupings within the species multivariate space for each transect did to some extent correspond with the salinity plume. The species clusters and ordination results of the six transects did show some spatial continuity, aligning with an onshore-offshore pattern that could be interpreted as a result of the salinity plume. This interpretation may be reasonable considering the multiplicity of confounding factors which may have distorted the data.

The fidelity analyses results revealed the degree of

faithfullness groups of species had for the onshore and offshore station groups. From the four transects which had this pattern (A,B,E,F), two groups of species for the coastal (34) and offshore (23) stations were revealed (Table 6). These groups contained most of the important discriminator species as identified by the discriminant analysis. The species groups were formed by those species which were faithful to their respective station groups to the extent that 80% of their biomass was found within these stations. Diatoms accounted for 68% of the coastal station species and 56% of the offshore species. Dinoflagellates represented 20% of the coastal species and 35% in the offshore stations.

Greater representation of summer lower Bay phytoplankton species were noted for the coastal oriented stations as revealed by comparison with the summer phytoplankton assemblages of Marshall (1980) for the lower Bay. For the coastal stations 47% of the highly faithful species were observed in summer phytoplankton samples from Marshall's study. For the offshore group only 26% of the faithful species were found in both studies.

The historical habitat distributions of the two groups (coastal and offshore) were generally the same. The majority of species from both groups have been

classified as neritic and oceanic temperate forms (Wood, 1968; Hendey, 1976; Cupp, 1943; Dodge, 1975). A difference between the two groups was three littoral temperate species having high fidelity to the coastal stations. These species were considered to be tycho-planktonic.

COMMENT ON ENVIRONMENTAL ORDINATION FAILURE

The present study, similar to other recent studies, has failed to ordinate phytoplankton community data to the desired scale of environment variability. Allen (1977) has proposed an explanation to account for this inability. The problem is one of scale. He defined scale to be "the phase over which signals are integrated to give messages". As an example he offers the scientist's pH probe as it measures the hydrogen ion concentraton of an aquatic environment. The most sensitive pH probe available may have precision capabilities well outside the ranges important to phytoplankton growth. As such, important hydrogen ion concentration changes (to the growth of phytoplankton) may go completely unnoticed.

Relative to the present study, scale problems may possibly be a source of the inability to relate

phytoplankton population shifts to the environment. Other controlling factors which could effect phytoplankton population dynamics are light, and grazing effects by zooplankters. Light data were available but because some of the stations were sampled in the dark the use of this parameter was abandoned.

Alternative reasons for the failure of the environmental ordinations may be the lack of the phytoplankton communities to be in equilibrium with their environments. Under such conditions, successfull environmental ordinations are unlikely.

NUMERICAL SUMMARY

1. During the sampling period, which coincided with atypically low freshwater drainage into the Bay, the salinity plume within the southern portion of the Chesapeake Bight was evident. This may suggest the near permanent nature of the plume in the continental shelf area.

2. Total phytoplankton biomass estimates were not statistically different within the stations which comprised the salinity plume stations and the non-plume areas.

3. Several multivariate analyses of the volumetric phytoplankton data demonstrated that species assemblages did moderately align to the observed salinity plume. The alignment was in both real and environmental space.

4. Environmental ordination failed to consistently order the stations along known environmental gradients other than the salinity gradients. Small scale (spatial) variation within the species population data did not strongly co-vary with the changes in the environmental

data.

5. The species volumetric data was very different from the normally used cell abundance data. The volumetric weighting of species abundances drastically changed the species contributions to each station's total composition.

6. Disjunctions within the multivariate species space showed assemblages to be different within the coastal and neritic waters. Different species having high fidelities to the coastal and offshore stations were defined. The coastal stations had a higher percentage of species which were found in previous studies of the lower Chesapeake Bay relative to the offshore waters.

7. The two phytoplankton groups (coastal and offshore) generally did not differ according to the classification of their respective species as to their historical habitat distributions. The species of the study area were mainly temperate neritic and oceanic species.

8. Problems of scale and species equilibrium with their environment were proposed to explain the inability to successfully relate the environment to the

phytoplankton community structure shifts.

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APPENDIX I

DCA PERFORMANCE ON SIMULATED COENOPLANE DATA

To ascertain the utility of the DCA ordinations used here, the following trials were executed to check the performance of DCA on data of known characteristics. The data, a 2-dimensional species distributional pattern or "coenoplane" was generated using the program and concepts of Gauch and Whitaker (1976). A 5 X 8 series of stations was simulated with a distribution of species having a spatial diversity similar in complexity to the most complex transect data observed during the present study (transect E, according to the initial DCA ordination).

For these 40 evenly spaced stations, 50 species distributions were simulated to be randomly spaced within the sampling grid. Each distribution was designed to be log-normal and have different standard deviations. The angles of rotation were assigned to be random, reflecting the low correlation between the axes of major variation and the measured environmental variables (of the real data).

