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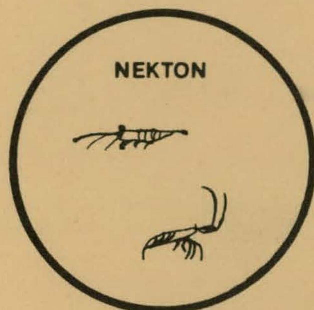

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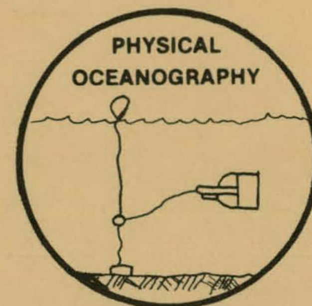

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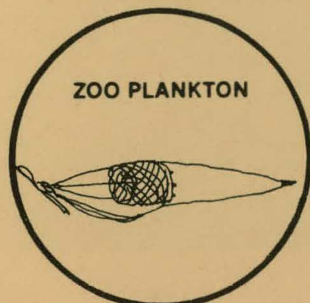

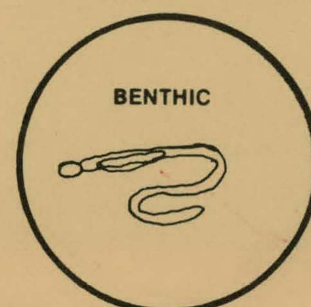

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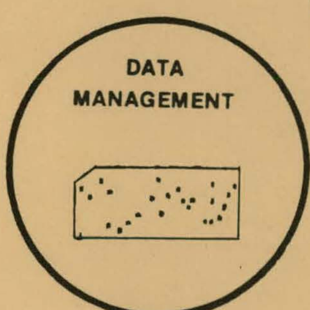

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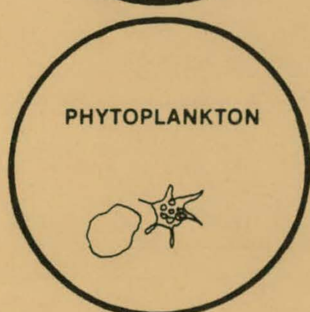

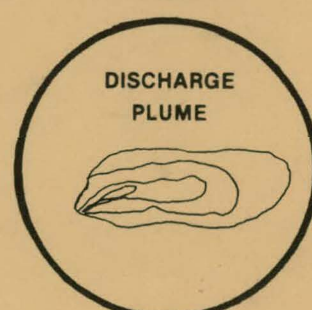

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EVALUATION OF BRINE DISPOSAL FROM THE BRYAN MOUND SITE OF THE STRATEGIC PETROLEUM RESERVE PROGRAM

Final Report of Predisposal Studies

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ABSTRACT

Texas A & M University scientists and engineers began a predisposal study of the environmental conditions of the coastal waters off Freeport, Texas in September 1977. These waters are the site for the discharge of brine from the Bryan Mound site of the Department of Energy's Strategic Petroleum Reserve Program. A buried pipeline has been laid from Bryan Mound to a location 12.5 statute miles (20 km) offshore, and the last 3060 feet (933 m) of the pipeline is a diffuser through which brine is being discharged at a rate up to a maximum of 680,000 barrels per day. The brine discharge falls to the bottom and spreads over the sea floor and is advected away by the bottom currents and diluted by turbulent diffusion.

The purpose of this report is to describe the environmental conditions found by the principal investigators during the predisposal study conducted from September 1977 through February 1980 prior to the start of brine discharge in March 1980. The major areas of investigation are physical oceanography, analysis of the discharge plume, water and sediment quality, nekton, benthos, phytoplankton, zooplankton, and data management.

The physical oceanography studies include the collection and analysis of data from monthly hydrographic cruises and continuously recording <u>in-situ</u> current meters. The salinity and temperature data are presented in the form of vertical cross sections and time depth plots, which show the variations in the hydrography are dominated by salinity rather than temperature. Current meters were initially placed near the surface and bottom at a single location in the study area, and by August 1979 there were three locations with meters at surface, middle, and bottom depths. The continuous data from these instruments are presented in the form of time series plots.

A towed monitoring system for tracking the brine plume is described

which is capable of detecting the brine plume 10 inches (25 cm) off the bottom. The system is capable of being towed at approximately three knots (1.5 m/s) through the brine disposal area while measuring the salinity continuously which will permit the evaluation of the areal extent of the plume.

The quality of the coastal waters and the bottom sediments in the diffuser area have been evaluated from data collected on a monthly and quarterly basis. These data show the considerable variability of water quality parameters and the very low dissolved oxygen levels which occurred in the summer of 1979.

Studies have been conducted to characterize the nekton community in the diffuser and surrounding areas with emphasis on commercially important species of shrimp and fish. Day and night trawling has been conducted aboard chartered commercial shrimp trawlers over in a depth range of three to 25 fathoms (5.5 to 45.7 m) which includes a detailed array of stations near the diffuser site. The diffuser site is described as an area of rapid ecological change between the fauna of the white and brown shrimp communities, and is near the outer bathemetric limit of the white shrimp. The area is dominated by the fish Atlantic bumper and silver seatrout. Sharp reductions in the biomass of both fish and shrimp have been observed on several occasions in June and July over a broad geographic area that encompassed the diffuser area, and these virtual eliminations of demersal nekton are presumed to be associated with the natural phenomena of low dissolved oxygen levels. Species compositions show great diversity and changes, and few species tend to dominate or be very abundant for long periods of time in the study area.

Monthly benthic data have been collected using small diver actuated Ekman dredges at predetermined sampling stations in the vicinity of the diffuser site and a nearshore site located five nautical miles (9.3 km) off the coast. Polychaete annelids dominated the populations at both sites with Paraprinonospio pinnata being the dominant species. A cluster analysis at the diffuser site indicates a high degree of ecological similarity between stations. A range of diversities, all the result of naturally occuring phenomena, are described which can be compared against any suspected change in diversity resulting from brine disposal. The effect of the hypoxic conditions on the benthic study areas are described, and it is postulated that similar diversity changes resulting from low dissolved oxygen would be expected if the benthic population is stressed as a result of brine disposal.

Collection of zooplankton data began in June 1979 and the data indicate that the seasonal variability in zooplankton biomass and density near the diffuser area is very high and that copepods dominate the population. Multiple range tests based on analysis of variance results are described which have been used to determine the similarity between sampling stations. The phytoplankton data have shown that diatoms dominate the population and that the phytoplankton community is typical of Gulf coastal waters. The Phytoplankton and other project components have compiled extensive data sets which have been validated and transmitted to the Environmental Data and Information Service of the National Oceanic and Atmospheric Administration.

EXECUTIVE SUMMARY

Texas A&M University scientists and engineers began a predisposal study of the environmental conditions of the coastal waters off Freeport, Texas in September 1977. These waters are the site for the discharge of brine from large underground salt domes while they are being leached and subsequently filled with crude oil. The salt dome is located at Bryan Mound which is bordered by the Brazos River to the west, Freeport, Texas to the north and east, and the Gulf of Mexico to the south. The storage of oil in the Bryan Mound salt domes is part of the Department of Energy's Strategic Petroleum Reserve Program.

A buried pipeline which has a diameter of 3 ft (.9 m) has been laid from Bryan Mound to a point 12.5 statute miles (20 km) off the Freeport, Texas coast in 70 ft (21 m) of water as illustrated in Figure 1. The latitude and longitude of the end of the diffuser is 28° 44'N and 95°14.5'W, respectively. The last 3060 ft (933 m) of the pipeline is the diffuser which consists of 52 diffuser ports of which 31 are open and extend vertically upward 6 ft (1.8 m) from the bottom. Presently brine is being discharged through the diffuser at a rate up to a maximum of 680,000 barrels per day with a concentration varying from 200-280 parts per thousand (°/oo). The brine discharge is heavier than the surrounding sea water, and after being diluted initially by jet mixing, it falls to the bottom and spreads over the sea floor. Subsequently, the brine is advected away by the bottom currents and further diluted by turbulent diffusion.

The purpose of this final report is to describe the findings of the principal investigators during the predisposal study which was conducted from September 1977 through February 1980 prior to the start

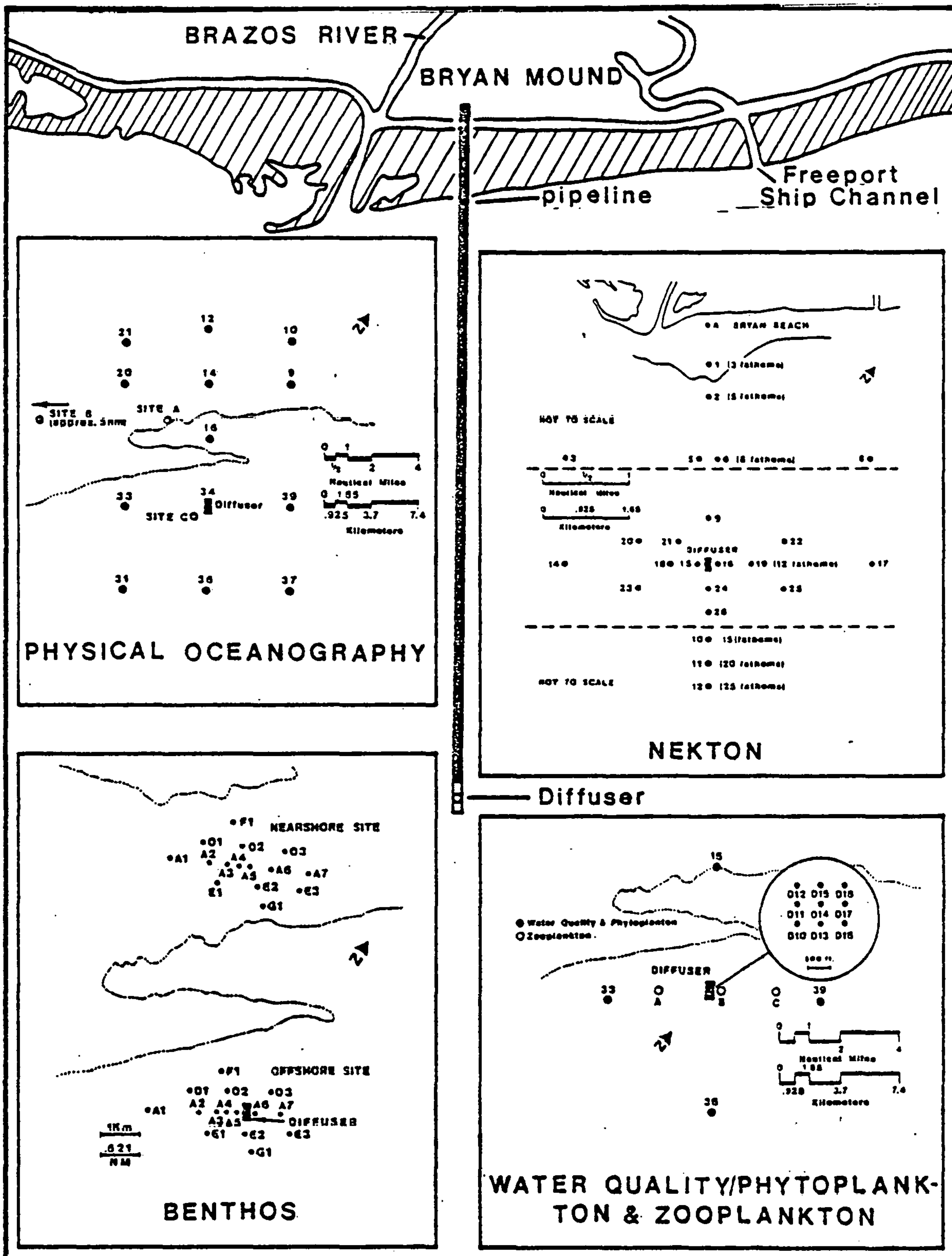

Figure 1. Composite of project sampling station locations.

of brine discharge in March 1980. The major areas of investigation are physical oceanography, analysis of the discharge plume, water and sediment quality, nekton, benthos, phytoplankton, zooplankton, and data management.

Progress in the predisposal study has been reported in four progress reports dated February 1978, July 1978, February 1979, and July 1979. These reports were submitted to the Department of Energy through the Marine Environmental Assessment Division of the Environmental Data and Information Service (EDIS) which is part of the National Oceanic and Atmospheric Administration (NOAA). In addition to these reports, a complete data set for the predisposal study has been submitted to EDIS. An early portion of the data was used for the Department of Energy's environmental impact statement for Bryan Mound.

The project data processing activities include the maintenance of a centralized data storage and retrieval system based on file processing techniques and the provision of statistical and programming support for project scientists and engineers. Each area of the project lends itself to one or more separate data sets, which are maintained on computer disk files safeguarded with periodic tape backups. Data sets are being maintained in the areas of physical oceanography, water and sediment quality, phytoplankton, zooplankton, benthos, and nekton. Data for each area is entered onto on-line computer storage from either cards, computer terminal or magnetic tape. Copies of the data are returned to the respective investigators for validation. Upon the return of the validated data sets they are forwarded to the Environmental Data and Information Service.

The physical oceanography studies include the collection and analysis of data from both bimonthly hydrographic cruises and continuously recording in-situ instruments. The location of sampling stations for the hydrographic cruises and the continuous recording instruments are shown in Figure 1. The salinity and temperature data along a cross shelf transect parallel to the pipeline and an alongshore transect through the diffuser site show that the variations in the hydrography off Freeport, Texas are dominated by salinity rather than temperature. Relatively low salinity water, primarily as a result of streamflow from the Mississippi/Atchafalaya River system, is frequently advected through the study area. Lowest salinities occur in April-May (~16-20 parts per thousand, ‰) corresponding to the spring maximum in streamflow. In April-May of 1979 this resulted in an extremely strong horizontal pycnocline which extended offshore past the diffuser area. At other times relatively low salinity water is confined near the coast and forms a frontal zone which is often situated near the diffuser site. Secondary salinity minima occurred in late September 1978 and in September and November 1979.

Vertical salinity gradients of up to 15‰ occurred in June at the diffuser site and 10‰ at a station 5 nautical miles from shore. A relatively isohaline water column occurred only in late July 1978, November 1978 and in early March, October and December 1979. In 1978, strong salinity stratification was more transient and less intense than in 1979.

Water temperature shows an annual cycle of lowest temperatures in February to highest temperatures in August. February of 1980 was considerably warmer, by about 5°C, than February of 1978 and 1979. Thermal stratification is relatively weak except from June through

August when the summer thermocline develops, and the maximum vertical temperature difference is about 5°C.

In terms of the Richardson number the upper half of the water column is generally stratified (Ri> 10) in the winter and spring months and transitional (0.1 < Ri < 10) in the summer and fall months; the bottom layer is transitional year-round with occasional well-mixed (Ri < 0.1) conditions in the fall and winter.

Current meters were originally deployed beginning in December 1977 at 3 m below the surface and 2 m above the bottom on a subsurface mooring system near an existing platform which is 6.5 nautical miles (nm) (12 km) offshore and 1.5 nm (2.8 km) southwest of the pipeline. This mooring system has been maintained throughout the predisposal period, although there are several data gaps in early 1978. A second current meter mooring system was installed in May 1979 near a platform located at the same depth and distance offshore but 9.5 nm (17.6 km) southwest of the pipeline. Upon completion of the brine pipeline in the summer of 1979, the third current meter mooring system was installed in late August approximately 300 meters southwest of the end of the pipeline. Beginning in the fall of 1979 new current meters, which measured salinity and temperature in addition to current speed and direction, were installed at all the mooring locations at 3 m below the surface, mid-depth and 2m above the bottom.

The volume of current meter data collected from the three locations is extremely large. In this report time series plots of 3-hour and 40-hour low passed current meter data are presented for all data from June 1978 through February 1980. This part of the report is intended to be a basic data report for reference. Auto- and cross spectral analysis among the instrument sites and wind data is in progress and will be covered in another report.

During the extremely strong stratification in April-May 1979 the highest cross shelf velocities of the study, up to 75 cm/s inshore, were recorded. The longshore velocities were also strong and directed downcoast. At the bottom, however, current velocities were low. Given the strong horizontal pycnocline which existed at that time, it is possible that a two layer system existed in which the lower layer was almost at rest. This would help account for the anoxic conditions which were recorded by other investigators of the project.

In preparation for the monitoring of the discharge plume, two water quality monitoring systems were designed, assembled, and tested for the purpose of tracking the brine plume. The probe monitoring system consists of a water quality probe, conductor cable, signal display, recorder, and tow sled. This system was designed to be towed on the sea floor with the conductivity, temperature and depth (CTD) probe located 10 in (25 cm) off the bottom, and the towing sled will break free of the towing line and instrument data cable if it should snag while being towed. The advantages of this system are that the measurement depth is always known, the probe is close enough to the bottom to insure plume detection, and the damage due to snagging is minimized as a result of the break away design . The probe system has been towed at a speed of 2-3 knots, and the probe has been used by itself for collecting CTD data since April 1979.

The pump monitoring system consists of a long suction hose, hose reel, on board pump, flow distribution board and two on board water quality monitors. This system has been used to measure the diffusion coefficients and could be used for tracking the plume if it was not too close to the bottom. However, indications are that the plume will be within 2-4 ft (0.6 - 1.0 m) from the bottom, and therefore, it is not the primary system for tracking the near bottom plume.

The pump monitoring system was used for the measurement of horizontal and vertical diffusion coefficients in the coastal waters off Freeport, Texas. For these measurements, a rhodamine dye was mixed with methyl alcohol and continuously discharged into the Gulf waters. The dye was detected by pumping a continuous water sample to a filter fluorometer onboard the research vessel while it was traversing the plume. The extent of the plume was determined by knowing the location of the ship as determined by the navigation system and comparing it to the strip chart recording of the plume profile concentration. The vertical diffusion coefficients were determined by measuring the distance from the dye source to the location of maximum concentration.

A relationship for predicting surface horizontal diffusion coefficient as a function of the standard deviation of the dye plume concentration profile was determined from the data collected in this study. The values obtained from this equation are an order of magnitude larger than those obtained from similar relationship used in the MIT transient plume model. Thus, the results of this study confirm that the diffusion coefficient values used in the MIT transient plume model are good conservative values.

The mid depth horizontal diffusion coefficient data indicate that the coefficients increase with depth and that the coefficients used in the MIT transient plume model remain to be conservative values. The conclusion of the effect of depth on the coefficients is based upon only two days of data, and it is recommended that more data be collected to further substantiate this conclusion.

Vertical diffusion coefficients were computed from a single day of experimental data which resulted in an average of 0.27 $ft^2 s^{-1}$ (0.025 $m^2 s^{-1}$). This result agreed with values reported for the Thames Estuary, but was generally an order of magnitude higher than other reported values. Like the horizontal data, the vertical diffusion data confirmed that the value (K = .001 $ft^2 s^{-1}$, K = 0.0009 $m^2 s^{-1}$) used in the MIT transient plume model is conservative.

Monthly water quality monitoring of the water column at the Bryan Mound diffuser site and adjacent control stations shown in Figure 1 over a seventeen (17) month period indicate these waters to be typical of those expected for this region of the Gulf of Mexico. Being coastal waters under the influence of local and regional runoffs, considerable variability was observed for most parameters. Some parameters exhibited typical seasonal variations which were further modified by factors associated with land runoff. The best example of this was the very low dissolved oxygen levels existing in the bottom waters over the entire area during much of the summer of 1979.

Nutrient levels were generally as expected with both seasonal and runoff effects contributing to their variability. The generally low nitrate levels, (10μg N/l) observed during this period of study were of special interest. Of all the nutrients, nitrate nitrogen may be the one most limiting for plant productivity in this area throughout much of the year.

Major cation, anion and heavy metal data for both water and sediment were collected on a quarterly basis starting in August 1979 and results during the predisposal period were typical for coastal waters.

Special samples collected during late summer and early fall 1979 consisted of sediments for heavy hydrocarbon, pesticide and PCB analyses and selected biota for heavy metals, pesticides and PCB. Metal analyses on the biota and hydrocarbon analyses of the sediments have been completed. However, delays in subcontracting analyses of the pesticides and PCB's have delayed their analyses, and these results will be presented in a later report.

The hydrocarbons in the disposal site and in the surrounding area appear to be very similar in composition and are predominantly of land and marine biogenic origin. All the resolved components certainly do not indicate any petrogenic input. The only possible indication of any petrogenic input is the presence of UCM (Unresolved complex mixture or humping) in the hexane fraction containing normal and branched chain alkanes and polyolefins. The other two fractions contained little or no UCM. The primary sources of hydrocarbons of the Bryan Mound area sediments are definitely of marine and terrestrial biogenic ones.

The initial nekton studies emphasized three penaeid shrimp species and eleven selected species of fishes that the literature had indicated would be the most abundant species expected in the area of the diffuser site. In the fall of 1978 and after it was decided to move the diffuser site further offshore, the study emphasis changed to include all species of fishes in addition to the three species of

Penaeid shrimp. The trawling initially was done on a monthly basis during the day, but with the change in diffuser location, the frequency of trawling increased to twice monthly cruises which consisted of five days of trawling at night and a separate five days during the daylight. Trawling was conducted aboard chartered commercial shrimp trawlers along a transect in a depth range of about 3-25 fathoms throughout the entire study period. Cruise tracks initially included about 19 trawl tows per cruise and were expanded to about 48 trawl tows at the stations shown in Figure 1. In addition to a basic transect station pattern maintained throughout the study, a detailed array of stations were occupied (Figure 1) in about 12 fathoms of water at the final offshore diffuser site.

More than 37,100 Penaeid shrimp of three species and 651,500 fishes of approximately 16 species were collected. Species compositions showed great variation depending on the period of year, time of day station and depths at which collections were made. The general nature of the findings support other published results that two distinctly different faunal communities exist off Freeport, Texas coast which have been designated as the white and brown shrimp communities. In general, comparatively few species dominated the catch at any one time in any one community. For example, only eight abundant species made up 81% of the fish catch in the area occupied by the white shrimp community, and only eleven abundant species made up 77% of the fish catch in the area occupied by the brown shrimp community. The white shrimp community was characterized by a less diverse fauna than the brown shrimp community.

An area designated as the inshore area (3-10 fathoms) supported the white shrimp community where the white shrimp, Penaeus setiferus, was dominant and the brown shrimp, Penaeus aztecus, was also abundant. Few specimens of the pink shrimp, Penaeus duorarum, were captured except in May when they were abundant. Generally, the fishes in the inshore area were dominated by Atlantic bumper and Atlantic croaker; although several other species were important, including silver seatrout, star drum, sand sea trout, bay anchovy, Gulf butterfish and sea catfish.

An area designated as the offshore area (15-25 fathoms) supported members of the brown shrimp community, where the dominant shrimp, by far, was the brown shrimp. The fishes in the offshore area were dominated by longspined porgy; although several other species were important including shoal flounder, Atlantic bumper, dwarf goatfish, rough scad, sand perch, lizzard fish, Gulf butterfish, big eye and rock seabass.

The nekton data in the diffuser area (12 fathoms) reflects an area of rapid ecological transition between the fauna of the white and brown shrimp communities. Although both major shrimps were abundant in this area, a detailed analyses of the life history of the white shrimp indicated that the diffuser region is near the outer bathymetric limit for this species. The fishes in the diffuser area were dominated by Atlantic bumper and silver seatrout although several other species were important including Gulf butterfish, shoal flounder, sand seatrout, longspined porgy, anchovy, sea robin, and rough scad. The fact that the diffuser area is located in a zone of rapid ecological transition was also indicated by a detailed analyses of life histories of fourteen nekton species which showed that many species experienced an abrupt decrease in abundance near the diffuser area, most from an inshore center of abundance and others from an offshore center of abundance.

Species composition exhibited diel variation in nature, although direct comparisons within 24 hour periods are needed to properly describe the nature of day-night variations. Penaeid shrimp showed the generally recognized patterns of periodicity with catches of the grooved (brown and pink) shrimp tending to be greatest at night while catches of ungrooved shrimp (white) tended to be greatest in the day. However, large numbers of brown shrimp were captured during the day in the inshore waters shallower than about 10 fathoms from June through December. Apparently this species may be active during the day as it migrates offshore. In contrast, virtually none were captured in offshore waters during the day. Several species of fishes seemed to be much more abundant during the day, in terms of catch size and percent composition which includes the Atlantic bumper, Gulf butterfish, rough scad, and Atlantic cutlass fish. Several other species were more important at night including silver sea trout, longspined porgy, sea robin, and Atlantic midshipmen.

Nekton catches showed general trends in abundance related to stations and bathymetric areas. Mean catches of Penaeid shrimp tended to be much greater at depths of about 3-5 fathoms than in deeper waters. Thus, the data indicate the abundance of Penaeid shrimp decreases as the depth increases. Mean catches of fishes were much greater at depths of about 3-5 fathoms than in deeper waters. In the 7-25 fathom depth range, there was a distinct but gradual trend of decreasing biomass. Catches of nekton in the diffuser area (12 fathoms) were nearly uniform between stations.

Sharp reductions in the biomass of both fish and shrimp were noted on several occasions in June and July over a broad geographic area that at times encompassed all or parts of the 7-13 fathom depth range which includes the diffuser area. Presumably, these virtual eliminations of demersal nekton are associated with the natural phenomena that cause low dissolved oxygen levels during this time of the year.

From October 1977 to February 1980 the typical annual cycle of abundance was observed in each of three different areas. The areas are defined as: 1) an inshore area (3-10 fathoms), 2) an offshore area (15-25 fathoms), and 3) the diffuser area (12 fathoms). In the inshore area, fishes were most abundant during the warmer months (May through October), except when presumed low oxygen conditions distorted the picture. Beginning in November, the abundance declined to low levels during the colder months of December through April. In the offshore area, catches progressively rose from low levels in the coldest part of the year (January through March) to the greatest abundance in June through October. In the diffuser area, catches were low from about November through April and rose to the greatest abundance in the June through October period, except when presumed low oxygen conditions distorted the picture. Penaeid shrimp catches in the inshore area were greatest during the September through December period when white shrimp entered the Gulf. Catches declined after December and remained at a low level through May. Shrimp catches tended to rise about June when the brown shrimp begin to enter the Gulf. Presumed low oxygen conditions at times distorted the picture of early summer abundance. Seasonal patterns of abundance were not clear in the offshore and diffuser area because of diel variation in the shrimp activity and/or presumed low oxygen conditions. The annual cycle of nekton abundance observed herein, ignoring oxygen related phenomena, is related to water temperature and species tolerance regimes inshore, annual spawning and movement cycles, high mortality rates, and short life spans.

Species compositions showed great diversity and changes. Few species tended to dominate or be very abundant for long periods of time in any of the three previously defined areas denoted as the inshore, offshore and diffuser areas. However, the fauna was very diverse and many species (36!) were abundant in the sense that they made up 5% or more of the catch at one time or another in one of the three areas. The very abundant species made up about 20% of the approximately 164 species of fishes encountered, and many other species made up 2% or more of the catch.

Despite the great diversity of species off Freeport, most of these species (to be conservative) seem to show the same basic dynamic nature in their life cycles. As suggested in the literature, the nekton of the white and brown shrimp communities are characterized by very short life cycles (about 1 or 2 years maximum) and high mortality rate. Because of these two driving factors for each species, there must be a rapid turnover of biomass each year. Therefore, these three factors dictate that there must be large changes in abundance of each species within each year, ignoring any other factors. That picture in fact seems to be apparent for the nekton fauna and probably explains how so many species could each be very abundant at one time or another in a given year. These three basic factors also dictate that the abundance of given nekton species off Freeport would tend to be subject to large, possibly violent, year-to-year fluctuations because very few year classes (one or two) or spawned groups (the number depends on patterns of reproduction) would be present to buffer changes in spawned group success due to background environmental variation. The magnitude of year-to-year fluctuations in abundance of a given species is probably tempered by the pattern of its reproductive periodicity. Several basic within-year patterns of reproductive periodicity exist in Gulf species. Some species seem to spawn once a year primarily within fairly short periods, and other species seem to spawn twice a year on a semiannual basis but still primarily within a fairly short period of time. Still other species seem to spawn more frequently but still within short periods of time for each spawning period.

Superimposed on the change in species composition and basic patterns of species population dynamics are other fluctuations associated with diel periodicity, seasonal movements, sediment types, possible low oxygen levels, and many other factors that determine counts of abundance. All in all, it appears that demersal nekton communities associated with shrimp in the northwestern Gulf are simply predisposed to change, and this basic ecological feature must be understood in the analysis of any effects due to brine disposal. It would not be surprising if one or more nekton species showed sharp decreases (or increases) in abundance coinciding with brine disposal or its onset, whether or not a cause effect relationship existed.

Further study on the poorly known life histories and population dynamics of the nekton communities off Freeport is badly needed. Life history and population dynamics factors could lend deep insight into analyses of the effects of brine disposal and could suggest ways to minimize or avoid adverse effects. It is clear that an understanding of spawning grounds and nurseries, seasonal movements, areas of distribution, growth, recruitment, and mortality provide important and essential background data which is necessary to determine any changes in abundance that might occur might be associated with brine disposal.

Benthic data have been collected monthly at predetermined sampling stations (Figure 1) in the vicinity of the offshore diffuser site from December 1977 through February 1980 and the nearshore site located approximately 5 nautical miles off the coast (original diffuser location) from September 1977 through February 1980.

During this period of study, more species were collected at the offshore site (232 offshore vs. 209 nearshore). The total number of individuals (all data summed) were quite different with the offshore population about 1.5 times larger (72717 offshore versus 48085) than nearshore. The larger number of species and individuals indicate the offshore site is the more productive in terms of benthic populations.

In the early stages of the study, relatively few species were collected at all 15 stations in either site. As would be expected, the number has increased at both sites as the study progressed, and at the termination of the predisposal study, both sites were relatively similar in terms of the percentage of species occurring at a given number of stations. Slightly higher percentages of species were ubiquitous (i.e. occurring at all 15 stations) and rare (i.e. occurring at only one station) at the offshore site.

Polychaete annelids dominated the populations at both sites, with amphipod crustaceans the second dominant. The combined polychaete and amphipod populations overwhelmingly dominated the offshore population (91.6% of all individuals), but were less dominant at the inshore site

About 90% of the individuals collected at each site belonged to the most abundant species at that site. Twelve of the species occur in both lists, but only 5 were among the 10 most abundant at both sites. The polychaete, Paraprionospio pinnata was the numerically dominant species at both sites, but its dominance was less at the offshore site. The number of species collected apparently decreased toward the northeastern part of the offshore study area. The cause of this gradient is unknown; no apparent gradient in sediments or other abiotic factors existed at the offshore site. The nearshore site also has a species gradient with a rather abrupt decrease in numbers of species occurring toward the northeast end of the site. It is speculated that this gradient may be related to increasing distance from the Brazos River.

The offshore total populations were generally in the 4500-5500 individuals range. There does not appear to be a population gradient corresponding with the species gradient. The nearshore site population distributional pattern suggests that an elliptical area with depressed populations occurred near the center of the study area, and that the benthos density increases to the northeast and southwest. The cause of this pattern is unknown; the population and diversity patterns were inverse with the smallest number of species in the northeast area where the largest populations were found.

A cluster analysis showed that all the offshore stations were contained in one tight cluster indicating a high degree of ecological similarity between stations. The 77 species used in the analysis all occurred 10 or more times during the study and comprised 98.6% of all individuals collected. The ecological similarity was also quite high between species (i.e. co-occurrence of many species at many stations). Principal components analysis, using the species that occurred at each station at least once, also indicated a high degree of similarity between stations.

The cluster analysis of the nearshore stations showed they were separated into two groups. The first group, the larger, was comprised of 10 stations while the second group was comprised of five stations in the northeastern part of the study area. The stations in the second group had two faunal components that were different from the first group. The existence of the smaller northeastern site group was also suggested by the principal components analysis; the second group stations of cluster analysis also formed a compact cluster in principal components analysis. The separation of the nearshore stations into two clusters has occurred consistently throughout the study. In April, May, and June 1978, three stations were added in the northeastern part of the study area to determine if the smaller station cluster was an isolated patch or part of a larger area. The additional stations clustered with the stations in the second group, indicating that the factors causing the population differences continue to the northeast an unknown distance.

Cluster analyses were performed comparing the co-occurrence of species and cruises (months). The offshore collections were separated into two major clusters, each of which was composed of smaller clusters. The larger major cluster contained three smaller clusters which together included the time blocks December 1977 through April 1979 and December 1979 through February 1980. The first (smallest) sub-cluster, December 1979 - February 1980, was characterized by a lack of dominance of any species. The second sub-cluster encompasses the time during which P. pinnata was very abundant. The third sub-cluster denotes the time in which amphipods were secondary on the ascendency and polychaete abundance was decreasing. The second major cluster is comprised of the months during and following hypoxia i.e. May-November 1979. The subclusters were caused by the virtual absence of certain of the smaller species groups in each time period.

The cruises to the nearshore site were separated into four clusters, none of which were as distinctly separated as the offshore clusters. The first cluster encompasses the time following hypoxic conditions in 1979 (except October) when populations were large or increasing. During this period the bivalve mollusk Abra aequalis the hemichordate Balanoglossus sp. and the polychaete Cirratulus hedgepethi set in large numbers. The second cluster is comprised of the initial 4 collections of the study when overall populations were quite low and were dominated by P. pinnata. The third cluster is the largest and is comprised of the February 1978 - April 1979 time period, except August 1978. During this period, P. pinnata was the dominant species even overriding the influence of the ascendent amphipod population in April and May 1979. The last cluster is comprised of cruises made when populations were very low, including the known hypoxic period May - July 1979, the suspected hypoxic period, August 1978 and October 1979 when very low populations occurred following the post-hypoxic irruption.

It was expected that the seasonal changes in total numbers of species would be similar at both sites. This was not always the case and the diversity trends can be divided into three periods. From December 1977 through June 1978 the offshore and inshore trends were similar, but were not coincident; the nearshore changes occurred one month later than at the offshore site. During this period the number of species increased gradually through April (offshore) or May (nearshore) and then declined rapidly. The second period was July through October 1978 when the trends were the inverse. The offshore species increased in number in August to the maximum yet recorded, held steady through September, and then declined rapidly. While the number of offshore species increased, the number of species at the nearshore site decreased and the lowest diversity was recorded while the offshore diversity was highest. It is suspected that the nearshore site experienced hypoxic conditions in early summer whereas the offshore site did not experience them. During the third period, November 1978 through January 1980, the trends were similar; a decrease in diversity from October to November was followed by an increase through April. The increases during both periods 1 and 3 appear to be correlated with the onset of fall temperature decreases and cold winter temperatures. Between April and July, the number of species declined and drastically concomitant with the hypoxia which affected both sites. After the hypoxic conditions were disrupted the number of species increased again through January 1980.

The monthly (pooled data, each collection) population changes were also expected to be similar at both sites, but this again was not always the case. The population trends were also divided into three periods. From December 1977 through March 1978 the populations increased at both sites, but there was a large difference in population totals. From April through July 1978 there was no similarity, and since August 1978, the population changes at the two sites have been synchronous. The consistent pattern through all three years was a population increase in the fall as the water temperature began to decrease culminating in a peak density in the March-May period, which was followed by a population decrease. In the summer of 1978, the nearshore population density decreased rapidly with a minimum density occurring in late August. The offshore population did not undergo a similar decrease, and it is speculated that hypoxic conditions occurred at the nearshore site, but not at the offshore site. In the summer of 1979, the severe hypoxia which affected both sites killed many organisms and caused low population densities. A brief population irruption occurred in August 1979, following re-oxygenation of bottom waters, as many species took advantage of the depopulated bottom and lack of competition. The irruption was immediately followed by a decrease in density in September-November 1979, the period in which lowest populations are expected.

The benthic population densities are undoubtedly being controlled by a combination of abiotic (temperature, salinity, D.O.) and biological (predation, competition) factors. Predation may play a great role. On numerous occasions young shrimp have been seen actively searching in the bottom with their thoracic legs. In the laboratory it has been observed that young brown or white shrimp would seize and eat any suitable sized polychaete presented. If numerous worms were offered, the shrimp would eat one while holding the others by the thoracic legs. Available nekton data (October 1977-May 1979) suggest a possible inverse correlation between nektonic and benthic populations. Nektonic abundance was greatest in the October-December period of both 1977 and 1978 when benthic population densities were low. Twice as many fish and shrimp were collected in 1977 as 1978, which may partly explain why the fall benthic populations were much lower in 1977 than 1978.

The temporal changes of the percent composition of the dominant taxa at each site were compared. At both sites, polychaetes were overwhelmingly dominant while Paraprionospio pinnata populations were large. At both sites, the polychaete percentage began to decrease about November 1978 with a concomitant increase in amphipods. This trend was abruptly reversed when hypoxic conditions occurred. The amphipods were virtually eradicated and had only slightly recovered by February 1980. The third most abundant groups were bivalve mollusks and nemerteans at the offshore and nearshore sites, respectively. Bivalves were usually abundant only in July and August when large numbers of juveniles were present. These populations were quickly reduced either by predation or natural death. Nemerteans were generally present in small numbers throughout the study at the nearshore site.

The polychaete Paraprionospio pinnata, because of its numerical dominance, was very influential in determining the monthly fluctuations of population densities at both sites during the first year of study. At the offshore site P. pinnata was less dominant and the total individuals of all other species usually exceeded the P.

pinnata population. The lack of continual dominance of one species was a partial cause of the rather erratic population fluctuations at the offshore site. Since December 1978, the P. pinnata populations have been very small except during the brief irruption in August 1979 following the disruption of hypoxic conditions.

P. pinnata was more dominant at the nearshore site and its population fluctuations largely determined the total population density through October 1979. A massive set of the bivalve Abra aequalis occurred in December 1979, and since then this species has dominated the population. In contrast to the offshore site, all other individuals usually did not exceed the P. pinnata population.

The bivalve mollusks appeared to be spring or early summer spawners; peak abundance occurred primarily in August, and usually the species occurred predominantly at one site or other. This rather uniform trend was disrupted by the large set of Abra aequalis in November or December 1979.

Like the bivalves, the amphipods displayed a pronounced seasonality increasing in abundance principally in the spring months, with lesser increases in the fall. The large amphipod population was virtually eradicated during the hypoxic period and had made only a slight recovery by early 1980.

Unlike either the bivalves or the amphipods the polychaete annelids did not display a well defined tendency to produce large populations in a particular part of the year. These apparently erratic trends may be caused by a variety of factors, i.e. predation, generation time, competition, etc.

The hypoxic conditions observed in the benthic study areas in the spring of 1979 affected both nearshore and offshore sites, as well as an extensive area of the Texas (and possibly Louisiana) coasts. It was also noted that hypoxia occurred inshore and apparently moved offshore later in the summer. It can thus be speculated that the extent of hypoxia is variable, depending on the magnitude of the causative factors, and that at times hypoxic conditions might not extend much further seaward than the nearshore site, as suggested in 1978 by low populations and diversities but for which we have no supporting dissolved oxygen data. If this was the case, then the infrequent development of hypoxic conditions could be expected to greatly influence the composition and diversity of the affected benthic communities. The nearshore community, more frequently subjected to hypoxia, would be more resilient and recover more rapidly under such circumstances. The offshore community, less often subjected to hypoxia, would lack this response and thus would be severely impacted by such an event. These responses appear to support the hypothesis that disturbances of intermediate effect maintain a certain level of diversity (usually maximum within environmental parameters), while other disturbances depress diversity (the Intermediate Disturbance Hypothesis). As indicated our data tend to support this view.

A range of diversities have been obtained, all the result of naturally occurring phenomena, to compare against any change in diversity which might result from brine disposal. In 1978, naturally occurring stress was limited to the inshore portion of our study area only. This was followed by a period during the following year (1979) in which benthic communities at both study areas were severely stressed. If brine induced stress occurs, it should be observable as a change in the diversity similar to the changes induced by low dissolved oxygen.

Collection of zooplankton data began in June 1979 at the stations shown in the previously mentioned Figure 1. These data show that the seasonal variability in zooplankton biomass and density near the diffuser area appears to be very high. This variability is probably due to the periodic influx of nutrients and estuarine species into the area during times of high river flow. Copepods dominated the zooplankton and populations of Acartia tonsa, a typical estuarine species, reached extremely high densities near the diffuser in June 1979. Copepod densities (mostly Acartia) during this June sampling period ranged between approximately 35,000 to 55,000 organisms/m^3. Densities dropped dramatically by July and density values for total zooplankton and copepods appeared to be typical for this coastal area during six other cruises. Elevated densities of total zooplankton in December and January were largely due to high densities of tornaria larvae (hemichordates). Meroplanktonic forms in general (including bivalve larvae and barnacle cypris larvae) were abundant from November through January.

The high temporal variability within the zooplankton near the diffuser will make it difficult to detect any effect of brine diffusion in the sampling area based on comparisons with previous sampling periods unless the effect is catastrophic. For this reason an analysis of variance (AOV) was used to measure spatial variability during each cruise. Replicate tow variability was used to test whether the three stations located near the diffuser were significantly different.

The stations were located 2 nautical miles (3.7 km) apart and the population densities at each station were expected to be similar. The analysis of variance which was based on total zooplankton densities, however, indicated that on four out of the seven cruises the stations were not similar. When the AOV was based on densities of the dominant groups of zooplankton and abundant species of copepods the results varied. Some groups and species however showed few significant differences between the stations. An examination of the spatial variability of these groups in the postdisposal samples should be of interest in determining possible effects of the brine.

For all groups, including total zooplankton, mutiple range tests based on the AOV results were used to determine which of the three stations were similar. In very few cases were all three stations dissimilar. The location of the dissimilar stations in relation to the brine plume in the postdisposal samples may also provide information on possible effects of disposal on zooplankton populations.

Beginning in June 1979 and continuing through February 1980, a study of the phytoplankton community off Freeport, Texas was conducted to characterize the existing phytoplankton in this area with regard to composition and abundance, to determine spatial differences in composition and abundance within a limited area of about 10 square miles (26 km) and to identify differences, if any, between the top and bottom water phytoplankton composition and abundance. A series of stations was established around the brine diffuser (the inner or experimental stations) surrounded by control (outer) stations.

Monthly surface and bottom samples, physical data (temperature and salinity) and relative chlorophyll a readings were taken at each station.

The phytoplankton population in the study area in general show effects of some nutrient deficiencies or mesotrophic conditions. Even when algal blooms occur, the numbers of phytoplankton individuals that can be supported is relatively low. The phytoplankton population is dominated by diatoms practically to the exclusion of other groups of algae. The assemblages of phytoplankton communities that were found are compatible with those of other workers in the Gulf, neritic, coastal waters. At times the dominant species complex shows some seasonality, as in January 1980 when the dominant genera were Skeletonema, Chaetoceros and Nitzschia. This assemblage is indicative of winter Gulf waters. At other times the genera complex was simply more typical of year-round, common Gulf phytoplankton.

Of a total of 36 taxa, 7 have been identified as dominant: Chaetoceros, Coscinodiscus, dinoflagellates, Navicula, Nitzschia, Rhizosolenia, and Thalassiosira.

The phytoplankton densities found during this study period were typical for nearshore Gulf waters. The showed the typical seasonal changes including the end of a spring bloom followed by low densities in the summer, followed by aother bloom in the fall. The winter peak is variable; it may or may not appear. Just as the neritic environment undergoes rapid physical and chemical changes, so, too, do phytoplankton densities which may rise or fall two orders of magnitude between monthly samplings.

INTRODUCTION

A project team consisting of scientists and engineers at Texas A&M University began an environmental study of the coastal waters off Freeport, Texas in September 1977. These waters are presently the site for brine discharge from large underground salt domes while they are being leached and subsequently filled with petroleum products. The salt domes are located near Freeport, Texas at the Bryan Mound site of the Department of Energy's Strategic Petroleum Reserve Program.

A buried pipeline which has a diameter of 3 ft (0.9m) was laid from Bryan Mound to a point 12.5 statute miles (20 km) off the Freeport, Texas coast in 70 ft (21 m) of water (See Figure 1). The location of the end of the diffuser is latitude 28°44' N and longitude 95°14.5' W. The last 3060 ft (933 m) of the pipeline is a diffuser which consists of 52 diffuser ports of which 31 are open and extend vertically 6 ft (1.8 m) from the bottom. These ports are 3 in (7.6 cm) in diameter and 60 ft (18 m) apart, and the brine is being discharged from the diffuser at a flow rate up to a maximum of 680,000 barrels per day ($1.08 \times 10^5 m^3 day^{-1}$) with a concentration varing from 200 - 280 parts per thousand (°/oo). Since the brine discharge is more dense than the receiving waters, it falls to the bottom and spreads over the sea floor. The brine plume is diluted and advected away by the natural ocean bottom currents and turbulent diffusion.

The purpose of this final report is to describe the findings of the project team during the predisposal study which was conducted from September 1977 through February 1980 prior to brine discharge which began in March 1980. The areas of investigation are physical oceanography, analysis of the discharge plume, water and sediment quality, nekton, benthos, phytoplankton,

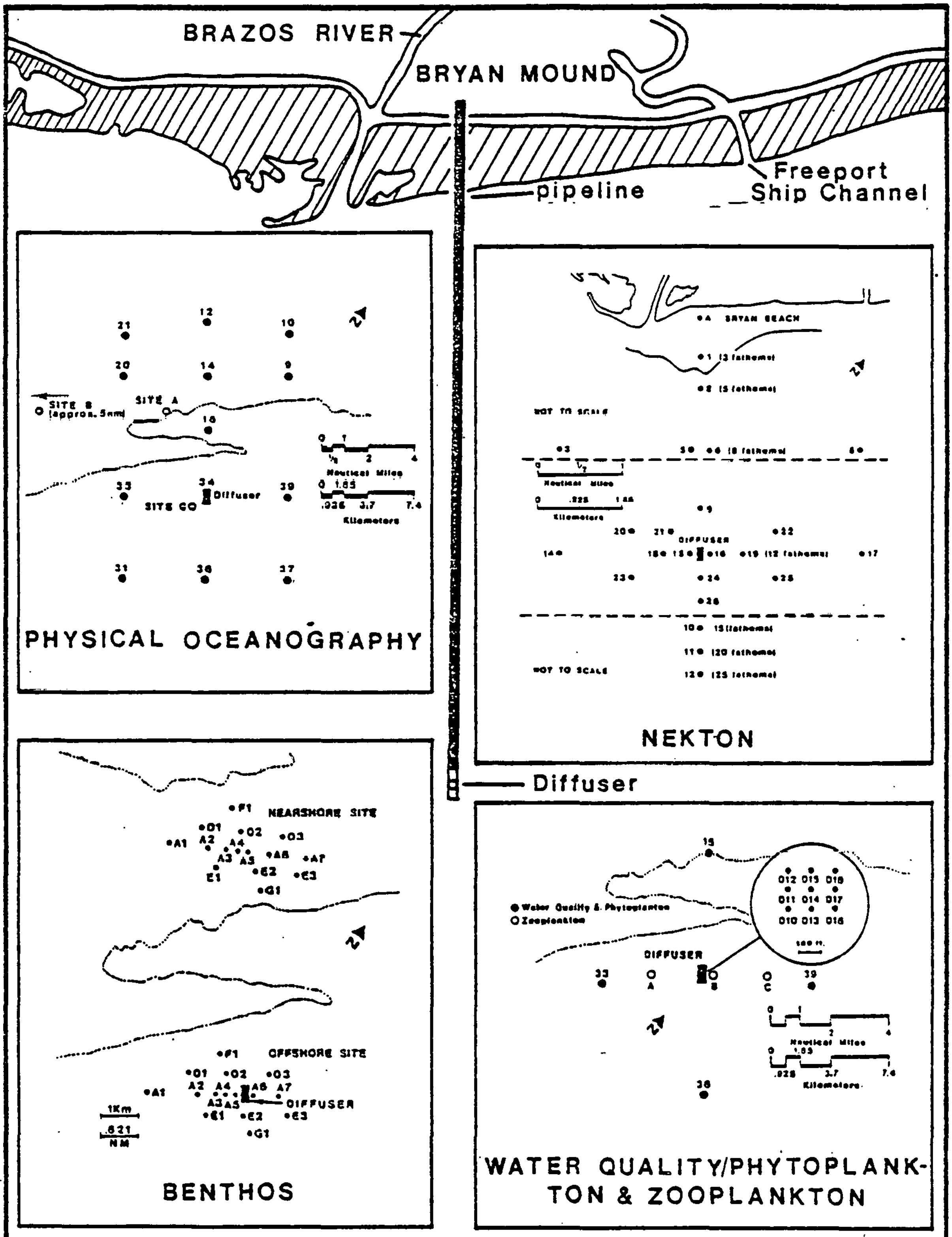

Figure 1. Composite of project sampling station locations.

zooplankton, and the data management. The specific objectives of this report are:

1) describe the physical oceanographic and meteorological conditions which have been measured at the offshore diffuser site and in the surrounding waters;

2) describe and compare the benthic community in the diffuser site area and a similar area approximately 7 nautical miles (13 km) inshore of the diffuser site;

3) characterize the planktonic community and the quality of the water and sediment in the vicinity of the diffuser site;

4) describe the design and testing of the monitoring system which is going to be used to track the brine plume;

5) characterize the nekton community in the vicinity of the diffuser and surrounding area with emphasis on commercially important species of shrimp and fish.

6) delineate the data management procedures used for the transmission of project data to the required data centers.

When this study was initiated in September 1977, it involved the areas of physical oceanography, water and sediment quality, analysis of the discharge plume, nekton community and the benthic community. The diffuser site had been selected for a location 5.5 miles (8.9 km) off the Freeport, Texas coast, and therefore, the sampling stations were centered around this nearshore site. However, environmental concerns made it apparent the diffuser would have to be moved to a location 12.5 statute miles (20 km) offshore. Therefore, additional sampling stations were added in the areas of physical oceanography and benthos in February 1978. In the winter of 1978-79 the laying of the pipeline from the Bryan Mound site to the diffuser location was begun and was completed in the summer. In the spring of 1979, the nekton component increased its sampling effort from a monthly basis to a twice monthly basis with both day and night cruises. Also, the physical oceanography component increased the number of current meter sites to two istes. Phytoplankton and zooplankton studies were added to the scope of the study in June 1979. When the pipeline was completed in July 1979 the third current meter site was installed near the diffuser. A composite of the sampling station locations for all the project team components is illustrated in Figure 1. This figure shows the most current sampling stations, but it should be kept in mind that some data was collected at stations which are not shown becuase the stations have been discarded as project changes have occurred.

Progress in the predisposal study has been reported in four progress reports dated February 1978, July 1978, February 1979 and July 1979. These reports were submitted to the Department of Energy through the Marine Environmental Assessment Division of the Environmental Data and Information Service EDIS, which is part of the National Oceanic and Atmospheric Administration (NOAA). In addition to these reports, a complete data set for the predisposal study has been submitted to EDIS. An early portion of the data from this study was used in the Department of Energy's environmental impact statement for Bryan Mound.

The physical oceanography studies include both bimonthly hydrographic cruises and continuously recording <u>in situ</u> instruments. The continuous recording current meters were originally deployed beginning in December 1977 at 3 m below the surface and 2 m above the bottom on a subsurface mooring system near an existing platform which is 6.5 nm (12 km) offshore and 1.5 nm (2.8 km) southwest of the pipeline. The mooring system has been maintained throughout the predisposal period. A second current meter mooring system was installed in May 1979 near a platform located at the same depth and distance offshore but 9.5 nm (17.6 km) southwest of the pipeline. Upon completion of the brine pipeline in the summer of 1979, the third current meter mooring system was installed in late August approximately 300 meters southwest of the end of the pipeline. Beginning in the fall of 1979 new current meters, which measured salinity and temperature in addition to current speed and direction, were installed at all the mooring locations at 3 m below the surface, mid depth and 2 m above the bottom. The volume of data from the three locations is extremely large and this report presents the data in the form of time series plots.

In addition to the continuous physical oceanographic data, bimonthly conductivity temperature and depth data were collected at top, middle and bottom depths at stations shown in Figure 1. The data are converted to salinity, temperature and density which are used to characterize the hydrography in the diffuser and surrounding areas in the form of vertical cross sections and time-depth plots of salinity, temperature and sigma-t. Meteorological and river discharge data are presented which complete the characterization of the environment.

The analysis of the discharge plume component is concerned with the actual measurement of the brine plume, and during this predisposal study, this component was involved with the design, development and testing of two different monitoring systems for tracking the brine plume. These two systems are described in detail. One of the monitoring systems was used to evaluate diffusion coefficients in the vicinity of the diffuser and these results are discussed.

The water and sediment component collected data which was used to characterize the quality of the sediment and water in the immediate vicinity of the diffuser and the surrounding area. Beginning in September 1978, limited water and sediment quality data was collected. In February 1979, full scale data collection commenced on a monthly basis at the stations shown in Figure 1, and the sediment data were collected quarterly. The monthly water quality data consisted of the salinity, dissolved oxygen, pH, nutrients, oil and grease, suspended solids, chlorophyll a, and pheophytin a pigments which were determined from top, middle and bottom water samples. The quarterly sediment samples were collected with a specially designed large box corer and were used to evaluate major cations, anions, heavy metals hydrocarbons, and pesticides.

Benthic data were collected monthly at the offshore diffuser site stations from December 1977 through February 1980 and from September 1977 through February 1980 at the inshore site stations which are shown in Figure 1. The data for this component was collected by divers who actuated small Ekman dredges on the sea floor and were able to observe the benthic environment which was being sampled. These data were used to characterize the population, species diversity, dominant species, natural variation of benthic organisms, and cluster analyses were completed to evaluate the ecological similarity in the area. Since the brine discharge is negatively bouyant, it is expected that the non-mobile benthic community should reveal the first indication of the effect of the brine discharge on the marine organisms in the diffuser area.

The initial nekton sampling program was conducted on a monthly basis, and the study emphasized three Penaeid shrimp species and the eleven most abundant fish species. In the fall of 1978, the study was expanded to consider all species of fish, and in the spring of 1979, the sampling program was expanded to twice monthly with one five-day cruise during the day and another separate five-day cruise at night. Trawling was conducted aboard chartered commercial shrimp trawlers along a transect in a depth range of 3 to 25 fathoms. Initially, the cruises included 19 trawls per cruise which expanded to 48 trawls per cruise at the trawling stations shown in Figure 1. The data were used to characterize the population and variation of species composition and to identify dominant species of commercially important shrimp and fish which are part of the large commercial shrimping and fishing industry in the Gulf of Mexico.

During the summer of 1979 the phytoplankton and zooplankton components of the project were added in order to provide a complete description of the marine environment of the Freeport coastal waters which would be impacted by the brine disposal. The phytoplankton monthly sampling stations were selected identical with those of the water and sediment quality component. The three zooplankton trawling stations were selected as shown in Figure 1. The data from these two components were used to describe the planktonic environment in the study area and its natural perturbations.

The project data processing activities include the maintenance of a centralized data storage and retrieval system based on file processing techniques and the provision of statistical and programming support for project scientists and engineers. Each area of the project lends itself to one or more separate data sets, which are maintained on computer disk files safeguarded with tape backups. Data sets are being maintained in the areas of physical oceanography, water and sediment quality, phytoplankton, zooplankton, benthos and nekton. Data for each area is entered onto on-line computer storage from either cards, computer terminal or magnetic tape.

Copies of the data are returned to the respective investigators for validation. Upon the return of the validated data sets, they are forwarded to the Environmental Data and Information Service.

The complexity of the Strategic Petroleum Reserve Program has required a multidisciplinary research effort which is coordinated by a management staff headed by Dr. Roy W. Hann, Jr., Program Manager, and Dr. Robert E. Randall, Associate Program Manager. The objectives of the management staff are to oversee the fiscal aspects of the project, act as laiason between principal investigators and sponsor, to coordinate program output such as reports and data transmittal, and to coordinate field operations. A separate unit of the management staff is the field organization located in Freeport, Texas. The field personnel are responsible for coordinating the use of the Civil Engineering Department's research vessel, R/V EXCELLENCE, and other contract vessels. In addition, the field personnel assist the principal investigators in the collection of field data. The contractural matters of the project are the responsibility of the Texas A&M Research Foundation

The final report of the predisposal studies is divided into two volumes. This volume, Volume 1, contains the technical description of the findings of the project team principal investigators. Volume 2 is an appendix volume which contains supporting data in the form of tables and figures.

Volume 1 is divided into chapters which correspond to the areas of responsibility of the principal investigators of the project team. These chapters are entitled Physical Oceanography, Analysis of the Discharge Plume, Water and Sediment Quality, Nekton, Benthos, Phytoplankton, Zooplankton and Data Management. The principal investigator for Physical Oceanography is Mr. Francis J. Kelly, who is a Research Associate in the Environmental Engineering Division of the Civil Engineering Department and a doctoral student in the Department of Oceanography. Dr. Robert E. Randall is the principal investigator for the Analysis of the Discharge Plume and he is associated with the Ocean and Hydraulics Engineering Division of the Civil Engineering Department. He also is responsible for the collection and description of the monthly hydrographic data discussed in the physical oceanography chapter. The principal investigator for Sediment and Water Quality is Dr. J. Frank Slowey of the Environmental Engineering Divison of Civil Engineering Department. Dr. Mark Chittenden is the principal investigator for the Nekton studies, and he is associated with the Wildlife and Fisheries Department. The principal investigators for the Benthos studies are Dr. Donald E. Harper and Dr. Larry D. McKinney who are associated with the Marine Science Department at Texas A&M University at Galveston. Mr. Robert J. Case is a Research Associate in the Environmental Enigneering Division of the Civil Engineering Department and is a doctoral student in computer science and statistics; he is the principal investigator for the Data Management section. Dr. Taisoo Park and Dr. Thomas Minello are the principal investigators for the Zooplankton studies and they are associated with the Marine Science Department at Texas A&M University at Galveston. The principal investigator for the Phytoplankton studies was Dr. William B. Wilson who unfortunately passed away in January 1980, and the responsibilities of writing his report have been assumed by Dr. Laurel A. Loeblich who is the present principal investigator for this component. She is associated with the Marine Science Department at Texas A&M University at Galveston.

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CHAPTER 1

PHYSICAL OCEANOGRAPHY

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1.1 Introduction

Since September 1977 physical oceanographic data have been collected in a region off Freeport, Texas as part of a multidisciplinary environmental study to establish a baseline and assess the impact of the disposal of brine resulting from salt dome leaching operations for the Strategic Petroleum Reserve (SPR) of the Department of Energy (DOE). The reasons for collecting the physical oceanographic data are fivefold:

1) to provide time-series of current velocity which are representative of the hydrographic seasons (Smith, 1979) and extreme conditions, i.e. periods of minimum and maximum current velocity, and time series which are coincident with periods of mapping of the discharge plume. These are used as input to the MIT Transient Plume Model developed for DOE (Gaboury and Stolzenbach, 1979).
2) to develop a hydrographic data base which permits an assessment of the magnitude of naturally occurring variations of salinity, temperature and density and defines ambient conditions during brine discharge.

3) to provide current velocity and hydrographic data to the other components of this project for use in the analysis and interpretation of their data.

4) to improve our understanding of the time-dependent dynamics of the waters of the shallow inner coastal zone, especially the near-bottom currents, and assess the relative importance of the various forcing factors: wind, air/sea heat exchange, tides and river runoff.

5) to serve as a prototype study for the development of efficient environmental monitoring plans for similar brine discharges in other areas.

The original design of this study was based on a brine diffuser located approximately five miles off Freeport, Texas, and a hydrographic sampling grid and current meter site were selected accordingly. In late 1977 an alternative diffuser site located approximately 12.5 miles offshore was proposed and subsequently selected, and the scope of this study was expanded. A larger but less dense hydrographic sampling grid which included the 12.5 mile diffuser site was established early in 1978, and additional current meter sites were established in May and August 1979. On March 10, 1980 the pumping of brine through the diffuser was begun, and the predisposal phase of this study ended.

The purpose of this report is to present in a comprehensive manner the hydrographic data and time series data collected from September 1977 through February 1980. Although the data collected from September 1977 through April 1979 are described in a series of pervious reports,(Hann et al., 1978a; Hann et al., 1978b; Hann, et al., 1979a; Hann et al., 1979b), they are included in this report for several reasons: the data from that period are spread over four separate reports; the formats in which the data are presented vary; and only representative hydrographic vertical sections and current velocity time series are shown. It is felt that a more comprehensive and consistent presentation of the data from the predisposal period, particularly the time series data, is needed to meet the goals of this study as stated above. The analysis and interpretation of this data is continuing, and although much has been included in this report, there are several areas of analysis which are still in progress at the time of writing. However, the need to have the physical oceanographic data base available for use dictated that there be some compromise in the scope of this report.

The hydrographic data and collection procedures are presented in Section 1.2. A dominant feature in many of the vertical sections is low salinity water runoff. Therefore, Section 1.3 presents some historical surface salinity data which cover the entire Louisiana-Texas shelf in order to place the Freeport, Texas, region in perspective. Streamflow data for Louisiana and Texas rivers for water years 1977 and 1978 have been analyzed to assess the relative importance of each river or combination of rivers in influencing the waters off Freeport, Texas. The meteorological wind data collected in our study area by NOAA/NDBO in shown in Section 1.4, and a summary of the meterological events during the 1977-1979 period, excerpted from Monthly Weather Review, is discussed. Finally, in Section 1.5, the time series data from the current meters are presented and discussed. Large groups of figures have been placed in appendices so as to avoid large breaks in the main text. In these cases, selected figures are duplicated in the main text for discussion. The data presentation formats, especially the time series figures, were chosen to convey as much detail as possible while still permitting trends to be visually discernible.

1.2 Monthly Hydrographic Data

1.2.1 Data Collection Equipment and Procedures

During the first four months, September through December 1977, a Beckman RS-5 portable induction salinometer was used to measure the salinity and temperature. The accuracy of this instrument is $\pm .5\ ^\circ/_{\circ\circ}$ and $\pm\ .5^\circ C$. Beginning in February 1978, a model TC-2 four-electrode type conductivity meter manufactured by Hydrolab Corporation was used to measure conductivity and temperature. A Plessey laboratory salinometer and collected water samples were used to obtain a calibration curve for the field conductivity meter after each sampling cruise. The accuracy of the laboratory salinometer is $\pm\ .003\ ^\circ/_{\circ\circ}$. The calibration curves are used to correct the field data, and the resulting accuracy for the salinity data is estimated to be $\pm\ .5\ ^\circ/_{\circ\circ}$. For temperature, the accuracy of the data is $\pm\ .5^\circ C$. Depth measurements were determined by the length of cable below the water line. The cable was marked every 1.5 meters, and the accuracy of this measurement is $\pm$ .3 meters. In April 1979, the Hydrolab 8000 water quality system was received and used to measure conductivity, temperature and depth. This instrument is also a four-electrode conductivity meter and also has a depth sensor. The Plessey laboratory salinometer was again used to obtain a correction curve for the field instrument. The resulting accuracy is estimated to be $\pm\ 0.2\ ^\circ/_{\circ\circ}$ and $\pm\ 0.2^\circ C$ for salinity and temperature respectively. The accuracy of the depth measurement is $\pm$ 1 meter.

Two types of remote reading current meters have been used to collect instantaneous current measurements at the locations and depths of hydrographic samples for use in stability calculations. From September 1977 to December 1979, a Hydroproducts Model 460 current speed sensor and a Model

465-A current direction sensor were used. This current meter system has a Savonius rotor for the speed sensor which has an accuracy of ± 3% of the reading. The direction sensor is vane coupled to a magnetic compass and its accuracy is ± 5°. Beginning in January 1980, an Endeco Type 923 remote reading current meter was used. This instrument is a ducted propeller type current meter which is tethered to a weighted line. The instrument is free to align itself with the current and uses a magnetic compass to determine current direction. The accuracy of this instrument is ± .15 knots (7.7 cm/s) and ± 10°.

Since September 1977, conductivity, temperature and depth data have been collected at the surface (2 m below surface), mid depth, and bottom (2 m above bottom) at stations 1 through 27 shown in Figure 1-1. The stations monitored and the frequency of cruises each month has varied because of weather and time available for sampling. It was planned to collect data two days per month and to cover three transects each day with the pipeline transect duplicated each day. The data were collected after arriving at the designated LORAN A coordinates of each staiton. LORAN C coordinates were used after August 1979. The depth of the water was recorded by the ship's fathometer and then the conductivity, temperature and depth (CTD) instrument was lowered over the side of the vessel, normally the R/V EXCELLENCE, on a weighted line so that only small wire angles were encountered to the desired depths. The depth was determined by the length of the cable payed out which was marked every 1.5 meters. Beginning in April 1979 the depth readout on the Hydrolab 8000 was used to determine the depth of the probe. The data were read from the top side instrument readout device and recorded in the field data book.

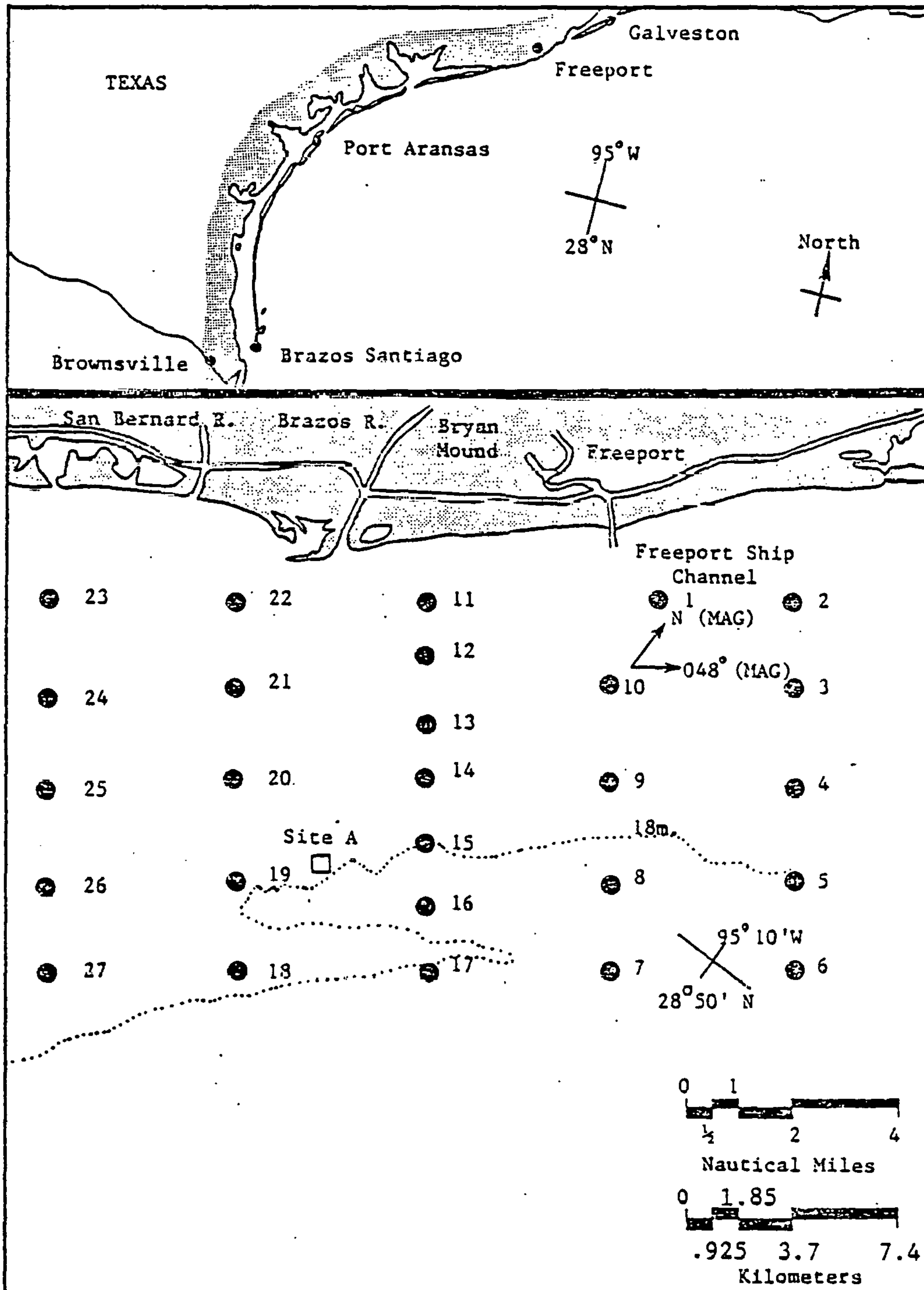


Figure 1-1. Location of study area and initial CTD measurement stations

Originally the diffuser was to be located at station 14 which was the center of the sampling grid (Figure 1-1). However, in the winter of 1977-1978, it became apparent that the diffuser might be moved further offshore. Therefore, the probable location of the diffuser (station 34) was determined, and beginning in February 1978, it was included in the routine data collection. In April 1978, a new sampling grid was approved and it is illustrated in Figure 1-2. The original outer transect lines were dropped and the entire grid was sampled each sampling day. In order to do this, some of the original sampling stations had to be deleted and were classified as secondary stations. Every effort was made to collect data for the stations along the pipeline transect and the alongshore transect (stations 39, 34, 33) through the diffuser site.

In February 1979 the pipeline transect was extended two nautical miles further offshore to include station 36 as shown on Figure 1-3. For this grid, stations 12, 14, 16, 34, 36, 33 and 39 were always to be sampled, and the secondary stations 10, 9, 20, 21, 31, and 37 were sampled when weather and time permitted. This sampling grid was maintained for the remainder of the predisposal study. The latitude and longitude of all the grid stations are tabulated in Table 1-1.

1.2.2 Calibration and Conversion of Raw Data

The conductivity data are corrected to 25°C by an internal compensation circuit within the Hydrolab TC-2 and 8000 instruments. The conductivity (C) data are converted to salinity (S) using:

$$S = 8.48 \times 10^{-4} C^2 + 6.56 \times 10^{-1} C - 2.10 \qquad (1.1)$$

which is a curve fit to the conversion curve presented in the operating instructions for the Hydrolab Model TC-2 conductivity meter (Hydrolab,

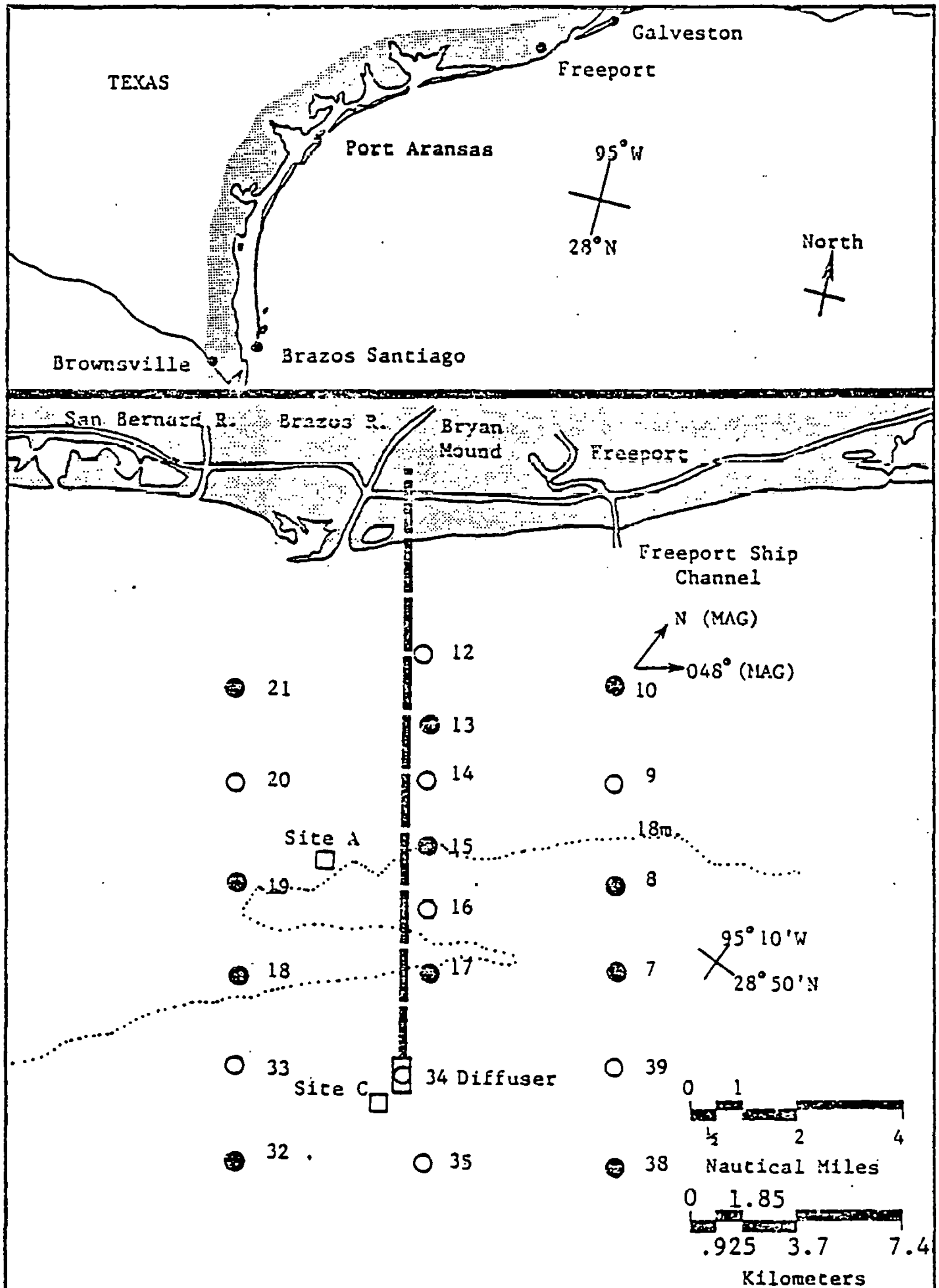


Figure 1-2. Location of CTD measurement stations. Primary and secondary stations are indicated by ○ and ⊜ respectively

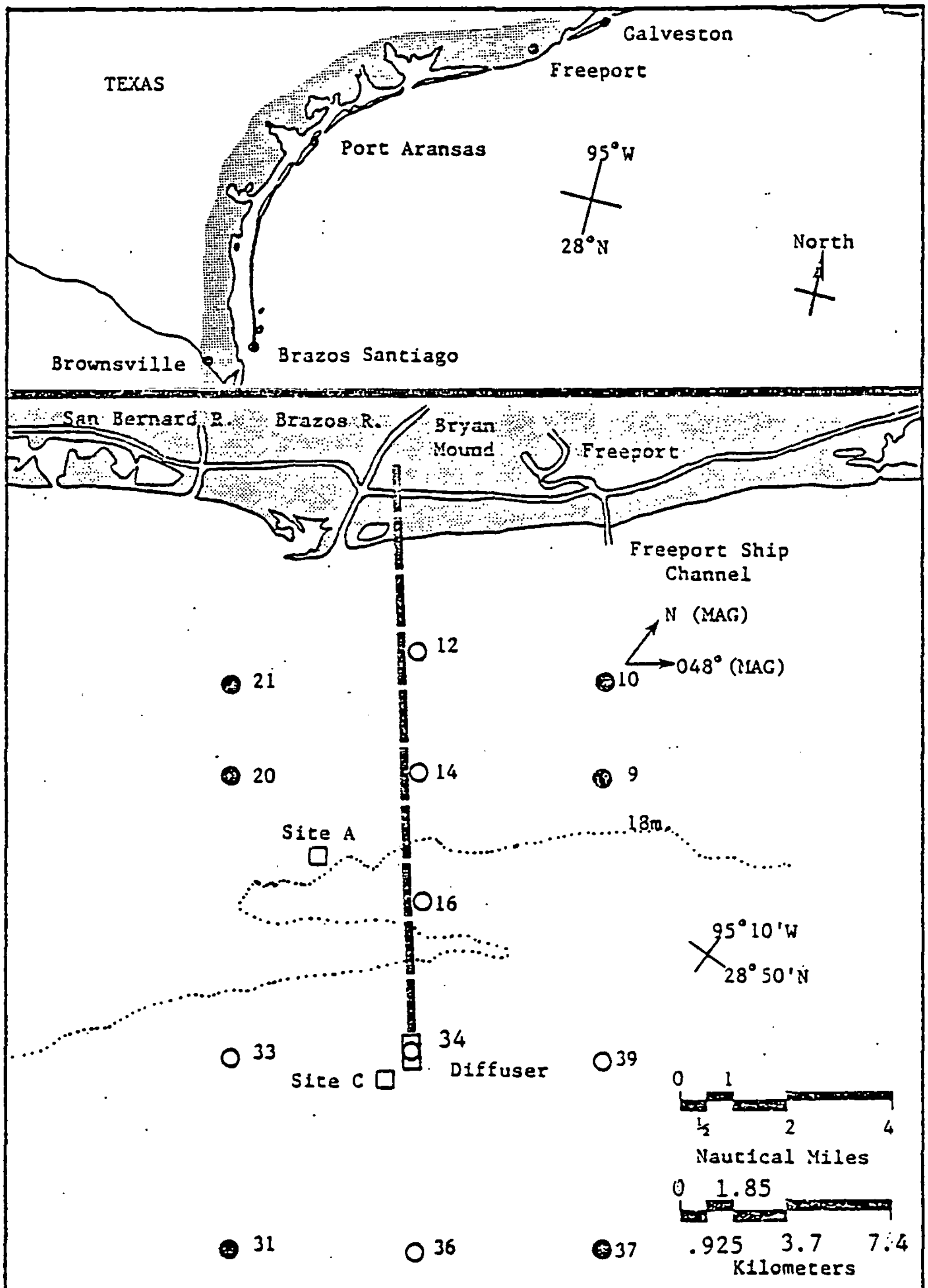


Figure 1-3. Final location of CTD measurement stations. Primary and secondary stations are indicated by ○ and ● respectively

Table 1-1. Latitude and longitude for conductivity, temperature, and depth field measurement stations

Station Number	Latitude	Longitude
1	28°55.67'N	95°16.05'W
2	28°57.40'N	95°13.28'W
3	28°55.80'N	95°11.96'W
4	28°54.20'N	95°10.68'W
5	28°52.56'N	95°09.35'W
6	28°50.90'N	95°08.00'W
7	28°48.58'N	95°11.68'W
8	28°50.20'N	95°13.00'W
9	28°51.83'N	95°14.28'W
10	28°53.44'N	95°15.60'W
11	28°52.75'N	95°20.65'W
12	28°51.69'N	95°19.74'W
13	28°50.60'N	95°18.89'W
14	28°49.50'N	95°17.99'W
15	28°48.44'N	95°17.11'W
16	28°47.33'N	95°16.20'W
17	28°46.26'N	95°15.35'W
18	28°43.93'N	95°19.00'W
19	28°45.58'N	95°20.31'W
20	28°47.19'N	95°21.60'W
21	28°48.80'N	95°22.96'W
22	28°50.43'N	95°24.30'W
23	28°48.12'N	95°27.93'W
24	28°46.50'N	95°26.61'W
25	28°44.87'N	95°25.32'W
26	28°43.25'N	95°24.00'W
27	28°41.67'N	95°22.68'W
31	28°39.10'N	95°15.05'W
32	28°40.70'N	95°16.30'W
33	28°42.30'N	95°17.70'W
34	28°44.45'N	95°14.67'W
35	28°43.05'N	95°12.75'W
36	28°41.40'N	95°11.45'W
37	28°43.70'N	95°07.80'W
38	28°45.40'N	95°09.10'W
39	28°47.00'N	95°10.40'W

1974) and Model 8000 water quality instrument (Hydrolab, 1978). Beginning in December 1979, the conversion of conductivity to salinity used equation 1-2 by Weyl (1964),

$$S = 1.80655 \times 10^{\frac{\log_{10}C - 0.57627}{0.892}} \tag{1-2}$$

where C is the conductivity in millimho/cm referenced to 25°C. (The conversion curve in the Hydrolab instruction was based upon data points obtained from Equation 1-2). The salinity data obtained from the conversion were then corrected as required by calibration results.

The temperature data were used as read from the instrument. To date the temperature measurements have been within manufacturers specifications. Corrections to the depth reading have been necessary for the Hydrolab 8000 as a result of a zero offset determined at the beginning of a sampling day.

The salinity, temperature, and depth data were used to compute the density of the water column which is presented in the customary oceanographic form of sigma-t (σ_t) defined as

$$\sigma_t = (\rho - 1.0) \times 10^3 \tag{1-3}$$

where the density (ρ) was expressed in gm/cm^3. Sigma-t values were computed from salinity, temperature and depth using the equation of LaFond (1951).

After the salinity was determined from the measured conductivity data, it was necessary to correct the salinity values with a calibration curve. This calibration curve was obtained for each field cruise by collecting water samples which covered the range of salinities observed in the study area that day. The field instrument was submerged in each water sample and the conductivity was recorded and converted to salinity.

The samples were then processed through the laboratory salinometer and the salinity readings were recorded. Next, the field instrument and laboratory salinometer readings for salinity were plotted and a linear curve fit was obtained for the data. This curve fit equation was then used to correct the field data. An example of one calibration plot is illustrated in Figure 1-4. Calibration of temperature was checked periodically and was found to be within $\pm$ .5°C so no corrections were made to the temperature data. These calibration procedures were applied as soon as possible, one to three days, after each cruise.

1.2.3 Vertical Cross Sections of Temperature, Salinity and Sigma-t

Conductivity, temperature, and depth (CTD) data have been collected for specified stations at top (2m below surface), mid depth, and bottom (2 m above bottom) beginning in September 1977. The conductivity was converted to salinity (S). Temperature and salinity were used to compute density which is expressed in terms of sigma-t. The effect of pressure on density at these shallow depths is negligible. These data were collected to assess the magnitude of naturally occurring variations in the study area and define the ambient state once discharge began.

The presentation of the CTD data is in the form of vertical cross sections for a transect parallel to the pipeline (cross-shelf) and a transect normal to the pipeline through the diffuser location (alongshore). The stations for the cross-shelf transect are numbers 12, 13, 14, 15, 16, 17, 34, 35, and 36. For the alongshore transect they are 39, 34, and 33; all are shown in Figures 1-1, 1-2, and 1-3. The entire set of vertical cross sections for each day of sampling for the predisposal period is contained in Appendix 1. In the remainder of this section representative

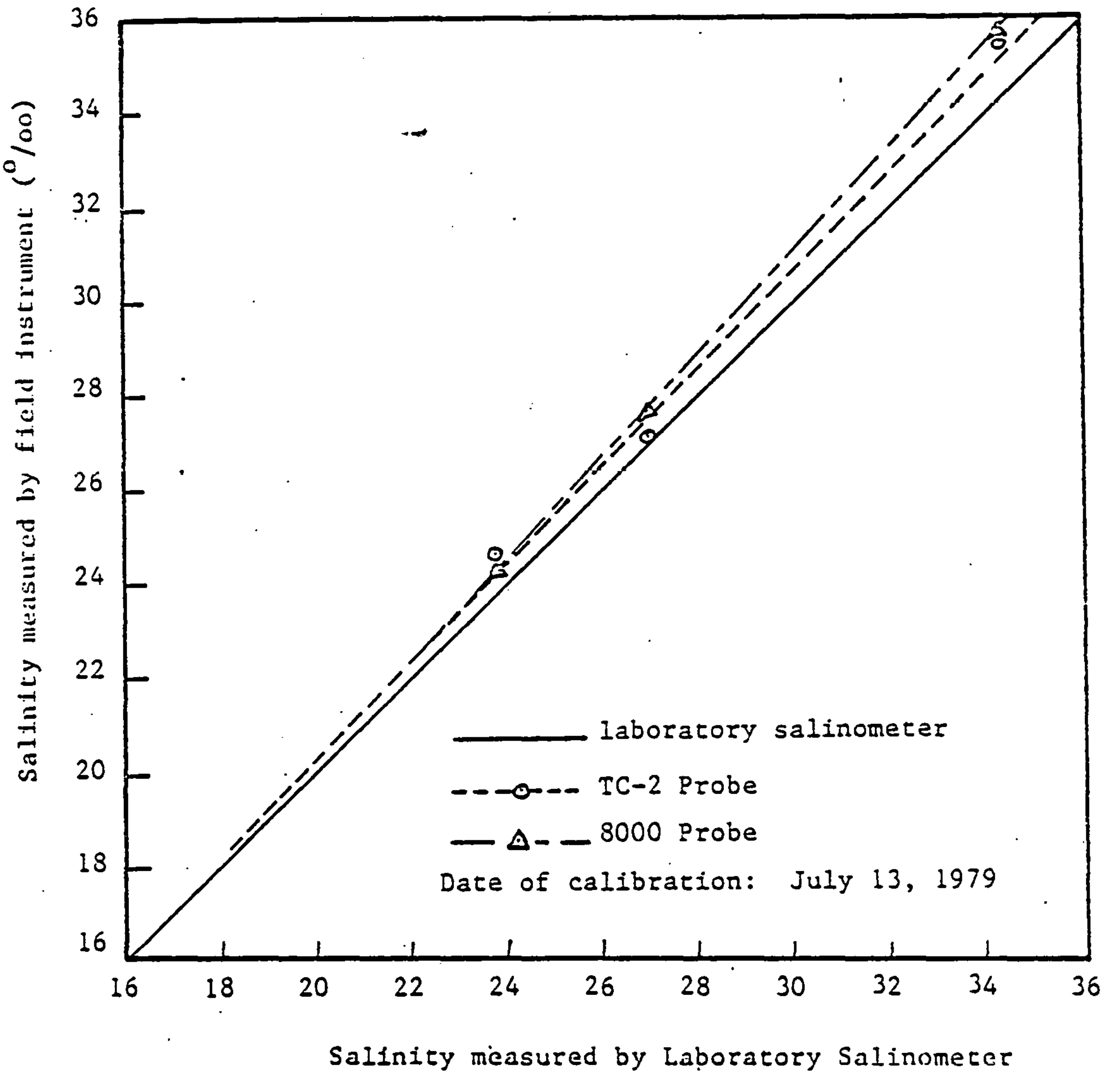


Figure 1-4. Sample calibration curve for field salinometer

cross sections will be used to describe the variations of the hydrography of the study area.

The data collected from September through November 1977 along the pipeline transect show that the water column was very weakly stratified. The November data (Figure 1-5) show that a slight decrease in surface salinity at the innermost stations occurred. The temperature of the water column was isothermal in September. In October and November there was a small top to bottom temperature difference. The sigma-t data indicate there was a slight increase in the density with depth. The salinity data for September may indicate a slight upwelling along the bottom, but in October and November the temperature indicates a slight downwelling or sinking. In the alongshore direction, the November 1977 data for stations 4, 9, and 14 show that the maximum temperature and salinity variation was 0.5°C at the bottom and 0.5°/oo at the surface. Thus, during this period, the surface nearshore salinities were slightly lower than the bottom offshore salinities, the warmer water was found offshore, and the water column was very slightly stratified.

The hydrographic conditions found in December 1977, Figure 1-6, are representative of the winter and early spring months of 1978. These data show the layering of the water column with isohaline, isothermal, and isopycnal lines being nearly horizontal. The thermocline and pycnocline occur just below mid depth, and the existence of this pycnocline inhibits turbulent mixing between the top and bottom layers. These conditions are a significant contrast to those found in the fall but are similar to those found in January through April. The variation alongshore was not large, but it was significant. For example, at 12 meters the salinity varies from 30.3°/oo at station 9 to 31.0°/oo at station 20, and the temperature varies from 17.2°C to 17.9°C.

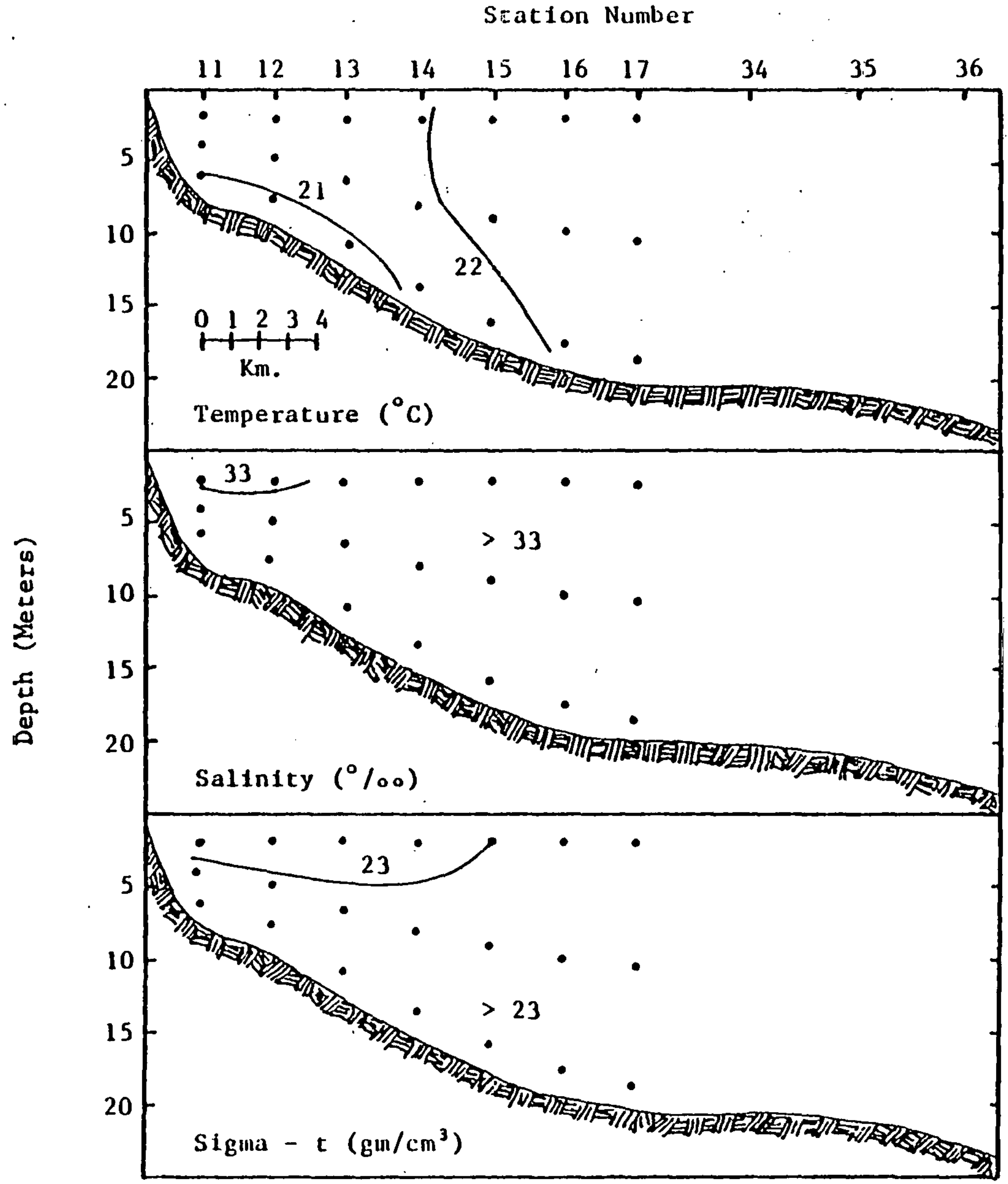


Figure 1-5. Hydrography for cross-shelf transect offshore Freeport, Texas for November 17, 1977.

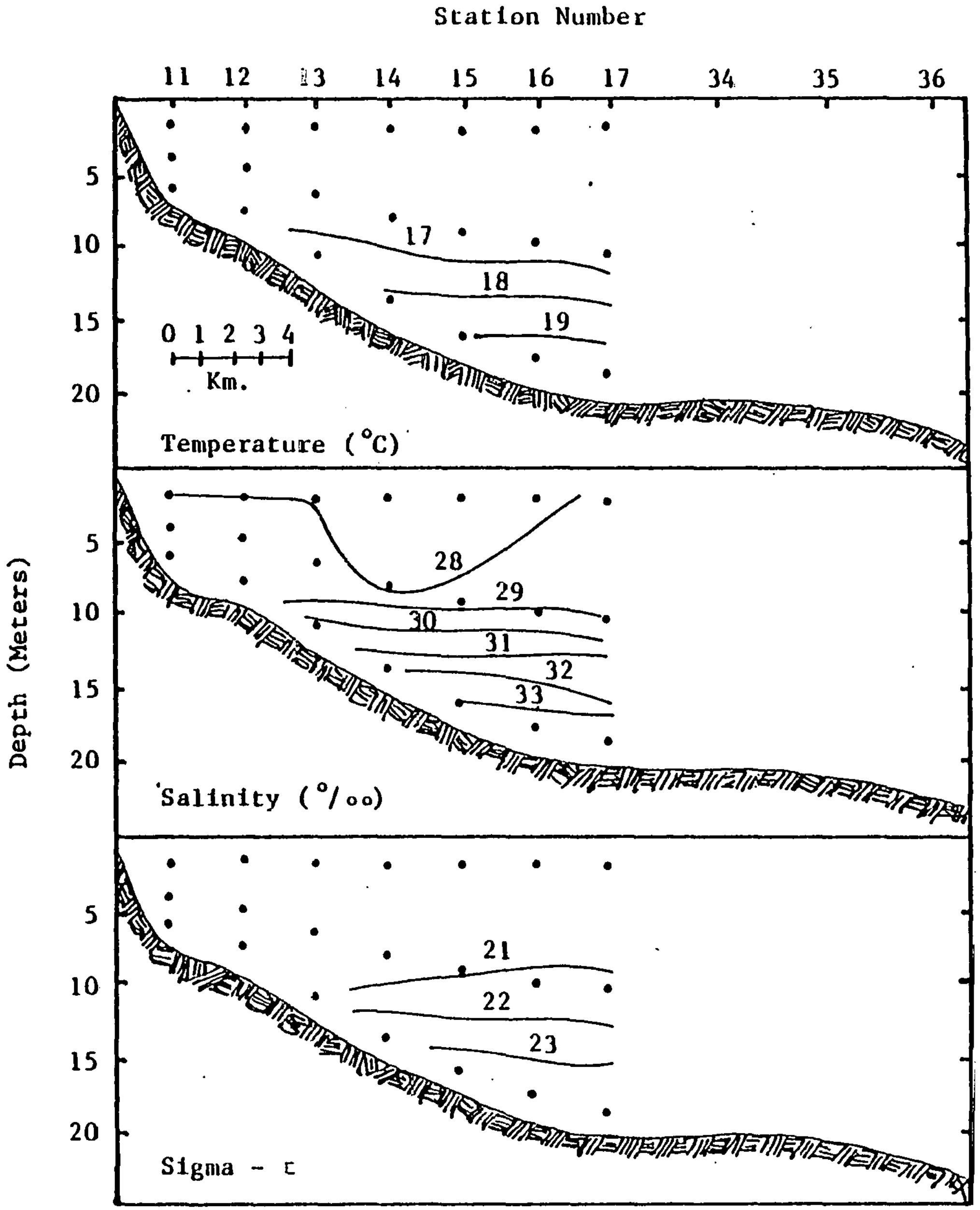


Figure 1-6. Hydrography for cross-shelf transect offshore Freeport, Texas for December 18, 1977.

The late spring months of 1978 are typified by the May 26 data (Figure 1-7). These data show the isopleths to be approximately at 45 degrees with the horizontal. The salinity and sigma-t values are increasing with distance offshore, and the temperature decreases with distance offshore. The thermocline and pycnocline are not present in the near shore area (station 14), but they are present at the diffuser site (station 34) and are weaker than those encountered in the winter. These conditions were typical for the pipeline transect during the months of May and June 1978. Salinity, temperature and density in the alongshore direction show small variation in the surface layer, and a larger variation in the bottom layer at 18 meters.

The August 30 and September 25, 1978 data are plotted on Figures 1-8 and 1-9. They are representative plots for the summer months of July, August, and September. In August (Figure 1-8) the cross-shelf and alongshore transects show the water column to be essentially isothermal. The salinity and sigma-t alongshore variation is extremely small and the cross-shelf transects of salinity and sigma-t show the isohalines and isopycnals are at approximately a 45 degree angle. The salinity and density increase rapidly across a frontal zone which is most often located inshore of the diffuser site. In the July sections there are indications of cooler, more saline water being upwelled along the bottom. The September 25, 1978 data, (Figure 1-9) show a continuation of the nearly isothermal water column, but the temperature had decreased from 30°C to 28°C. The salinity data show a gradient of approximately 5°/oo from top to bottom except for the nearshore region where the water column is nearly isohaline. The August 1978 vertical salinity gradient was not as strong. The isopycnal lines are about 45 degrees from the horizontal, and the sigma-t values vary from 17 to 20 at station 34 which indicates a more stable water column than that of the previous month. The data show that during the summer months

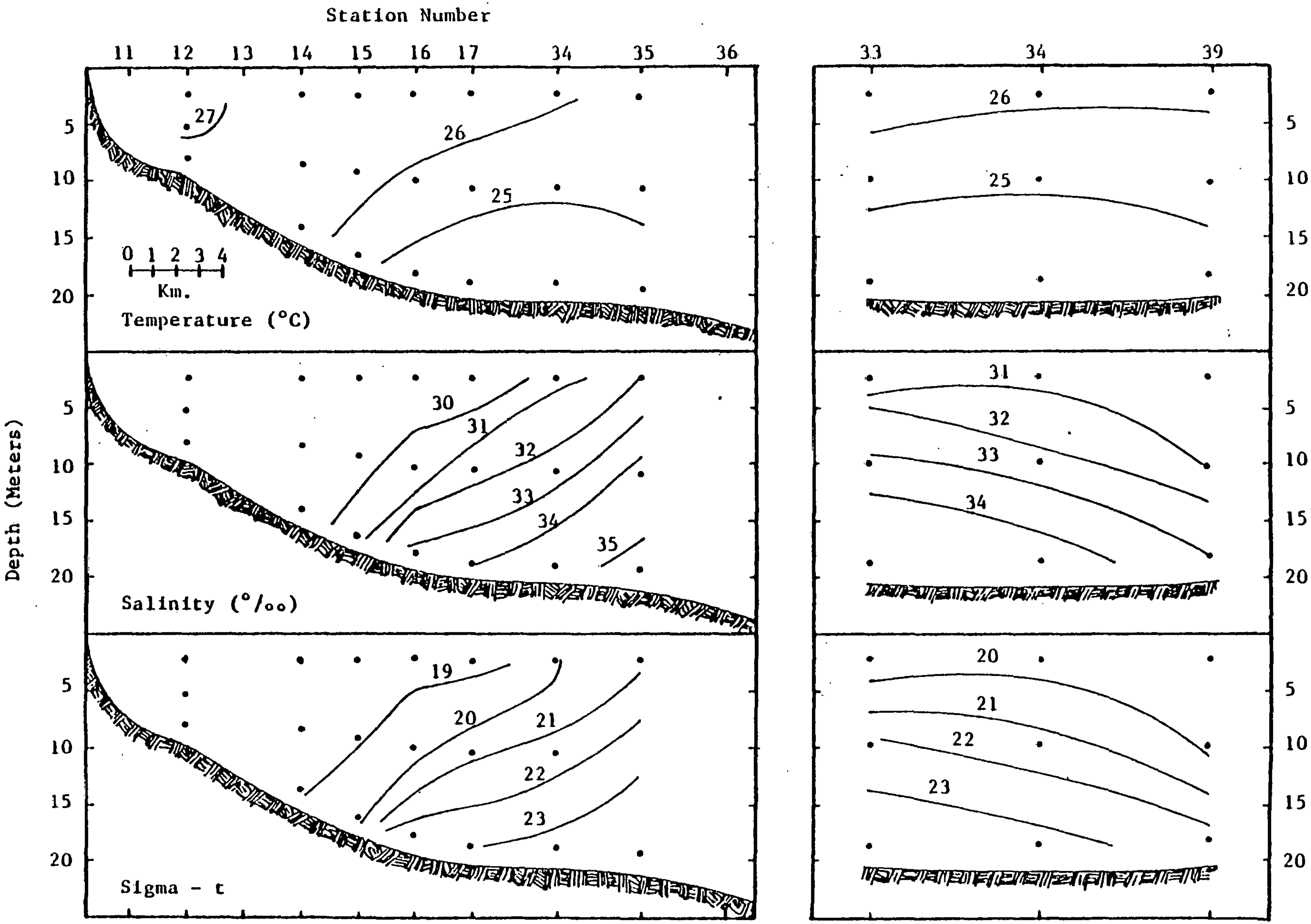


Figure I-7. Hydrography for cross-shelf (left) and alongshore (right) transects offshore Freeport, Texas for May 26, 1978.