The diversity along the two axes were 1.4 half-changes X 1.1 half-changes for axis I and II

respectively. These values were determined to be characteristic of the complexity of transect E, as assessed by the previous DCA ordinations.

Figure 10 shows the initial spatial interrelationships of the 5 X 8 sampling grid. This plot is similar to a simple presentation of the station locations within a study area on a map. Figure 11 presents the 2-dimensional results of the DCA ordination of the coenoplane data, with no noise interference (e.g. no factors interferred with the collection of the data which represented the parametric distributions of the species on the plane). Minimal distortion and a slight rotation of the overall station pattern with respect to the axes were the results.

Figure 12 displays the 2-dimensional results of the same data base having a noise level similar to real data sampled from a terrestrial situation. Noise levels for phytoplankton data have not yet been estimated but suggestions that these values would be quite low have been expressed (Matta, personnal communication), owing to the apparent ease of sampling the aquatic medium for phytoplankton sized cells. The distortion in this plot may demonstrate the combined effects of low beta-diversity and the noise levels. Other trials having greater noise

levels were performed and increased distortion was observed.

The DCA ordinations of the simulated data show DCA to effectively order data of complexity similar to that found in the present study if the noise level is low. Variations in the sampling noise appear to be important in causing distortion in the ordinations.

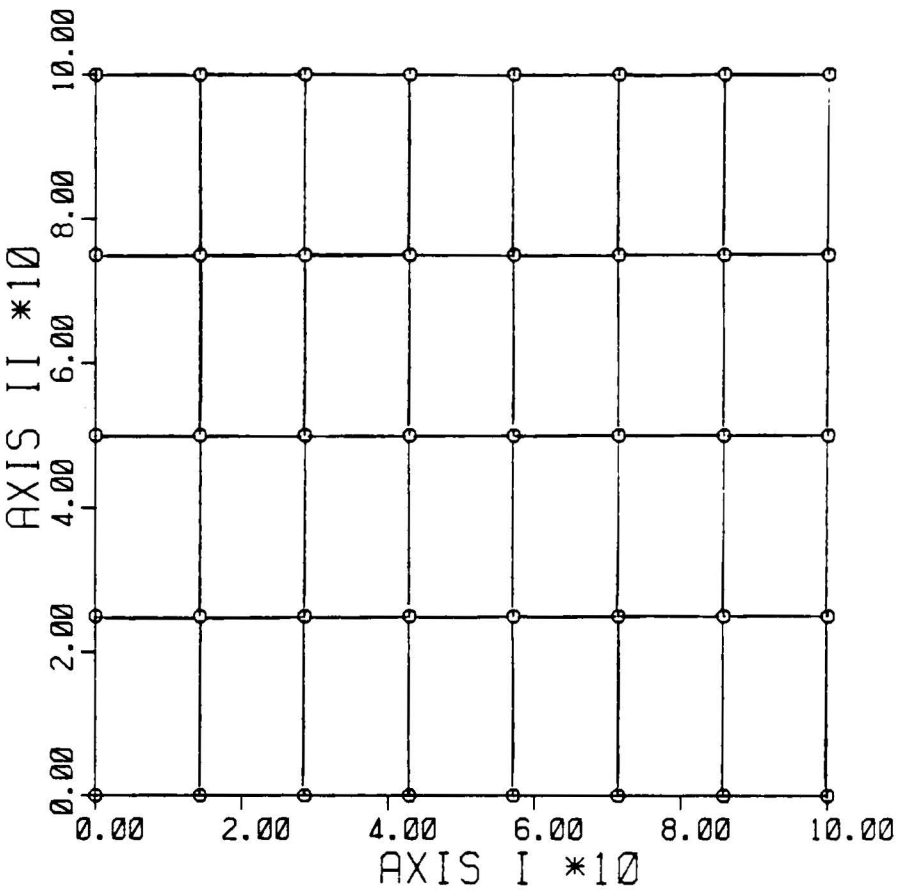

Figure 10. Scattergram of the distribution of sampling stations for the coenoplane trial.