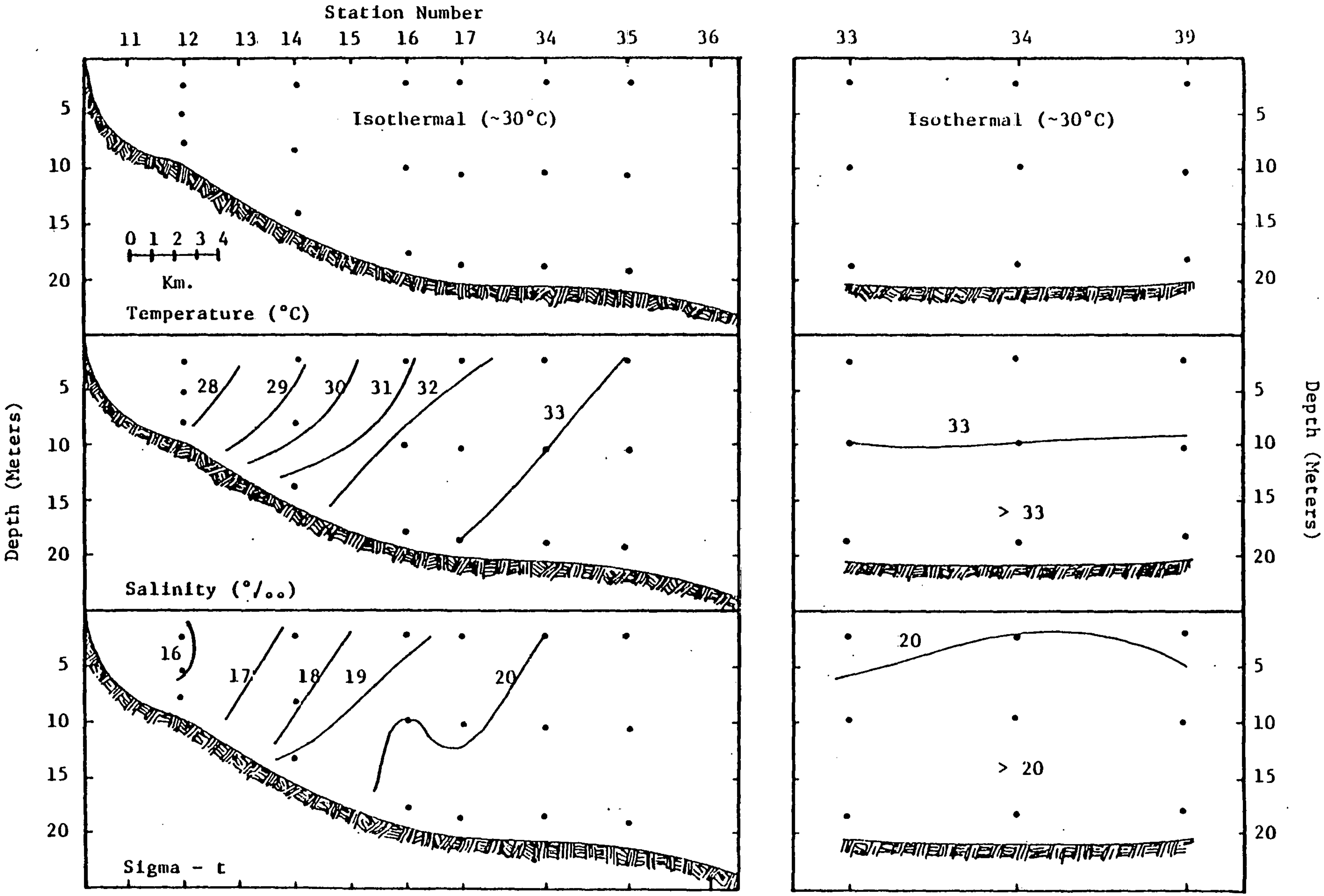


Figure I-8. Hydrography for cross-shelf (left) and alongshore (right) transects offshore Freeport, Texas for August 30, 1978.

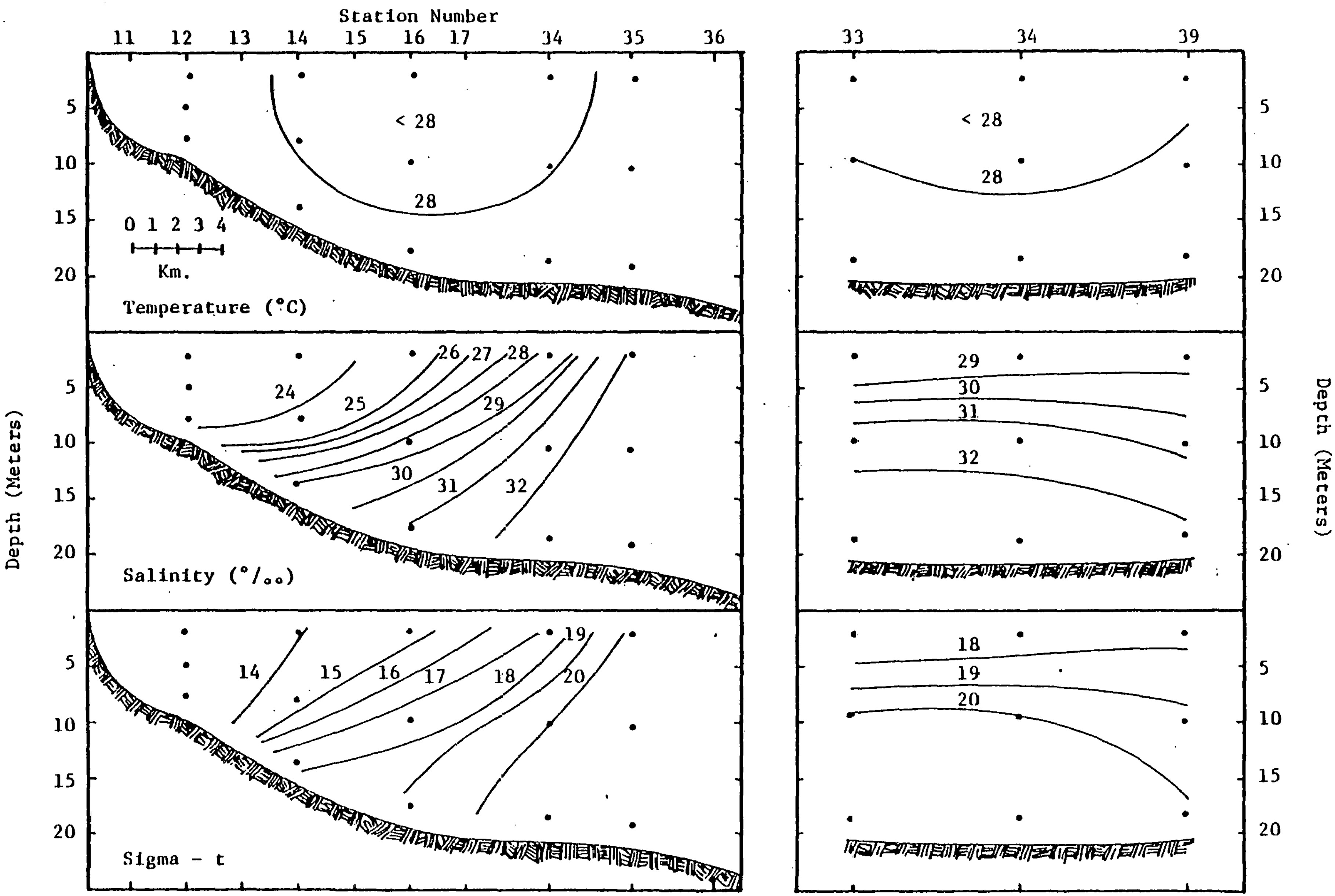


Figure 1-9. Hydrography for cross-shelf (left) and alongshore (right) transects offshore Freeport, Texas for September 25, 1978.

of 1978 the coastal waters in the study area were nearly isothermal, but a frontal zone was often present because of lower salinity water near the coast.

In October 1978 (see Appendix 1), the water temperature of the study area further decreased to 24°C and a very slight thermal stratification developed. The vertical variations in salinity and sigma-t were approximately 2°/oo and 1, respectively. The pycnocline frontal zone weakened and moved inshore. The data of November 1978 (Figure 1-10) are typical of conditions for the fall of 1978. These data show an isothermal and well mixed water column with no pycnocline. The salinity and density increase with distance offshore, and the isopleths are vertical. The temperature variation alongshore on a transect through the diffuser site is less than 0.3°C, and salinity and sigma-t vary by approximately 0.5 °/oo and 0.5, respectively. The data for November 17, 1977 (Figure 1-5) were not collected as far offshore, but they also showed a well mixed condition. The data taken on December 18, 1978 (see Appendix 1) indicate a well mixed condition similar to the November 1978 data. This is in contrast to the stratified conditions of December 1977 when the isopleths of salinity and sigma-t were horizontal.

In the winter (Jan., Feb., March) of 1979 the stratification increased and the frontal zone indicated by the isohalines and isopycnals was at an approximate 45 degree angle with the vertical was shown by the February 12, 1979 data, Figure 1-11. At the diffuser site (station 34), the salinity changes from 32 to 35 °/oo from top to bottom and sigma-t increases from 25 to 27. This indicates a stratified water column with the pycnocline occurring near mid depth in the vicinity of the diffuser site. However, there is only a slight variation in the alongshore direction of salinity and sigma-t (0.8°/oo and 0.6). Similar conditions were found in March 1979. There is an indication of upwelling along the bottom in March. The

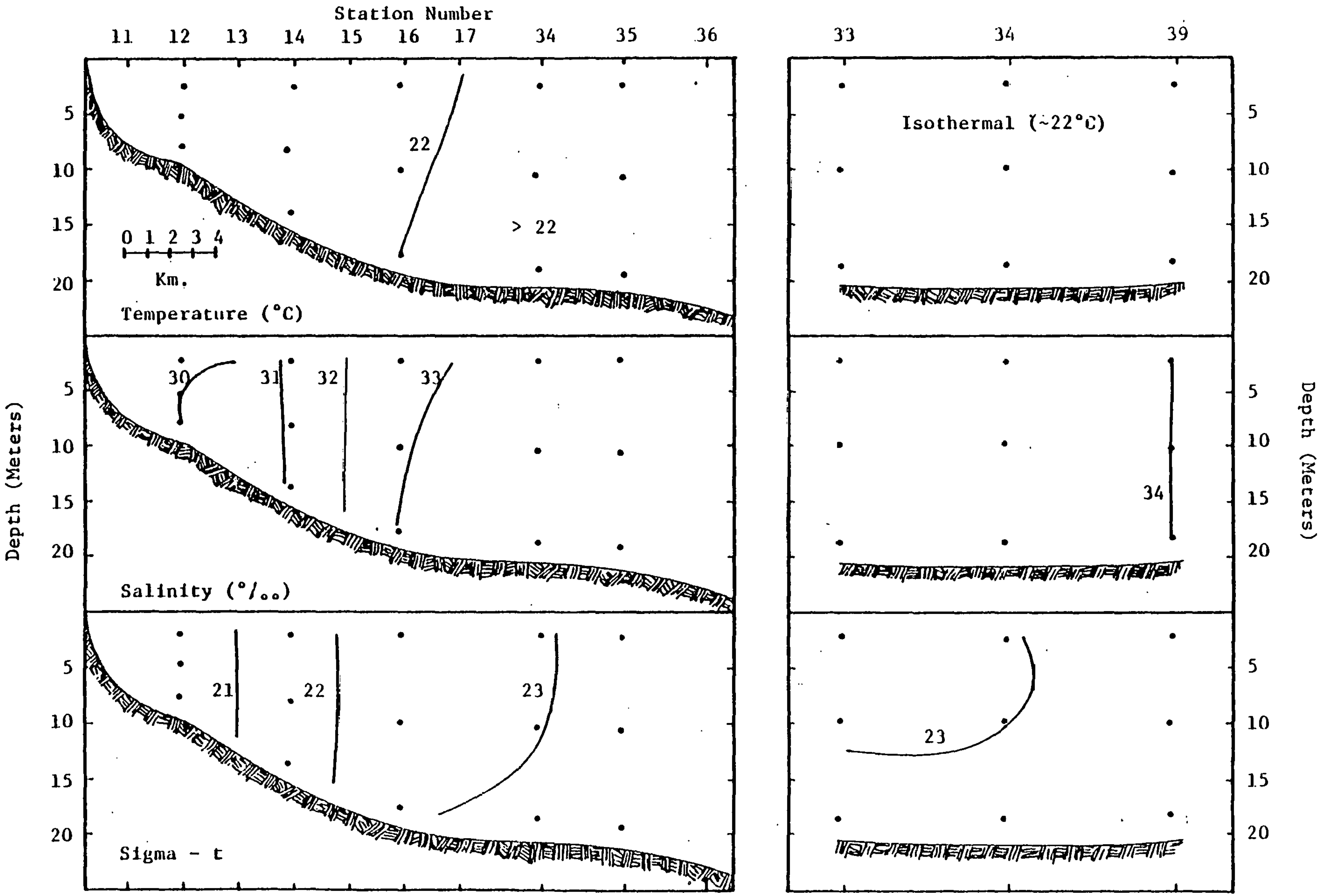


Figure 1-10. Hydrography for cross-shelf (left) and alongshore (right) transects offshore Freeport, Texas for November 18, 1978.

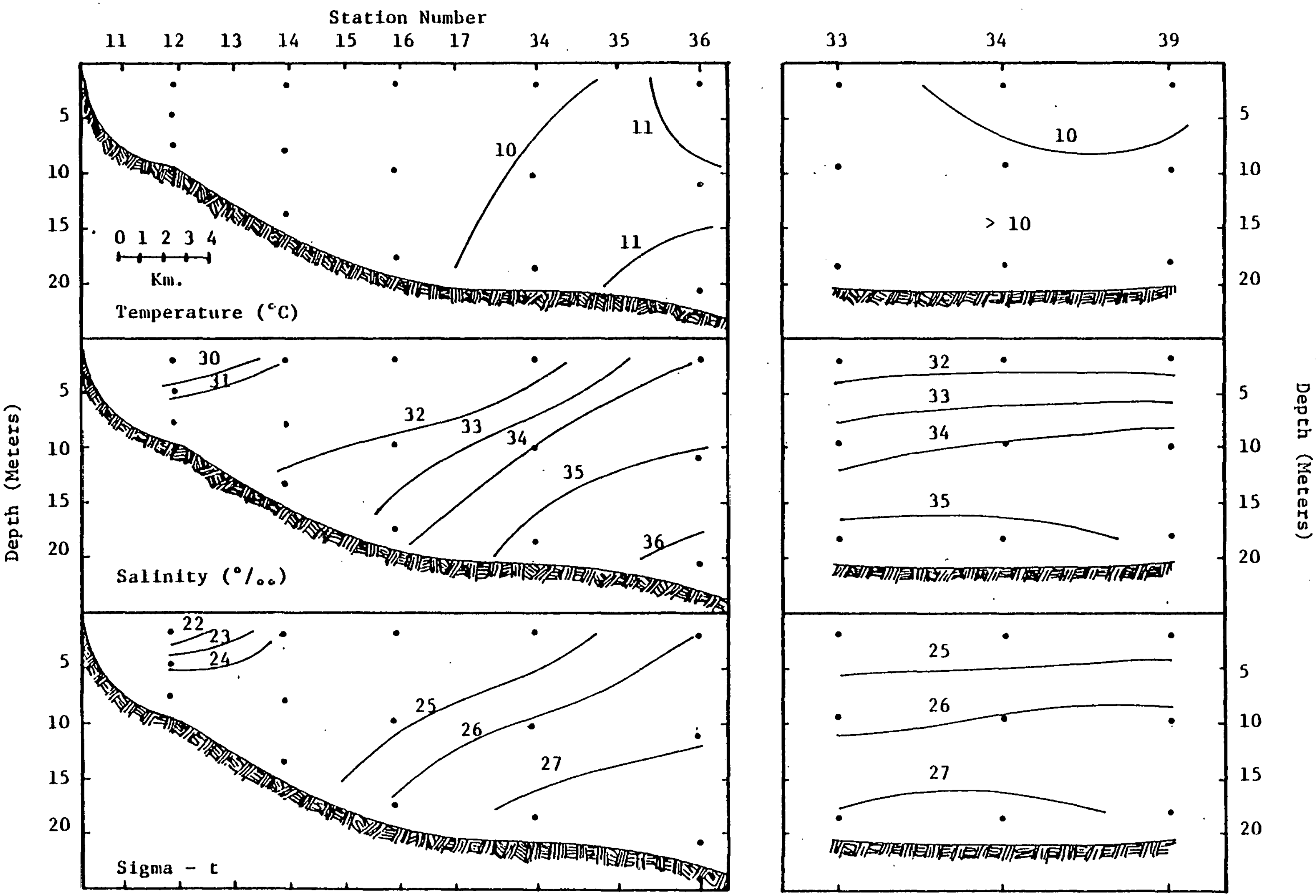


Figure 1-11. Hydrography for cross-shelf (left) and alongshore (right) transects offshore Freeport, Texas for February 12, 1979

hydrographic data collected in the winter of 1979 have characteristics similar to those in 1978, but the pycnocline and the resulting stratification are not as strong.

During the winter months, wave heights greater that two meters occur frequently, and this normally occurs when a frontal system passes through the area. At the start of the project it was believed that the water column would be well mixed due to turbulent mixing action of waves and currents. Since a majority of our winter data collection cruises occur immediately following a frontal system passage, well mixed conditions should be observed during the cruises if a high sea state is to result in well mixed conditions. However, the data do not support this belief but indicate the water column remains stratified.

During April 1979 very strong stratification existed as shown in Figure 1-12. The temperature decreases with distance offshore and a slight thermocline exists. The isohalines and isopycnals are nearly horizontal, and a strong pycnocline exists at station 14, approximately 5 nautical miles offshore. At this location the salinity changes from 21 to 31^{o}/oo from top to bottom, and sigma-t increases from 13 to 21. The alongshore transect through the diffuser site (station 34) shows a small variation of temperature, salinity and sigma-t (i.e. 0.4^{o}C, 0.1^{o}/oo, 0.05) at the bottom, and the pycnocline in the upper layer is evident. Conditions found in April were much more severe than those found in the spring of 1978 which were typified by the May 26, 1978 data previously shown in Figure 1-7. The strong stratification due to the warm, relatively fresh water persisted through mid-July. The origin of the fresher water which causes the strong stratification, is runoff from the Mississippi/Atchafalaya river system. This is supported by GUS III data and meteorological data which are discussed in section 1.3.

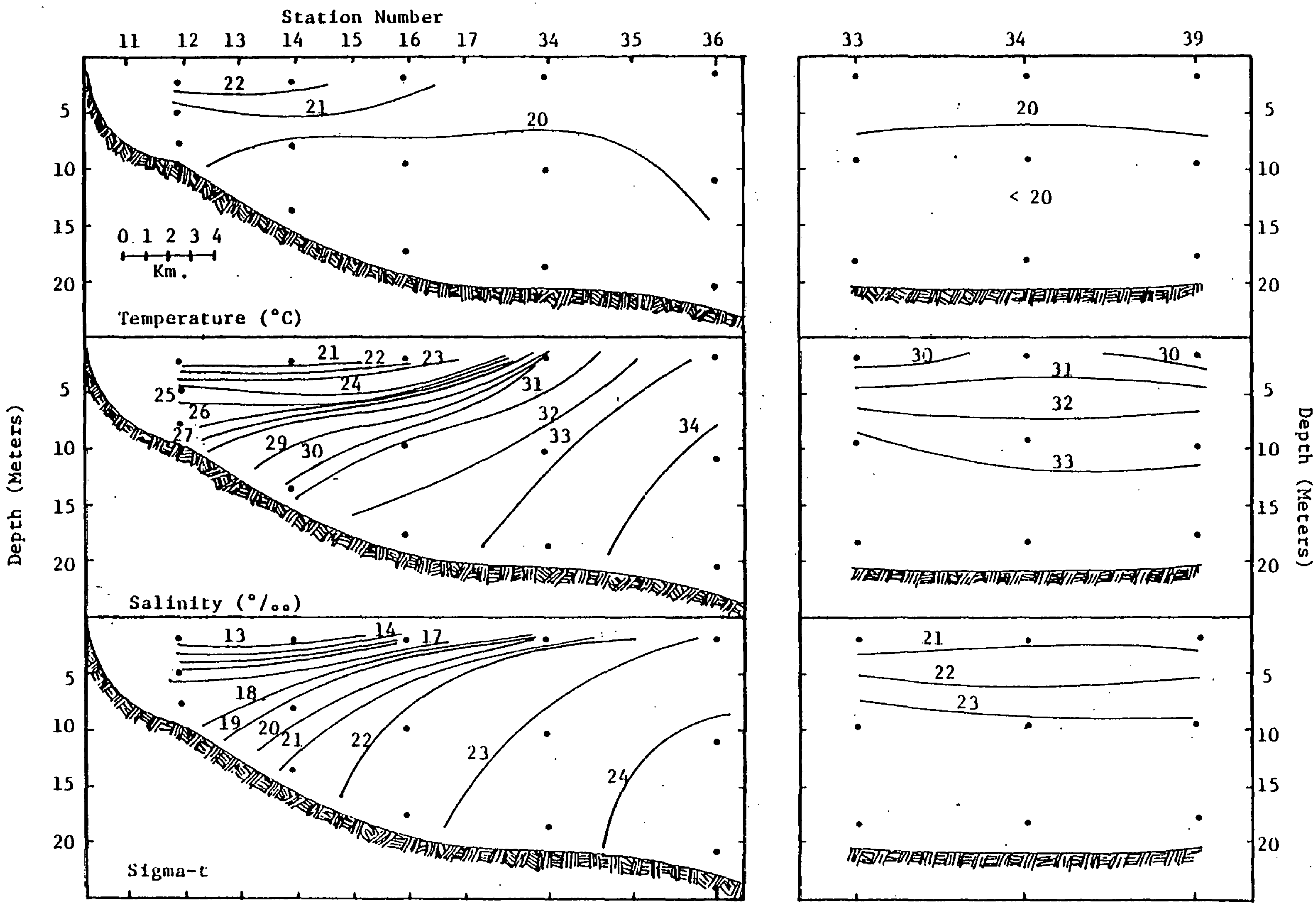


Figure 1-12. Hydrography for cross-shelf (left) and alongshore (right) transects offshore Freeport, Texas for April 13, 1979

The early summer months of 1979 are typified by the June 28, 1979 data shown in Figure 1-13. This shows a very large temperature difference from top to bottom (31°C to 24°C) and the isotherms are nearly horizontal and close together indicating a strong thermocline. The isohalines and isopycnals are also horizontal and close together which leads to a strong pycnocline and a highly stratified water column. For example, the sigma-t units at the diffuser site (station 34) vary from 13 at the top to 23 at the bottom. This is more extreme than 1978 where the variation in sigma-t was 15 to 21 (see Appendix 1). These extreme conditions are the result of a very wet spring and the large runoff from the rivers northeast of the study area. The alongshore variation is very small as shown by the alongshore transect.

During the remainder of the summer months the magnitude of vertical stratification for temperature, salinity, and sigma-t decreased except near the surface at the inner stations. The isopleths remained relatively horizontal for all the cruises, but they were farther apart than earlier in the year. For example, the August 15, 1979 data (Figure 1-14) shows the temperature variation is 4°C over the depth and the sigma- t increases from 18 to 23 at station 34. This is a significant contrast to the conditions found August 31, 1978 when the temperature was essentially isothermal, the isohalines and isopycnal were vertical and increased in value from nearshore to offshore.

In the fall of 1979 the stratification began to weaken as shown in Figure 1-15. The November 6, 1979 data show a small variation in temperature approximately 2°C from top to bottom and 1°C in the alongshore direction. The isopycnal and isohalines are at 45° with the horizontal and the salinity and density increases with distance offshore and down the coast. Stratification is mild, but is much stronger than that found in November 1977 and 1978

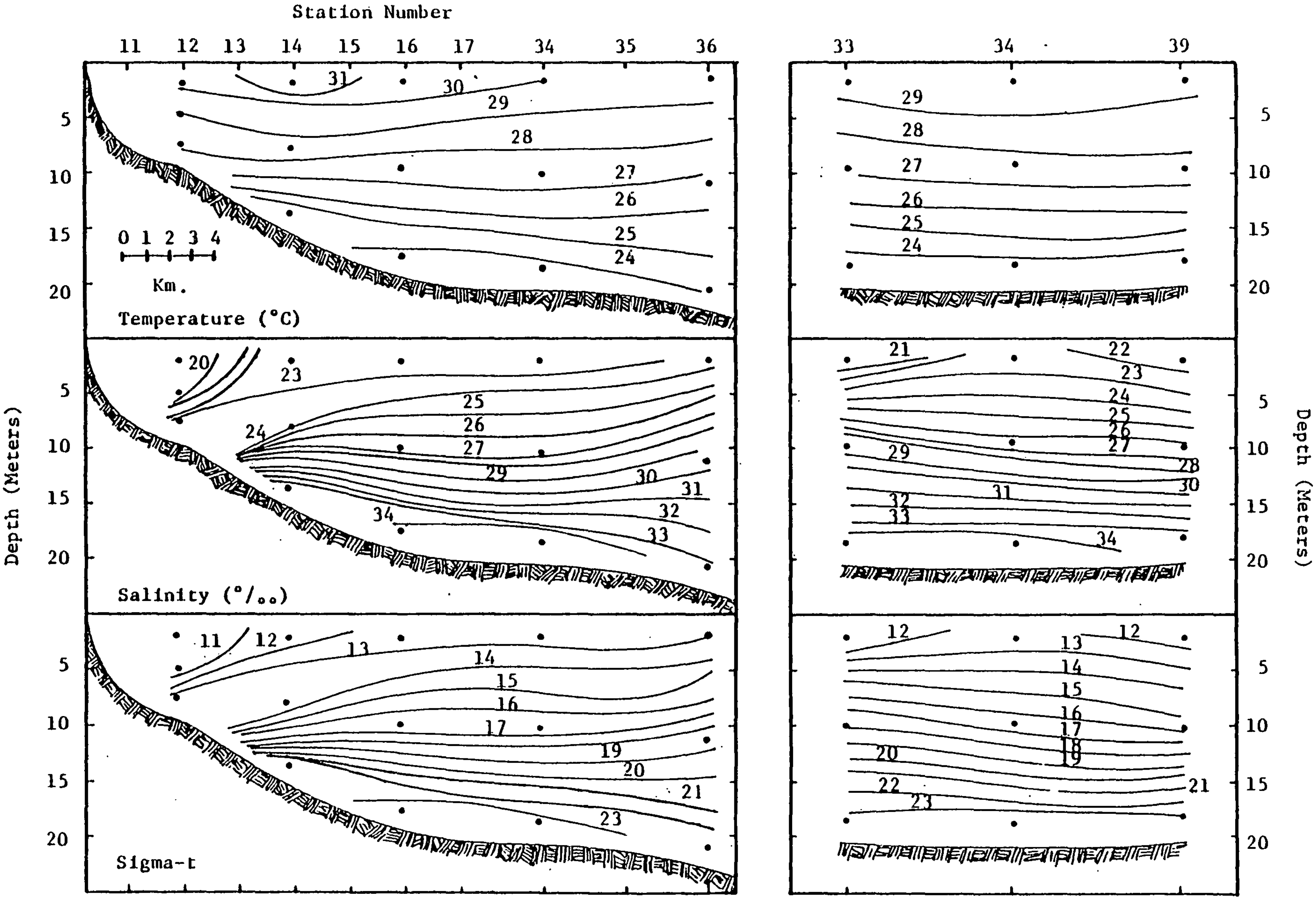


Figure 1-13. Hydrography for cross-shelf (left) and alongshore (right) transects offshore Freeport, Texas for June 28, 1979

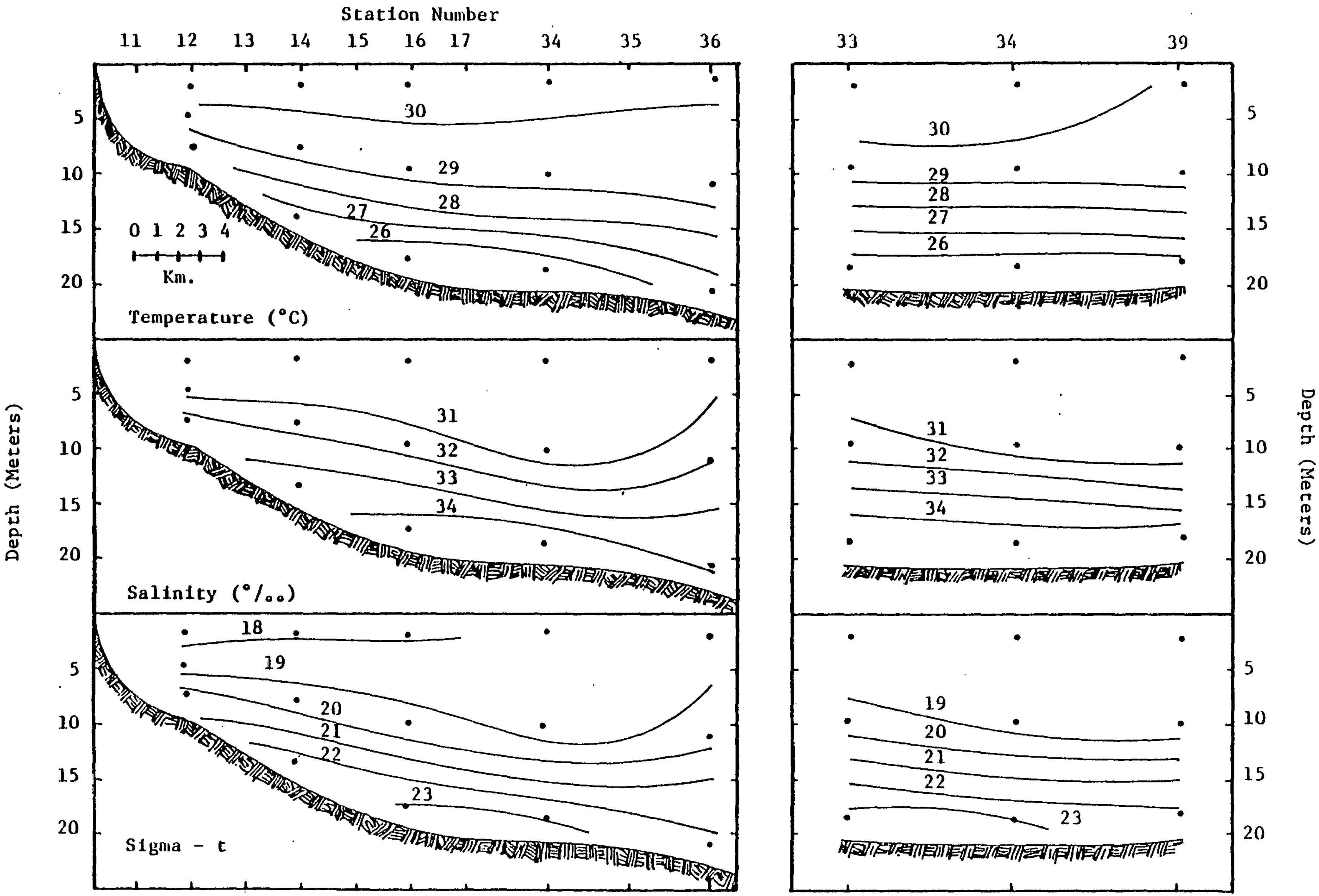


Figure 1-14. Hydrography for cross-shelf (left) and alongshore (right) transects offshore Freeport, Texas for August 15, 1979.

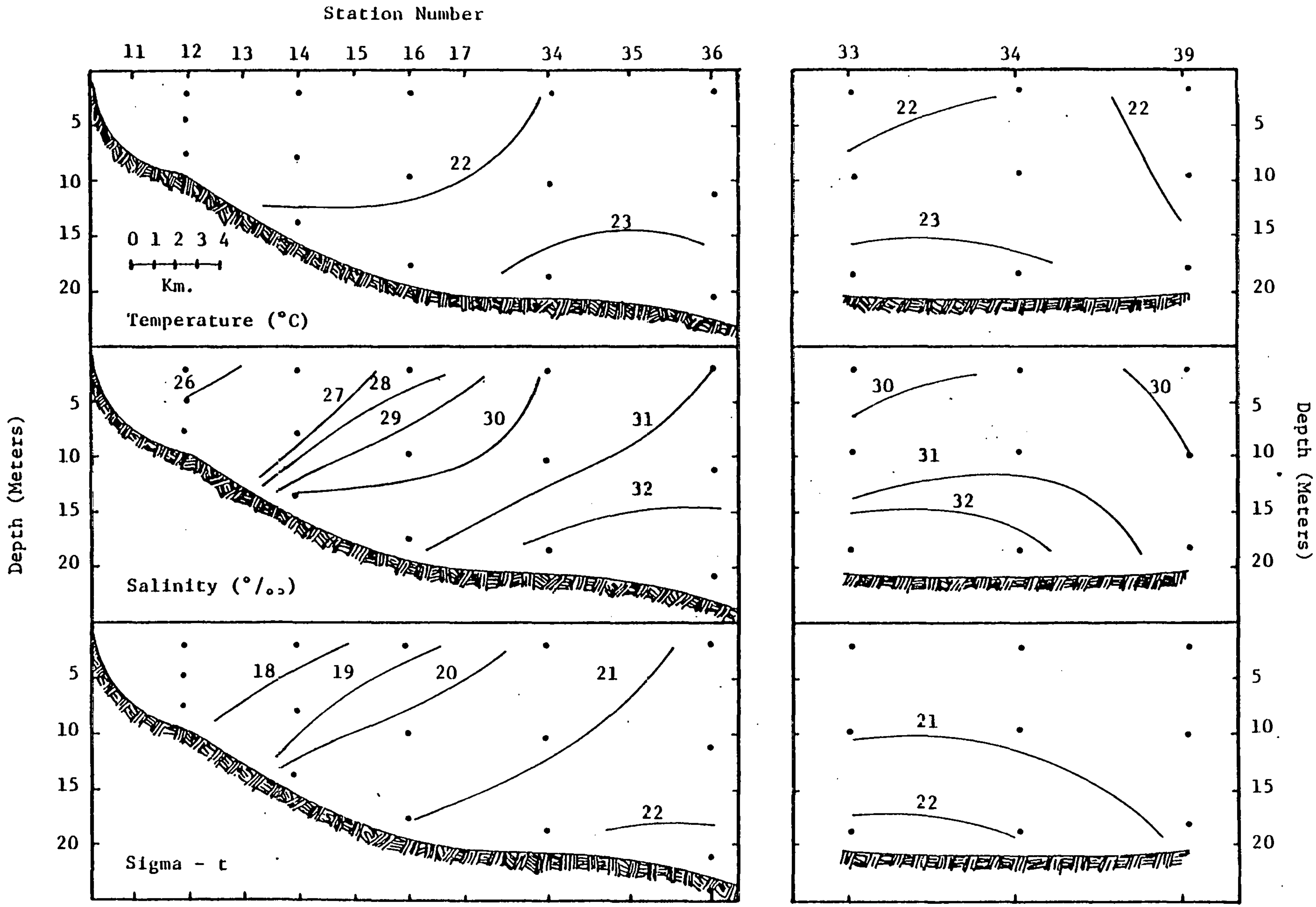


Figure 1-15. Hydrography for cross-shelf (left) and alongshore (right) transects offshore Freeport, Texas for November 6, 1979.

where conditions were considered to be well mixed.

The winter months of 1980 showed the water column returned to the strong stratification experienced in previous winters, which is illustrated by the February 22, 1980 data in Figure 1-16. The temperature increases in the offshore direction, but only a small variation exists in the vertical direction. The isohalines and isopycnals are horizontal above mid depth and a strong pycnocline is present in the upper layer.

In summary, the vertical cross sections of the predisposal data from September 1977 through February 1980 show some very interesting contrasts. The fall months show the coastal waters in an area of Freeport, Texas to be generally well mixed with the surface water temperature decreasing and the salinity increasing with distance offshore. The isopleths are usually vertical to nearly 45° with the horizontal. During the winter the frontal systems begin passing through the area, runoff is increased due to rainfall, and the strong offshore winds tend to force fresher waters from inshore areas out over the Gulf. This results in the isopleths being horizontal to 45° with the horizontal. A strong pycnocline is dependent upon the severity of the frontal systems passing through the area. Although the high winds result in high sea state conditions (wave heights greater than 2 m) and strong surface currents, the conditions do not break down the stratification.

The winter of 1978 was extremely cold and considered a severe winter for the study area (see Section 1.4) and it also resulted in some highly stratified coastal waters. In contrast the winter of 1979 was less severe and stratification was not as strong. A still milder winter was experienced in 1980 which even permitted sampling in January. Previous Januaries were not evaluated.

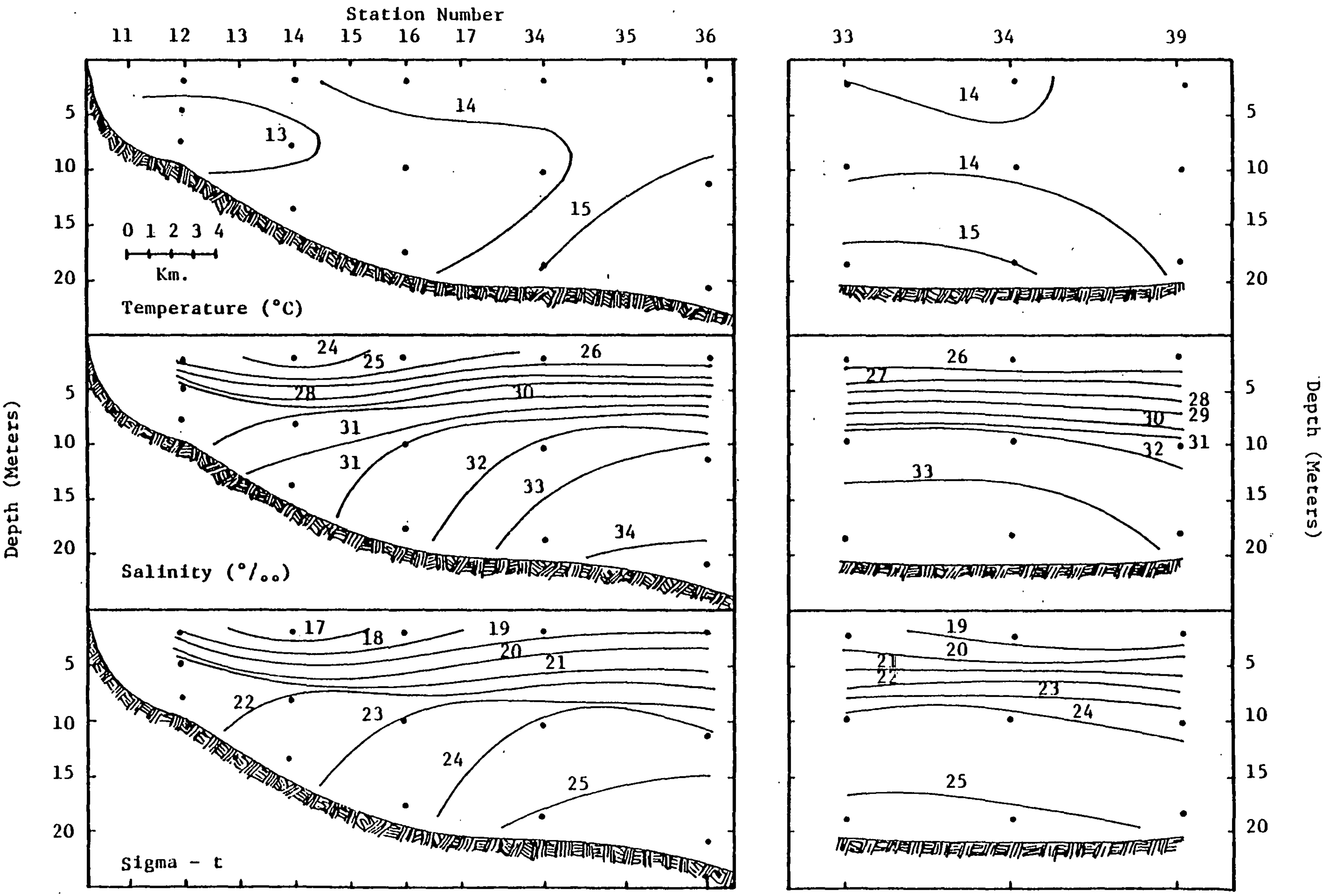


Figure 1-16. Hydrography for cross-shelf (left) and alongshore (right) transects offshore Freeport, Texas for February 22, 1980.

1.2.4 Stability of Water Column

The Richardson number is a dimensionless parameter which is used to indicate stratification. It considers the effects of both density and velocity gradients and is defined as

$$Ri = \frac{g}{\bar{\rho}} \frac{\frac{\Delta\rho}{\Delta z}}{\left(\frac{\Delta v}{\Delta z}\right)^2} \tag{1-4}$$

where $\bar{\rho}$ is the average density, v the velocity, z the depth, and g the local acceleration due to gravity. When the Richardson number is positive the water column is stable, and the degree of stratification increases as the Richardson number increases. According to Officer (1976) the water column can be classified as well mixed for $Ri \leq 0.1$, in transition for $0.1 < Ri \leq 10$, and stratified for $Ri > 10$.

The Richardson number was computed for the diffuser site (station 34) using the salinity, temperature and depth data collected during monthly hydrographic surveys and current data collected at the same time with a remote reading current meter. The water column was divided into a surface and bottom layer. Of these, the bottom layer is of most interest because the far field portion of the negatively buoyant brine plume is expected to be in the bottom layer.

For the top layer the surface and mid depth data for salinity, temperature and depth were used to calculate $\bar{\rho}$ and $\Delta v/\Delta z$. The surface and mid depth current data, each a 2.5 minute vector average of readings taken every 15 seconds, were used to calculate $\Delta v/\Delta z$. In the bottom layer a similar procedure was used to evaluate $\bar{\rho}$ and $\Delta\rho/\Delta z$ using mid depth and bottom data; however, the bottom current was assumed to be zero.

The Richardson numbers are shown in Figure 1-17 for each hydrographic survey beginning in February 1978 when station 34 was first sampled. This figure shows that during the winter and early spring (Feb. - April 1978) the surface layer was stratified ($Ri > 10$) on every cruise except one which was in the transition region ($0.1 < Ri \leq 10$). The bottom layer varied from being well mixed ($Ri < 0.1$) in early February to transitional at the end of February. During the month of May 1978, the Richardson numbers in both layers were transitional. In June, no current data were available. For the remainder of the year, the bottom layer was transitional, except for occasional well mixed periods. The surface layer was mostly transitional with occasional stratified and well mixed periods.

In 1979 the data for February and March show the surface layer is stratified and the bottom layer is transitional. Unlike the previous year, the April 1979 data indicate that both layers are transitional with $Ri \approx 1$. The figure shows the effect of the spring runoff in the latter part of May when the surface layer is observed to be stratified and the bottom layer is very close to the stratified classification with $Ri \approx 9$. The stratified condition in both layers is shown to occur through the summer except for the bottom layer on one survey in July. The Richardson numbers during late spring and all summer of 1979 are an order of magnitude greater than those found in 1978. The increased stratification is attributed to the unusually wet spring 1979 which caused flooding in Texas and Louisiana. The stratification weakened in the late summer and became more typical of conditions found in the previous summer. In October and November the data shows the surface layer to be switching between stratified and transitional. For example, the Ri was 0.9 on October 5 and 60 on October 11 which is an indication of how rapidly the stratification can change.

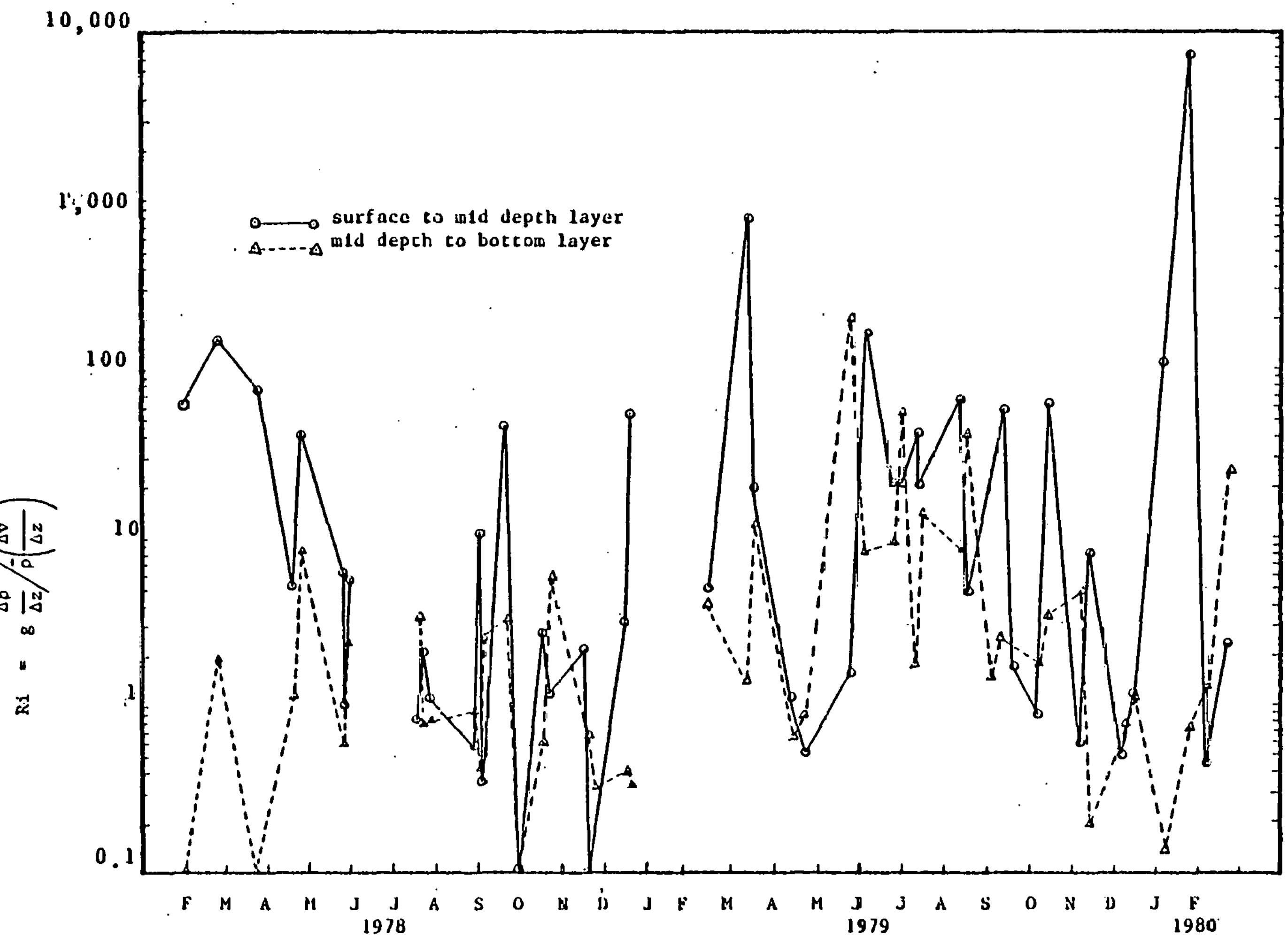


Figure 1-17. Richardson number for the diffuser site (Station 34))for February 1978 through February 1980. (Ri > 10, stratified; 0.1 < Ri < 10, transitional; Ri < 0.1, well mixed.)

The stratification was transitional during November and December in both layers with the bottom layer being very close to the well mixed classification.

A dramatic increase in the surface layer stratification is shown in Figure 1-17 for the month of January 1980, and it rapidly decreases in February. The bottom layer shows a nearly well mixed condition in early January and then a gradual increase to a stratified condition in the latter part of February. The stratification is attributed to the passage of a strong meteorological frontal system through the area.

The Richardson number data indicate that in general the bottom layer is transitional year round with occasional well mixed conditions in the winter and fall. However, unusually large runoff conditions along the upper Texas coast can cause several months of near stratified conditions as happened in May through August 1979. Also, rapid changes in the stratification have occurred between cruises which have been spaced as close together as one day. This demonstrates the high variability of the stratified conditions that can be encountered in the study area. The surface layer is generally stratified in the winter and spring months and transitional in the summer and fall. However, in the summer of 1979 the strong stratification continued as a result of the unusally high runoff.

1.2.5 Variation of Temperature, Salinity and Density at the Diffuser Site and in the General Study Area

In this section, the variations with time of temperature, salinity and density (sigma-t) for the period February 1978 through February 1980 are discussed. The data are plotted as a function of time in several forms in order to more easily interpret the time dependence. It is emphasized that the sampling dates are not evenly spaced in time, and there are no data for January 1978 and January 1979. Within a given month the sampling dates are usually closely spaced when there is data from more than one cruise. In some instances the change within one or two days is quite large. This is a result of the frontal zone, noted in the discussion of vertical sections, changing its orientations and/or position. Data closely spaced (in time) were not averaged because they provide some indication of the magnitude of short term variation in the study area. However, the long gaps between months followed by rapid changes over a few days gives a somewhat distorted picture, and this should be kept in mind.

1.2.5.1 Temperature

Figure 1-18 shows temperature plotted as a function of time for the surface, mid depth and bottom samples at station 34. A depth versus time plot with contours of temperature for stations 34 and 14 are given in Figures 1-19 and 1-20, and Figure 1-21 shows the cross-shelf gradient, station 34 minus station 14. The tick marks above each year's data in Figures 1-19, 1-20, and 1-21 mark the date of a cruise.

There is a clear annual cycle in the temperature data within a minimum in January - February and a maximum in July - August. Station 14 generally

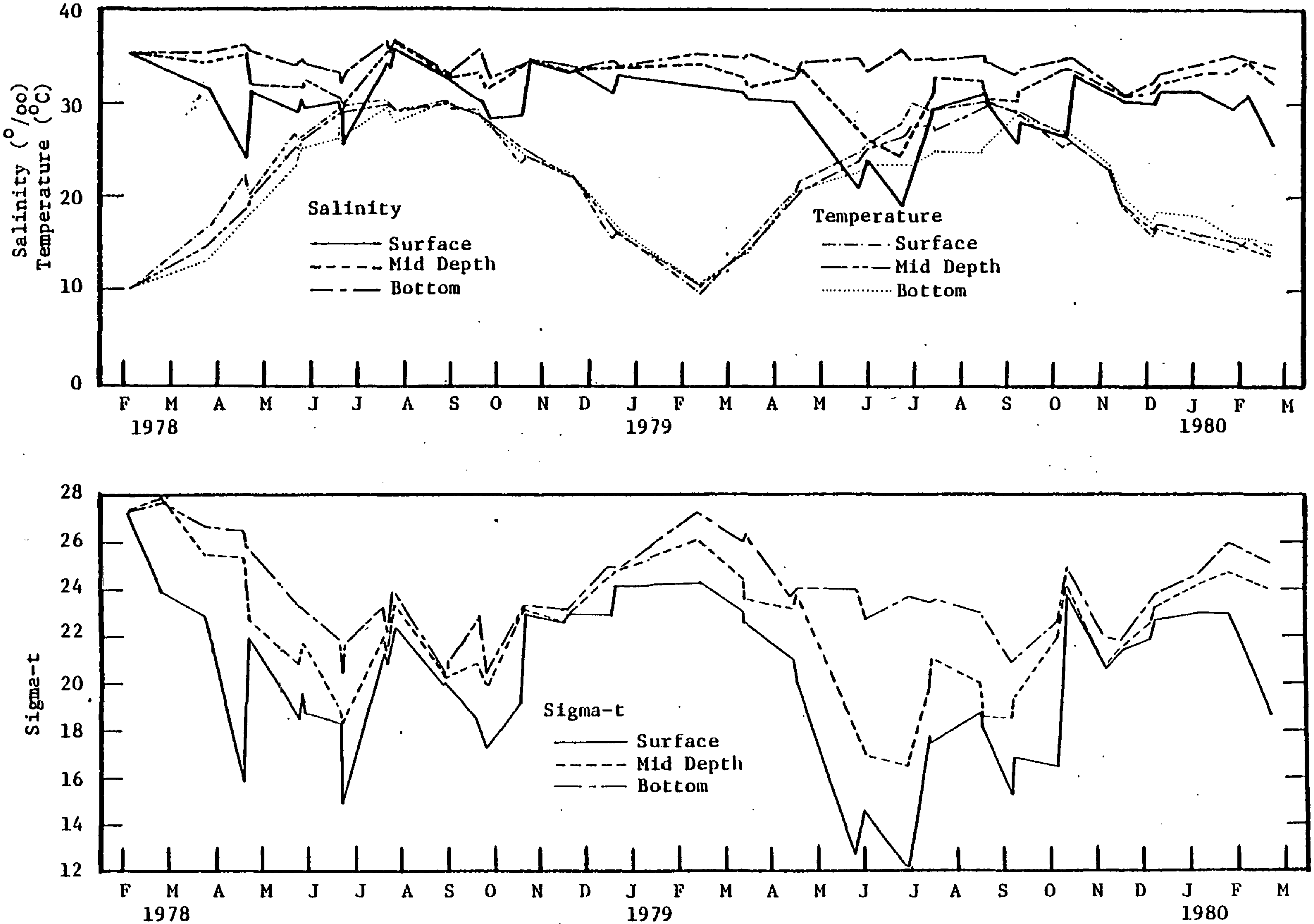


Figure 1-18. Variation of temperature, salinity, and sigma-t at the diffuser site (Station 34).

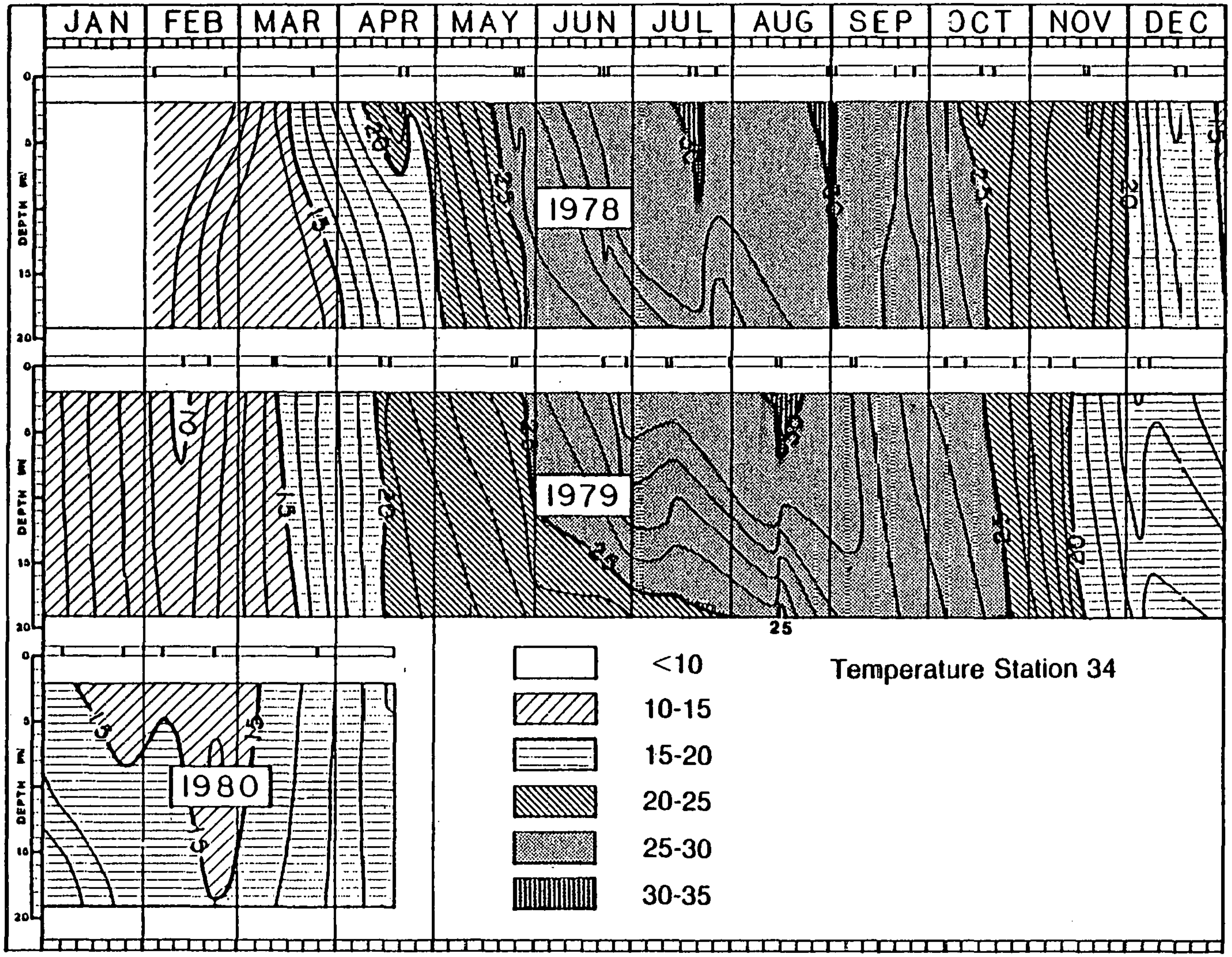


Figure 1-19. Time-depth plot of temperature in ^{o}C at station 34 for 1978, 1979 and early 1980. Tick marks indicate dates of cruises.

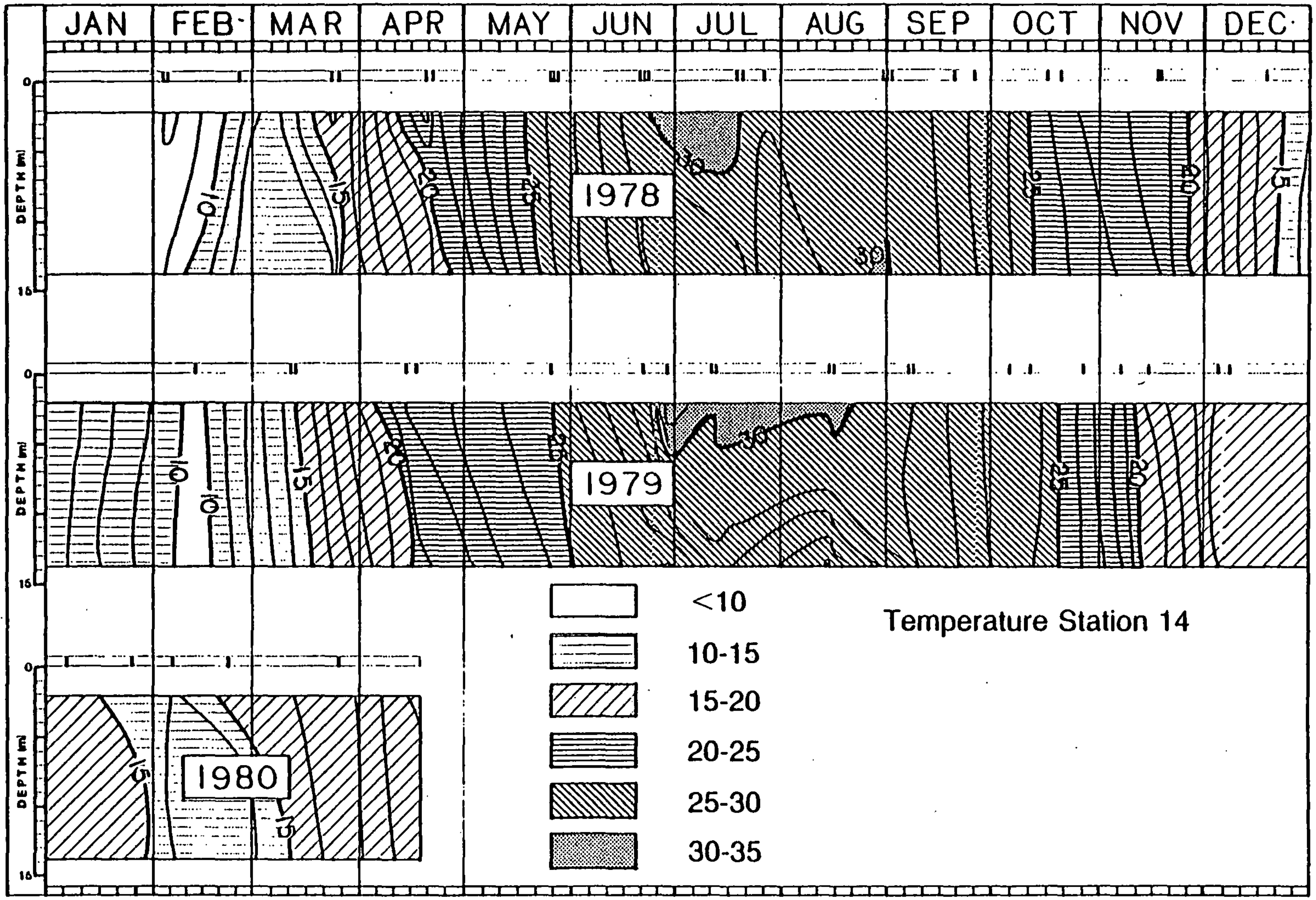


Figure 1-20. Time-depth plot of temperature in ^{o}C at station 14 for 1978, 1979 and early 1980. Tick marks indicate dates of cruises.

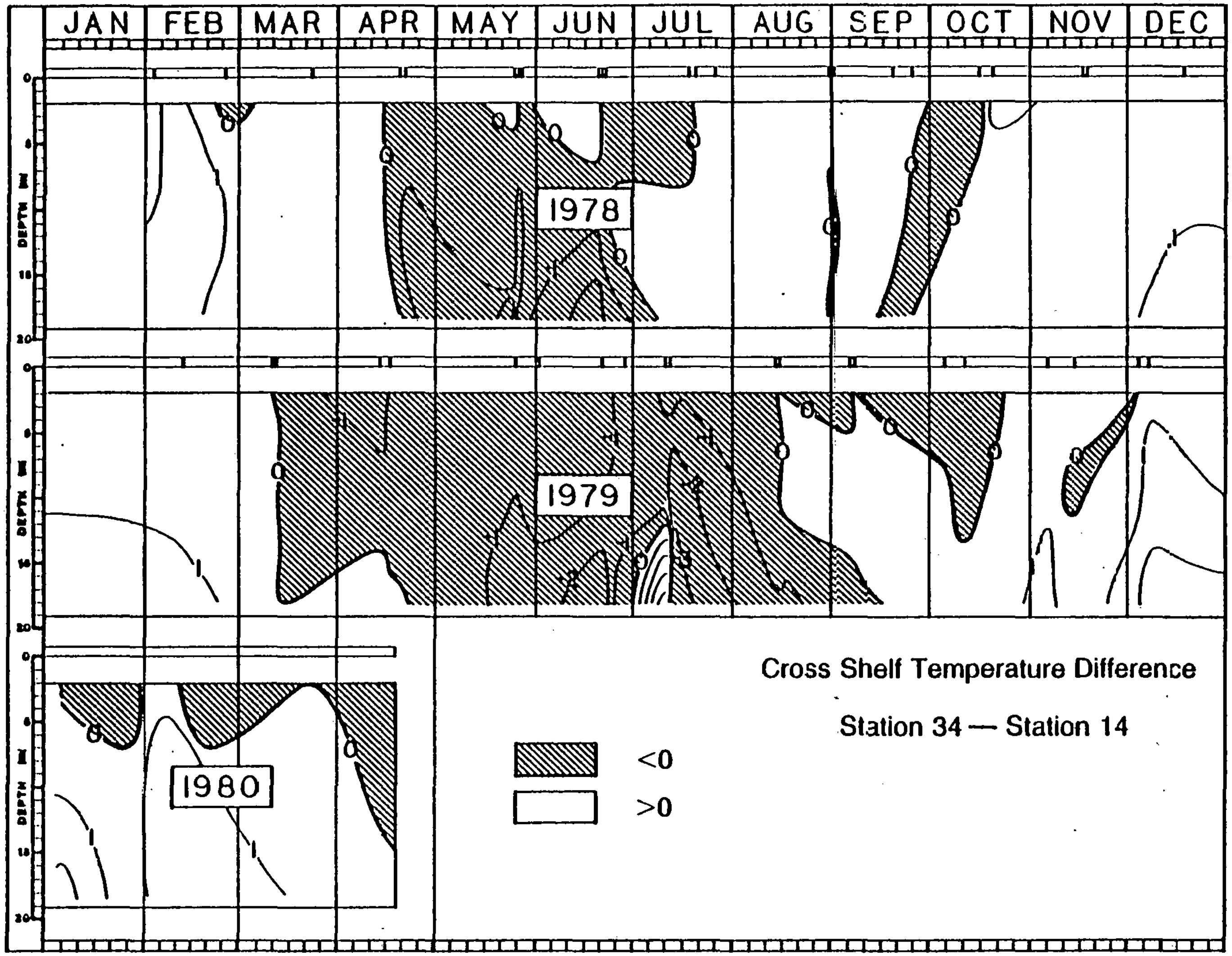


Figure 1-21 Time depth plot of cross-shelf temperature difference in ^{o}C (station 34 minue station 14) for 1978, 1979 and early 1980. Tick marks indicate dates of cruises

has slightly colder temperatures in the summer than station 34. Warming of the water column occurs most rapidly in late March through late May and cooling in December through January. The mild winter of 1979-1980 produced water temperatures which were about 5° warmer than those of the preceding two winters.

The vertical temperature gradient is negative from about mid-March through August at station 14 and December at station 34. The thermocline gradually strengthens and deepens from mid-March through about July at the inner station and August at the outer station. During the period September through December, station 34 data indicate a slight thermal stratification with an occasional near-isothermal water column. Station 14 is isothermal from late August to November and isothermal in December.

The cross-shelf temperature difference in Figure 1-21 indicates that in 1978 station 34 was cooler than station 14 only in April, May and June and a brief period in the fall; the magnitude of the difference was about $2^{\circ}C$ near the bottom in June. In 1979, however, this trend began in mid-March and lasted until mid-August. In June 1978 and June-July 1979, there are indications of upwelling of cooler water along the bottom.

1.2.5.2 Salinity

Figure 1-18 also shows the variation of salinity at the diffuser site for February 1978 through February 1980 as a salinity versus time plot. Figures 1-22 and 1-23 present the salinity variations at stations 34 and 14 and Figure 1-24 their difference (34 minus 14) as depth versus time plots with contoured values.

Salinity variations, as compared to temperature variations, are quite large and occur on several time scales. Stations 14 and 34 show the same

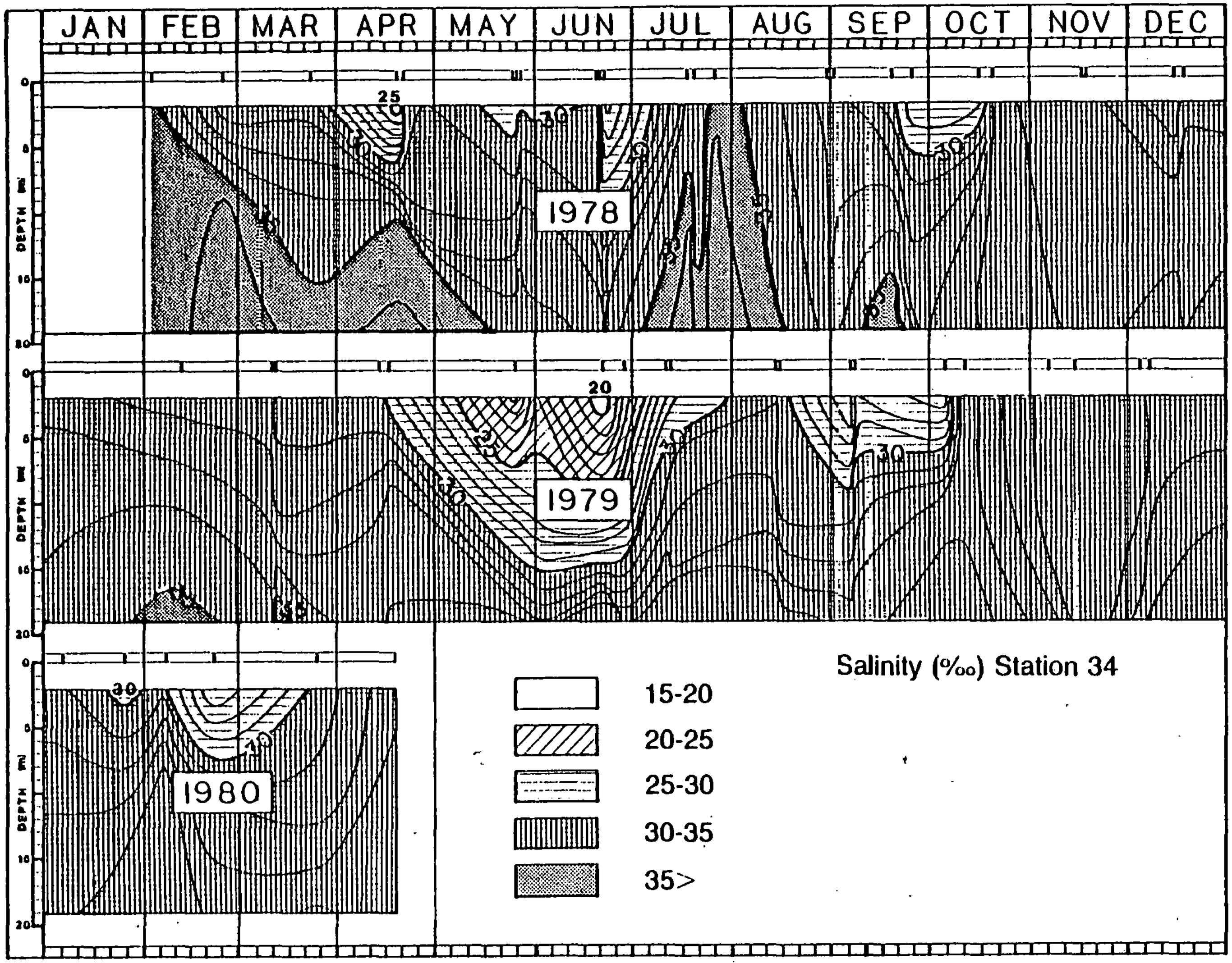


Figure 1-22. Time-depth plot of salinity in $^{o}/oo$ at station 34 for 1978, 1979 and early 1980. Tick marks indicate dates of cruises.

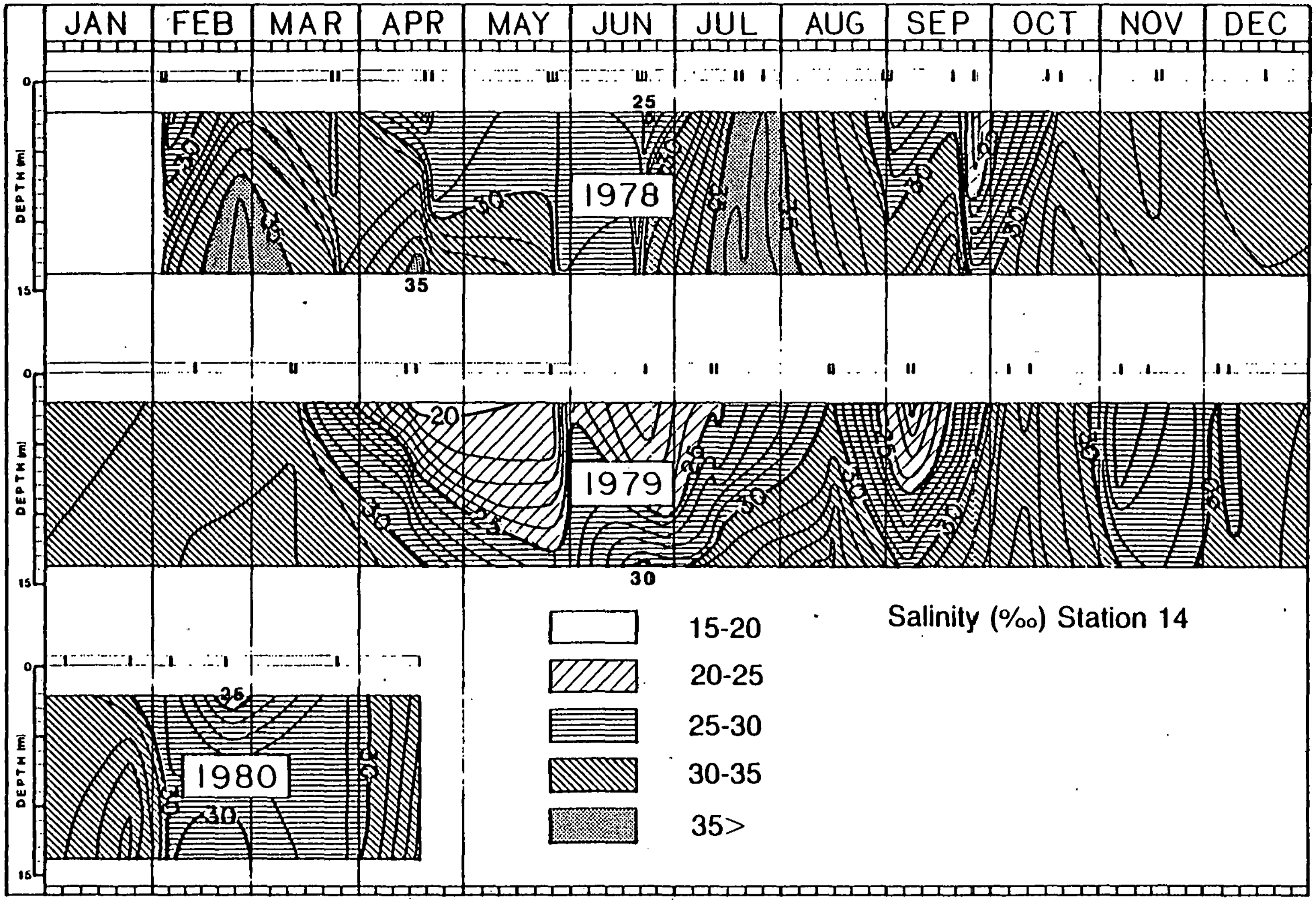


Figure 1-23. Time depth plot of salinity in $^{o}/oo$ at station 14 for 1978, 1979 and early 1980. Tick marks indicate the dates of cruises.

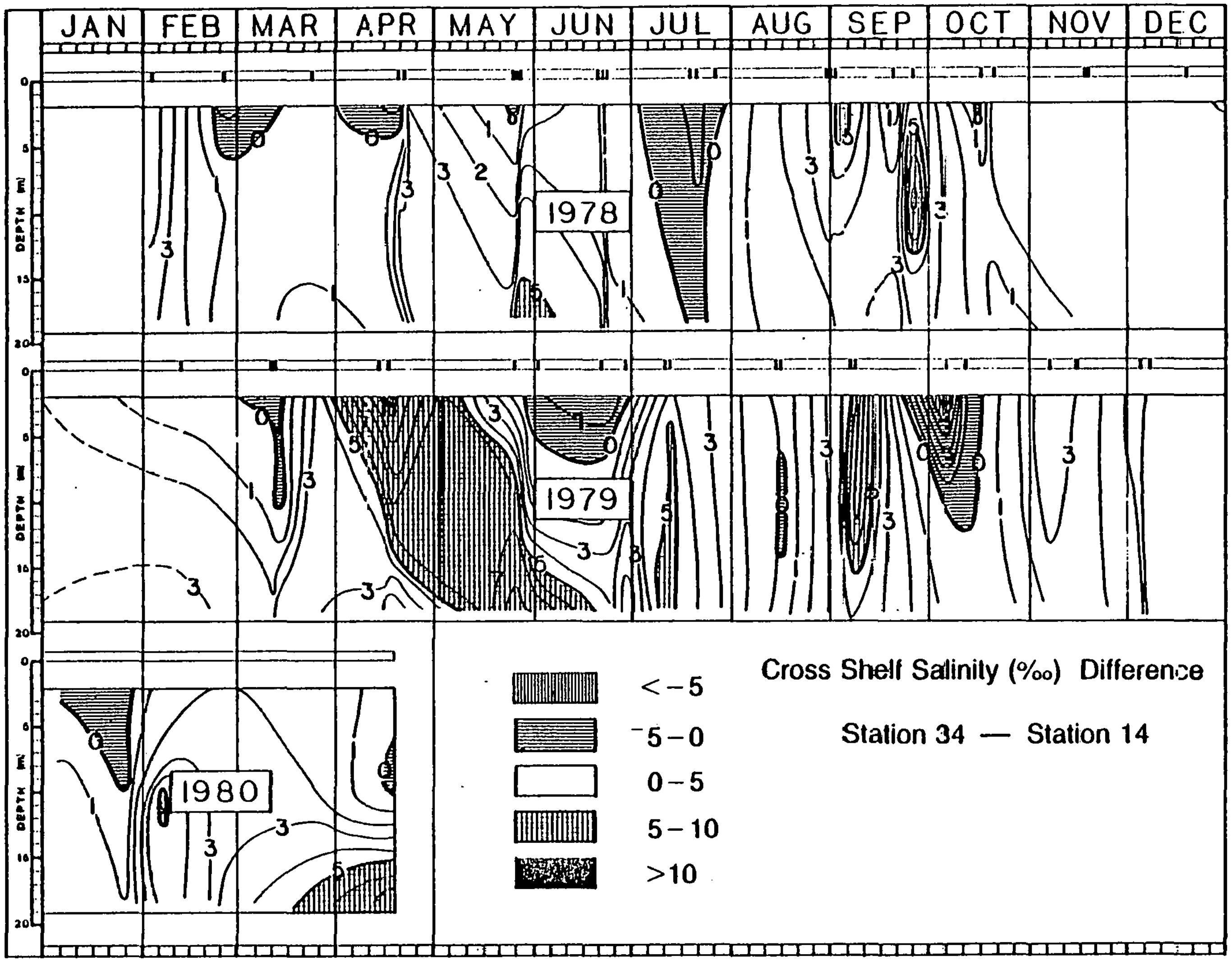


Figure 1-24. Time-depth plot of cross-shelf difference in $^{o}/oo$ (station 34 minus station 14) for 1978, 1979 and early 1980. Tick marks intidate dates of cruises.

pattern of variation, but in general, station 34 is more saline by at least $3^{o}/oo$ and vertical gradients are weaker. An interannual variation or trend is present in the lower half of the water column. In 1978, at station 34, salinities greater than $35^{o}/oo$ occurred at the bottom in February-May and July 1978. In 1979 salinities of $35^{o}/oo$ were present only in February and March near the bottom, and in winter of 1980 no salinity of $35^{o}/oo$ were measured. The principal salinity minima in 1978 and 1979 occurred in June, but the spring minimum was much more pronounced in 1979. Values less than $20^{o}/oo$ at the surface were recorded at some time in the spring of each year. Secondary salinity minima occurred in late September 1978 and in September and November 1979. The river runoff which produces these lower salinities is discussed in section 1.3.

Vertical salinity gradients are quite pronounced throughout much of the year. At station 14, a relatively isohaline water column occurred only during portions of June, July and August, 1978, throughout November and December 1978, and in February, October and December 1979. At station 34, the salinity stratification was weak in November and December of 1978 and 1979 and late July 1978. The strongest vertical salinity gradients occurred in 1979. At station 34, the top was almost $15^{o}/oo$ less than the bottom in June, while differences of up to $10^{o}/oo$ occurred at station 14 in April, May, June and September. In 1978, strong salinity stratification was more transient and less intense than in 1979.

The cross-shelf salinity differences in Figure 1-24 gives some indication of the presence and strength of the frontal zone which was noted in the discussion of vertical sections. In general, the cross-shelf gradients were stronger in 1979. The $10^{o}/oo$ difference in April 1979 probably indicates the initial arrival of the low salinity from spring river runoff before it spread past station 34. The strong cross-shelf gradients in September of 1978 and 1979 represent the effect of the shift in the longshore wind component and/or major storms (see Section 1.3). However, the volume of low-salinity water advected from the northeast in September is not as large as that from spring runoff and tends to be closer to the coast, thus producing a salinity front between stations 14 and 34. The negative gradient in early October 1979 appears to be a result of the low salinity water from September moving offshore as a lens of low salinity water. The vertical sections for October 1979 clearly imply that upwelling was occurring. Transient negative gradients near the surface occur at other times in 1978 and 1979, and may also be associated with upwelling conditions.

The large volume of low salinity water in 1979 appears to represent an extreme condition corresponding to a flood year in Mississippi runoff (see Section 1.3). The conditions of 1978 may be closer to the average; however, 1980 gives all indications of being an extreme case in the opposite direction. Because of the large year to year variance in runoff totals, it may be that is is unusual for "average" conditions to actually occur.

1.2.5.3 Density

The variation of density at the diffuser site is also shown in Figure 1-18, and corresponding depth-time plots in Figures 1-25, 1-26 and 1-27 for stations 34 and 14 and their cross-shelf difference. Density (or sigma-t), represents the combined effect of temperature and salinity, and since thermal stratification is weak, the figures for sigma-t closely resemble the figures for salinity just discussed. During January and February, when small positive thermal gradients occur, the water column is stabilized by salinity stratification. In fact, no density inversions were observed over the past 24 months of observations.

The figures show that the density of the water column generally

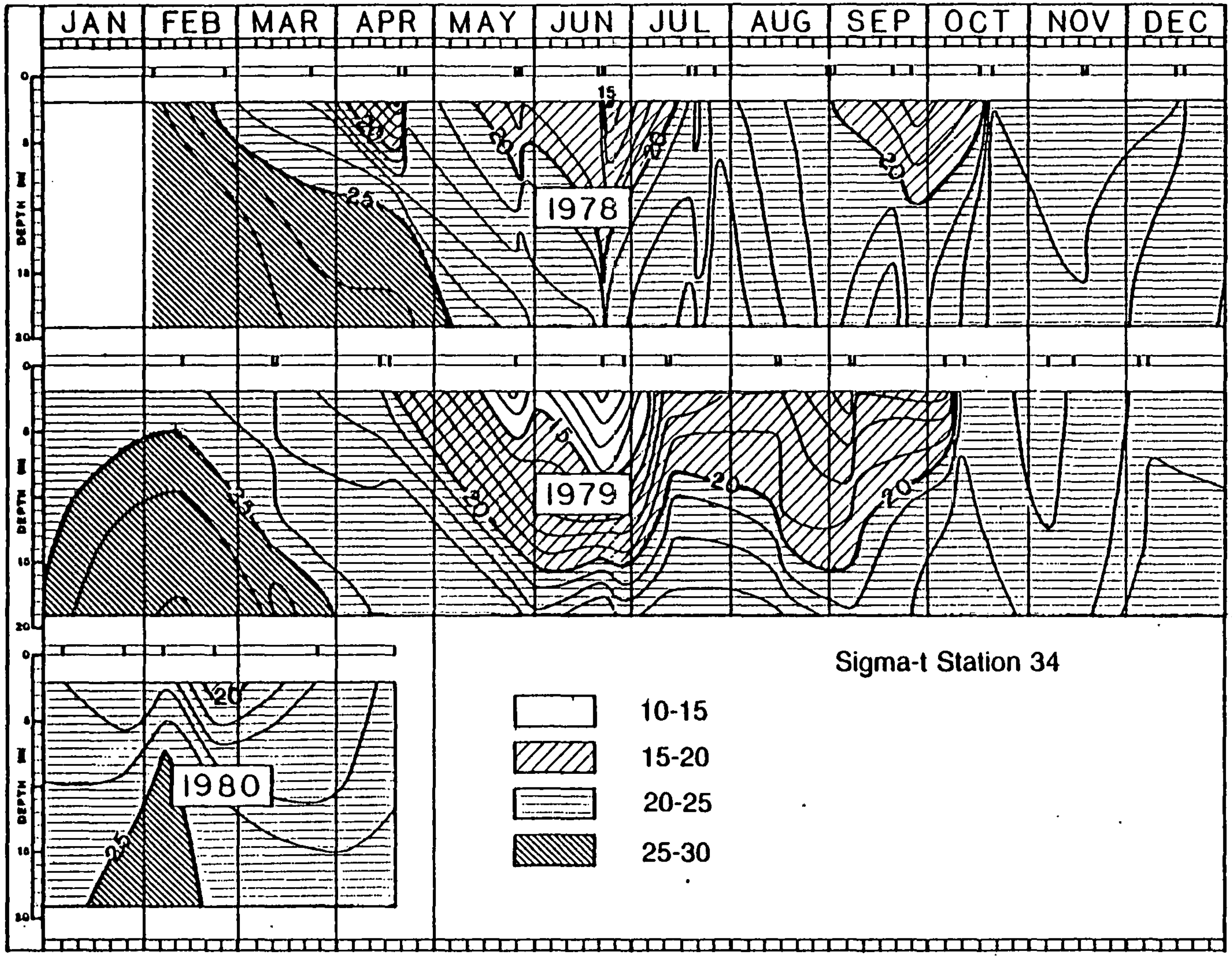


Figure 1-25. Time-depth plot of density in units of sigma-t at station 34 for 1978, 1979 and early 1980. Tick marks indicate the dates of cruises.

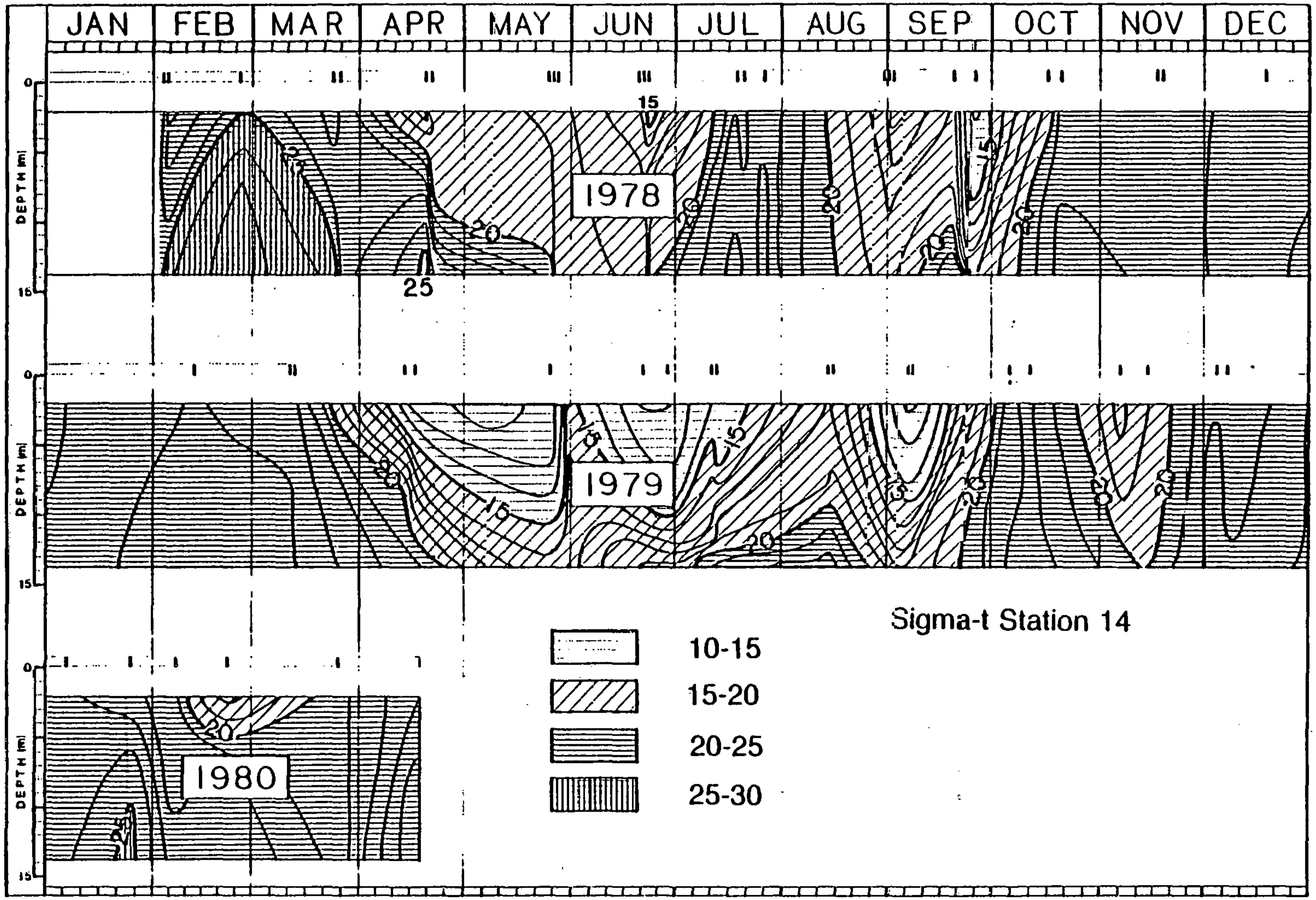


Figure 1-26. Time-depth of density in units of sigma-t at station 14 for 1978, 1979 and early 1980. Tick marks indicate the dates of cruises.

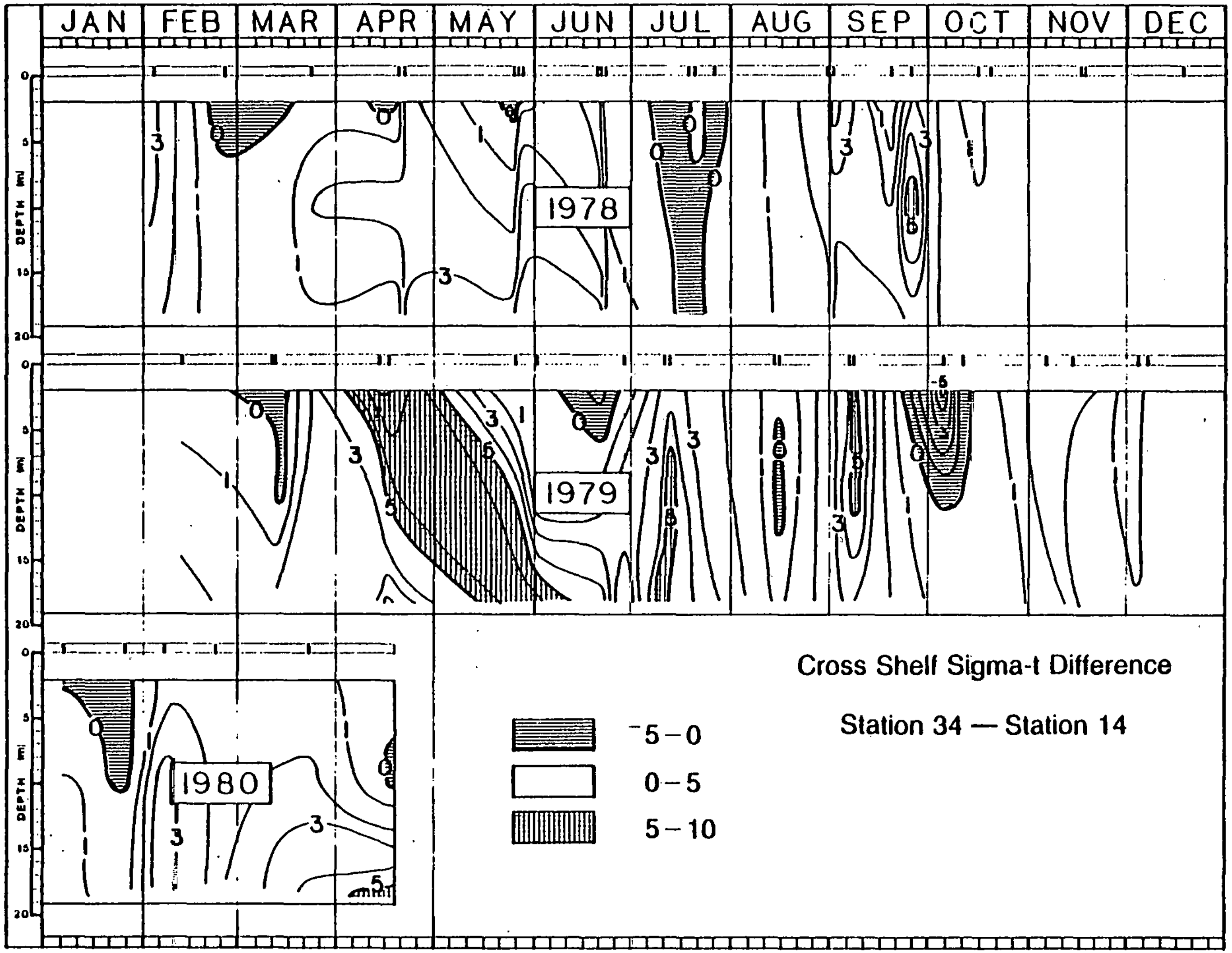


Figure 1-27. Time-depth plot of cross-shelf density difference (station 34-station 14) in units of sigma-t for 1978, 1979 and early 1980. Tick marks indicate dates of cruises.

decreases in the mid-winter, spring, and early summer months, February to June 1978. The density increased in July, decreased in August and September, and increased once again from October through February 1979. In March and April 1979, the density decreased as in the similar period in 1978. During May, June, and July the surface sigma-t values (12) were the lowest observed during the entire predisposal study. However, the bottom sigma-t values were not as low as those found in late spring and summer of 1978. In late July and August the surface and mid depth density increased rapidly, but in September it decreased sharply again. The entire water column had a more uniform density in October and November, and the overall density increased from September through February 1980.

In general, sigma-t reached a maximum value of up to 27 at the bottom in February of each year. Very low values of sigma-t occurred in June and again in September. The lowest value was 11 in June of 1979. Secondary minima occurred in August through September of each year and also in November of 1979.

At Station 34, the pycnocline strengthened and deepened from February through June in 1978 and 1979. In 1978, the pycnocline then weakened in July and August, strengthened in September and finally became extremely weak in November and December. In 1979, however, a strong pycnocline persisted through mid-October, and then became very weak. Station 14 followed a similar pattern but with lower values of sigma-t and a weaker pycnocline than at Station 34. The location of the pycnocline in the surface layer should not affect the brine plume but when it occurs in the bottom layer (e.g. July 1978 and 1979) there may be some reduction in the turbulent mixing process. These conditions may increase both the area covered by the plume and the maximum salinity above the ambient, and this effect would be enhanced if the bottom currents were small which does occur at times during the summer and fall.

The cross-shelf density gradient (Figure 1-28) is of interest because it is related to a baroclinic component of the longshore velocity through the thermal wind equation:

$$\frac{\delta v}{\delta z} \propto \frac{\delta \rho}{\delta x}$$

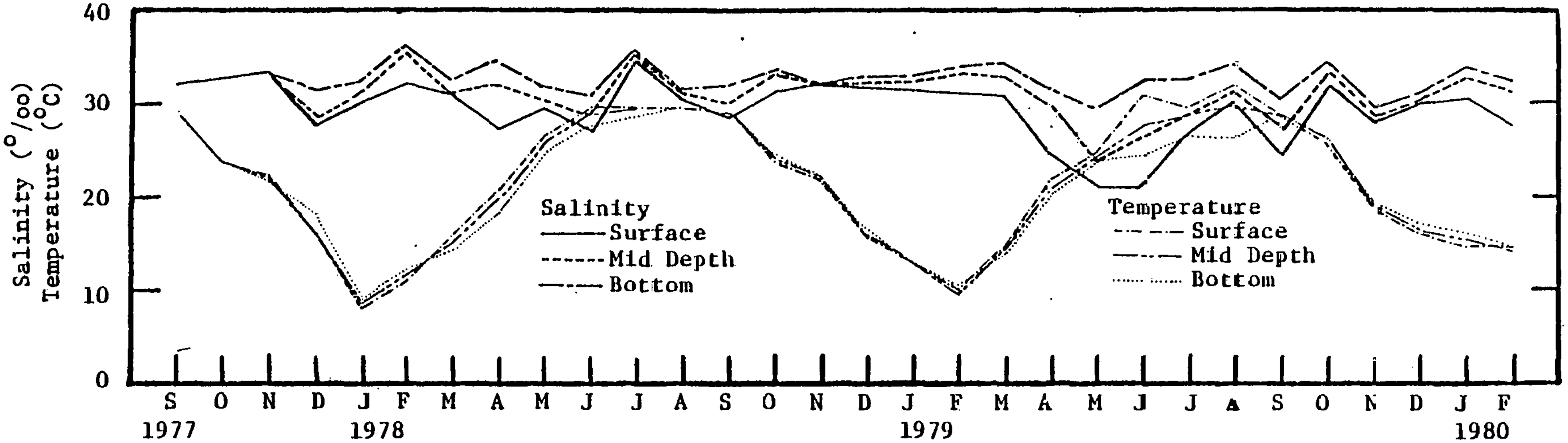
where +v is the longshore velocity to the northeast, +x is directed offshore and +z is vertically upward. Thus, large positive values in Figure 1-27 imply large currents to the southwest in the upper layers. The general trend in Figure 1-27 is small positive values expect during periods associated with strong salinity fronts when the cross-shelf density gradient can become quite large.

1.2.5.4 Average Variation of Temperature, Salinity and Sigma-t in the Study Area

As mentioned earlier, the hydrographic stations have changed over the duration of the predisposal study due to the change in the diffuser location, sea conditions, and time constraints. In order to see if the trends of the hydrographic variations at the diffuser site were typical of the entire study area, monthly averages were computed for stations 9, 12, 14, 16, 20, 33, 34, 36, and 39. These stations were used and most of them were sampled on all the cruises. These average values are plotted on Figure 1-28, and it shows the general trends discussed previously for the diffuser site are typical for the entire study area.

1.3 River runoff and Surface Salinities in the Texas and Louisiana Coastal Zone

In the preceding section salinity was shown to be the dominant factor



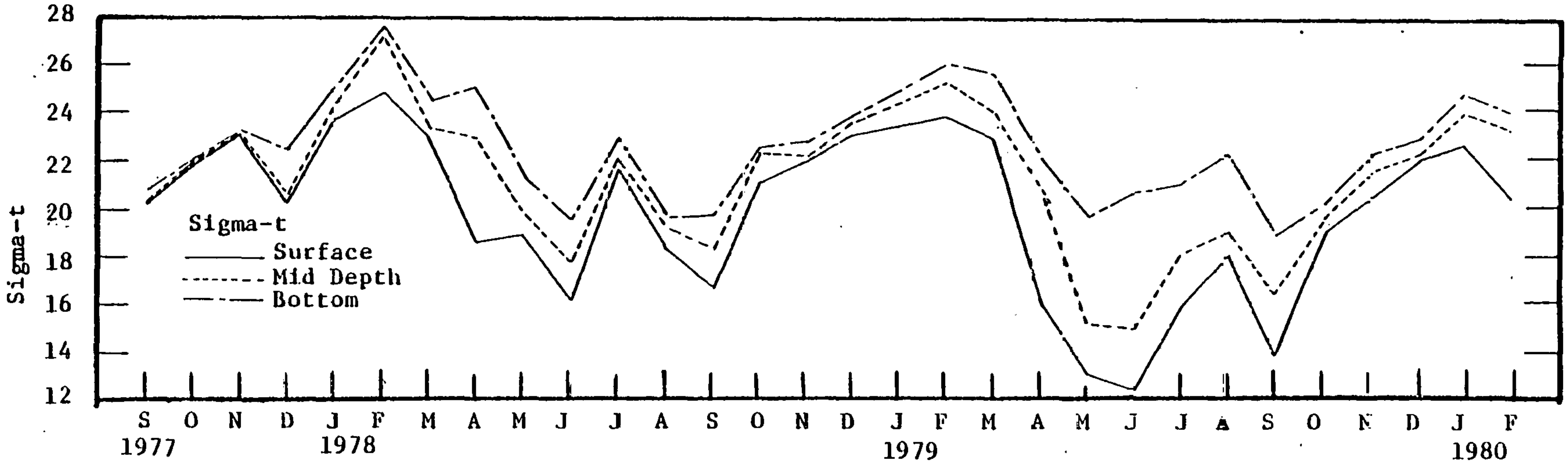


Figure 1-28. Variation of the average temperature, salinity, and sigma-t of Stations 9, 12, 14, 16, 20, 33, 34, 36, and 39.

in determining the structure of the mass field and degree of stratification in the study area. Salinity in turn is related, but not necessarily proportional to the volume of streamflow, i.e. river runoff, into the coastal areas of Texas and Louisiana. The lower salinity water which is produced is advected along the coast and displaces the higher salinity water of middle and outer continental shelf origin. The nominal salinity of the middle and outer continental shelf water is about 36°/oo (Smith, 1980). Thus, the variations in salinity in the study area are controlled by processes well removed from it; the purpose of this section is to give some perspective to the data recorded in the study area by looking at streamflow and surface salinity along the entire Texas and Louisiana coast to the Mississippi delta.

The most extensive, long running synoptic data set collected from the Texas-Louisiana continental shelf is that collected for the National Marine Fisheries Service by the Research Vessel GUS III for the years 1963 through 1965. Surface salinity maps were constructed for 1963 (Harrington, unpublis. manuscr.) but apparently not for 1964 and 1965. These years are of interest because the streamflow during the period 1963-1965 appears to have been similar in pattern and magnitude to the period 1977-1979. In general, the trend during both of these three-year periods was from low streamflow, in 1963 and 1977, to flood year, in 1965 and 1979 (Hall, 1963; Gunter, 1979).

Surface salinity maps for 1964 and 1965 have been constructed from the GUS III data and are shown in Appendix 2. Based on the above discussion it is felt that they may be similar to the period 1978-1979 for which no large scale synoptic data is available.

From January through mid-March 1964 the surface salinity isohalines were located parallel to the coast and the cross-shelf gradient was relatively weak. Lower salinity water of about 32^{o}/oo appears along the coast from Vermilion Bay, Louisiana to Freeport, Texas. There is a slight decreases to 31^{o}/oo off the Sabine River in early February 1964. During the period April through June 1964 the effect of spring runoff is quite dramatic. Intense cross-shelf gradients develop rather suddenly in April along the entire Texas-Louisiana coast. During May and June lower salinity water persists along the Louisiana and northeast Texas coast, but southwest of Freeport the lower salinity water begins to move offshore and retreat to the northeast. This is probably related to a shift in the wind to the southwest, which historically occurs about this time along the lower Texas coast. Salinities off Freeport rise from 26-27^{o}/oo in April to 32-33^{o}/oo in June. High salinity water of the middle shelf continues to displace low salinity water in July and August, and salinities off Freeport rise to 36^{o}/oo.

In August, a region of low salinity persists between the Mississippi delta and Vermilion Bay and is apparently transported rapidly down the coast in September when the winds historically shift to the northeast. It appears that this water is mixed to higher salinities along its path. Salinities off Freeport decrease to 31-32 ^{o}/oo.

There is a slight rise in salinity along the entire coast in October 1964. In November and December salinities decrease to about 30^{o}/oo along the entire coast, and the cross-shelf gradient intensifies.

During January through March 1965 the salinities are lower and the cross-shelf gradient is stronger than during that period in 1964. It should also be noted that a ridge of higher salinity values extends to the coast just west of Vermilion Bay and separates the lower salinity off the Mississippi delta from the lower salinity off the Sabine River. It is not clear whether the latter is a result of increased local river runoff or intermittent pulses of lower salinity water which are moving westward from the Mississippi River region. Hall's (1969) study and the streamflow results presented next do indicate maxima in streamflow during the January through March period for the rivers near the Texas-Lousiana border. This is an interesting point because it may indicate that the lower salinities off Freeport during this period have a more local origin than the Mississippi/Atchafalaya river system.

Beginning in April 1965 the effects of spring runoff again appear suddenly and are more intense than in 1964. The water year of 1965 was a flood year for the Mississippi (Gunter, 1969), and this is clearly seen in the data as a pulse of very low salinity, $<20^{o}/oo$, which moves from the Mississippi/Atchafalaya area, along the coast and past the Freeport area. Again note that in the vicinity of the Sabine river the salinity decreases to $11^{o}/oo$ which may indicate the effect of local rivers.

The data from July through December, 1965 are sparse but generally indicate the trend described for that period in 1964.

Thus, the surface salinity maps for 1964-1965 indicate that the low salinity encountered off Freeport is predominantly a result of the outflow of the Mississippi/Atchafalaya river system. The low salinity is at times part of a continuous band of low salinity along the Texas-Louisiana coast, and at other times it represents the passage of pulses of relatively fresh water along the coast. There are also indications that during January-March the rivers between Freeprot and the Texas-Louisiana border may significantly augment the low salinity water of the inner coastal zone.

Stream flow records for water years 1977 and 1978 (U.S.G.S., 1977a, 1977b, 1978a, 1978b; U.S. Army Corps of Engineers, personal communication) have been obtained for all rivers from the Mississippi River to the Rio Grande. Water year 1977 covers the period October 1, 1976 through September 30, 1977 and similarly for water year 1978. The data for water year 1979 have not been received as of the writing of this report.

The stream gaging stations used in the calculations were the most downstream stations for all rivers reporting continuous discharge records. If gaging stations on major rivers were upstream of tributaries or distributaries, the mean daily discharge value was adjusted to reflect the inflow or diversion. Where mean daily discharge records for a month were incomplete, the average of the reported discharge was calculated and substituted for missing data. This resulted in a complete set of daily discharge values for each of the rivers during the time period under consideration. Drainage from the unmetered region between the gaging station and the river's mouth is an unknown factor but is probably small. In all, fifty-three stations have been used to determine fresh water outflow along the 1100 km of coast from the mouth of the Mississippi at North Pass, Louisiana to the Rio Grande at Brownsville, Texas. Instantaneous discharge data from other rivers and streams were not incorporated in the analysis. Figure 1-29 shows the location of each gaging station.

The river data have been divided into five groups to allow correlation with data collected at the Bryan Mound Disposal site. See Table 1-2. The major rivers affecting Texas-Louisiana shelf water properties are the Mississippi and the Atchafalaya Rivers. Because their outflow exceeds all other sources of runoff combined, they have been grouped together in Region I. The remaining Louisiana rivers comprise Region II. The San Bernard and

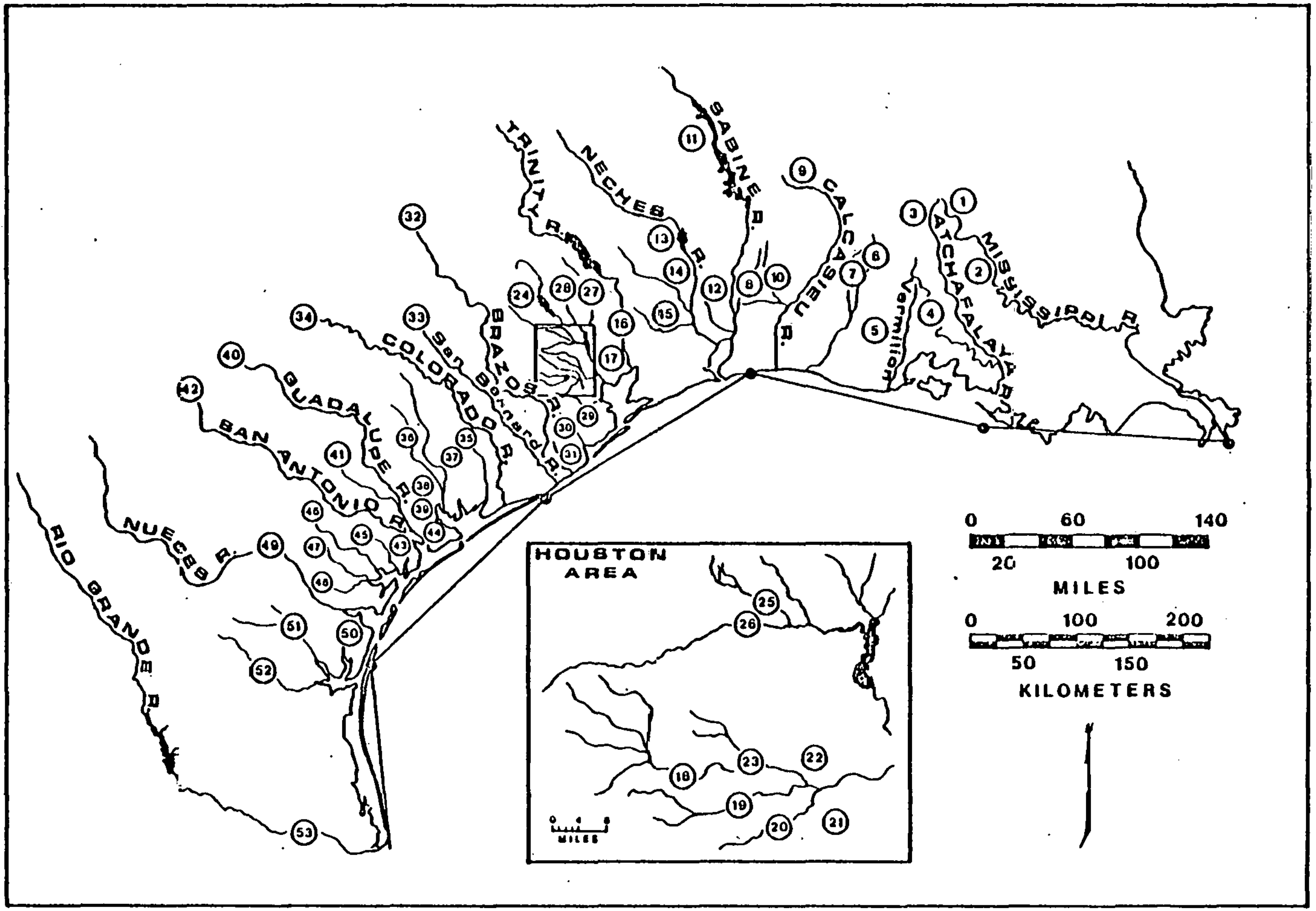


Figure 1-29. Locations of gaging stations used in streamflow calculations. The circled numbers correspond to the gaging stations list in Table 1-12. The streams have been grouped into regions corresponding to about 225 km of coastline indicated by straight lines. Regions are designated I-V from right to left.

Table 1-2. Gaging stations used in the calculation of streamflow into coastal waters. The numbers correspond to the circled numbers in Figure 1-29. Each group represents about 225 km of coastline.

GROUP 1:

1. Mississippi River at Tarbert Landing, Miss
2. South Canal near Baker, La
3. Atchafalaya at Simmesport, La
4. Bayou Teche at Keystone Lock, near St. Martinville, La

GROUP 2:

5. Vermillion River at Surrey St., at Lafayette, La
6. Bayou Des Cannes near Eunice, La
7. Bayou Nezpique near Basile, La
8. Bear Head Creek near Starks, La
9. Calcasieu River near Kinder, La
10. Beckwith Creek near DeQuincy,La

GROUP 3:

11. Sabine River near Ruliff, Tx
12. Cow Bayou near Mauriceville, Tx
13. Neches River at Evadale, Tx
14. Village Creek near Kountze, Tx
15. Pine Island Bayou near Sour Lake, Tx
16. Trinity River at Romayor, Tx
17. Cedar Bayou near Crosby, Tx
18. Buffalo Bayou at West Belt Drive, Houston, Tx
19. Brays Bayou at Houston, Tx
20. Sims Bayou at Houston, Tx
21. Vince Bayou at Pasadena, Tx
22. Hunting Bayou at Interstate 610, Houston, Tx
23. Whiteoak Bayou at Houston, Tx
24. West Fork San Jacinto River near Conroe, Tx
25. Spring Creek at Spring, Tx
26. Cypress Creek near Westfield, Tx
27. East Fork San Jacinto River near Cleveland, Tx
28. Caney Creek near Splendora, Tx
29. Clear Creek near Pearland, Tx
30. Chocolate Bayou near Alvin, Tx
31. Oyster Creek near Angleton, Tx
32. Brazos River near Rosharon, Tx
33. San Bernard River near Boling, Tx

Table 1-2. Cont'd

GROUP 4:

34. Colorado River near Bay City, Tx
35. Tres Palacios River near Midfield, Tx
36. LaVaca River near Edna, Tx
37. Navidad River near Ganado, Tx
38. Garcitas Creek near Inez, Tx
39. Placedo Creek near Placedo, Tx
40. Guadalupe River near Victoria, Tx
41. Coleto Creek near Schroeder, Tx
42. San Antonio River at Goliad, Tx
43. Guadalupe-Blanco River Authority Calhoun Canal Flume No. 1 near Long Mott, Tx *
44. Guadalupe-Blanco River Authority Calhoun Canal Flume No. 2 near Long Mott, Tx *
45. Copano Creek near Refugio, Tx
46. Mission River at Refugio, Tx
47. Aransas River near Skidmore, Tx
48. Chiltipin Creek at Sinton, Tx

GROUP 5:

49. Nueces River near Mathis, Tx
50. Oso Creek at Corpus Christi, Tx
51. San Fernando Creek at Alice, Tx
52. Los Olmos Creek near Falfurrias, Tx
53. Rio Grande near Brownsville, Tx and Matamoros, Tamaulipas

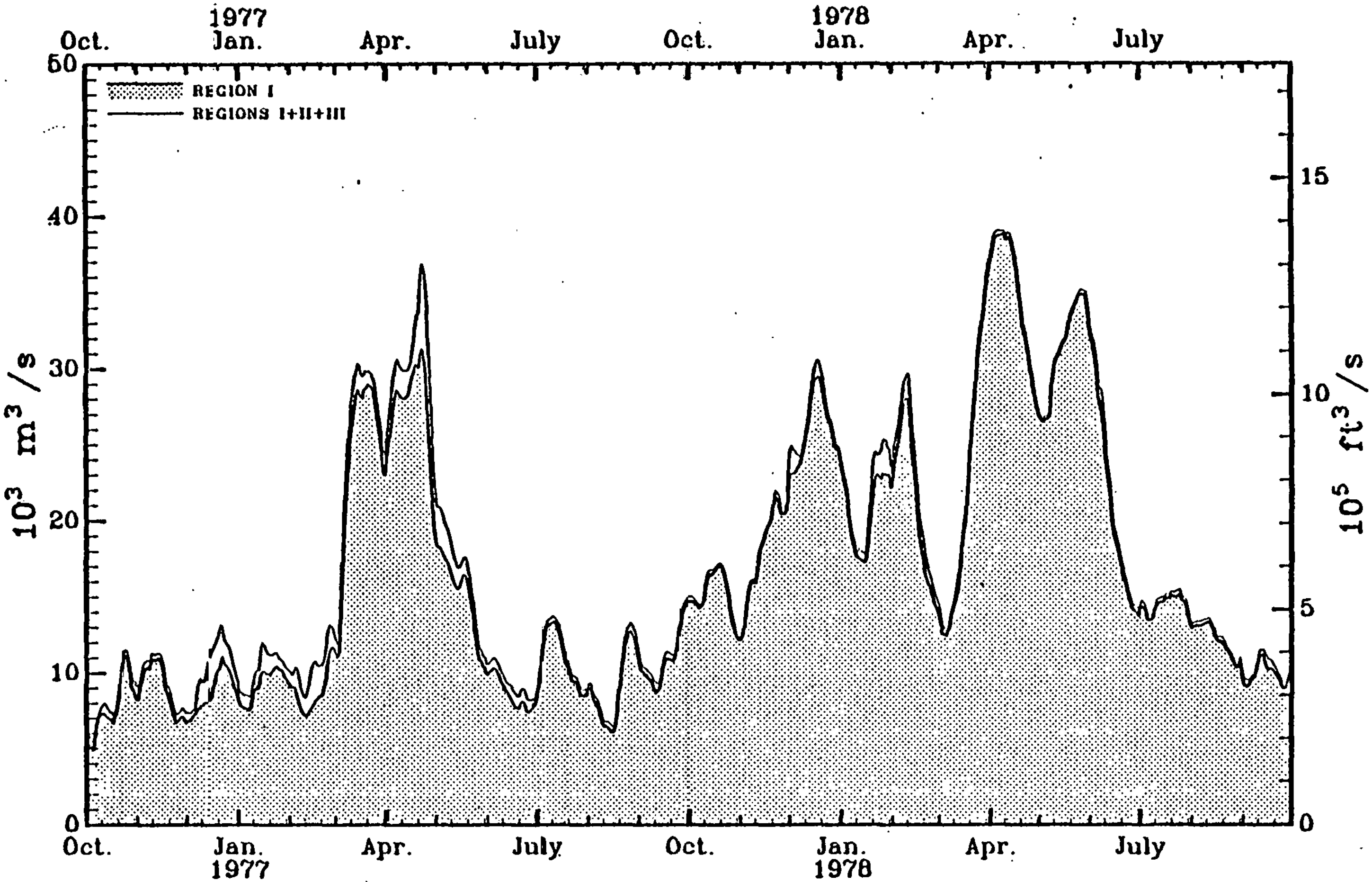
* Distributary

rivers east to the Sabine are grouped in Region III. Their fresh water output enters the Gulf of Mexico east of the "brine disposal site" and likely has a more immediate effect on the area. Region IV contains those rivers entering the Gulf between Matagorda Bay and Corpus Christi. These rivers drain to the west of the work site, downstream for most of the year. At that time of year when currents along parts of the Texas shelf reverse direction and flow east, these rivers have extremely low discharge rates. The Texas rivers in Group V represent drainage from arid west Texas.

Figure 1-30 shows the average daily streamflow for Region I, the Mississippi/Atchafalaya river system. The Atchafalaya actually represents a distributary of the Mississippi river and now diverts about 34% of the total flow reaching their junction (Gunter, 1979). The sum of Regions I, II, and III is also plotted on Figure 1-30 to emphasize the order of magnitude difference between Region I and the other regions. Figures 1-31 and 1-32 show the average daily streamflow for the rivers of Regions II, III, and IV, V respectively, but note that they area plotted on a scale which is an order of magnitude smaller than that for Region I.

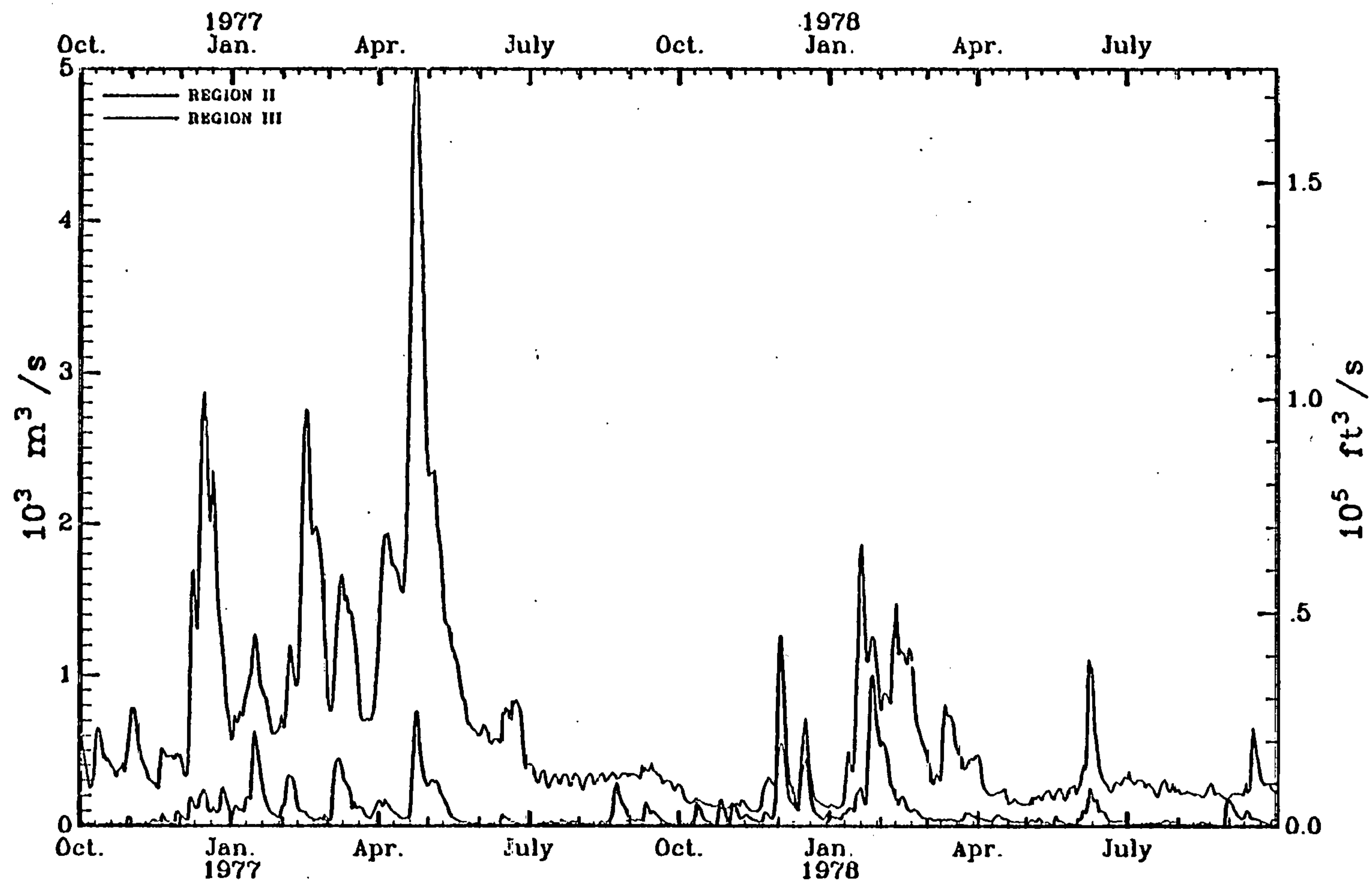
In general, the streamflow was greater in water year 1978 than 1977 in Region I, about equal in Region II, but it was less in 1978 than in 1977 in Regions III, IV, and V. The second largest streamflow after Region I occurs in Region III. During December 1976 and February 1977, when the streamflow in Region I is at a minimum, the streamflow of Region III rose to about 25% of that in Region I. More typically Region III has streamflow about 10% as large as in Region I, and the flows in Regions II, IV and V are about 10% of Region III or 1% of Region I.

Until the records for water year 1979 are received a detailed comparison of Region I and III streamflows with the salinities encountered off Freeport



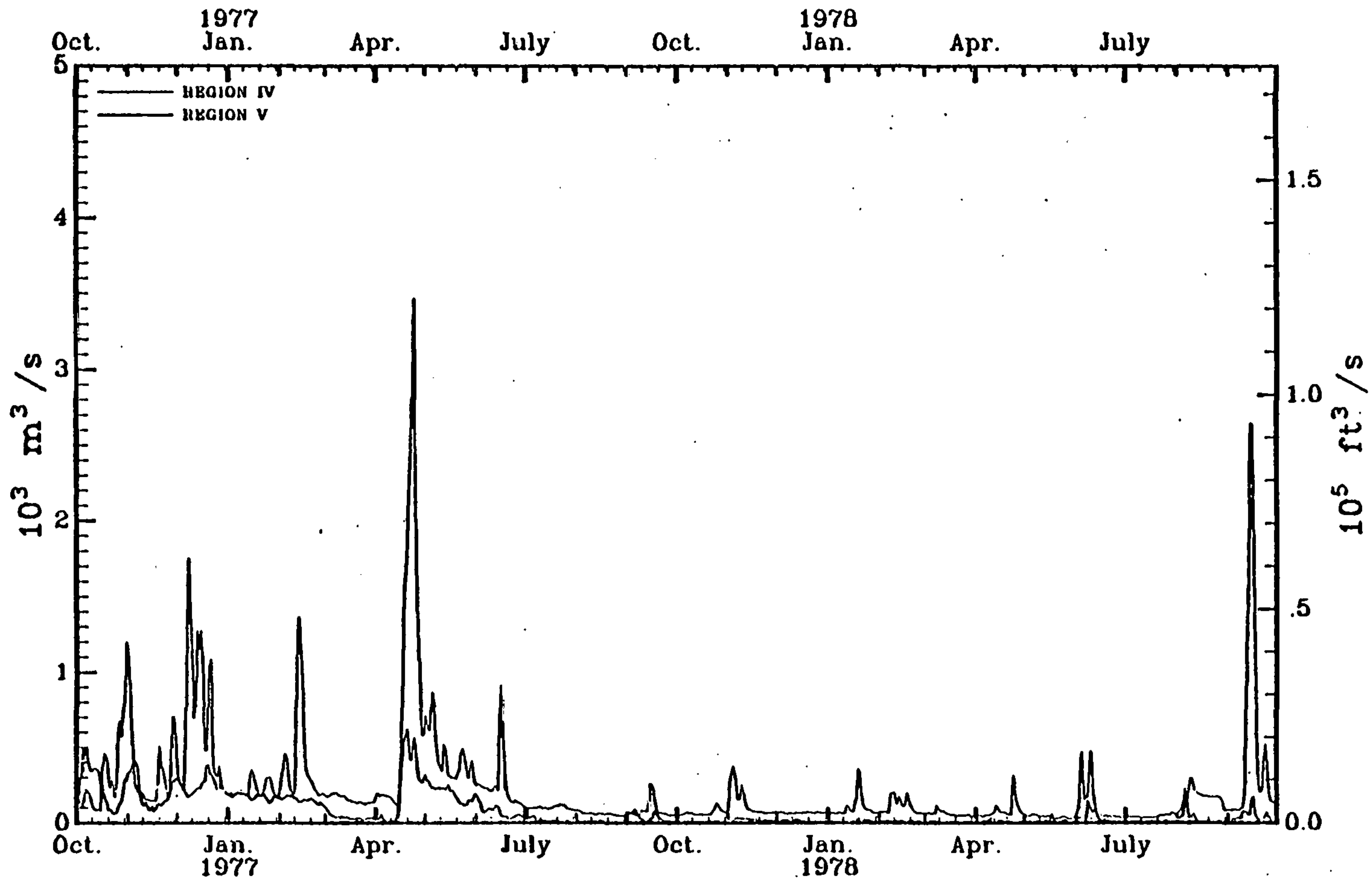
STREAMFLOW INTO TEXAS AND LOUISIANA COASTAL WATERS

Figure 1-30. Streamflow versus time for water years 1977 and 1978 for Region I (heavyline with shading underneath) and the sum of Regions I, II and III (light line). Streamflow is average daily flow



STREAMFLOW INTO TEXAS AND LOUISIANA COASTAL WATERS

Figure 1-31. Streamflow versus time for water years 1977 and 1978 for Region II (heavy line) and Region III (light line). Stream flow is average daily flow.



STREAMFLOW INTO TEXAS AND LOUISIANA COASTAL WATERS

Figure 1-32. Streamflow versus time for water years 1977 and 1978 for Region IV (light line) and Region V (heavy line). Stream flow is average daily flow.

during this period is not possible. However, the maxima in Figure 1-30 during December 1977, early February 1978 and early April correspond to periods of decreased surface salinity off Freeport (see Figure 1-33). The increase in salinity in July 1978 corresponds to a decrease in Region I streamflow. On the other hand there are only slight streamflow increases in Regions I, II and III in September 1978 when low surface salinity values again occurred off Freeport. There is a significant increase in Region IV's streamflow in September , but the surface currents should be the southwest during this time. There is a gap in the surface current data for September 1978 (see Section 1.5), but the longshore component of the wind data is towards the southwest on the average at this time (see Table 1-3). As was noted in the surface salinity maps for the GUS III data there us typically a region of low salinity trapped west of the Mississippi delta which moves rapidly westward along the coast when the longshore component of the wind shifts to that direction in September. Thus, despite the absence of supporting current meter data, this mechanism seems to be responsbile for the low salinity off Freeport in September, 1978 rather than any unusal increases in streamflow in Regions I, II, and III.

The magnitude of the streamflow in Region III deceptively appears to be small in the presence of the Mississippi flow. However, it is comparable to runoff along the east coast of the U.S. for which some studies have been done on the effect of runoff or "buoyancy flux" on the circulation of the inner continental shelf (Stommel and Leetmaa, 1972; Bishop and Overland, 1977; Endoh, 1977; Pietrafesa and Janowitz, 1979). For instance, Bumpus (1972) lists average streamflows into major segments of the Atlantic coast as follows: Gulf of Mexico, 1.7 x $10^3 m^3/s$; Middle Atlantic Bight, 5 x $10^3 m^3/s$; South Atlantic Bight 3.3 x $10^3 m^3/s$. On a streamflow per unit length of

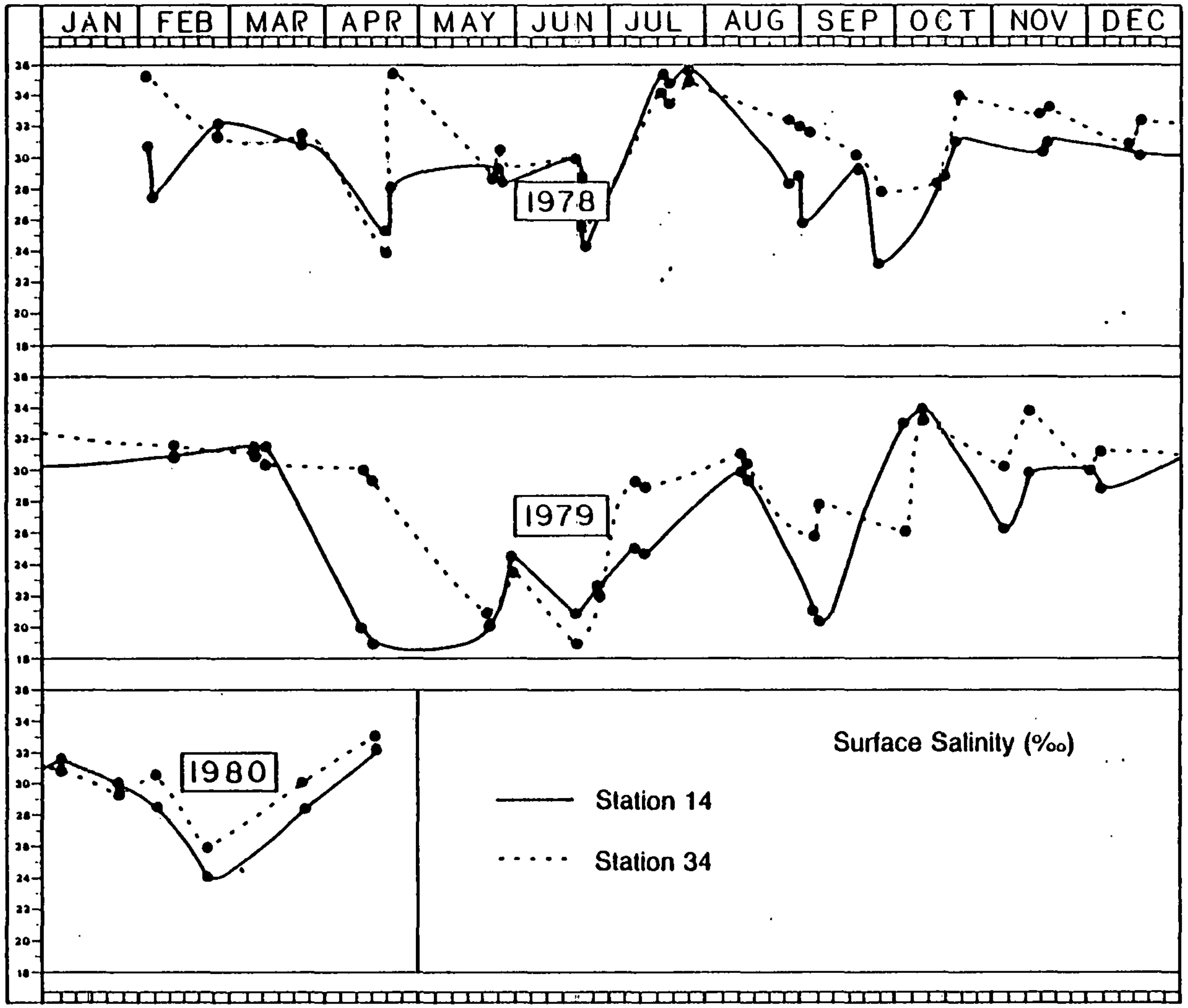


Figure 1-33. Surface salinity at stations 14 and 34 for 1978, 1979 and early 1980.

Table 1-3 Basic statistics for 15½ day intervals of the NOAA/NDBO wind velocity data from July 1978 through September 1979. A three hour low pass filter was applied to the entire 15 month record prior to the computation of statistics for the intervals. The start time of the first interval is 0000 hours (CST)

Interval dates		Longshore component (m/s)					Cross shelf component (m/s)				
START	STOP	N	MIN	MAX	$\overline{X}$	SD	N	MIN	MAX	$\overline{X}$	SD
7-03-78	7-18-78	366	-6.7	8.7	0.1	2.4	366	-9.6	10.2	3.6	3.7
7-18-78	8-02-78	366	-12.1	14.9	0.7	4.8	366	-10.2	18.9	3.1	5.7
8-02-78	8-17-78	366	-6.4	5.7	0.4	2.8	366	-6.1	8.5	2.8	3.3
8-17-78	9-01-78	366	-7.6	5.2	-1.7	2.6	366	-10.1	8.4	2.6	3.2
9-02-78	9-17-78	366	-8.6	5.4	-1.2	3.2	366	-5.1	11.2	4.7	3.2
9-17-78	10-02-78	366	-12.4	2.8	-4.3	3.0	366	-9.5	8.7	0.0	4.5
10-02-78	10-17-78	366	-13.8	5.3	-3.1	4.0	366	-9.7	7.1	1.2	3.6
10-17-78	11-01-78	366	-7.9	3.7	-2.8	2.7	366	-7.5	7.1	-0.1	3.6
11-02-78	11-17-78	366	-5.8	5.4	-1.6	2.2	366	-12.8	10.6	1.7	5.0
11-17-78	12-02-78	366	-13.8	9.4	-3.4	4.2	366	-12.6	9.0	-0.7	5.1
12-02-78	12-17-78	366	-11.9	8.4	-2.0	3.9	366	-16.8	10.6	-1.5	6.8
12-17-78	1-01-79	366	-11.8	6.0	-2.4	4.1	366	-15.1	8.9	-0.1	5.8
1-02-79	1-17-79	366	-17.5	4.0	-4.1	3.8	366	-17.4	9.9	-2.7	6.9
1-17-79	2-11-79	366	-12.5	8.7	-1.5	4.3	366	-16.1	12.9	-1.6	7.1
2-01-79	2-16-79	366	-14.6	4.8	-2.7	4.2	366	-14.3	9.0	0.2	5.3
2-16-79	3-03-79	366	-8.7	6.4	-2.5	3.1	366	-14.3	9.3	-0.8	5.9
3-04-79	3-19-79	366	-13.2	10.7	-2.2	5.1	366	-15.3	12.9	0.7	5.1
3-19-79	4-03-79	366	-13.5	7.2	-1.6	4.2	366	-16.1	11.5	2.6	5.5
4-03-79	4-18-79	366	-11.8	6.5	-3.7	3.3	366	-11.2	13.2	2.1	5.3
4-18-79	5-03-79	366	-15.6	8.1	-2.6	4.7	366	-9.5	11.3	1.6	4.8
5-04-79	5-19-79	366	-16.2	4.9	-2.8	2.7	366	-14.2	10.4	1.4	5.7

Table 1-3 Basic statistics for 15¼ intervals of the NOAA/NDBO wind velocity data from July 1978 through September 1979. (cont'd.)

Interval dates		Longshore component (m/s)					Cross shelf component (m/s)				
START	STOP	N	MIN	MAX	X	SD	N	MIN	MAX	X	SD
5-19-79	6-03-79	366	-14.6	7.3	-0.4	2.9	366	-8.2	14.0	3.7	5.2
6-03-79	6-18-79	366	-11.0	5.6	-1.8	3.2	366	-12.4	11.9	2.9	5.2
6-18-79	7-03-79	366	-5.2	6.0	1.0	2.3	366	-4.6	11.1	4.9	2.9
7-04-79	7-19-79	366	-6.7	8.7	-0.1	2.5	366	-9.6	10.2	3.1	3.9
7-19-79	8-03-79	366	-12.1	14.9	1.4	4.8	366	-10.2	18.9	3.5	5.5
8-03-79	8-18-79	366	-6.7	6.6	-0.7	2.6	366	-7.4	7.6	2.7	2.7
8-18-79	9-02-79	366	-11.2	7.4	-1.4	4.0	366	-7.4	14.2	3.3	3.2
9-03-79	9-18-79	366	-14.3	3.8	-5.3	3.0	366	-9.5	5.7	-3.0	4.1
9-18-79	9-30-79	298	-14.8	5.5	-2.8	4.5	298	-9.7	9.9	-1.3	3.3

coastline these become 22.8, 47.0 and 21.8 cm^2/s, respectively. Regions I-V each were chosen to have a length of coastline of 225 km. Then 1 $x10^3 m^3/s$ of streamflow in Figure 1-31 and 1- 32 can be interpreted as 44.4 cm^2/s flow per unit length of coastline, and Region III is thus quite comparable to the east coast rivers.

The Mississippi River, however, is more than an order of magnitude greater than east coast rivers, and the effect of such a large "buoyancy flux" (Pietrafesa and Janowitz, 1979) on the dynamics of the inner coastal zone needs further study.

1.4 Meteorological Data

Meteorological data including wind speed and direction has been collected by the NOAA Data Buoy Office (NOAA/NDBO) from an instrumentation package placed atop an offshore fixed structure owned by Rutherford Oil Co. It is located approximately 150 ft east of current meter site "A", North Latitude 28°47.7' and West Longitude 95°18.7'. The data are transmitted on an hourly basis via satellite to a ground station. Magnetic computer tapes of processed, qualified data are sent monthly to Texas A&M University.

The wind data have been converted to Central Standard Time (CST) and oceanographic heading convention and then resolved into orthogonal components parallel to the local orientation of the coast (055°T) and perpendicular to it (325°T). Data gaps of less than 24 hours duration have been filled by linear interpolation and the monthly records joined to form long time series. Data for June 1978 and October 1979 have too many long data gaps to permit processing. The individual time series have been filtered with 3 hour and 40 hour low-pass filters and plotted, as described in Section 1.4 for current velocity time series. The monthly time series plots have been placed in Appendix 3.

To summarize the wind data, basic statistics for the period July 1978 through September 1979 have been computed for 15½ day intervals and are shown in Table 1-3. The values for mean longshore wind for this period follow the multiannual mean wind pattern. They indicate northeast component (oceanographic direction convention) in July and mid-August followed by a shift to the southwest or "downcoast" from late August 1978 through mid-June 1979. The longshore component is weak from mid-May through mid-August, 1979 and is upcoast in late June and July. Beginning in mid-August the winds shift back to downcoast and increase in strength in September 1979. The cross-shelf wind component is predominantly onshore, but mean offshore winds occurred from mid-November, 1978 through January 1979 and in September 1979. The standard deviations for these averages are large, particularly in the winter and spring. The time series plots indicate a distinct three to five day period which reflects the passage of fronts through the area.

Appendix 3 also contains a monthly summary of precipitation, temperature and miscellaneous information which has been excerpted from the Monthly Weather Review. It is intended to be a meteorological reference source for all the components of this project. The cold winter of 1978, the above normal precipitation in 1979 and various tropical storms and hurricanes are of note.

1.5 Current Meter Data

1.5.1 Site Locations and Mooring Configurations

Current meter Site A, which is located near a large fixed offshore gas platform, was established in late 1977 after earlier attempts to establish sites in more "open" waters failed. A major problem of the early periods of this project has been the loss of current meter moorings, presumably a result of collision with commercial fishery vessels. Two short records were obtained in late December 1977 and late March 1978. (These are not shown because after filtering they are too short to be of use). Since June 1978, however, a relatively unbroken series of records have been collected at Site A.

The choice of the location of Site A was based on the presence of a protective platform near the originally proposed location for the brine diffuser. In May 1979 a second current meter site, Site B was established about 8 nautical miles downcoast (southeast) from Site A and along the same depth contour, 62 feet. Site B is also located near a fixed gas platform. The purpose of Site B is to study the longshore coherence of the currents and the effect, if any, of the discharge of the Brazos River on Site A. (At times the turbid water from the Brazos was visible at Site A.) A third current meter site was established in late August 1979 at the diffuser site immediately after completion of the construction of the brine pipeline and diffuser. Site C is located about 5 nautical miles offshore from Site A and thus, some information about the cross-shelf coherence may be obtained. The coordinates for each of the three sites are:

Site A: 28° 47' 03.0" N, 095° 18' 46.8" W

Site B: 28° 41' 57.5" N, 095° 25' 42.4" W

Site C: 28° 43' 53.9" N, 095° 14' 34.3" W

Environmental Devices Corporation (ENDECO) Type 105 current meters were used until August 17, 1979 when a phase-in of ENDECO Type 174 current meters began. By October 1979, Type 174 current meters were being used almost exclusively. Both models are neutrally buoyant, ducted impeller, tethered meters with an internal magnetic compass. The Type 105 records internally on film while the 174 records internally on digital magnetic tape. The Type 174 also has temperature and conductivity sensors. The sample period is 30 minutes for the Type 105 and 2, 3, or 5 minutes for the Type 174. The two minute rate was used intially, but now the three minute rate is used for the top and mid depth meters and the 5 minute rate for the bottom meters. This provides better resolution and accuracy at low velocities.

ENDECO current meter mooring configuration is shown in Figure 1-34. Until May 15, 1979 a low tension mooring line was used. It was similar to the one in Figure 1-34 except that there was no middle current meter. The surface marker buoys during this time were small Automatic Power BA-17's (not shown in Figure 1-34) with light and radar reflector. These buoys had a conventional mooring line with a scope of about 1.7 -2.0 times the depth, and thus they moved in a watch circle which had a radius of about 80 feet. The subsurface current meter mooring, therefore, had to be located at least 80 feet from the surface marker buoy, and when the surface marker buoy was located on the far side of its watch circle it was 160 feet from the subsurface current meters it was intended to protect. Larger conventional buoys would require even more scope in the mooring line.

To solve this problem of marking and protecting the subsurface instruments a new type buoy mooring system marketed by NAICO, Inc. was installed in May 1979. It has a set of strong elastic tethers in the mooring line but permits the buoy to move vertically as it follows the motion of the sea surface. A large 6' dimater steel buoy was used. This is shown in Figure 1-34. The watch circle of the elastically tethered NAICO buoy is less than 5% of depth, i.e. less than 3 feet.

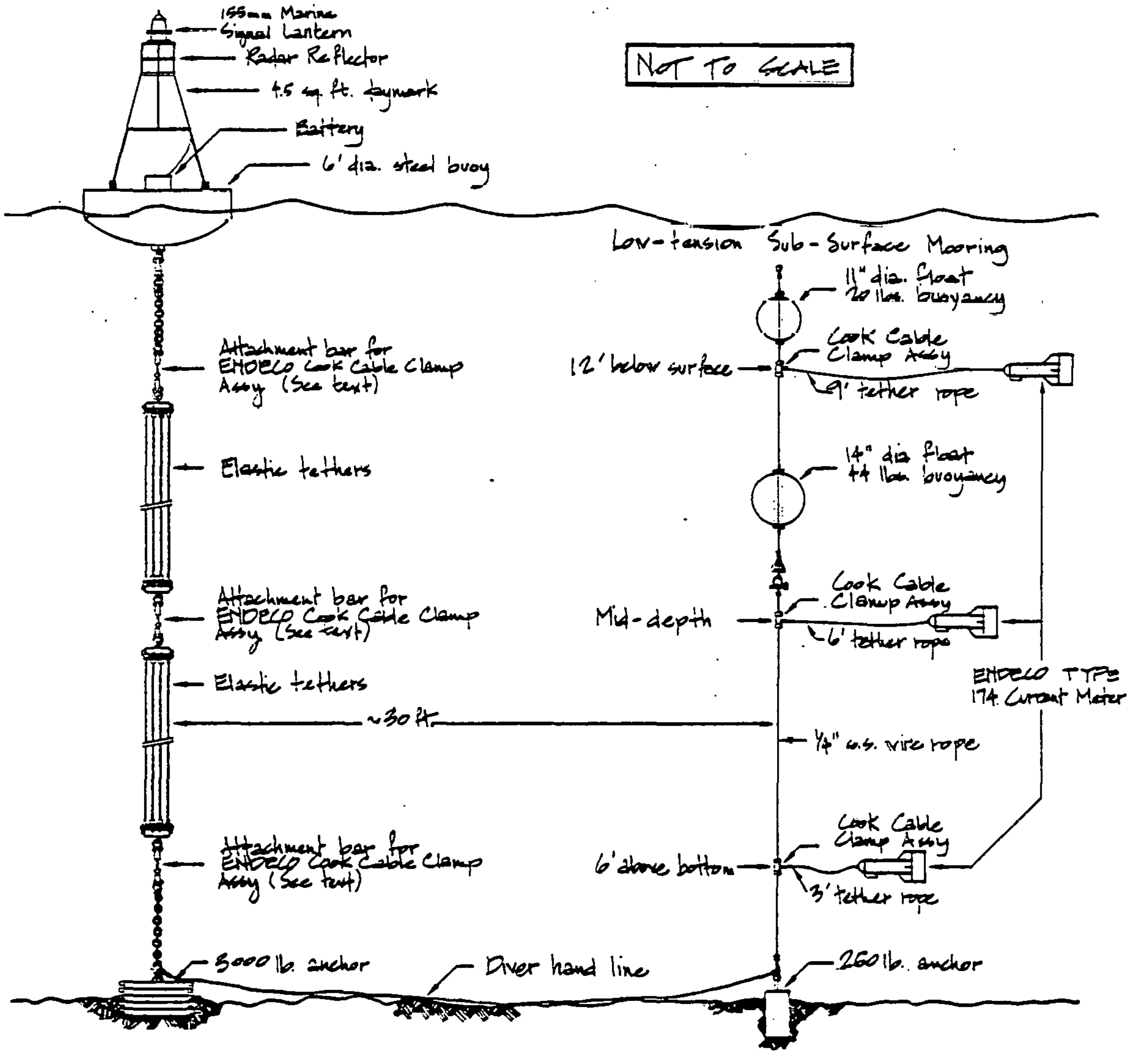


Figure 1-34. Typical mooring design for current meter and surface marker buoy. Elastic tethers in surface buoy mooring line reduce watch circle of buoy to less than 5% of depth.

Because ENDECO current meters are decoupled from mooring line motion by long tether ropes, it was believed that they could be attached directly to the NAICO mooring line via a special stainless steel bar designed for the ENDECO Cook Clamp swivel assembly. From May 15 through about October 1979 the current meters were attached in this manner to the surface marker buoy mooring line (see Figure 1-34). The initial results were encouraging. However, apparently as a result of fouling the Cook Clamp swivels began to seize causing the ENDECO tether ropes to wrap up around the mooring line. The reduced length of the tether rope caused the current meter to collide with the mooring hardware and several instruments were damaged. Therefore, beginning in November 1979, low-tension subsurface current meter moorings were installed about 30 feet from the NAICO marker buoys as shown in Figure 1-34. The system as depicted in Figure 1-34 has proved highly successful. It should be noted that no instruments have been lost because of collisions with commercial fishing vessels since the NAICO elastically tethered buoy system was adopted.

1.5.2 Data Processing

Current meters are rotated every three to five weeks to prevent long data gaps in the event an instrument is lost or damaged and to reduce problems from biofouling. The data packs, i.e. film for Type 105 meters and magnetic tapes for Type 174, follow two different processing routes. Film packs must be sent to the manufacturer to be developed and digitized. The manufacturer maintains a computerized file of calibration data for each instrument, and magnetic tapes of processed, calibrated data are returned to the user. The turn-around time is from four to six weeks. Translation of Type 174 magnetic tapes is done here at Texas A&M University by means of a Model 2051 ENDECO tape translator and the raw data is entered directly and automatically into the AMDAHL 470V/6 via a remote terminal. The raw data is processed through several stages of computerized and visual checking and editing, and then the data are converted to scaled units and calibration constants applied. Turn around time on a priority basis can be one day.

The basic calibrated Type 174 data has a sample interval of 2, 3, or 5 minutes. Speed and direction are resolved into longshore (055°T) and cross-shelf (325°T) perpendicular components. Salinity is computed from conductivity using the equation of Daniel and Collias (1971) which has the advantages of being computationally simple and sufficiently accurate over a large range of temperature and conductivity. More precise conversion formulas are applicable over limited ranges of temperature and conductivity and can become unstable if extended past the intended limits of use. Encountering unusually high conductivities is a possibility in the diffuser area. The resolution and accuracy of temperature and salinity for the Type 174 meter are 0.098°C, ± 0.2°C and 0.12°/oo, ± 0.5°/oo respectively.

The resulting time series, i.e. longshore and cross shelf currents, temperature and salinity, are then passed through a 2 hour low pass filter and decimated to half-hourly data. The response function for the filter is shown in Figure 1-35. It results in a loss of one and a half hours of data on each end of a data record. The filter eliminates high frequency sampling noise and produces current velocity records which are compatible with the half-hourly Type 105 records. The half-hourly data from each type meter are reported to NOAA/EDIS.

In the next step of processing, the data records from a given instrument location , for example, Site A, Top, are joined to form long time series.

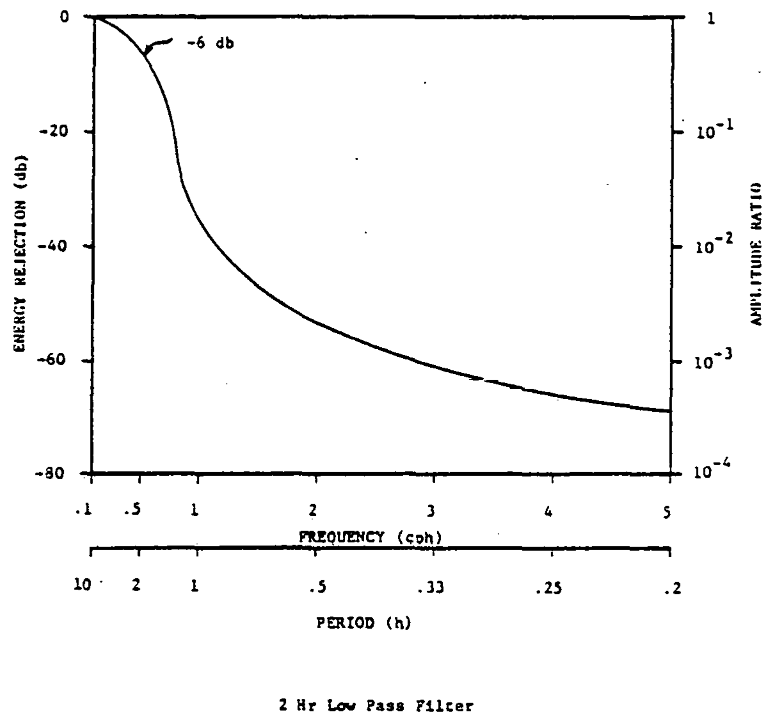


Figure 1-35. Smoothed response function for the two-hour low pass Lanczos filter. The rejection equals or exceeds the smoothed curve.

Gaps of less than twenty-four hours between records are filled by linear interpolation. A gap longer than twenty-four hours marks the end of one joined record and the start of another. Joined time series records are then filtered with three-hour and forty-hour low pass filters and decimated to hourly data. The response functions are shown in Figure 1-36 and 1-37. The result is a data loss of eight hours and four days respectively from each end of the record. The three-hour low pass filter further eliminates high frequency noise and aliasing, and the forty-hour filter eliminates the diurnal , semi-diurnal and inertial frequencies.

For all filters, the specified cutoff period is the -6db point, i.e. the point at which the output energy is 25% of the input. Lanczos tapers were used for each filter. The filtering and time series analysis utilize the FESTSAcomputer software system (Brooks, 1976).

1.5.3 Time Series Plots of Current, Temperature and Salinity

The three-hour low passed and forty-hour low passed time series have been plotted on a monthly basis and are located in Appendix 4 . The temperature and salinity plots are from the forty-hour low pass filter. The stick plots representing current vectors are also from the forty-hour low pass filter, but decimated to 6 hour intervals. Note that in the stick plots, true north is vertically upward. The longshore and cross-shelf plots include both the three-hour and forty-hour low passed data. Vertically upward is 055°T for longshore and 325°T for cross-shelf.

Time series plots are shown for all data from Type 105 and 174 meters except for two short records in late December 1977 and late March 1978. The plots are fairly self-explanatory and are organized by instrument location so that the complete sets of joined records for each can easily be

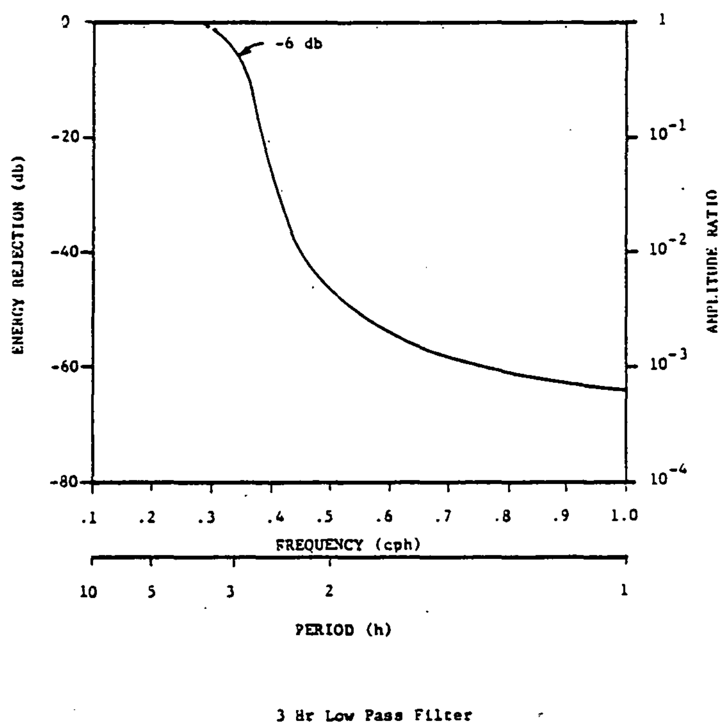


Figure 1-36. Smoothed response function for the three-hour low pass Lanczos filter. The rejection equals or exceeds the smoothed curve.

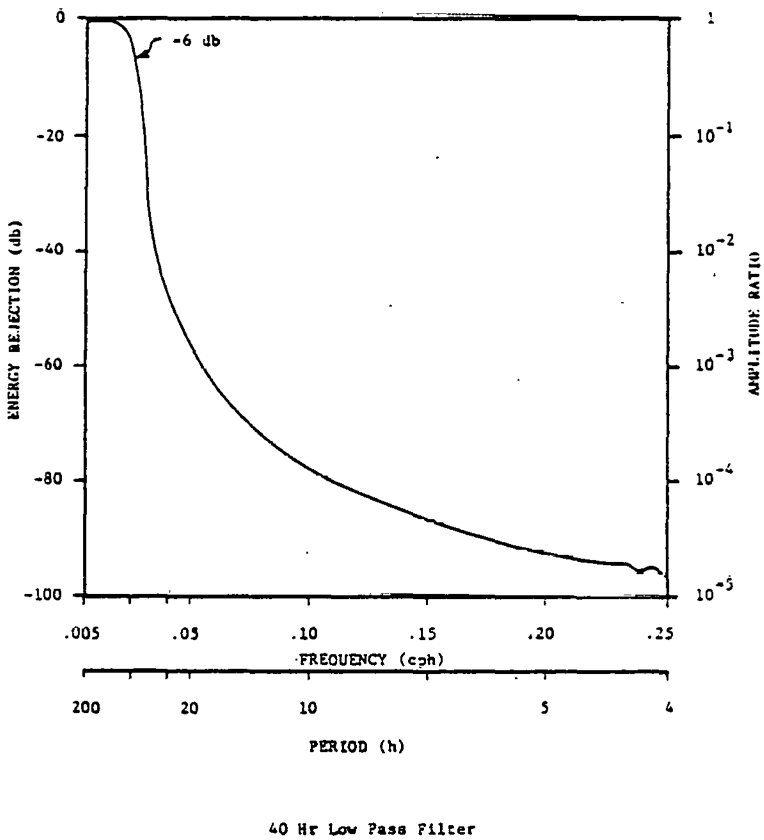


Figure 1-37. Smoothed response function for the 40-hour low pass Lanczos filter. The rejection equals or exceeds the smoothed curve.

viewed. An alternative arrangement, that of all data from all meters for a given month was tried and found to be too cumbersome. A detailed recapitulation by month or season is not part of this report because the autospectral and cross-spectral analyses are still being computed and will appear in a subsequent report. The time series plots are intended to meet the objectives stated in the introduction of providing a data base for other components of this project.

In general, however, there seems to be qualitative agreement between the longshore component of the wind and the longshore component of the current. Cross-shelf currents appear to be fairly more complex to interpret. Also, the magnitude of the currents at tidal frequencies appears to be fairly significant at the bottom. This can be seen in the cross-shelf plots of three-hour low pass filtered currents. The band-pass, i.e. 3-40 hour, time series are being investigated to further define the relative importance of tidal currents at the bottom. These could provide some mechanism for brine dispersion in the absence of a mean current.

During April, May and June of 1979 when anoxic conditions were reported (see chapter on water quality for example), the data indicate very low currents. However, there is some question about the data because the bottom meter was negatively buoyant and rested on the bottom at times. (The extreme low density due to the high volume of river runoff was not anticipated.) The current velocity data collected during this time by NOAA/NDBO with a meter eight feet off the bottom also show low currents. It is probable that the ENDECO meter underestimated the currents when the velocities were below about 5 cm/s. There was probably threshold velocity, between about 5 and 10 cm/s, above which the negative buoyancy of the meter would be overcome, and the meter would lift off the bottom. There is no doubt, however, that bottom currents were low during this time.

However, at the surface the highest cross shelf velocities of the study, up to 75 cm/s onshore, were recorded in April 1979. The longshore velocities were also strong and directed down coast. The vertical sections of hydrographic data showed a strong horizontal pycnocline and it is entirely possible that a two layer system existed, with the lower layer at rest.

Low current velocities usually existed in August of each year which is in agreement with the low mean wind velocities.

Temperature and salinity time series follow the trends discussed in Section 1.2 but provide more information about variability on time sales of less than two weeks. There is usually close agreement between the temperature and salinity measured during hydrographic cruises and the temperature and salinity recorded in-situ by the Type 174 meters. At the scale used in plotting the temperature and salinity time series data, the fluctuations of the three-hour low passed data about the 40-hour curve are too small to warrant plotting. A study of the magnitude and time scales of salinity variations is in progress and will appear in a subsequent report.

To summarize the current meter data, basic statistics have been computed for 15.25 day intervals and are shown in Tables 1-4 through 1-12. The statistics are taken from the 40-hour low-pass filtered time series data. The minimum and maximum values, therefore, do not include extremes caused by tidal components or bad-data spikes. The mean values for the 3-hour and 40-hour low-pass filtered data are equal if they cover identical intervals. The length of 15.25 days was chosen to provide a uniform approximation to a semi-monthly average. There are exactly 24 such intervals in 366 days. Intervals in which no data was recorded are left blank in

Table 1-4. Basic statistics for 15 1/4-day intervals for Site A, Top, current velocity data. A 40-hour low-pass filter was applied to the data prior to the computation of statistics for the intervals. (*An incomplete interval; data is missing on the side which has the asterisk.)

Interval dates		Longshore component (m/s)					Cross shelf component (m/s)				
START	STOP	N	MIN	MAX	$\overline{X}$	SD	N	MIN	MAX	$\overline{X}$	SC
6-14-78*	6-17-78	73	-26.3	-4.8	-11.1	4.1	73	1.5	16.0	8.6	4.7
6-17-78	7-2-78	366	-40.0	46.8	3.1	23.5	366	-15.3	32.9	2.7	12.8
7-3-78	7-18-78	366	1.0	49.2	20.8	14.9	366	-19.9	7.0	-6.9	6.0
7-18-78	8-2-78	366	-20.1	43.7	13.5	14.6	366	- 6.4	18.9	3.9	6.2
8-2-78	8-17-78	366	- 7.9	37.8	12.7	14.0	366	- 9.2	18.8	3.5	7.6
8-17-78	9-1-78*	348	-66.3	28.2	-16.2	25.2	348	- 4.6	17.4	6.7	6.1
9-2-78	9-17-78										
9-17-78	10-2-78										
10-2-78	10-17-78										
10-23-78	11-1-78	240	-61.1	-7.9	-34.8	11.6	240	- 1.6	16.8	9.0	4.3
11-2-78	11-17-78	366	-57.3	3.7	-33.0	13.1	366	-13.1	11.5	1.7	6.6
11-17-78	12-2-78	366	-62.4	-10.7	-38.7	15.2	366	-12.4	5.6	-0.7	4.1
12-2-78	12-17-78	366	-52.2	14.6	-25.4	17.6	366	-17.6	5.8	-1.2	5.2
12-17-78	1-1-79	366	-58.6	19.8	-28.9	18.8	366	-23.6	7.8	-7.3	8.9
1-2-79	1-17-79	366	-68.3	19.9	-36.0	18.6	366	-37.4	3.4	-16.5	11.0
1-17-79	2-1-79	366	-56.4	60.5	-16.5	28.6	366	-22.6	11.6	0.2	8.1
2-1-79	2-16-79	366	-69.5	10.3	-32.7	19.8	366	-12.0	13.3	2.6	6.3
2-16-79	3-3-79	366	-75.3	41.9	-34.0	31.2	366	-19.2	32.7	5.6	11.3
3-4-79	3-19-79	366	-32.0	46.2	- 7.7	19.7	366	-13.5	38.8	13.3	14.8
3-19-79	4-3-79	366	-42.4	41.4	- 8.6	23.2	366	-10.6	54.6	17.9	15.7

Table 1-4. Basic statistics for 15 1/4-day intervals for Stie A, Top, current velocity data. A 40-hour low-pass filter was applied to the data prior to the computation of statistics for the intervals. (*An incomplete interval; data is missing on the side which has the asterisk.) (Continued)

Interval dates		Longshore component (m/s)					Cross shelf component (m/s)				
START	STOP	N	MIN	MAX	$\overline{X}$	SD	N	MIN	MAX	$\overline{X}$	SD
4-3-79	4-18-79	366	-71.2	-30.1	-52.3	11.8	366	8.3	49.2	35.3	8.7
4-18-79	5-3-79	366	-69.0	5.8	-44.2	16.9	366	-10.7	52.3	24.9	12.8
5-4-79	5-19-79	366	-69.1	- 3.4	-38.4	19.3	366	-8.6	47.3	22.1	10.6
5-19-79	6-3-79	366	-33.7	29.3	-2.2	19.3	366	-27.6	31.7	4.9	16.2
6-3-79	6-18-79	366	-53.6	43.3	-8.3	25.1	366	-16.4	42.9	12.5	15.4
6-18-79	7-3-79	366	-22.6	62.3	17.2	22.5	366	-7.4	25.4	5.1	9.0
7-4-79	7-12-79*	196	-56.1	39.8	12.8	30.5	196	-18.2	5.6	-9.1	5.7
7-19-79	8-3-79										
8-3-79	8-18-79										
8-18-79	9-2-79										
9-3-79	9-18-79										
9-18-79	10-3-79										
10-3-79*	10-18-79	359	-41.0	50.7	9.4	25.2	359	-9.3	20.3	0.3	6.7
10-18-79	11-2-79	366	-69.1	2.0	-27.7	18.2	366	-13.0	7.8	-5.3	5.4
11-3-79	11-18-79	366	-63.8	4.5	-26.9	16.0	366	-10.9	10.7	-3.2	3.3
11-18-79	12-3-79	366	-48.7	23.3	-9.8	18.0	366	-17.9	21.2	-1.7	8.2
12-3-79	12-18-79	366	-45.6	-9.8	-29.2	8.8	366	-11.1	3.3	-4.6	3.6
12-18-79	1-2-80	366	-71.6	40.2	-6.6	28.0	366	-8.2	6.0	-1.5	3.4
1-3-80	1-18-80	366	-47.3	7.4	-20.7	13.7	366	-24.7	10.3	-1.5	5.9
1-18-80	2-2-80	366	-70.7	34.4	-26.8	29.4	366	-29.3	6.3	-7.2	7.4
2-2-80	2-17-80	366	-96.5	-9.5	-48.7	21.9	366	-16.8	3.1	-7.1	4.9
2-17-80	3-3-80	366	-45.7	14.3	-20.4	14.8	366	-11.7	12.0	-1.1	5.4

Table 1-5. Basic statistics for 15 1/4-day intervals for Site A, Middle, current velocity data. A 40-hour low-pass filter was applied to the data prior to the computation of statistics for the intervals. (* An incomplete interval; data is missing on the side which has the asterisk.)

Interval dates		Longshore component (m/s)					Cross shelf component (m/s)				
START	STOP	N	MIN	MAX	$\overline{X}$	SD	N	MIN	MAX	$\overline{X}$	SD
8-22-79*	9-2-79	285	-40.6	4.3	-15.6	13.5	285	-5.3	5.1	-0.4	2.4
9-3-79	9-18-79	366	-46.4	17.9	-23.3	18.1	366	-5.9	8.2	-0.3	3.1
9-18-79	10-3-79	366	-53.0	36.1	-4.9	24.2	366	-6.5	7.4	-0.5	3.3
10-3-79	10-18-79	366	-43.2	31.9	1.2	22.1	366	-9.6	3.6	-1.9	2.8
10-18-79	11-2-79	366	-36.0	-4.0	-17.6	9.1	366	-7.2	4.9	-2.0	2.9
11-3-79	11-18-79	366	-35.6	14.3	-9.6	10.4	366	-4.5	9.5	2.1	3.1
11-18-79	12-3-79	366	-31.0	32.4	-4.8	15.2	366	-6.1	8.9	1.7	3.3
12-3-79	12-18-79	366	-36.6	-3.0	-19.8	8.8	366	-3.4	5.4	0.5	2.1
12-18-79	1-2-80	366	-46.2	47.4	5.2	22.2	366	-28.3	4.5	-3.9	6.7
1-3-80	1-18-80	366	-42.7	9.0	-15.2	12.4	366	-8.4	6.8	-0.2	3.3
1-18-80	2-2-80	366	-48.7	45.6	-16.7	24.1	366	-8.7	12.1	0.4	4.4
2-2-80	2-17-80	366	-63.5	4.9	-27.9	16.9	366	-10.9	8.5	1.2	4.2
2-17-80	3-3-80	366	-34.8	13.4	-9.7	12.9	366	-4.8	8.8	0.8	3.1

Table 1-6. Basic statistics for 15 1/4-day intervals for Site A, Bottom, current velocity data. A 40-hour low-pass filter was applied to the data prior to the computation of statistics for the intervals. (* An incomplete interval; data is missing on the side which has the asterisk.)

Interval dates		Longshore component (m/s)					Cross shelf component (m/s)				
START	STOP	N	MIN	MAX	$\overline{X}$	SD	N	MIN	MAX	$\overline{X}$	SD
6-14-78	6-17-78	74	-14.7	-4.5	-7.8	2.2	74	-8.1	-0.7	-3.9	2.5
6-17-78	7-2-78	366	-16.3	21.5	-0.8	10.6	366	-6.9	5.8	-0.8	3.2
7-3-78	7-18-78	366	- 7.0	21.0	8.8	8.7	366	-5.0	7.6	2.2	3.6
7-18-78	8-2-78	366	-18.2	23.4	1.4	11.3	366	-14.2	7.9	-0.4	5.9
8-2-78	8-17-78	366	-15.9	23.3	1.4	10.8	366	-10.7	8.7	-1.2	5.8
8-17-78	9-1-78	366	-33.0	9.6	-10.6	9.8	366	-11.7	5.3	-4.0	4.9
9-2-78	9-17-78	366	-20.5	6.8	-5.0	8.0	366	-8.4	7.5	0.5	3.8
9-17-78	9-23-78*	144	-25.2	1.5	-9.5	5.6	144	-7.2	2.6	-2.6	2.2
10-2-78	10-17-78										
10-23-78*	11-1-78	240	-24.0	6.6	-10.8	7.9	240	-8.9	3.5	-1.8	3.2
11-2-78	11-17-78	366	-20.9	7.5	-9.3	6.0	366	-6.5	6.0	-1.0	2.4
11-17-78	12-2-78	366	-38.4	2.6	-14.2	11.7	366	-6.9	11.7	2.8	3.7
12-2-78	12-17-78	366	-23.2	16.4	-4.6	9.7	366	-9.2	9.7	-0.3	5.2
12-17-78	1-1-79	366	-32.4	17.7	-7.3	10.8	366	-7.1	12.8	0.4	4.7
1-2-79	1-17-79	366	-40.9	20.3	-11.8	14.6	366	-10.3	13.0	1.1	5.4
1-17-79	2-1-79	366	-35.7	36.5	-3.4	16.9	366	-7.3	10.8	1.5	4.7
2-1-79	2-16-79	366	-39.0	18.2	-9.9	12.4	366	-9.1	12.9	-1.1	5.5
2-16-79	3-3-79	366	-26.7	34.1	-4.9	12.5	366	-5.7	12.8	0.4	4.0
3-4-79	3-19-79	366	-23.9	15.5	-2.2	8.6	366	-1.8	20.8	4.0	6.2
3-19-79	4-3-79	366	-19.1	24.6	-0.4	9.2	366	-0.8	15.8	4.3	4.8
4-3-79	4-18-79	366	-20.6	12.7	-4.1	6.8	366	-5.9	15.3	0.8	3.6

Table 1-6. Basic statistics for 15 1/4-day intervals for Site A, Bottom, current velocity data. A 40-hour low-pass filter was applied to the data prior to the computation of statistics for the intervals. (*An incomplete interval; data is missing on the side which has the asterisk.) (Continued)

Interval dates		Longshore component (m/s)					Cross shelf component (m/s)				
START	STOP	N	MIN	MAX	$\overline{X}$	SD	X	MIN	MAX	$\overline{X}$	SD
4-18-79	5-3-79	366	-25.1	1.8	-4.0	7.1	366	-1.7	12.6	0.9	2.9
5-4-79	5-19-79	366	-13.7	9.0	-1.7	4.7	366	-2.2	4.2	0.9	1.6
5-19-79	6-3-79	366	-13.3	7.9	-4.3	5.6	366	-8.5	7.9	0.0	3.7
6-3-79	6-18-79	366	-27.8	3.8	-4.9	7.9	366	-12.3	3.6	-0.7	3.9
6-18-79	7-3-79	366	-7.8	9.7	0.9	4.6	366	-2.0	8.6	1.7	2.8
7-4-79	7-19-79	366	-13.8	10.4	0.1	5.4	366	-3.9	8.5	0.0	3.4
7-19-79	8-3-79	366	-45.4	36.4	1.5	17.8	366	-11.9	23.8	0.5	7.4
8-3-79	8-18-79	366	-10.8	11.4	-1.9	5.5	366	-5.6	4.2	-0.9	2.5
8-18-79	9-2-79	366	-38.0	6.8	-9.0	11.7	366	-14.2	2.7	-2.3	4.0
9-3-79	9-18-79	366	-40.8	19.1	-12.2	15.7	366	-8.9	6.6	-1.4	4.7
9-18-79	10-3-79	366	-53.1	21.5	-2.9	20.7	366	-8.7	14.7	2.2	5.4
10-3-79	10-13-79*	231	-0.9	19.4	9.2	6.1	231	0.4	15.1	6.9	4.1
10-18-79	11-2-79										
11-12-79*	11-18-79	130	-14.3	8.5	-0.7	6.3	130	-9.4	6.2	1.4	4.7
11-18-79	12-3-79	366	-19.7	19.6	-1.3	9.6	366	-6.5	12.4	2.5	5.9
12-3-79	12-18-79	366	-21.4	6.4	-7.0	6.6	366	-5.7	7.3	-0.5	3.4
12-18-79	1-2-80	366	-19.3	28.0	3.2	11.7	366	-12.3	12.5	3.3	6.1
1-3-80	1-18-80	366	-24.2	6.5	-6.6	8.6	366	-10.6	6.3	-2.4	3.4
1-18-80	2-2-80	366	-21.2	20.2	-6.5	11.8	366	-9.9	15.1	0.5	6.7
2-2-80	2-17-80	366	-39.6	9.9	-6.8	11.8	366	-12.4	5.6	-0.6	3.9
2-17-80	3-3-80	366	-20.5	11.4	0.3	7.2	366	-8.9	9.5	1.2	3.6

Table 1-7. Basic statistics for 15 1/4-day intervals for Site B, Top, current velocity data. A 40-hour low-pass filter was applied to the data prior to the computation of statistics for the intervals. (* An incomplete interval; data is missing on the side which has the asterisk.)

Interval dates		Longshore component (m/s)					Cross shelf component (m/s)				
START	STOP	N	MIN	MAX	$\overline{X}$	SD	N	MIN	MAX	$\overline{X}$	SD
5-19-79	6-2-79*	318	-41.0	27.2	-8.5	19.8	318	-8.1	26.9	6.3	9.1
6-3-79	6-18-79										
6-28-79*	7-3-79	144	-19.6	60.1	22.0	28.6	144	-20.4	16.0	-8.8	9.3
7-4-79	7-19-79	366	-23.3	33.4	13.1	14.4	366	-20.4	18.3	-4.2	8.4
7-19-79	8-3-79	366	-54.9	62.9	16.7	27.2	366	-25.8	27.0	-3.7	12.8
8-3-79	8-18-79	366	-19.3	16.2	0.6	10.3	366	-11.5	9.7	0.5	5.2
8-18-79	9-2-79	366	-51.0	-1.9	-22.9	14.9	366	-6.4	19.4	3.4	5.2
9-3-79	9-18-79	366	-66.9	-4.9	-47.4	13.9	366	-8.4	26.2	11.8	7.2
9-18-79	10-3-79	366	-73.1	57.5	-21.5	35.0	366	-10.7	47.4	8.6	13.2
10-3-79	10-18-79	366	-40.0	53.0	12.6	25.3	366	-13.3	21.9	-1.1	9.3
10-18-79	10-25-79*	174	-32.0	6.1	-15.4	13.0	174	-11.6	5.9	0.5	5.3
11-3-79	11-18-79										
11-18-79	12-3-79										
12-6-79*	12-18-79	305	-52.9	0.8	-33.4	11.2	305	-9.5	12.8	2.3	5.0
12-18-79	1-2-80	366	-77.4	29.6	-14.1	28.4	366	-15.0	9.2	0.1	5.1
1-3-80	1-18-80	366	-48.4	2.2	-21.0	13.0	366	-8.9	13.3	2.1	5.7
1-18-80	2-2-80	366	-67.9	18.2	-26.7	23.8	366	-18.5	14.8	0.1	9.4
2-2-80	2-17-80	366	-79.3	-17.1	-41.2	16.3	366	-11.7	12.2	2.6	5.6
2-17-80	3-3-80	366	-42.0	5.4	-18.1	12.7	366	-9.6	7.9	0.7	4.9

Table 1-8. Basic statistics for 15 1/4-day intervals for Site B, Middle, current velocity data. A 40-hour low-pass filter was applied to the data prior to the computation of statistics for the intervals. (* An incomplete interval; data is missing on the side which has the asterisk.)

Interval dates		Longshore component (m/s)					Cross shelf component (m/s)				
START	STOP	N	MIN	MAX	$\overline{X}$	SD	N	MIN	MAX	$\overline{X}$	SD
5-19-79*	6-3-79	350	-26.1	13.7	-7.9	9.3	350	-9.4	12.5	2.8	5.7
6-3-79	6-18-79	366	-43.1	16.8	-4.0	15.5	366	-14.7	22.6	1.3	9.2
6-18-79	6-19-79*	13	-0.1	3.3	1.0	1.1	13	7.5	9.8	8.6	0.7
7-4-79	7-19-79										
7-19-79	8-3-79										
8-3-79	8-18-79										
8-18-79	9-2-79										
9-3-79	9-18-79										
9-18-79	10-3-79										
10-3-79	10-18-79										
10-18-79	11-2-79										
11-12-79*	11-18-79	129	-30.0	8.3	-8.1	11.6	129	-9.5	6.7	1.0	4.8
11-18-79	12-3-79	366	-31.2	23.9	-6.8	13.8	366	-3.4	9.5	2.1	2.7
12-3-79	12-18-79	366	-42.0	-0.0	-23.4	10.5	366	-4.8	9.9	2.8	3.3
12-18-79	1-2-80	366	-46.3	36.8	-4.6	23.3	366	-16.4	13.8	-1.0	5.8
1-3-80	1-18-80	366	-39.6	11.2	-14.4	13.8	366	-6.4	7.8	1.4	2.9
1-18-80	2-2-80	366	-49.0	33.9	-17.9	22.3	366	-11.2	8.6	0.4	4.5
2-2-80	2-17-80	366	-70.6	-6.9	-29.6	16.0	366	-3.3	12.7	3.4	4.2
2-17-80	3-3-80	366	-33.1	14.5	-10.9	13.1	366	-3.6	6.6	2.4	1.9
3-4-80	3-6-80*	53	-8.3	15.5	10.6	6.0	53	-10.3	1.0	-4.1	3.6

Table 1-9. Basic statistics for 15 1/4-day intervals for Site B, Bottom, current velocity data. A 40-hour low-pass filter was applied to the data prior to the computation of statistics for the intervals. (* An incomplete interval; data is missing on the side which has the asterisk.)

Interval dates		Longshore component (m/s)					Cross shelf component (m/s)				
START	STOP	N	MIN	MAX	$\overline{X}$	SD	N	MIN	MAX	$\overline{X}$	SD
5-19-79*	6-3-79	350	-17.5	12.3	-3.7	8.5	350	-5.9	4.3	-0.9	2.8
6-3-79	6-18-79	366	-26.9	16.0	-3.4	12.7	366	-12.2	12.6	0.2	5.3
6-18-79	7-3-79	366	-7.8	12.0	2.0	5.6	366	-6.0	7.2	-0.3	3.4
7-4-79	7-19-79	366	-15.8	12.6	1.2	7.1	366	-8.2	2.8	-1.7	2.3
7-19-79	8-3-79	366	-48.4	44.8	5.0	21.1	366	-10.1	10.3	-1.7	4.4
8-3-79	8-18-79	366	-12.0	8.1	-0.6	5.6	366	-5.7	6.0	-0.9	3.2
8-18-79	9-2-79	366	-44.0	6.8	-10.1	13.5	366	-8.2	6.4	1.0	3.2
9-3-79	9-18-79	366	-40.2	9.1	-16.6	12.8	366	-9.4	10.1	1.4	5.3
9-18-79	10-3-79	366	-56.7	19.7	-4.8	21.9	366	-7.0	9.5	2.4	3.9
10-3-79	10-13-79*	229	-1.7	19.0	9.3	5.7	229	-3.7	8.8	2.8	3.2
10-18-79	11-2-79										
11-12-79*	11-18-79	129	-13.2	11.5	-0.4	6.6	129	-7.5	5.3	0.8	3.8
11-18-79	12-3-79	366	-20.1	20.0	0.1	11.3	366	-4.1	9.2	1.8	3.4
12-3-79	12-18-79	366	-27.1	12.6	-8.8	9.8	366	-6.8	12.2	0.4	3.7
12-18-79	1-2-80	366	-15.0	27.6	4.9	10.6	366	-5.9	10.8	1.3	4.2
1-3-80	1-18-80	366	-29.5	5.2	-7.5	10.3	366	-9.1	12.1	0.7	4.1
1-18-80	1-20-80*	47	-16.9	-4.7	-14.3	3.6	47	-5.3	-1.4	-3.4	1.6

Table 1-10. Basic statistics for 15 1/4-day intervals for Site C, Top current velocity data. A 40-hour low-pass filter was applied to the data prior to the computation of statistics for the intervals. (* An incomplete intervals; data is missing on the side which has the asterisk.)

Interval dates		Longshore component (m/s)					Cross shelf component (m/s)				
START	STOP	N	MIN	MAX	$\overline{X}$	SD	N	MIN	MAX	$\overline{X}$	SD
8-22-79	9-2-79	288	-49.1	13.2	-12.1	21.8	288	-10.5	4.3	-1.9	4.2
9-3-79	9-18-79	366	-53.7	31.1	-23.3	24.0	366	-12.0	38.0	13.7	15.8
9-18-79	10-3-79	366	-66.4	63.7	-16.7	31.0	366	-28.1	36.0	11.0	15.3
10-3-79	10-15-79*	278	-36.6	61.6	27.0	22.7	278	-18.4	21.9	-1.9	10.0
10-18-79	11-2-79										
11-4-79*	11-18-79	330	-53.6	8.2	-18.9	17.8	330	-15.9	10.7	-3.1	5.3
11-18-79	12-3-79	366	-51.2	11.5	-14.7	16.6	366	-10.7	19.3	1.3	7.9
12-3-79	12-11-79*	185	-36.0	1.7	-18.8	10.0	185	-1.6	20.3	7.3	5.5

Table 1-11. Basic statistics for 15 1/4-day intervals for Site C, Middle, current velocity data. A 40-hour low-pass filter was applied to the data prior to the computation of statistics for the intervals. (* An incomplete interval; data is missing on the side which has the asterisk.)

Interval dates		Longshore component (m/s)					Cross shelf component (m/s)				
START	STOP	N	MIN	MAX	$\bar{X}$	SD	N	MIN	MAX	$\bar{X}$	SD
9-14-79*	9-18-79	83	-48.5	-38.1	-42.2	2.6	83	-3.6	4.9	0.8	2.2
9-18-79	10-3-79	366	-68.9	49.0	-8.1	31.0	366	-9.1	16.5	1.5	5.9
10-3-79	10-18-79	366	-46.2	46.5	1.8	22.3	366	-15.3	8.6	-1.3	5.4
10-18-79	11-2-79	366	-34.2	1.1	-15.6	10.4	366	-6.8	3.6	-1.3	2.8
11-3-79	11-18-79	366	-35.2	16.2	-7.0	11.9	366	-3.7	5.5	2.0	1.9
11-18-79	12-3-79	366	-33.1	25.2	-2.9	14.2	366	-2.0	7.3	1.9	2.6
12-3-79	12-18-79	366	-32.7	7.8	-12.4	10.5	366	-5.9	8.6	0.3	3.0
12-18-79	1-2-80	366	-27.6	38.9	4.2	17.4	366	-8.5	6.5	0.4	3.6
1-3-80	1-18-80	366	-40.2	14.9	-13.4	14.6	366	-9.4	8.1	-0.8	4.3
1-18-80	1-20-80*	46	-35.1	-16.0	-26.4	7.4	46	-5.1	-1.4	-3.5	1.3

Table 1-12. Basic statistics for 15 1/4 day intervals for Site C, Bottom, current velocity data. A 40-hour low-pass filter was applied to the data prior to the computation of statistics for the intervals. (* An incomplete interval; data is missing on the side which has the asterisk.)

Interval dates		Longshore component (m/s)					Cross shelf component (m/s)				
START	STOP	N	MIN	MAX	$\overline{X}$	SD	N	MIN	MAX	$\overline{X}$	SD
8-22-79	9-2-79	286	-39.2	16.5	-2.6	16.6	286	-9.6	5.9	-2.4	3.6
9-3-79	9-18-79	366	-35.7	19.7	-9.3	16.8	366	-10.5	6.4	-2.1	4.8
9-18-79	10-3-79	366	-47.6	20.6	-3.8	20.1	366	-7.7	15.9	3.5	5.7
10-3-79	10-15-79*	278	-30.5	18.1	3.2	11.3	278	-14.6	15.5	2.5	7.3

the tables. Intervals in which data is incomplete are noted with an asterisk which is placed on the side which is missing the data.

1.6 Summary and Conclusions

Variations in the hydrography off Freeport, Texas are dominated by salinity rather than temperature. Relatively low salinity water, primarily a result of streamflow from the Mississippi/Atchafalaya river system, is frequently advected through the study area. Lowest salinities occur in April-May (< 20^{o}/oo) corresponding to the spring maximum in streamflow. In April-May of 1979 this resulted in an extremely strong horizontal pycnocline which extended offshore past the diffuser area. At other times relatively low salinity water is confined near the coast and forms a frontal zone which is often situated near the diffuser site. Secondary salinity minima occurred in late September 1978 and in September and November 1979.

Vertical salinity gradients of up to 15^{o}/oo occur in June at Station 34 and 10^{o}/oo at Station 14. A relatively isohaline water column occurred only in late July 1978, November 1978 and in early March, October and December 1979. In 1978, strong salinity stratification was more transient and less intense than in 1979.

Water temperature follows an annual cycle from lowest temperatures in February to highest temperatures in August. February of 1980 was considerably warmer, by about 5^{o}C than February of 1978 and 1979. Thermal stratification is relatively weak except from June through August when the summer thermocline has developed. Maximum vertical temperature difference is about 5^{o}C.

In terms of the Richardson number, the upper half of the water column is generally stratified ($Ri > 10$) in the winter and spring months and transitional (0.1<Ri<10) in the summer and fall months; the bottom layer is transitional year-round with occasional well-mixed (Ri<0.1) conditions in the fall and winter.

Streamflow data computed for five contiguous section of the Texas-Louisiana coast confirm that the Mississippi/Atchafalaya River system is the source of most of the low salinity water encountered off Freeport. In January, February, and March the rivers between Freeport and the Texas-Louisiana border have a relative maximum in streamflow which may significantly augment, in the inner coastal zone, the low salinity water propagating down the coast from Louisiana.

Time series plots of 3-hour and 40-hour low passed meter data are presented for all data from June 1978 through February 1980. This part of the report is intended to be a basic data report for reference. Auto- and cross spectral analysis among the instrument sites and wind data is in progress and not covered in this report.

During the extremely strong stratification in April-May 1979, the highest cross shelf velocities of the study, up to 75 cm/s inshore, were recorded. The longshore velocities were also strong and directed downcoast. At the bottom, however, current velocities were low. Given the strong horizontal pycnocline which existed at that time, it is possible that a two layer system existed in which the lower layer was almost at rest. This would help account for the anoxic conditions which were recorded by other investigators of the project.

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CHAPTER 2

ANALYSIS OF THE DISCHARGE PLUME

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2.1 Introduction

The Strategic Petroleum Reserve Program is discharging a 250-300 parts per thousand brine solution through a multiport diffuser at a location 12.5 statute miles (20 kilometers) off the Freeport, Texas coast and at a water depth of 70 feet (22 meters). The brine discharge is the result of solution mining of underground salt domes located at Bryan Mound near Freeport and the filling of these domes with crude oil. The need for environmental assessment of the discharge required that a monitoring system be designed and procedures developed to track the brine plume and evaluate its impact. The purpose of this chapter is to describe two monitoring systems which were designed, tested, and assembled for use aboard the Civil Engineering Department's research vessel, the R/V EXCELLENCE. One monitoring system is called the Pump Monitoring System and the other the Probe Monitoring System. The pump monitoring system was used for experimental determination of diffusion coefficients in the vicinity of the diffuser and the results from these experiments are described.

2.2 Engineering Design of the Pump Monitoring System

2.2.1 Comparison of Submersible and On Board Pump Systems

A pump monitoring system was initially considered because the water quality instruments and recording equipment were already available aboard the R/V EXCELLENCE, and this system could also be used for experimentally determining diffusion coefficients which would be valuable input information for the MIT transient plume model developed by Adams et al. (1975). A detailed description of the design of the pump monitoring system is described in a thesis by Bolen (1980), and his work is summarized in the following discussion.

The concept of pumping water on board a research vessel while maintaining headway has the following advantages:

(1) Development of in situ towed equipment is not required to profile selected layers of the water column.

(2) Typical land equipment can be adapted for offshore use.

(3) Vertical profiling equipment can be used to monitor horizontal changes while the ship is underway.

Wilson (1975) described the adaptation of an oceanographic instrument intended for the vertical profiling of conductivity, temperature, and dissolved oxygen. The instrument was converted for use as a monitor for horizontal profiling by supplying a continuous water sample from depth to a holding tank on deck which housed the instrument. The water was supplied by a submersible pump suspended from a rigid pipe. Practical depth of intake was limited due to the drag forces on the rigid pipe. Other on board pumping systems have been described in detail by researchers studying diffusion measurements and these are described later in this chapter in discussions on the measurement of diffusion coefficients.

The pumping system on board the R/V EXCELLENCE was required to deliver a continuous water sample to on board water quality monitors from a desired depth while the vessel proceeded at a speed of 3 to 5 knots

(5.1 to 8.4 m/s). The sampling depth was selected as 90 ft (27 m) which was the maximum depth in the general vicinity of the brine diffuser. The water quality monitors aboard the R/V EXCELLENCE were manufactured by Schneider Instrument Co. (Anonymous, 1973), and they required a continuous supply of water at a rate of 6 to 15 gpm (0.4 l/s to 0.9 l/s) at a pressure of 15 psi (103 kilopascal, kPa). Using these design requirements, a pumping system was designed for use in diffusion studies and for tracking a negatively buoyant brine plume which would be located near the sea floor.

Two types of pumping systems were originally investigated and compared to determine the best design concept. The first concept used a submersible pump, continuous discharge hose, and hose reel to transport water from the selected depth, and the second concept consisted of a conventional pump on board the research vessel, a continuous suction hose, and hose reel. The submersible pump system requires the manufacture of a special hose consisting of a power cable, water hose, and strength member. This special hose is stored on a reel which is also used to control the amount of hose in the water, and the electrical power for the pump is supplied through a slip ring assembly on the hose reel. The second concept requires a hose that can withstand a suction of 25 ft (7.6 m) of water, but it doesn't require slip rings for the electrical power supply or the manufacture of a special water hose, strength member, and power cable assembly. A cost comparison was made and it showed that the on board pumping system was a few hundred dollars less than the submersible pumping system.

The advantages of the submersible pump system are that a smaller diameter hose can be used and no suction hose is required. The advantages of the on board pump system are: a) simplicity, b) pump accessibility for maintenance, c) special hose assembly not required, d) no slip ring assembly required, e) slightly less cost, and f) less possibility of pump damage. The disadvantages of the submersible pump system are: a) possible damage to pump if it hits bottom while towing, b) manufacture of special hose assembly, c) use of slip rings, and d) slightly greater cost. The long suction line, larger diameter hose and bulkiness of the on board pump system are its chief disadvantages. After this comparison, it was decided to proceed with the design of the on board pump system because of the reduced risks and lower cost.

2.2.2 Suction Hose Length for On Board Pump System

The hose length required to reach a depth of 90 ft (27.4 m) for a given outside diameter, submerged unit weight in water, and ship speed was calculated using a computer program developed by Cuthill (1968). This program calculates the equilibrium configuration of a flexible hose in a uniform stream. Ranges of the ship speed, hose outside diameter, and hose submerged unit weight were used to develop design charts. The results of the program for a 2 in (5.1 cm) outside diameter hose are shown in Figure 2-1. This figure shows that the maximum ship speed is obtained with the smaller outside diameter hose and the largest submerged unit weight.

An important factor in determining the length of hose is to evaluate the head loss resulting from the flow of water through the hose. A minimum of 6 gpm (0.4 l/s) is required by the water quality monitors, and thus the head loss per unit length of hose (h_f/L) was computed for flow rates from 6 gpm (0.4 l/s) to 20 gpm (1.3 l/s) using the expression

$$\frac{h_f}{L} = \frac{fV^2}{2Dg} \qquad (2\text{-}1)$$

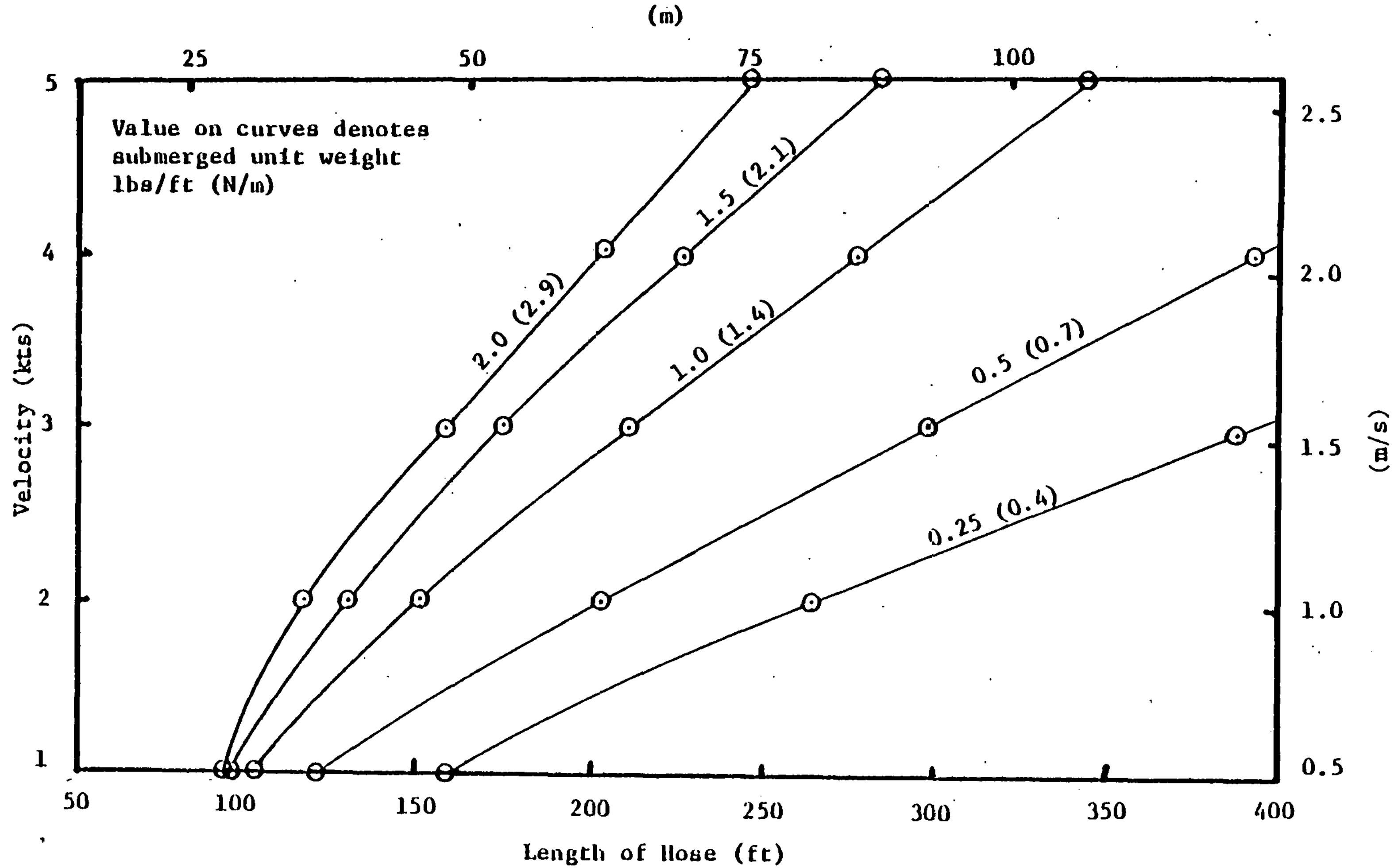


Figure 2-1. Towed Lengths of 2.0 in (5.1 cm) outside diameter hose required to reach 90 ft (27 m).

where f is a friction factor, V is average velocity of flow, D is inside diameter of the hose, and g is acceleration due to gravity. The friction factor, f, is determined from the Moody diagram, Streeter and Wylie (1975). A typical value for the hose relative roughness was selected as 0.0005 ft (0.0002) m. The results for the non-dimensional head loss per unit length for several hose sizes are tabulated in Table 2-1.

The next step was to select a hose which would withstand the suction pressure, would not collapse on a hose reel, and would have high submerged unit weight. A suction hose manufactured by Goodyear met the above design criteria. This particular hose is capable of withstanding a full vacuum and has a minimum bend radius of 7 in (17.8 cm).

Three different diameter hoses were compared to determine the optimum size. Several submerged unit weights were computed and used along with the desired ship speed of 3 knots (1/5 m/s) to determine the approximate length which will reach the desired depth. For example, the submerged unit weight for a 2.0 in (5.1 cm) outside and 1.5 in (3.8 cm) inside diameter hose is 2.7 lbs/ft (0.4 N/m), and referring to the previous Figure 2-1, it is shown that the length of hose required to reach 90 ft (27.4 m) is 390 ft. Therefore, the length of hose selected was 400 ft (122 m).

The hose reel was selected next, and it had to be capable of storing the total length of hose, have a suction swivel to allow rotation of the reel while pumping, and a positive locking mechanism. A hose reel manufactured by Hannay Reel Co. was selected which had a reel diameter of 15.5 in (39.4 cm) and a width of 30 in (76.2 cm).

There is an increased head loss resulting from the flow of fluid through the hose while it is wrapped on the reel. The head loss, h_f,

Table 2-1. Dimensionless head loss for various flow rates.

Flow Rate		Dimensionless Head Loss Per Unit Length (h_f/L)		
		Hose Inside Diameter		
gpm	l/s	1.0 in (2.5 cm)	1.5 in (3.9 cm)	2.0 in (5.1 cm)
6	0.38	0.041	0.005	0.001
8	0.50	0.070	0.010	0.002
10	0.63	0.110	0.013	0.003
12	0.76	0.158	0.019	0.005
14	0.88	0.209	0.025	0.006
16	1.01	0.273	0.033	0.008
18	1.14	0.335	0.042	0.010
20	1.26	0.414	0.050	0.012

was evaluated using the expression

$$h_f = \frac{KV^2}{2g} \tag{2-2}$$

where K is a loss coefficient. The determination of K is described by Bolen (1980), and for the selected hose and hose reel, this coefficient was determined to be 44, 38, and 33 for hoses with an outside diameter of 1.5 in (3.8 cm), 2.0 in (5.1 cm), and 2.5 in (6.4 cm) respectively. These loss coefficients were used to compute the real head loss which are tabulated in Table 2-2.

The hose diameter was determined by computing the combined losses due to the flow through the hose and the wrapping of the hose on the reel. These combined losses are illustrated in Figure 2-2 for the three different diameter hoses. The average pump suction head is 25 ft (7.6 m) of water, and thus the 1.0 in (2.5 cm) inside diameter hose was not feasible because of the high suction pressure requirement. The 1.5 in (3.8 cm) inside diameter hose was acceptable especially at the lower flow rates. The larger diameter hose was also acceptable based upon the suction pressure requirements, but a 400 ft (121.9 m) length would not fit on available hose reels. Also, the smaller diameter hose resulted in less water drag, and therefore, it could reach a greater depth at a given ship speed. Thus, the 2 in (5.1 cm) outside and 1.5 in (3.8 cm) inside diameter petroleum suction hose which weighed 0.27 lbs/ft (0.4 N/m) in water was selected. The hose was special ordered to be a continuous length hose to avoid air leaks at connector fittings and to facilitate even wrapping on the reel.

Table 2-2. Head loss due to hose reel.