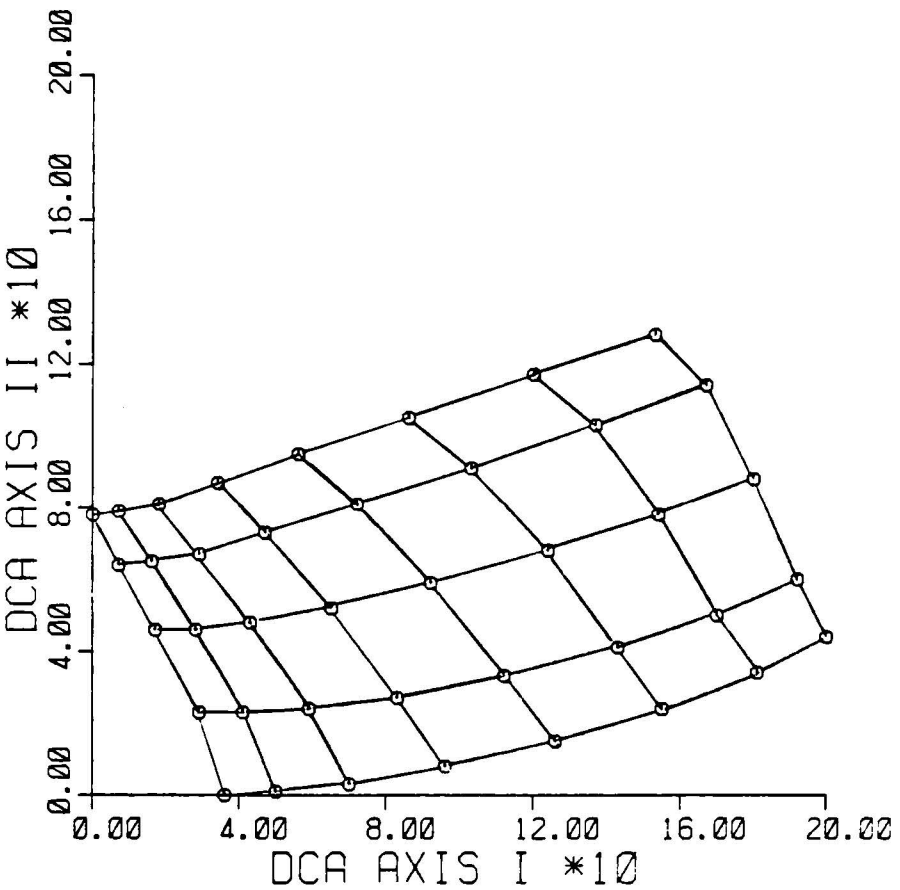

Figure 11. Scattergram of the two dimensional results of the DCA for the simulated data with no noise.

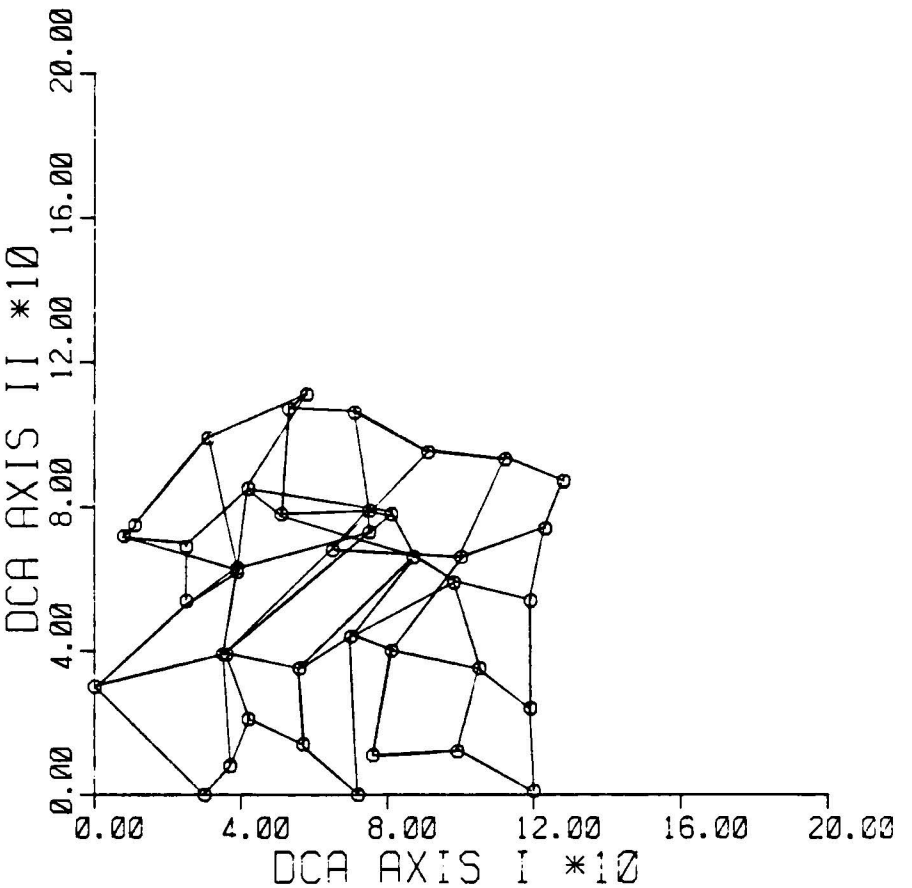

Figure 12. Scattergram of the two dimensional results of the DCA for the simulated data with noise introduced.