Flow Rate		Head Loss for Given Inside Diameter Hose 1.0 in (2.5 cm)		1.5 in (3.8 cm)		2.0 in (5.1 cm)	
gpm	(l/s)	ft	(m)	ft	(m)	ft	(m)
6	0.4	4.1	1.3	0.6	0.2	0.2	0.1
8	0.5	7.4	2.2	1.1	0.3	0.3	0.1
10	0.6	11.5	3.5	1.7	0.5	0.5	0.1
12	0.8	16.6	5.0	2.4	0.7	0.8	0.2
14	0.9	22.5	6.9	3.3	1.0	1.0	0.3
16	1.0	29.4	9.0	4.3	1.3	1.4	0.4
18	1.1	37.2	11.4	5.5	1.7	1.7	0.5
20	1.3	46.0	14.0	6.8	2.1	2.1	0.7

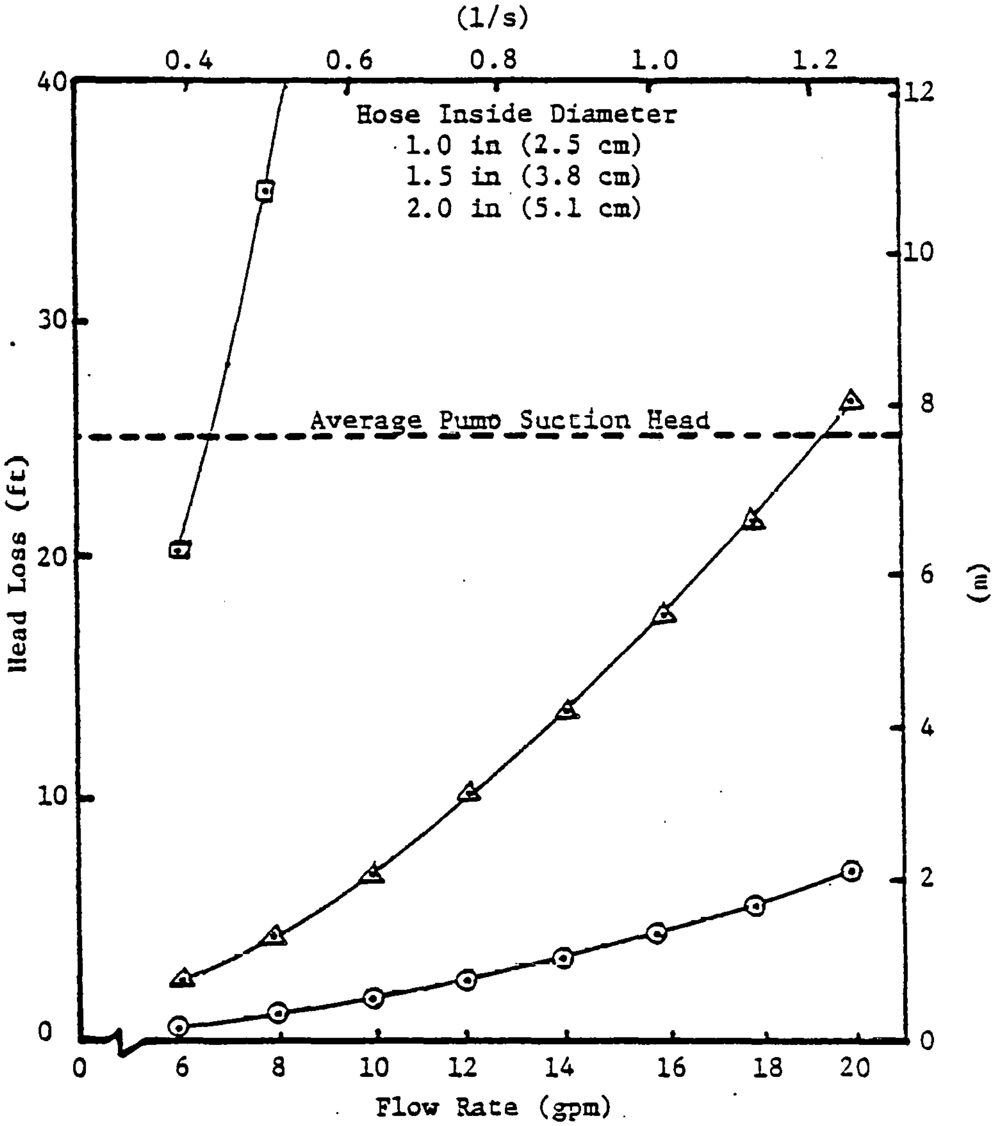


Figure 2-2. Combined hose and reel head loss.

2.2.3 Pump Selection

The selection of the pump depends on the desired flow rate and the total dynamic head (TDH) requirement for the pump. A flow rate range of 6 - 20 gpm (0.1 - 1.3 l/s) was used to select the pump. The total dynamic head (TDH) for the pump was evaluated using the one dimensional, incompressible energy equation,

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + Z_1 + TDH = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + Z_2 + L_{1-2} \qquad (2\text{-}3)$$

Subscripts 1 and 2 refer to the inlet of the pump and the inlet of the water quality monitor as shown in Figure 2-3. The other notation is pressure (P), velocity (V), elevation (Z), energy losses (L), specific weight of sea water (γ), and local acceleration of gravity (g).

The energy losses due to the flow through the distribution board shown in Figure 2-3 were calculated using standard loss coefficients for fittings and valves such as found in Streeter and Wylie (1975) using an equation of the form

$$L_{1-2} = \sum_{i=1}^{n} \frac{K_i V_i^2}{2g} \qquad (2\text{-}4)$$

The results of these computations are tabulated in Table 2-3.

The total dynamic head (TDH) was evaluated using Equation 2-3 where the inlet pressure was determined from the losses in the hose and reel, and the pressure at the monitors was 15 psi (103.4 kPa), Anonymous (1973). The elevation difference (Z_2-Z_1) between pump inlet and water quality monitor inlet is 3.5 ft (1.1 m). The results of this computation are plotted on Figure 2-4 as the theoretical total dynamic head.

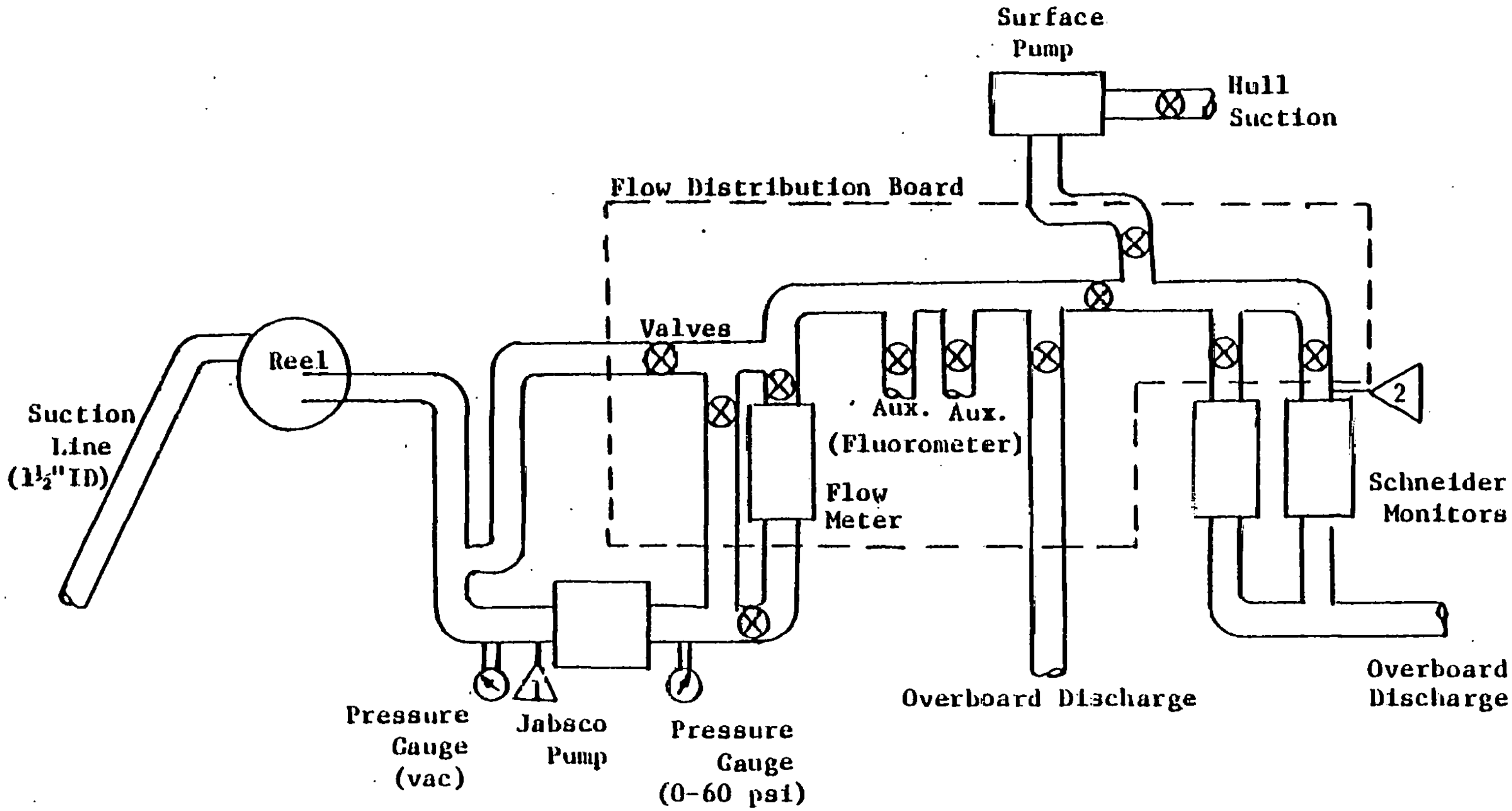


Figure 2-3. Piping schematic for pumping system aboard the R/V EXCELLENCE.

Table 2-3. Losses due to flow distribution board.

Flow Rate		Head Loss	
gpm	(l/s)	ft	(m)
6	0.4	9.4	2.9
8	0.5	16.4	5.0
10	0.6	25.5	7.8
12	0.8	36.2	11.0
14	0.9	49.3	15.0
16	1.0	63.8	19.4
18	1.1	80.9	24.7
20	1.3	100.4	30.6

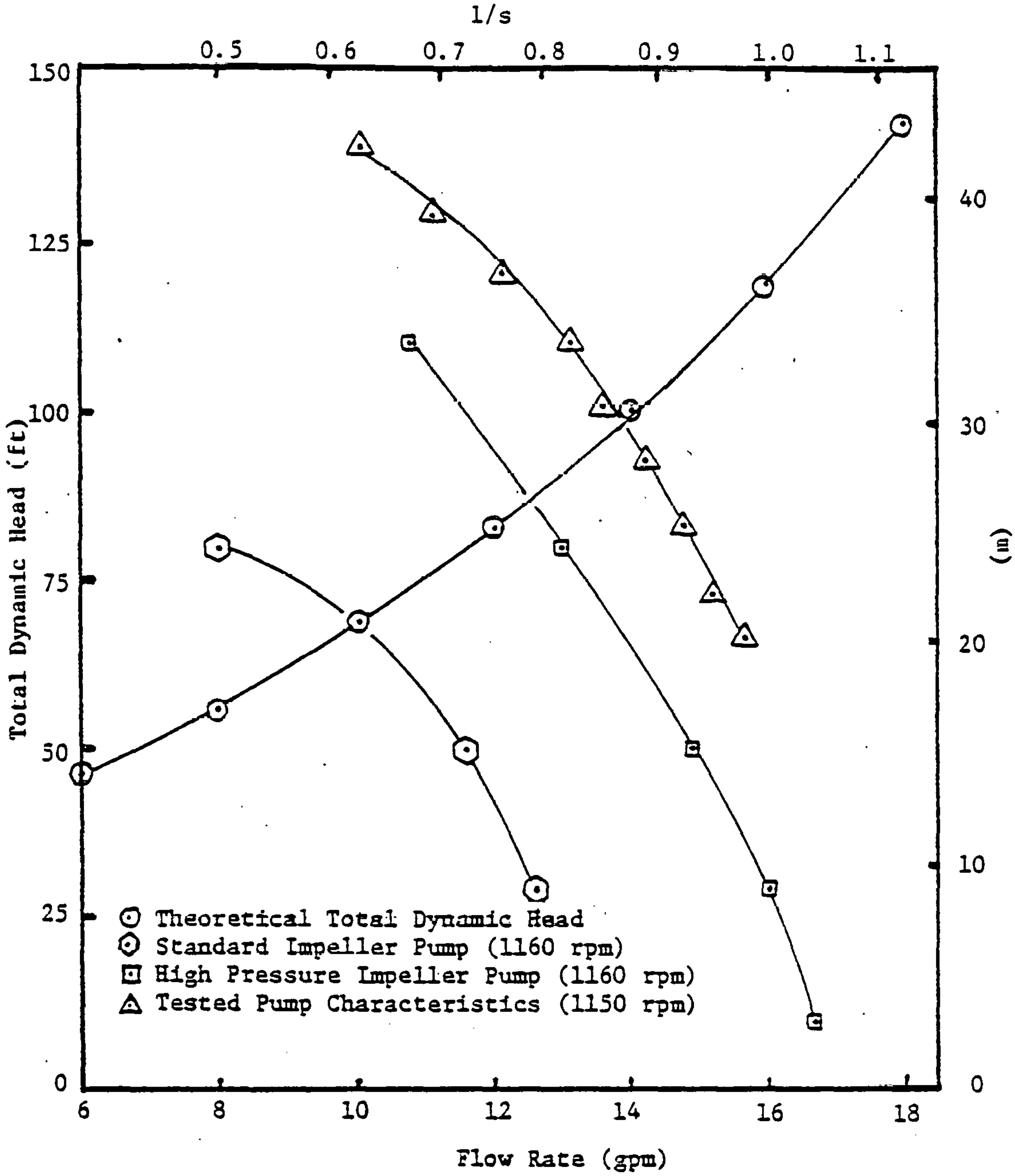


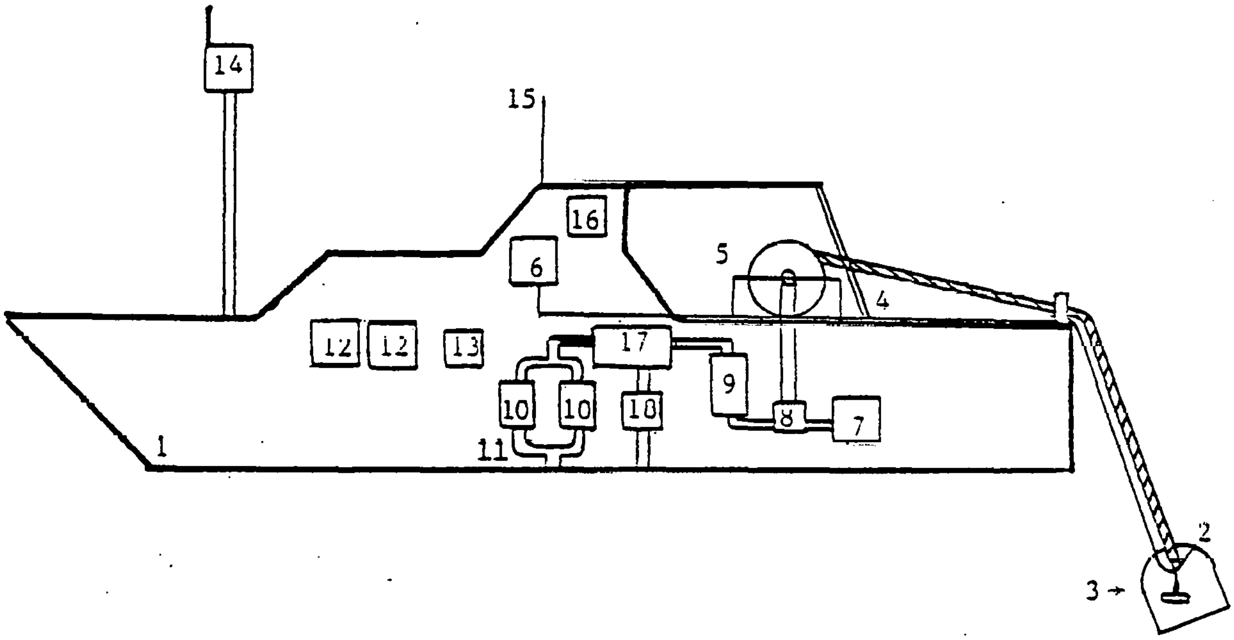
Figure 2-4. Total head requirement.

Pump product catalogs were reviewed to determine a pump which would operate in the range of flow rates and total head. A Jabsco flexible impeller pump with a 1 in (2.5 cm) intake and discharge pipe diameter was found to meet the necessary requirements. A Newman electric motor rated at 1.5 horsepower (1.1 kw) and 1150 rpm was obtained to drive the pump. The manufacturer's specifications for this pump with a standard and a hi-pressure impeller are illustrated in Figure 2-4. Both impellers satisfied the design criteria, but the hi-pressure impeller was selected because of its higher flow rate and greater head characteristics. The higher flow rate reduced the residence time of the water in the pump system. Figure 2-4 predicts the operating condition for the selected pump will be 14 gpm (0.9 l/s) at a total head of 80 ft (24.4 m).

After preliminary laboratory testing, the system was assembled and installed on board the R/V EXCELLENCE as shown in Figure 2-5. The system was tested by placing the suction hose inlet just below the water surface so most of the hose remained on the reel to maximize reel losses, and therefore maximize the total losses in the system. The suction pressure, discharge pressure, and flow rate were monitored for several flow rate settings and used to compute TDH curve for the pumping system. The results are shown in the previously mentioned Figure 2-4. A comparison of predicted and actual TDH curves demonstrates that the calculated design estimates were accurate and the actual operating condition was very close to the theoretical value.

2.2.4 Depth Sensor Suction Hose Inlet

An acoustic transducer exactly like the one used for the ship's fathometer is attached at the end of the hose in a protective cage to



1. R/V EXCELLENCE (55 ft)
2. Screened Suction Inlet
3. Raytheon Transducer
4. Suction Hose (1-1/2" I.D., 2" O.D., 400 ft)
5. Hannay Hose Reel (Hand Wind, Reversible Electric Rewind, Tension Brake)
6. Raytheon Fathometer (DE 719B)
7. Newman Electric Motor (1150 RPM, 1-1/2 HP)
8. Jabsco Flexible Impeller Pump (10-16 GPM)
9. Fisher Porter Rotameter
10. Schneider Water Quality Monitors (Conductivity, Temperature, pH, Dissolved Oxygen)
11. Overboard Discharge
12. Texas Instrument Servo Riter Recorders
13. Del Norte Trisponder Display
14. Trisponder Antenna
15. LORAN A & C Antennas
16. LORAN A & C Display Units
17. Flow Distribution Board
18. Turner Model 111 Fluorometer

Figure 2-5. Schematic of pump monitoring system.

determine the depth of the hose intake as illustrated in Figure 2-6. A hinge was devised to permit adjustment of the transducer angle with respect to the hose and thus compensates for the hose towing angle. The transducer cable was connected directly to the fathometer and the recorder paper displayed the height of the hose intake above the sea floor. When the hose was deployed, the transducer conductor cable was attached to the first few feet of the suction hose with some slack to prevent strain damage to the connection. The cable length was adjusted by hand with each adjustment to the length of the suction hose in the water.

2.2.5 Operating Procedures for the Pump Monitoring System

The first task is to prime the pump and the hose with a separate pump which was interconnected through the distribution flow board. This process is not complete until all pockets of air at the top of each hose loop on the reel are purged, which takes about 15 minutes. Once the system is primed, the various valves are adjusted for pumping water to the overboard discharge. When the pump is started, a suction and discharge pressure should appear on the gauges, but if no pressure measurements or apparent flow are registered, the pump should be immediately turned off to prevent damage to the flexible impeller due to running dry. Once flow has been established, the auxiliary outlets are opened to direct the water flow to selected monitoring equipment, and the overboard discharge is closed to increase flow to equipment. The normal operating conditions of the system are a suction pressure of 15 to 20 in (38.1 to 50.8 cm) of mercury, discharge pressure of 25 to 30 spi (1.7×10^2 to 2.1×10^2 kPa), and flow rate of 15 gpm (0.9 l/s). These values are for operating with no excessive back pressure from the equipment.

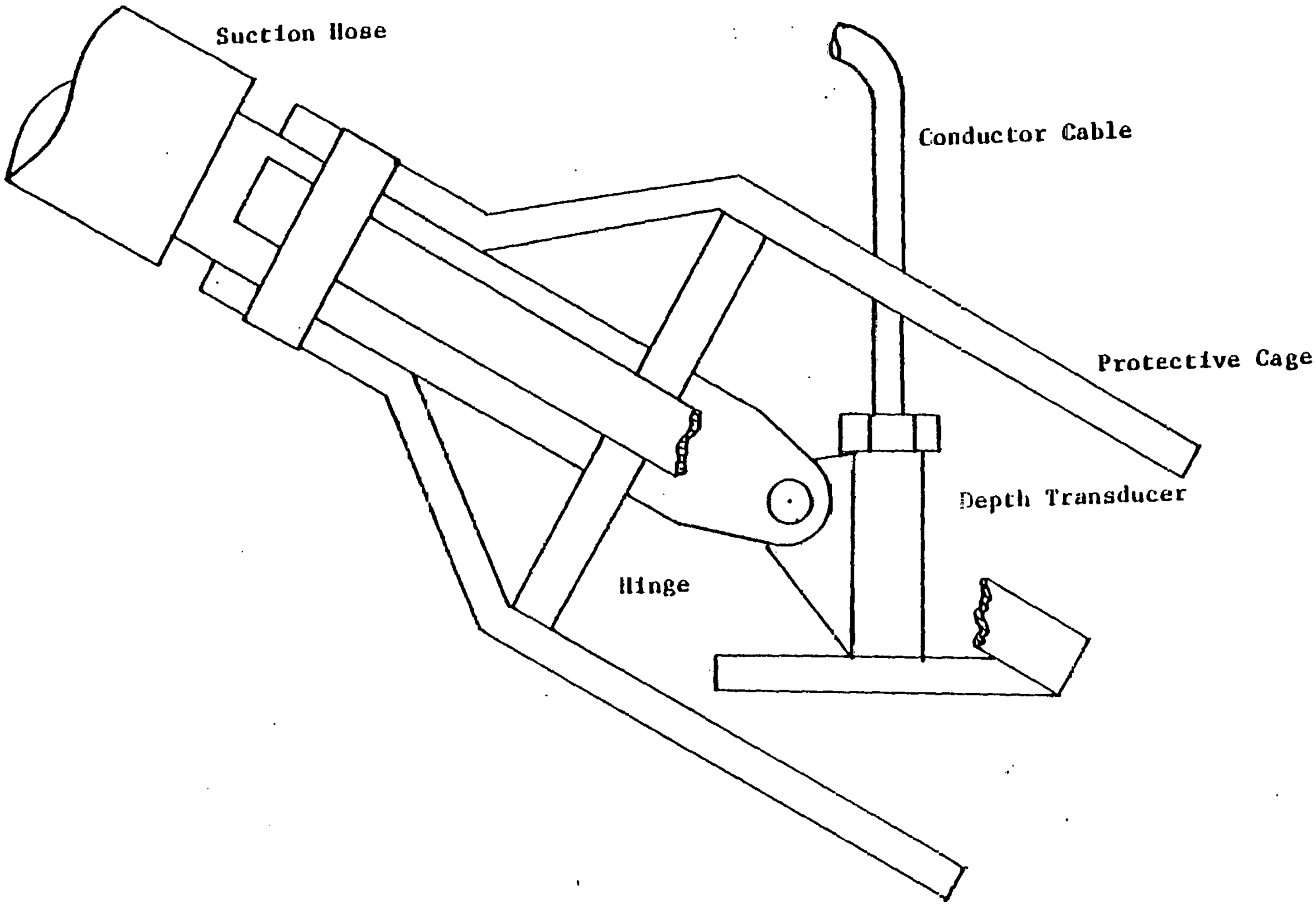


Figure 2-6. Protective cage for depth transducer.

The residence time for a sample of water to travel from intake to equipment had to be determined for data analysis. The residence time was calculated for various flow rates and is listed in Table 2-4.

Table 2-4. Residence time for pump monitoring system.

Flow Rate gpm	Flow Rate (1/s)	Residence Time (s)
6	0.4	370
8	0.5	270
10	0.6	230
12	0.8	190
14	0.9	170
16	1.0	140
18	1.1	130
20	1.3	120

2.2.6 Description of Water Quality Monitors

There are two identical Schneider water quality monitors on board the R/V EXCELLENCE and they are equipped to measure temperature, conductivity, dissolved oxygen, and pH. The parameter of interest in plume tracking is the conductivity. The accuracy of the monitor depends on calibration and according to specifications the monitors can be calibrated to 0.5 percent of a standard solution. Therefore, it is estimated that the accuracy is approximately ±0.3°/₀₀.

2.3 Engineering Design of the Probe Monitoring System

2.3.1 Rationale for the Probe Monitoring System

The probe monitoring system, Figure 2-7, is an alternative to the pump monitoring system for tracking the brine plume. In 1978, new

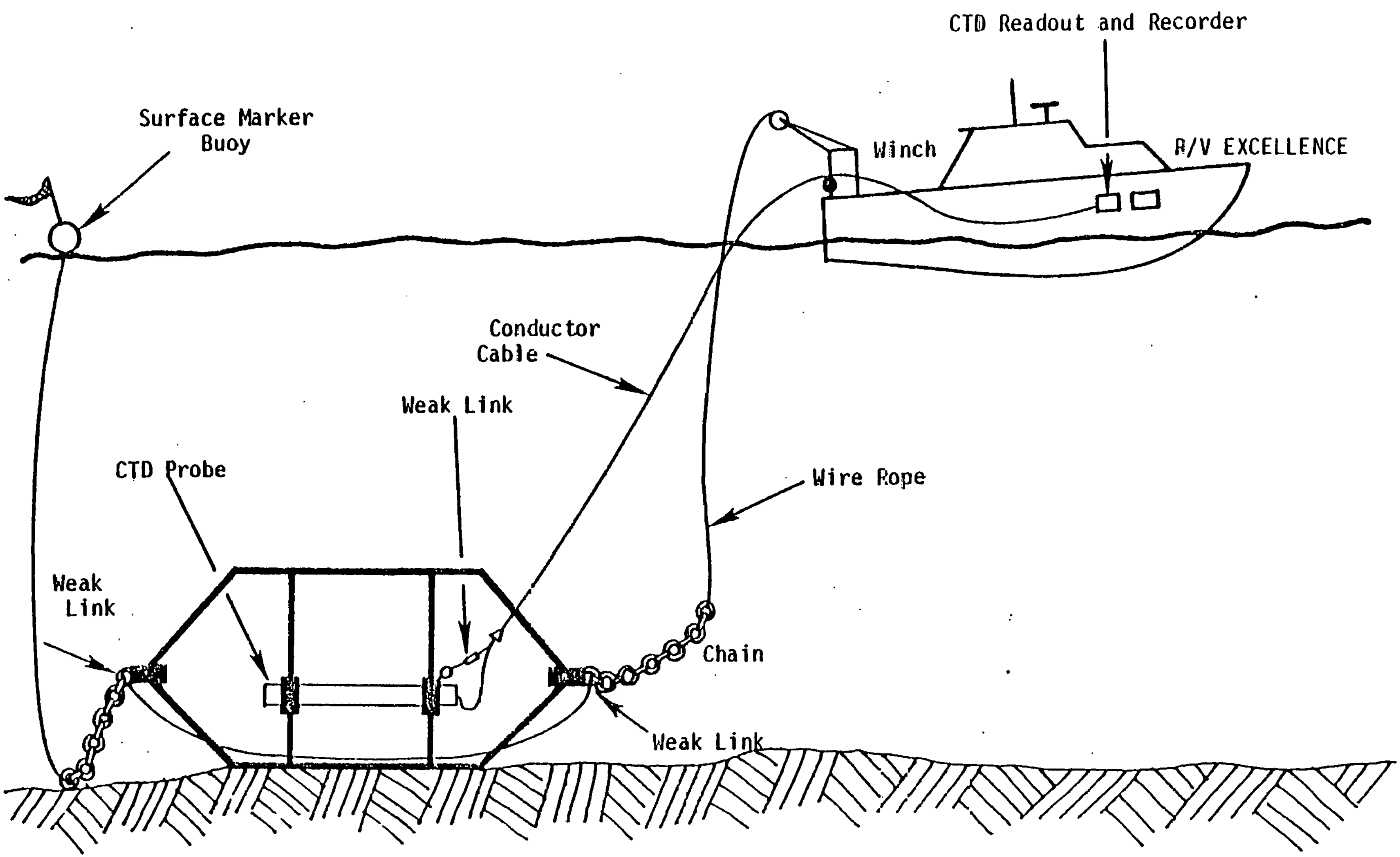


Figure 2-7. Schematic of probe monitoring system.

conductivity, temperature and depth (CTD) probes became available with digital readouts and use of such a system became very attractive. Later discussions of laboratory experimental results by MIT investigators concerning the nearness of the brine plume to the seafloor indicated the plume would be within 2 - 4 ft (.6 - 1.2 m) of the bottom. Trying to tow the suction hose for the pump monitoring system at a constant depth that close to the bottom was not possible for any reasonable expectation of wave height conditions (i.e. 3 - 5 ft). Also the possibility of snagging would increase significantly, and a release mechanism for the hose would have to be designed. The idea of an *in situ* probe at the bottom gave increased credibility to the data over the pumped water sample. Also, the probe would be mounted in a towing sled and rigged to break free if it should become snagged on the bottom. This system could be designed so that the probe was a constant distance off the bottom and the sled would be towed by the R/V EXCELLENCE at a slow speed of 3 kts (1.5 m/s) while in constant contact with the bottom. The depth sensor on the probe would indicate whether the probe stayed on the bottom. This system was selected for the plume tracking, and its design and use are now described.

2.3.2 Sled Design

The water quality probe has an outside diameter of 3.1 in (7.9 cm) and an overall length of 16.5 in (41.8 cm). When the sled is lowered to the bottom, it is necessary for the probe to be at a known distance off the bottom. Therefore, the cross section of the sled was designed to be an equilateral triangle, and the probe was located at the centroid of the triangle. The probe must be in direct contact with the ambient sea water, and therefore, the sled was designed to allow free flow of water past the probe. It was decided to construct the legs, or runners, out of 3/4 in (1.9 cm) black iron pipe and attach braces out of the same pipe to support the bracket for holding the probe. A detailed drawing of the towing sled is shown in Figure 2-8. The length of the sled was picked as 6 ft (1.8 m) because that size and weight could be handled on the stern deck of the R/V EXCELLENCE. The sled was built to the specifications shown in Figure 2-8. With this design, the probe was always 10 in (25.4 cm) off the bottom no matter which set of legs on the sled were in touch with the bottom. This was very important because the sled could be deployed without concern for its orientation, and it could tumble without affecting the probe distance off the bottom.

Since the sled was going to be towed on the sea floor, the possibility of snagging would always be present. Therefore, a means for releasing the sled and probe from the tow cable and data bus cable respectively was devised. A drawing of the weak links for the data bus and towing cables is shown in Figure 2-9. The weak link for the towing cable is connected between the chain and the sled and will release with a tension of 500 lb (2224 N). Another cable is shackled to the towing cable so that in case the sled is snagged it will attempt to tumble the sled over the obstacle on which it is snagged. If it is freed, the sled will be winched to the boat, rerigged and redeployed. If the sled remains snagged, the second weak link will release at the same tension, the data bus cable will release with 200 lbs (896 N) tension, and the sled is completely free from the boat. The sled is marked with a buoy which is attached at all times during the tracking operation. Therefore, the boat can locate the sled and attempt to recover it or send divers down to investigate and retrieve the probe.

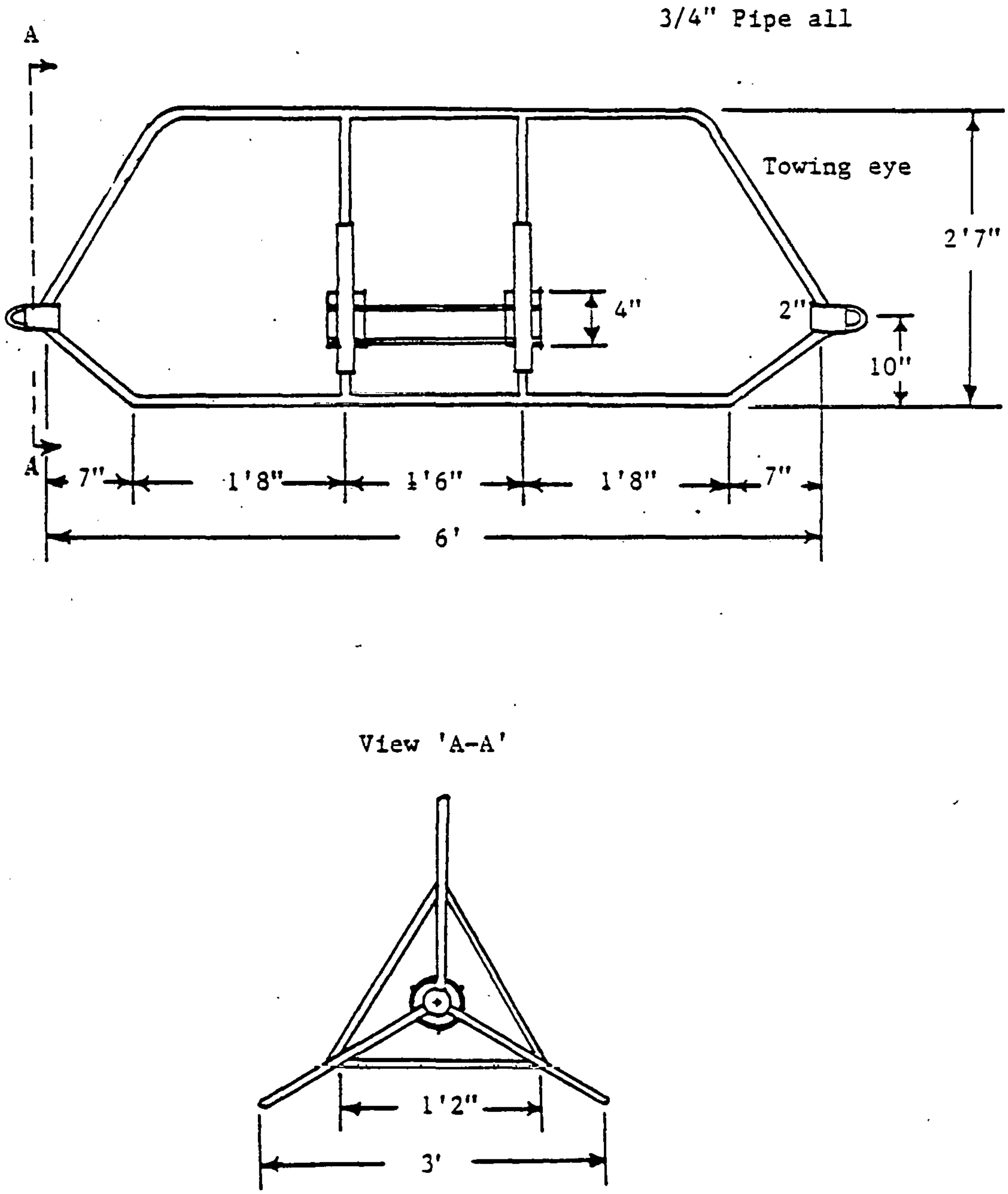
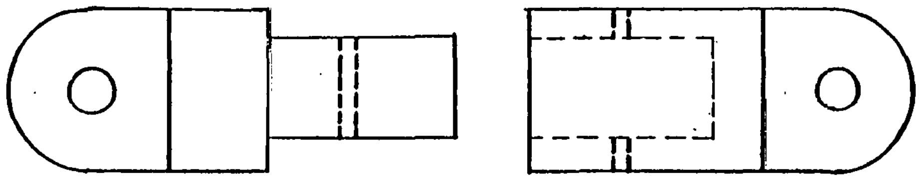


Figure 2-8. Detailed drawing of towing sled.

Towing Cable Weak Link - 500 lb release



Data Bus Cable Weak Link - 200 lb release

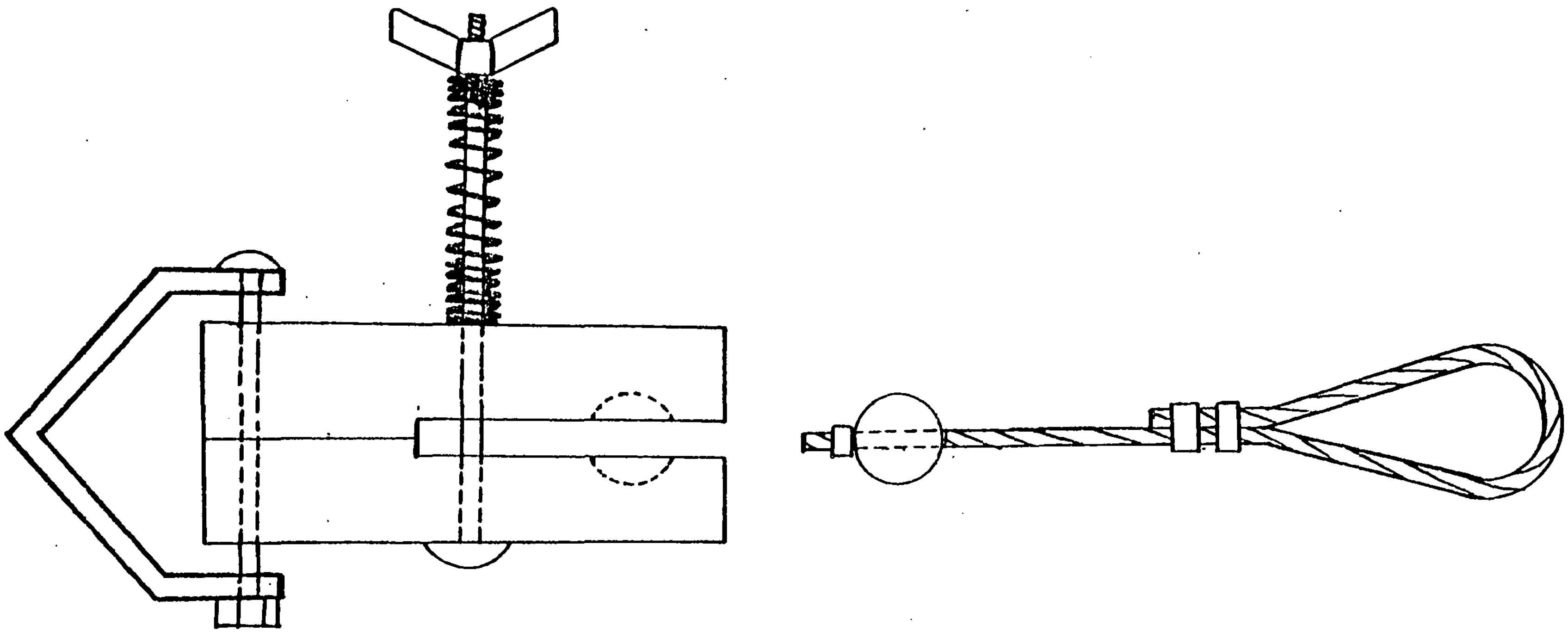


Figure 2-9. Schematic of sled weak links.

2.3.3 Description of Water Quality System

The Hydrolab 8000 water quality system, Anonymous (1980), which is manufactured by the Hydrolab Corporation is used in the Probe Monitoring System. The water quality system has three components: the data transmitting unit (probe), the data bus cable, and the data control unit (readout). The probe is capable of measuring conductivity (0-200 mmho/cm), depth (0-200 m), temperature (-5 - +45°C), dissolved oxygen (0-20 ppm), and pH/ORP. The latter two parameters are used in the water and sediment portion of the project. There are two probes available, but one doesn't have the DO and pH/ORP capability. The probe is inserted in a cylindrical Lexan housing which contains a small stirring device to move water past probes. This device is necessary for measuring dissolved oxygen and will not be used during plume tracking. Two data bus cables are available, and one is 328 ft (100 m) and the other is 492 ft (150 m) long. Two data control units are on hand which display selected outputs in a digital format and provide parallel analog output data signal for conductivity, temperature, and depth which will be recorded on a Texas Instrument strip chart recorder.

The accuracy of the conductivity sensor is ±.5 percent of full scale which is 200 mmho/cm at 25°C. This corresponds to ±1 mmho/cm or +0.7°/₀₀. To improve the conductivity accuracy, the probe is calibrated with standard solutions using a Grunde laboratory salinometer which has an accuracy of ±.003°/₀₀, Anonymous (1978). The data control unit displays the conductivity to one tenth of a mmho/cm and thus a change of that magnitude can be resolved by the sensor. The temperature and depth sensors have an accuracy of ±.2°C and ±3 ft (1 m). The accurancy of these sensors are more than adequate for plume tracking.

2.3.4 Testing of the Probe Monitoring System

In August, 1979 the sled was towed at a speed of 2-3 kts and various turns were made to determine its performance. A second line was also towed with the sled to simulate the probe cable. No serious cable twisting problems were encountered, and thus the towing test of the sled proved to be satisfactory.

The weak links for the towing cable were tested in the laboratory and each link released within a reasonable range near the specified 500 lb tension. The data bus cable weak link is an adjustable device and it was tested satisfactorily by manual methods.

The water quality system was well tested because it was used to collect the CTD data described in Chapter 1 since April 1979, and it has performed satisfactorily. Thus, the entire system has been tested and its performance has been satisfactory.

2.4 Instrumentation and Procedures for Measuring Diffusion Coefficients

2.4.1 Background on Experimental Techniques

Until the 1960's, field measurements to determine diffusion coefficients were sparse due to technical difficulties in tracer material and profiling equipment. Two basic choices of tracer material and measuring equipment were available. These were organic dyes measured by filter fluorometers and radioactive material measured by scintillation counters. The radioactive sources have inherent risks, are encumbered with government regulations, and the public is wary of their use. Even with these adverse factors, successful use of the radioactive sources have been reported by Crickmore (1972). The organic dyes presented problems due to extreme photodecay and adhesion to particulates in the water column. Wilson (1968), Feuerstein and Selleck (1963), and Pritchard and Carpenter (1960) summarized the photo and other decay effects of organic dyes. An inexpensive lightfast organic dye, rhodamine, was developed which has no appreciable photodecay or adhesion on particulates. Rhodamine became the major tracer material used by the researchers, and Bolen (1980) discusses the properties and advantages of this dye.

An early tracing technique was the instantaneous release of tracer material, and the subsequent dye cloud was followed in time while simultaneously making cross plume dye concentration profiles. Ichiye (1962) and Okubo (1971) have used this technique successfully for studies of macro diffusion in the open ocean. Reinert (1973) discussed the problems associated with this technique which are summarized as follows:

(1) Large quantities of tracer were required to tag a sufficiently large mass of water to delineate the dye cloud.

(2) In lakes and estuaries, currents were usually weak and the trajectory of the dye cloud was easily traced. Moving to oceanic environments, greater current velocity increases the difficulty of tracking the cloud in time.

(3) Theories used in the determination of diffusion coefficients required locating the maximum concentration profile through the dye cloud. Since only one run could be made before the dye cloud moved and diffused further, uncertainty arose in locating the maximum concentration profile.

Many of the problems associated with instantaneous release of tracer material were overcome with a new technique called the continuous point or line source. When using this technique dye is released at a constant rate and at essentially a point or along a line within the water mass. The plume develops from the point or line source and trails down current.

The advantages of a continuous point source, Reinert (1973), are summarized as follows:

(1) During the time frame of the experiments, steady environmental conditions persisted and the plume remained in place.

(2) Most theories on oceanic diffusion rely on locating the peak concentration profile of the diffusing plume. By adjusting the profiling equipment to the depth of the source, each pass of the vessel will measure the peak concentration profile.

(3) The continuous point source experiments lend to greater accuracy in determining the diffusion coefficients for near field studies.

(4) An average of several crossings is possible at a set distance from the source.

Pritchard and Carpenter (1960) were the first to implement the new light-fast dye, rhodamine, and the continuous point source. The continuous point source was a tank with a pump and discharge hose which emitted dye at the desired depth. The pump assembly that was used to obtain the continuous water sample used a streamlined aircraft strut around the intake hose to reduce drag. The intake hose was connected to the filter fluorometer and then to the suction side of the pump. Profiles of the subsequent dye plumes were collected by passing at right angles to the plume axis. The concentration of the dye was monitored from the water pumped on board, as it was pumped through the filter fluorometer, and the output signal was recorded continuously on an analog recorder to produce a hard copy of the plume profile.

Diffusion experiments were conducted by Csanady (1963) in Lake Huron, and he used a constant head syphon to regulate the dye discharge rate. The dye was emitted at the surface of the water as a point source. The dye chosen was rhodamine mixed with alcohol and water to match the specific gravity of the receiving water. The plume was sampled from a research vessel equipped similarly to the vessel reported by Pritchard and Carpenter (1960). Bowden and Lewis (1973) reported on continuous release experiments in coastal environments where currents were greater than those reported for lakes and estuaries. They also used essentially the same type of experimental equipment described by Pritchard and Carpenter (1960) and conducted diffusion experiments in the Irish Sea. Karabashev and Ozmidov (1965) did similar experimental work in the Black Sea, and Foxworthy (1968) conducted similar experiments along the southern California coast.

2.4.2 Experimental Equipment for Measuring Diffusion Coefficients

For the experimental research conducted in the predisposal studies, five component systems are necessary to successfully conduct the diffusion experiments. The required systems are: (1) the source, (2) the sampling equipment, (3) the monitoring equipment, (4) the navigation equipment, and (5) the support vessels. A schematic of the system layout used for the diffusion studies is shown in Figure 2-10.

The source is composed of dye and the continuous point or line discharge equipment. Dyes available for the experiments are described by Feuerstein and Selleck (1963), Wilson (1968) and Bolen (1980). A rhodamine dye, Rhodamine WT produced by Dupont, was used in this research because it was least affected by the environmental conditions. This dye has a specific gravity of 1.19 compared to an average of 1.02 for coastal

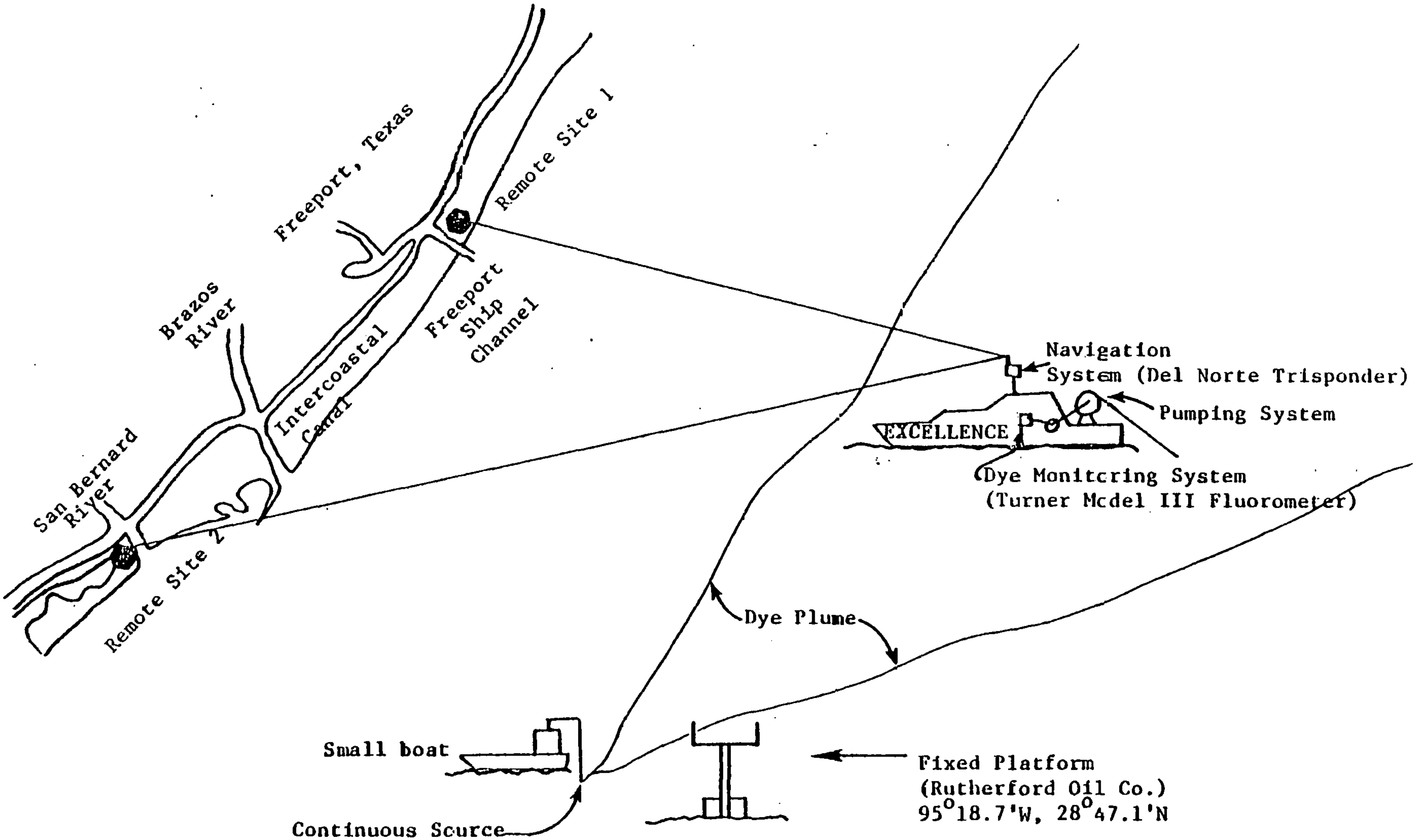


Figure 2-10. Diffusion coefficient measuring system layout.

waters in the Gulf of Mexico. Since the dye had a greater specific gravity it would sink when discharged into the sea water, and therefore, methanol was mixed with the dye at a ratio of 5 parts methanol to 7 parts dye to produce a mixture with a specific gravity of 1.02.

The discharge equipment, Figure 2-11, consists of a dye container, a small battery powered pump, and the discharge hose. This equipment was designed to deliver a constant flow of dye over a period of approximately four hours and to have the capability of discharging at depths of 80 ft (24 m). Initially a 16 gallon (64 l) plastic container was used, but more recently, small 5 gallon (19 l) containers with valves at the bottom have been used. The smaller containers are easier to handle and priming problems are greatly reduced with the valve at the bottom of the container. The discharge hose is a clear flexible tubing which is 100 ft (30.5 m) long and has a 0.25 in (.6 cm) inside diameter. During the experiments for surface horizontal diffusion, this hose was used as a point source. Later, the hose was used as a line source in which small 1/16 in (0.2 cm) diameter holes were drilled 12 in (30 cm) apart over a length of 20 ft (6.1 m). This configuration, Figure 2-11, was used to determine horizontal diffusion coefficients near mid depth. Finally, the flexible tubing was attached to a long PVC pipe which also has small 1/16 in (0.2 cm) holes spaced 12 in (30.5 cm) apart. The PVC pipe is 30 ft (9 m) long and has a 0.5 in (1.3 cm) inside diameter. It is made slightly positively buoyant by adding buoyant disks and is held in place by weights attached to two 10 ft (3 m) lines. This horizontal line source was used to determine vertical diffusion coefficients in the bottom waters.

The pump monitoring system was used for the sampling equipment and it has been described in detail in a previous section. This delivers a

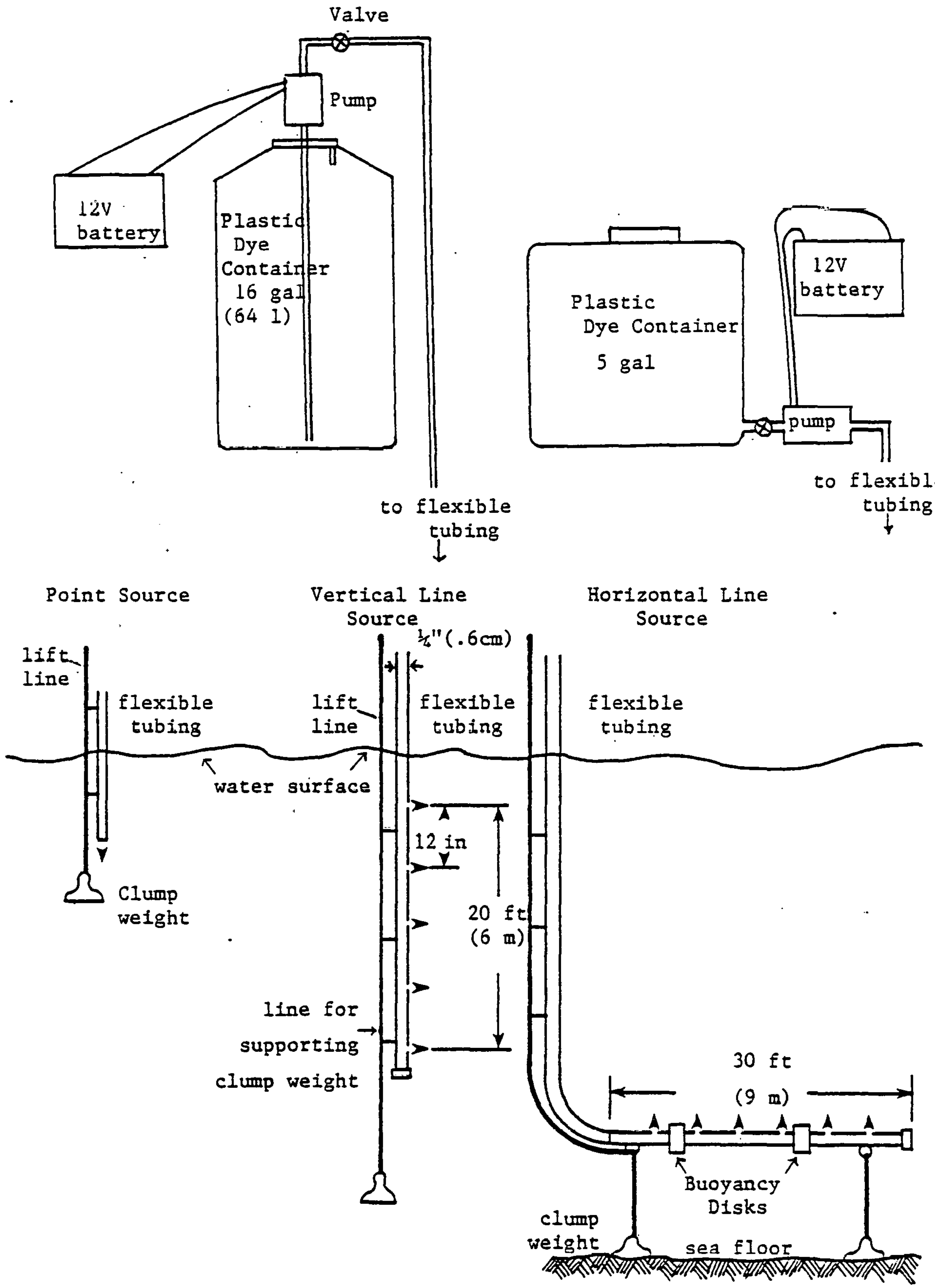


Figure 2-11. Continuous dye source equipment.

continuous water sample at a depth while the ship is underway. This water sample was delivered to the monitoring equipment which was a Turner Model 111 filter fluorometer with a flow through door attachment. The dial reading on the fluorometer is proportional to the dye concentration of the water sample, and this reading is recorded on a strip chart recorder.

There are three navigation systems which have been used for the diffusion experiments. The primary system is the Del Norte Trisponder positioning system which is a microwave ranging system. Two slave remote units are triggered by the master unit on board the support vessel and the position of the support vessel (master unit) is determined by the intersection of range circles representing the distance from the remote units. A schematic of the location of the remote and master units is shown in the previous Figure 2-10. This yields accuracies in the range of ±13 ft (±4 m), Anonymous (1977). Several early experiments were conducted using the traditional LORAN A navigation system when the trisponder was not operational. Although the absolute accuracy of the LORAN A was not satisfactory, the relative accuracy for determining ship speed and width of plume proved to be satisfactory. When using LORAN A the distance from the source was determined with the ship's radar. LORAN C is now operational in the Gulf of Mexico, and it has also been used satisfactorily when the trisponder system was not operational or malfunctioned.

2.4.3 Experimental Procedure

Substantial preparation was required before the ship left the dock. A summary of the preparatory work is as follows:

(1) The trisponder system was activated at both remote sites. The down shore site, remote site 2 shown in Figure 2-10, required a 45 minute trip down the Intercoastal Canal to change out batteries to activate the system. On board, the master unit was installed on a 4 ft (1.2 m) mast located above the helm, or the 20 ft (6.1 m) mast located on the forward deck. The distance readout equipment on board was connected and a check of the system was made.

(2) The hose and pump required priming which usually requires a minimum of 10 minutes. The long priming time was necessary to purge the air trapped in each loop on the hose reel.

(3) The fluorometer and recorder were warmed up, and the fluorometer was nulled and calibrated to a known water sample.

(4) The dye was mixed and brought on board and the source equipment was tested.

On location the ship was anchored, a current profile was determined using a remote reading current meter, the dye and source equipment were loaded into a small inflatable boat and transported to a platform or buoy. If the seas were rough the continuous dye source was placed on the platform, otherwise the operation was conducted over the side of the small boat. The discharge hose for the dye source was located at the desired depth and the operators waited until a signal was given to discharge the dye. When vertical diffusion studies were conducted the horizontal line source was deployed from the R/V EXCELLENCE. Next, the EXCELLENCE weighed anchor and proceeded to the source location and recorded the navigational coordinates. A trial run was made to make a final check of the operation of all the equipment. If all systems were operational, the signal was given to discharge the dye and profiling commenced.

For horizontal diffusion studies the ship was headed perpendicular to the predominant current direction after allowing sufficient time for the dye front to pass the first profile station. The depth of the intake hose was adjusted to the depth of the dye discharge by adjusting the ship speed and length of hose in the water. During this time, trisponder distances were continuously monitored throughout the crossing of the plume and the profile was viewed on the strip chart recorder. After viewing the profile, the range selection on the fluorometer was adjusted by increasing or decreasing sensitivity. The ship reversed course and the same track was covered to repeat the profile. Several crossings at the same distance from the source were made for comparison. The distance from the source was increased and the procedure was repeated. Typically, distances of 1/4, 1/2, 1, and 2 miles (0.4, 0.8, 1.6 and 3.2 km) were profiled in any one day of experimentation.

For vertical diffusion studies, the horizontal line source was located 10 ft (3 m) off the bottom, and the ship towed the hose over the plume with the intent of determining the distance from the source to the location of the peak concentration. For this situation, the vessel traveled in the same direction as the mid depth to bottom current, and navigational and fluorometer readings were continuously recorded as was done in the previous diffusion studies.

2.5 Theoretical Background for Evaluation of Diffusion Coefficients

2.5.1 Horizontal Diffusion

A standard approach (Grace, 1978) for evaluating the horizontal diffusion coefficient in a marine environment is to use the relationship

$$K_y = \frac{1}{2}\frac{d\sigma_y^2}{dt} \qquad (2\text{-}5)$$

where K_y is the diffusion coefficient, σ_y^2 is the variance of the concentration profile normal to the direction of the current, t is time, and y is a subscript denoting the axis direction. The origin of the rectangular coordinate system is located at the dye source, and the x axis is in the direction of the mean current, the y axis is normal to the mean current direction, and z is vertically downward.

The derivation of Equation 2-5 from the one-dimensional diffusion equation is described by Fischer et al. (1979). The variance is determined from

$$\sigma_y^2 = \frac{\int_{-\infty}^{\infty} C(y-\bar{y})^2 dy}{\int_{-\infty}^{\infty} C\ dy} \qquad (2\text{-}6)$$

where C is dye concentration for a specific crossing of the plume at a downstream location (x). The dye travel time from the source to point of measurement is determined from the mean current velocity (U) and the distance (x) from the source (t = x/U).

The variance (σ_y^2) and the travel time (t) are plotted on a log-log plot, and a linear regression curve fit to the data is obtained which results in an equation of the form

$$\sigma_y^2 = At^n \qquad (2\text{-}7)$$

where A and n are the coefficients which are determined by the linear regression analysis. This expression assumes the variance is zero when the time is zero. Next, the diffusion coefficient is evaluated by substituting Equation 2-7 into 2-5 which results in

$$K_y = \frac{1}{2} nAt^{n-1} \qquad (2\text{-}8)$$

When the variance is a linear function of time, the exponent n is one, and the diffusion coefficient is a constant and can be evaluated by

$$K_y = \frac{\sigma_y^{\,2}}{2t} \qquad (2\text{-}9)$$

The variance is evaluated from the cross plume profile by using statistical techniques outlined by Bowden and Lewis (1973), and the numerical techniques described by Bolen (1980). The navigation data, trisponder or LORAN readings, are used to determine the ships location and speed when measuring the plume profile. The plume location is determined by matching the analog recording of the dye concentration with the navigational position of the ship after a correction has been made for the residence time of the water sample in the hose. The width of the plume is calculated by dividing the width of the plume on the analog trace by the chart speed and multiplying this result by the ship speed.

The plume width is the most critical measurement in these experiments. The magnitude of error in the diffusion coefficient varies with the square of the error in plume width measurements. Other variables only contribute a proportional share of the error. Vertical movement of the hose intake is one source of plume width error. Other sources of error are due to inaccuracies in application of LORAN measurements to determine distance and low dye concentrations masked by natural fluorescence which tends to clip the tails of the profiles.

2.5.2 Vertical Diffusion

The theory used for determining horizontal diffusion coefficients can be used to evaluate vertical diffusion coefficients, but it is very difficult to obtain the data to determine the variance σ_z^2. Therefore, an alternate method described by Sutton (1953) was used. The theoretical solution for a line source at a depth (z) shows that the concentration at any other depth (z') increases with the distance (s) from the source up to a maximum value which occurs at the distance s_{max}. Further down current, the concentration decreases. Sutton (1953) expressed the distance at which the concentration is maximum as

$$s_{max} = \frac{U\ (z' - z)^2}{2K_z} \qquad (2\text{-}10)$$

where K_z is the vertical diffusion coefficient, U is the average current. K_z and U are assumed to be constant. The value for s_{max} is measured experimentally and then K_z is calculated from Equation 2-10.

2.6 Results of Experimental Measurements of Diffusion Coefficients

2.6.1 Surface Horizontal Diffusion Coefficients

The results of the data analysis of the cross plume profiles obtained on September 5 and November 2, 1978 are shown in Tables 2-5 and 2-6. The September 5 results show the maximum K_y determined by Equation 2-9 was 1.05 ft^2s^{-1}(0.098 m^2s^{-1}) and the minimum value was 0.40 ft^2s^{-1} (0.037 m^2s^{-1}). On November 2 a greater variation of distances was obtained and the diffusion coefficient varied from 0.41 ft^2/s (0.038 m^2s^{-1}) to 1.51 ft^2/s (0.14 m^2s^{-1}). The expected increase in K_y with distance

Table 2-5. Results of plume analysis from 9/5/78.

September 5, 1978 Current: 1.1 ft/s (0.34 m/s) Wind: SE Light

Seas: 2-3 ft (0.6-0.9 m) Stability: No Data Water Depth: 60 ft (18m)

Run No.	Distance from Source		Variance		Horizontal Diffusion Coefficient ($K_y=\sigma_y{}^2/2t$)	
	ft	m	ft^2	m^2	$ft^2\ s^{-1}$	$m^2\ s^{-1}$
7	600	183	450	42	0.43	0.040
9	600	183	430	40	0.40	0.037
10	600	183	480	45	0.44	0.041
11	600	183	660	61	0.60	0.056
12	1500	457	760	71	0.68	0.063
13	1500	457	1140	106	0.42	0.039
17	600	183	1140	106	1.05	0.098
18	600	183	550	51	0.50	0.046
			Mean:		0.57	0.052
			Standard Deviation:		0.22	0.021

Table 2-6. Results of plume analysis from 11/2/78.

November 2, 1978 Current: 1.4 ft/s (0.43 m/s) Wind: NW Light

Seas: 2-3 ft (0.6-0.9 m) Stability: No Data Water Depth: 60 ft (18 m)

Run No.	Distance from Source		Variance		Horizontal Diffusion Coefficient ($K_y=\sigma_y{}^2/2t$)	
	ft	m	ft^2	m^2	$ft^2\ s^{-1}$	$m^2\ s^{-1}$
4	1320	402	1360	126	0.74	0.069
5	1320	402	1170	109	0.64	0.059
6	2640	805	3220	299	0.88	0.082
7	2640	805	3440	320	0.94	0.087
9	5280	1609	4320	401	0.59	0.055
10	5280	1609	11090	1030	1.51	0.140
11	7920	2414	4490	417	0.41	0.038
12	10560	3219	21470	1995	1.46	0.136
13	10560	3219	11930	1108	0.81	0.075
			Mean:		0.89	0.082
			Standard Deviation:		0.38	0.035

was not always demonstrated as evidenced by the minimum K_y occurring at an intermediate distance.

Table 2-7 shows the results for the January 9, 1979 plume analysis. An example cross plume concentration profile for this date is shown in Figure 2-12 which illustrates a near Gaussian distribution. All of the plume profiles which are contained in Appendix 6 were not as close as this to a Gaussian distribution and some had double peaks. The lowest diffusion coefficients were obtain from this data with values ranging from 0.08 ft^2/s (.007 m^2s^{-1}) to 0.68 ft^2/s (0.063 m^2s^{-1}).

Talbot (1975) presented a summary of near surface diffusion coefficients which were determined with Equation 2-9, and these results, those of Foxworthy (1968), and the Freeport data are tabulated in Table 2-8 for comparison purposes. The Freeport values are most similar to those found in Lake Huron. The low values suggest that the turbulent diffusion in the Freeport area is less than that found in the Cumberland and California coasts. The period of these experiments was limited to the fall and early winter and perhaps higher values would be measured in the spring and early summer months.

A more general and more accurate method for presenting the diffusion coefficient data is to use a power-law equation which relates the variance (σ_y^2) of the profile to time (t) of dye travel from the source. The power-law equation is

$$\sigma_y^2 = At^n \tag{2-11}$$

where A and n are constants determined by a curve fit to the variance data plotted versus time on log-log paper. The variance-time data collected on September 5 and November 2, 1978 and January 9, 1979 are plotted on Figure 2-13. Curve C in this figure is the best fit to all the

Table 2-7. Results of plume analysis from 1/9/79.

January 9, 1979 Current: 1.6 ft/s (0.49 m/s) Wind: NW Light to Moderate

Seas: 4-5 ft (12.-1.5 m) Stability: No Data Water Depth: 60 ft (18 m)

Run No.	Distance from Source		Variance		Horizontal Diffusion Coefficient ($K_y=\sigma_y^2/2t$)	
	ft	m	ft^2	m^2	$ft^2\ s^{-1}$	$m^2\ s^{-1}$
1	1800	549	1520	141	0.68	0.063
2	2160	658	208	19	0.08	0.007
3	2270	693	320	30	0.11	0.010
4	2740	835	1860	173	0.54	0.050
5	4160	1268	1330	124	0.26	0.024
			Mean:		0.33	0.031
			Standard Deviation:		0.27	0.025

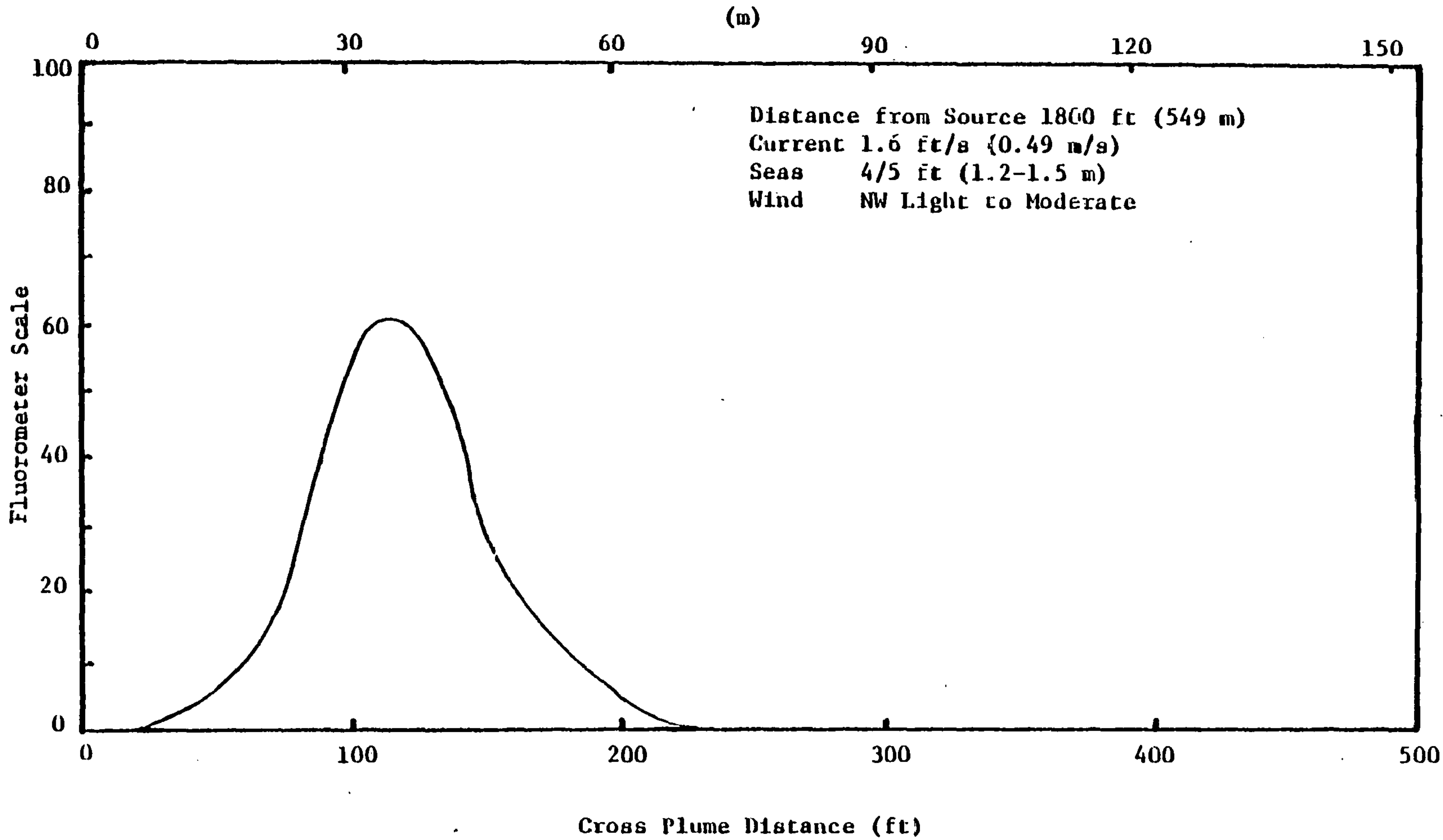


Figure 2-12. Cross plume profile No. 1, 1/9/79.

Table 2-8. Comparison of near surface horizontal diffusion coefficients determined by $K_y = \sigma_y{}^2/2t$ from continuous release experiments.

Location	Horizontal Diffusion Coefficients (ft^2/s)	(m^2/s)
Freeport	0.08-1.51	0.007-0.14
Lake Huron*	0.067-1.5	0.006-0.14
Lake Ontario*	0.2-4.6	0.019-0.43
Lake Erie*	0.8-4.7	0.074-0.44
Black Sea*	0.81	0.075
Holy Loch*	1.4	0.13
Red Wharf Bay*	4.6	0.43
Cumberland Coast*	22.3	2.1
Thames Estuary*	1.07-16.8	0.10-1.6
California Coast**	0.42-5.16	0.039-0.48

*Talbot (1975)
**Foxworthy (1968)

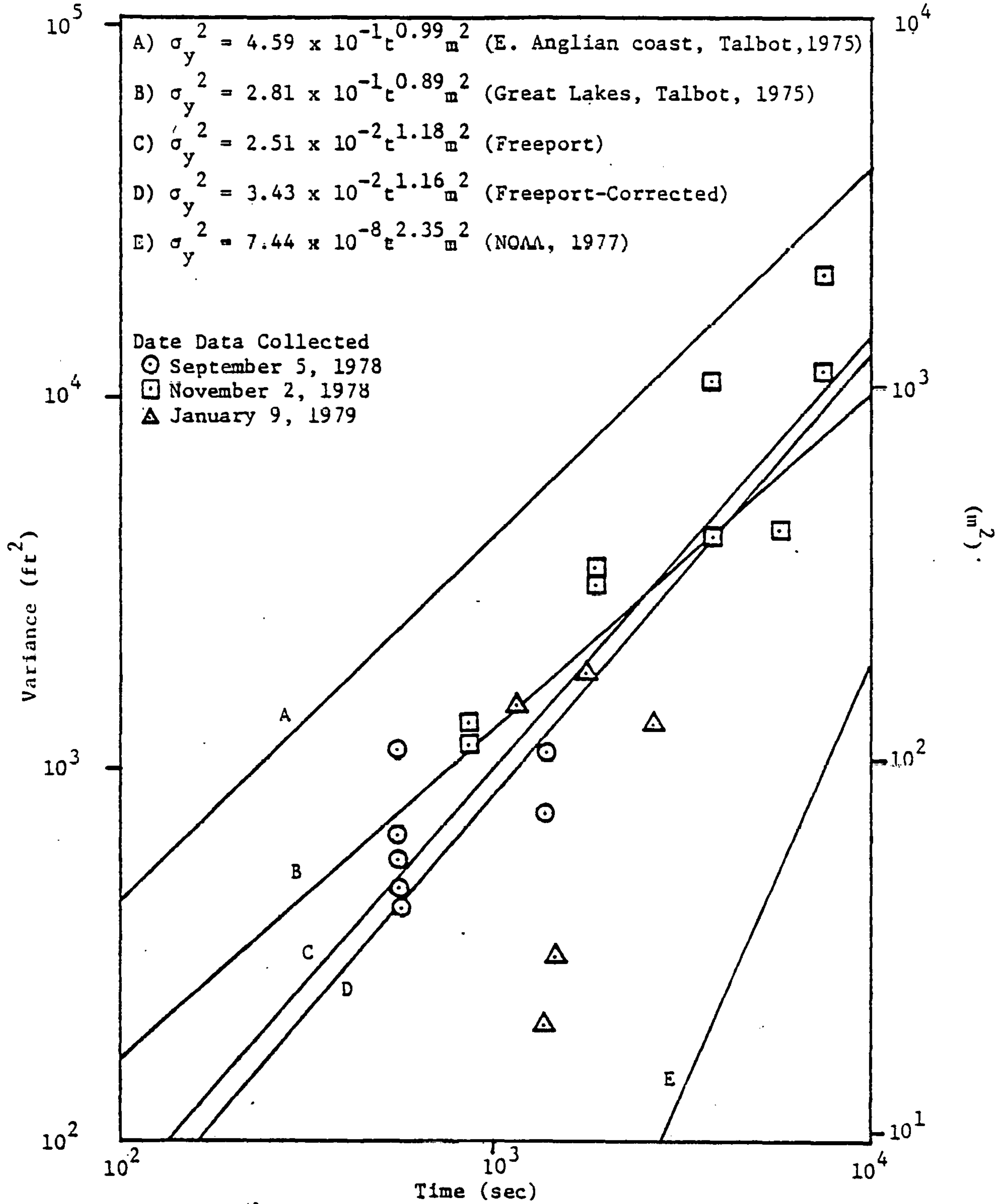


Figure 2-13. Power Law Comparison of Surface Horizontal Diffusion Coefficient Data.

Freeport data, and curves A and B are from data summarized by Talbot (1975) for tidal and wind driven currents respectively. Near the source or for short time periods, the Freeport data is lower than the other data. However, the slope of curve C is greater than the other data and after a long time frame it surpasses curves A and B. Two low values for diffusion coefficients were computed for profiles 2 and 3 on January 9, 1979. If these two low points are deleted from the data base, the power-law curve shown as curve D in Figure 2-13 is obtained and is believed to be the best curve fit to the data. Curve E represents the variance-time relationship derived from the diffusion coefficient relationship used in the MIT transient plume model (Adams et al., 1975). The model has been used to predict the areal coverage and concentration of a brine plume in the coastal waters off Freeport, Texas, NOAA (1977).

Once the curve fit to the variance-time data is determined, the horizontal diffusion coefficient relationship, Equation 2-8, can be evaluated. Substituting the constants from curve D of the Freeport data into Equation 2-11, the result is

$$\sigma_y^2 = 3.43 \times 10^{-2}\, t^{1.16} \qquad (2\text{-}12)$$

where the units of σ_y^2 and t are square meter and seconds respectively. When the coefficients of Equation 2-12 are substituted into Equation 2-8, the result is an expression for the horizontal diffusion coefficient

$$K_y = 0.02\, t^{0.16} \qquad (2\text{-}13)$$

where the units of K_y are square meters per second (m^2s^{-1}). The diffusion time for the data used to derive Equation 2-13 varied from approximately 500 to 10^4 seconds.

The MIT transient plume model uses a power law relationship between

K_y and the concentration profile standard deviation σ_y which is written as

$$K_y = .0003\ \sigma_y^{1.15} \qquad (2\text{-}14)$$

where the units of K_y are $m^2 s^{-1}$. Using Equation 2-12 a similar expression was developed for the Freeport data which is

$$K_y = 0.032\ \sigma_y^{0.28} \qquad (2\text{-}15)$$

A comparison of these two equations is shown on Figure 2-14. The Freeport data is characterized by Equation 2-15, and using it as a comparison Equation 2-14 estimates a smaller value for the horizontal diffusion coefficients within the range of measured profile standard deviations. Thus, the expression for the horizontal diffusion coefficient used in the MIT transient plume model is conservative and would likely result in a more adverse prediction than would be expected as a result of the data collected in this study.

2.6.2 Mid Depth Horizontal Diffusion Coefficients

For most diffusion models the horizontal diffusion coefficient is assumed to be constant over the depth of the water column. In this study data was collected for the purpose of evaluating the effect of depth on the horizontal diffusion coefficient which could be accomplished by comparing coefficients measured at mid depth to those at the surface. The data was collected with the same experimental equipment as was used for the surface coefficients with the exception of a vertical line source instead of the point source. This was necessary to overcome the impossible task of keeping the intake hose and the point source at the exact same depth. Then, the previously described procedures for measuring the surface

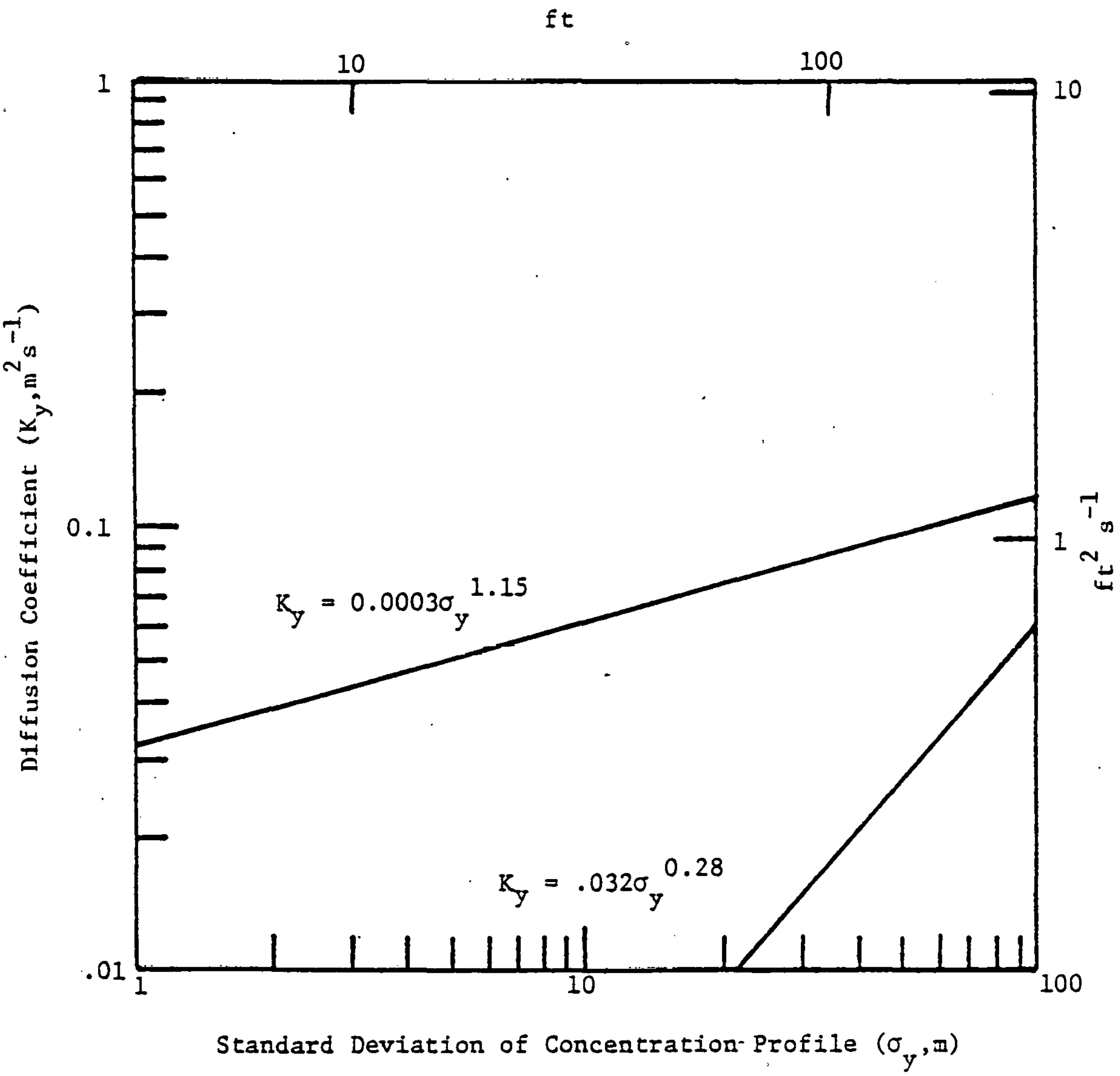


Figure 2-14. Comparison of horizontal diffusion coefficient expressions.

diffusion coefficients were used to evaluate the coefficients at mid depth.

The results for the mid depth horizontal diffusion coefficients determined by Equation 2-9, the variance, and distance data are summarized in Tables 2-9 and 2-10 for the data collected on October 3 and 12, 1979, respectively. The October 3 coefficients are smaller than the surface coefficients obtained on November 2, 1978 (Table 2-6) for distances less than one half mile from the source. However, the October 3 coefficients are much larger than the November 2 values for greater distances from the source. The October 12 data yielded coefficients which were smaller than those obtained on October 3 and on January 9, 1979. The very low current regime on October 3 was believed to be the main reason for the low coefficient values.

The variance, σ_y^2, data for the mid depth horizontal diffusion are plotted versus time of diffusion in Figure 2-15. A least squares curve fit, curve B, to the combined October 3 and 12 data is

$$\sigma_y^2 = 1.78 \times 10^{-4}\ t^{1.69} \qquad (2\text{-}16)$$

where σ_y^2 and t have units of square meter (m^2) and seconds (s) respectively. Substituting the coefficients of this power-law expression into Equation 2-8, results in a power-law relationship for the horizontal diffusion coefficient

$$K_y = 1.5 \times 10^{-4}\ t^{0.69} \qquad (2\text{-}17)$$

where K_y has units of $m^2 s^{-1}$. An expression for K_y as a function of the profile standard deviation, σ_y, is

$$K_y = 7.13 \times 10^{-3}\ \sigma_y^{0.82} \qquad (2\text{-}18)$$

These expressions show that the mid depth diffusion coefficients increase at a greater rate than those at the surface but their magnitude is

Table 2-9. Results of mid depth horizontal diffusion coefficients for coastal waters offshore Freeport, Texas on October 3, 1979.

October 3, 1979 Current: 0.9 ft/s (0.27 m/s) Seas: 4-6 ft (1.2 - 1.8 m)

Wind: 12-18 kts, SW Stability: Ri = 0.26 Water Depth: 60 ft (18 m)

Run No.	Distance from Source		Variance		Horizontal Diffusion Coefficient ($K_y = \sigma_y^2/2t$)	
	ft	m	ft^2	m^2	$ft^2\ s^{-1}$	$m^2\ s^{-1}$
1	2690	820	1,150	107	.19	0.02
2	2180	665	3,820	355	.79	0.07
3	3090	942	710	66	.10	0.01
4	3020	921	7,300	679	1.09	0.10
5	6130	1869	42,430	3,944	3.11	0.29
6	6700	2043	117,440	10,916	7.89	0.73
7	11,590	3534	293,470	27,278	11.39	1.06
			Mean:		3.50	0.33
			Standard Deviation:		7.36	0.41

Table 2-10. Results of mid depth diffusion coefficients for coastal waters offshore Freeport, Texas on October 12, 1979.

October 12, 1979 Current: 0.13 ft/s (0.04 m/s) Seas: 3-5 ft

Wind: 10-15 kts, SSW Stability: Ri = 0.36 Water Depth: 60 ft (18 m)

Run No.	Distance from Source		Variance		Horizontal Diffusion Coefficient ($K_y = \sigma_y^2/2t$)	
	ft	m	ft^2	m^2	$ft^2\ s^{-1}$	$m^2\ s^{-1}$
1	860	262	860	80	0.06	0.006
2	640	195	300	28	0.03	0.003
3	620	189	590	55	0.06	0.006
4	450	137	810	75	0.11	0.010
5	760	232	6470	601	0.53	0.049
6	1990	607	1140	106	0.04	0.004
			Mean:		0.14	0.013
			Standard Deviation:		0.19	0.018

decreased. Thus, the limited amount of data show that the mid depth K_y decreases with depth. Murthy (1972) found that K_y increased with depth in his studies in Lake Huron. Because of this contradiction and the limited spread on the time axis more data is needed to verify the effect of depth on the diffusion coefficients. This effect is important for brine discharge because the diffusion of negatively buoyant brine discharge occurs in the lower half of the water column. Figure 2-15 also shows a curve (C) which represents the previously described variance time relationship derived from the diffusion coefficient, Equation 2-14, used in the MIT transient plume model. This confirms the conservative estimates obtained with Equation 2-14 for mid depth horizontal diffusion coefficients as well as for the surface coefficients.

2.6.3 Vertical Diffusion Coefficients

On December 2, 1979, an experiment near the Rutherford Oil Co. platform (90° 18.7'W, 28° 47.1'N) was conducted to evaluate the vertical diffusion coefficient for the coastal waters off Freeport. In this experiment the previously described 30 ft (9 m) horizontal line source was deployed at a depth of 50 ft (15 m) where the dye was discharged. The intake hose was towed at a depth of 32 ft (10 m) and the distance between the source and point of maximum concentration was measured. These data were then substituted in Equation 2-11 from which the vertical diffusion coefficient was determined. The results are tabulated in Table 2-11, and they show the average vertical diffusion coefficient is 0.27 ft^2/s (.025 m^2/s). A comparison of the Freeport data with selected values from Talbot (1975) are shown in Table 2-12. This comparison shows that the Freeport data is the same order of magnitude as the Thames Estuary but about double that measured along the Suffolk coast.

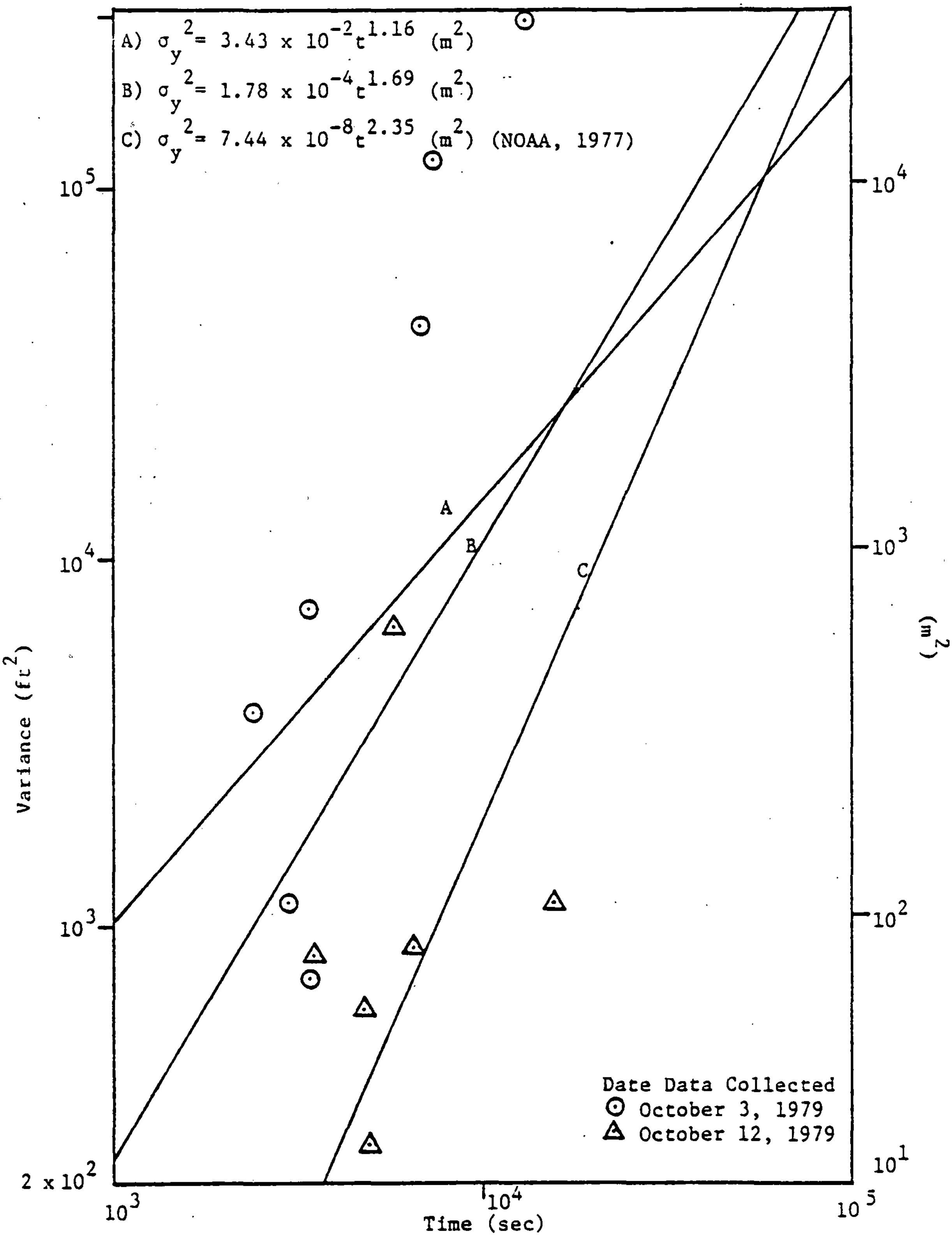


Figure 2-15. Power Law Comparison of Mid-Depth and Surface Horizontal Diffusion Data

Table 2-11. Results of vertical diffusion coefficients for coastal waters offshore Freeport, Texas on December 2, 1979.

December 2, 1979 Current: 1.0 ft/s (0.3 m/s) Seas: 3-5 ft (0.9-1.5 m)

Wind: 10-15 kts, ENE Stability: Ri = 0.62 Water Depth: 60 ft (18 m)

Run No.	z'		z		s_{max}		Vertical Diffusion Coefficient	
	ft	m	ft	m	ft	m	ft^2/s	m^2/s
1	32	9.8	50	15	1050	320	0.16	.015
2	32	9.8	50	15	400	122	0.41	.038
3	32	9.8	50	15	650	198	0.25	.023
4	32	9.8	50	15	650	198	0.25	.023
				Mean:			0.27	0.025
				Standard Deviation:			0.10	0.010

Table 2-12. Comparison of vertical diffusion coefficients K_z, ft^2/s (m^2/s)

Location, reference and date		Diffusion Coefficient	
	Min	Mean	Max
Freeport, 1979	0.16 (0.015)	0.27 (0.025)	0.41 (0.038)
Lake Huron, Csanady (1964), and Murthy and Csanady (1971)	0.002 (0.0002)	0.007 (.00062)	0.016 (.0015)
Suffolk Coast Talbot (1975)	.05 (0.005)	0.08 (0.0075)	0.13 (.0125)
Thames Estuary Talbot (1975)	0.13 (0.012)	0.24 (0.022)	0.34 (0.032)

The MIT transient plume model uses a K_z of .001 ft^2/s (.00009 m^2/s) which is on the order of one hundred times smaller than that determined in this study. The 30 ft (9 m) horizontal line source was used to help eliminate the effect of horizontal diffusion and was the longest line source which could be effectively deployed, but it may have not been long enough to minimize the effects of horizontal diffusion. The effect of horizontal diffusion would tend to increase the value of the vertical diffusion coefficient determined by the described procedure. The desire to use a conservative estimate in the MIT transient plume also contributes to the difference in the values. Additionally, more than one day of data is really needed to evaluate the vertical diffusion coefficient.

2.6.4 Summary of Diffusion Coefficient Measurements

In this study a continuous release of a Rhodamine WT dye mixed with methyl alcohol was discharged into the coastal waters off Freeport, Texas, where the depth is 60 ft (18 m). The dye plume was detected by pumping a continuous water sample to a filter fluorometer on board the research vessel while it was traversing the plume. The extent of the plume was determined by knowing the location of the ship as determined by the navigation system, and comparing it to the strip chart recording of the plume profile concentration. The plume profile was used to determine its variance, and the measured current was used to evaluate the time of dye travel. The variance (σ_y^2) and travel time (t) data were plotted on log-log paper and a linear regression analysis resulted in a power law expression for the variance. This was used to derive expressions for the horizontal diffusion coefficient as a function of time (t) and the plume profile standard deviation (σ_y), Equations 2-13 and 2-15 respectively. These results were shown to compare well with other experimental results obtained for lakes and the California coast. The horizontal diffusion coefficient expression, Equation 2-14, used in the MIT transient plume model was compared to the results of this study which confirmed that Equation 2-14 is a good conservative estimate. The mid depth diffusion coefficients generally showed a decrease over those found at the surface, but more data is desired to substantiate this result.

The vertical diffusion coefficients (K_z) were determined by measuring the horizontal distance from the dye source to the location of the maximum concentration, the mean current, and the square of the depth differences between the source and the concentration measurement depth. One day of vertical diffusion coefficient data resulted in an average K_z of 0.27 ft^2s^{-1} (0.025 m^2s^{-1}) which compares well with the values for the Thames Estuary, but it is one to two orders of magnitude greater than other values for coastal waters. It is two orders of magnitude greater than the value .001 ft^2s^{-1} (.00009 m^2s^{-1}) used in the MIT transient plume model. This large difference may be partially attributed to the effects of horizontal diffusion and to the desire to use conservative values for diffusion coefficients in the MIT transient plume model.

2.7 Conclusions and Recommendations

Two monitoring systems have been designed, assembled, and tested for the purpose of monitoring the brine plume from the Bryan Mound discharge site. The pump monitoring system has worked well for measuring diffusion coefficients and could be used for tracking the plume if it is not too close to the bottom. However, indications are that the plume will be within 2-4 ft (0.6-12.2 m) from the bottom. Therefore, it is not recommended that the pumping monitoring system be used in tracking the near bottom plume, but it could be used for some of the near field measurements.

The probe monitoring system was designed to be towed on the sea floor with the CTD probe located 10 in (25 cm) off the bottom, and it will break free of the towing line and instrument data cable if it should snag while being towed. The advantages of this system are that the measurement depth is always known, the probe is close enough to the bottom to insure detection of a plume which is 10 in (25 cm) or greater off the sea floor, and the damage due to snagging is minimized as a result of the break away design. The probe system has been towed at a speed of 2-3 knots, and the probe has been used by itself for collecting CTD data since April, 1979. Because of the above mentioned advantages and successful testing of the probe monitoring system, it is recommended for use in the plume tracking.

A relationship for predicting surface horizontal diffusion coefficients (Equation 2-15) was determined from the data collected in this study. The values obtained from this equation are an order of magnitude larger than those obtained from the relationship (Equation 2-14) used in the MIT transient plume model. Thus, the results of this study confirms that the diffusion coefficient values used in the MIT transient plume model are good conservative values.

The mid depth horizontal diffusion coefficient data indicate that the coefficients decrease with depth and that the coefficients used in the MIT transient plume model remain to be conservative values. The conclusion of the effect of depth on the coefficients is based upon only two days of data, and it is recommended that more data be collected to further substantiate this conclusion.

Vertical diffusion coefficients were computed from a single day of experimental data which resulted in an average value of 0.27 $ft^2 s^{-1}$ (0.025 $m^2 s^{-1}$). This result agreed with values reported for the Thames Estuary, but was generally an order of magnitude higher than other reported values. Like the horizontal data, the vertical diffusion data confirmed that the value (K_z = .001 ft^2s^{-1}, K_z = 0.0009 m^2s^{-1}) used in the MIT transient plume mode is conservative.

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CHAPTER 3

WATER AND SEDIMENT QUALITY

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3.1 Introduction

In evaluating the environmental impact of brine disposal on water and sediment quality, it is essential that sufficient baseline information be available prior to brine discharge so that proper assessment of the effect of the brine be made should environmental changes occur during the period of discharge. This baseline information must include areas outside the immediate discharge area so that changes resulting from natural or other man-made activities outside of the brine diffuser site can be differentiated from those related to brine disposal. This report contains the results of a study designed to provide such chemical baseline data prior to brine discharge from the Bryan Mound Strategic Petroleum Reserve site.

This baseline data consists of two parts. First, those water quality parameters that assess the general quality, chemical fertility and biological habitability of the area and that are influenced by natural processes were measured on a monthly basis over a period of at least one year. Limited sampling commenced in September 1978 and full scale sampling in February 1979. Baseline sampling continued through February 1980.

In coastal waters such as those proposed for the Bryan Mound disposal site, these parameters should and did include salinity, dissolved oxygen, nutrients (nitrogen, phosphorus and silica), and estimates of organic matter (oil and grease), turbidity (suspended solids) and productivity (chlorophyll a and pheophytin a pigments). These parameters are affected not only by physical and chemical processes that occur naturally in the ocean but because of the area's proximity to shore also by terrestrial inputs resulting from local and regional runoff. Such runoffs can lead to greatly reduced salinities, increased nutrients, organic detritus and suspended matter. The increased nutrients could further lead to algal blooms which in the process of decaying along with the organic detritus introduced by the runoffs can lead to reduced dissolved oxygen levels, especially within the bottom waters of this and adjacent areas. Thus, terrestrial runoff reaching the brine diffuser area can have two opposing effects - increased nutrients that can lead to increased biological productivity and decreased salinities and dissolved oxygen which may have an adverse effect on habitability of the area by marine organisms.

A second part of the baseline study concerns those water and sediment characteristics that can be influenced by the brine discharge itself. Among these parameters are included the major and minor ions associated with the brine as well as heavy metals and organics such as normal and chlorinated hydrocarbons and pesticides that might be introduced from the river water used to leach out the salt dome caverns. The impact of these various components of the brine upon the discharge area can be an alteration of general salinity levels (ionic strength changes), ionic imbalance and introduction of toxic substances such as heavy metals and certain organics. More subtle changes than these can occur, however. The increased levels of major ions may alter the existing chemical balance between the water column and sediments thereby leading to an exchange of components between the two phases (Lee, 1970). For example, heavy metals already associated with the sediments and unavailable to marine organisms might become mobilized and transfer across the sediment-water interface. On the other hand, some biologically significant metals could be removed from the water column by precipitation as a result of salinity (ionic strength) increases. Since the effect of both ionic imbalance and ionic strength changes upon the complex water-sediment interface chemistry cannot be predicted beforehand; we must insure that sufficient baseline information exists so that changes in this complex system can be spotted should they occur.

Parameters chosen for this second part of the baseline study include for the water column the major or bulk ions (Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, SO_4^{--}, Br^- and I^-) and the soluble heavy metals (Al, Cd, Cr, Cd, Hg, Fe, Ni, Pb, and Zn). Sediment analyses include the same heavy metals plus the major ions (Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, SO_4^{--}) and total dissolved solids present in the interstitial or pore waters of the sediment. Secondary sediment characteristics such as Eh, pH and oil and grease were also included.

Since parameters chosen for this second part of the baseline study are of a more conservative nature than those contained in the first part and therefore undergo slower changes in the environment, their analyses have been confined to a quarterly basis commencing in August, 1979.

Standard analytical procedures were available for all of the above mentioned parameters with the exception of sediment heavy metals. The problem of how to analyze these metals is complicated by the fact that such metals can occur in many different chemical and physical forms. Among these are (1) water soluble in interstitial solution, (2) on normal exchange sites, (3) on specific sorption sites, (4) occluded with hydrous oxides, (5) in organic matter, (6) as sulfides, and (7) in the lattice of minerals. Numerous recent studies have been carried out to develop methods for estimating the metal content of each form and, in some cases, to determine which form(s), if any, express biological availability of the metals (Jenne and Luoma, 1975; Chen, et al., 1976; Brannon et al., 1977; Trefry, 1977; and Neff, et al., 1978). It is apparent from these studies that no single extractant can be used to evaluate chemical and biological availability. The only obvious conclusion is that total or bulk analysis is not an indication of availability. As pointed out in the Science Applications, Inc. 1978 report on the environmental survey of Texoma brine diffuser sites, the use of 1N HNO_3 leach provides an approximation of the maximum sediment sorbed metals subject to changes as a result of ionic strength alterations due to brine disposal or as a result of input from the river water used for leaching the salt dome deposits. If anything, such acid leaching probably errors on the side of safety, i.e., it probably measures more of the metal than actually can be desorbed from the sediment. For this reason, 1N HNO_3 leach was used in this study.

In addition to the monthly and quarterly sampling program, a special study that included measurement of heavy hydrocarbons, pesticides and PCB's in sediments and heavy metals, pesticides and PCB's in selected biota was carried out on a one time basis. Sediment sampling occurred in late August 1979 but absence of biota in the area delayed their collection until early October 1979.

Sedimentary hydrocarbons accumulate over long periods of time from the water column, which may contain both marine and terrestrial biogenic inputs as well as anthropogenic input, from *in situ* production by bacteria, from sediment transport and even from subsurface oil-bearing sediments and rocks. In a nearshore area there may be seasonal differences, because decomposition and production of hydrocarbons occur simultaneously.

Hydrocarbon concentrations alone appear to be of limited use in assessing petroleum contamination of sediments, because there is a great deal of variation in concentrations of naturally occurring hydrocarbons, due to differing rates of sedimentation, grain size of sediment, mineral content and organic content. Results of several investigations have shown that in cases of marginally petroleum contaminated sediments that marine and terrestrial biogenic hydrocarbons far exceed those of petrogenic origin (Kaplan, et al., 1976). Consequently both concentration levels and composition of hydrocarbons from sediments must be carefully examined using the most modern techniques available to detect marginal petroleum contamination in sediments. Capillary gas chromatography is a very sensitive tool for separating the isomers of hydrocarbons and other very similar hydrocarbons. Capillary gas chromatography coupled with a mass spectrometer has proven to be an essential tool for identifying the compounds separated by the capillary column.

Several criteria have been developed over the past few years to assess the sources of hydrocarbons in sediments from gas chromatography and mass spectrometry. Sediment hydrocarbons in the hexane fraction of marine biogenic origin are characterized by the dominance of pristane and/or some polyolefins eluting between C-20 and C-21 alkanes (Kaplan, et al., 1976 and Gearing, et al., 1976). Most marine alkanes are in the range of C-14 to C-21 and exhibit an odd to even carbon chain preference greater than 1, usually 3 to 5 (Clark, 1966 and Farrington and Tripp, 1977). Terrestrial vascular plants tend to produce high molecular weight hydrocarbons in the range of C-23 to C-36 with high odd to even ratio of the normal alkanes. Petroleum derived alkanes have an odd to even ratio of near 1 (National Academy of Science, 1975). In addition terrestrial biogenic hydrocarbons (alkane or hexane fraction) exhibit an unresolved complex mixture (UCM) or "hump" in the high molecular weight region of the chromatogram (C23-C36), which reportedly is a combination of partly degraded organic compounds. A UCM or hump in the low molecular weight region (C15-C21) is often indicative of a medium or light distillate petroleum input. In addition, petrogenic hydrocarbons exhibit very complex chromatograms with many more resolved components than natural hydrocarbons. In nearshore sediments, often a combination of all these inputs may be apparent on a gas chromatogram.

Another compositional feature to study in sediments to determine petrogenic input is to identify the aromatic hydrocarbons present. Sediments can contain both natural and petrogenic aromatic hydrocarbons. Unsubstituted aromatic hydrocarbons, like phenathrene and pyrene, may indicate the dominance of a combustion source(result of fires) as opposed to a petrogenic source. The latter tends to have alkylated homologs of the various high molecular weight aromatics (Farrington and Tripp, 1977).

Since one objective of this program is to evaluate ultimately any actual input of stored petroleum reserves as well as hydrocarbons contained in the river leach water into the marine environment, identification of pre-existing hydrocarbon levels and sources is necessary. The disposal site is affected by river or terrestrial input, marine and possibly anthropogenic inputs and there may also be seasonal changes in these inputs.

Due to delays in obtaining subcontract permission from the Department of Energy for analyses of pesticides and polychlorinated biphenyls (PCBs), discussion of this phase of the baseline study will be postponed until their analyses have been completed and a separate report covering this portion will be prepared.

3.2 Sampling and Analytical Methods

3.2.1 Sample Station Locations

A sampling grid of 13 stations was chosen for these studies. Nine (9) stations were located in the diffuser area and 4 stations at about four nautical miles from the diffuser for control purposes. The 9 diffuser stations were chosen so that 3 stations were located along the diffuser at 500 foot intervals to evaluate near field effects and 3 stations located on each side of the diffuser at a distance of 500 feet to evaluate the intermediate field effects. These outer diffuser stations were also spaced 500 feet from each other. Upon completion of the diffuser line in July 1979, it was found that the original diffuser stations (MM, D2 through D9) were about 1,000 feet from the actual diffuser and a new set of similar stations (D10 through D18) were established over the actual diffuser location. The present 13 water and sediment sampling stations are shown in Figure 3-1. Station coordinates for all stations including the original discontinued diffuser grid are given in Table 3-1. In addition to the main 13 stations, three additional stations (D19-21) were added to the diffuser grid during February 1980 only. These were located 500 feet seaward of the primary diffuser stations. Their locations are also given in Table 3-1.

3.2.2 Sample Collection

Water samples were collected in 5-ℓ Niskin PVC bottles suspended on a stainless steel hydrowire. Samples were taken at 3 depths (surface, mid and bottom). Three hundred ml smaples were withdrawn for dissolved oxygen analysis by the Winkler method and 100 ml for pH analysis aboard ship. Two hundred ml samples were placed in WhirlPak bags and immediately frozen for laborabory analysis of nutrients. The remainder was placed in clean 4ℓ polyethylene Cubitainers,

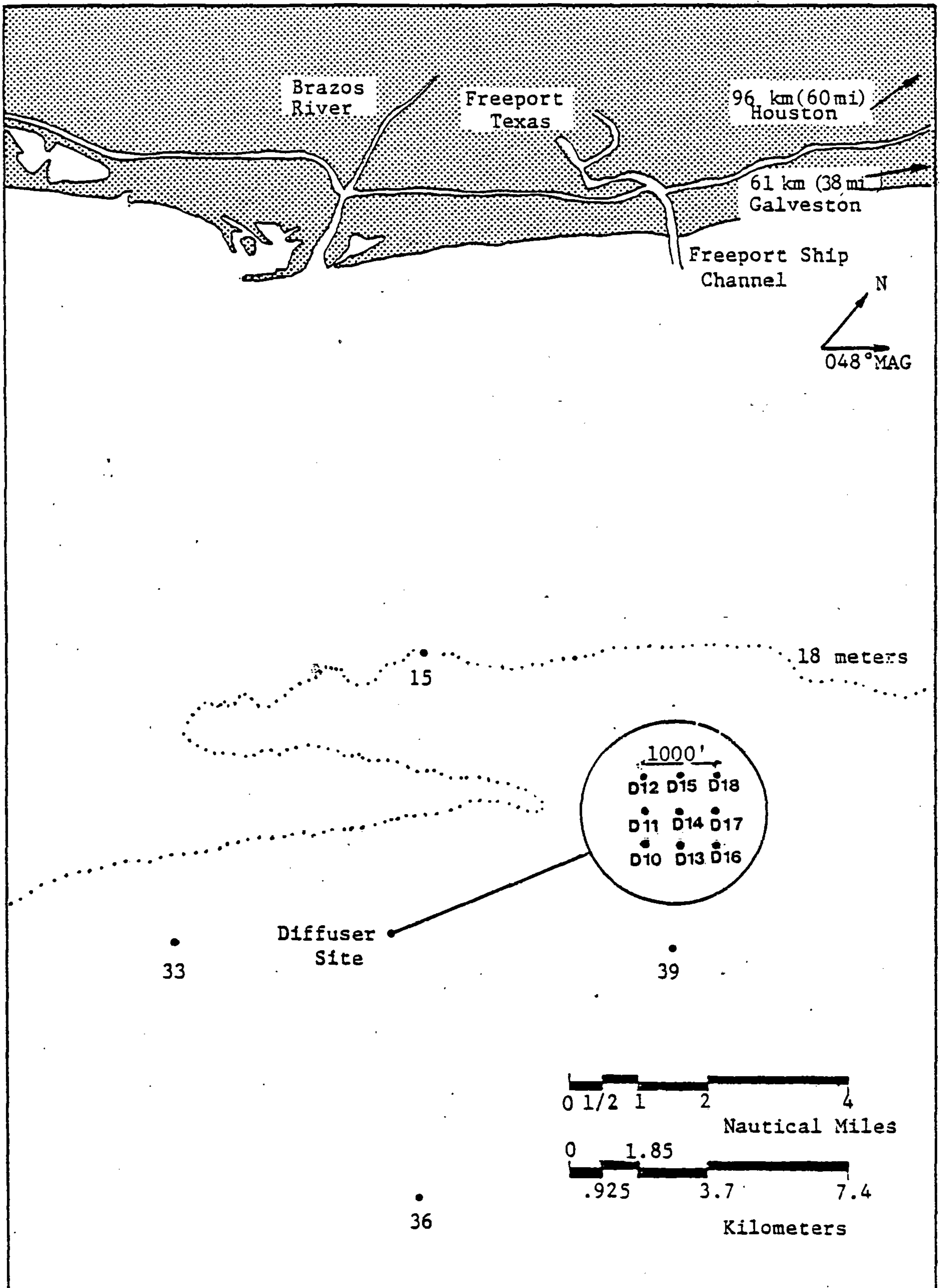

Figure 3-1. Water and sediment sampling stations

Table 3-1. Station coordinates for water and sediment quality stations

Station	Latitude (N)	Longitude (W)
Control stations		
15	28° 48' 26"	95° 17' 07"
33	28° 42' 18"	95° 17' 42"
36	28° 41' 24"	95° 11' 27"
39	28° 47' 00"	95° 10' 24"
Diffuser grid to July 1979		
MM	28° 44' 26"	95° 14' 41"
D2	28° 44' 30"	95° 14' 38"
D3	28° 44' 27"	95° 14' 33"
D4	28° 44' 23"	95° 14' 28"
D5	28° 44' 20"	95° 14' 31"
D6	28° 44' 23"	95° 14' 36"
D7	28° 44' 16"	95° 14' 35"
D8	28° 44' 19"	95° 14' 40"
D9	28° 44' 23"	95° 14' 44"
Diffuser grid after July 1979		
D10	28° 44' 04"	95° 14' 34"
D11	28° 44' 07"	95° 14' 37"
D12	28° 44' 11"	95° 14' 40"
D13	28° 44' 06"	95° 14' 30"
D14	28° 44' 10"	95° 14' 33"
D15	28° 44' 13"	95° 14' 35"
D16	28° 44' 08"	95° 14' 25"
D17	28° 44' 12"	95° 14' 28"
D18	28° 44' 16"	95° 14' 31"
Extra diffuser stations during February 1980		
D19	28° 43' 58"	95° 14' 32"
D20	28° 44' 01"	95° 14' 26"
D21	28° 44' 04"	95° 14' 22"

iced and returned to shore for analyses. Replicate samples were taken at least 10% of the time. On a quarterly basis, one liter of the water from each station and depth was filtered through precleaned 0.45μ millipore membrane filters in all glass filter apparatus as soon as possible upon return to shore, placed into cleaned 1ℓ Cubitainers and acidified to pH<2 with trace metal analysis grade nitric acid prior to storage for later heavy metal analyses. Since it was desired to determine "dissolved" heavy or trace metals, it was necessary to filter the samples prior to acidification. Since the potential for contamination during the filtering process is especially great aboard small vessels such as used in this study, it was decided that any error due to metal loss during the time delay prior to acidification, especially for one day cruises, would be less than resulted from contamination from filtration aboard the vessel. In addition, the Niskin samplers used latex rubber closures rather than the black rubber normally used to reduce metal contamination of samples. Water samples were also taken at a number of stations for laboratory analyses of conductivity (salinity) to verify measurements taken <u>in situ</u> with a Hydrolab 8000 conductivity probe. This probe was also used to take <u>in situ</u> dissolved oxygen, temperature, pH and depth. On several occasions where conflicting cruise schedules occurred, a Hydrolab TC-2 was used to obtain conductivity and temperature. Because of difficulties with the oxygen probe on the Hydrolab 8000, all dissolved oxygen data used in this study were determined by the Winkler method.

Sediment samples were taken with a pre-cleaned stainless steel 25x25 cm box corer. The upper 5 cm of sediment was sampled through the top opening of the sampler. Samples used for general sediment quality and heavy metal analyses were taken from the center surface area using an acid cleaned plastic spatula and placed into clean conventional polyethylene cartons, These cartons were filled to their top, sealed and immediately iced until their return to shore. Eh and pH of sediments were taken as soon as possible after sampling. The samples collected for metal analyses were kept refrigerated until they were returned to the laboratory and split into individual analysis fractions. When sediment samples were to be used for hydrocarbon, pesticide and PCB analyses they were taken from the top 5 cm of the box corer with pre-cleaned jars and frozen with dry ice for return to the laboratory. For hydrocarbon samples pre-cleaned teflon lid liners were used, and for pesticide and PCB samples fired pre-cleaned aluminum sheets were placed under the lids. Nanograde hexane (Burdick and Jackson) was used to pre-clean the jars and lid liners. Sediment samples used for organics were kept frozen at -20°C until shipped or transferred to the appropriate analytical laboratory. Sediment samples for all analyses were taken in duplicate for each station.

Collection of macroepifauna and demersal fish were made using an otter trawl that had been weathered by several months of trawling. Weathered trawls were used to reduce potential of sample contamination that might result from new trawls. In other words, water soluble contaminants that could migrate to samples would be rinsed from the nets by previous trawling. Tow periods of 20 to 30 minutes were normally used. Samples chosen for analyses were Micropogonias undulatus (Atlantic croaker), Penaeus setiferus (white shrimp) and Penaeus aztecus (brown shrimp). Zooplankton samples were collected using a 1-meter nylon net (240μm mesh) equipped with a PVC straining bucket. Zooplankton were of mixed species but consisted mostly of copepods (Ascartia tonsa and Paracalanus quasimodo predominated).

For all biota, appropriate size pre-cleaned jars with fired, pre-cleaned aluminum liners were used for pesticides and PCB samples and clean polyethylene cartons or bags for metal analyses samples. Samples were frozen immediately after collection and remained frozen until time of analysis.

3.2.3 Analytical Methods

Analytical procedures used in these studies are based upon those contained in the American Public Health Association's Standard Methods for the Examination of Water and Wastewater, 14th edition, 1975 or in the Environmental Protection Agency's Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 of March 1979 where possible. Specific analytical methods follow.

3.2.3.1 General Water Quality Analyses

Analyses of general water and pore water quality parameters were made in accordance with the following methods.

Chloride (Cl) was determined by the mercuric nitrate method described in method #408B of Standard Methods, after a 1:200 volumetric dilution.

Sulfates (SO_4) were determined by the barium sulfate turbidimetric method #427C of Standard Methods, after a 1:50 volumetric dilution.

Orthophosphate phosphorus ($O-PO_4-P$) was measured by the ascorbic acid-molybdate method #425F in Standard Methods. Total phosphorus (T - P) was determined by persulfate digestion to ortho phosphate using method #425C-III in Standard Methods followed by analysis of the produced ortho phosphate as described above.

Reactive silica (SiO_2) was determined by the molybdosilicate method #426B in Standard Methods.

Both nitrite and nitrate nitrogen (NO_2-N and NO_3-N, respectively) were determined using a Technicon Autoanalyzer II system. The nitrite was first determined by the azo dye colorimetric method and the nitrate was reduced to nitrite using the cadmium reduction method and the resultant nitrite, including the original nitrite, was determined by the azo dye method. Nitrate was obtained by difference. The procedure is described in method #605 of Standard Methods.

Ammonia nitrogen (NH_3-N) was determined by a modification of the phenate method (#418C in Standard Methods). Because of difficulties with the manganous sulfate catalyst, this method was modified to use sodium nitroprusside according to the method described for analysis of ammonia in seawater by Strickland and Parsons (1972). In this respect, the method is similar to the automated phenate method described under method #604 in Standard Methods.

Those organic compounds lumped together and referred to under the general term "oil and grease" were measured using the freon extraction, infrared spectrophotometric method contained in method #502B of Standard Methods.

Determination of the plant pigments chlorophyll a and its degradation product pheophytin a were made by filtering 1000 ml of sea water through a 0.45μm membrane filter, extraction of the pigments from the membrane with aqueous acetone and spectrophotometric measurement of the absorbance of the extract at 750, 663, 645 and 630 nm followed by acidification and re-measurement at 663 and 750 nm. This procedure was in accordance with methods 1002G-1 and 1002G-3 in Standard Methods. All laboratory processing was conducted under reduced light and filters were kept frozen between filtration and acetone extraction of the pigments whenever time delays were encountered.

Total and volatile suspended solids or residue were measured by filtering 500 ml water samples through Reeve Angel 934-AH glass fiber filters followed by drying of the filter at 103°C (total) and ignition at 550°C. Loss between 103°C and 550°C is defined as volatile suspended solids. This follows methods #208D and #208E in Standard Methods.

Iodide was analyzed by converting to iodate with bromine water and titrating the iodate iodometrically with phenylarsine oxide (PAO). Bromides plus iodides were measured together by converting to bromate and iodate with calcium hypochlorite and titrating iodometrically with PAO. Bromides were then obtained by difference. These procedures were taken from methods #302.1 and #345.1 in the EPA, Methods for Chemical Analysis of Water and Wastes, 1979.

3.2.3.2 Metals and Major Cation Analyses

All heavy metals in the water column and major cations in both the water column and pore waters were measured by atomic absorption spectrophotometry (AAS) using a Perkin-Elmer Model 403 atomic absorption spectrophotometer equipped with either a 3-slot burner or a HGA2100 graphite furnace and AS-1 autosampler and using procedures contained under Part 300 of Standard Methods. The major cations (sodium, potassium, calcium and magnesium) were determined by direct flame aspiration after appropriate dilution and treatment. Sodium (Na) required a 1:200 dilution followed by a 1:50 dilution. Potassium (K) required a 1:200 dilution followed by a 1:25 dilution. Calcium (Ca) and magnesium (Mg) both were diluted 1:200 volumetrically prior to analyses. Mercury (Hg) was analyzed on 100 ml aliquots using the cold method of AAS. Aluminum (Al) was measured in 100 ml samples by chelation with 8-hydroxyquinoline and extraction into methyl isobutyl ketone. The aluminum in the extract was then analyzed using the heated graphite furnace method of AAS. The remaining heavy metals, iron (Fe), cadmium (Cd), chromium (Cr), lead (Pb), nickel (Ni) and Zinc (Zn) were measured in 200 ml samples by chelation with ammonium pyrrolidine dithiocarbamate and extraction into methyl isobutyl ketone. The metals contained in the extract were then measured by direct aspiration into an air-acetylene flame. Standard curves were prepared by the method of standard additions using at least 3 different concentrations for each metal.

Pore waters used for both major cation and anion analyses were obtained by centrifugation of sediments for 20 minutes followed by membrane filtration (0.45μm) of the supernatant from the centrifugation process.

Heavy metal analyses were also performed on 1$\underline{N}$ HNO_3 extracts obtained from the sediments, Three grams (dry weight) of each sediment were placed into 250 ml wide-mouth, capped polypropylene centrifuge tubes. 50 mls of 1$\underline{N}$ HNO_3 were added and the tubes shaken for 2 hours. They were then centrifuged for 20 minutes and the supernatant transferred to polypropylene bottles for storage until analyses were performed. All metals were determined by direct flame aspiration. Working standards were prepared in 1$\underline{N}$ HNO_3 from Fisher Certified Atomic Absorption Standards. Deuterium background correction was used in all atomic absorption analyses where required.

3.2.3.3 Heavy Hydrocarbons in Sediments

Before extraction, each sample was thawed overnight in a refrigerator and then stirred thoroughly with a clean rod so that a representative sample aliquot could be obtained. The mixed sediment was transferred to a pre-combusted, pre-weighed ceramic thimble. The thimble and sediment sample were Soxhlet extracted with Burdick and Jackson nanograde methanol twice for 8 hours each to remove water. The methanol extracts were combined and extracted three times with nanograde hexane (Burdick and Jackson). The sediment samples were then further extracted with a 9:1 mixture of methylene chloride/methanol for 8 hours. After this last extraction, the hexane extracts and the methylene chloride/methanol extracts of each sample were combined. Elemental sulfur was removed from the combined extracts with activated copper wool by refluxing for 4 hours. Then the copper wool was removed and the solvents were filtered through a pre-combusted fiberglass filter with a pore size of 0.3 micrometer. The extracts were then evaporated to near dryness in a rotary evaporator and then transferred to 7 ml vials with teflon lined caps, dried and weighed.

The extracts were then fractioned into four fractions on 20 x 1 cm columns packed with Davidson 923 grade silica gel of activity 1 slurried with nanograde hexane. The extract was applied uniformly to the surface of the silica gel in benzene (.2ml) with a 100 microliter syringe. The first fraction was eluted with 100 ml nanograde hexane, the second with 100 ml 40% benzene in hexane, the third with 100 ml benzene and the fourth with methanol. The fractions were reduced in volume on a rotary evaporator to about 5 ml and then transferred to pre-combusted, pre-weighed vials with teflon lined caps. After evaporation the sample vials were weighed.

Blanks were run through this fractionation procedure and no weighable or chromatogramable residue was detected. Standard mixtures of alkanes, aromatics and methyl esters were also fractionated on silica gel as described above. Recovery of the standards was 98% and the alkanes were recovered in the hexane fraction and the aromatic hydrocarbons and methyl esters in the 40% benzene in hexane fraction.

The dried fractions were then diluted with 100 or 200 microliters of benzene and 1 microliter aliquot were gas chromatogrammed . Gas chromatography of three fractions (methanol fraction showed no resolved peaks) of each extract was accomplished with a Model 5830 Hewlett Packard gas chromatograph equipped with a flame ionization detector and a 30 meter glass SCOT Supelco 2100 (OV-101) capillary column. Program conditions were: injection port temperature 300°C, FID temperature 350°C, initial column temperature 80°C with a ten minute hold and them temperature programmed at a rate of 2.5°/ minute to 270°C with a 40 minute hold at the upper temperature. The injection port was glass lined and splitless injection was used. The gas chromatograph was standardized with a quantitative alkane standard containing alkanes from C-14 through C-32 and pristane and phytane. Standards and blanks were run daily. Sample retention times were compared to those of the standard mixture and also quantified by the Hewlett Packard 1885A GC terminal and recorder when matches were obtained. Quantitation of peaks that did not match were done manually with a separate computer. Kovats indices were calculated for each peak or compund. The "unresolved complex mixture" or hump was calculated by measuring the area by planimetry and converting the area to micrograms using the average response factor of all the alkanes occurring in the range of the UCM.

Mass spectrometry of the sample fractions from station 15 (nearest shore) and station D13 were analyzed separately on a Hewlett Packard 5980 GC-MS system coupled with a Hewlett Packard 5933 data system. Each fraction was chromatogrammed on capillary columns similar to those used for routine analysis. A splitless injection technique was used with an injector flush 50 seconds after injection. No splitter or carrier gas separator was used. The total column effluent was routed directly into the ion source of the mass spectrometer. Ionization was accomplished using 70 EV electrons. The mass spectrum was repetitively scanned from M/E 35 to 500 every 2 seconds.

3.3 Results

3.3.1 General Water Quality

The general water quality measurements included in the predisposal studies have included salinity (S^{o}/oo) by conductivity, temperature, dissolved oxygen, pH, total volatile suspended solids, oil and grease, the nutrients (nitrate, nitrite and ammonia nitrogen, silica, ortho and total phosphate phosphorus) and the plant pigments chlorophyll a and its degradation product pheophytin a. Since the results in their entirety are too voluminous (over 275 tables) for incorporation in this report, the data has been stored in the computer data bank described elsewhere in the overall report (Chapter 8) and is available from NOAA/EDIS in Washington. However, results of the monthly sampling program over a period of at least 12 months have indicated general water quality typical of that expected for these Gulf of Mexico coastal waters with a few exceptions (SEADOCK, 1973; Sackett and Brooks, 1978, Science Applications, Inc., 1978 and Brooks, 1979). Water quality in these waters exhibited considerably more variability than observed for the Gulf of Mexico in general (El-Sayed, et al., 1972).

Salinities have ranged from $16^{o}/oo$ to $37^{o}/oo$, temperatures 10.5°C to 31.5°C and pH from 7.0 to 8.7. Since salinity and temperature distribution in the area is covered in detail in Chapters 1 and 2, they will not be discussed here. Although pH values covered a wider range than expected for seawater, most values were in the range expected of 8.2 to 8.4. Lowest pH values were observed during the periods of high runoff and the highest value probably represents instrumental error. Total and volatile suspended solids ranged from <0.1 mg/l up to a high of 264 mg/l each with values mostly below 50 mg/l.

The plant pigment chlorophyll a ranged from <0.01 mg/m^3 up to 3.3 mg/m^3 with highest value observed in May 1979. Due to an analytical error, values prior to that date and including the anticipated spring bloom period are not available. However, it is interesting to note that the degradation product of chlorophyll a, pheophytin a, was generally highest in June 1979. During the year, pheophytin a ranged from <0.01 mg/m^3 to 7.5 mg/m^3. Although the highest single value was observed in January 1980, most elevated levels occurred during June and in the fall. June results correspond to the period of poor biological conditions discussed in Chapter 5 of this report covering benthic studies.

Dissolved oxygen (D.O.) distribution for the diffuser area (average of all diffuser stations) is shown in Figure 3-2 and for one of the control stations, #39, in Figure 3-3. These indicate typical seasonal oxygen distribution with highest values during the winter (up to 10.3 mg/l) and lowest in the summer bottom waters (down to 1.1 mg/l). Since the bottom water samples were collected within 1 meter of the bottom but not necessarily within the lowest 25 cm, lower D.O. levels may have existed at the sediment-water interface as discussed in Chapter 5. Values shown in Figures 3-2 and 3-3 do, however, indicate anoxic or near anoxic conditions over a broad area of the bottom during the summer of 1979. Although low D.O. levels (2 to 3 mg/l) had been encountered during the summer of 1973 SEADOCK studies within this vicinity (Fig. 3-4), they were observed at only a few stations and did not suggest that such a broad area might be affected. During the present studies oxygen was influenced by mixing processes in the area, being well mixed from fall to spring and stratified in the summer.

Nutrient results were generally within the ranges expected although periods of high and low values were not always anticipated. Total

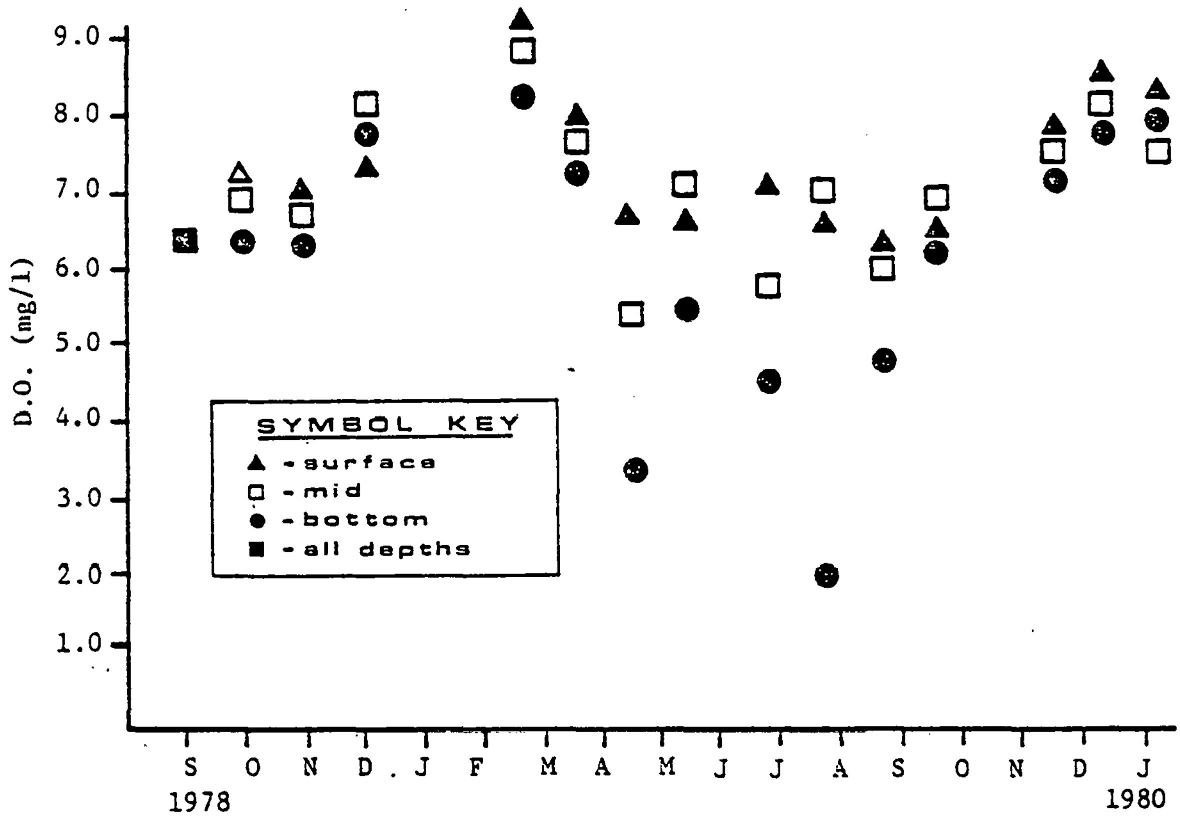

Figure 3-2. Dissolved oxygen at diffuser site.

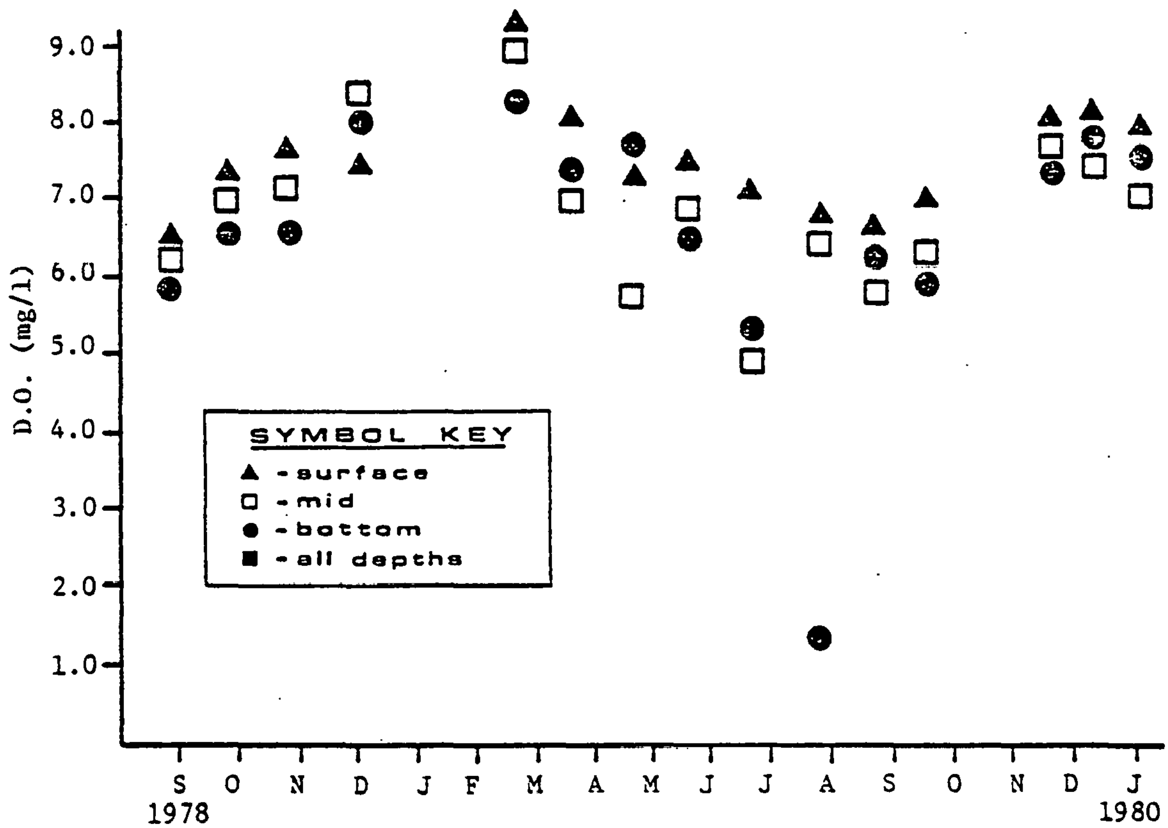

Figure 3-3. Dissolved oxygen at control station 39.

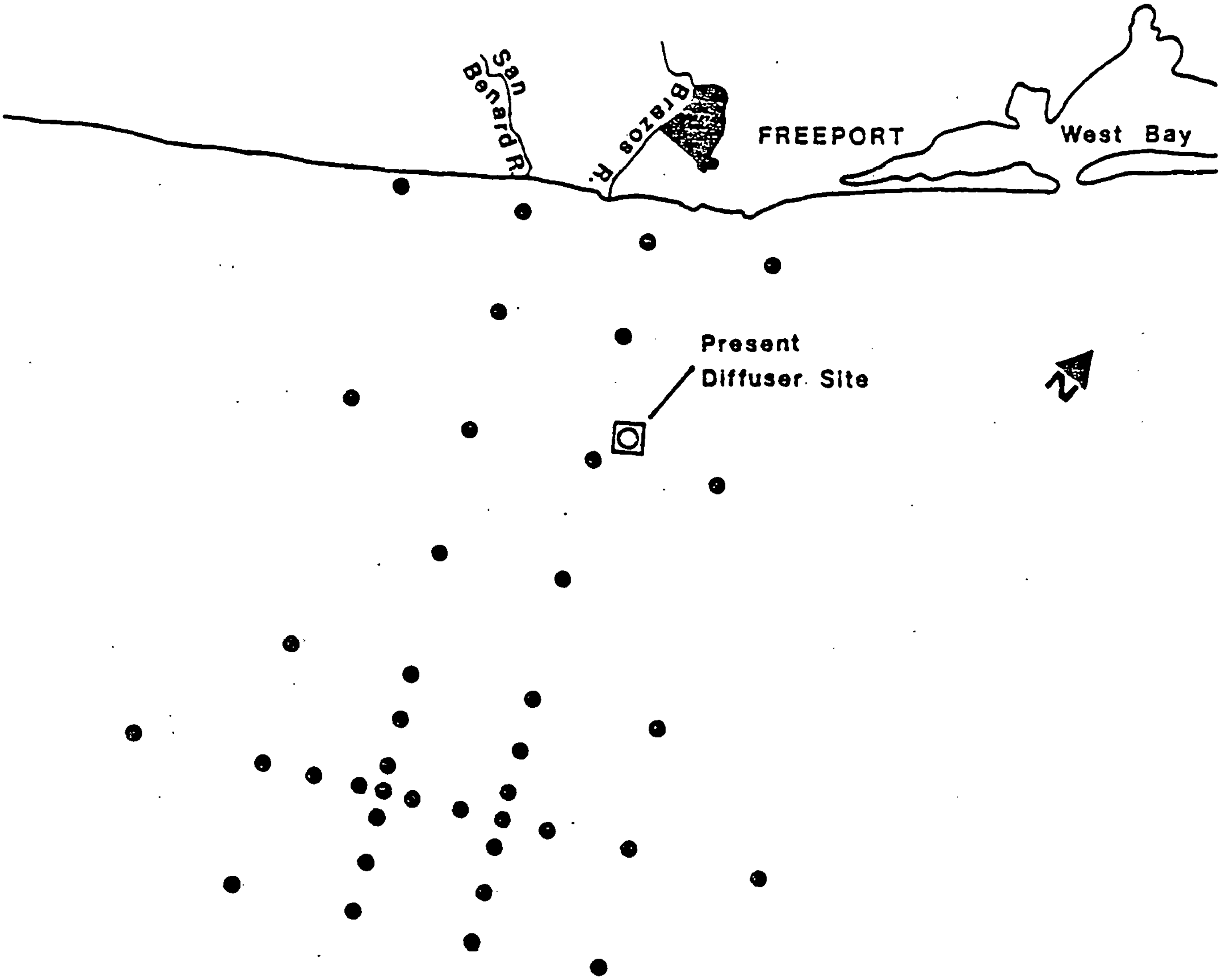

Figure 3-4. Offshore Sampling Station Locations (from SEADOCK, 1975).

phosphorus ranged from <10 μgP/1 up to 120 μgP/1. As indicated for the diffuser site in Figure 3-5 and control site in Figure 3-6, total phosphorus was usually below our detection limits of 10 μgP/1 with the highest values occurring in late April 1979 and during the winter months of 1979-1980. The April period corresponded to the period of high runoff both locally and from the Mississippi river and the winter months to periods of usual regeneration from organic matter. Sackett and Brooks (1978) in studies of the South Texas outer continental shelf also observed highest phosphorus levels during the winter. Their values during 1977 ranged from <1μgP/1 to 152μgP/1. Brooks (1979) in studies for the Texoma and Capline site of the Strategic Petroleum Reserve reported mixed results with highest phosphorus occurring in the winter at one site and in the summer at the other. His levels were from 12 μgP/1 up to 127 μgP/1. Both studies reported phosphorus levels were usually just below or slightly above 10 μgP/1 and both attributed the higher winter values observed in the bottom waters to regeneration from organic matter degradation.

Silica values shown in Figure 3-7 and 3-8 indicate considerably more variation than observed for phosphorus. Levels during the year were from <0.05 mg SiO_2/1 up to 4.2 mg SiO_2/1 (3.5 mg/1 for station included in Figures). Brooks (1978) reported a range of from 0.02 to 3.77 mg SiO_2/1 and suggested silicates were also influenced by bacterial regeneration from organic matter. Data for the Bryan Mound site does not appear to be that conclusive.

Data for the most prevalent nitrogen forms, nitrate and ammonia are shown for the diffuser site and control station 39 in Figures 3-9 through 3-12. Nitrate levels were mostly below our detection limit of 10μg N/1 although values to 670 μg N/1 were observed during late April. Previous

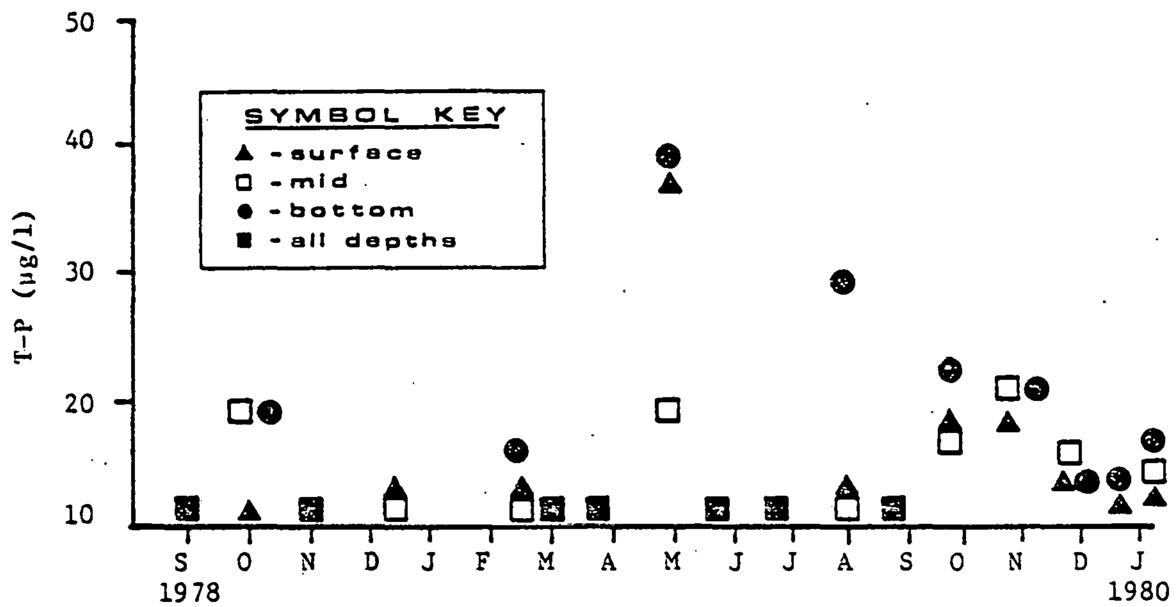

Figure 3-5. Total phosphorous at diffuser site.

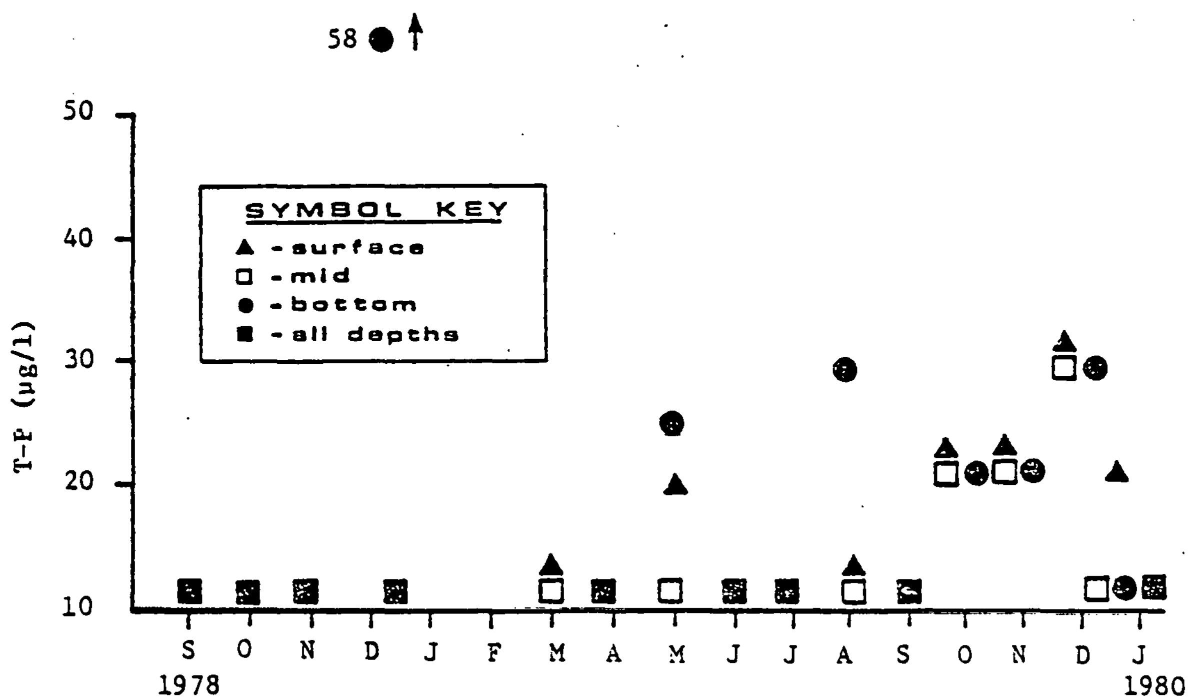

Figure 3-6. Total phosphorous at control station 39.

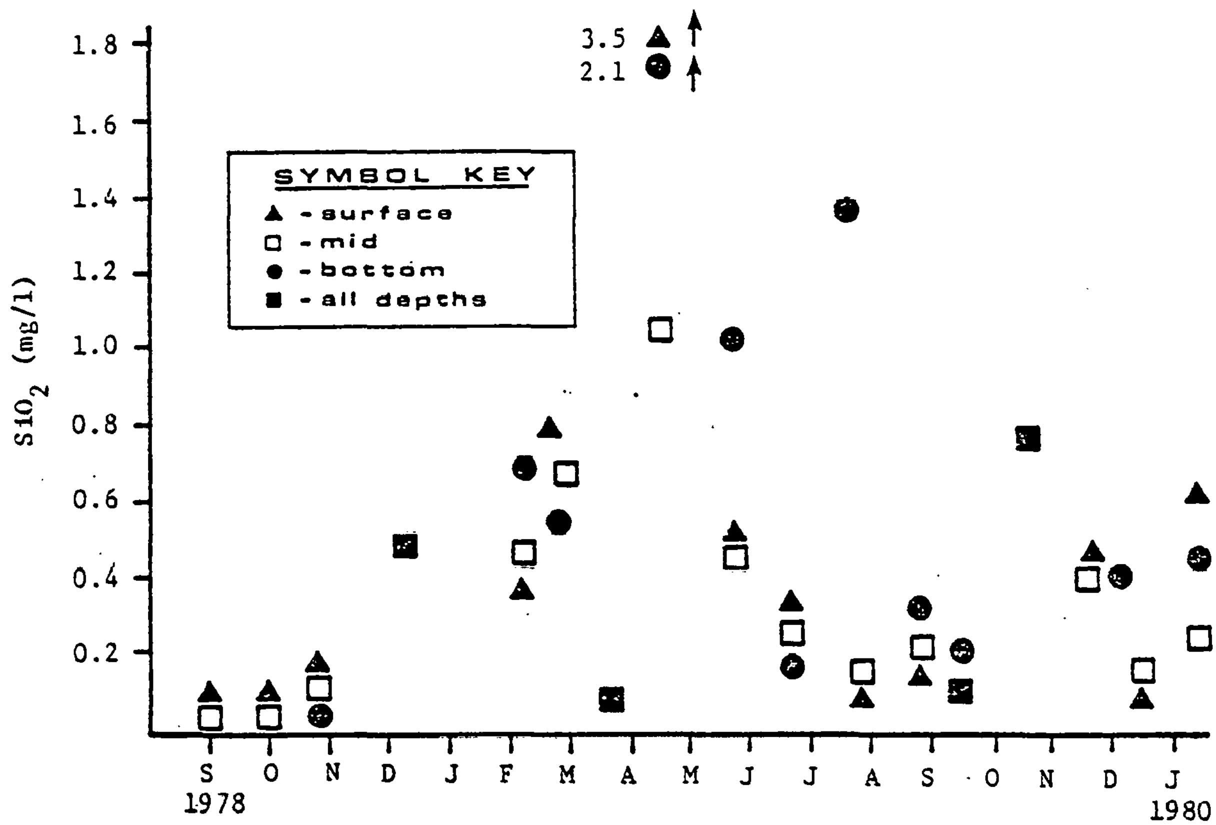

Figure 3-7. Silica at diffuser site.

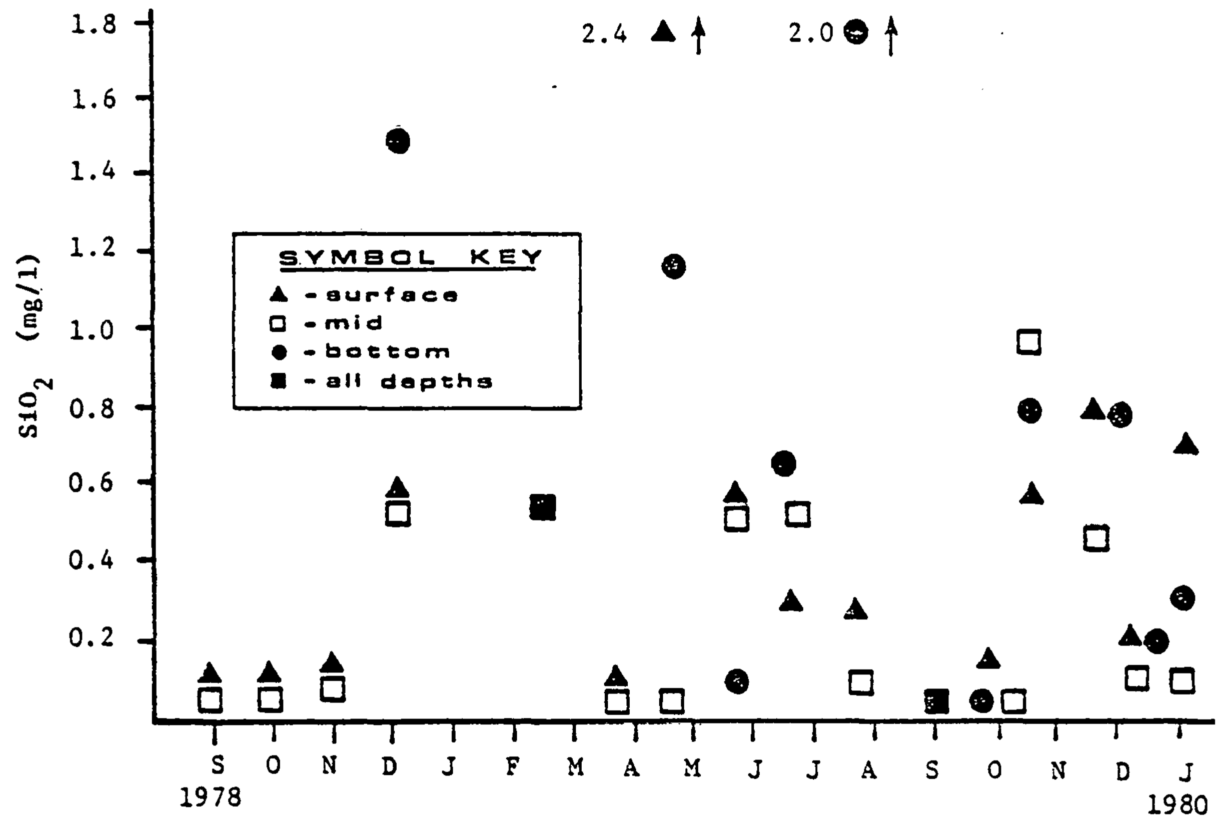

Figure 3-8. Silica at control station 39.

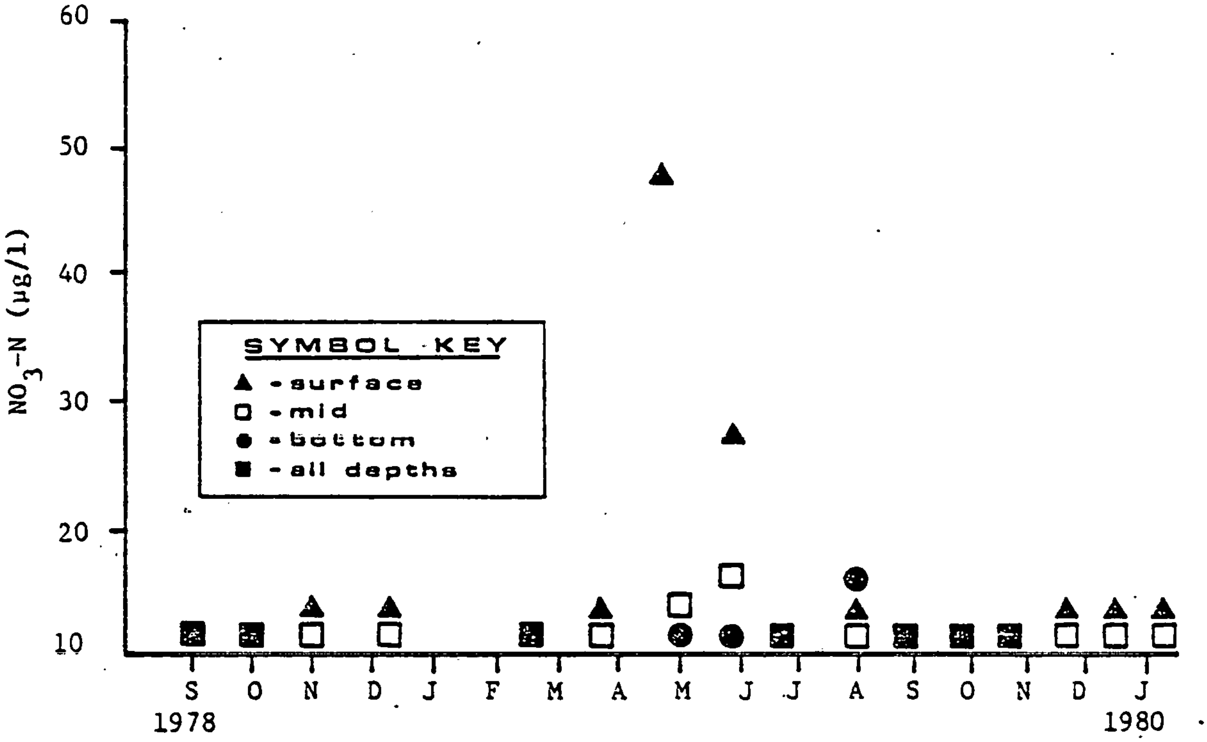

Figure 3-9. Nitrate nitrogen at diffuser site.

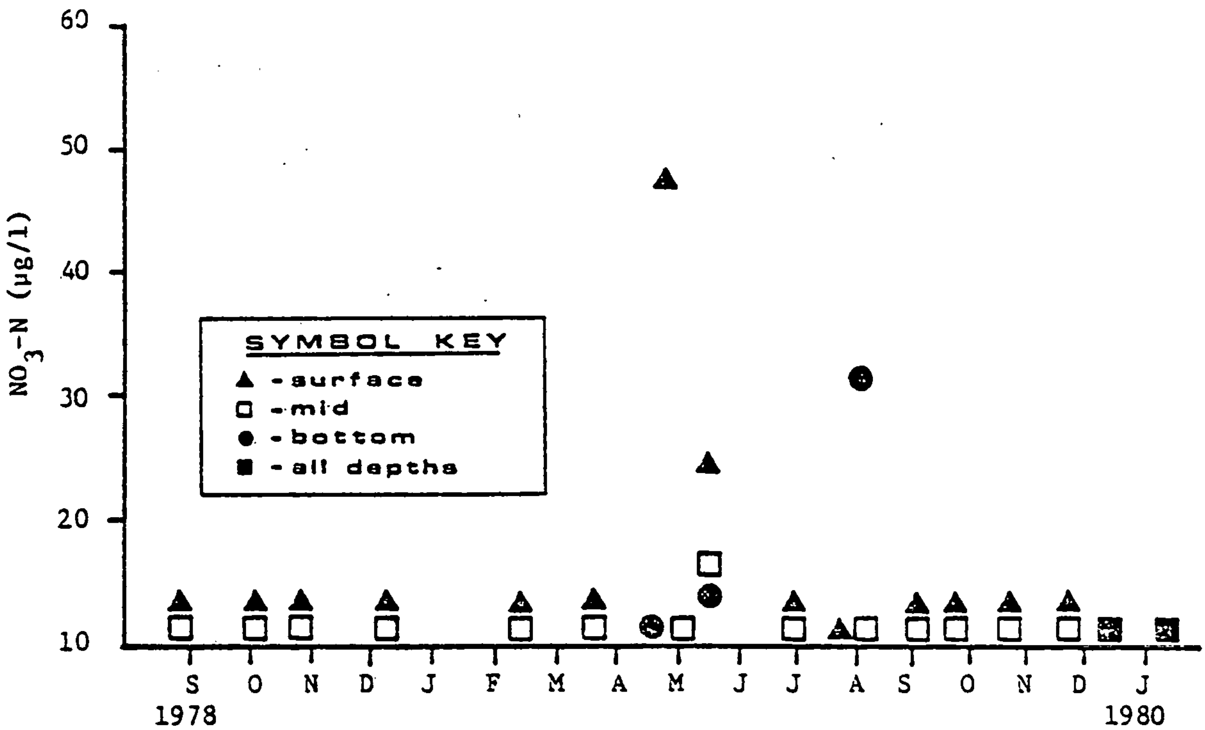

Figure 3-10. Nitrate nitrogen at control station 39.

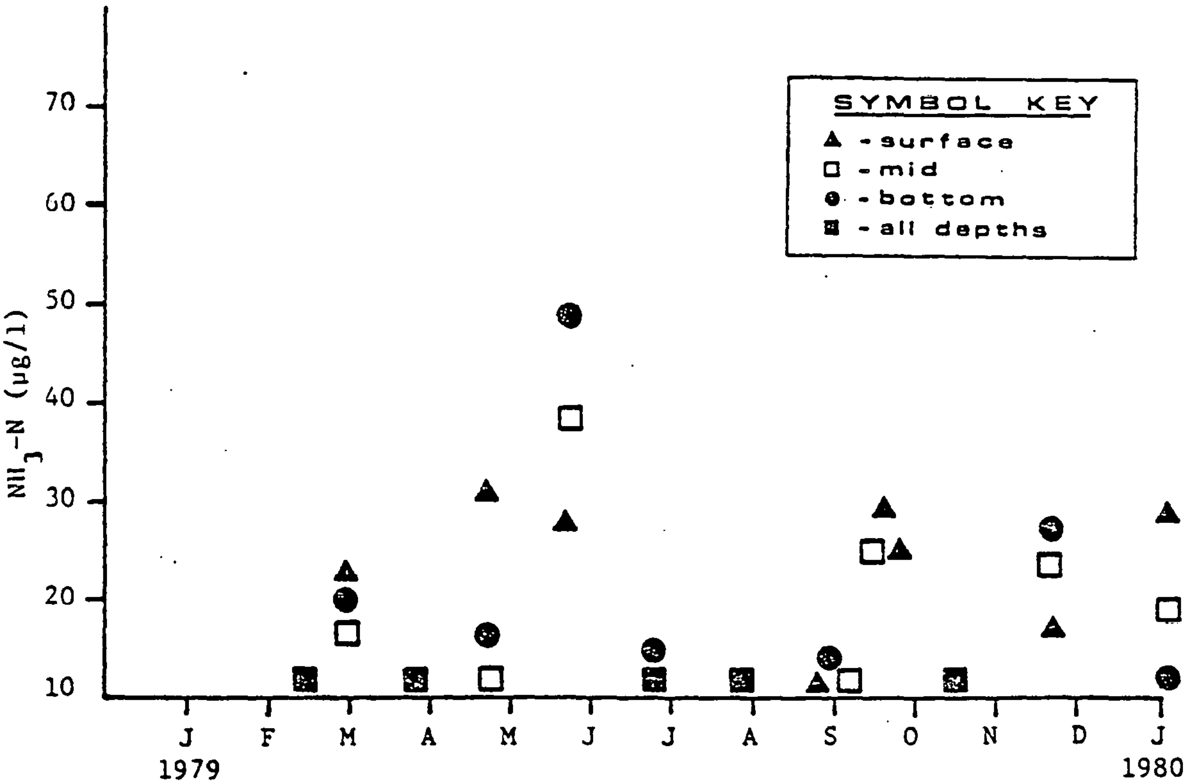

Figure 3-11. Ammonia nitrogen at diffuser site.

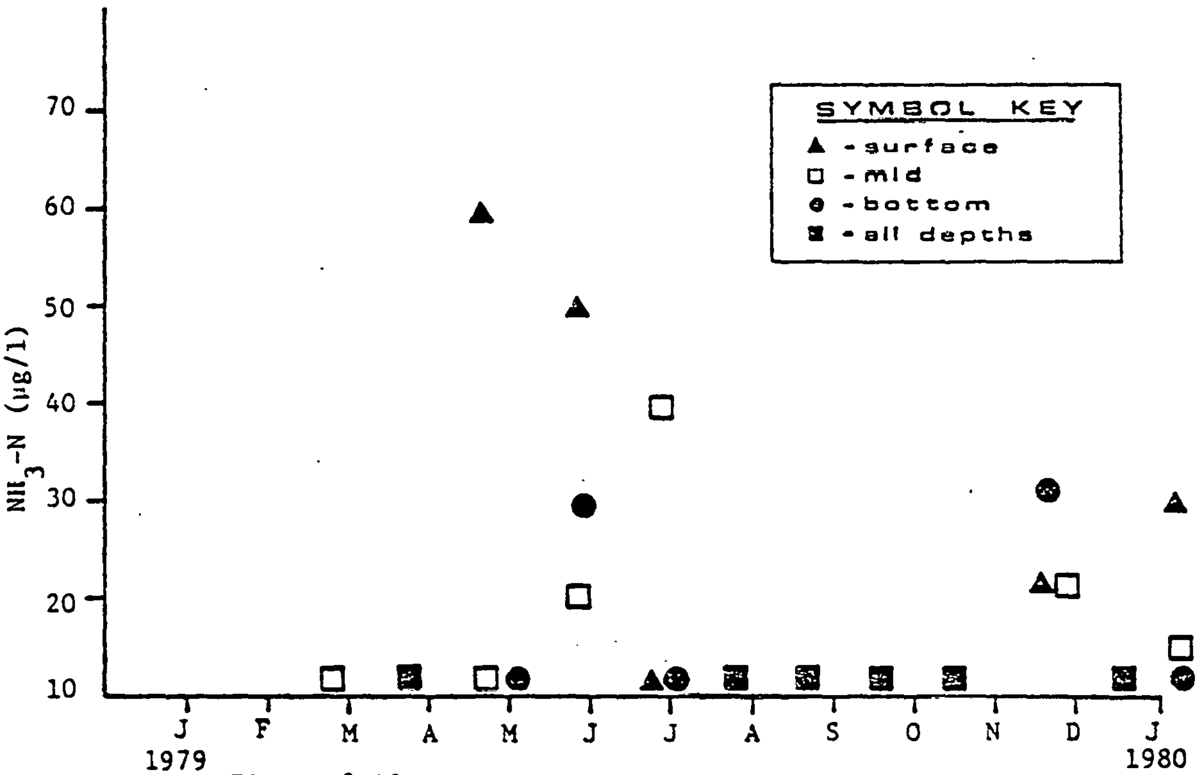

Figure 3-12. Ammonia nitrogen at control station 39.

SEADOCK data from 1973 had indicated highest values (mean values of 50 and 40 μg N/1) occurred during winter and fall and corresponded to periods of high local runoff. Brooks (1979) also reported extremely low nitrate levels off the Louisiana coast during 1978-1979. Levels were usually below his detection limit of 1.4 μg N/1 but values as high as 207 μg N/1 were observed during the spring of 1979. Results of these 2 studies appear to complement each other for nitrates for the period of fall 1978 through spring 1979 and suggest that, overall, nitrate nitrogen levels were exceedingly low and probably resulted in decreased fertility of the waters except during the spring. In other words, the fertility of the area might be nitrogen limited. Some question as to runoff's influence on nitrate levels was raised when 2 large floods occurred in the Galveston Bay area during the late summer 1979 but no nitrate increases in adjacent coastal water was observed. Ammonia levels for the period of the present study were also low (from $<$10μg N/1 to 100μg N/1) but, in general, were slightly higher than for nitrate with some indication of regeneration during the winter months. Results of this and other area related water quality studies are summarized in Table 3-2.

3.3.2 Major Ions and Trace Metals in Water Column

The concentration of major and several minor cations and anions (Na, K, Ca, Mg, SO_4, Br, I) at the Bryan Mound diffuser site and four control stations have been measured on a quarterly basis beginning in August 1979. Results for the August 30, 1979 samples are given in Table 3-3, November 30, 1979 samples in Table 3-4 and February 29, 1980 samples in Table 3-5. With the exception of iodide, all results are in good agreement with those expected for typical seawater especially since the so-called

Table 3-2. Range of general water quality values for Freeport, Texas and West Louisiana coastal waters.

Parameters	Present studies	SEADOCK(1973)[a]	West Louisiana Coast (1978-79)[b]
S^o/oo	16.1-36.9	15.1-33.6	--
T (^oC)	10.5-31.5	11.1-30.6	--
pH	7.2- 8.7	7.8- 8.4	--
D.O. (mg/l)	1.1-10.3	0.2-10.9	--
O&G (mg/l)	<0.5-23.4	<0.3-2.6	--
TSS (mg/l)	<0.1-264	5-85	--
NO_2-N (mg/l)	<0.01-0.04	<0.01-0.07	<0.001-0.013
NO_3-N (mg/l)	<0.01-0.67	<0.01-0.14	<0.001-0.15
NH_3-N (mg/l)	<0.01-0.10	<0.01-0.29	0.004-0.22
O-PO_4 (mg/l)	<0.01-0.01	--	0.01-0.13
T-P (mg/l)	<0.01-0.12	<0.1-0.74	--
SiO_2 (mg/l)	<0.05-4.2	--	0.17-2.4

a. SEADOCK, "SEADOCK, Environmental Report," Vol. II, Houston, Texas, 1975. (8 stations nearest present study area).

b. Brooks, J.M., Inorganic Nutrients at Proposed Brine Disposal Sites (Texoma and Capline Sectors) off Louisiana. Report to NMFS by Texas A&M University, College Station, Texas, 31 pp., 1979.

Table 3-3. Major ionic species in water column at Bryan Mound Disposal site and control sites

August 30, 1979

Sta. No.	Depth m	S^o_{oo}	Na g/l	K g/l	Ca g/l	Mg g/l	Cl g/l	SO_4 g/l	Br mg/l	I mg/l
D10	1.4	29.3	8.4	0.304	0.35	1.11	15.2	2.28	53.7	0.14
	9.1	30.0	8.4	0.294	0.36	1.14	15.6	2.28	53.7	0.16
	21.7	35.6	10.2	0.354	0.42	1.32	18.5	2.73	64.5	0.16
D11	1.2	29.5	8.0	0.304	0.36	1.14	16.1	2.23	50.7	0.20
	7.2	30.0	8.8	0.296	0.36	1.13	16.4	2.30	53.5	0.12
	21.5	35.7	10.5	0.364	0.43	1.36	19.6	2.65	64.1	0.15
D12	1.7	29.5	7.2	0.310	0.36	1.11	14.7	2.23	51.8	0.18
	8.7	30.1	8.4	0.308	0.36	1.09	16.4	2.50	53.7	0.17
	21.6	35.7	10.0	0.372	0.42	1.27	19.8	2.58	64.4	0.17
D13	1.5	29.5	8.1	0.312	0.35	1.07	16.1	2.23	51.6	0.18
	9.9	30.3	8.3	0.300	0.35	1.07	16.1	2.30	51.7	0.15
	21.5	35.8	9.4	0.372	0.42	1.26	19.7	2.70	64.3	0.18
D14	1.3	29.6	8.4	0.298	0.33	1.05	16.1	2.28	52.1	0.06
	7.5	30.0	8.6	0.296	0.36	1.09	15.2	2.30	55.5	0.16
	21.5	35.7	9.5	0.356	0.41	1.21	18.3	2.73	67.2	0.18
D15	1.4	29.4	8.4	0.296	0.35	1.09	16.3	2.15	54.2	0.15
	8.9	30.4	8.3	0.298	0.36	1.11	16.2	2.15	53.8	0.16
	21.4	35.7	10.0	0.354	0.41	1.28	19.8	2.70	64.0	0.14
D16	1.5	29.6	8.4	0.296	0.34	1.03	16.0	2.23	51.6	0.15
	7.9	30.1	8.6	0.304	0.36	1.09	15.4	2.20	53.5	0.20
	20.1	35.5	9.2	0.350	0.41	1.28	19.5	2.55	63.5	0.17
D17	1.2	29.5	9.2	0.312	0.36	1.07	16.3	2.25	50.6	0.17
	9.1	30.2	9.3	0.322	0.36	1.09	15.6	2.23	54.6	0.15
	21.3	35.7	8.8	0.352	0.36	1.14	16.5	2.30	60.8	0.14
D18	1.4	29.4	8.2	0.314	0.35	1.07	15.9	2.15	53.6	0.20
	8.0	30.2	9.4	0.310	0.36	1.07	16.2	2.23	53.8	0.20
	18.3	34.7	10.3	0.348	0.38	1.14	18.2	2.43	60.1	0.15
15	1.8	29.2	9.4	0.308	0.34	1.02	15.0	2.00	50.5	0.15
	8.8	29.3	8.4	0.308	0.35	1.00	15.9	2.23	51.7	0.16
	18.8	29.8	7.8	0.352	0.33	1.10	16.2	2.18	53.1	0.10
33	1.2	29.6	10.5	0.310	0.35	1.19	15.3	2.18	52.5	0.16
	9.0	30.2	7.8	0.352	0.36	1.16	17.2	2.23	54.0	0.18
	21.3	35.4	10.2	0.374	0.40	1.25	19.2	2.58	63.5	0.21

Table 3-3. Major ionic species in water column at Bryan Mound Disposal site and control sites (cont'd.)

August 1979

Sta. No.	Depth m	S^{o}_{oo}	Na g/l	K g/l	Ca g/l	Mg g/l	Cl g/l	SO_4 g/l	Br mg/l	I mg/l
36	1.1	29.8	8.4	0.314	0.36	1.14	16.1	2.28	53.8	0.19
	10.1	29.9	10.0	0.322	0.36	1.07	15.7	2.23	53.8	0.20
	21.1	35.7	9.9	0.366	0.42	1.28	17.9	2.58	63.3	0.19
39	1.3	28.8	8.0	0.302	0.34	1.16	15.6	2.23	50.6	0.20
	8.3	29.0	9.2	0.312	0.33	1.16	15.6	2.23	51.7	0.18
	18.7	30.5	8.3	0.322	0.36	1.04	16.0	2.30	54.0	0.13

Table 3-4. Major ionic species in water column at Bryan Mound Disposal site and control sites

November 30, 1979

Sta. No.	Depth m	S °/oo	Na g/l	K g/l	Ca g/l	Mg g/l	Cl g/l	SO_4 g/l	Br mg/l	I mg/l
D10	1.0	31.9	8.5	0.328	0.40	1.44	16.8	2.32	57.5	0.16
	10.2	31.7	8.2	0.336	0.38	1.22	18.9	2.52	58.5	0.17
	20.6	33.0	8.2	0.357	0.42	1.20	17.4	2.58	59.6	0.19
D11	2.4	32.0	8.7	0.338	0.39	1.28	17.6	2.50	59.5	0.17
	8.8	31.9	8.5	0.344	0.41	1.36	17.1	2.52	62.0	0.19
	20.5	33.0	8.7	0.376	0.38	1.36	17.1	2.52	58.8	0.20
D12	0.4	31.8	8.2	0.359	0.38	1.31	16.7	2.40	58.8	0.21
	9.6	31.8	8.7	0.332	0.38	1.31	16.5	2.40	56.2	0.19
	18.9	32.9	8.7	0.364	0.42	1.35	17.3	2.52	57.4	0.12
D13	1.0	31.8	8.2	0.336	0.38	1.31	17.0	2.40	57.5	0.19
	8.6	31.9	8.7	0.332	0.38	1.30	16.7	2.48	58.2	0.13
	15.1	32.9	8.5	0.356	0.40	1.34	17.5	2.52	57.8	0.17
D14	1.8	31.8	8.5	0.375	0.38	1.45	16.7	2.40	57.8	0.15
	9.2	31.9	8.5	0.328	0.38	1.30	17.1	2.48	58.0	0.18
	18.7	33.0	8.2	0.344	0.40	1.33	18.5	2.55	62.0	0.15
D15	1.1	31.7	8.7	0.344	0.38	1.36	17.0	2.40	57.4	0.25
	8.1	31.7	8.8	0.344	0.38	1.29	17.7	2.35	57.2	0.24
	20.0	32.9	9.2	0.368	0.40	1.34	16.6	2.58	60.3	0.21
D16	1.2	31.8	8.5	0.364	0.40	1.30	17.2	2.48	56.7	0.17
	9.5	32.5	8.7	0.336	0.38	1.31	17.8	2.45	58.5	0.27
	19.4	33.0	8.7	0.344	0.39	1.35	18.2	2.58	59.2	0.16
D17	1.0	31.8	8.7	0.340	0.38	1.31	17.9	2.40	60.4	0.25
	9.8	31.9	8.5	0.344	0.40	1.34	17.1	2.45	58.8	0.20
	18.5	32.9	8.5	0.344	0.40	1.31	18.2	2.58	63.3	0.23
D18	1.0	31.5	9.7	0.359	0.42	1.34	17.9	2.08	56.9	0.18
	10.2	31.6	9.5	0.336	0.40	1.34	17.8	2.40	59.5	0.21
	20.1	32.7	7.7	0.336	0.38	1.29	16.8	2.52	62.2	0.22
15	1.2	31.1	9.2	0.358	0.38	1.31	17.4	2.48	58.9	0.26
	9.0	31.1	9.2	0.359	0.39	1.29	16.6	2.60	58.7	0.20
	16.1	31.3	9.2	0.359	0.41	1.29	17.9	2.42	59.5	0.22
33	1.2	32.1	9.2	0.376	0.42	1.30	17.0	2.48	59.1	0.23
	9.0	33.3	9.6	0.359	0.40	1.31	17.4	2.28	59.2	0.16
	19.9	33.3	9.7	0.364	0.42	1.34	18.7	2.58	63.2	0.16

Table 3-4. Major ionic species in water column at Bryan Mound Disposal site and control sites (cont'd.)

November 30, 1979

Sta. No.	Depth m	S^o_{oo}	Na g/l	K g/l	Ca g/l	Mg g/l	Cl g/l	SO_4 g/l	Br mg/l	I mg/l
36	1.1	32.5	9.2	0.375	0.39	1.34	18.5	2.58	61.3	0.21
	8.5	32.6	9.0	0.357	0.38	1.35	18.1	2.48	59.8	0.23
	20.6	33.4	9.0	0.364	0.39	1.41	19.1	2.58	62.5	0.22
39	0.8	31.2	9.2	0.348	0.38	1.29	17.4	2.40	58.4	0.21
	8.5	31.4	8.7	0.359	0.38	1.30	17.7	2.45	60.3	0.22
	19.2	32.7	9.2	0.364	0.37	1.31	17.8	2.60	59.5	0.18

Table 3-5. Major ionic species in water column at Bryan Mound Disposal site and control sites

February 29, 1980

Sta. No.	Depth m	S^o/oo	Na g/l	K g/l	Ca g/l	Mg g/l	Cl g/l	SO_4 g/l	Br mg/l	I mg/l
D10	0.5	29.8	7.8	0.321	0.35	0.96	16.8	2.30	54.3	0.22
	9.2	32.3	9.0	0.347	0.37	1.10	17.9	2.40	60.2	0.21
	18.8	34.2	9.6	0.374	0.39	1.17	18.6	2.20	62.8	0.19
D11	0.7	29.9	7.6	0.326	0.34	1.01	16.0	2.25	-	-
	9.5	32.2	8.4	0.358	0.37	1.22	18.4	2.40	60.1	0.13
	18.8	33.9	10.5	0.379	0.38	1.19	18.6	2.45	64.5	0.19
D12	0.5	29.6	9.4	0.329	0.35	1.03	16.0	2.25	51.9	0.21
	8.7	32.3	9.0	0.353	0.33	1.14	17.4	2.35	60.4	0.21
	18.6	32.9	9.0	0.384	0.39	1.17	18.9	2.60	64.5	0.19
D13	0.8	30.4	7.4	0.337	0.36	1.03	15.4	2.25	55.0	0.21
	9.6	32.3	7.8	0.347	0.39	1.14	19.0	2.45	56.4	0.21
	18.3	34.2	7.6	0.374	0.40	1.22	18.9	2.40	65.1	0.17
D14	0.9	29.9	7.8	0.332	0.36	1.07	16.6	2.40	58.0	0.24
	9.3	32.6	10.1	0.353	0.38	1.12	17.5	2.45	60.6	0.27
	18.3	33.8	9.2	0.368	0.39	1.17	18.6	2.60	-	0.21
D15	0.5	30.4	9.4	0.332	0.36	1.04	16.2	2.35	55.8	0.21
	9.2	32.4	9.4	0.358	0.38	1.17	17.9	2.60	59.2	0.21
	18.5	34.0	8.7	0.363	0.39	1.22	19.0	2.90	61.0	0.19
D16	0.8	30.2	7.8	0.314	0.34	1.10	16.2	2.20	56.5	0.19
	9.2	32.2	7.8	0.329	0.36	1.14	17.9	2.45	60.7	0.16
	18.3	34.4	9.0	0.344	0.36	1.17	18.6	2.55	63.7	0.21
D17	0.9	30.1	8.3	0.304	0.34	1.03	17.0	2.55	53.7	0.21
	9.3	32.4	9.0	0.329	0.35	1.14	17.6	2.40	59.2	0.17
	18.5	33.9	8.7	0.349	0.38	1.22	18.9	2.45	62.8	0.19
D18	0.9	30.5	7.8	0.353	0.34	1.07	16.5	2.75	54.2	0.19
	9.0	32.6	9.0	0.412	0.37	1.17	18.9	2.50	64.0	0.19
	18.9	34.0	8.8	0.344	0.36	1.17	18.6	2.75	60.0	0.21
D19	1.0	31.2	7.8	0.305	0.33	1.03	16.5	2.35	58.8	0.19
	9.0	32.3	9.0	0.347	0.36	1.14	16.7	2.55	62.8	0.24
	18.9	34.2	8.7	0.358	0.37	1.17	18.7	2.55	64.5	0.21
D20	0.5	30.1	8.1	0.334	0.33	1.07	15.7	2.35	54.9	0.17
	10.0	32.6	8.4	0.347	0.35	1.10	17.8	2.50	59.3	0.21
	18.5	33.6	9.1	0.379	0.36	1.17	18.6	2.85	62.5	0.16

Table 3-5. Major ionic species in water column at Bryan Mound Disposal site and control sites (cont'd.)

February 29, 1980

Sta. No.	Depth m	S^o/oo	Na g/l	K g/l	Ca g/l	Mg g/l	Cl g/l	SO_4 g/l	Br mg/l	I mg/l
D21	0.7	30.9	8.4	0.304	0.33	1.07	16.4	2.25	55.4	0.22
	9.5	32.5	8.7	0.341	0.36	1.14	17.8	2.45	59.9	0.17
	19.3	33.9	8.4	0.331	0.36	1.17	18.8	2.55	63.0	0.32
15	0.5	29.6	7.8	0.340	0.34	1.03	15.8	2.30	53.5	0.22
	9.0	31.2	8.7	0.369	0.35	1.14	—	2.40	61.0	0.21
	18.0	33.0	7.4	0.338	0.34	1.03	18.9	2.15	55.2	0.21
33	0.9	28.8	7.1	0.320	0.32	1.07	16.1	2.15	55.2	0.17
	9.5	31.0	7.9	0.338	0.35	1.07	17.2	2.15	60.0	0.19
	18.9	33.8	8.5	0.357	0.36	1.07	19.1	2.40	63.7	0.21
36	0.7	30.9	9.5	0.313	0.34	1.07	16.8	2.10	57.7	0.19
	9.5	33.2	8.2	0.340	0.36	1.17	18.9	2.45	62.3	0.21
	18.9	34.5	8.2	0.340	0.37	1.19	19.5	2.45	62.8	0.17
39	0.7	29.6	6.5	0.287	0.33	1.03	16.5	2.35	52.8	0.24
	9.5	32.8	6.8	0.313	0.34	1.07	16.8	2.95	56.3	0.22
	18.4	34.1	7.8	0.327	0.36	1.17	19.6	2.30	71.3	0.21

"constancy of composition" tends to become altered in coastal waters. Levels of these ions reported for typical seawater (Riley and Skirrow, 1965) are: Na = 10.5 g/l. K = 0.38 g/l, Ca = 0.40 g/l, Mg = 1.35 g/l, Cl = 19.0 g/l, Br = 65 mg/l and I = 0.06 mg/l. The reason for the discrepancy in expected and measured iodide values is not known. Whether the measured values are real or result from some as yet undetected analytical error has not been established. Although analyses of spiked seawater samples and other known samples have produced accurate results using this method (EPA, 1979), we are continuing our investigation of this matter.

The principal reason for establishing the levels of these major ions is that the ratio of the ions is considerably different between seawater and brines. The ratios for typical seawater are: Na/K=27.6, Ca/Mg=0.30, SO_4/Cl=0.143 and Br/I=1083. Major cation ratios for the Bryan Mound diffuser area are given in Table 3-6 and major anion ratios in Table 3-7. Based upon preliminary analysis of Bryan Mound brine (James, 1977), the brine ratios were expected to be Na/K=397, Ca/Mg=80 and SO_4/Cl=0.010. Our preliminary results for present Bryan Mound brine indicate the ratios to be Na/K=146, Ca/Mg=1.2, SO_4/Cl=0.024 and Br/I=27. Obviously, considerable differences exist between the seawater and brine ion ratios and the potential exists for ionic imbalance in the diffuser area.

Distribution of soluble heavy metals in the diffuser area for October are presented in Table 3-8, for November in Table 3-9 and for February in Table 3-10. A number of these metals were below detection limits and the remainder are within levels expected for seawater. Copper levels ranged from 0.4 to 11.5 μg/l. Previously, a range of 0.4 to 4.9 μg/l

Table 3-6. Major cation ratios in water column near Bryan Mound diffuser

Sta. No.	Depth*	Calcium/Magnesium			Sodium/Potassium		
		August	November	February	August	November	February
D10	S	0.32	0.28	0.36	27.6	25.7	24.3
	M	0.32	0.31	0.34	28.6	24.3	25.9
	B	0.32	0.35	0.33	28.8	22.9	25.7
D11	S	0.32	0.30	0.34	26.3	25.7	23.3
	M	0.32	0.30	0.30	29.9	25.0	23.5
	B	0.32	0.28	0.32	28.8	24.0	27.7
D12	S	0.32	0.29	0.34	23.1	22.9	28.6
	M	0.33	0.29	0.29	27.3	26.5	25.5
	B	0.33	0.31	0.33	26.9	24.3	23.4
D13	S	0.33	0.29	0.35	25.9	24.3	22.0
	M	0.33	0.29	0.34	27.7	26.5	22.5
	B	0.33	0.30	0.33	25.4	23.6	20.3
D14	S	0.31	0.26	0.34	28.1	22.4	23.5
	M	0.33	0.29	0.33	28.9	25.8	28.6
	B	0.34	0.30	0.33	26.6	24.3	25.0
D15	S	0.32	0.28	0.34	28.4	25.7	28.3
	M	0.32	0.30	0.32	27.8	26.0	26.3
	B	0.32	0.30	0.32	28.2	24.9	24.0
D16	S	0.33	0.31	0.31	28.4	23.6	24.8
	M	0.33	0.29	0.32	28.3	25.7	23.7
	B	0.32	0.29	0.31	26.3	25.7	26.2
D17	S	0.34	0.29	0.33	29.6	25.7	27.3
	M	0.34	0.30	0.31	28.9	25.0	27.4
	B	0.32	0.28	0.31	25.1	25.0	24.9
D18	S	0.33	0.31	0.32	28.0	27.0	22.1
	M	0.34	0.30	0.32	30.4	27.8	21.8
	B	0.33	0.30	0.31	29.5	28.6	25.6
15	S	0.33	0.29	0.33	30.6	24.3	22.9
	M	0.35	0.30	0.31	27.2	25.6	23.6
	B	0.30	0.32	0.33	22.1	25.6	21.9
33	S	0.29	0.32	0.30	33.9	24.3	22.2
	M	0.31	0.30	0.33	22.3	26.7	23.4
	B	0.32	0.31	0.34	27.3	27.0	23.8

*S = surface, M = mid, B = bottom

Table 3-6. Major cation ratios in water column near Bryan Mound diffuser (cont'd.)

Sta. No.	Depth	Calcium/Magnesium			Sodium/Potassium		
		August	November	February	August	November	February
36	S	0.32	0.29	0.32	26.7	24.3	30.4
	M	0.34	0.28	0.31	31.1	25.0	24.1
	B	0.33	0.28	0.31	27.0	25.0	24.1
39	S	0.29	0.30	0.32	26.4	25.6	22.6
	M	0.28	0.29	0.31	29.5	24.3	21.7
	B	0.35	0.28	0.31	25.8	25.6	23.9

Table 3-7. Major anion ratios in water column near Bryan Mound diffuser

Sta. No.	Depth*	Sulfate/Chloride			Bromide/Iodide		
		August	November	February	August	November	February
D10	S	0.150	0.138	0.137	384	359	247
	M	0.146	0.133	0.134	336	344	287
	B	0.148	0.148	0.118	403	314	331
D11	S	0.139	0.142	0.141	254	350	---
	M	0.140	0.147	0.130	446	326	462
	B	0.135	0.147	0.132	426	294	339
D12	S	0.152	0.144	0.141	288	280	247
	M	0.152	0.145	0.135	316	296	288
	B	0.130	0.146	0.138	378	478	339
D13	S	0.139	0.141	0.146	287	303	262
	M	0.143	0.149	0.129	345	448	269
	B	0.137	0.144	0.127	357	340	383
D14	S	0.142	0.144	0.145	868	385	242
	M	0.151	0.145	0.140	347	327	224
	B	0.149	0.138	0.140	373	413	---
D15	S	0.132	0.141	0.145	361	230	266
	M	0.133	0.133	0.145	336	238	282
	B	0.136	0.155	0.153	457	287	321
D16	S	0.139	0.144	0.136	344	334	297
	M	0.143	0.138	0.137	336	217	379
	B	0.131	0.142	0.154	457	370	303
D17	S	0.138	0.134	0.150	298	242	256
	M	0.143	0.138	0.136	364	294	348
	B	0.139	0.142	0.130	434	275	331
D18	S	0.135	0.116	0.167	268	316	285
	M	0.138	0.135	0.132	269	283	337
	B	0.134	0.150	0.148	401	283	286
15	S	0.133	0.143	0.146	337	227	243
	M	0.140	0.157	----	323	294	290
	B	0.135	0.135	0.114	531	270	263
33	S	0.142	0.146	0.134	328	257	325
	M	0.130	0.131	0.125	300	370	316
	B	0.134	0.136	0.126	302	394	303
36	S	0.142	0.139	0.125	283	292	304
	M	0.142	0.143	0.130	269	260	297
	B	0.144	0.135	0.126	333	284	369
39	S	0.143	0.138	0.142	253	278	220
	M	0.143	0.138	0.157	287	274	256
	B	0.144	0.146	0.169	415	331	340

*S = surface, Mid = mid, B = bottom

Table 3-8. Soluble heavy metal distribution in waters around Bryan Mound diffuser and control sites

August 30, 1979

Sta. No.	Depth m	Al µg/l	Cd µg/l	Cr µg/l	Cu µg/l	Fe µg/l	Hg µg/l	Ni µg/l	Pb µg/l	Zn µg/l
D10	1.4	0.9	<0.5	<3	0.6	6	<0.2	<5	<2	7
	9.1	<0.4	<0.5	<3	0.6	10	<0.2	<5	<2	6
	21.7	0.6	<0.5	<3	0.6	14	<0.2	<5	<2	7
D11	1.2	0.5	<0.5	<3	0.8	10	<0.2	<5	<2	4
	7.2	0.5	<0.5	<3	0.8	10	<0.2	<5	<2	5
	21.5	0.5	<0.5	<3	0.8	26	<0.2	<5	<2	7
D12	1.7	1.2	<0.5	<3	0.8	6	<0.2	<5	<2	4
	8.7	0.8	<0.5	<3	1.0	10	<0.2	<5	<2	4
	21.6	0.5	<0.5	<3	0.6	6	<0.2	<5	<2	4
D13	1.5	<0.4	<0.5	<3	0.8	8	<0.2	<5	<2	7
	9.9	<0.4	<0.5	<3	0.6	8	<0.2	<5	<2	6
	21.5	0.6	<0.5	<3	0.4	24	<0.2	<5	<2	6
D14	1.3	0.5	<0.5	<3	2.5	7	<0.2	<5	<2	8
	7.5	---	<0.5	<3	1.8	12	<0.2	<5	<2	8
	21.5	0.5	<0.5	<3	1.2	34	<0.2	<5	<2	9
D15	1.4	<0.4	<0.5	<3	1.2	11	<0.2	<5	<2	9
	8.9	0.5	<0.5	<3	2.5	11	<0.2	<5	<2	7
	21.4	<0.4	<0.5	<3	1.8	30	<0.2	<5	<2	8
D16	1.5	<0.4	<0.5	<3	1.2	5	<0.2	<5	<2	6
	7.9	<0.4	<0.5	<3	1.5	9	<0.2	<5	<2	6
	20.1	<0.4	<0.5	<3	1.0	9	<0.2	<5	<2	7
D17	1.2	0.7	<0.5	<3	2.5	11	<0.2	<5	<2	7
	9.1	<0.4	<0.5	<3	1.8	12	<0.2	<5	<2	8
	21.3	0.6	<0.5	<3	1.6	10	<0.2	<5	<2	5
D18	1.4	0.7	<0.5	<3	0.9	6	<0.2	<5	<2	6
	8.0	0.5	<0.5	<3	0.4	5	<0.2	<5	<2	6
	18.3	0.7	<0.5	<3	1.2	11	<0.2	<5	<2	5
15	1.8	0.8	<0.5	<3	1.0	5	<0.2	<5	<2	11
	8.8	0.6	<0.5	<3	1.2	7	<0.2	<5	<2	10
	18.8	0.7	<0.5	<3	0.9	20	<0.2	<5	<2	9

Table 3-8. Soluble heavy metal distribution in water around Bryan Mound diffuser and control sites (cont'd)

August 30, 1979

Sta. No.	Depth m	Al µg/l	Cd µg/l	Cr µg/l	Cu µg/l	Fe µg/l	Hg µg/l	Ni µg/l	Pb µg/l	Zn µg/l
33	1.8	<0.4	<0.5	<3	0.9	5	<0.2	<5	<2	4
	9.0	<0.4	<0.5	<3	0.9	8	<0.2	<5	<2	4
	21.3	<0.4	<0.5	<3	0.9	83	<0.2	<5	<2	4
36	1.1	0.5	<0.5	<3	1.6	6	<0.2	<5	<2	5
	10.1	<0.4	<0.5	<3	0.6	4	<0.2	<5	<2	4
	21.1	0.5	<0.5	<3	0.4	6	<0.2	<5	<2	4
39	1.3	0.7	<0.5	<3	1.2	5	<0.2	<5	<2	3
	8.3	0.8	<0.5	<3	0.6	4	<0.2	<5	<2	4
	18.7	0.7	<0.5	<3	0.6	10	<0.2	<5	<2	4

Table 3-9. Soluble heavy metal distribution in waters around Bryan Mound diffuser and control sites

November 30, 1979

Sta. No.	Depth m	Al µg/l	Cd µg/l	Cr µg/l	Cu µg/l	Fe µg/l	Hg µg/l	Ni µg/l	Pb µg/l	Zn µg/l
D10	1.0	0.5	<0.5	<3	1.5	6	<0.2	<5	<2	5
	10.2	0.9	<0.5	<3	1.1	6	<0.2	<5	<2	3
	20.6	0.6	<0.5	<3	1.2	6	<0.2	<5	<2	6
D11	2.4	0.7	<0.5	<3	1.2	6	<0.2	<5	<2	4
	8.8	0.5	<0.5	<3	1.2	6	<0.2	<5	<2	5
	20.5	<0.4	<0.5	<3	0.9	5	<0.2	<5	<2	3
D12	0.4	0.5	<0.5	<3	0.9	5	<0.2	<5	<2	3
	9.6	0.7	<0.5	<3	0.9	6	<0.2	<5	<2	8
	18.9	<0.4	<0.5	<3	0.9	6	<0.2	<5	<2	4
D13	1.0	0.7	<0.5	<3	1.1	6	<0.2	<5	<2	5
	8.6	1.5	<0.5	<3	1.1	4	<0.2	<5	<2	3
	15.1	1.3	<0.5	<3	1.1	5	<0.2	<5	<2	4
D14	1.8	0.4	<0.5	<3	0.4	5	<0.2	<5	<2	4
	9.2	1.1	<0.5	<3	1.1	5	<0.2	<5	<2	7
	18.7	0.7	<0.5	<3	0.7	5	<0.2	<5	<2	4
D15	1.1	1.4	<0.5	<3	1.4	9	<0.2	<5	<2	6
	8.1	1.4	<0.5	<3	1.4	5	<0.2	<5	<2	16
	20.0	1.4	<0.5	<3	1.4	5	<0.2	<5	<2	5
D16	1.2	1.1	<0.5	<3	1.2	9	<0.2	<5	<2	3
	9.5	0.4	<0.5	<3	1.1	9	<0.2	<5	<2	5
	19.4	2.0	<0.5	<3	0.9	7	<0.2	<5	<2	4
D17	1.0	0.8	<0.5	<3	1.2	4	<0.2	<5	<2	4
	9.8	1.2	<0.5	<3	0.8	5	<0.2	<5	<2	13
	18.5	1.6	<0.5	<3	0.7	4	<0.2	<5	<2	5
D18	1.0	1.0	<0.5	<3	1.2	4	<0.2	<5	<2	7
	10.2	0.7	<0.5	<3	0.9	6	<0.2	<5	<2	19
	20.1	2.0	<0.5	<3	1.0	4	<0.2	<5	<2	6
15	1.2	0.7	<0.5	<3	0.9	5	<0.2	<5	<2	5
	9.0	0.7	<0.5	<3	1.4	7	<0.2	<5	<2	4
	16.1	1.0	<0.5	<3	0.7	4	<0.2	<5	<2	4

Table 3-9. Soluble heavy metal distribution in waters around Bryan Mound diffuser and control sites (cont'd)

November 30, 1979

Sta. No.	Depth m	Al µg/l	Cd µg/l	Cr µg/l	Cu µg/l	Fe µg/l	Hg µg/l	Ni µg/l	Pb µg/l	Zn µg/l
33	1.2	<0.4	<0.5	<3	1.5	5	<0.2	<5	<2	4
	9.0	<0.4	<0.5	<3	1.2	4	<0.2	<5	<2	4
	19.9	<0.4	<0.5	<3	0.7	4	<0.2	<5	<2	3
36	1.1	0.5	<0.5	<3	0.9	5	<0.2	<5	<2	4
	8.5	2.0	<0.5	<3	1.5	5	<0.2	<5	<2	4
	20.6	<0.4	<0.5	<3	3.0	6	<0.2	<5	<2	4
39	0.8	0.6	<0.5	<3	1.2	6	<0.2	<5	<2	5
	8.5	0.6	<0.5	<3	0.9	5	<0.2	<5	<2	3
	19.2	0.5	<0.5	<3	0.8	5	<0.2	<5	<2	3

Table 3-10 Soluble heavy metal distribution in waters around Bryan Mound diffuser and control sites

February 29, 1980

Sta. No.	Depth m	Al µg/l	Cd µg/l	Cr µg/l	Cu µg/l	Fe µg/l	Hg µg/l	Ni µg/l	Pb µg/l	Zn µg/l
D10	0.5	1.9	<0.5	<3	3.2	4	<0.2	<5	<2	6
	9.2	1.7	<0.5	<3	1.7	3	<0.2	<5	<2	1
	18.8	2.5	<0.5	<3	1.9	3	<0.2	<5	<2	4
D11	0.7	0.8	<0.5	<3	1.7	4	<0.2	<5	<2	2
	9.5	0.3	<0.5	<3	1.4	6	<0.2	<5	<2	4
	18.8	1.7	<0.5	<3	1.4	6	<0.2	<5	<2	4
D12	0.5	1.7	<0.5	<3	2.4	3	<0.2	<5	<2	3
	8.7	1.1	<0.5	<3	1.4	2	<0.2	<5	<2	2
	18.6	0.8	<0.5	<3	1.9	3	<0.2	<5	<2	5
D13	0.8	0.4	<0.5	<3	1.1	4	<0.2	<5	<2	1
	9.6	0.8	<0.5	<3	1.9	3	<0.2	<5	<2	3
	18.3	<0.3	<0.5	<3	0.8	3	<0.2	<5	<2	1
D14	0.9	0.3	<0.5	<3	3.2	3	<0.2	<5	<2	4
	9.3	3.0	<0.5	<3	1.7	3	<0.2	<5	<2	2
	18.3	1.4	<0.5	<3	3.2	3	<0.2	<5	<2	4
D15	0.5	<0.3	1.1	<3	1.7	4	<0.2	<5	<2	2
	9.2	1.7	<0.5	<3	1.3	2	<0.2	<5	<2	2
	18.5	3.6	<0.5	<3	1.5	8	<0.2	<5	<2	2
D16	0.8	1.7	2.4	<3	2.8	2	<0.2	<5	<2	3
	9.2	1.7	<0.5	<3	2.8	4	<0.2	<5	<2	5
	18.3	0.3	<0.5	<3	1.9	4	<0.2	<5	<2	6
D17	0.9	1.4	<0.5	<3	1.8	4	<0.2	<5	<2	2
	9.3	<0.3	<0.5	<3	2.3	7	<0.2	<5	<2	4
	18.5	1.9	<0.5	<3	2.3	4	<0.2	<5	<2	4
D18	0.9	0.8	<0.5	<3	2.3	3	<0.2	<5	<2	8
	9.0	2.8	<0.5	<3	11.6	3	<0.2	<5	<2	6
	18.9	1.9	<0.5	<3	1.9	3	<0.2	<5	<2	6
D19	1.9	0.8	<0.5	<3	1.6	2	<0.2	<5	<2	2
	9.0	1.9	<0.5	<3	1.0	3	<0.2	<5	<2	1
	18.9	1.7	<0.5	<3	6.9	3	<0.2	<5	<2	1
D20	0.5	1.1	<0.5	<3	1.8	5	<0.2	<5	<2	3
	10.0	1.1	<0.5	<3	1.4	2	<0.2	<5	<2	1
	18.5	1.1	<0.5	<3	1.1	9	<0.2	<5	<2	2

Table 3-10. Soluble heavy metal distribution in waters around Bryan Mound diffuser and control sites (continued)

February 29, 1980

Sta. No.	Depth m	Al µg/l	Cd µg/l	Cr µg/l	Cu µg/l	Fe µg/l	Hg µg/l	Ni µg/l	Pb µg/l	Zn µg/l
D21	0.7	0.3	<0.5	<3	1.4	3	<0.2	<5	<2	3
	9.5	<0.3	<0.5	<3	1.4	3	<0.2	<5	<2	1
	19.3	0.6	<0.5	<3	0.7	2	<0.2	<5	<2	2
15	0.5	<0.3	<0.5	<3	2.8	3	<0.2	<5	<2	6
	9.0	1.1	<0.5	<3	1.2	2	<0.2	<5	<2	4
	18.0	1.1	<0.5	<3	6.5	6	<0.2	<5	<2	2
33	0.9	1.1	<0.5	<3	2.4	3	<0.2	<5	<2	5
	9.5	1.7	<0.5	<3	3.2	5	<0.2	<5	<2	6
	18.9	1.1	<0.5	<3	1.3	1	<0.2	<5	<2	2
36	0.7	1.1	1.1	<3	2.4	3	<0.2	<5	<2	4
	9.5	2.8	<0.5	<3	2.3	4	<0.2	<5	<2	4
	18.9	1.4	<0.5	<3	0.8	1	<0.2	<5	<2	2
39	0.7	1.7	<0.5	<3	2.2	2	<0.2	<5	<2	5
	9.5	1.1	<0.5	<3	2.3	5	<0.2	<5	<2	6
	18.4	0.6	<0.5	<3	0.7	3	<0.2	<5	<2	3

for coastal Gulf of Mexico waters was reported (Slowey and Hood, 1971). Aluminum levels were <0.3 to 3.0 μg/l, below earlier accepted levels of 10μg/l (Riley and Skirrow, 1965) but well within the recent data range of 0.5 to 2.25 μg/l reported by Hydes (1979). Iron ranged from 1 to 83 μg/l with highest levels near the bottom during August. Since anoxic conditions as reported for the bottom waters in the summer of 1979 are known to release iron from sediments, the higher values were not unexpected although typical seawater levels are near 10 μg/l (Riley and Skirrow, 1965). Zinc ranged from 1 to 19 μg/l about the same as previously reported (Slowey and Hood, 1971).

3.3.3 Major Ions and Trace Metals in Sediment

Sediment samples were collected on August 30 and November 30 at stations shown in Figure 3-1. February 29, 1980 samples were collected at these stations plus three additional stations (see Table 3-1). Results of selected general sediment quality parameters (Eh, pH and oil and grease) are shown in Table 3-11. The only significant changes from earlier sediment analysis (Hann, et al., 1979) were a reduction in the redox potential (Eh) since April 1979. Whereas all samples tested in April had positive Eh, 5 samples in August and November, each, were negative. This reduction probably resulted from the anoxic benthic conditions that developed in the area between April and August. In addition, oil and grease levels at 3 of the control stations (#33, #36, and #39) increased considerably between August and November. This could have resulted from the BURMAH AGATE oil spill that occurred after the August sampling period. No other evidence for more permanent impact on the sediment or water column from this oil spill were found. By February 29, 1980, Eh values had risen until only one negative potential was found and oil and grease values had, in most cases, dropped from the previous two periods.

Table 3-11. Eh, pH and oil and grease for Bryan Mound and control site sediments in August and November, 1979 and February 1980.

Sta. No.	Eh mv			pH			oil and grease mg/kg		
	Aug. 30	Nov. 30	Feb. 29	Aug. 30	Nov. 30	Feb. 29	Aug. 30	Nov. 30	Feb. 29
D10	+6	+82	+92	7.0	7.4	7.1	45	52	94
D11	+108	---	+94	7.0	---	7.0	94	--	67
D12	-51	+52	+81	7.2	7.5	7.0	66	41	34
D13	-25	-8	+102	7.4	7.2	7.2	62	55	80
D14	+50	-48	-66	7.0	7.3	7.1	121	81	53
D15	-90	---	+79	7.0	---	7.1	63	--	46
D16	+20	-48	+111	7.2	7.2	7.3	57	46	23
D17	-37	-63	+72	7.0	7.2	7.2	43	45	39
D18	-14	---	+104	7.2	---	7.2	28	--	13
15	+12	+12	+87	6.9	7.3	7.4	149	139	50
33	+88	-28	+82	7.2	7.2	7.0	63	248	48
36	+19	+42	+122	7.2	7.3	7.0	19	298	<10
39	+26	-38	+123	7.3	7.2	7.0	77	321	14

Major ions were measured in the pore waters taken from August, November and February sediments and are presented in Tables 3-12, 3-13 and 3-14, respectively. These results indicate that the major ions in pore waters were similar in levels to the overlying bottom waters with possible exception of magnesium in the November pore water. Levels at that time were approximately 14% lower than in August. Also, most ions in the February sediment pore waters were about 10% higher than the overlying bottom waters at that time.

Heavy metal analyses of 1N HNO_3 leachate of the sediments are given in Tables 3-15, 3-16, and 3-17. These levels are similar to those reported for the area in April 1979 (Hann, et al., 1979) with the exception of lead whose level in April was lower than anticipated and probably was in error. Present levels are more in line with those reported for 1N HNO_3 leachate of similar sediments off Louisiana (Science Applications, Inc., 1978). Metal/iron ratios for these leachates are given in Table 3-18 and indicate the range of these ratios for the diffuser and control stations with time. Some of the changes in the area of the diffuser are as a result of deeper sediments being exposed between April and August during construction of the diffuser. Diffuser area stations in April were about 1,000 ft (305 m) from the actual diffuser.

3.3.4 Metals in Biota

Heavy metal analyses of biota collected on October 13, 1979 as part of our special background studies are tabulated in Table 3-19. Biota collected at one control station (#15 in Figure 3-1) and along the diffuser proper included *P. setiferus* (white shrimp), *P. aztecus* (brown shrimp), *M. undulatus* (Atlantic croaker), and mixed zooplankton (mostly copepods). *P. setiferus* was available only at station 15 and *P. aztecus* at the diffuser. Data in

Table 3-12. Total dissolved solids and major ionic species in sediment pore waters at Bryan Mound disposal site and control sites

August 30, 1979

Sta. No.	TDS g/l	Na g/l	K g/l	Ca g/l	Mg g/l	Cl g/l	SO_4 g/l
D10	38.2	10.0	0.37	0.39	1.27	18.6	2.42
D11	37.7	9.8	0.38	0.40	1.36	18.7	2.58
D12	36.0	9.4	0.34	0.41	1.27	17.5	2.50
D13	36.5	9.7	0.37	0.38	1.29	17.8	2.54
D14	36.2	10.1	0.34	0.40	1.26	17.8	2.58
D15	38.0	10.1	0.38	0.41	1.35	19.1	2.42
D16	38.4	10.4	0.40	0.41	1.43	19.6	2.62
D17	36.7	10.0	0.37	0.40	1.30	18.0	2.65
D18	32.9	9.4	0.33	0.38	1.26	17.2	2.42
15	33.3	8.6	0.30	0.37	1.21	15.9	2.28
33	37.0	10.3	0.34	0.39	1.34	18.4	2.57
36	35.0	9.0	0.35	0.34	1.21	16.9	2.42
39	36.2	10.0	0.37	0.40	1.30	18.1	2.58
Typical seawater	-	10.5	0.38	0.40	1.35	19.0	2.71
Overlying bottom water (8/30/79)	-	9.6	0.36	0.40	1.31	18.4	2.54

Table 3-13. Total dissolved solids and major ionic species in sediment pore waters at Bryan Mound Disposal site and control sites

November 30, 1979

Sta. No.	TDS g/l	Na g/l	K g/l	Ca g/l	Mg g/l	Cl g/l	SO_4 g/l
D10	36.8	14.5	0.35	0.42	1.23	18.4	2.50
D12	38.6	9.7	0.36	0.42	1.12	19.1	2.55
D13	37.6	9.7	0.31	0.41	1.10	18.6	2.65
D14	36.2	9.3	0.32	0.45	1.13	18.2	2.45
D16	36.8	10.0	0.35	0.39	1.08	18.3	2.50
D17	34.9	9.7	0.37	0.38	1.10	17.8	2.50
15	34.9	9.0	0.35	0.34	1.07	17.9	2.50
33	36.5	9.7	0.36	0.39	1.16	18.7	2.50
36	36.5	10.0	0.37	0.38	1.12	18.0	2.60
39	35.8	9.3	0.35	0.37	1.07	18.0	2.35
Typical seawater	-	10.5	0.38	0.40	1.35	19.0	2.71
Overlying bottom water (11/30/79)	-	8.8	0.36	0.40	1.41	17.8	2.55

Table 3-14. Total dissolved solids and major ionic species in sediment pore waters at Bryan Mound disposal site and control sites.

February 29, 1980

Sta. No.	TDS g/1	Na g/1	K g/1	Ca g/1	Mg g/1	Cl g/1	SO_4 g/1
D10	36.6	12.1	0.44	0.41	1.18	19.9	2.90
D11	35.9	11.3	0.44	0.42	1.22	19.0	2.70
D12	36.5	11.4	0.45	0.42	1.22	19.3	2.90
D13	35.7	11.6	0.43	0.42	1.27	19.9	2.95
D14	39.6	12.8	0.48	0.43	1.33	21.1	2.95
D15	37.2	11.4	0.48	0.42	1.30	20.1	2.70
D16	37.5	11.9	0.46	0.42	1.28	19.5	3.05
D17	38.2	11.9	0.47	0.42	1.20	19.7	2.70
D18	37.0	11.9	0.48	0.42	1.22	20.7	2.90
D19	38.5	12.8	0.44	0.43	1.24	19.7	2.90
D20	38.1	11.4	0.45	0.43	1.17	20.1	2.80
D21	38.0	11.4	0.45	0.42	1.30	20.5	2.95
15	35.1	11.3	0.40	0.41	1.22	19.7	2.42
33	37.2	11.4	0.43	0.43	1.35	19.7	2.70
36	40.2	12.6	0.45	0.43	1.32	20.6	2.80
39	38.4	12.1	0.42	0.42	1.34	17.5	2.65
Typical Seawater	-	10.5	0.38	0.40	1.35	19.0	2.71
Overlying bottom water (2/29/80)	-	8.7	0.36	0.37	1.17	18.9	2.51

Table 3-15. Heavy metal concentrations in leached (1N HNO_3) sediments from Bryan Mound diffuser and control sites (dry weight basis)

August 30, 1979

Sta. No.	Al mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Fe mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
D10	1050	0.02	1.8	2.8	2960	3.4	5.5	15.9
D11	785	0.02	1.6	1.5	2550	1.4	3.7	13.7
D12	880	0.02	2.0	2.1	3170	2.8	4.2	16.0
D13	605	0.02	1.2	1.3	2110	1.5	3.2	10.7
D14	395	0.02	0.9	1.0	2160	1.6	1.7	9.3
D15	405	0.02	0.9	1.0	1375	1.8	1.5	8.0
D16	600	0.02	1.4	1.7	2240	2.3	3.6	12.8
D17	1390	0.06	2.0	6.3	4230	5.7	6.1	19.0
D18	685	0.02	1.4	1.6	2290	2.0	3.7	11.4
15	2615	0.05	4.4	2.6	6415	5.1	10.0	25.4
33	995	0.04	1.8	2.0	3060	3.5	4.6	16.2
36	1215	0.03	3.2	3.4	3570	4.0	6.6	19.0
39	1025	0.03	3.0	2.4	3075	3.1	5.4	18.3

Table 3-16. Heavy metal concentrations in leached (1N HNO_3) sediments from Bryan Mound diffuser and control sites (dry weight basis)

November 30, 1979

Sta. No.	Al mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Fe mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
D10	980	0.01	2.3	3.6	2665	2.0	4.2	15.0
D12	675	0.01	2.0	3.0	2190	1.7	4.3	13.3
D13	640	0.01	1.6	1.6	2250	1.9	4.1	11.8
D14	1475	0.02	2.6	4.0	4205	3.0	6.9	17.8
D16	750	0.01	1.8	2.7	2640	2.2	4.2	12.9
D17	1405	0.03	3.3	3.0	3655	2.3	7.3	17.7
15	2270	0.03	4.2	5.2	5870	4.0	12.4	25.1
33	1065	0.02	2.5	2.2	3330	2.1	5.5	17.9
36	1030	0.01	2.9	2.1	3600	2.4	5.5	17.9
39	1330	0.02	3.6	3.6	4030	2.7	7.4	19.6

Table 3-17. Heavy metal concentrations in leached (1N HNO_3) sediments from Bryan Mound diffuser and control sites (dry weight basis)

February 29, 1980

Sta. No.	Al mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Fe mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
D10	795	0.01	1.7	2.0	2370	1.8	3.8	12.4
D11	815	0.02	1.8	1.8	2420	1.9	3.0	14.0
D12	530	0.01	1.0	1.8	1570	2.0	1.1	8.2
D13	630	0.01	1.2	0.9	1675	1.4	1.6	8.4
D14	520	0.01	0.7	0.8	1325	0.9	0.7	7.8
D15	1020	0.01	2.1	2.4	2650	3.0	2.8	13.6
D16	1040	0.03	2.0	2.8	2935	2.9	3.3	16.7
D17	745	0.01	1.5	2.7	2320	3.2	2.7	13.3
D18	795	0.01	2.5	2.4	2355	2.6	1.6	13.0
D19	1505	0.02	2.5	3.4	4020	6.4	5.5	19.3
D20	960	0.02	2.0	2.9	2875	3.2	3.9	15.8
D21	1235	0.02	2.9	3.6	3320	4.0	5.9	18.0
15	2690	0.04	4.9	5.3	5640	8.4	12.2	25.9
33	1225	0.02	3.1	3.3	3525	6.7	4.2	18.4
36	980	0.01	2.4	3.4	3170	4.8	4.0	17.7
39	1025	0.02	2.0	2.8	3350	6.1	3.6	18.5

Table 3-18. Comparison of metal to Fe ratios for 1N HNO_3 sediment leach for April, August and November, 1979 and February 1980.

Metal / Fe	April			August			November			February		
	A	B	C	A	B	C	A	B	C	A	B	C
Al	0.33	0.30	0.34	0.41	0.33	0.28	0.39	0.31	0.33	0.48	0.32	0.36
Cd (10^{-5})	0.66	0.61	0.49	0.78	1.04	0.94	0.51	0.46	0.50	0.71	0.50	0.61
Cr (10^{-3})	0.93	0.93	0.99	0.69	0.82	0.57	0.72	0.82	0.78	0.87	0.75	0.73
Cu (10^{-3})	1.31	1.03	1.07	0.41	0.79	0.76	0.89	0.71	1.04	0.94	0.95	0.90
Ni (10^{-3})	1.08	0.98	1.06	0.80	1.09	0.95	0.68	0.66	0.76	1.49	1.74	1.07
Pb (10^{-3})	0.27*	0.28*	0.34*	1.56	1.71	1.41	2.11	1.67	1.76	2.16	1.17	1.13
Zn (10^{-3})	4.8	5.9	6.1	4.0	5.5	5.0	4.3	5.1	5.1	4.6	5.4	5.4

A = nearshore control station (1)

B = offshore control stations (3)

C = diffuser site stations (9, except 6 for November)

* error suspected in April data but source has not been determined

Table 3-19. Heavy metal content of selected biota.

October 13, 1979
(dry weight basis)

Location or Station	Description (species)	Al mg/kg	Fe mg/kg	Cu mg/kg	Cr mg/kg	Cd mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
15	Croaker-filet (M. undulatus)	<0.9	12.5	1.8	<0.5	<0.06	0.071	<0.5	<0.2	15
15	Croaker-filet (M. undulatus)	<0.7	17.0	1.8	<0.5	<0.04	0.054	<0.5	<0.2	17
Diffuser	Croaker-filet (M. undulatus)	<0.7	18.6	2.0	<0.5	<0.05	0.059	<0.5	<0.2	17
Diffuser	Croaker-filet (M. undulatus)	<0.7	9.3	1.4	<0.5	<0.05	0.056	<0.5	<0.2	15
15	White Shrimp-flesh (P. setiferus)	7.0	15.3	32	<0.5	0.04	<0.02	<0.5	<0.2	59
15	White Shrimp-flesh (P. setiferus)	4.9	13.3	27	<0.5	0.04	<0.02	<0.5	<0.2	55
Diffuser	Brown Shrimp-flesh (P. aztecus)	0.9	5.3	24	<0.5	0.13	0.040	<0.5	<0.2	67
Diffuser	Brown Shrimp-flesh (p. aztecus)	0.5	4.3	23	<0.5	0.04	0.032	<0.5	<0.2	59
15	Zooplankton-whole (mixed, mostly copepods)	3.9	335	41	2.54	0.46	0.062	0.95	<0.2	70
Diffuser	Zooplankton-whole (mixed, mostly copepods)	2.8	73	9	0.67	0.53	0.049	0.92	<0.2	51

Table 3-19 (continued). Heavy metal content of selected biota.

October 13, 1979
(dry weight basis)

Location or Station	Description (species)	Al mg/kg	Fe mg/kg	Cu mg/kg	Cr mg/kg	Cd mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
Comparison Data*										
Louisiana	White Shrimp-flesh (P. setiferus)	6.5	6.5	24	<0.006	0.023	--	0.057	<0.007	57.5
		3.7	9.3	14	<0.005	0.049	--	0.034	0.041	54.4
		2.3	9.6	27	<0.005	0.052	--	0.085	0.011	35.2
Louisiana	Croaker-filet (M. undulatus)	3.9	19.7	2.0	0.008	0.020	--	0.04	0.22	22.3
		10.2	18.4	1.5	0.005	0.011	--	<0.03	<0.006	21.9
Louisiana	Zooplankton-whole (mixed)	745	607	16.7	0.56	2.3	--	3.2	0.32	119
		676	609	13.5	0.94	1.6	--	1.2	0.97	57

* West Hackberry site data (Science Applications, Inc., 1978)

Table 3-19 represents two tows in each area of 30 minute duration each. Comparison of data with that for similar organisms at the West Hackberry site (Science Applications, Inc., 1979) indicates good agreement with the exception of Al for the croaker and Al and Fe for the zooplankton. The higher Al and Fe reported for West Hackberry for the zooplankton results from the mixed nature of the samples. Incorporation of clay particles or diatoms (both known to be high in Al and Fe) could have led to the higher values reported for the West Hackberry site.

3.3.5 Hydrocarbons in Sediment

3.3.5.1 Concentrations of Heavy Hydrocarbons in Sediments

The hydrocarbon composition of sediments reflects a time average of hydrocarbons from marine, river and anthropogenic sources. The natural hydrocarbon composition of a given sediment is a function of grain size, mineral content, sedimentation rate and total organic carbon. Consequently, hydrocarbon concentrations may vary somewhat in a small area as a consequence of variation of the above factors.

Total hydrocarbon concentration data, determined by gas chromatography, along with other pertinent information, are shown in Table 3-20 for the sediments collected in August 1979, prior to the diffuser turn-on. The average total extract concentration for stations D13, D14 and D15 was 1.46 micrograms/gram dry sediment, which was about one third of the concentrations for Stations D10, D11 and D 12 (4.22 micrograms/gram) and for stations D16, D17 and D18 (4.29 micrograms/gram). The average for all diffuser site stations (D10-D18) was 3.32 micrograms/gram. The control station (39) had an extract concentration of 2.92 micrograms/gram. Concentrations for the remaining stations were somewhat higher and for station 15 nearshore,

Table 3-20. Sediment hydrocarbon data for the Bryan Mound site

August 30, 1979

Sta. No.	Mg/g in hexane fraction		Mg/g in 40% benzene in hexane fraction	Mg/g in benzene fraction	Total concen-tration (Mg/g)	Odd to even ratio
	resolved	UCM*				
D10	0.580	1.019	3.889	0.365	5.853	5.74
D11	1.345	1.154	0.858	0.029	3.386	3.46
D12	0.410	1.171	1.254	0.582	3.417	4.58
D13	0.302	0.396	0.589	0.081	1.368	3.50
D14	0.147	0.578	0.320	1.088	2.133	1.23
D15	0.087	0.551	0.146	0.086	0.870	11.00
D16	0.324	1.082	3.924	0.187	5.517	3.02
D16 (dupl)	0.385	0.603	1.524	0.519	3.031	7.29
D17	0.913	1.470	0.653	0.320	3.356	4.63
D18	0.198	0.395	2.186	0.691	4.010	2.23
33	0.994	1.658	6.130	0.648	9.430	5.20
33 (dupl)	0.881	1.374	3.898	0.377	6.530	4.52
36	0.626	1.492	2.973	0.278	5.369	5.70
39	0.915	1.352	0.352	0.204	2.823	4.73
15	2.405	4.285	37.434	1.332	45.456	3.75
15 (dupl)	3.860	3.378	32.099	3.555	42.892	4.90

* UCM = unresolved complex mixture

the extract concentrations were nearly 10 times that of the other station sediments. See Figure 3-1 for station locations and Figure 3-13 for total gas chromatography derived extract concentrations at the various locations. The concentrations of the total sediment extracts of the Bryan Mound area were somewhat lower than those reported from the West Hackberry and control sites (7.58 - 20.77 micrograms/gram).

The total extract concentrations do not necessarily reflect the total hydrocarbon concentrations, because after examination of the GC-mass spectrometry results, many of the compounds are methyl esters and other biologically derived compounds. The components of the hexane fraction, however, are hydrocarbons (normal and branched chain alkanes and alkenes). The gas chromatography (GC)-derived concentrations of the hexane fractions are shown in Figure 3-14 and tabulated in Table 3-20. The relative magnitudes of the hexane fraction concentration between stations parallel that of the total extract concentrations, in that the lowest concentrations are found in the middle row of diffuser stations (D13, D14 and D15) and the highest hexane fraction concentrations are the nearshore station (15). The average hexane fraction concentrations for the 9 stations on the diffuser site was only .40 micrograms/gram dry sediment. The control station (39) contained .92 micrograms/gram.

All the gas chromatograms of the hexane fractions of the sediments exhibited an "unresolved component mixture" (UCM) or humping. The calculated concentrations based on an average response factor for normal alkanes in the area of the UCM, were mostly greater than the resolved components but were sometimes nearly equal to the total resolved components concentration. See Table 3-20 for UCM concentrations. The sums of the resolved hydrocarbons and UCM of the hexane fractions ranged from 0.64

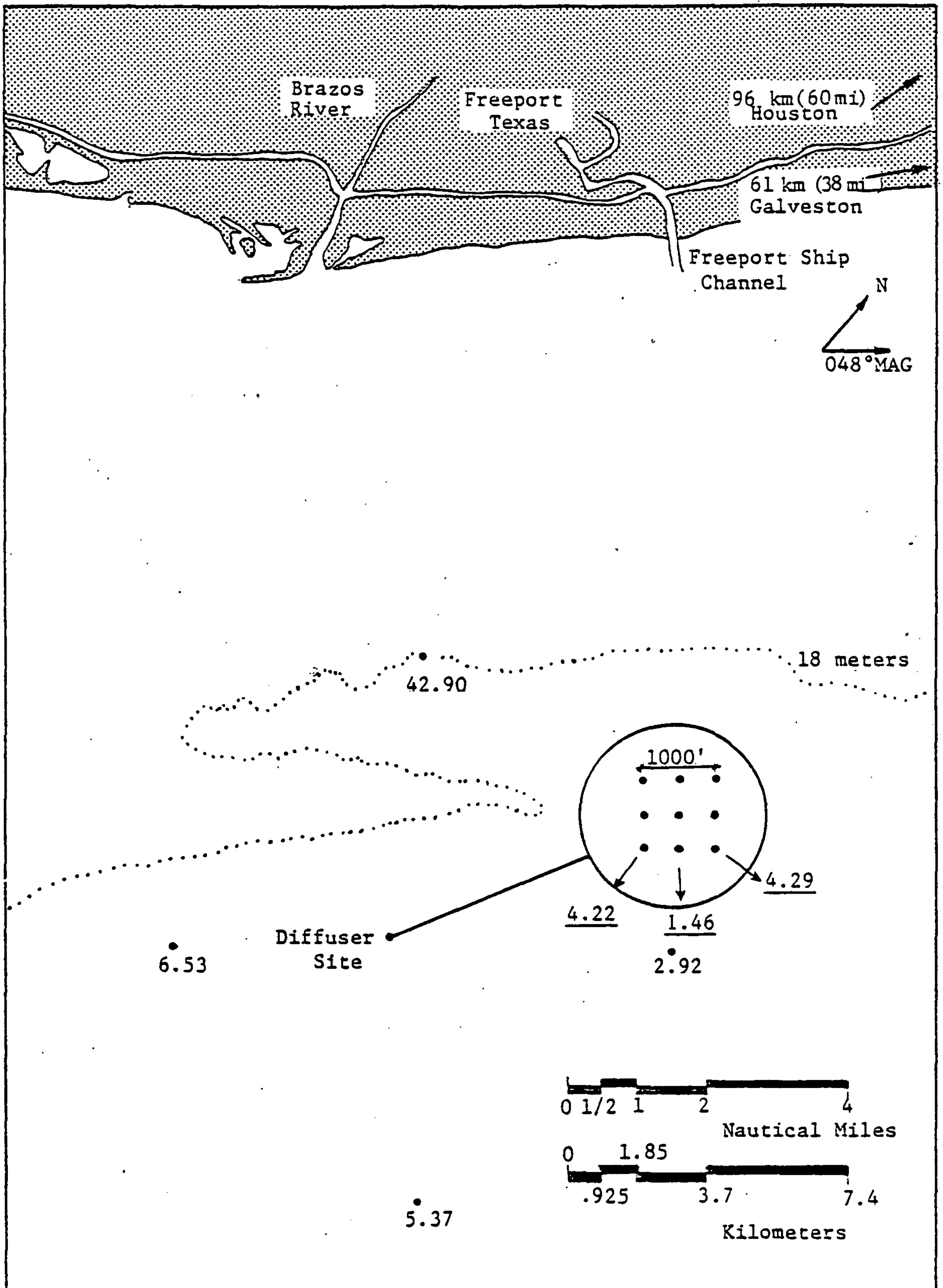

Figure 3-13. Total sediment extract concentrations (µg/g)

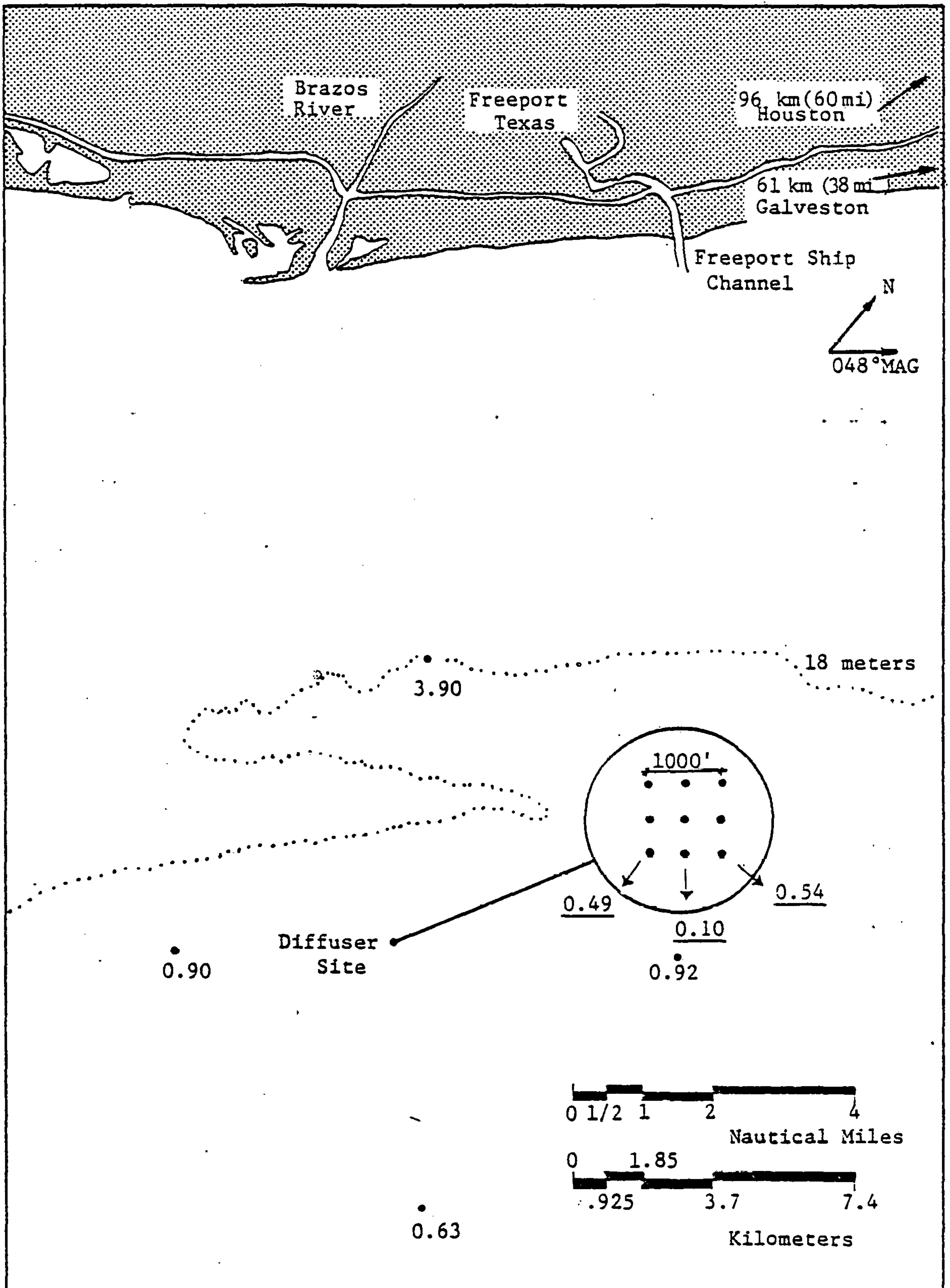

Figure 3-14. Aliphatic fraction concentrations (μg/g)

at diffuser stations D15 to 7.14 micrograms per gram at the nearshore station 15. The average for the 9 diffuser stations was 1.345 and for the control station (39) was 2.27 micrograms/gram. Again, the total hexane fraction concentrations are lower than those reported for the West Hackberry disposal and control sites, primarily because the UCM concentrations for the Bryan Mound disposal site are considerably lower. In general the concentrations of the resolved hydrocarbons in the hexane fraction of the Bryan Mound site are comparable to those reported for the West Hackberry site and control stations.

The concentrations of the 40% benzene in hexane fraction, containing any aromatic hydrocarbons present and also biologically derived compounds of similar polarity, were extremely variable (See Figure 3-15 and Table 3-20). The average concentration of this fraction for the 9 diffuser site stations was 1.12 and for the control station (39) was 0.24 micrograms/gram. The other stations in the area had higher concentrations from 2.97 to 37.4 micrograms/gram. The reasons for the variability in concentrations of this fraction are not readily apparent. Since the compounds were predominantly biological esters, perhaps the differences can be related to microbiological variability in the area.

The benzene fraction concentrations were much more uniform. See Figure 3-16 for concentrations at all stations. They were all less than one microgram/gram.

3.3.5.2 Gas Chromatography and Mass Spectral Analyses

Although low concentrations of hydrocarbons may be one indication of a lack of hydrocarbon pollution, it is still necessary to examine the gas chromatograms to assess the sources of hydrocarbons, In this dis-

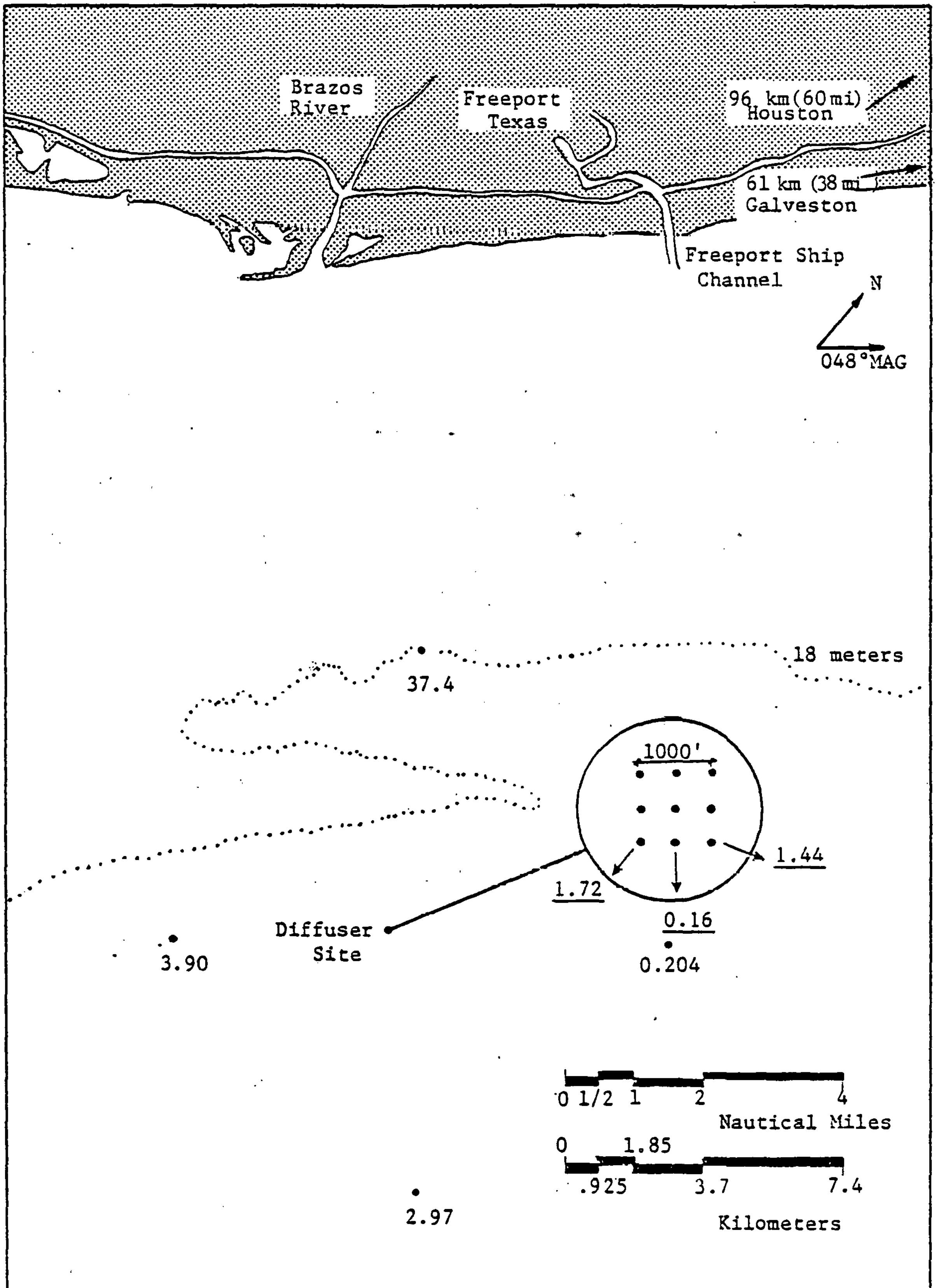

Figure 3-15. 40% Benzene/Hexane fraction concentrations (μg/g)

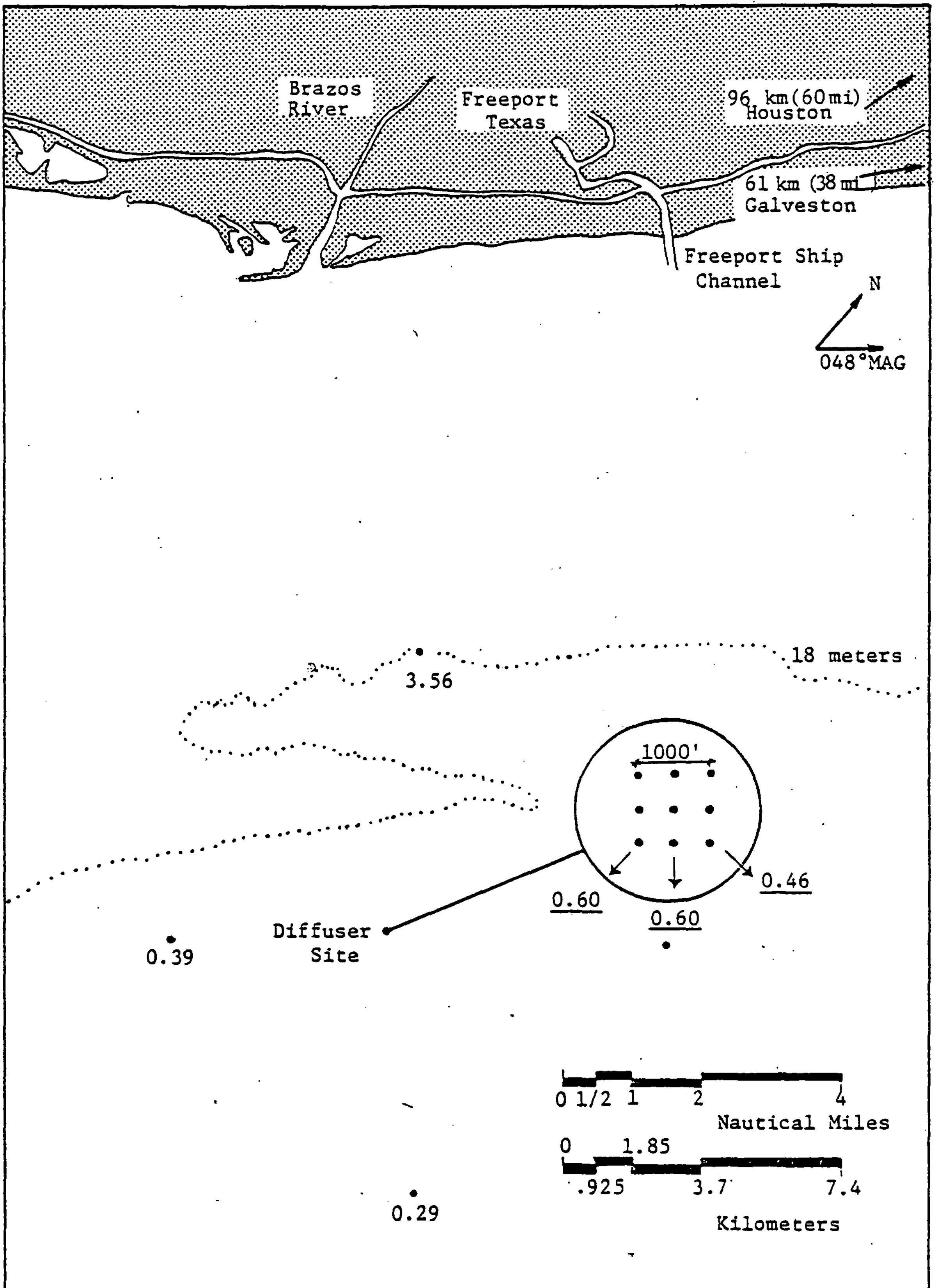

Figure 3-16. Benzene fraction concentrations (μg/g)

cussion we will evaluate the sediment extract fractions with reference where pertinent to mass spectrometer results.

The hexane fractions of all sediment extracts contains normal alkanes in varying amounts with carbon numbers ranging from C-15 to C-34. The odd to even ratio was mostly in the range of 3 to 5, a strong indication of recent biogenic hydrocarbons. See Table 3-20 for odd to even ratios. Figure 3-17 shows a chromatogram of a typical hexane fraction. However, the dominant peaks in the hexane fraction were not usually n-alkanes, but some polyolefins eluting between C-20 and C-21 alkanes. These compounds have a Kovats Index (KI) of 2074-2085 and were dominant at all stations except stations D10 and D11 where C-31 was the most abundant compound. The polyolefins are of marine biogenic origin and have been found in most marine sediments. Figure 3-18 shows a mass spectrum of a polyolefin with a KI of 2077. Figure 3-19 shows a mass spectrum of a normal alkane.

Another feature of the hexane fraction chromatograms is the occurrence of terrestrially derived n-alkanes with carbon numbers between C-23 and C-34 with a strong odd to even ratio. Generally, N-C-31 was the dominant compound in this carbon number range.

All the hexane fractions had a large UCM, typified in Figure 3-17. Part of this UCM that is below the resolved peaks with carbon numbers between C-23 and C-34 may be due to degraded organics and the portion between C-17 and C-22 may be due to a low grade petrogenic source which is nearly completely over-shadowed by biologically derived compounds.

From thorough examination of the gas chromatograms and mass spectra of the hexane fractions, it can be concluded that the resolved peaks are of marine (C-17 - C-22) and terrestrial (C-23 - C-34) biogenic origin but

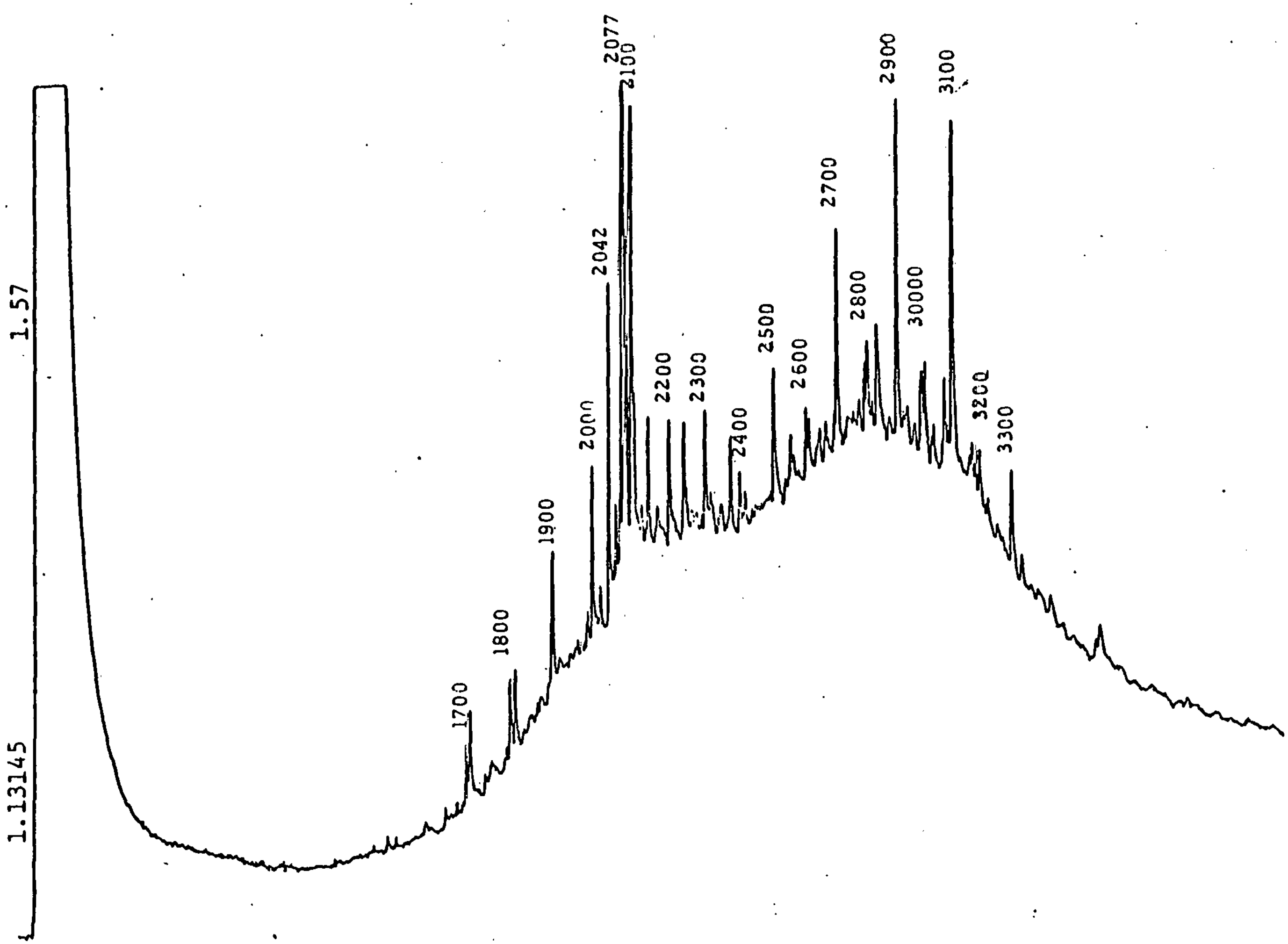

Figure 3-17. Gas chromatogram of a hexane fraction of a sediment extract.

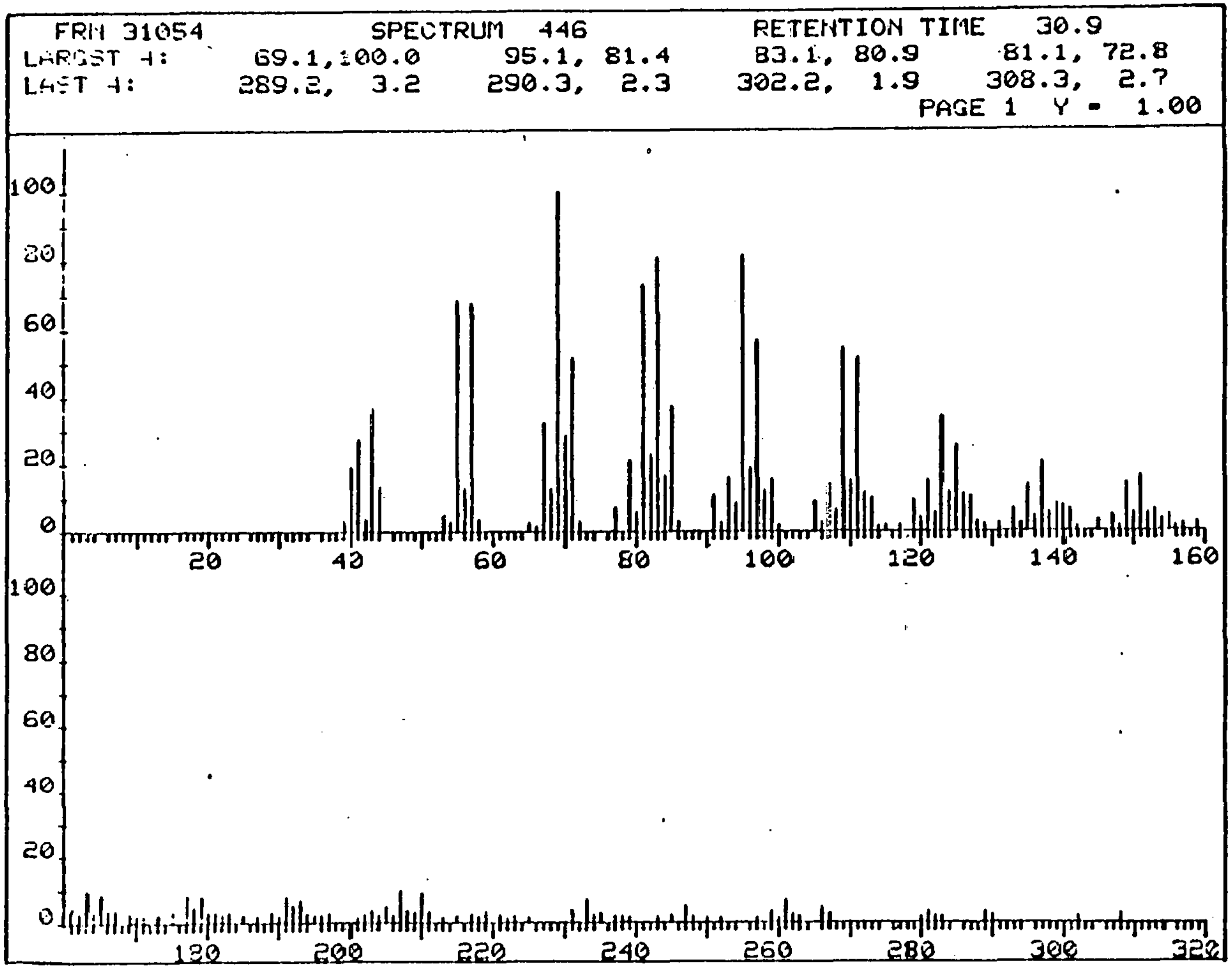

Figure 3-18. Mass spectrum of a polyolefin (KI 2077) in a hexane fraction of a sediment extract

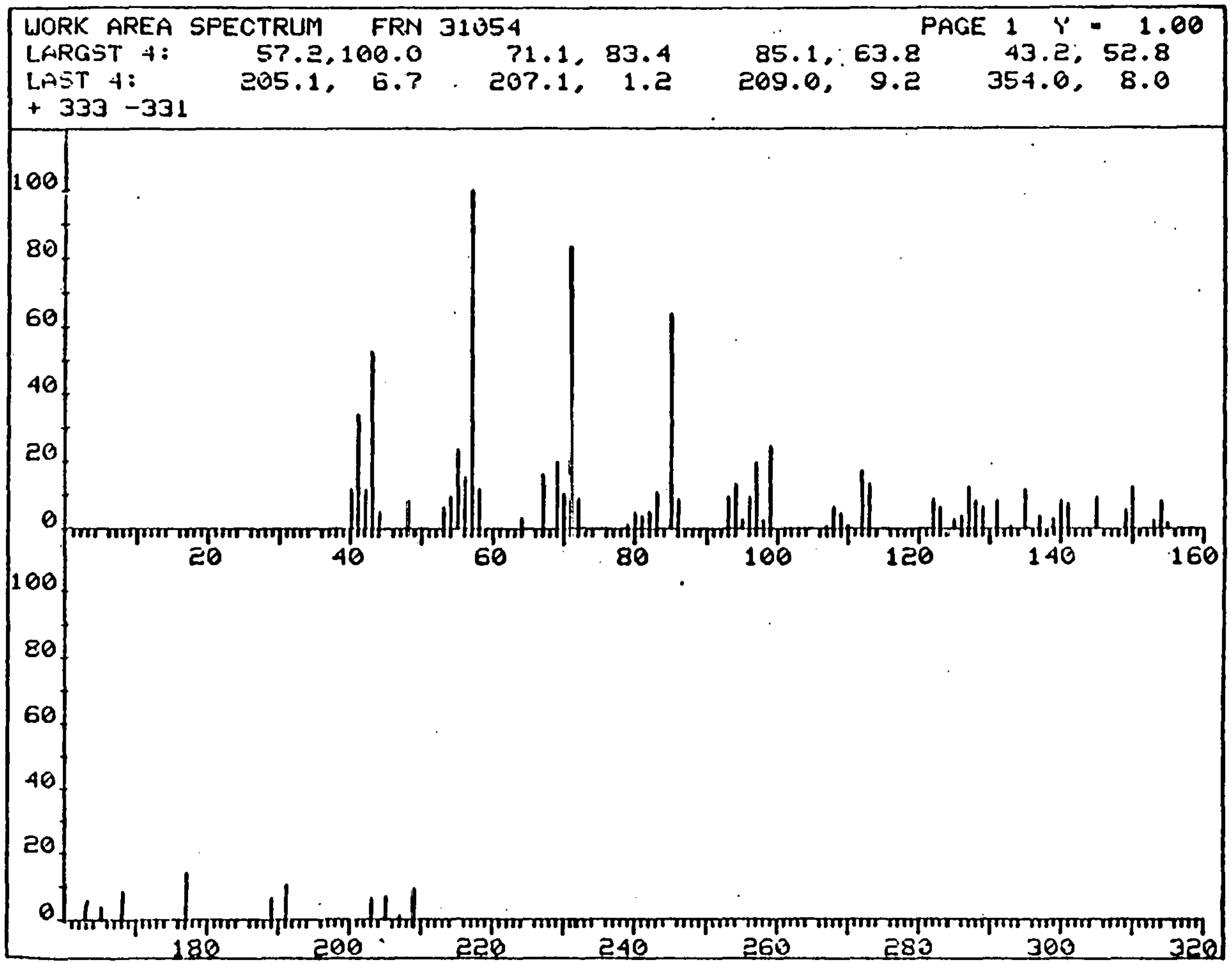

Figure 3-19. Mass spectrum of an n-alkane in a hexane fraction

portions of the UCM may be degraded petroleum residues. All sediments in both the disposal site area and other stations have very similar hydrocarbon compositions. The primary differences between stations are concentration and minor component concentration and composition, as far as the hexane fraction is concerned.

The 40% benzene in hexane fraction should contain the aromatic hydrocarbons, if present, as well as other components of similar polarity. Examination of the mass spectra of the resolved components of the gas chromatograms showed that all but one resolved compound were esters of fatty acids. See Figure 3-20 for a typical gas chromatogram of this fraction. Figure 3-21 shows a mass spectrum of one of the biological esters whereas Figure 3-22 shows a mass spectrum of an aromatic compound that appears to be perylene, a 5 ring aromatic. This was the only aromatic detected and is a naturally occurring hydrocarbon.

Again, the second fraction (40% benzene in hexane) appears to be predominantly of biogenic origin, The concentrations appear to be quite variable, and the composition a little more variable than that of the hexane fraction.

The third fraction, the 100% benzene fraction, contained fewer resolved compounds than the other two and showed no UCM. A typical gas chromatogram of the benzene fraction is shown in Figure 3-23. Mass spectra of this fraction indicated that the compounds were also mostly biologically derived methyl esters (See Figure 3-24).

The methanol fraction had no resolvable peaks on a gas chromatogram, which was anticipated, because this fraction contains polar lipids, which are not analyzable by gas chromatography. This fraction by weight exceeded

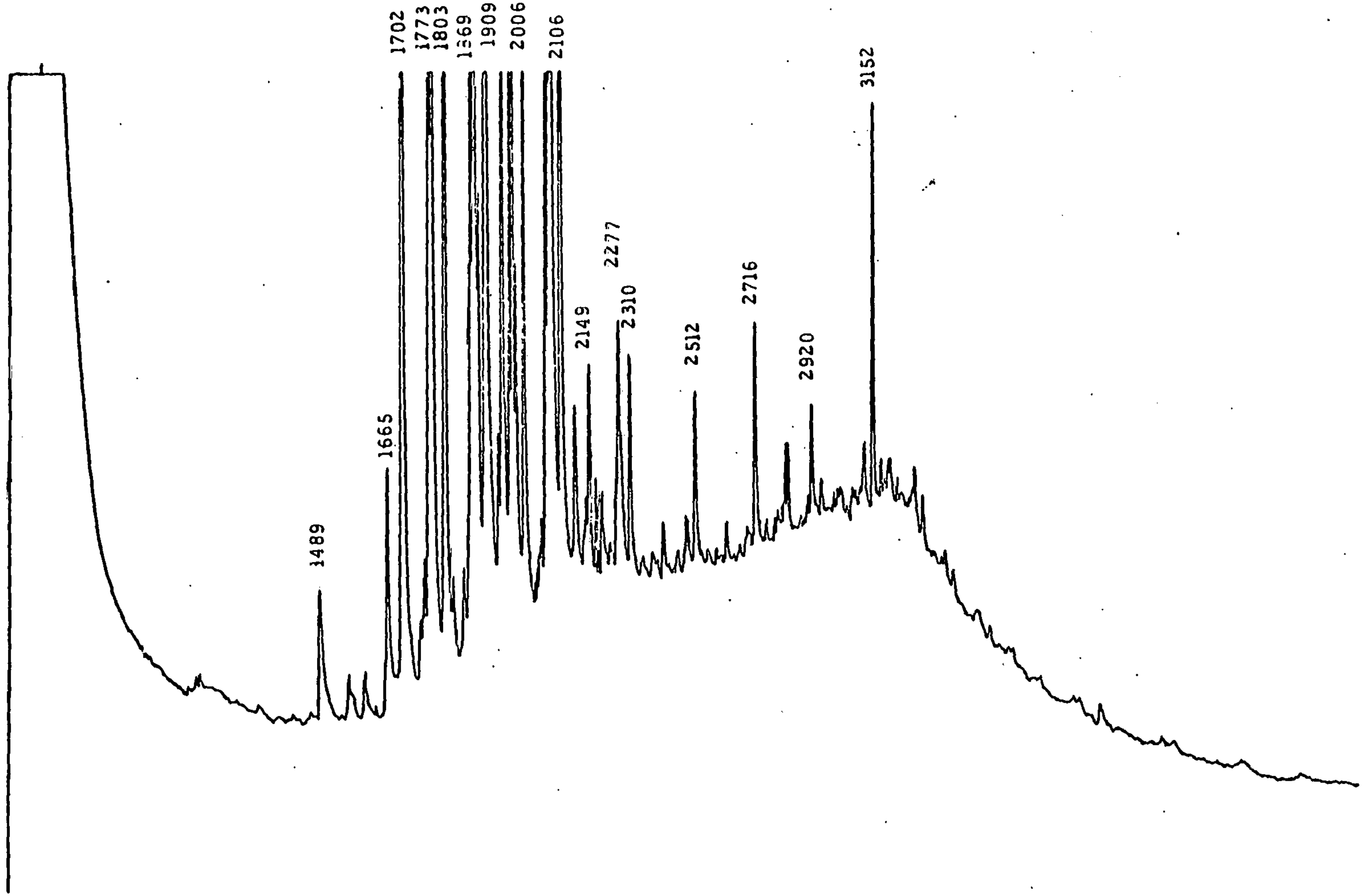

Figure 3-20. Gas chromatogram of a 40% benzene in hexane fraction of a sediment extract.

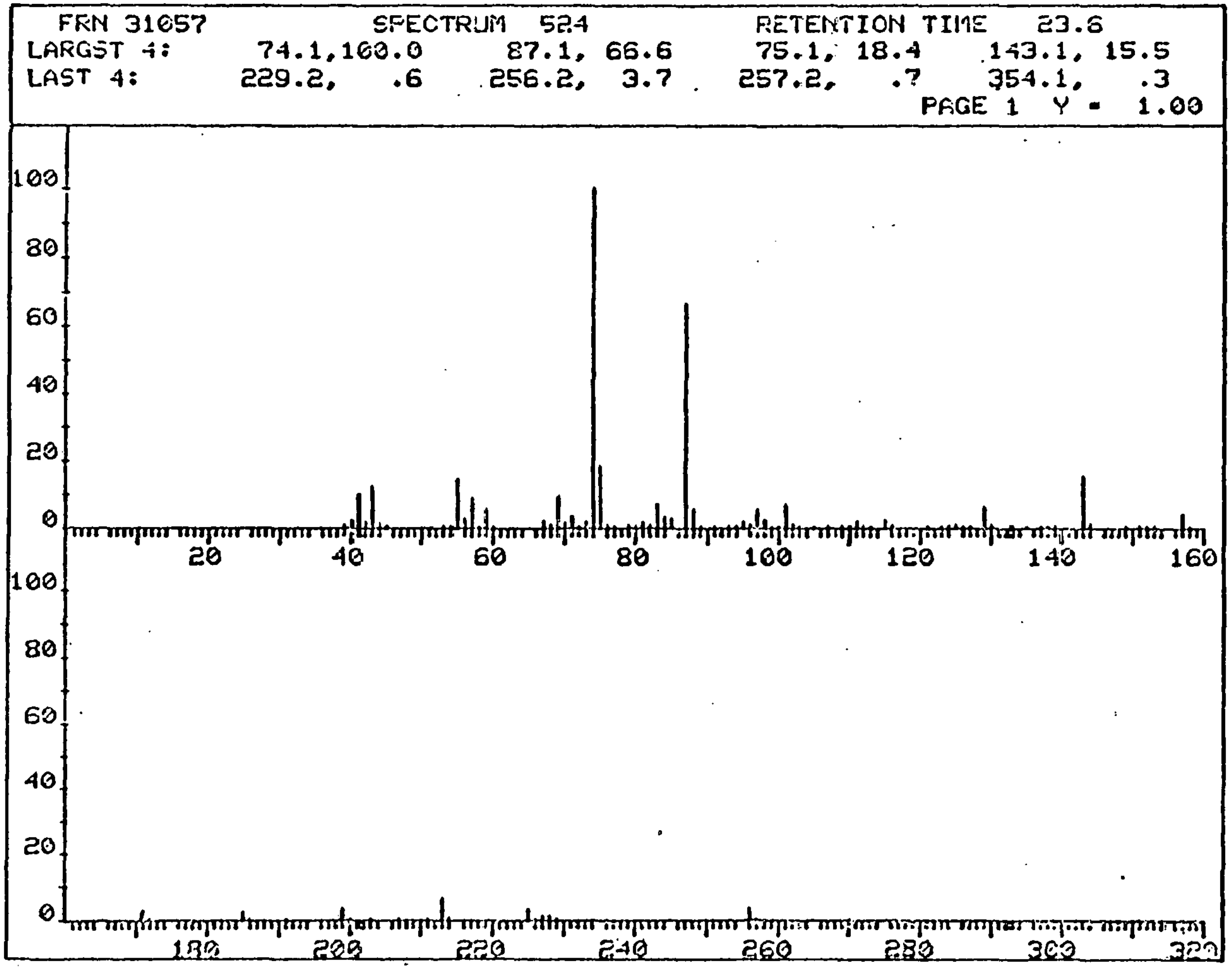

Figure 3-21. Mass spectrum of a methyl ester of a fatty acid in the 40% benzene in hexane fraction

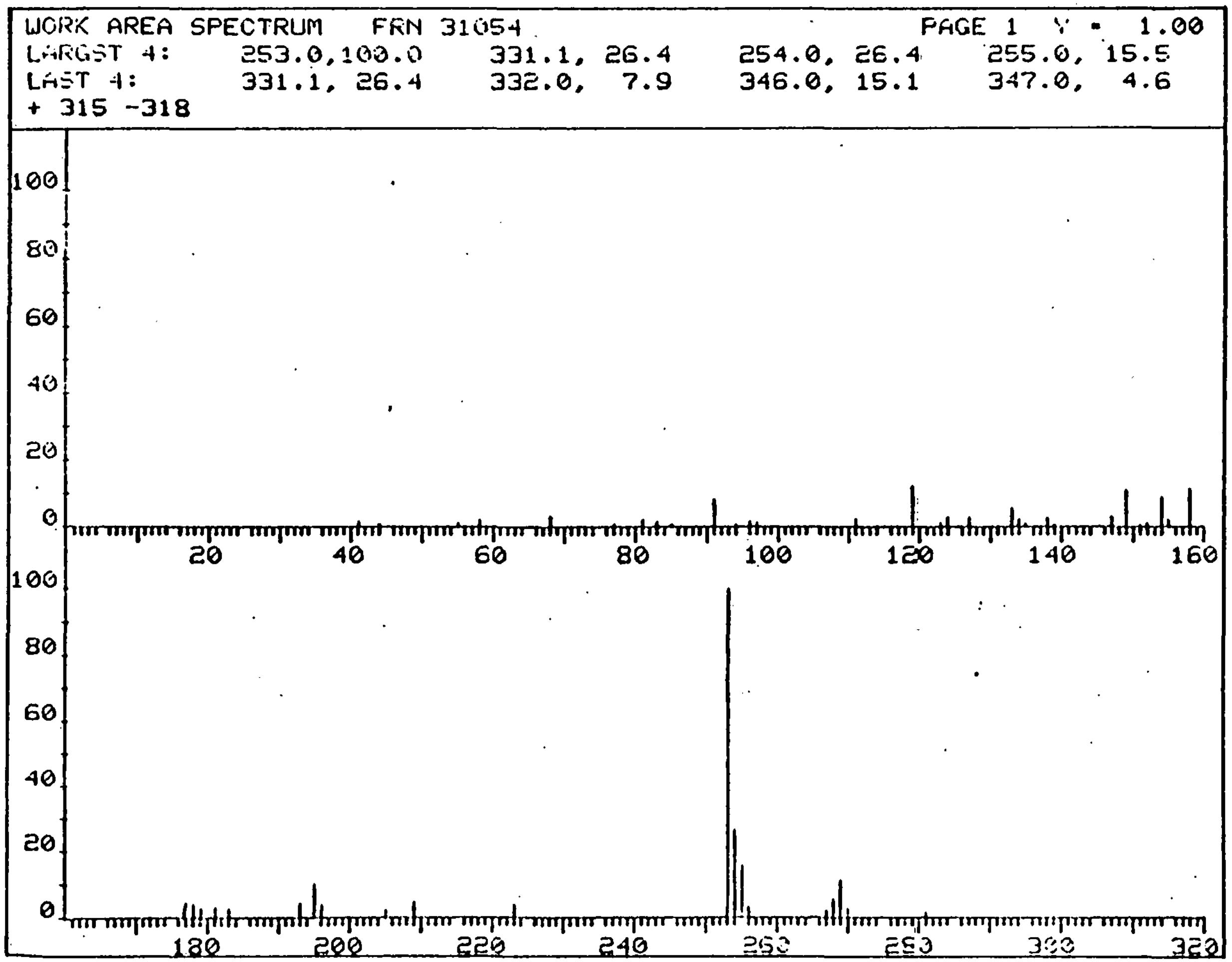

Figure 3-22. Mass spectrum of a naturally occurring aromatic hydrocarbon (perylene) in the 40% benzene in hexane fraction

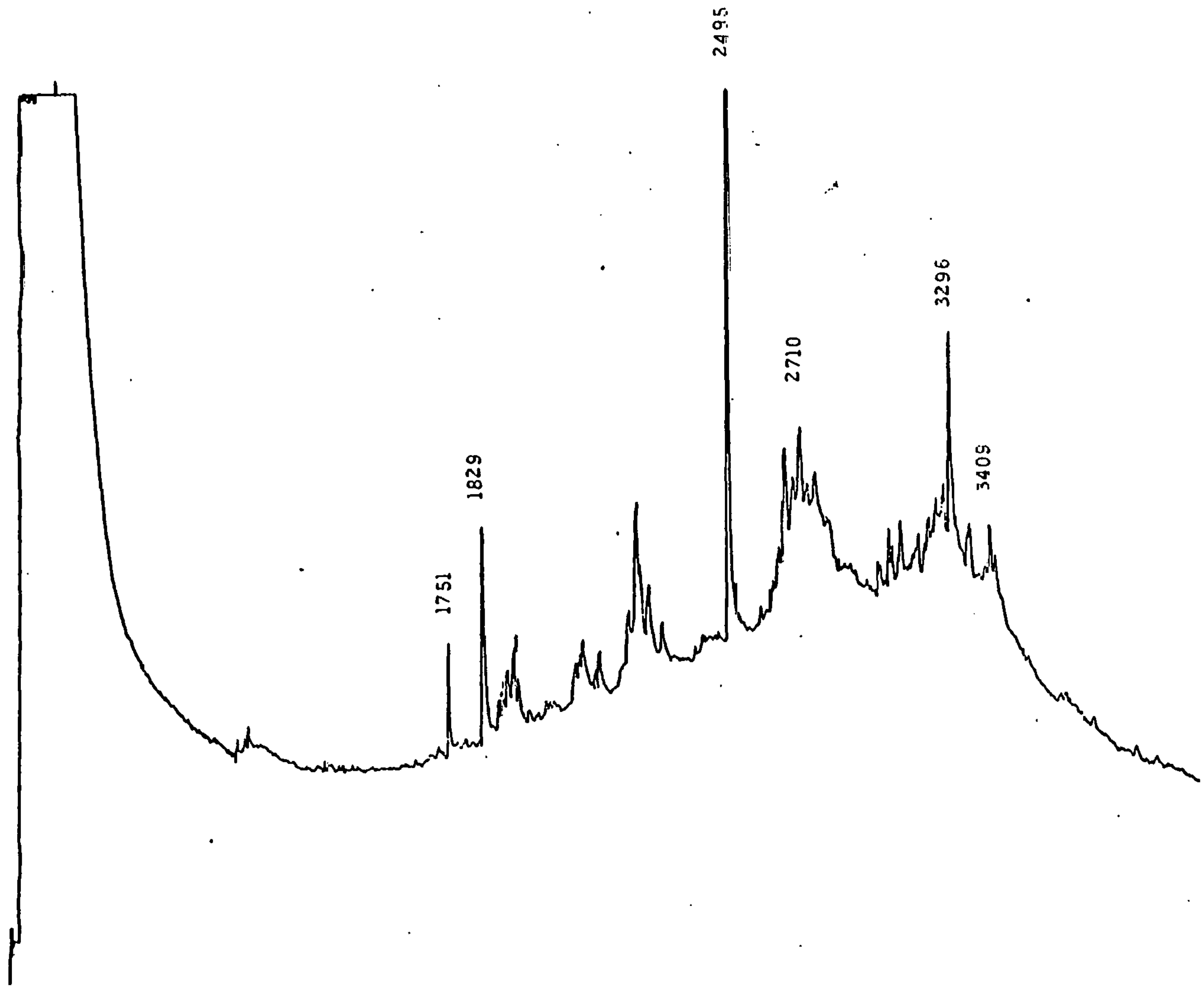

Figure 3-23. Gas chromatogram of a benzene fraction of a sediment extract.

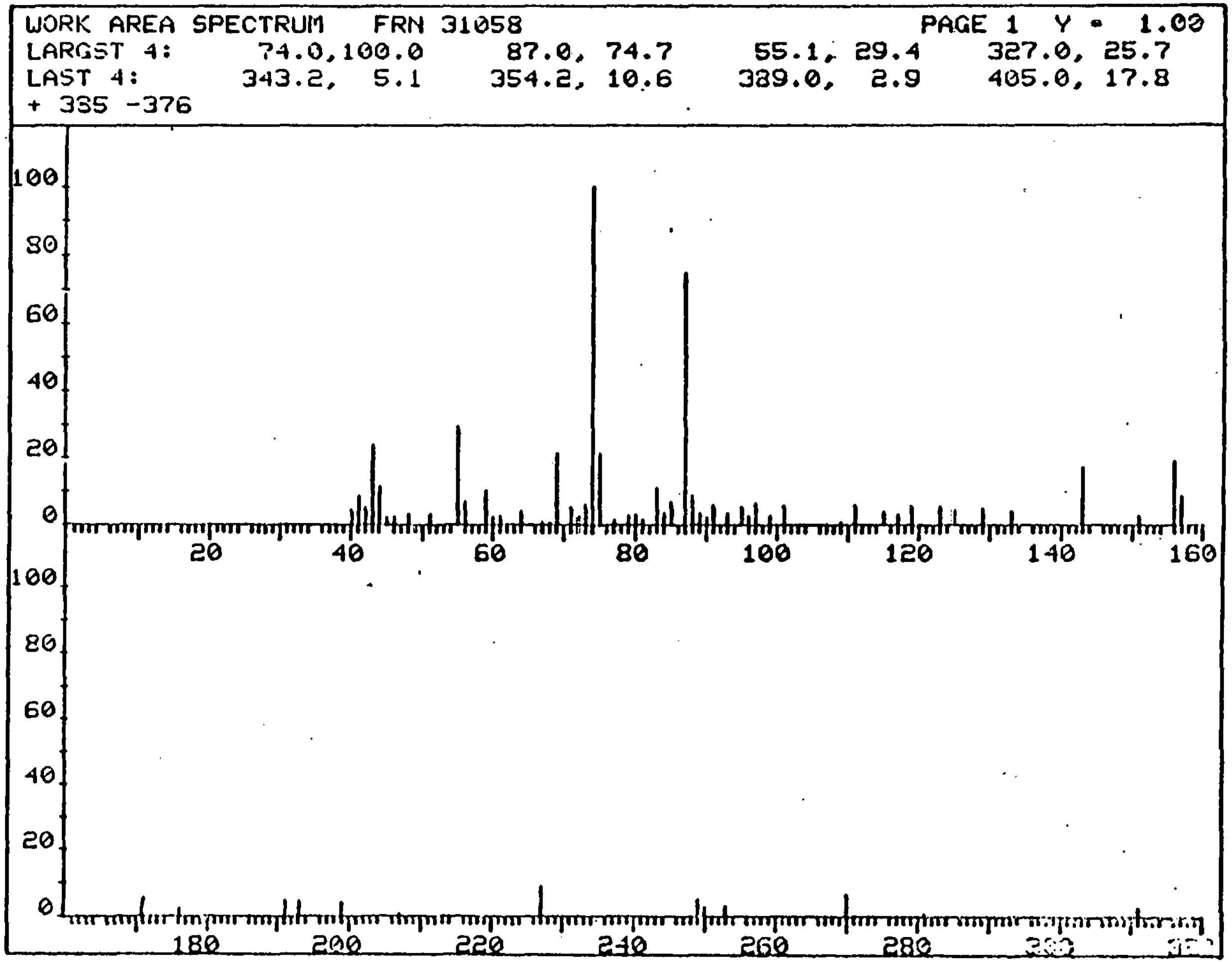

Figure 3-24. Mass spectrum of a methyl ester from the benzene fraction

that of the first three by several orders of magnitude. This fraction was not analyzed further, since it would not add additional information on the question of sediment hydrocarbons.

3.4 Conclusions

Monthly water quality monitoring of the water column at the Bryan Mound diffuser site and adjacent control stations over a seventeen (17) month period indicate the quality parameters of these waters were within the range of values reported for this region of the western Gulf of Mexico. Being coastal waters under the influence of local and regional runoffs, considerable varaibility was observed for most parameters. Some parameters exhibited typical seasonal variations which were further modified by factors associated with the land runoff. The best example of this was the very low dissolved oxygen levels existing in the bottom waters over the entire area during much of the summer of 1979.

Nutrient levels were generally as expected, both seasonal and runoff effects contributing to their variablity. The generally low nitrate levels, (<10μg N/1)observed during this period of study were of special interest. Of all the nutrients, nitrate nitrogen may be the one most limiting for plant productivity in this area throughout much of the year.

Major cation, anion and heavy metal data for both water and sediment were collected on a quarterly basis starting in August 1979 and results during the predisposal period were as expected.

Special samples collected during late summer and early fall consisted of sediments for heavy hydrocarbon, pesticide and PCB analyses and selected biota for heavy metals, pesticides and PCB. Metal analyses on the biota and hydrocarbon analyses of the sediments have been completed. However, delays in subcontracting analyses of the pesticides and PCB's have delayed their analyses. The results will be presented in a later report.

The hydrocarbons in the disposal site and in the surrounding area appear to be very similar in composition and are predominantly of land and marine biogenic origin. All the resolved components certainly do not indicate any petrogenic input. The only possible indication of any petrogenic input is the presence of UCM (unresolved complex mixture or humping) in the hexane fraction containing normal and branched chain alkanes and polyolefins. The other two fractions contained little or no UCM. The primary sources of hydrocarbons of the Bryan Mound area sediments are definitely of marine and terrestrial biogenic ones.

NEKTON

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Chapter 4 has been delayed and will be submitted at a later date. An outline of the contents of this chapter is shown below.

Outline of Chapter 4 Contents

4.1 Introduction.

4.2 Materials and Methods.

4.3 Overall Compositions of the Penaeid Shrimp and Fish Catches.

4.4 Compositions of the Penaeid Shrimp Catches by Day and by Night.

4.5 Compositions of the Penaeid Shrimp Catches and Fish Catches.

4.6 Trends by Station and Area in Nekton Abundance.

4.7 Monthly Trends in Shrimp Abundance and Fish Abundance During the Year.

4.8 Compositions of the Penaeid Shrimp Catches and Fish Catches by Month During the Annual Cycle.

4.9 Comments on Fluctuation in Year Class Strength or Spawned Group Strength of the Nekton.

4.10 Comments on the Effects of Seasonally Occurring Low Dissolved Oxygen Levels on Fish and Penaeid Shrimp Off Freeport.

4.11 Comments of the Occurrence of the Red Drum and Black Drum in the Study Area.

4.12 Compositions of the Penaeid Shrimp Catches and Fish Catches by Cruise.

4.13 Summary and General Discussion.

CHAPTER 5

BENTHOS

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5.1 Introduction

The benthic macrofauna make ideal subjects to study the acute and chronic effects associated with discharge of organic and toxic pollutants into the marine environment. The benthos are primarily non-motile or slow moving, small organisms that cannot easily escape an environmental stress; those that cannot tolerate the stress perish. If the stress is caused by an organic substance, i.e. sewage, one tolerant, opportunistic spcies may successfully invade the habitat and completely dominate the population. If the stress is caused by a toxic substance, both the number of species (diversity) and number of individuals are usually greatly reduced compared with non-impacted control areas (Filice, 1959). We consider brine to be included in the latter category, inasmuch as it contains no organic material.

The data presented herein represent the results of 2 1/3 years of field research to obtain baseline data on the benthic communties offshore from Freeport, Texas. prior to construction and operation of a brine diffuser by the Strategic Oil Reserve Program office of the Department of Energy (D.O.E.). Two separate study areas were investigated. The near-shore (5.5 mi (8.9 km)) site was the original site selected for brine disposal; the offshore site (12.5 mi (20 km)) was the alternate, and finally accepted, location for installation of the brine diffuser (Fig. 5-1).

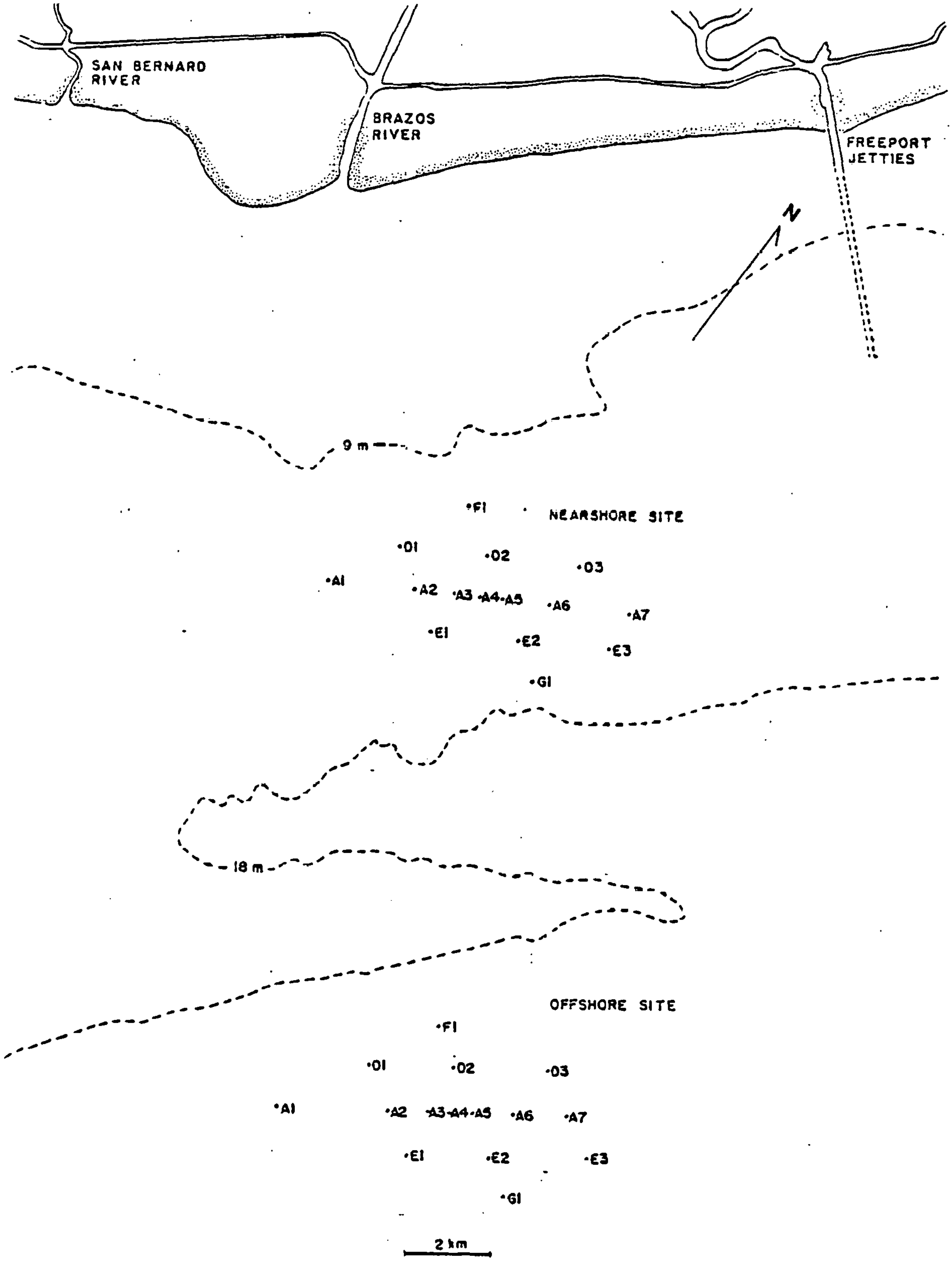


Figure 5-1. Chart of the area offshore from Freeport, Texas, showing the station locations of the nearshore and offshore study areas.

5.2 Historical Review

The soft bottom benthic assemblages offshore from the upper Texas coast have been little studied compared with many other areas of the United States. Prior to 1973, most benthic surveys were conducted using non-quantitative collecting gear (trawls, dredges), with no seasonal repetition of sampling, and often ignored the soft bodied invertebrates in favor of mollusks, whose shells are important to petroleum companies as indicators of geological strata (Ladd 1951; Hedgpeth 1953, 1954; Hildebrand 1954; Hulings 1955; Ladd, Hedgpeth and Post 1957; Parker 1960; Harper 1970). The first attempt to gather seasonal data and analyze the entire benthic community was made during the SEADOCK environmental impact study conducted by the Environmental Engineering Department, Texas A&M University (Harper and Case 1975). The present study areas were included in the SEADOCK study area and limited baseline data are available from the latter study. Three recent qualitative studies of the benthic assemblages in the general vicinity of Freeport have been conducted by Henry (1976) and Harper (1977a) off Galveston and by Harper (1977b) at the Buccaneer Oil/Gas Field 50 km south of Galveston; of these, only Henry (1976) collected monthly samples. Available data indicate that benthic populations begin to increase in early winter, attain maximum densities in the spring, then decline through the summer, reaching the lowest numbers in September or October. However, relatively little is known of the annual seasonal changes or the year to year changes in benthic populations offshore from the upper Texas coast. The present study is unique in that monthly samples have been collected for over 2 years from two different habitats, a sandy bottom and a muddy bottom. This will allow the investigators to study the changes in populations and abiotic characteristics of the sites from year to year instead of trying to extrapolate data from another study area.

There are virtually no data on the effects of pure brine on biological communities. Johnson (1974, 1977) conducted studies in two areas, Cedar Bayou (upper Galveston Bay) and the San Bernard River, where brine was being dicharged. In both areas, water moved slowly and the dense brine formed a persistent stratified bottom layer that was occasionally displaced during high freshwater discharge. The San Bernard River site had maximum recorded bottom salinities of 18.9 ppt, but the salinity was not detrimental to fish or invertebrates because more specimens were collected at the affected station that at a station 9 km downstream where the bottom salinity was much lower. The Cedar Bayou site, which received brine from salt dome cavern leaching, experienced bottom salinities as high as 118 °/oo. The brine limited penetration of fish and nektonic invertebrates into the affected area.

Most studies concerned with brine discharge have investigated the impact of oil field "bleedwater" brine, i.e. brine that is discharged into the environment after separating from the oil with which it was mixed when pumped to the surface. Separation is not 100% complete and some quantity of oil is also discharged. If the Bryan Mound salt dome is refilled with oil a second or third time, the disposed brine will probably, like bleedwater, contain oil. In shallow bodies of water, bleedwater oil becomes incorporated in the sediments, as was found in Louisiana (Mackin and Hopkins 1962) and Texas (Mackin 1971; Armstrong et al. 1979); oily bottoms caused depressed benthic populations. Such an effect has not yet been clearly demonstrated in offshore waters. The greater potential for mixing because of deeper water reduces the possibility of traces of oil being incorporated in the sediments. In Louisiana, studies comparing a production platform with a control area produced mixed results. Waller (1974) reported that oil field stations were less productive than control areas. However, Kritzler (1974), Farrell (1974) and Fish et al. (1974) found no differences in benthic fauna between production and control areas. Harper et al. (1976) found oil in the sediments adjacent to one Buccaneer Field platform, 50 km south of Galveston, that probably resulted from an accidental spill. The fauna at this site was quite depressed compared with nearby uncontaminated areas. In a subsequent study at the same location, depressed populations were found all around both platforms, but it was not clear whether the depression was caused by differences in the substrate or to discharges from the platforms (Harper, 1977b).

5.3 Sampling Pattern

The station pattern was nearly identical at both the nearshore and offshore sites (Fig. 5-2). Basically, the rationale for the pattern was to align the major transect (A) southwest, in the direction of known net current flow (alongshore). It has been found that any discharged substance will flow with the current and with increasing distance from the discharge point, the substance becomes more dilute, finally becoming undetectable. Biological effects due to a dicharged substance tend to be most severe near the discharge point and become less evident with increasing distance from the discharge. The stations on transect A were established to reflect the dilution effect. Station A5 was located in the middle of the proposed diffuser array. Stations A4, A3, A2 and A1 were 500, 1000, 2000 and 4000 m downcurrent from A5. Stations A6 and A7

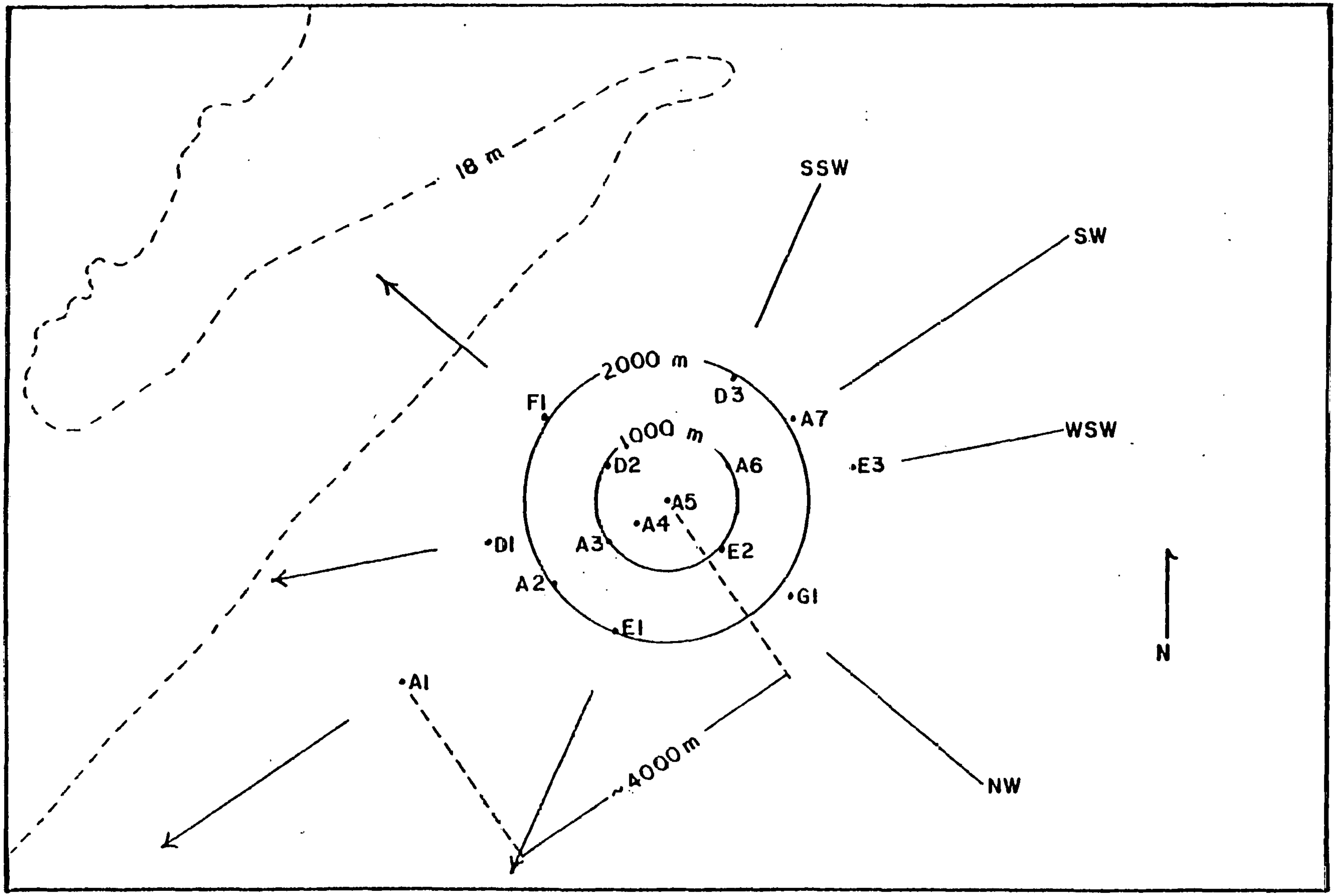


Figure 5-2. Map of the offshore study area showing locations of sampling stations.

were 1000 and 2000 m upcurrent from station A5.

The lesser transects, D and E, were oriented parallel with transect A. However, stations D1, A5, E3 and E1, A5, D3 provide WSW and SSW trending transects, respectively. Stations F1, D2, A5, E2, G1 provide a NW trending transect. Figure 5-2 also illustrates that the stations are arranged roughly in two rings of 1000 and 2000 m from the center of the discharge area, providing a second approach to data analysis.

From September 1977 through November 1978, the relatively inaccurate ($\pm$400 m) LORAN A navigation system was used to locate stations. Since December 1978 the LORAN C navigation system has been used. Between December 1978 and September 1979 the LORAN C coordinates were based on LORAN A coordinates. However, when the diffuser was installed, we determined that station A5 was about 600 m seaward of its intended location--the center of the diffuser--and the entire sampling pattern was shifted inshore. The "new" sites have been sampled since October 1979.

Concurrent with the station location move, four new stations were added to the 15 existing offshore stations. Stations B1, A9 and C1 were located 500 m inshore, northeast (upcurrent) and offshore of Station A5, at the diffuser, respectively. Station A8 was located 200 m southwest (downcurrent) of station A5 (Figure 5-3). The addition of these stations was to enhance the ability to detect nearfield biological stress, and was made practical by the installation of 6 buoys which could be used for navigation aids. Station coordinates are listed in Table 5-1.

5.4 Field Techniques

Sampling utilized three Ekman grabs (232 cm^2 each) attached to a

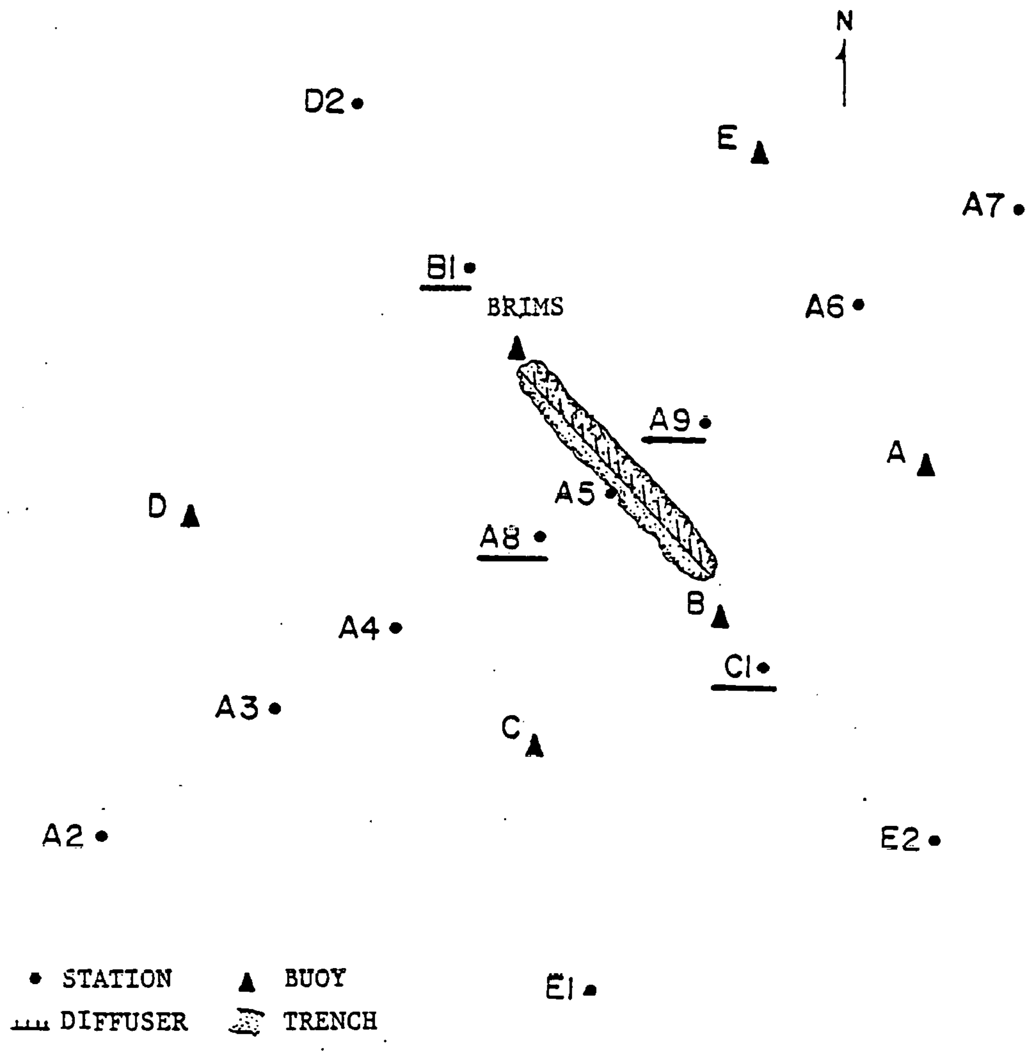


Figure 5-3. Details of the offshore study area showing the nearfield sampling stations in relation to the diffuser array in its trench. Buoys are indicated by solid triangles. Stations A8, A9, B1 and C1, which were added in October 1978, are underlined.

Table 5-1. Coordinates of benthic sampling stations at the offshore and nearshore study areas.

Offshore

	Pre-Oct. 1979		Post-Oct. 1979	
Station	Latitude (N)	Longitude (W)	Latitude (N)	Longitude (W)
A1	28°42'32"	95°16'29"	28°42'42"	95°16'38"
A2	28°43'12"	95°15'12"	28°43'27"	95°15'32"
A3	28°43'30"	95°14'49"	28°43'46"	95°15'03"
A4	28°43'38"	95°14'30"	28°43'58"	95°14'48"
A5	28°43'54"	95°14'15"	28°44'08"	95°14'28"
A6	28°44'10"	95°13'51"	28°44'28"	95°14'04"
A7	28°44'26"	95°13'09"	28°44'48"	95°13'35"
D1	28°43'24"	95°15'30"	28°44'03"	95°15'47"
D2	28°43'51"	95°14'32"	28°44'33"	95°14'57"
D3	28°44'32"	95°13'27"	28°45'06"	95°14'01"
E1	28°43'02"	95°14'42"	28°43'09"	95°15'05"
E2	28°43'37"	95°13'57"	28°43'41"	95°14'10"
E3	28°44'09"	95°13'57"	28°44'12"	95°13'18"
F1	28°44'32"	95°15'40"	28°44'59"	95°15'19"
G1	28°43'06"	95°13'00"	28°43'17"	95°13'47"
A8			28°44'05"	95°14'37"
A9			28°44'18"	95°14'18"
B1			28°44'20"	95°14'45"
C1			28°43'53"	95°14'23"

Nearshore

Station	Latitude (N)	Longitude (W)
A1	28°48'00"	95°19'38"
A2	28°48'32"	95°18'40"
A3	28°48'38"	95°18'03"
A4	28°48'46"	95°17'45"
A5	28°48'58"	95°17'32"
A6	28°49'11"	95°16'53"
A7	28°49'22"	95°16'18"
D1	28°48'47"	95°18'58"
D2	28°49'20"	95°18'09"
D3	28°49'36"	95°16'11"
E1	28°48'16"	95°18'15"
E2	28°48'44"	95°17'17"
E3	28°49'09"	95°16'47"
F1	28°49'42"	95°18'39"
G1	28°48'28"	95°16'48"

line having an anchor at one end and a buoy at the other. When the vessel came on station, the line with the attached grabs was dropped overboard while the vessel was in reverse. This caused the anchor to dig into the bottom and the grabs to spread apart. The divers descended the line to the bottom. The Ekman grabs were pushed into the bottom by hand, triggered, and the vent flaps were secured with an elastic band. While on the bottom, the divers collected a water sample, and if the water was clear enough, they visually examined the substrate for large organisms and the presence of burrow entrances. Since January 1979, a fourth Ekman added to the line, or a diver carried plastic jar, has been used to collect sediment samples at stations along transect A monthly, and all stations quarterly, at the offshore site only.

When the Ekman grabs were brought aboard the vessel, the contents were placed in plastic tubs and the sediment temperature was recorded. A description of the sediments based on visual and textural examination was recorded. Each sample was then washed separately on a 0.5 mm mesh sieve to remove fine sediments, and the material remaining on the sieve was fixed in 5% seawater-formalin. Surficial sediments for sediment analysis were removed from the fourth Ekman and placed in a glass jar.

The temperature and salinity of the bottom water sample were recorded as soon as the divers returned to the vessel. The temperature and salinity of a surface water sample were also recorded. Since October 1978, the dissolved oxygen (D.O.) content of at least the bottom water has been measured. Prior to January 1979, temperature was measured with a Celsius thermometer, salinity with a refractometer and dissolved oxygen with a Hach kit. Since then, water temperatures and salinities have been measured using a YSI Model 33 Temperature-Salinity-Conductivity meter, and dissolved oxygen using a YSI Model 57 Dissolved Oxygen meter.

5.5 Laboratory Techniques

The benthic samples were washed with fresh water to remove the formalin and any remaining fine sediment. The entire sample was preserved in rose bengal stained 70% ethanol. The material was subsquently examined microscopically and all stained organisms were removed, identified to lowest possible taxon, classified as adult or young based on size and counted. Because several persons made initial identifications, all samples were examined by Harper to standardize the nomenclature and size classifications.

The sediment samples were refrigerated at 4°C until analysis began, if not air dried immediately. Each sample was air dried and then analyzed for grain size using the methods of Folk (1974), including sieve analysis for sand fractions and pipette analysis for silts and clays. Organic and carbonate carbon were also determined. A dried, weighed sediment sample was subjected to 10% hydrogen peroxide. When effervescence ceased the sample was rinsed, dried and reweighted to determine the amount of organic carbon. The sample was then treated with concentrated hydrochloric acid to determine the carbonate carbon.

5.6 Data Analysis

The abiotic data collected from each level of the water column were averaged for each cruise. The discussion of abiotic factors will principally concern the sediment temperature, and bottom water salinity and dissolved oxygen because these are the factors affecting the benthos directly.

Sediment data were plotted on probability paper, and from the graph, the percent sand, silt and clay were determined, along with mean grain size, skewness and kurtosis. The sediment characteristics are presented in monthly Shepard sediment diagrams.

Biological data were analyzed in two ways. The first was descriptive, comparing total species and average populations/^{2} per station at the two sites, comparing the dominant taxonomic groups at the two sites, and comparing the areal and seasonal distribution of the species and individuals within each site. The second method involved the use of cluster analysis (Bray-Curtis dissimilarity measure, flexible sorting, elimination of the species that occurred fewer than 10 times during the study period) following the methods of Clifford and Stephenson (1978), principal components analysis using the 25 most abundant species and pooled data from each of 15 stations at each site, and mean Shannon-Weiner diversity for each cruise, followed by Duncan's multiple range test to establish the hierarchy of means. The graphic output for cluster analysis included station group and species group dendrograms, and two way tables comparing co-occurrence of stations and species. Principal components analysis displays were plots of each station location relative to each of the first three axes. Duncan's multiple range test results display was a list of stations ranked by mean diversity.

5.7 Results and Discussion

5.7.1 Sediments and Bathymetry

The offshore site was located seaward of the so-called Freeport Bank, on what Neinaber (1958, 1963) has described as a drowned deltaic plain built during the Pleistocene by the Brazos-Colorado River. The bottom is nearly level, ranging in depth from 19.5 to 21 m. The sediments at the offshore site were primarily sand to muddy sand, but patches of clay or silt have been encountered occasionally. A thin veneer of very fine silt may or may not overlie the firmer sediments, depending on whether the sampling cruise was preceded by a period of stormy weather. The Shepard diagrams (Figure 5-4) indicate that most of the sediments have been either silty or clayey sand or sand-silt-clay with more sand than silt or clay, and there have been several shifts in grain size ratios as might be expected in a dynamic area. The mean grain size at the seven original stations in the A transect (the only ones sampled monthly) was in the 5.0 to 7.0 ϕ range (Table 5-2). The mean percent total organic carbon at the seven stations in A transect ranged from 1.8 to 2.2 (Table 5-2), and there was little continuity at any station from month to month.

The nearshore site was located on the Recent subaqueous delta of the Brazos River. Sediments were primarily firmly packed silts and clays (no grain size analyses have been made) that were or were not covered by a thin veneer of very fine silt, depending on preceding weather conditions. The shallower stations had clays that were red or gray, or layered red and gray clay that appeared bioturbated. Gray clays occurred more consistently at deeper stations. The nearshore bottom sloped gradually seaward; the inshore-most station was in about 11-m depth and the offshore-most station in about 17-depth.

5.7.2 Temperature

The water column at the offshore site tended to be isothermal or nearly so during most of the study period with temperature differences between the top and bottom of the water column usually less than 1.5°C

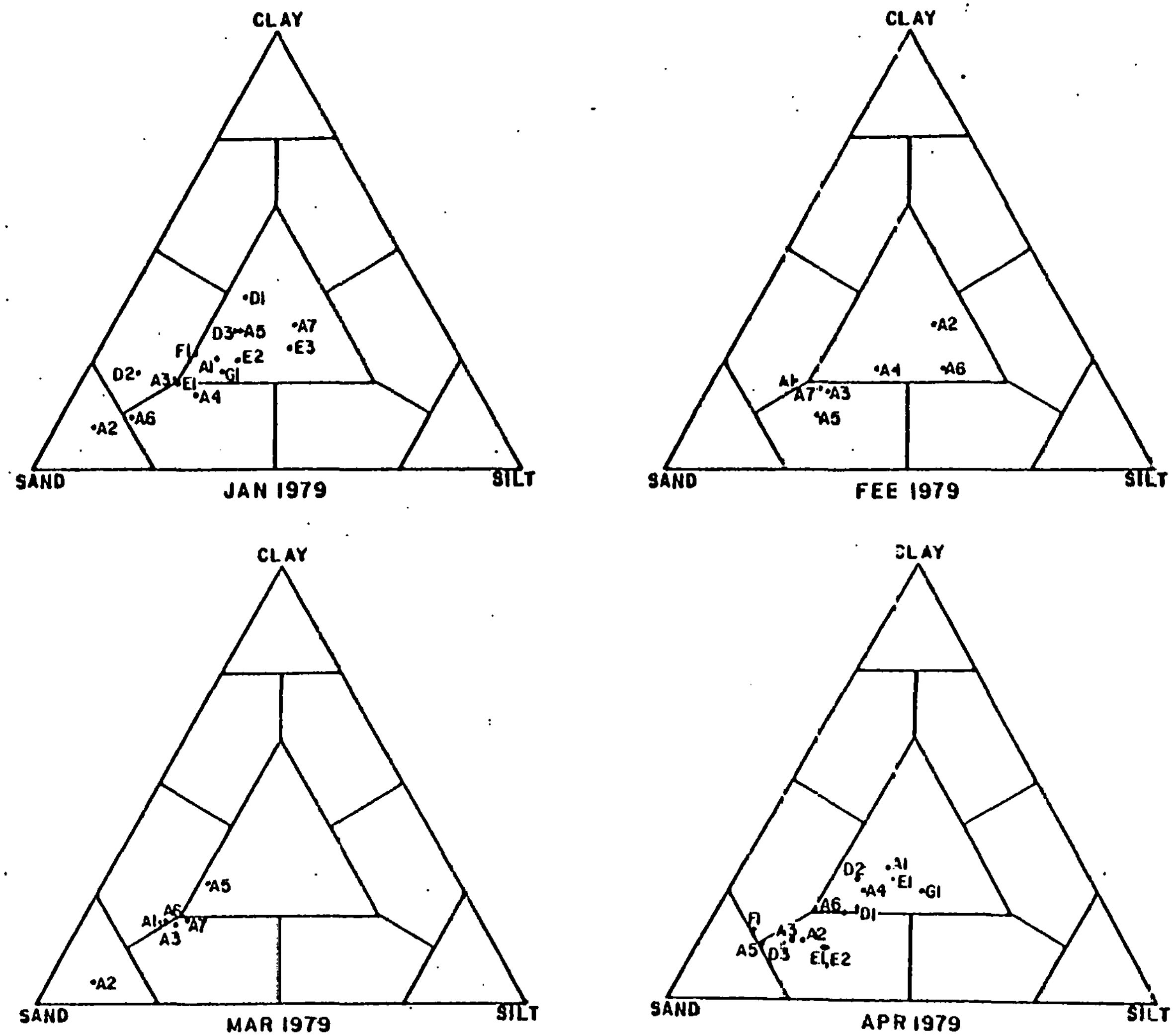


Figure 5-4. Shepard diagrams indicating the sediment characteristics of offshore stations, January - July 1979.

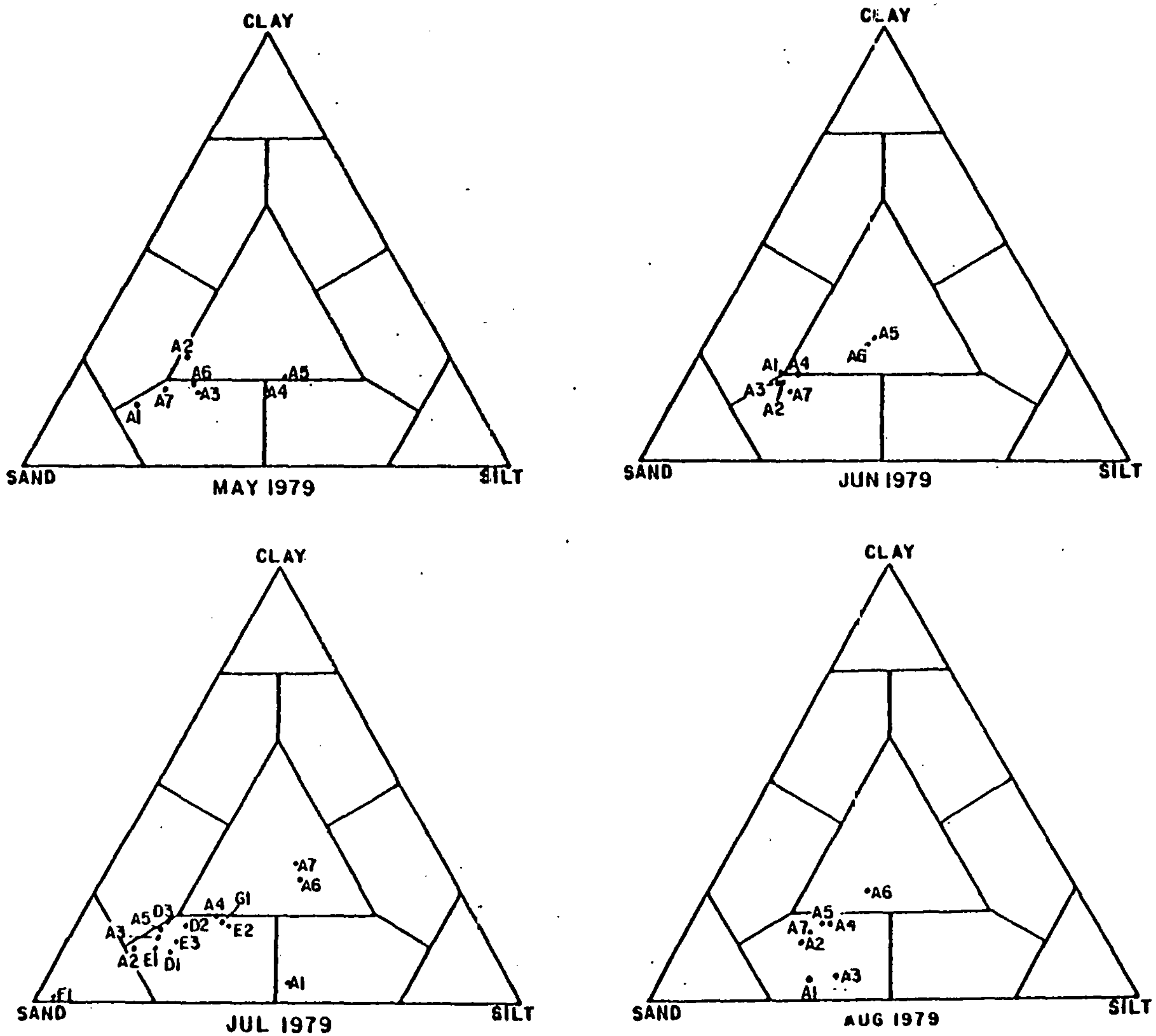


Figure 5-4 (continued). Shepard diagrams indicating the sediment characteristics of offshore stations, January 1979 - March 1980.

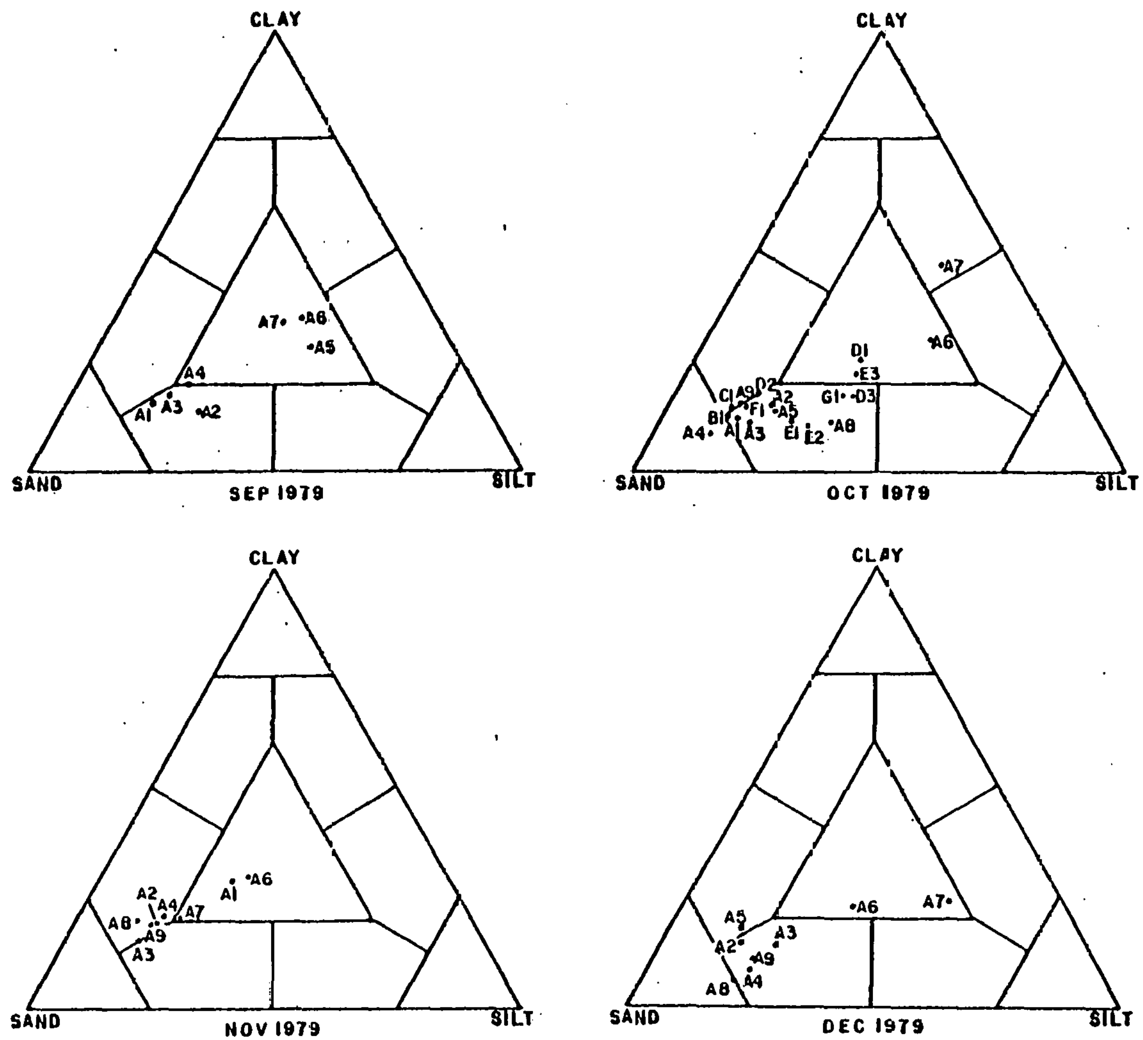


Figure 5-4. (continued) Shepard diagrams indicating the sediment characteristics of offshore stations, January 1979 - March 1980.

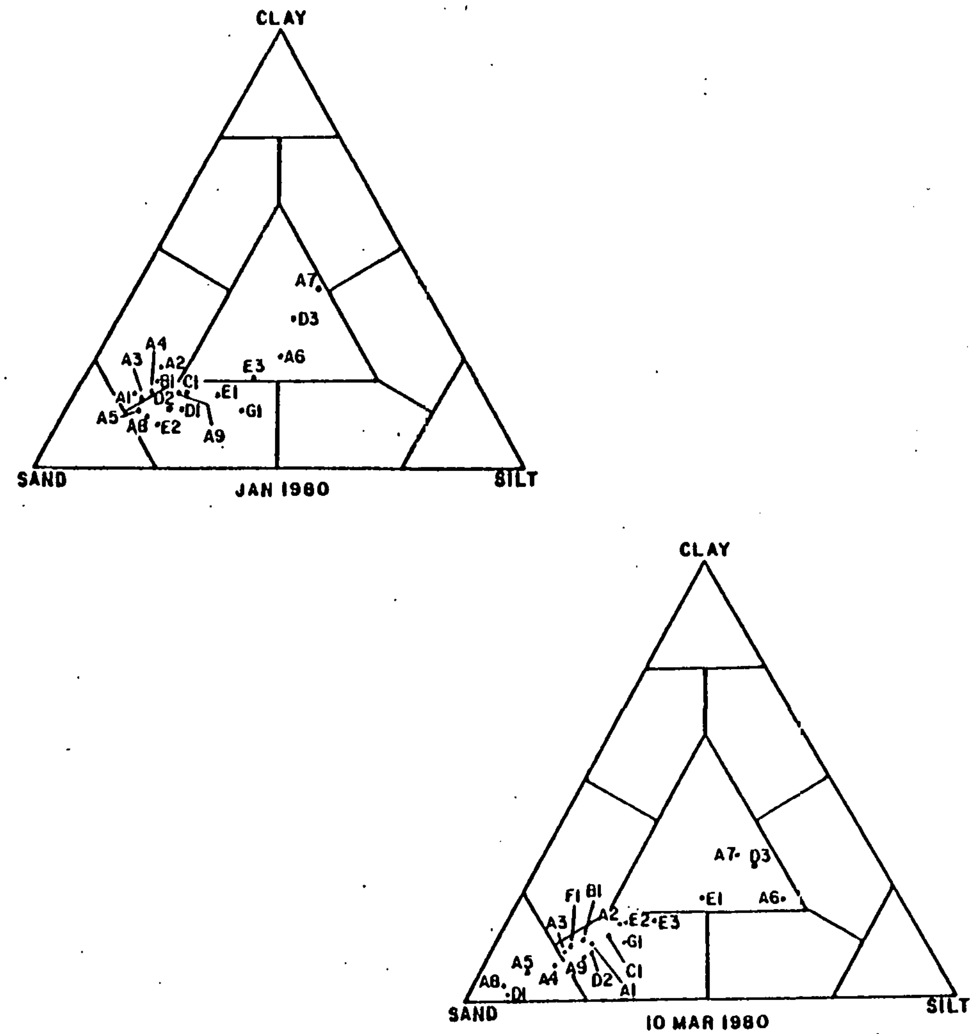


Figure 5-4. (continued) Shepard diagrams indicating the sediment characteristics of offshore stations, January 1979 - March 1980.

Table 5-2. Sediment data from the original seven stations in transect A, offshore site: mean grain size from January 1979 through March 1980, excluding February 1980; mean total organic carbon (TOC) from January through October 1980.

Station	Mean ϕ	Mean TOC
A1	5.81	1.80
A2	5.46	1.79
A3	5.31	1.48
A4	5.66	1.76
A5	5.44	2.20
A6	6.50	1.89
A7	6.83	1.83

(Table 5-3). The exceptions were caused by the bottom water remaining cooler in the summer months, i.e. July and August 1978 and June-August 1979, when 2 to 4°C gradients occurred. The sediment temperature was usually similar to the bottom water temperature during fall through winter, but warmed more slowly during spring and summer. The seasonal sediment temperature changes were rather uniform at the two sites during the 30 months of study (Figure 5-5). The principal differences thus far were the more rapid cooling in the fall of 1977 than in 1978 or 1979, and the long period of low temperatures in winter 1978; the temperature fell more slowly in the fall of 1978 than 1977, but from January through 15 February 1978 the beach water temperature at Galveston remained almost continuously below 10°C and was below 15°C through mid-March. The water temperatures in the study areas were probably not much warmer during this time. In January 1979, the upper Texas coast experienced 5 freezes which temporarily decreased the beach water temperature each time; the temperatures did not remain below 10°C for very long, and thus the water warmed quickly through March. The lowest recorded sediment temperatures at the offshore site were about the same in 1978 and 1979. The winter of 1979-80 was, in contrast, relatively mild. The recorded sediment temperatures did not fall below 13°C, and rose to 16°C during a warm period in January 1980.

At the nearshore site the water column was nearly isothermal also, with differences between surface and bottom temperatures usually less than 1.5°C (Table 5-4). There is slight evidence that the bottom water cooled more slowly in the fall and an evident lag occurred during the spring warming phase. The exceptions to isothermality occurred in July 1978 and June-July 1979, when 3-5°C gradients existed. The sediment

Table 5-3. Comparison of the average monthly temperature, salinity and dissolved oxygen of the surface and bottom of the water column and the sediment temperature at the offshore site.

	Temperature (°C)			Salinity (°/₀₀)		Dissolved Oxygen (ppm)	
	Surface	Bottom	Sediment	Surface	Bottom	Surface	Bottom
1977							
2 Dec	21.2	19.9	17.9	28.6	34.5		
1978							
4 Jan	14.0	14.5	15.0	33.5	33.9		
24 Feb	10.9	11.8	12.9	--	--		
17 Mar	14.0	14.0	14.0	32.3	35.7		
15 Apr	21.2	20.3	17.9	29.3	34.4		
24 May	24.7	24.8	23.2	30.2	34.9		
20 Jun	28.6	27.7	26.0	30.0	31.9		
17 Jul	30.7	27.0	25.4	33.1	35.1		
21 Aug	30.1	28.0	26.5	34.5	35.7		
27 Sep	27.9	28.6	27.4	31.5	32.0		
30 Oct	24.8	25.3	24.3	33.7	35.0	--	5.4
30 Nov	21.4	22.9	21.6	31.1	33.6	--	6.7
1979							
17 Jan	14.7	14.4	14.1	34.6	35.7	--	--
28 Jan	13.0	13.0	13.0	32.5	32.7	8.1	8.0
26 Feb	13.4	13.7	13.5	28.4	32.6	7.8	6.6
25 Mar	18.2	17.2	17.1	26.4	35.2	6.0	5.6
24 Apr	22.8	21.2	19.1	20.1	32.9	7.4	5.3
24 May	24.5	23.0	22.1	25.3	33.8	5.7	3.3
25 Jun	30.3	25.0	25.0	19.4	32.8	6.2	1.9
30 Jul	28.0	26.2	26.2	28.4	32.5	5.4	1.6
21 Aug	28.7	26.9	26.8	30.5	32.0	5.2	2.9
24 Sep	24.5	25.5	25.5	24.7	28.7	6.4	4.8
18 Oct	25.1	24.7	25.0	30.3	31.6	5.6	5.5
15 Nov	19.9	20.5	20.8	30.3	30.5	6.1	5.9
16 Dec	15.2	15.6	16.0	30.9	32.2	7.0	6.8
1980							
18 Jan	15.4	15.2	16.5	28.8	30.6	6.9	6.7
13 Feb	13.7	14.1	14.1	30.8	31.7	7.5	7.5
27 Feb	15.1	14.9	15.0	29.5	30.9	7.5	6.4

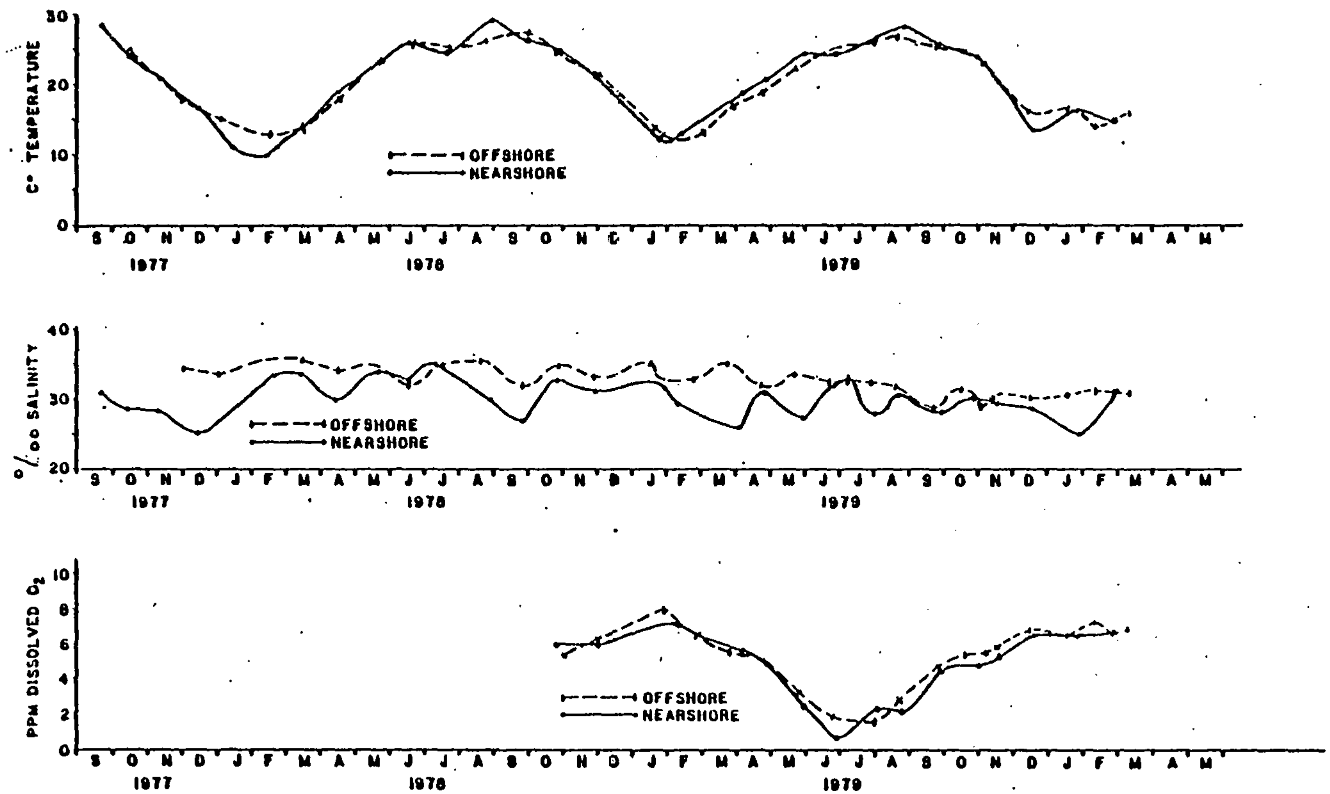


Figure 5-5. Comparison of the sediment temperature, near bottom salinity and dissolved oxygen concentrations of the offshore and nearshore study areas.

Table 5-4. Comparison of the average monthly temperature, salinity and dissolved oxygen of the surface and bottom of the water column and the sediment temperature at the nearshore site.

	Temperature (°C)			Salinity °/oo		Dissolved Oxygen ppm	
	Surface	Bottom	Sediment	Surface	Bottom	Surface	Bottom
1977							
22 Sep	29.1	28.7	28.6	30.3	31.0		
14 Oct	23.5	23.4	24.0	28.5	28.6		
11 Nov	21.3	20.8	21.9	28.0	28.1		
15 Dec	16.1	16.8	16.8	22.8	25.2		
1978							
14 Feb	8.5	10.0	10.0	--	--		
20 Feb	10.2	10.8	11.3	27.8	33.5		
15 Mar	14.5	14.0	14.0	31.2	33.7		
14 Apr	21.3	20.1	18.9	26.5	30.1		
26 May	26.8	25.4	23.3	29.9	33.9		
16 Jun	29.7	28.2	25.9	28.0	33.0		
13 Jul	30.1	24.9	24.5	33.1	35.2		
31 Aug	29.4	30.5	29.4	28.3	29.9		
28 Sep	28.0	28.0	26.2	25.1	26.7		
25 Oct	24.6	24.1	25.0	31.4	32.3	--	6.0
1 Dec	20.3	21.3	21.2	25.7	31.2	--	6.0
1979							
28 Jan	12.0	12.0	11.8	32.0	32.0	8.2	7.7
13 Feb	13.9	12.7	12.9	24.9	29.4	8.8	7.3
5 Apr	20.7	21.4	18.7	23.5	26.2	6.5	5.7
26 Apr	23.1	22.0	20.7	22.7	31.1	5.5	5.0
1 Jun	25.6	24.6	24.4	24.3	27.5	5.5	2.5
28 Jun	29.3	25.0	24.3	19.8	32.0	5.6	0.7
8 Jul	28.0	25.0	--	27.5	33.0	4.5	2.0
2 Aug	28.1	27.5	26.8	28.0	30.4	4.9	3.3
23 Aug	28.0	27.8	28.2	27.6	30.8	5.4	3.2
26 Sep	24.1	25.0	25.6	22.5	28.4	6.3	4.5
29 Oct	22.9	23.1	23.9	26.7	30.5	6.5	4.8
19 Nov	19.1	19.5	20.5	27.1	29.4	6.3	5.4
19 Dec	13.5	14.2	13.7	26.7	28.5	7.6	6.9
1980							
28 Jan	13.2	13.8	16.3	24.1	25.1	7.5	6.7

temperature varied much the same as at the offshore site with a slow warming trend in the spring. The seasonal sediment temperature trend (Figure 5-5) was similar to the offshore trend except that nearshore sediments were about 2.5°C colder in the winter 1977-78 period. Thus the populations at both sites were subjected to equivalent temperature changes.

There is evidence that organisms are periodically subjected to cooler water from deeper parts of the Gulf flowing across the continental shelf and encroaching on both study areas. During July 1978 the warming trend at both sites was interrupted temporarily by a decrease in both bottom water and sediment temperatures. The decrease was particularly evident at the nearshore site where the average sediment temperature was 5.5°C cooler than the surface water. Such a cold water transgression occurs at least periodically during the summer; data published by Temple, Harrington and Martin (1977) also indicated cold water intrusion across the northern Gulf of Mexico continental shelf.

5.7.3 Salinity

At the offshore site the bottom water usually averaged 2 to 4 °/₀₀ (parts per thousand) more saline than surface waters (Table 5-3). However, following heavy spring rains in 1979, gradients of 5 to 14 ppt were recorded. The bottom water salinity was fairly stable, generally varying between 32 and 36 °/₀₀ (Figure 5-5). The lowest average bottom salinity, 28.7 °/₀₀ in September 1979, followed flooding caused by two tropical depressions, one in July and one in August.

The bottom water at the nearshore site usually averaged more than 2 °/₀₀ more saline than surface waters, but because of proximity to local rivers and shallower depths, was usually less saline than the offshore water; the salinity has frequently been depressed below 30 °/₀₀ (Table 5-3). and there were often considerable differences between the bottom water salinities at the offshore and nearshore sites (Figure 5-5). Thus the benthos at the nearshore site are subjected to a less stable salinity regime than at the offshore site.

The surface water at both sites and the bottom water at the nearshore site are influenced by both local river discharge and Mississippi River discharge. The local influence was particularly evident during the February through June 1979 and August 1979-January 1980 periods. Very heavy rainfall on the watersheds of the Brazos, San Jacinto, Trinity and Sabine Rivers caused inland flooding and sent large quantitites of water into the Gulf, lowering the surface salinities to near 20 °/₀₀. According to Temple, Harrington and Martin (1977), Mississippi River water can be detected off the Texas coast 1.5 to 2 months after high discharge rates occur.

5.7.4 Dissolved Oxygen

Dissolved oxygen measurements were not made until October 1978. The values obtained with the Hach kit were not consistent with those obtained by the YSI instrument and will not be discussed. The D.O. at both sites was near 8 ppm (parts per million), as expected, when the water was cold (Tables 5-3, 5-4). As the temperature increased and the oxygen solubility decreased, the D.O. in the water decreased (Figure 5-5). The surface waters were always well oxygenated (>4.5 ppm), but the D.O. in bottom water fell below 2.0 ppm in June and July at both sites, concomitant with pronounced stratification of the water column. This phenomenon, termed hypoxia, had profound biological effects (discussed in section 5.7.5.3). Once the stratification was disrupted, D.O. increased to concentrations above 3.0 ppm, and continued to rise as the water cooled toward the end of the year.

5.7.5 Biota

The data being compared are from 26 collections at the offshore site made over a 26 month span (December 1977 - February 1980) and 26 nearshore site collections made over a span of 29 months (September 1977 - January 1980). During this period of study, more species were collected at the offshore site--232 offshore vs. 209 nearshore. The total number of individuals (all data summed) were quite different with the offshore population about 1.5 times larger--72717 offshore vs. 48085 nearshore (Table 5-5). The larger numbers of species and individuals indicate the offshore site is the more productive in terms of benthic populations.

In the early stages of the study, relatively few species were collected at all 15 stations in either site. As would be expected, the number has increased at both sites as the study progressed, and at the termination of the predisposal study, both sites were relatively similar in terms of the percentage of species occurring at a given number of stations (Table 5-5). Slightly higher percentages of species were ubiquitous (i.e. occurring at all 15 stations) and rare (i.e. occurring at only one station) at the offshore site.

Polychaete annelids dominated the populations at both sites, with amphipod crustaceans the second dominant. The combined polychaete and amphipod populations overwhelmingly dominated the offshore population (91.6% of all individuals), but were less dominant at the inshore site

Table 5-5. Comparison of the biological characteristics of the offshore and nearshore study areas (all data summed).

	Offshore	Nearshore
Total number of species	232	209
Total number of individuals	72717	48085
% of species occurring at all 15 stations	20.3	16.3
% of species occurring at 10 or more stations	31.9	30.1
% of species occurring at 5 or more stations	48.3	51.2
% of species occurring at only 1 stations	33.6	30.1
% polychaete individuals	79.7	69.5
% amphipod individuals	11.3	7.5
% bivalve individuals	3.0	8.4
% nemertean individuals	2.4	7.4
% "other" individuals	3.0	7.2

(77.0%) (Table 5-4).

About 90% of the individuals collected at each site belonged to the 20 most abundant species at that site (Table 5-6). Twelve of the species occur in both lists, but only 5 were among the 10 most abundant at both sites. The polychaete, *Paraprionospio pinnata* was the numerically dominant species at both sites, but the dominance was less at the offshore site.

5.7.5.1 Areal Distribution of the Benthos

5.7.5.1.1 Numbers of Species

The numbers of species collected apparently decreased toward the northeastern part of the offshore study area (Figure 5-6). The cause of this gradient is unknown; no apparent gradient in sediments or other abiotic factors existed at the offshore site.

The nearshore site also had a species gradient with a rather abrupt decrease in numbers of species occurring toward the northeast end of the site (Figure 5-7). We speculate this gradient may be related to increasing distance from the Brazos River.

5.7.5.1.2 Numbers of Individuals

The offshore total populations were generally in the 4500-5500 individuals range (Figure 5-8). The exceptions were at station F1, which had the lowest number of individuals, and at station A3, which had over 5800 individuals; station A3 appears to have been the center of an area with slightly larger populations than the surrounding stations. There does not appear to be a population gradient corresponding with the species gradient.

Table 5-6. Comparison of the 20 most abundant species at the offshore and nearshore study areas. Also listed are the total numbers of individuals and the cumulative percentage of the total population.

Rank	Offshore Site Species	# ind	cum %	Nearshore Site Species	# ind	cum %
1.	*Paraprionospio pinnata**	24869	34.0	*Paraprionospio pinnata**	20655	43.0
2.	*Nereis micromma**	6642	43.1	*Abra aequalis*°	5773	55.0
3.	*Ampelisca abdita*+	5425	50.6	*Magelona phyllisae**	3907	63.1
4.	*Aricidea* sp.*	5322	57.9	*Ampelisca agassizi*+	2511	79.3
5.	*Magelona phyllisae**	3862	63.2	*Cerebratulus lacteus*	1841	72.1
6.	*Lumbrineris tenuis**	3246	67.7	*Mediomastus californiensis**	1232	74.7
7.	*Prionospio cristata**	2692	71.4	*Nereis micromma**	1180	77.2
8.	*Armandia maculata**	1730	73.8	*Armandia maculata**	1018	79.3
9.	*Mediomastus californiensis**	1690	76.1	*Ampharete americana**	813	81.0
10.	*Ampelisca verrilli*+	1688	78.4	*Nephtys incisa**	667	82.4
11.	*Prionospio cirrobranchiata**	1624	80.6	*Sigambra tentaculata**	591	83.6
12.	*Cossura delta**	1282	82.4	*Balanoglossus* sp.	532	84.7
13.	*Photis macromanus*+	1034	83.8	*Diopatra cuprea**	402	85.5
14.	*Ampelisca agassizi*+	1008	85.2	*Photis macromanus*+	396	86.3
15.	*Nephtys incisa**	601	86.0	*Cossura delta**	361	87.1
16.	*Cerebratulus lacteus*	564	86.8	*Ampelisca abdita*+	355	87.8
17.	*Tharyx marioni**	563	87.6	*Lumbrineris tenuis**	340	88.5
18.	*Corbula operculata*°	505	88.3	*Cirratulus hedgpethi**	319	89.2
19.	*Ceratocephale* sp.*	490	89.0	*Polydora ligni**	319	89.8
20.	Nemertean (yellow band)	462	89.6	*Phoronis architecta*	305	90.4
	Others	5789	100.0	Others	4567	100.0

* - Polychaeta
\+ - Amphipoda
° - Bivalvia

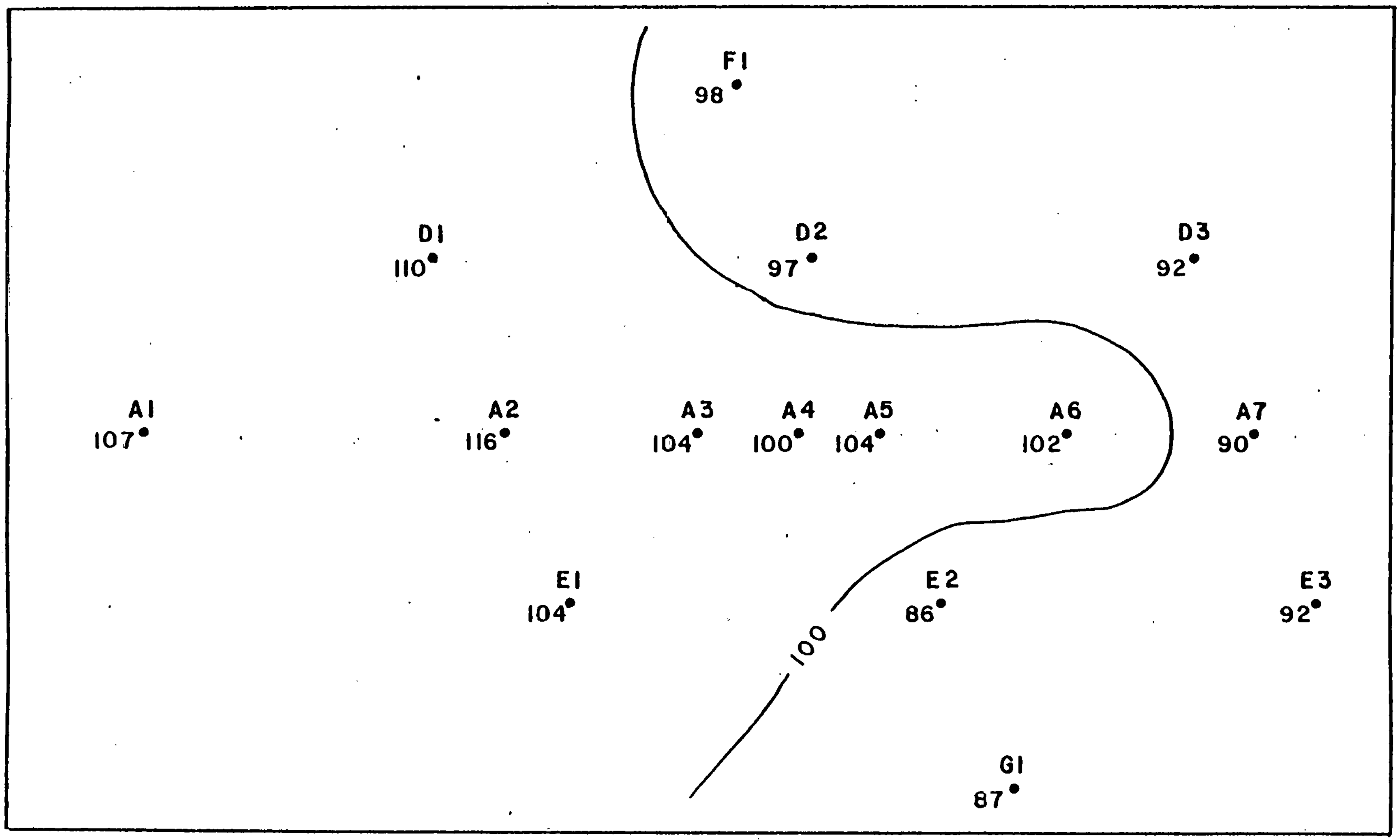


Figure 5-6. Areal distribution of total species collected at the offshore site. Suggested isodemes have been superimposed.

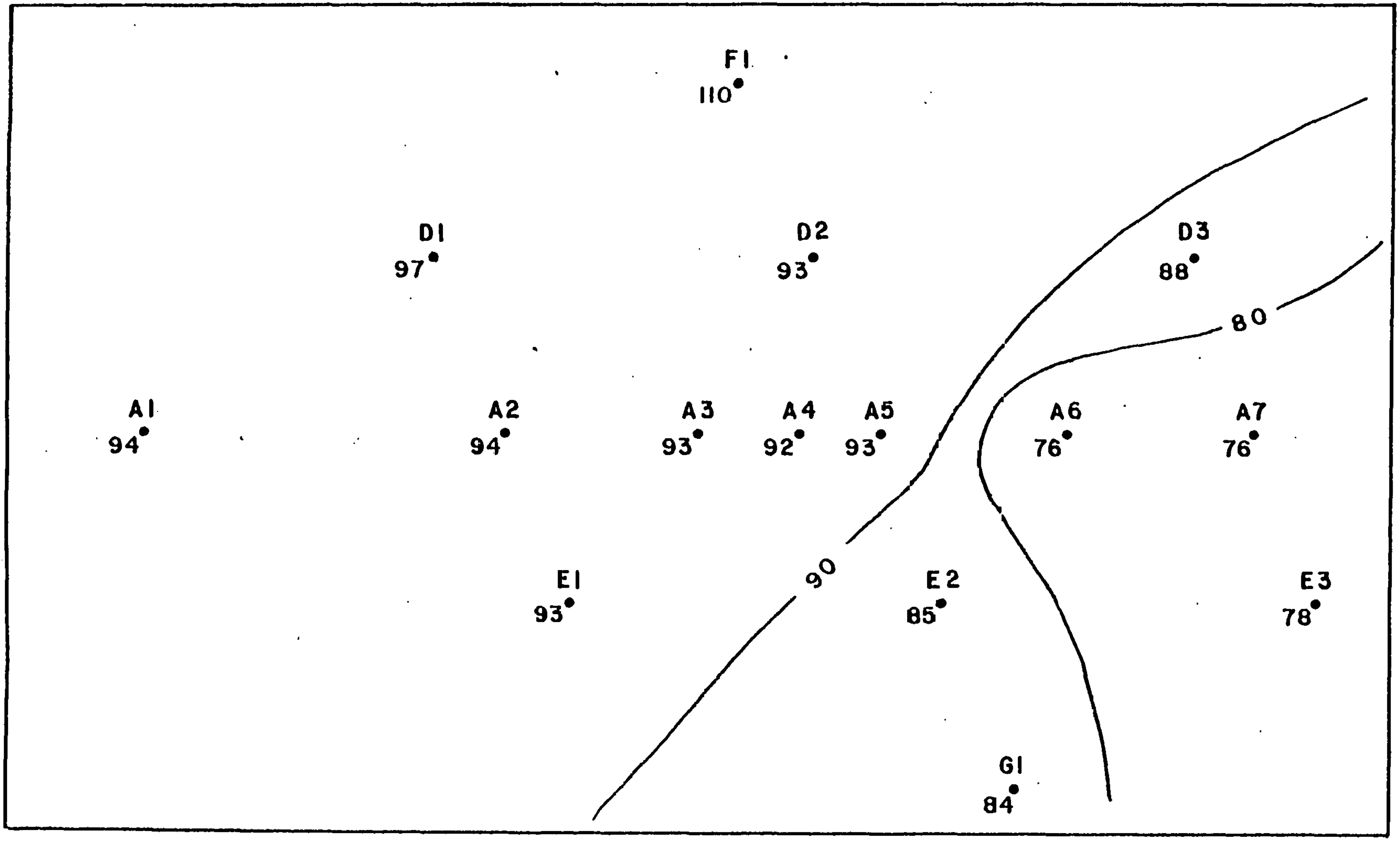


Figure 5-7. Areal distribution of total species collected at the nearshore site. Suggested isodemes have been superimposed.

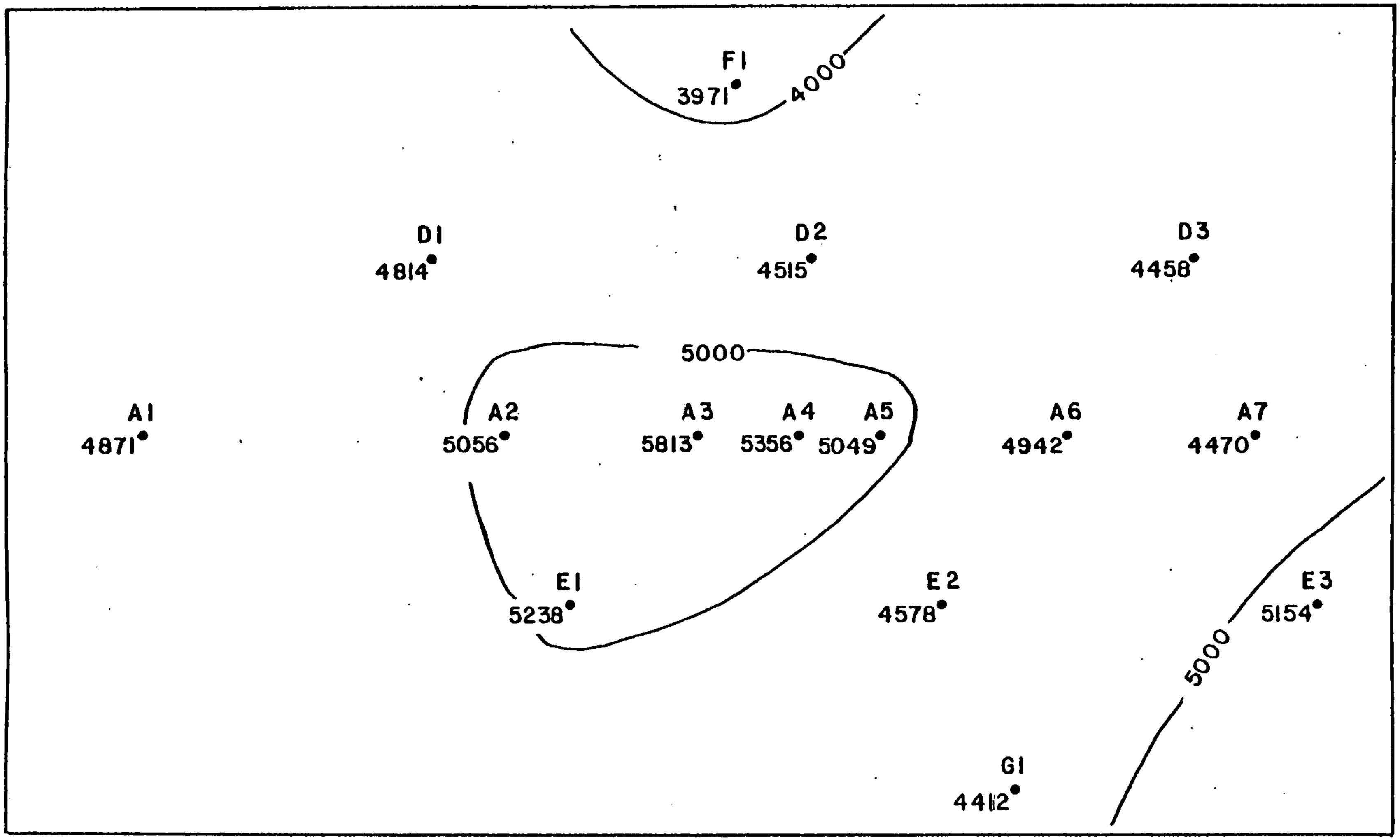


Figure 5-8. Areal distribution of total populations collected at the offshore site. Suggested isodemes have been superimposed.

The nearshore site population distributional pattern suggests that an elliptical area with depressed populations, centered at station A3, occurred near the center of the study area, and that the benthos density increased to the northeast and southwest (Figure 5-9). The cause of this pattern is unknown; the population and diversity patterns were inverse with the smallest number of species in the northeast area where the largest populations were found. The large populations at stations F1, D1, A1, and A2 resulted from a massive set of the bivalve *Abra aequalis* between November and December 1979. Why this set was principally confined to these four stations is unknown, although possibly related to proximity to the Brazos River (Figure 5-1).

5.7.5.1.3 Cluster Analysis

All the offshore stations were contained in one tight cluster indicating a high degree of ecological similarity between stations (Figure 5-10). This was expected. The 77 species used in the analysis all occurred 10 or more times during the study and comprised 98.6% of all individuals collected. The ecological similarity was also quite high between species (i.e. co-occurrence of many species at many stations). Principal components analysis, using the species that occurred at each station at least once, also indicated a high degree of similarity between stations (Figure 5-11).

The nearshore stations were separated into two groups, I and II (Figures 5-12, 5-13). Group I, the larger, was comprised of 10 stations, while group II was comprised of five stations in the northeastern part of the study area. Group II stations had two faunal components that were different from Group I, viz: species group IV members occurred

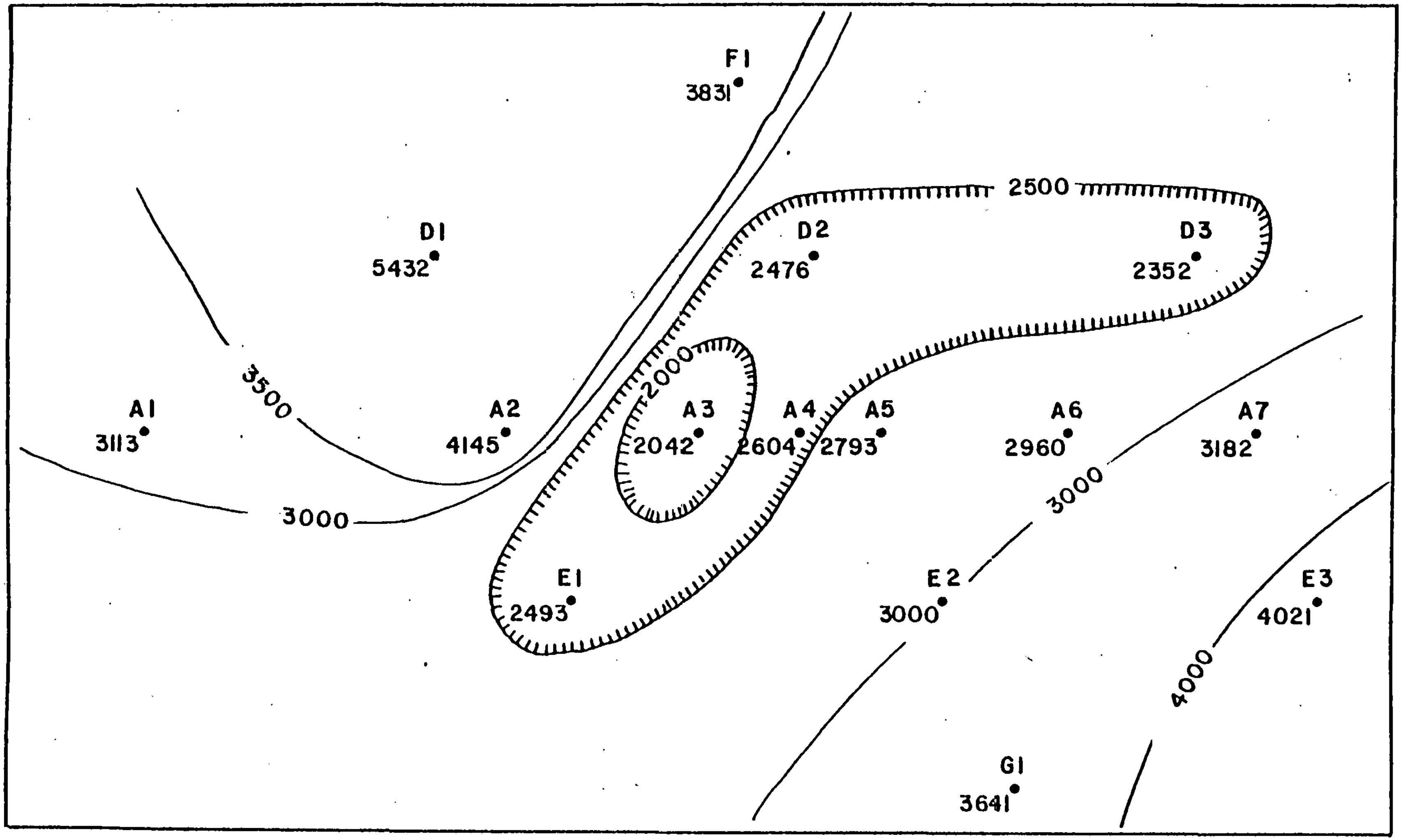
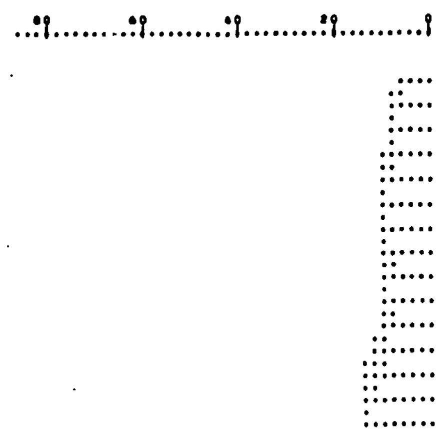
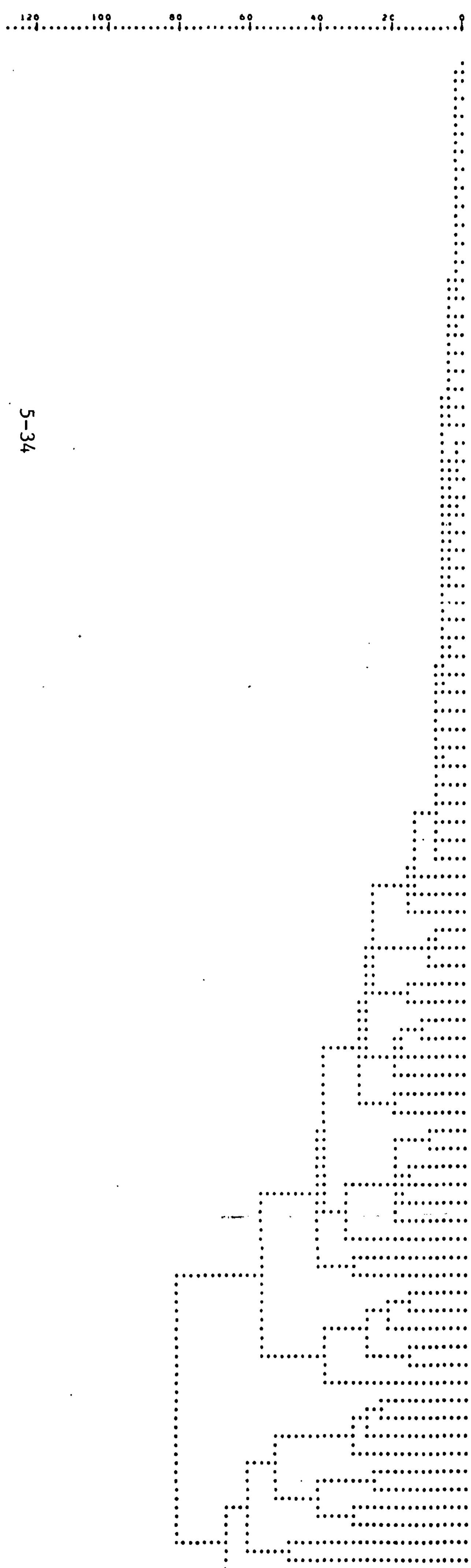


Figure 5-9. Areal distribution of total populations collected at the nearshore site. Suggested isodemes have been superimposed.





STATIONS	3	4	2	9	11	1	5	6	8	7	13	12	15	10	14
PARAPRIONOSPIO PINNATA	1569	1606	1743	1465	1493	1281	1725	1645	1748	1881	2005	1863	1888	2126	1302
AMPELISCA VERRILLI	118	107	112	98	125	107	107	112	104	132	132	124	55	142	73
NEREIS MICROMMA	570	472	434	857	484	455	453	445	434	353	438	380	416	324	427
MAGELONA PHYLLISAE	347	333	285	322	233	358	293	281	269	219	225	169	186	171	201
COSSURA DELTA	78	89	76	73	109	80	102	101	89	110	98	82	84	83	58
ARICIDEA SUECICA	606	592	318	295	475	463	318	395	384	216	293	209	271	145	232
PRIONOSPIO CRISTATA	315	225	250	145	258	185	225	166	133	130	114	170	176	64	96
PRIONOSPIO CIRROBRANCHIATA	167	133	118	97	126	217	77	80	86	100	87	98	55	50	89
MEDIOMASTUS CALIFORNIENSIS	128	169	171	90	115	108	100	111	149	100	83	65	81	75	149
NEMERTEA (YELLOW BANDED)	36	28	39	32	27	27	29	31	47	28	33	22	38	22	26
NINOE NIGRIPES	43	25	22	27	32	28	25	23	17	18	15	27	19	12	27
THARYX MARIONI	62	57	53	40	52	34	27	34	44	20	29	15	21	18	47
GLYCERA AMERICANA	25	27	21	25	24	21	35	24	28	24	33	11	14	15	22
CERATOCEPHALE SP	55	32	22	31	44	38	22	31	57	26	23	26	43	14	26
LUMBRINERIS TENUIS	360	314	351	201	271	397	383	152	260	69	90	115	123	100	280
ARICIDEA FRAGILIS	26	22	20	13	23	25	7	14	21	5	12	5	8	4	20
NEMERTEA (WHITE)	30	24	27	19	26	48	26	18	18	21	22	13	18	24	16
TELLINA VERSICOLOR	37	30	25	20	27	47	29	21	18	11	11	21	11	7	22
DIOPATRA CUPREA	11	13	13	13	13	7	14	7	11	6	5	8	6	6	9
AMPHARETE ACUTIFRONS	26	36	13	27	38	38	34	19	14	21	16	20	14	16	13
TEREBRA PROTEXTA	15	13	12	6	6	14	7	13	7	7	6	5	5	4	10
AMPELISCA ABDITA	332	343	268	309	466	232	452	461	205	221	501	546	424	340	205
STHENELAIS BOA	42	26	24	15	42	15	26	22	20	28	41	25	34	36	20
AUTOMATE EVERMANNI	33	18	14	12	26	7	16	17	14	14	19	20	17	18	16
ARMANDIA MACULATA	139	59	102	95	105	65	87	133	129	114	164	114	115	150	115
CEREBRATULUS LACTEUS	34	30	28	28	31	24	34	64	52	35	50	53	30	26	47
NEPHTYS INCISA	30	40	46	5	45	23	33	41	24	60	51	89	28	48	24
SIGAMBRA TENTACULATA	31	36	31	26	23	18	16	27	19	38	27	17	32	31	18
PRIONOSPIO PYGMAEA	16	9	7	11	15	8	12	11	12	11	7	23	15	11	11
TRACHYPENEUS SIMILIS	4	4	5	3	6	6	4	7	7	7	5	15	8	4	4
SPIOCARCINUS LOBATUS	12	8	11	14	14	15	5	9	9	9	11	24	13	6	13
PHOTIS MACROMANUS	59	55	52	59	77	69	136	131	35	63	50	78	41	71	61
MAGELONA ROSEA	17	6	9	11	17	14	14	11	3	12	18	11	11	11	5
LISTRIELLA BARNARDI	6	5	2	4	9	6	4	6	2	2	5	4	7	4	1
ABRA AEQUALIS	39	33	23	45	23	25	42	16	29	33	24	33	17	13	16
NOTOMASTUS LATERICEUS	12	14	8	23	12	4	6	6	15	2	8	6	7	7	14
CORBULA BARRATTIANA	34	18	15	21	11	28	36	7	29	24	32	31	17	14	62
NATICA PUSILLA	14	11	6	6	4	10	10	7	1	11	13	12	8	2	7
ALPHEUS FLORIDANUS	1	3	3	3	3	3	3	1	3	7	4	5	2	6	3
ANAITIDES ERYTHROPHYLLUS	1	3	3	2	2	1	3	3	1	3	2	6	1	2	2
AMPELISCA AGASSIZI	55	65	52	18	43	26	88	94	121	22	102	146	37	88	17
MAGELONA FILIFORMIS	4	8	5	1	10	4	8	6	6	12	10	5	10	5	1
VITRINELLA HELICOIDEA	5	9	3	6	6	2	4	6	4	25	10	6	8	8	3
SYNCHELIDIUM AMERICANUM	2	3	6	3	6	1	2	2	1	3	7	4	7	6	2
PRIONOSPIO CIRRIFERA	45	9	13	4	18	1	10	8	10	15	21	12	8	10	9
PHORONIS ARCHITECTA	27	16	5	23	2	13	17	9	6	10	21	2	7	2	18
CORBULA (VARICORBULA) OPER	62	14	15	31	29	65	10	7	15	20	106	86	18	17	6
ASYCHIS ELONGATA	2	3	1	4	5	4	2		1	3	5	8	3		4
GYPTIS BREVIPALPUS	3	3	8	4	4	1		3	1		2	1	4	2	8
AMPHARETE AMERICANA	6	2	3	3	7	5		4	1		1	1	3	2	4
CHASMOCARCINUS MISSISSIPPI	1	4	3	3	3	4		2	4	2	1	1	4	2	4
LEPIDASTHENIA SP		1	1	1	3	1	2	1	3	1	1	1	1		1
PINNIXA B		3	2	1	1	2	1	5	1		1	4	4		1
PRIONOSPIO DAYI	5	4	3	3	5	6	3	2	1		4	3		7	1
DOSINIA SP.	3	1	1	3	2	2	1	2	1		4	1			1
SPIOPHANES BOMBYX	3	7	5	6	4	6	11	3	6		1			1	3
UNCIOLA IRRORATA	1	1	4	3	1		1	2	1	2	2	2		1	1
OXYUROSTYLIS SMITHI	3	3		3	4	2	4			2	2	8	1	6	12
PINNIXA (BULBOUS ROSTRUM)	1	1	2	3	6	4	1				1	1	2	3	1
PINNIXA SAYANA	2	4	1	8	5	5	2	4	1	2	1	6	1	2	
POLYDORA LIGNI	1		1	3	4	4	6	5	3	4	1	5	1	1	
OXYUROSTYLIS SALINOI	3	3	3	1	1	2	4	5	5	2	1	2			
GYPTIS VITTATA	1	2	2		2	3	4	2	3	2		2	2		
MONOCULODES EDWARDSI	1	3	3		2		4	2	2	3	2	8	2	1	
PARAONIS GRACILIS	2	2	1	1		1	3	1		2	1	2	1	1	
VOLVULELLA TEXASIANA	2	1		1	1			1		1	2	2	2	2	
LEMBOS BRUNNEOMACULATA MAC	4		2	1		2		5	7	3	6	8		6	3
NEPHTYS CF PARVA	1		7		2	3		1	1	1	1	1	4		3
SPIOCHAETOPTERUS OCULATUS	2	4	5	1			6	4	3	4	2		3		3
ANCISTROSYLLIS JONESI	2	3	1	2			1	1	2	3	1			1	1
MALACOCEROS VANDERHORSTI	4	8		3	6		7	3	2	1	2		2	2	1
NEREIS SUCCINEA	4	8		1	2	2	3	2	1	2	2				3
ANADARA TRANSVERSA	8	3		8	2	2	4		7	2	1			1	4
OWENIA FUSIFORMIS		2		1	4	6	1		1	1			3		1
LITOCORSA CF STENNA	5	6	2	6	2	2		1	1				1		5
TURBONILLA, BROWN BAND	2	2	3	2	3	2						1			2
GIANT SPERM		1	3	1	1	4		1	5			1			9
NUCULANA CONCENTRICA	1	1	3	8		3		1						4	3
ANCISTROSYLLIS HARTMANAE			2	2	2	1	1	2	2		2				
NEMERTEA (YELLOW & PURPLE)			2	2	1	1	1		1			2			
AGLAOPHAMUS VERRILLI	3	1	6	3		1	3		9		2				2
SCOLOPLOS (LEODAMUS) RUBRA	1	1	21	1	1	1			7						
TEREBELLIDES STROEMI		1	6		1		1	1	1				1	1	
PSEUDEURYTHOE AMBIGUA	3		1	1				3	1				1		
MYSIDOPSIS BAHIA	14	1	2			2	16				3	4		1	

Species groups: 1 (PARAPRIONOSPIO PINNATA through NEPHTYS CF PARVA); 2 (SPIOCHAETOPTERUS OCULATUS through OWENIA FUSIFORMIS); 3 (LITOCORSA CF STENNA through NUCULANA CONCENTRICA); 4 (ANCISTROSYLLIS HARTMANAE through SCOLOPLOS (LEODAMUS) RUBRA); 5 (TEREBELLIDES STROEMI, PSEUDEURYTHOE AMBIGUA)

Figure 5-10. Dendrogram and two way table of the offshore benthic data, comparing stations and species.

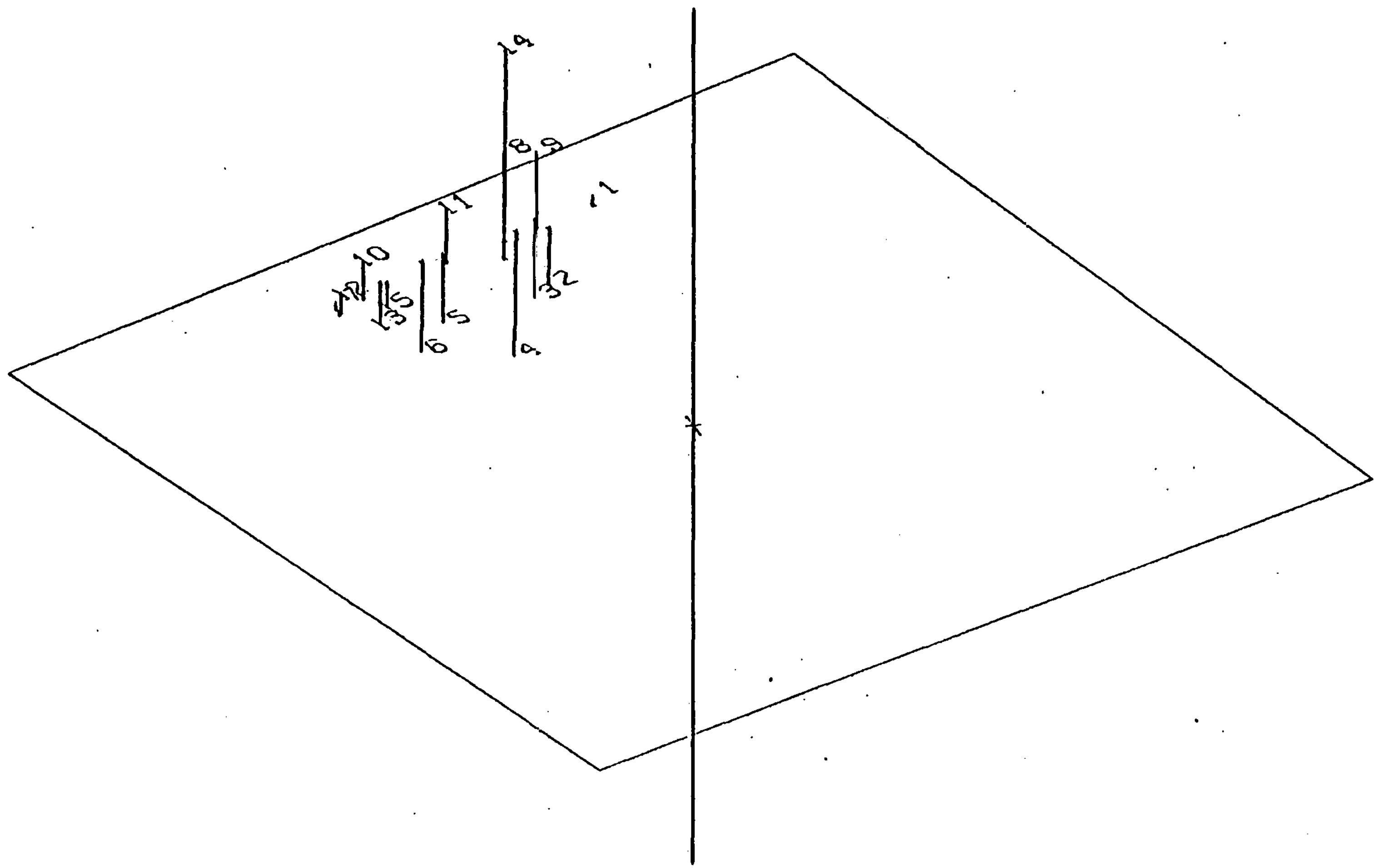
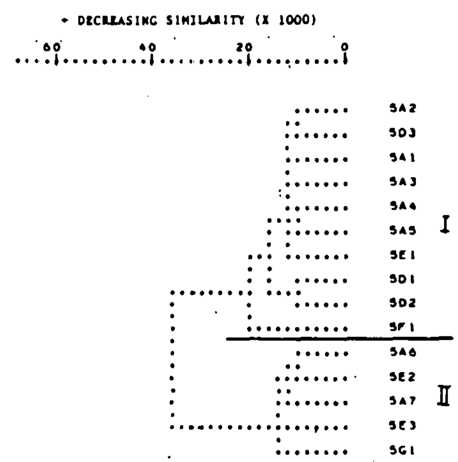
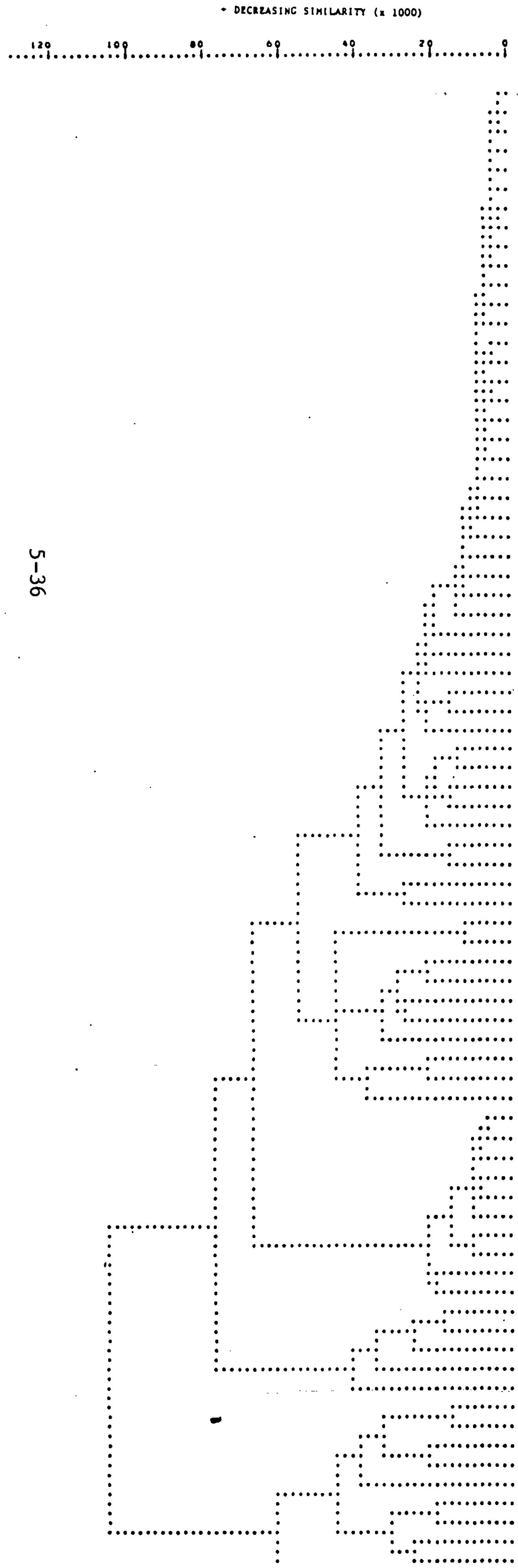


Figure 5-11. Results of principal components analysis of the offshore site benthic data using those species which occurred at all stations at least once.





STATIONS

Group	Species	2	10	1	3	5	11	4	9	8	14	6	12	7	13	15
	PARAPRIONOSPIO PINNATA	1305	1096	1168	915	1298	1338	1009	1119	1517	651	1619	1760	1763	2235	1822
	MEDIOMASTUS CALIFORNIENSIS	105	62	90	64	85	80	64	75	78	52	81	108	111	101	76
	CEREBRATULUS LACTEUS	183	103	136	134	131	126	113	123	118	104	91	141	50	93	155
	NEREIS MICROMMA	92	68	113	61	59	62	54	100	97	157	70	59	53	67	68
	NEMERTEA (YELLOW BANDED)	15	13	15	14	16	16	12	5	11	18	21	22	16	15	18
	STHENELAIS BOA	14	21	21	7	8	17	22	16	30	17	29	19	32	11	27
	NEPHTYS INCISA	43	34	20	32	53	39	49	21	34	7	53	79	69	58	85
	COSSURA DELTA	22	15	16	13	31	16	21	7	14	8	31	32	40	49	46
	ARMANDIA MACULATA	72	49	51	55	56	70	61	50	25	40	104	79	63	59	74
	NOTOMASTUS LATERICEUS	2	5	6	3	8	6	6	5	5	2	10	6	4	9	6
	SIGAMBRA TENTACULATA	18	40	22	22	27	38	29	37	125	15	70	41	38	38	27
	AUTOMATE EVERMANNI	9	5	6	9	17	5	5	4	4	2	6	8	11	8	5
	NEMERTEA (WHITE)	6	6	3	11	8	6	10	11	3	9	10	7	7	4	10
	MAGELONA PHYLLISAE	300	239	389	194	163	145	179	265	555	966	124	89	55	107	67
	NUCULANA CONCENTRICA	13	12	21	8	14	8	13	18	30	28	6	9	5	8	4
	DIOPATRA CUPREA	50	19	65	28	22	25	30	41	35	32	13	14	6	11	8
	AMPHARETE AMERICANA	59	77	102	23	80	43	58	89	105	22	28	16	37	28	16
	PINNIXA SAYANA	82	14	18	17	30	20	27	28	13	38	19	12	3	7	9
	NATICA PUSILLA	8	11	6	12	8	6	5	12	17	11	4	10	6	1	4
	MAGELONA ROSEA	3	6	6	9	2	6	5	7	9	9	5	2	5	3	5
	CORBULA BARRATTIANA	23	11	22	30	22	27	25	31	6	7	13	34	19	9	11
	THARYX MARIONI	3	4	2	5	4	1	3	2	2	7	5	2	4	1	4
	TRACHYPENEUS SIMILIS	5	4	1	2	1	2	2	2	5	4	5	2	3	4	4
1	LEPIDASTHENIA SP	10	12	8	7	7	18	20	16	8	11	13	4	4	1	3
	NINOE NIGRIPES	5	9	2	6	3	4	14	4	7	17	8	7		4	3
	GLYCERA AMERICANA	5	5	6	2	5	6	11	4	5	12	2		1	3	2
	POLYDORA LIGNI	21	26	24	16	85	6	56	10	8	21	5	13	20	5	3
	OXYUROSTYLIS SALEMOI	9	7	6	7	2	3	7	31	9	14	5	5	5	1	
	PHORONIS ARCHITECTA	4	8	16	62	28	7	39	19	32	82	3	5		1	
	LEMBOS BRUNNEOMACULATA MAC		3	13	3	4	2	73	9	3	7	8	1	5	1	1
	PRIONOSPIO CIRROBRANCHIATA		2	1	1	4	1	6	2	1	9	1	2		4	6
	TEREBRA PROTEXTA	1	8	1	2	3	5		4	9	13	3	5	3	2	3
	PRIONOSPIO CRISTATA	1	1	4	1	5	5		8	7	3	2	2		3	4
	NEMERTEA (YELLOW & PURPLE)	3	1			6	2	2	1	3	3	3	1	1	1	4
	LUMBRINERIS TENUIS	22	10	47	15	6	13	7	38	58	59	6	4	2	4	9
	ABRA AEQUALIS	1471	127	447	42	57	47	36	84	2283	033	17	47	60	11	41
	MICROPHOLIS ATRA	5	3	12	2	1	4	2	3	8	10					1
	SIGAMBRA BASSI	5	8	3	4	4	3	2	4	9	2	1		1		1
	ANEMONE UN ID	10	3	14	2	7	4	11	1	6	1		3		1	1
	SPIOCHAETOPTERUS OCULATUS	5	5	5	2	2	6	5	3	10			1	4	2	
	SPIOCARCINUS LOBATUS	3	2	1	1		5	2	5	3			2	2	1	7
	STYLOCHUS ELLIPTICUS	4	1	1			1	4	4	1	3	1	2		1	
	ANADARA (LUNARCA) OVALIS	1	1			1	1		1	1	2		1		1	
	LOVENELLA GRACILIS (COL)	3	3	6	3	3	3	6	1			1	1			
	HOLOTHUROIDEA	6	5	6	4	2	1	3				1	2			
	LIMA PELLUCIDA	1		1	1	2	1			1	1	1	4	1		3
	CEREBRATULUS LURIDUS			3	1	4	2			1	2	1	1		1	1
	PRIONOSPIO CIRRIFERA	3	4	1	4	5	2				1	2		3	1	3
	AMPHARETE ACUTIFRONS	2	2	2	3	2		1		2	6	2	1	2	1	
	THALASSEMA HARTMANI	3	1	1	5	2			1	1		1	2	10		1
	PALEONOTUS HETEROSETA		1	2	3	5	3		2	4	2		3			3
	SQUILLA EMPUSA		1	1		1	1		2		1	1	1			1
	ANADARA TRANSVERSA	1	1	8		1		1	1		1	1				1
	CIRRATULUS HEDGPETHI	10	22	12	10	15	32	27	2	6	10	17	35	19	35	53
	ANCISTROSYLLIS JONESI	1	6	1	2	2	3	3	2	2	2	2	5	4	7	6
	VITRINELLA HELICOIDEA	2	10	9	3	5	17	11	5	11	6	7	10	11	45	25
	AMPELISCA ABDITA	12	11	32	5	46	6	34	7	4	11	62	21	39	36	25
2	ALPHEUS FLORIDANUS	4	2	4	1	8	5	16	1	3	5	12	12	7	6	4
	ARICIDEA SUECICA	1	2	1	1	3	5	3		5	4	13	4	10	13	6
	BALANOGLOSSUS	14	20	7	21	68	47	141	38	19	17	52	13	16	43	7
	PHOTIS MACROMANUS	4	11	25	25	67	16	100	5	2	9	27	11	34	26	38
	AMPELISCA AGASSIZI	16	60	9	38	71	26	42	15	5	1	229	148	384	726	741
	AMPELISCA VERRILLI		1	5	1	8	5	4		1	2	1	5	13	26	2
	VOLVULELLA TEXASIANA		4	1	2	3	3	6				2	6	5	3	3
	CHASMOCARCINUS MISSISSIPPI	2			1	1	1	2				1	1	3	1	3
3	POLYDORA SOCIALIS				4	2	2	2	4			4	2	3		1
	LISTRIELLA BARNARDI	1			2			2	2			3	2	6	1	
	ANEMONE (BRWN SPOT RIM)				1		1		2		1		1	2	2	1
	NEREIS SUCCINEA	7	1	1	1	1		2	6	3	7			1	1	
	PHASCOLION STROMBI	4	2	1	3	2		1	4	4	9					
	PAGURUS ANNULIPES			3	2	1	2	1	4	3	15	1	1	3		
	NASSARIUS ACUTUS	1	1	2	1		2		4	5	14		1	1		
	HEMIPHOLIS ELONGATA	2		2	1	1	2			1	4					
4	TELLINA VERSICOLOR			3	1	1	2	3	2		4			1		2
	ANAITIDES ERYTHROPHYLLUS			1	1	2	1	1	1		4					
	PRENNIA SP.			3	6	1		3	2	1	4				1	
	LEPIDONOTUS SUBLEVIS			6		1		1	3	1	4					
	PINNIXA CRISTATA		2	3	3					8	2	1			1	

Figure 5-12. Dendogram and two way table on the nearshore benthic data, comparing stations and species.

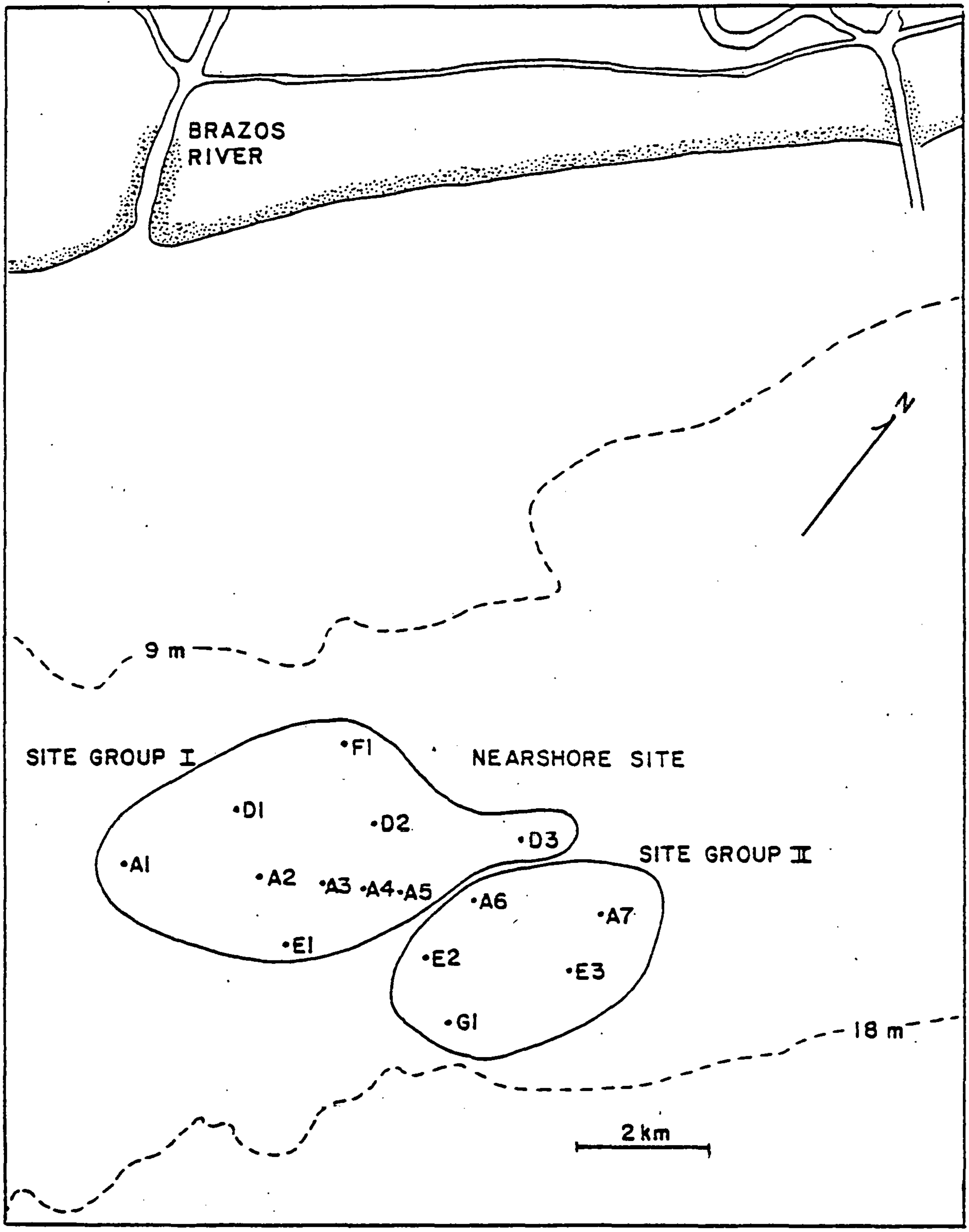


Figure 5-13. Map of the nearshore study area showing the division of stations into site groups.

rarely in site group II, while species group II members occurred somewhat more frequently. The existence of the smaller northeastern site group was also suggested by principal components analysis; the group II stations of cluster analysis also formed a compact cluster in principal components analysis (Figure 5-14).

The separation of the nearshore stations into two clusters has occurred consistently throughout the study. In April, May, and June 1978, three stations were added in the northeastern part of the study area to determine if the smaller station cluster was an isolated patch or part of a larger area. The additional stations clustered with the group II stations, indicating that the factors causing the population differences continue to the northeast an unknown distance (Figures 5-15, 5-16).

5.7.5.2 Temporal Changes of the Benthos

5.7.5.2.1 Numbers of Species

It was expected that the seasonal changes in total numbers of species would be similar at both sites. This was not always the case and diversity trends can be divided into three periods (Figure 5-17). From December 1977 through June 1978 the offshore and inshore trends were similar, but were not coincident; the nearshore changes occurred one month later than at the offshore site. During this period, the number of species increased gradually through April (offshore) or May (nearshore), then declined rapidly. The second period was July through October 1978 when the trends were inverse. The offshore species increased in number in August to the maximum yet recorded, held steady through September, then declined rapidly. While the number of offshore species

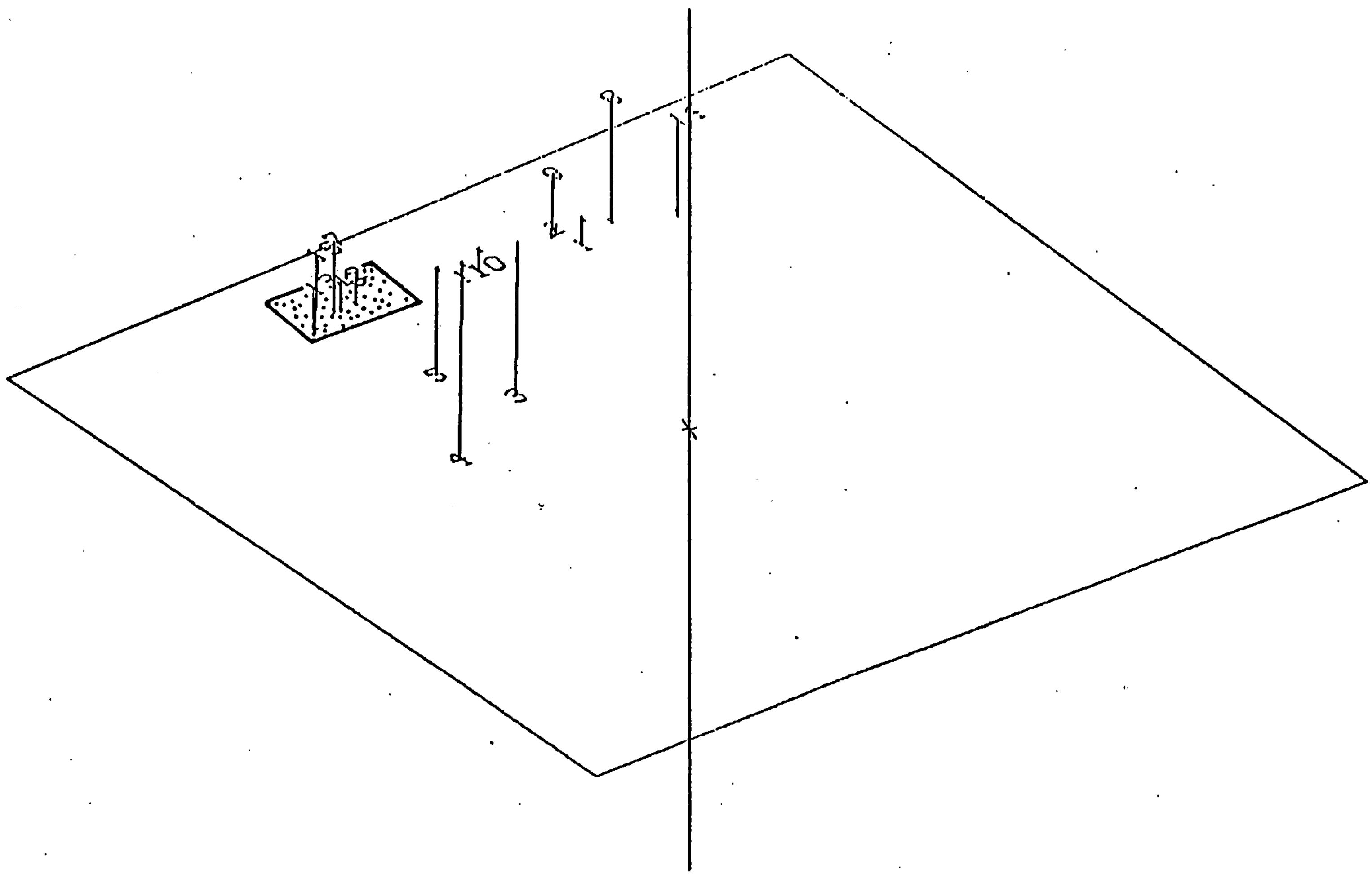


Figure 5-14. Results of principal components analysis of the nearshore site benthic data using those species which occurred at all stations at least once. Stations in the northeast station group is indicated by the enclosed block.

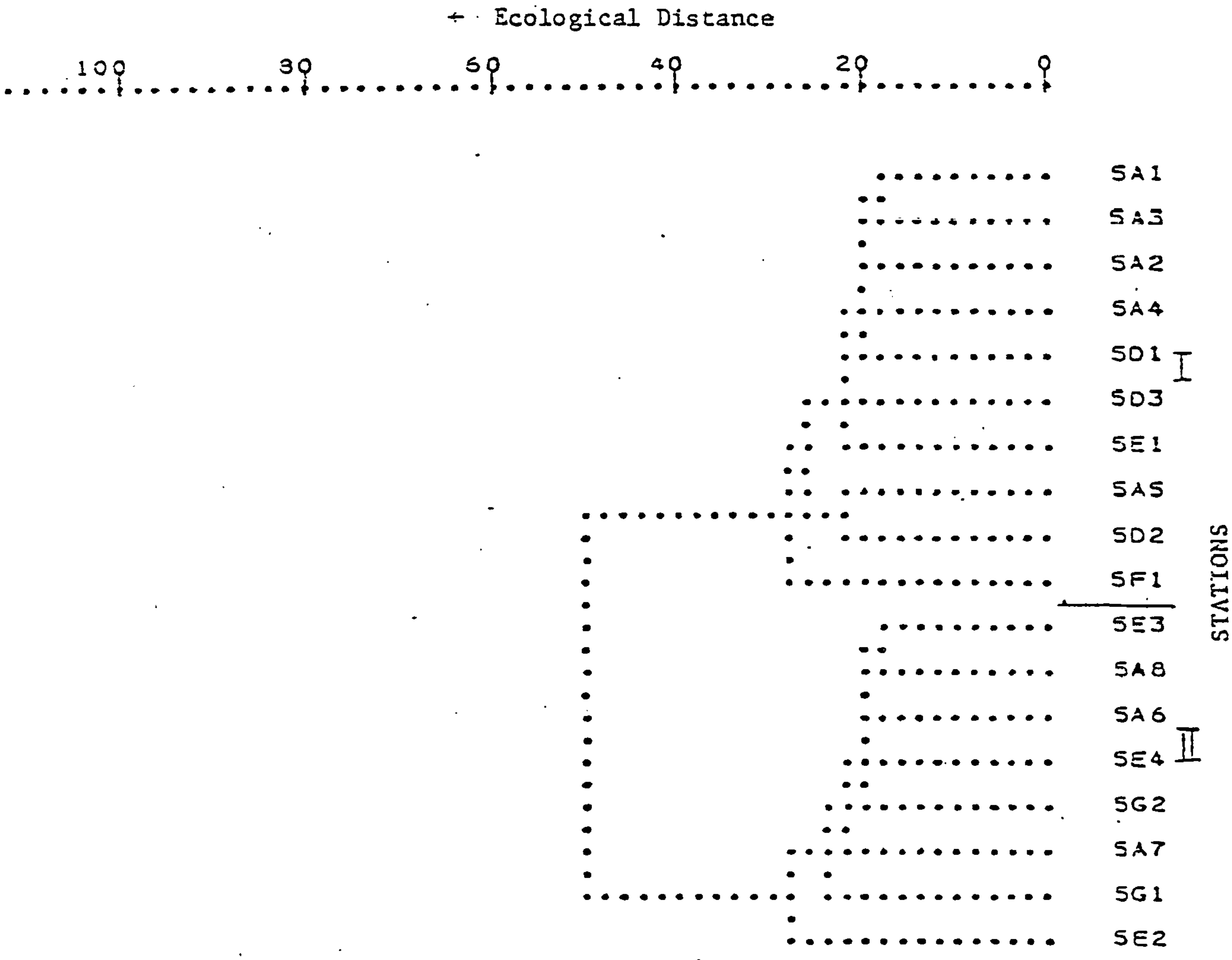


Figure 5-15. Dendrogram of the nearshore site benthic data comparing the data from 18 stations, April-June 1978.

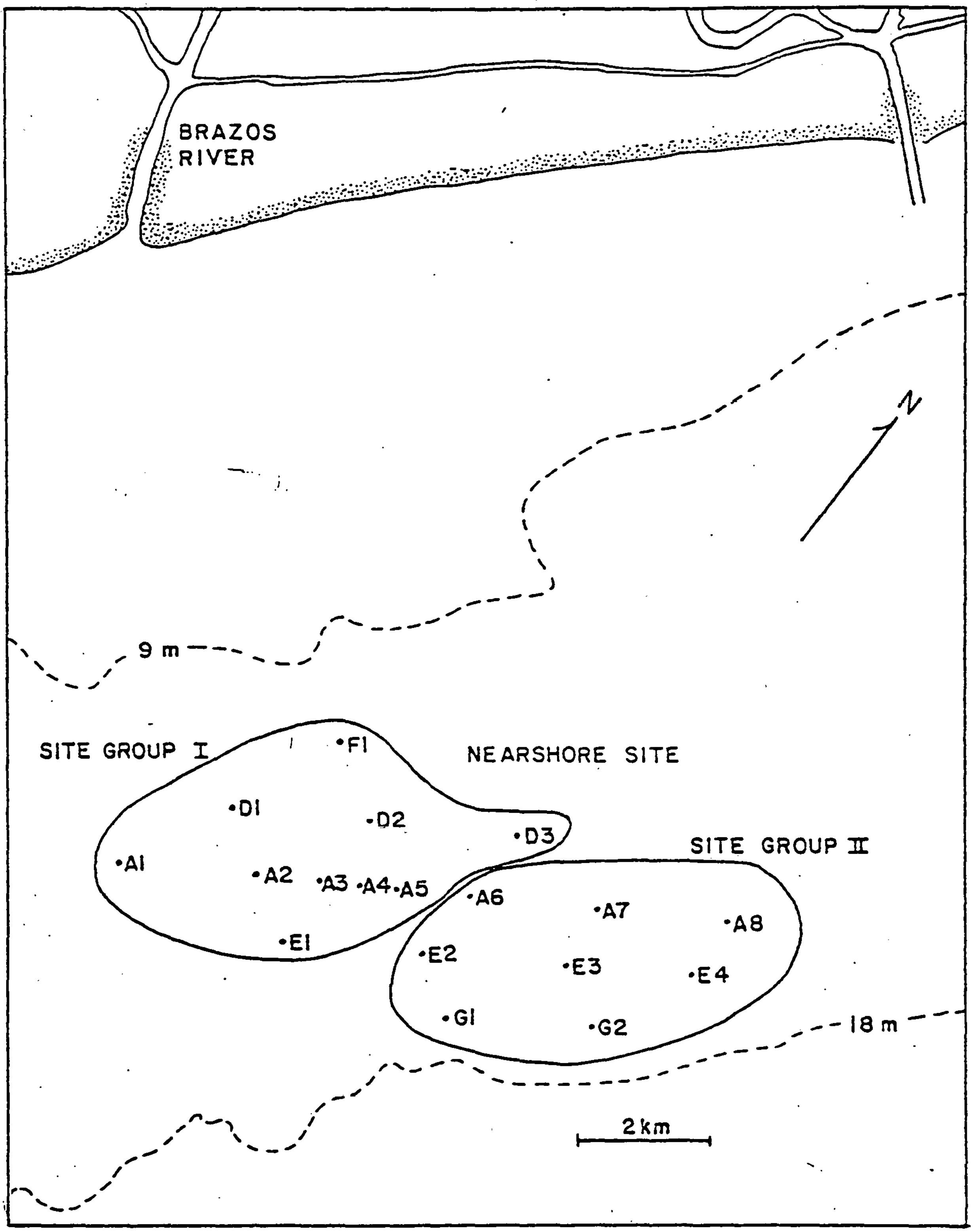


Figure 5-16. Map of the nearshore study area showing the division of 18 stations into two site groups.

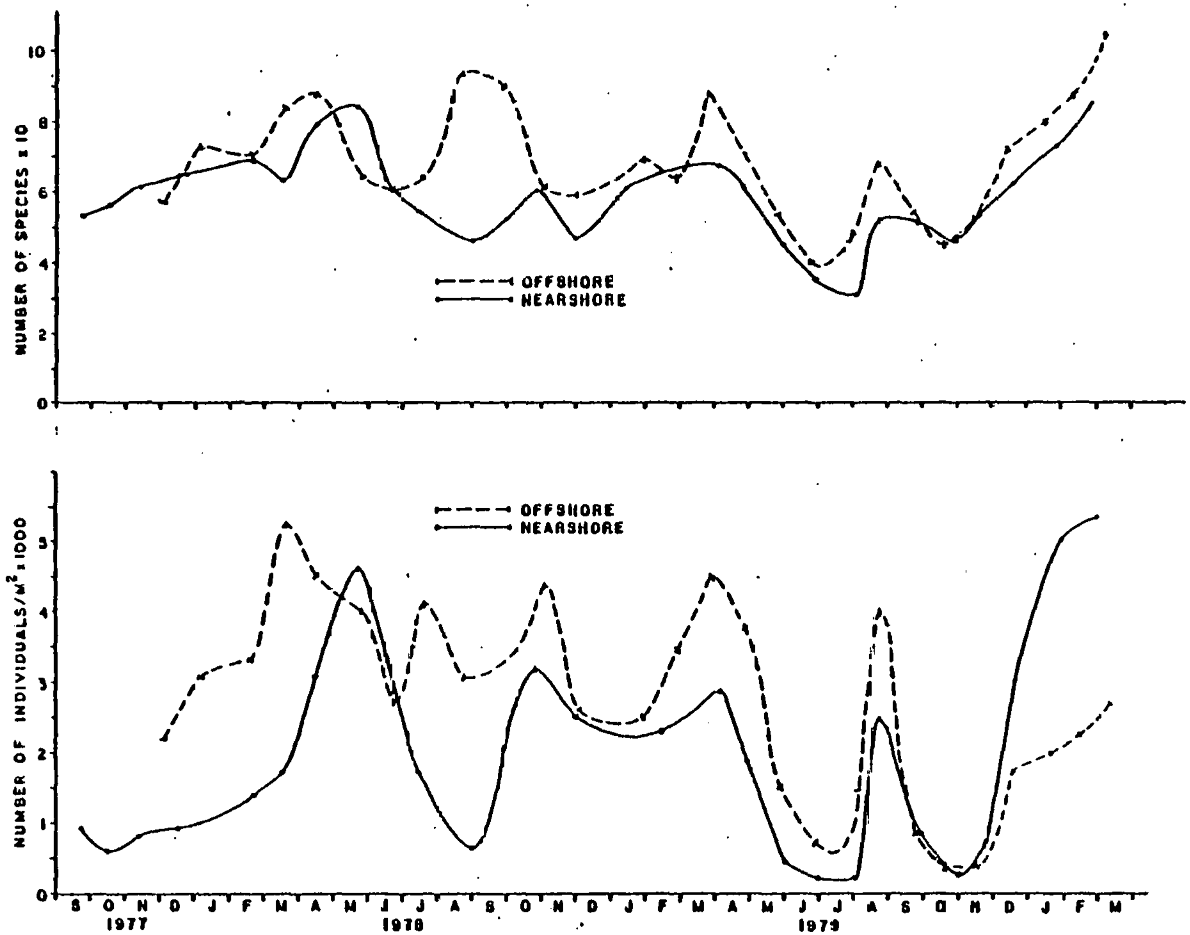


Figure 5-17. Comparison of the temporal trends of the total numbers of species and individuals collected at the offshore and nearshore study areas.

increased, the number of species at the nearshore site decreased and the lowest diversity was recorded while the offshore was highest. We suspect the nearshore site experienced hypoxic conditions in early summer whereas the offshore site did not (D.O. was not recorded at that time). During the third period, November 1978 through January 1980, the trends were similar; a decrease in diversity from October to November was followed by an increase through April (the increases during both periods 1 and 3 appear to be correlated with the onset of fall temperature decreases and cold winter temperatures). Between April and July, the number of species declined drastically concomitant with the hypoxia that affected both sites. After the hypoxic conditions were disrupted, the number of species increased again through March 1980.

5.7.5.2.2 Populations

The monthly population (pooled data, each collection) changes were also expected to be similar at both sites, but this again was not always the case (Fig. 5-17). The population trends can also be divided into three periods. From December 1977 through March 1978 the populations increased at both sites, but there were large differences in population totals. From April through July 1978 there were no similarities, and since August 1978, the population changes at the two sites have been synchronous. The expected population trend was an increase beginning in the fall as water temperatures decreased, culminating in peak densities in the spring (March-May), followed by a population decrease through late fall (October-November). This pattern basically occurred in 1977-1978 at least through August, but was better defined at the nearshore site. In summer 1978, nearshore population densities decreased rapidly with a minimum density occurring in late August, whereas the conditions occurred at the nearshore site only. Immediately after the low density at the nearshore site, the population increased and did not decrease in the fall as expected. In the summer of 1979, the severe hypoxia which affected both sites (see section 5.7.3) killed many organisms and caused low population densities. A brief population irruption occurred in August 1979, following reoxygenation of bottom waters, as many species took advantage of depopulated bottoms and lack of competition. The irruption was immediately followed by a decrease in density in September-November, the period in which lowest populations are expected.

The benthic population densities are undoubtedly being controlled by a combination of abiotic (temperature, salinity, D.O.) and biological (predation, competition) factors. Predation may play a great role. On numerous occasions we have seen young shrimp (probably *Trachypenaeus similis*) actively searching in the bottom with their thoracic legs. In the laboratory we determined that young shrimp of related species (*Penaeus setiferus, P. aztecus*) would seize and eat any suitably sized polychaete presented. If numerous worms were offered, the shrimp would eat one while holding the others by the thoracic legs. Available nekton data (October 1977-May 1979) suggest a possible inverse correlation between nektonic and benthic populations. Nektonic abundance was greatest in the October -December period of both 1977 and 1978 when benthic population densities were low. Twice as many fish and shrimp were collected in 1977 as 1978 which may partly explain why the fall benthic populations were much lower in 1977 than 1978 (Fig. 5-18).

5.7.5.2.3. Percent Composition of Dominant Taxa

The temporal changes of the percent composition of the dominant

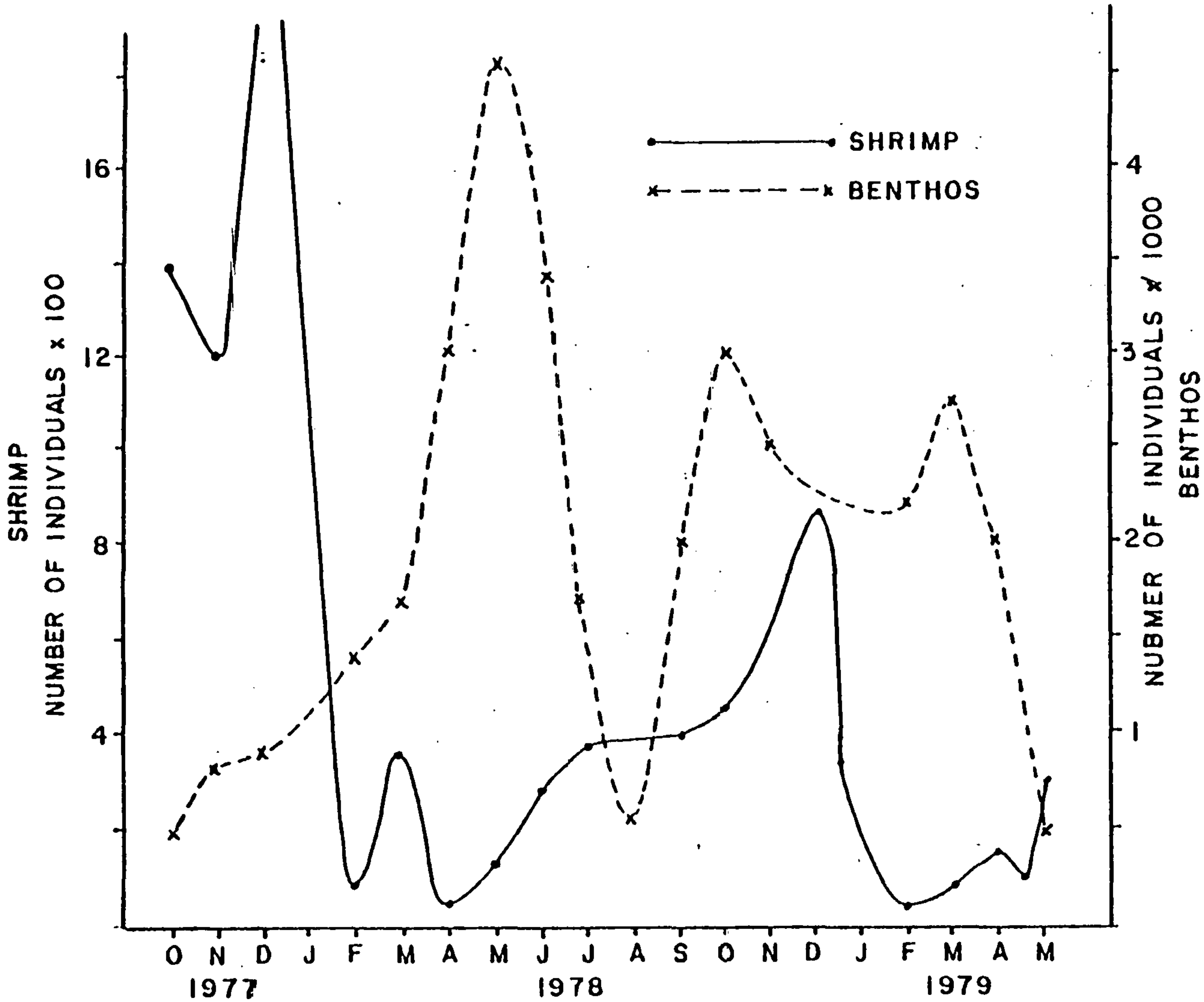


Figure 5-18. Comparison of shrimp populations and benthic populations at the nearshore study area.

taxa at each site were compared (Figure 5-19). At both sites, polychaetes were overwhelmingly dominant while *Paraprionospio pinnata* populations were large. At both sites, the polychaete percentage began to decrease about November 1978 with a concomitant increase in amphipods. This trend was abruptly reversed when hypoxic conditions occurred. The amphipods were virtually eradicated and had only slightly recovered by February 1980. The third most abundant groups were bivalve mollusks and nemerteans at the offshore and nearshore sites, respectively. Bivalves were usually abundant only in the July-August periods when large numbers of juveniles were present. These populations were quickly reduced either by predation or natural death. Nemerteans were generally present in small numbers throughout the study at the nearshore site.

5.7.5.2.4 Selected Species

The monthly abundance of several species were plotted. These species were principly selected because they were among the numerical dominants at one or both sites.

The polychaete *Paraprionospio pinnata*, because of its numerical dominance, was very influential in determining the monthly fluctuations of population densities at both sites during the first year of study. At the offshore site *P. pinnata* was less dominant and the total individuals of all other species usually exceeded the *P. pinnata* population (Figure 5-20). The lack of continual dominance of one species was a partial cause of the rather erratic population fluctuations at the offshore site. Since December 1978, the *P. pinnata* populations have been very small, except during the brief irruption in August 1979, following the disruption of hypoxic conditions.

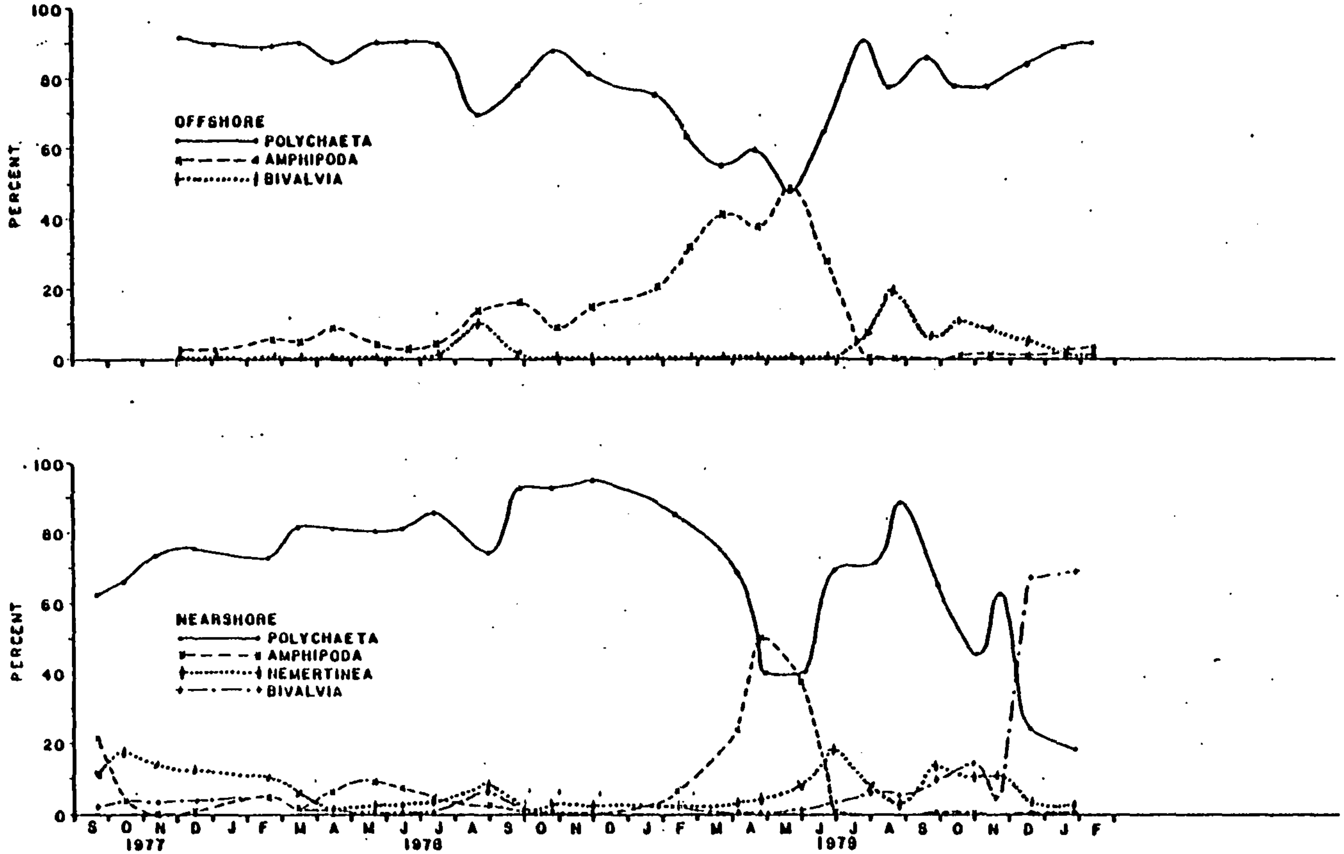


Figure 5-19. Comparison of the temporal trends of the dominant taxa at the offshore and nearshore sites.

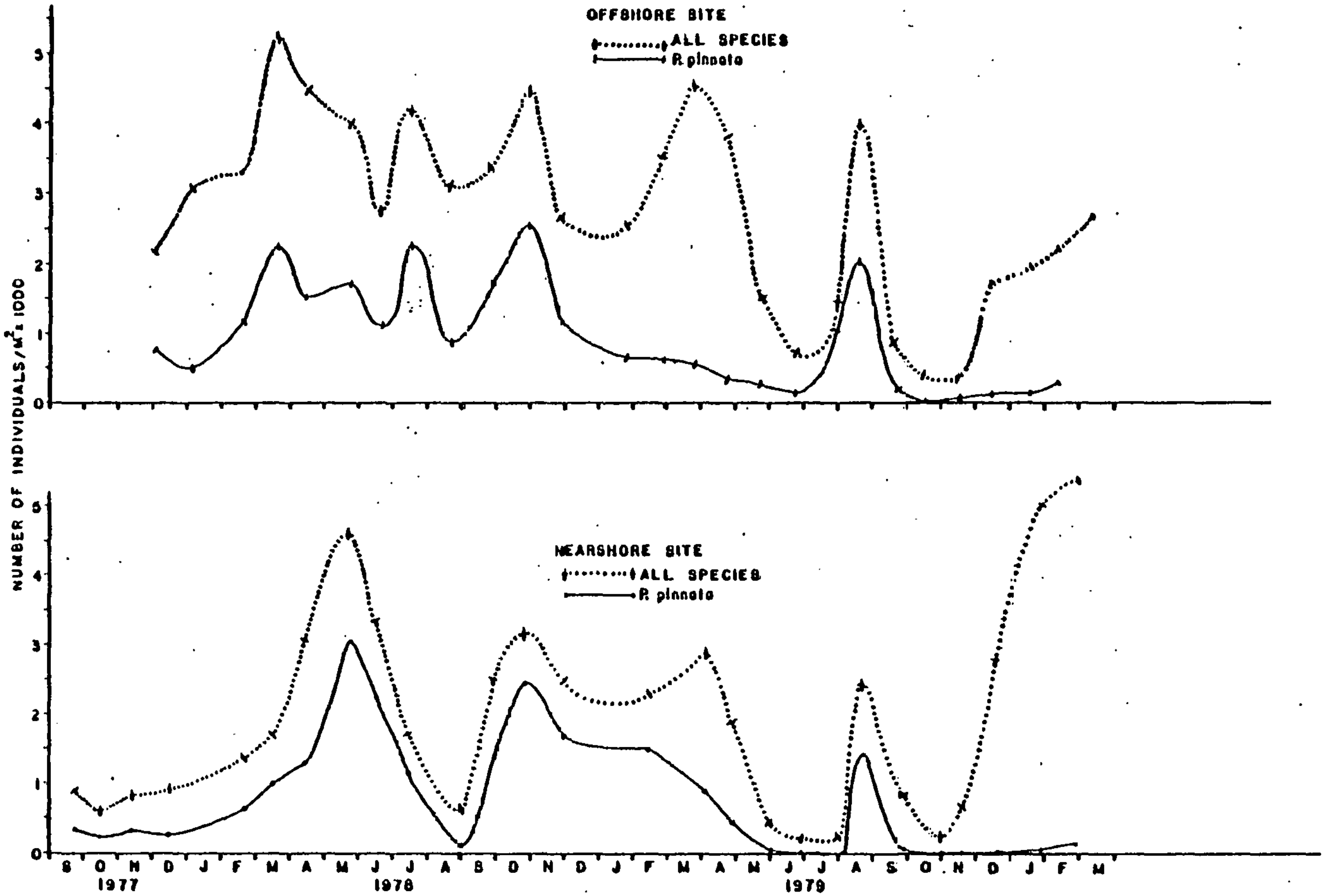


Figure 5-20. Comparison of the Paraprionospio pinnata populations and total benthic populations at the offshore and nearshore sites.

P. pinnata was more dominant at the nearshore site and its population fluctuations largely determined the total population density through October 1979. A massive set of the bivalve *Abra aequalis* occurred in December 1979, and this species has dominated the population since then (Figure 5-20). In contrast to the offshore site, all other individuals usually did not exceed the *P. pinnata* population.

The bivalve mollusks (Figure 5-21) appeared to be spring or early summer spawners; peak abundance occurred primarily in August, and usually the species occurred predominantly at one site or the other. This rather uniform trend was disrupted by the large set of *Abra aequalis* in November or December 1979.

Like the bivalves, the amphipods displayed a pronounced seasonality, increasing in abundance principally in the spring months, with lesser increases in the fall (Figure 5-22). The large amphipod population were virtually eradicated during the hypoxic period and had made only a slight recovery by early 1980.

Unlike either the bivalves or the amphipods the polychaete annelids did not display a well-defined tendency to produce large populations in a particular part of the year (Figure 5-23). These apparently erratic trends may be caused by a variety of factors, i.e. predation, generation time, competition, etc.

5.7.5.2.5 Cluster Analysis

Cluster analyses were performed comparing the co-occurrence of species and cruises (months). The offshore collections were separated into two major clusters, each of which was composed of smaller clusters (Figure 5-24). The larger major cluster contained three smaller clust-

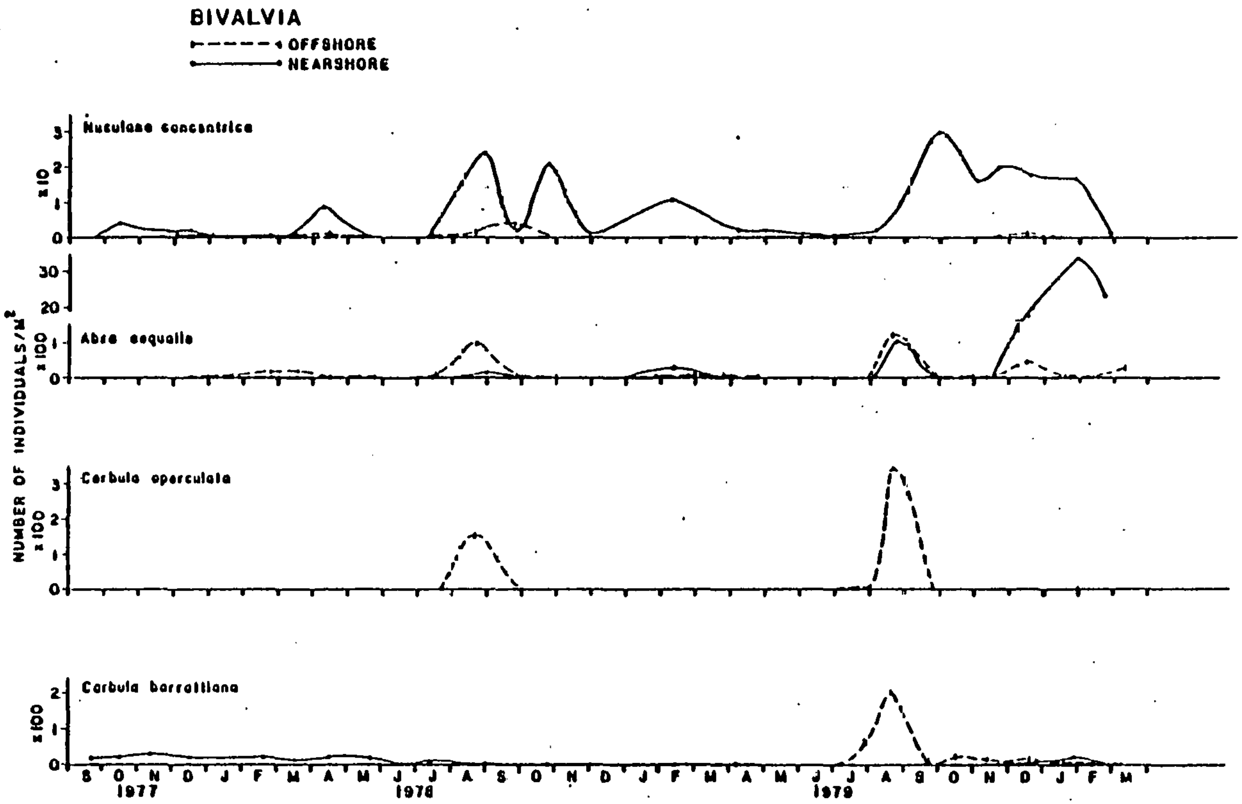


Figure 5-21. Comparison of the temporal trends of selected species of bivalve mollusks at the offshore and nearshore sites.

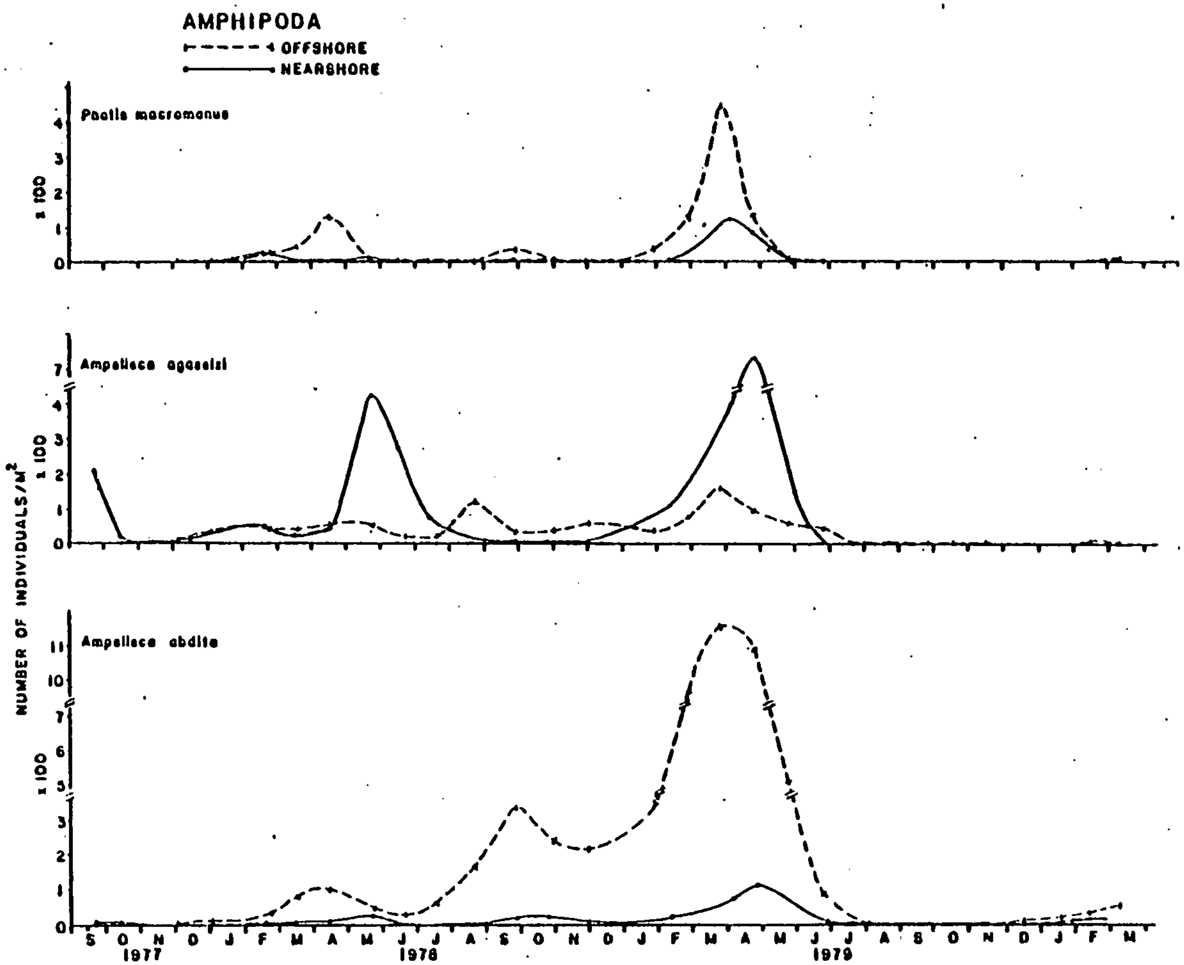


Figure 5-22. Comparison of the temporal trends of selected species of amphipod crustaceans at the offshore and nearshore sites.

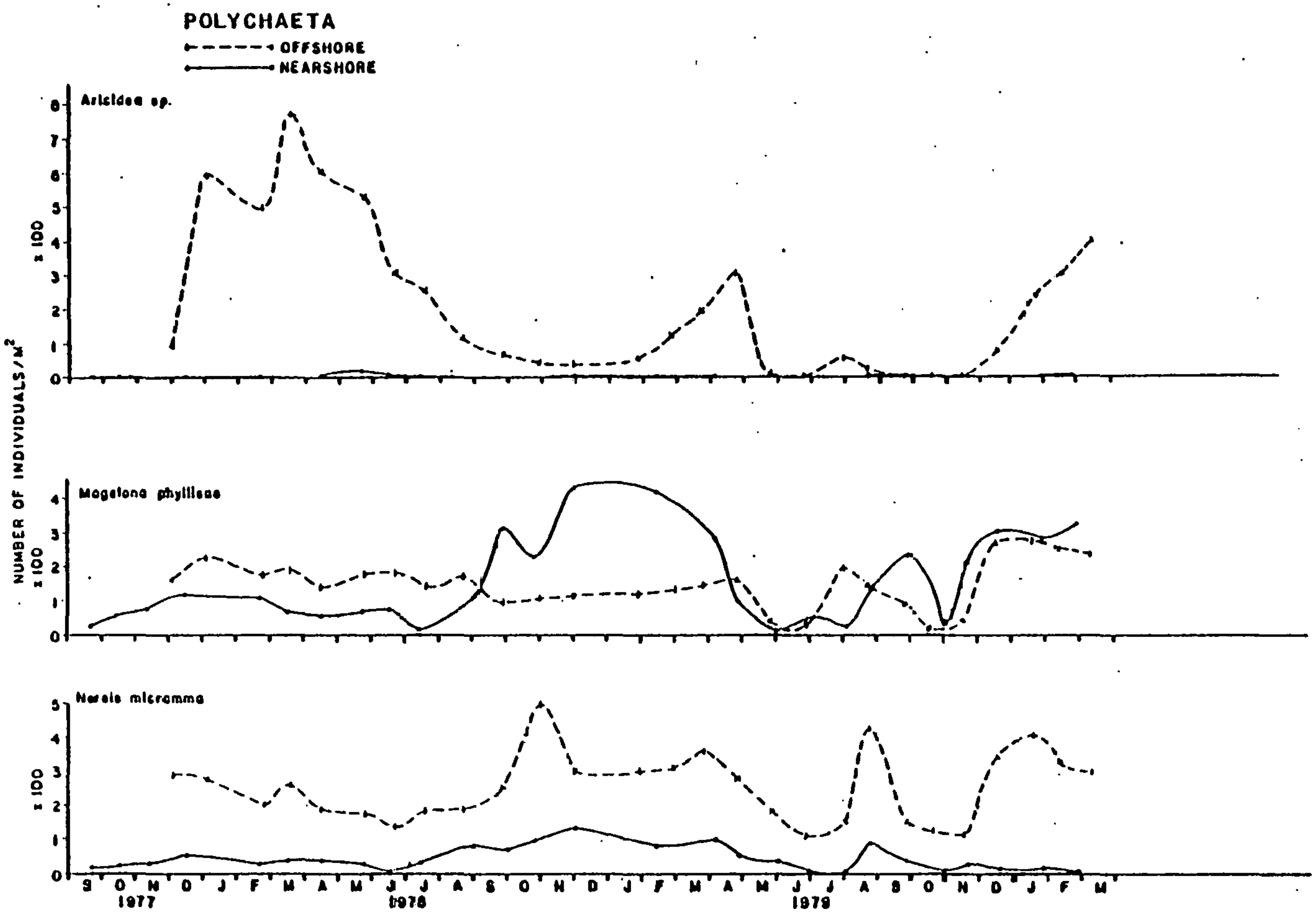


Figure 5-23. Comparison of the temporal trends of selected species of polychaetous annelids at the offshore and nearshore areas.

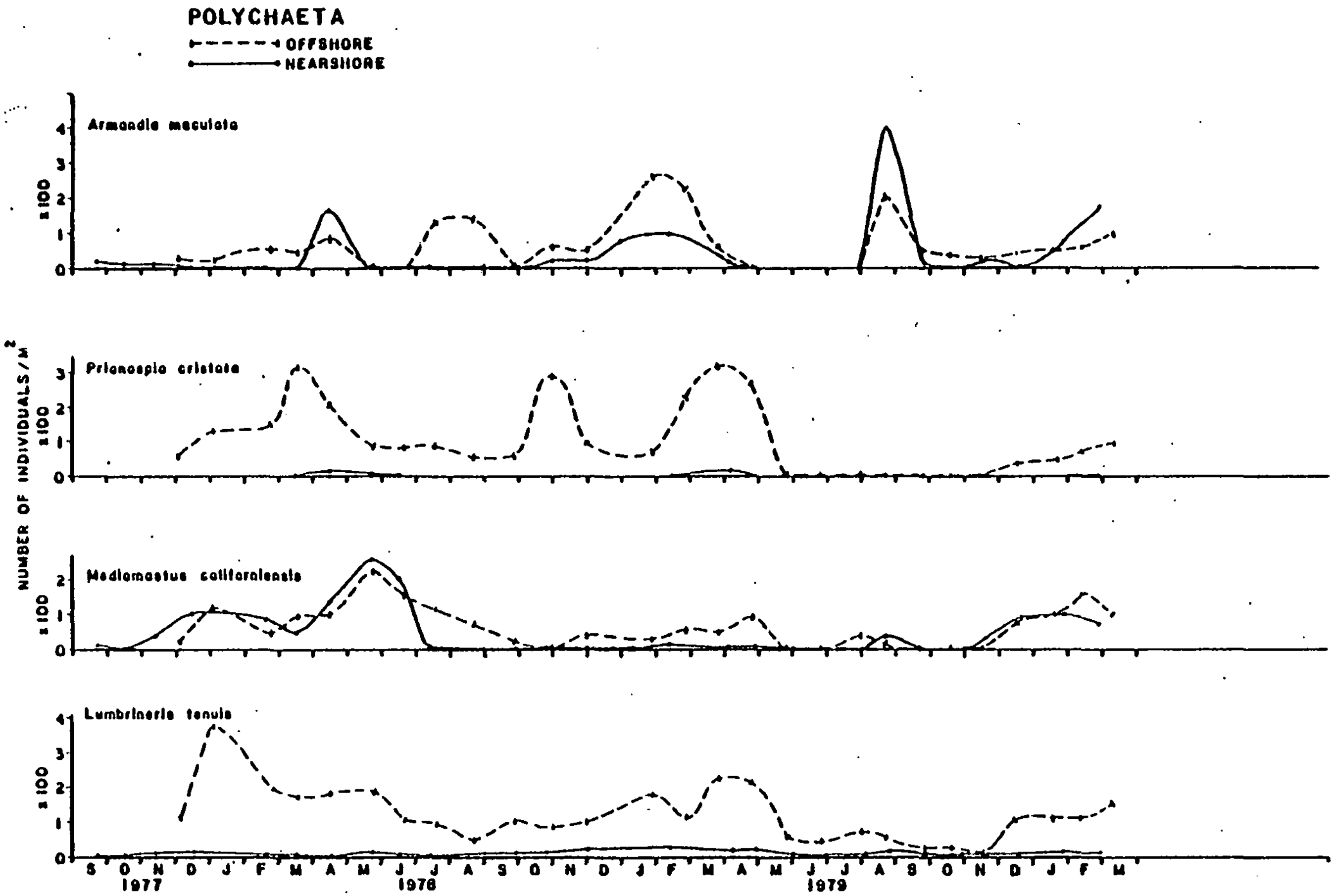


Figure 5-23 (continued). Comparison of the temporal trends of selected species of polychaetous annelids at the offshore and nearshore areas.

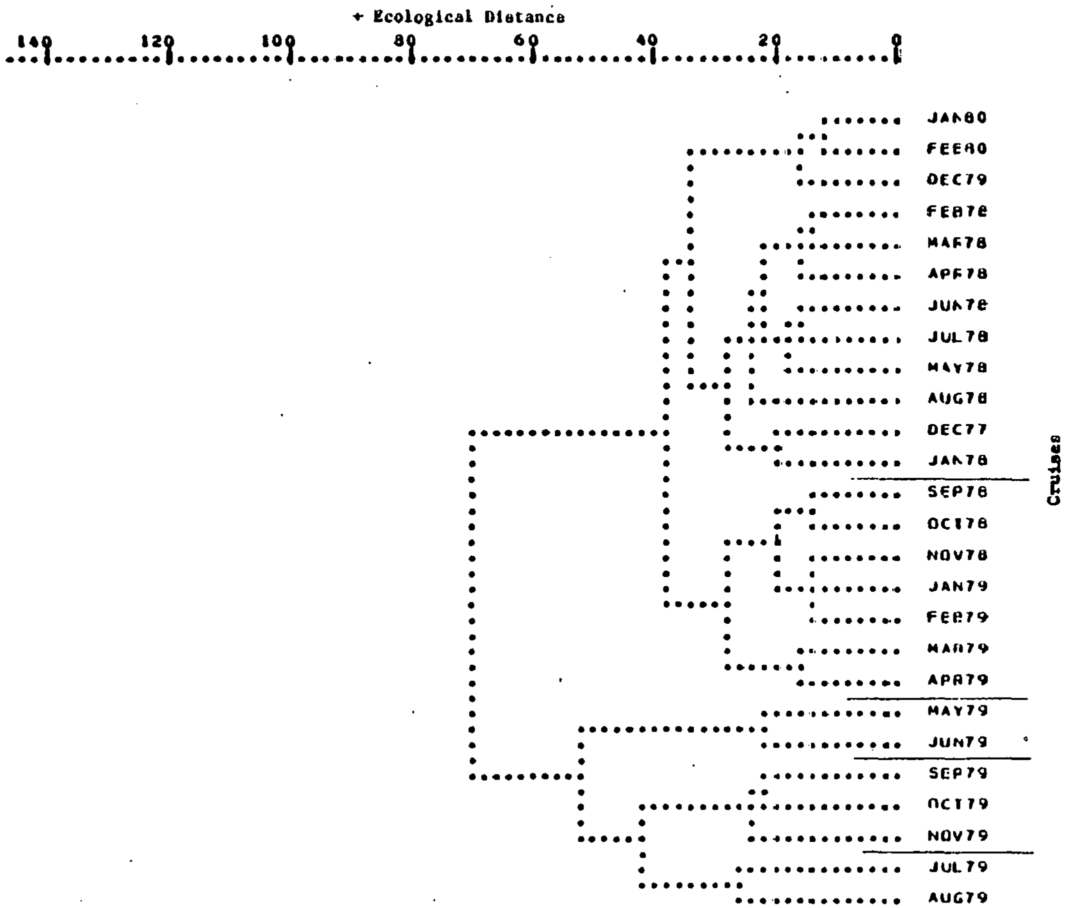


Figure 5-24. Dendrogram of the offshore site benthic data comparing months and species.

ers which together included the time blocks December 1977 through April 1979 and December 1979 through February 1980. The first (smallest) sub-cluster, December 1979 - February 1980, was characterized by a lack of dominance of any species. The second sub-cluster encompasses the time during which *P. pinnata* was very abundant. The third sub-cluster denotes the time in which amphipods were on the ascendency and polychaete abundance was decreasing.

The second major cluster is comprised of the months during and following hypoxia i.e. May-November 1979. The sub-clusters were caused by the virtual absence of certain of the smaller species groups (not shown) in each time period.

The cruises to the nearshore site were separated into four clusters, none of which were as distinctly separated as the offshore clusters (Figure 5-25). The first cluster encompasses the time following hypoxic conditions in 1979 (except October) when populations were large or increasing. During this period the bivalve mollusk *Abra aequalis* the hemichordate *Balanoglossus* sp. and the polychaete *Cirratulus hedgepethi* set in large numbers. The second cluster is comprised of the initial 4 collections of the study when overall populations were quite low and were dominated by *P. pinnata*. The third cluster is the largest and is comprised of the February 1978 - April 1979 time period, excepting August 1978. During this period, *P. pinnata* was the dominant species, even overriding the influence of the ascendent amphipod population in April and May 1979. The last cluster is comprised of cruises made when populations were very low, including the known hypoxic period May-July 1979, the suspected hypoxic period, August 1978 and October 1979 when very low populations occurred following the post-hypoxic irruption.

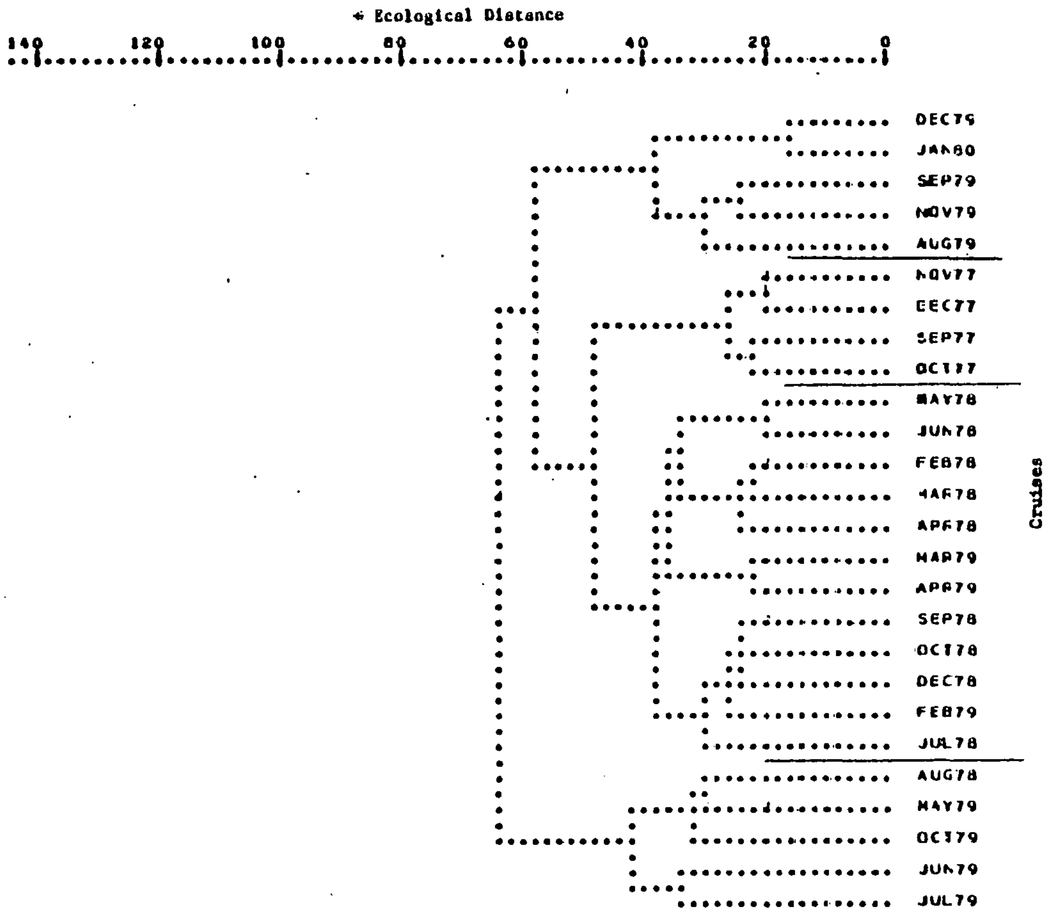


Figure 5-25. Dendrogram of the nearshore site benthic data comparing months and species.

5.7.5.3 Analysis of the Effects of Hypoxia on the Benthic Communities

The occurrence of hypoxia (< 2.0 ppm of dissolved oxygen) in offshore waters has resulted in mortalities of marine organisms in many parts of the United States and the world (Brongersma-Sanders 1957; Garlo, Milstein and Jahn 1979). However, to our knowledge, extensive depletion of oxygen has not been documented off the Texas coast, one of the most productive, yet least studied, estuarine-marine ecosystems in the world.

The effects of hypoxia were observed during the previously described baseline environmental study prior to disposal of concentrated brine offshore from Freeport, Texas. It was fortunate that our sampling program included two sites, because as a result of our baseline work before, during and after the onset of hypoxia we have some of the most complete data available on such an occurrence. Because the hypoxic conditions caused mass mortalities within the study area, similar to what might be expected from severe pollution, a careful analysis of the phenomenon may be useful in determining if the disposed brine produces measurable effects.

Numerous naturally occurring events can cause hypoxia (May 1973; Fotheringham and Weissberg 1979: Garlo, et al. 1979); in this case, large quantities of fresh water discharged from area rivers caused water column stratification, which was then intensified by lack of vertical mixing during calm weather, and, probably by decomposition of river borne organic material. A rather extensive area of the upper Texas coast was apparently affected by hypoxic conditions, based on our data and reports from fishermen, during the spring and summer of 1979. (Fig. 5-26)

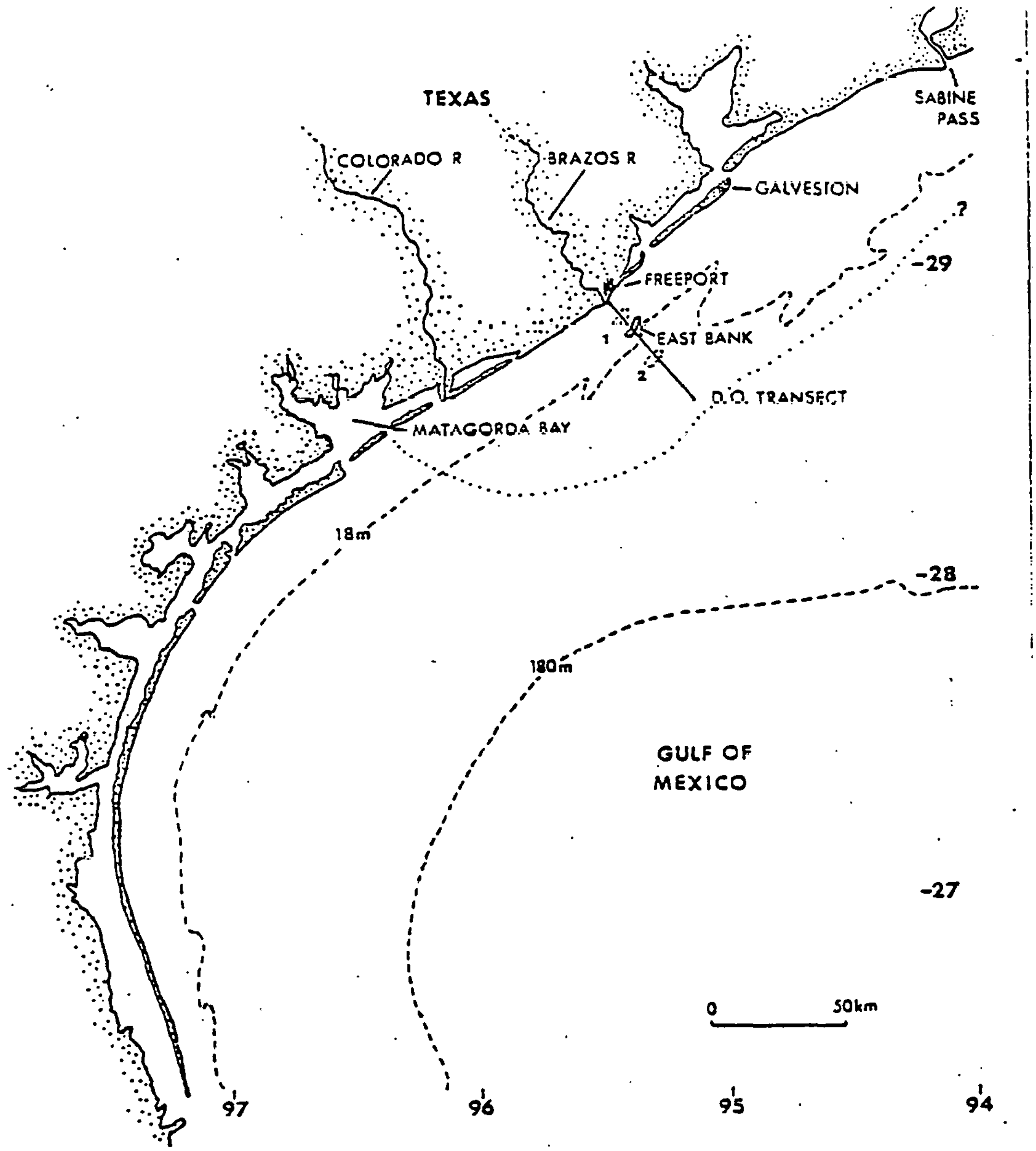


Figure 5-26. Chart of the northwestern Gulf of Mexico showing the locations of the nearshore (1) and offshore (2) study areas, East Bank, and the cross-shelf transect, and the probable extent of hyposix water (····).

5.7.5.3.1 Chronology of Events

The spring of 1979 was unusually wet; 53 cm of rain had fallen on Galveston by May, which was 36 cm above average. Other weather stations in the watershed affecting the study areas recorded above normal rainfall quantities equal to or greater than those recorded at Galveston (NOAA 1979a, 1979b). The large amounts of rain that fell in March and April caused rivers to flow at capacity or to flood in mid-to late April, and high discharge rates continued through early July. Winds were light to moderate during most of June, and were dead calm during the last week of June.

As the water warmed, the D.O. of near-bottom waters decreased from winter maxima (7-8 ppm) to about 3 ppm by May. The D.O. was < 2.0 ppm at a few nearshore stations during the May cruise (actually conducted on 1 June), but biological effects were not obvious until the next cruise to the nearshore site on 28 June. The wind had been calm for a week prior to sampling and the water was quite clear. We observed numerous dead benthic organisms, including polychaete worms, brachyuran crabs, mantis shrimp and hemichordates strewn about the bottom in various states of decay. Large patches of black material (that smelled of hydrogen sulfide when samples were returned to the vessel), and a filamentous material, thought to be colonies of bacteria, covered most of the bottom of each station sampled. The D.O. content of the bottom water varied from 0.5 to 1.7 ppm, but averaged only 0.67 ppm (Table 5-3).

Also on 28 June we investigated East Bank, a rocky structure lying just inshore of the 18-m isobath (Figure 5-27), which rises from 17.5-m depth to a crown depth of 12 m. During prior visits (which were regulated by water clarity, and thus were irregular), this bank had a

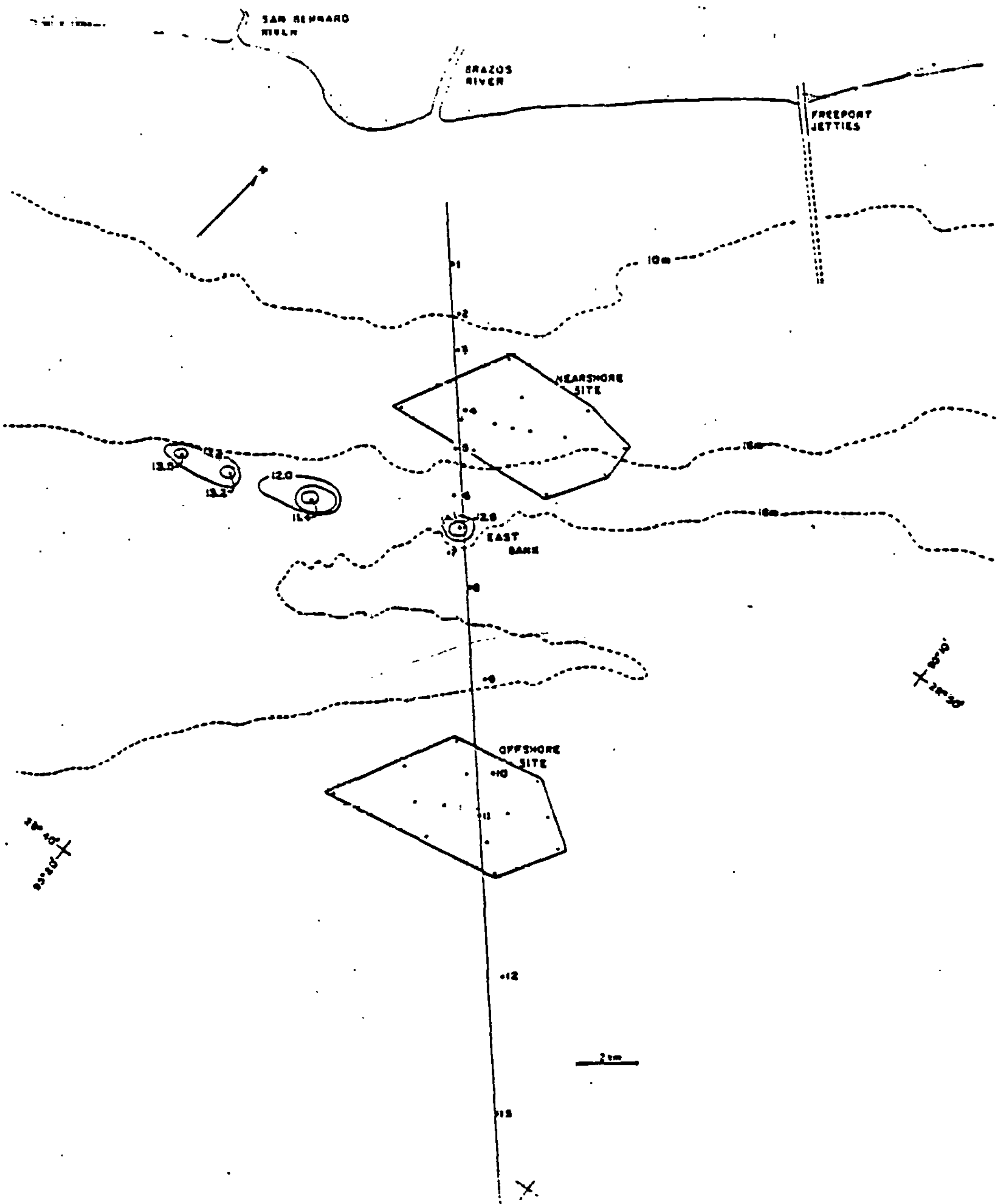


Figure 5-27. Chart of the area offshore from Freeport showing the locations of the nearshore and offshore study areas, East Bank and the cross-shelf transect sampled on 8 July 1979.

healthy assemblage of sea whips (*Leptogorgia* sp.), solitary corals (*Astrangia* sp.), sea urchins (*Arbacia punctulata*), mollusks, crabs and associated reef fish. By 28 June, the fauna had experienced considerable mortalities. Every sea urchin observed was dead. Many sea whips were missing sections of the colony and the internal axial skeletons were exposed. All corals collected were dead. Hermit crabs were clustered at the edges of rock slabs and many were dead. The large gastropod mollusks observed were sluggish and retracted very slowly when picked up. The only fish seen were three toadfish; the normal component of reef fish was not present.

On 8 July a special cruise was conducted to determine the extent of low D.O. in the Freeport area. The water column was sampled along a transect from off the Brazos River mouth in 9-m depth to about 50 km offshore in 33-m depth (Figure 5-27). Temperature, salinity and D.O. measurements made on water samples revealed a thermocline-halocline at about 10-m depth (Figure 5-28, 5-29); above this boundary the D.O. was > 4.0 ppm, but below the D.O. was < 2.0 ppm, and was < 1.0 ppm near the bottom at some stations (Figure 5-30). Also evident is a lens of water with lower temperature and salinity characteristics than adjacent surface water. This lens was probably the result of freshwater runoff from either local rivers or the Mississippi River.

Tropical Storm Claudette raked the upper Texas coast in mid-July, generating large offshore waves. On 30 July the offshore site was sampled and we determined that mixing had occurred to 18.5-m depth; the bottom water at all stations was still hypoxic. The East Bank was also inspected on 30 July and 3.7 ppm D.O. was measured. The invertebrate fauna had suffered considerable mortalities, but the reef fish population had returned.

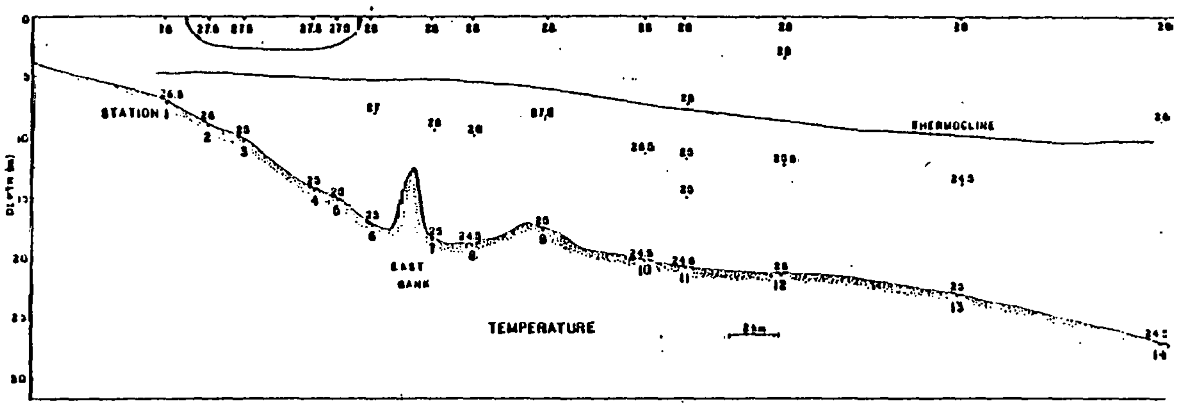


Figure 5-28. Cross-shelf temperatures recorded during the cruise of 8 July 1979.

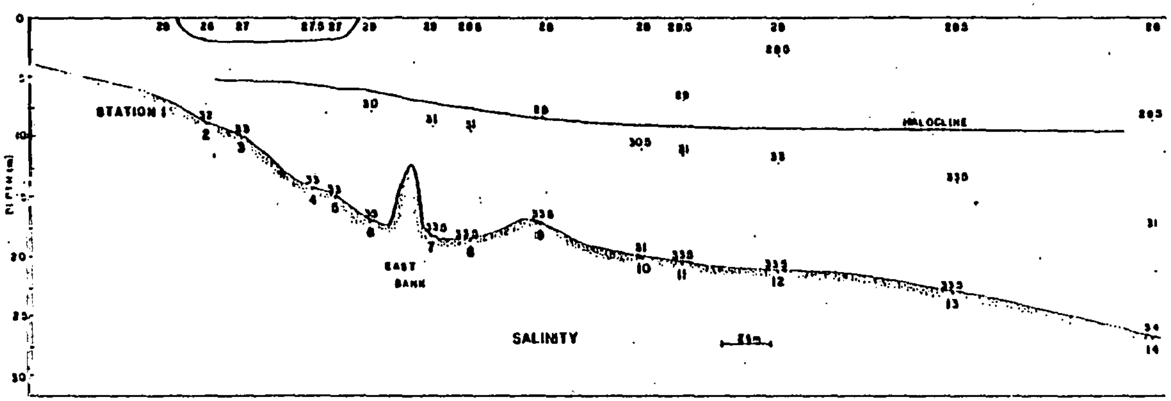


Figure 5-29. Cross-shelf salinities recorded during the cruise of 8 July 1979.

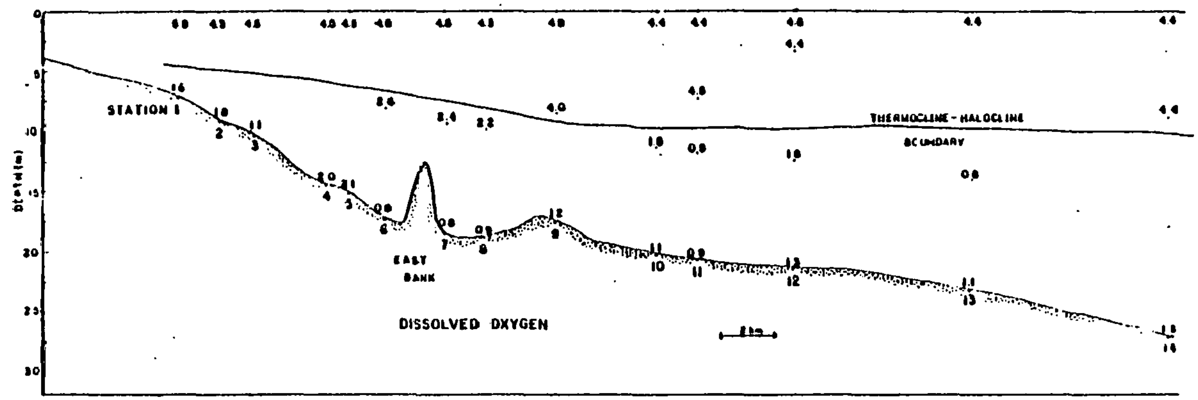


Figure 5-30. Cross-shelf dissolved oxygen concentrations recorded during the cruise of 8 July 1979.

It is not known exactly how long hypoxic conditions persisted at the offshore site after 30 July; on the next sampling date (31 August) the D.O. had risen to 2.5 ppm, and monthly samples have shown neither site to be hypoxic since then.

5.7.5.3.2 Effects of Hypoxia on the Benthic Biota

As previously described, the benthic communities at the two study sites were composed of somewhat different assemblages, the offshore site generally being more diverse (more species and individuals) than the nearshore site. The proximity to shore, type of substrate, and other physical parameters influence community composition and thus diversity. The infrequent occurrence of such a drastic phenomenon as hypoxia may also play an important role in determining community structure and thus diversity. Such events form the basis for the "Intermediate Disturbance Hypothesis" (Connell 1978) which states that the greatest diversity is maintained when environmental disturbances are intermediate in effect, degree, and frequency of occurrence. Figure 5-31 is a graphic representation of this hypothesis. Over a long period of time these disturbances have more effect in determining the level of diversity than do more regular seasonal abiotic variations. The latter, such as length of seasons, seasonal temperature range, etc. affect the species composition by establishing environmental parameters to which they must adapt or be displaced. The former appears to be more important in establishing a range of diversity through which a community might oscillate through the seasonal cycle. The disturbances on which this hypothesis are based include not only naturally occurring ones such as hypoxia, but also can include artificial ones such as the influx of concentrated brine. A

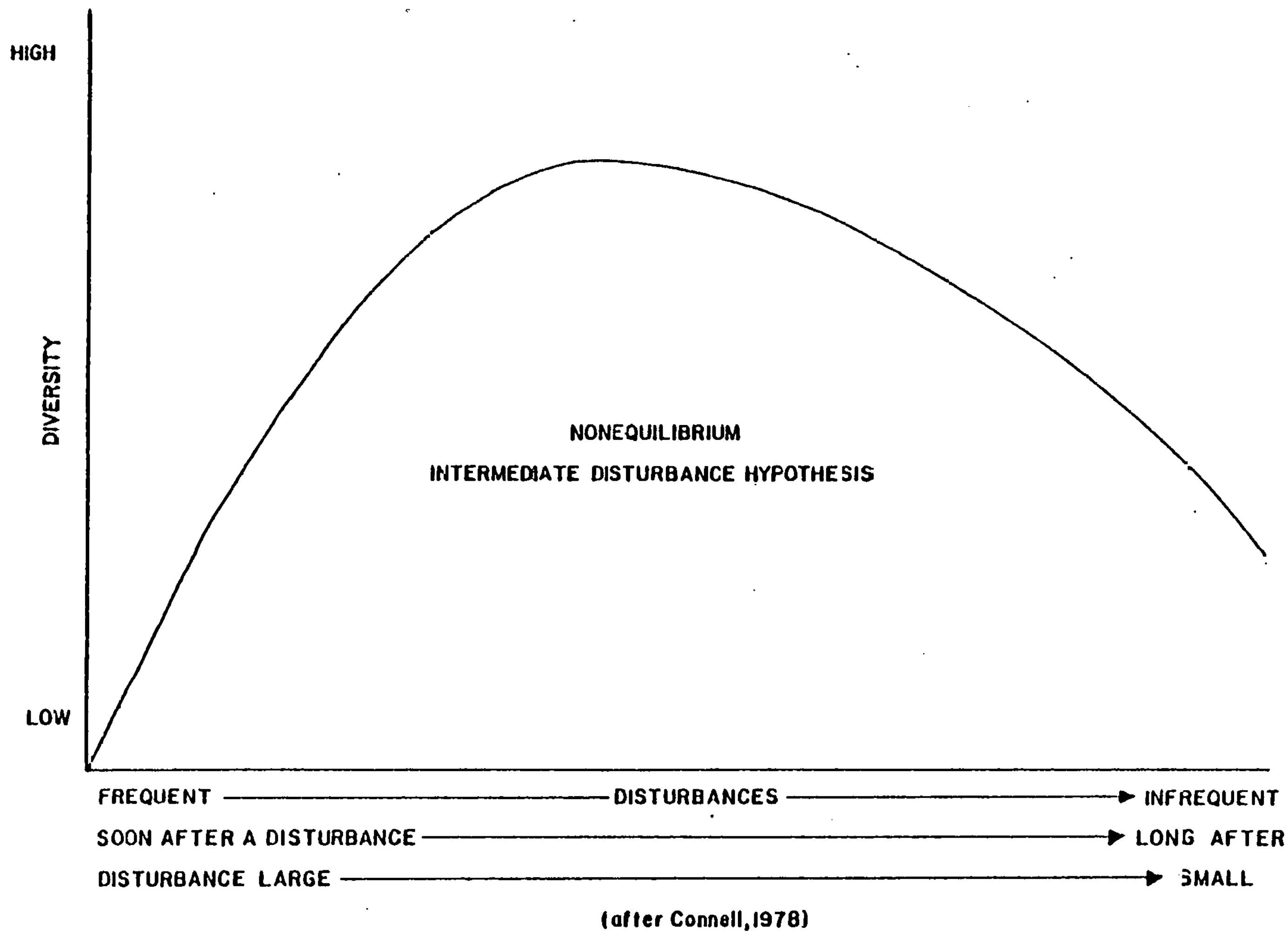


Figure 5-31. Representation of the intermediate disturbance hypothesis.

change in diversity can therefore be expected as a result of such disturbances and can readily reflect the severity of the disturbances. Whether or not community diversity rebounds to normally observed diversity after an artificially induced disturbance (i.e. concentrated brine disposal) should indicate if the effect was within naturally occurring parameters.

One way of quantifying and therefore analyzing changes in diversity is by reducing numbers of individuals and numbers of species into a single number representing a diversity index. There are several diversity indices, all with deficiencies, but the Shannon-Weiner has been widely used (Smith, 1974), is better known than others, and thus was chosen as the basis for our analyses. In ecological use the function describes the degree of uncertainty of predicting the species of any individual picked at random from a community. The greater the index, the more uncertainty of what species a randomly picked individual may be, i.e. the more species present and the more evenly divided the individuals among species, the greater the index. The least diverse community would have an index of 0.0 (one species with any number of individuals) and the most diverse community would have every individual belonging to a different species (index values increasing infinitely). The general formula for this index is:

$$H' = \sum_{i=1}^{s} \left(\frac{N_i}{N}\right) \log_2 \left(\frac{N_i}{N}\right)$$

where s = the total number of species collected, N = total number of individuals of all species; N_i = total number of individuals in the ith species.

A diversity index for each month was calculated for both nearshore and offshore sites (Table 5-7). This number is the average diversity index of 45 samples (15 stations per site, 3 replicates per station). Figure 5-32 represents the average diversity index trends for both offshore and nearshore sites. As expected, the offshore site diversity was higher than the nearshore site through most of the study. Unlike data presented in Figure 5-17, changes in diversity appear synchronous throughout all but the hypoxic months and immediately thereafter. The hypoxic conditions of the summer of 1979 severely affected both sites as demonstrated by the rapid decrease of the index (Fig. 5-32). Recovery at the near-shore site was, however, more rapid than offshore and was approaching normal levels (relative to the previous year) by November. The offshore diversity dropped below nearshore levels for the first time in the study in August 1979 and remained almost continuously below until December; normal diversity levels (i.e. as in early 1978 and 1979) did not occur until early in 1980.

An analysis of variance indicated there were significant differences between cruises and station-cruise (Table 5-8) and Duncan's multiple range test was used to analyze for significant change in diversity between months (Figs. 5-33, 5-34); months in which there was no significant change in the means are grouped by I-bars along the horizontal axis. A detailed comparison of the index and D.O. values at the nearshore site during 1979 is shown in Figure 5-33. The declining D.O. values through June were closely followed by a decrease in diversity. The period of low diversity from May to July is indicative of the relatively long duration of hypoxic conditions. Because diversity reached a low and no significant change occurred throughout this period it can be assumed that hypoxic effects were maximum. In other

Table 5-7. Comparison of the average diversity index (H') for each month at both offshore and nearshore study areas, 1979.

Offshore		Nearshore	
Date	H'	Date	H'
28 Jan	2.1		
26 Feb	2.0	13 Feb	1.3
25 Mar	2.0	5 Apr	1.8
24 Apr	2.3	26 Apr	1.7
24 May	1.9	1 Jun	1.1
25 Jun	1.8	28 Jun	0.9
30 Jul	1.7	2 Aug	0.9
21 Aug	2.3	23 Aug	1.6
24 Sep	1.7	28 Sep	1.7
18 Oct	1.5	29 Oct	1.3
15 Nov	1.7	19 Nov	1.7

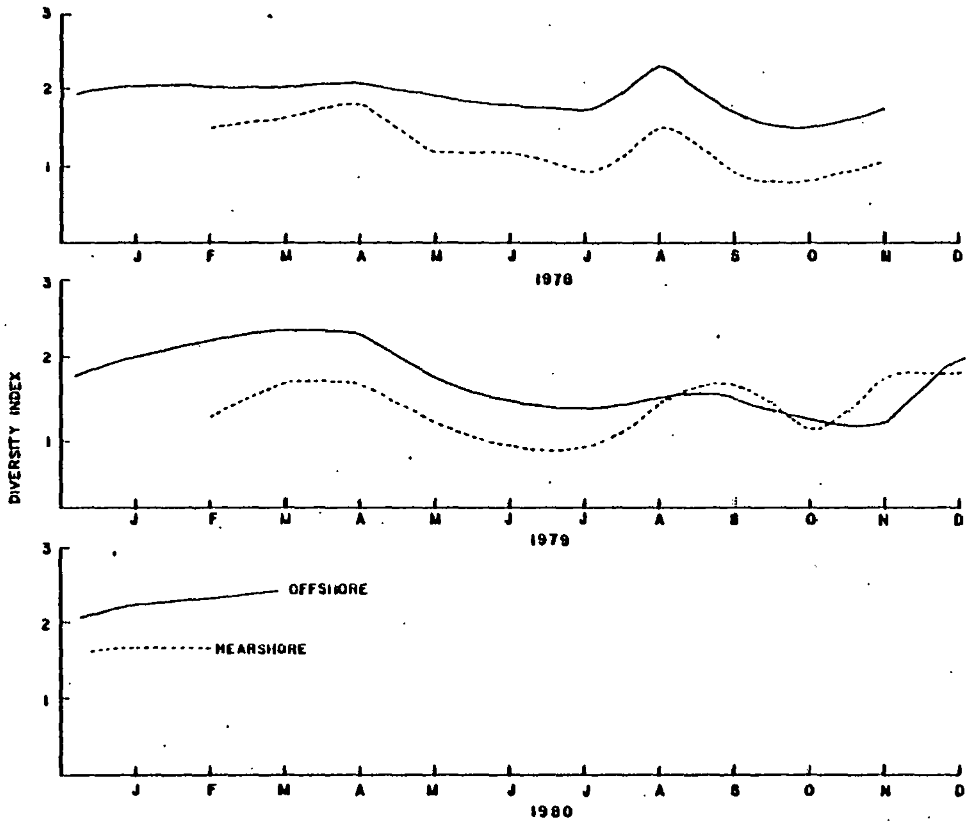


Figure 5-32. Comparison of the temporal trends of the diversity indices at the offshore and nearshore study areas, 1977-1980.

Table 5-8. ANOVA results testing the calculated means of Shannon diversity index for 15 stations, 10 cruises, at the offshore site and 15 stations, 10 cruises at the nearshore site, 3 replicates per station.

Offshore Site

Source	DF	SS	F value	Pr > F
Station	14	4.04	2.42	0.0031
Cruise	10	68.14	57.03	0.0001
Station*Cruise	140	32.16	1.92	0.0001
Error	330	39.42		
Total	494	143.77		

Nearshore Site

Source	DF	SS	F value	Pr > F
Station	14	10.43	2.65	0.002
Cruise	9	44.29	28.06	0.0001
Station*Cruise	129	35.42	1.60	0.0006
Error	300	56.62		
Total	449	142.76		

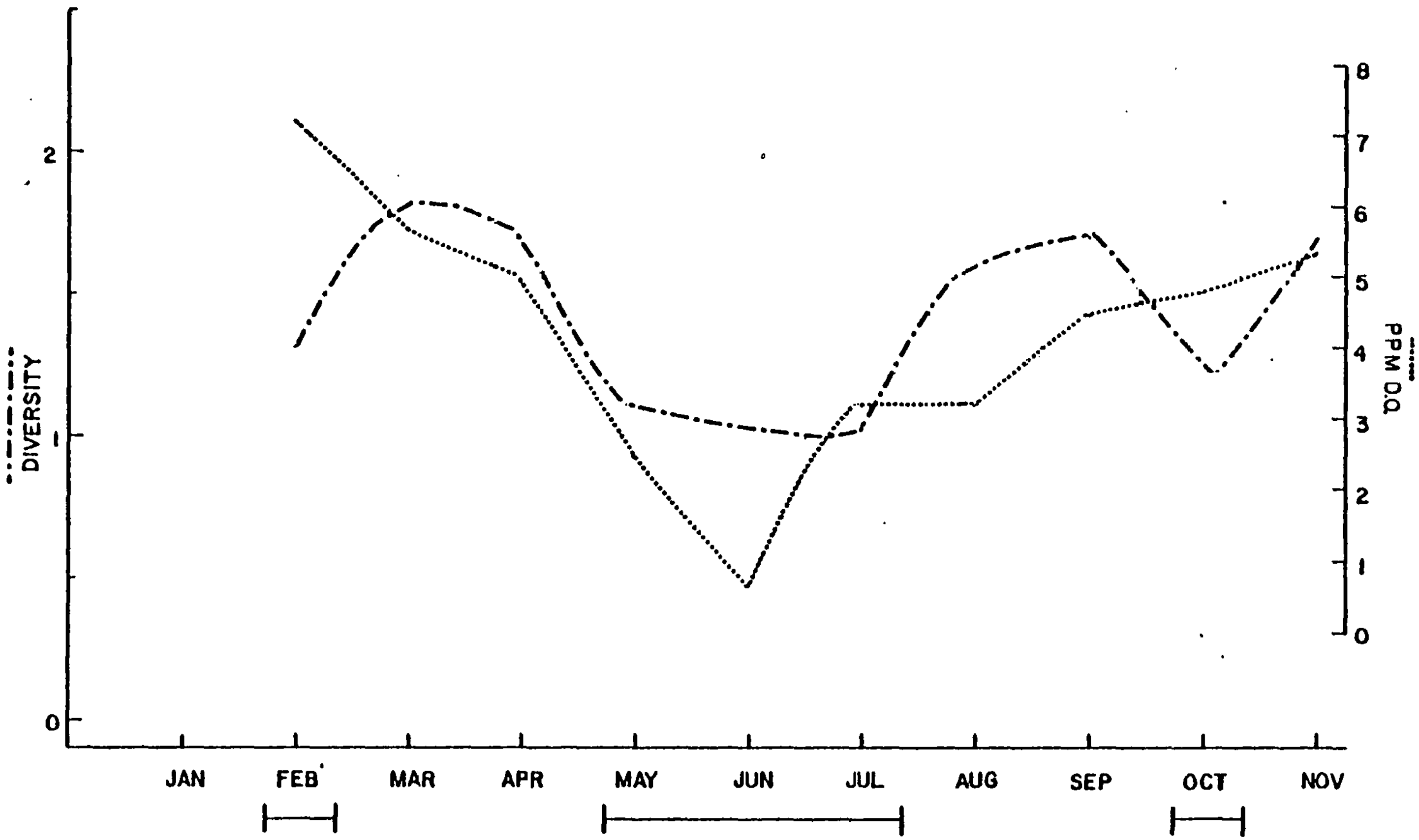


Figure 5-33. Comparison of the diversity and dissolved oxygen concentration at the nearshore site, February through November 1979. I-bars along the horizontal axis represent months with no significant difference as determined by Duncan's Multiple Range test.

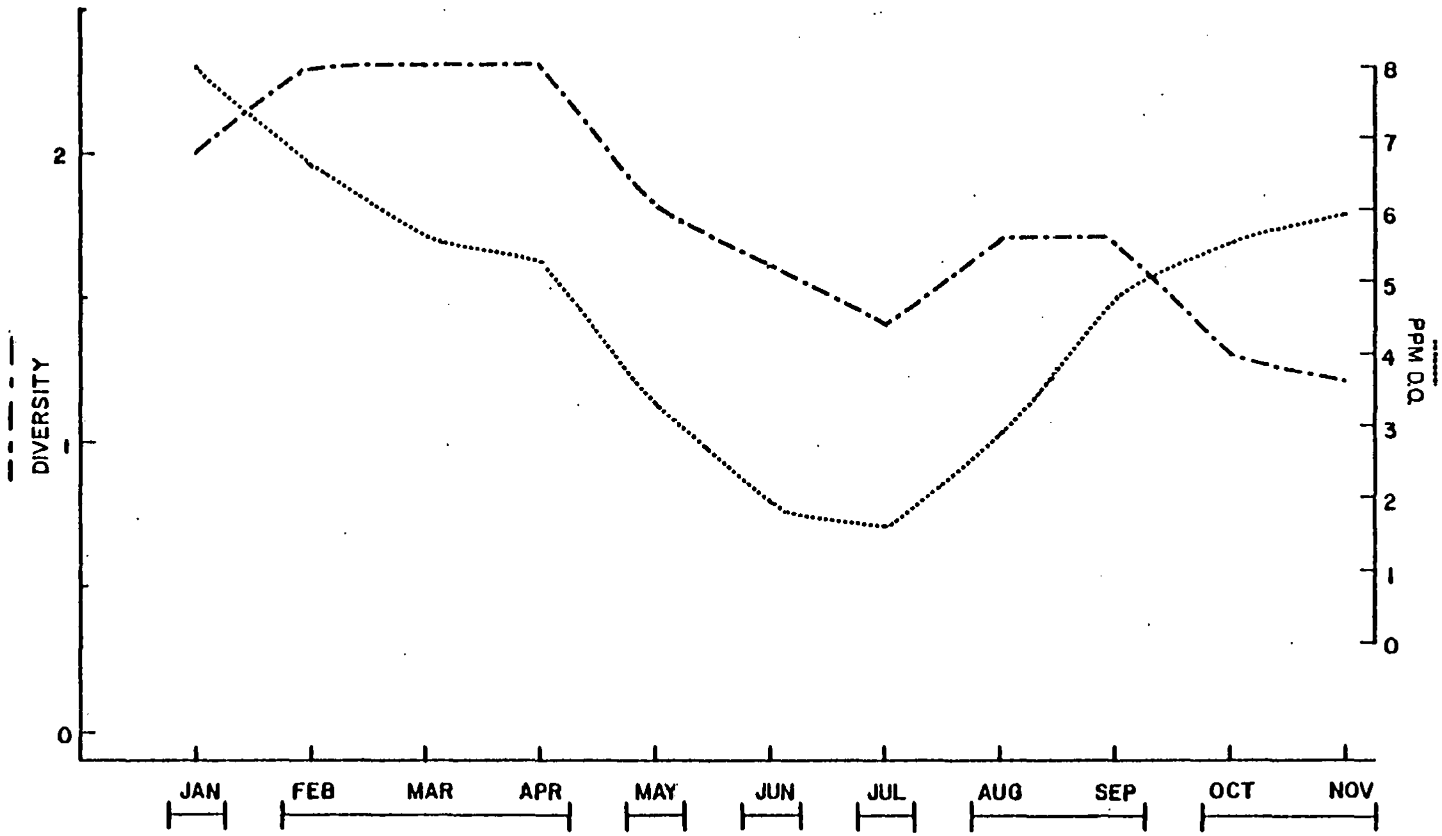


Figure 5-34. Comparison of the diversity and dissolved oxygen concentration at the offshore site, January through November 1979. I-bars along the horizontal axis represent months with no significant difference as determined by Duncan's Multiple Range test.

words, hypoxia had eliminated all but a particular balance of species and individuals and that balance was probably maintained until physical conditions changed (i.e. increase or decrease in D.O.). Upon recovery from hypoxia, diversity underwent a broadly oscillating response. Such would be the expected response in the area if it was subject to such disturbances on a periodic basis. In such situations, opportunistic species (always a component of communities) take advantage of reduced competition to rapidly repopulate the area. This response is illustrated in the peak and subsequent drop in diversity from July to October. Upon initial recovery from hypoxia nearly all species (those which survived) increased in numbers either by rapid reproduction and disperal or immigration. During this period, opportunitic species underwent even more rapid reproduction to the point of dominating the community. Abnormal numbers of any few species is reflected in the index by a decrease in diversity.

Figure 5-35 shows some typical responses of members of the nearshore benthic community to the hypoxic period. *Ampelisca verrilli* (Amphipoda) is demonstrative of the response of most inshore Crustacea to hypoxic conditions. The increasing trend was reversed and by June no individuals were collected in the area. Recovery was slow and population levels were reduced throughout the winter. As a result the population base for the expected spring reproductive cycle was smaller than might normally be expected. *Nereis micromma* (Polychaeta) illustrated the response of a component of this benthic community which, although affected by hypoxia, was able to maintain itself and recover rapidly to near normal population levels. *Paraprionospio pinnata* (Polychaeta) is one of the opportunistic species mentioned earlier. Following hypoxia and mortality of most of the benthic community *P. pinnata* re-

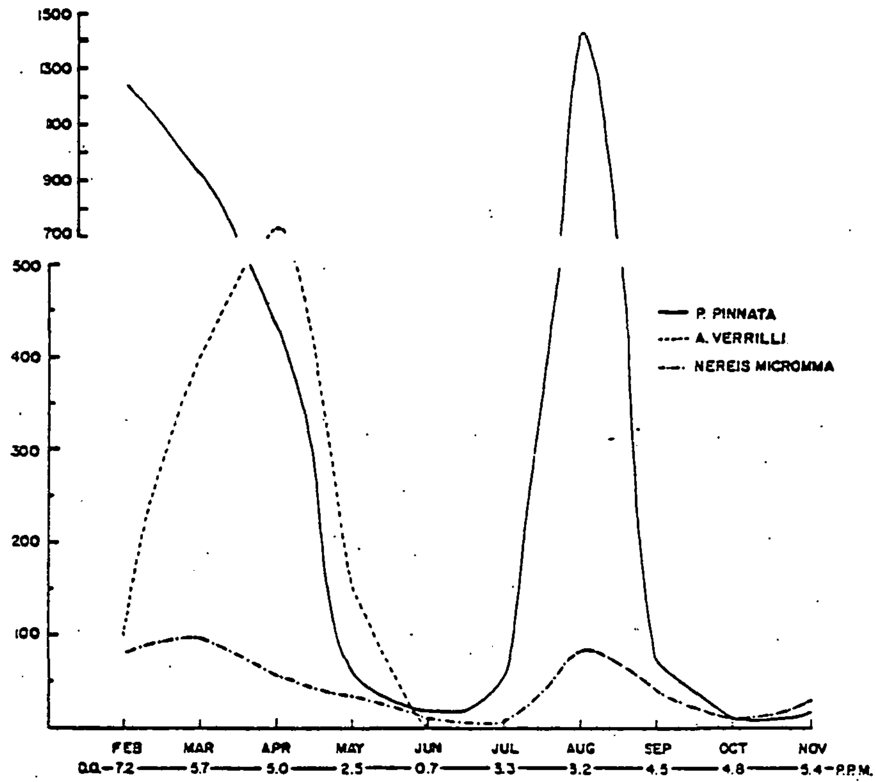


Figure 5-35. Comparison of the temporal trends of selected nearshore species during the hypoxic period.

sponded to a reduced competition for resources with a tremendous population increase. This species maintained a dominant role in the community throughout recovery and until other species began to approach more normal numbers.

Figure 5-34 compares the D.O. and diversity at the offshore site. As at the nearshore site, the diversity declined with increasingly hypoxic conditions. In contrast to the nearshore site, the offshore site showed little recovery at the end of hypoxic conditions. This reduced level of diversity persisted throughout the winter of 1979. The results of the Duncan's Test is represented on Figure 5-34. Under normal conditions changes in diversity offshore were less rapid than such changes inshore. This is reflected on Figure 5-34 by the generally longer periods in which no significant change in diversity occurred. The rapid month by month change noted during hypoxia is apparently a result of the severe effect of such a disturbance. These changes also indicate that the hypoxic period was of relatively short duration (in contrast to the nearshore site) and therefore may not affect the offshore site as often as the nearshore site. The relative infrequency of hypoxia offshore is also indicated by the lack of return of normal conditions. After only a brief rise, diversity continued on a downward trend through November. This was the only time in almost two and one third years that offshore diversity dropped below that of the nearshore community. Initial examination of samples from the spring of 1980 seems to indicate a recovery to more normal offshore diversity.

The development and resonse to hypoxia, as noted previously, lagged behind that of the nearshore site. This is another indication that hypoxic conditions moved from shoreward out and that the nearshore site was covered by hypoxic waters for a longer period than the offshore

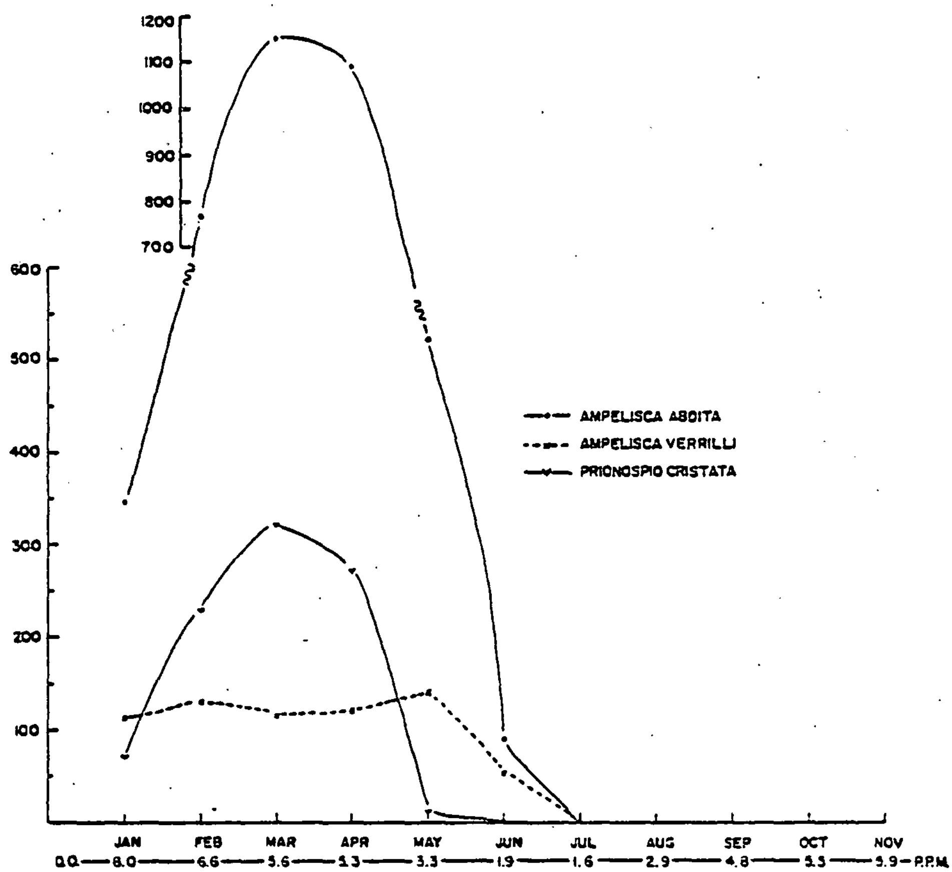


Figure 5-36. Comparison of the temporal trends of selected offshore species during the hypoxic period.

site. This temporal displacement is reflected in the D.O. and diversity minima in Figures 5-33 and 5-34.

Figure 5-36 represents some of the typical responses of benthic fauna at the offshore site to hypoxia. Once again the Crustacea appeared to have been the most severely affected of the benthos. *Ampelisca abdita* (Amphipoda) is a colonial species which typically shows a tremendous population increase in the spring. This pattern was evident until foreshortened by the hypoxic conditions of 1979. As a result this species disappeared from the offshore site until the following spring (April, 1980). Population levels of this species appear to be as much as an order of magnitude lower than might be expected as a result of hypoxia. *Ampelisca verrilli* (Amphipoda), also found at the inshore site, occurred in fewer numbers at the offshore site. Its response offshore was, however, the same because no individuals appeared to survive hypoxia. *Prionospio cristata* (Polychaeta) exemplifies many of the other species of the benthos at the offshore site. These species were severely affected and were still present in lower than expected numbers in 1980.

5.7.5.3.3 Summary of Hypoxic Effects

The hypoxic conditions of the spring of 1979 affected both nearshore and offshore sites, as well as an extensive area of the Texas (and possibly Louisiana) coasts (Figure 5-26). It was also noted that hypoxia first occurred inshore and apparently moved offshore later in the summer. It can thus be speculated that the extent of hypoxia is variable, depending on the magnitude of the causative factors, and that at times hypoxic conditions might not extend much further seaward than the nearshore site, as suggested in 1978 by low populations and diversities (Figure 5-17), but for which we have no supporting D.O. data. If this was the case, then the infrequent development of hypoxic conditions could be expected to greatly influence the composition and diversity of the affected benthic communities. The nearshore community, more frequently subjected to hypoxia, would be more resilient and recover more rapidly under such circumstances. The offshore community, less often subjected to hypoxia, would lack this response and thus would be severely impacted by such an event. These responses appear to support the hypothesis that disturbances of intermediate effect maintain a certain level of diversity (usually maximum within environmental parameters), while other disturbances depress diversity (the Intermediate Disturbance Hypothesis). As indicated our data tend to support this view.

A range of diversities, all the result of naturally occurring phenomena, are now available to compare against any change in diversity which might result from brine disposal. In 1978, naturally occurring stress was limited to the inshore portion of our study area only. This was followed by a period during the following year (1979) in which benthic communities at both study areas were severely stressed. If brine induced stress occurs, it should be observable as a change in the diversity similar to the changes induced by low D.O.

The results of this study emphasize the need to gather adequate baseline data before human activities impact the environment. If brine discharge had begun concurrent with the onset of hypoxic conditons, the resultant mortalities would most certainly have been blamed on the brine (local fishermen were convinced that discharge operations had begun until told of the low amounts of D.O. in the water), and D.O.E. would probably have been forced to cease pumping.

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CHAPTER 6

ZOOPLANKTON

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6.1 Introduction

Zooplankton populations in coastal waters are generally characterized by overall high densities and by large fluctuations in density both in time and space. Most zooplanktonic organisms in these waters are herbivorous and they provide a major trophic link between the primary producers (phytoplankton) and the carnivores. Since coastal areas are among the most productive marine habitats, the zooplankton populations in these neritic waters are important ecologically, and as food for many benthic and nektonic organisms, they are also important commercially. A large number of benthic and nektonic organisms also have meroplanktonic larval and developmental stages. These larval and developmental stages are sensitive to environmental perturbations whether they are natural or of human origin. Studies of the zooplankton community are vital therefore in any effort to determine factors affecting coastal marine ecosystems.

A major objective of this predisposal report is to characterize the zooplankton populations and communities in this general area off Freeport, Texas. Parameters such as biomass, total density, species composition, dominant organisms, species groups, and species diversity have been measured. The variability of these parameters over the sampling period (seven cruises) has been examined. Spatial variability has also been examined during each cruise between the three closely spaced stations (2 nautical miles apart) positioned near the diffuser site. This measure of the normal amount of spatial variability in the area, which is detectable by our sampling methods, should be important in order to determine any possible spatial effects on the zooplankton after the initiation of brine disposal.

Historical data from two stations (W2 and W3) located near the diffuser which were sampled monthly in 1963 and 1964 have also been examined in order to obtain additional seasonal information on the zooplankton populations of the area. These samples were provided by the National Marine Fisheries Service Laboratory in Galveston, Texas. They were originally collected in a major study to determine the distribution of larval penaeid shrimp in the coastal waters of the northern Gulf of Mexico (Kutkuhn, 1963).

Until recently, little comprehensive work on the zooplankton populations in the coastal waters of the northwestern Gulf of Mexico has been conducted. The analysis of seasonal data by Park (1979) and Park and Turk (1980) off the South Texas coast and by Minello (1980) in the coastal waters off Texas and western Louisiana has increased our knowledge of the dominant zooplankton groups and species and their seasonal and spatial distributions in these areas. Much of the other zooplankton work done in the coastal areas off Texas has been associated with samples taken in the 1960's by the National Marine Fisheries Service Laboratory in Galveston, Texas. Temple and Fischer (1965) examined the vertical distribution of larval penaeid shrimp over a 6-month period in 1963 at one station approximately 80 km south of Galveston. Other studies using these samples include work on chaetognaths (Adelmann, 1967) and copepods (Allison, 1967). Temple and Fischer (1967) and Temple (1976) reported on an extensive examination of the seasonal and spatial distribution of *Penaeus* spp. larvae in the shelf waters off Texas and Louisiana from samples taken between 1961 and 1965. Harper (1968) studied the seasonal distribution of *Lucifer faxoni* off the Texas coast from monthly samples taken in 1962. Seasonal data on ichthyoplankton from 12 stations sampled in 1974 and 1975 off the South Texas coast have been recorded by Finucane (1976). A limited amount of seasonal work on zooplankton populations has also been conducted off Freeport, Texas in 1973 (SEADOCK, 1975). Although some of the stations sampled in this analysis were very close to the area of brine diffusion, samples were taken quarterly, and few zooplankton forms were delineated.

6.2 Methods and Materials

6.2.1 Samples Collected Near the Diffuser in 1979 - 1980

6.2.1.1 Field Sampling

The locations of the three stations currently being sampled near the brine diffuser are shown in Figure 6-1. Station B (28°44.0' N, 95°14.4' W) was located near the end of the diffuser and Stations A (28°42.8' N, 95°16.2' W) and C (28°45.3' N, 95°12.5' W) were located two nautical miles away, one up the coast and the other down the coast. Seven zooplankton cruises were made on an 80 ft shrimping vessel between June 1979 and January 1980:

Cruise	Date
1	June 27, 1979
2	July 18, 1979
3	September 29, 1979
4	October 24, 1979
5	November 20, 1979
6	December 20, 1979
7	January 24, 1980

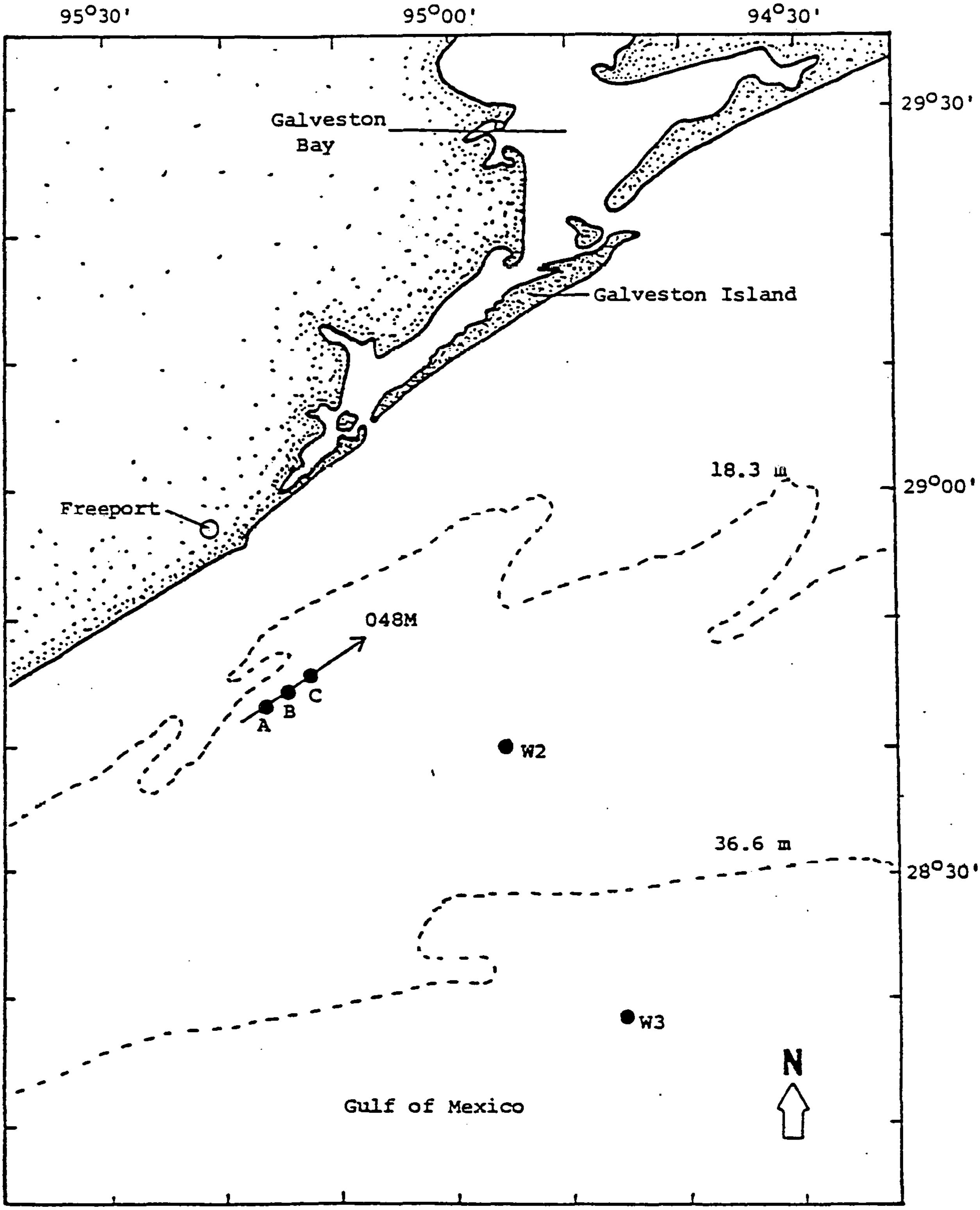

Figure 6-1. Location of sampling stations off Freeport, Texas. Brine diffuser is located near Station B. Historical data was collected at Stations W2 and W3.

On each cruise, three replicate oblique tows were taken to near the bottom at each station. An additional oblique tow (tow 4) from the surface to the 1/2 depth level was also taken at each station in order to estimate the vertical distribution of the zooplankton. The sampling gear consisted of a one meter mouth diameter Nitex net (length = 3.7 m) with a mesh size of 240 μm. A digital flowmeter positioned in the center of the net mouth was used to estimate the amount of water filtered during each tow. The amount of wire out was measured with a wire meter and this value along with the wire angle was used to determine the tow depth. All sampling was generally completed between 1100 and 1400 hours. This was done in an attempt to minimize variability resulting from the vertical migrations of animals. Tow durations averaged around two minutes and the amount of water filtered in each tow generally ranged between 50 and 150 m^3 and averaged 86 m^3. Samples were preserved on board in a 5-10% solution of formalin. During five of the cruises, temperature and salinity profiles were measured at each station using a Hydrolab Model TC-2 Conductivity Meter.

6.2.1.2 Laboratory Analysis

Twelve samples were obtained on each cruise. Subsampling was necessary in the laboratory due to the large number of organisms collected in the tows. Subsamples were taken with a Stempel pipette. One subsample from each sample was used to determine biomass. Biomass was measured as displacement volume using the mercury immersion method of Yentsch and Hebard (1957). Three smaller subsamples of equal size were also taken from each sample for the zooplankton counts. This subsample size was adjusted so that each contained approximately 500 organisms. Mean densities ($\#/m^3$) determined from each sample, therefore, were based on a count of approximately 1500 total organisms. Aliquot sizes ranged from 1/200 to 1/6000 of a sample. Major zooplankton groups were then identified and counted and since the copepods generally dominated the zooplankton, adult female copepods were identified to the species level.

6.2.1.3 Data Analysis

Statistical analyses were calculated through the use of the Statistical Analysis System (SAS) language and procedures. Log transformations were used on the zooplankton densities in order to normalize the data. Station variability among the three stations during each cruise was examined through a nested analysis of variance. In this AOV, the pooled variance from the three replicate tows taken at each station was used to test for significance in the variability among the three stations. Duncan's multiple range test was then used to examine the relationships among the three stations in more detail.

6.2.2 Historical Samples

Stations W2 and W3 were located slightly offshore from the diffuser site in 28 and 46 m of water, respectively (Figure 6-1). Monthly zooplankton samples were collected in 1963 and 1964 at these stations by the staff of the National Marine Fisheries Service Laboratory in Galveston, Texas. The samples were taken with a Gulf V net having a mouth diameter of 40.5 cm and a mesh size of approximately 200 μm (Arnold, 1958). Tows were of the step oblique type from just off the bottom to the surface. Twenty two samples were analyzed from Station W2 and 20 samples from Station W3. Various fractions of these samples were obtained from the NMFS and larval penaeid shrimp had already been removed. A Folsom Plankton Splitter was used to conveniently split the samples into manageable aliquots. The size of the aliquot examined was adjusted so that at least 1000 organisms were identified from each sample. The identification and counting procedures were identical to those used for the recently collected samples.

Temperatures and salinities were measured at each station at the time of sampling. Measurements were taken at the surface, 3, 11, 24 and 46 m depending on the water depth. These data have been reported by Temple, Harrington, and Martin (1977).

6.3 Results and Discussion

6.3.1 Data From Entire Water Column for the Seven Predisposal Cruises (1979-1980)

6.3.1.1 Biomass

Displacement volumes measured during the June cruise were approximately an order of magnitude greater than the values measured during the other cruises (Figure 6-2). Values measured from July through January were similar to the biomass estimates made off the South Texas coast in the 1970's (Park, 1979). The June values were atypically high and were approximately an order of magnitude greater than any values measured off South Texas by Park (1979). When the three stations samples on each cruise were compared, variability appeared especially high during the January cruise where Station B (near the diffuser) had a significantly higher biomass compared to Stations A and C.

6.3.1.2 Densities

The pattern exhibited by total zooplankton densities was similar to that shown in the biomass data (Figure 6-3). Mean zooplankton densities during June were very high ranging from approximately 35,000 to 58,000 organisms/m^3. The mean densities from the July through January cruises generally ranged from 1000 to 14,000 organisms/m^3. The high densities in June were almost entirely due to calanoid copepods and the dominant species was *Acartia tonsa*. Total zooplankton densities were also relatively high

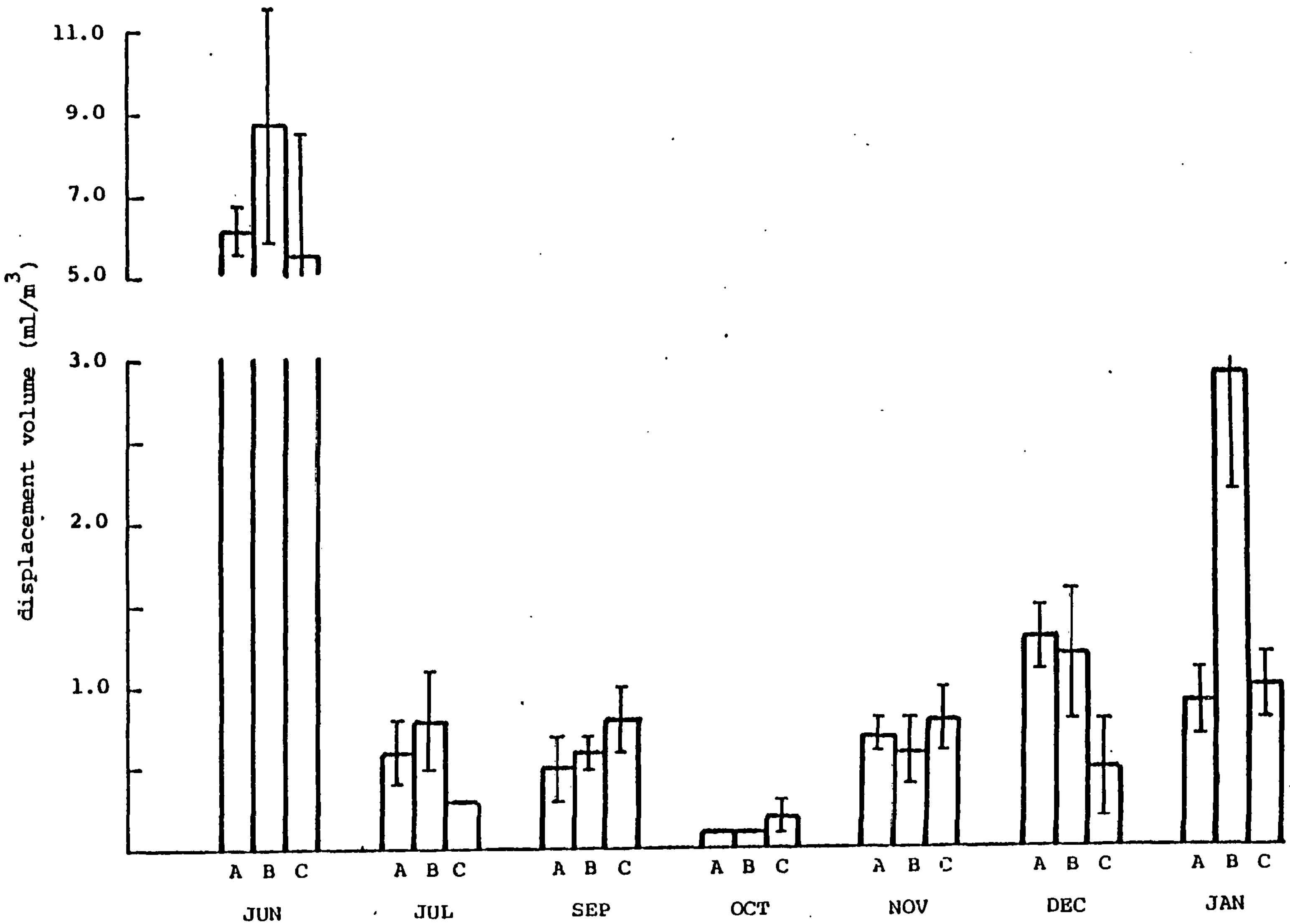

Figure 6-2. Zooplankton biomass data from the seven predisposal cruises. Mean displacement volumes are shown for each station on every cruise. The error bars indicate ± one standard deviation based on three replicate tows over the entire water column.

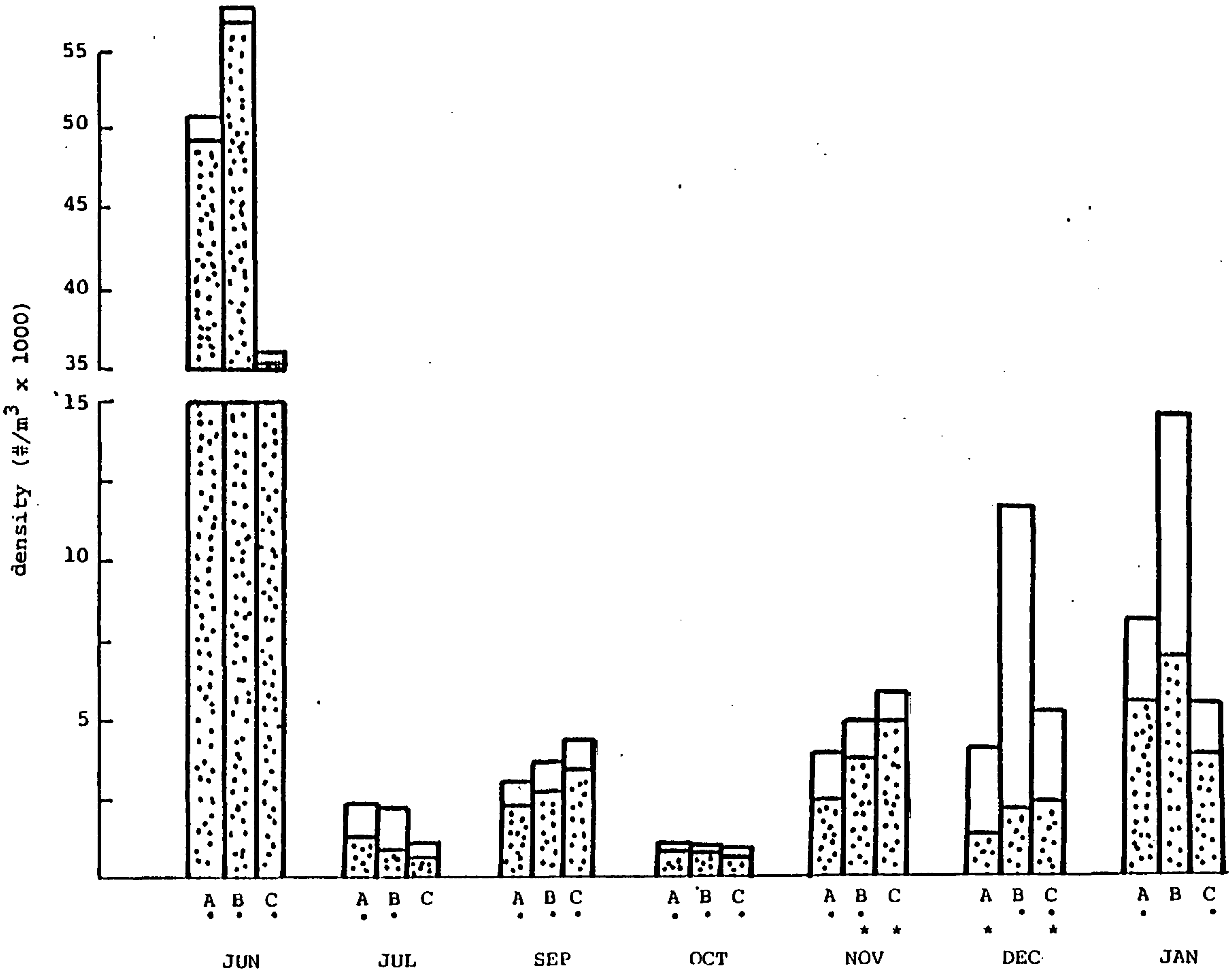

Figure 6-3. Mean zooplankton (white) and copepod (stippled) densities from the seven predisposal cruises. Bars represent mean values from three replicate tows taken over the entire water column. Stations with the same symbols (• or *) were similar at the 1% significance level based on a Duncan's multiple range test done on log transformed densities of total zooplankton.

in the December and January samples. A large proportion of these organisms were meroplanktonic tornaria larvae (hemichordates). Station C in the July cruise and Station B in the January cruise appeared to be significantly different from the other stations.

Densities from each tow taken on the seven cruises are listed for all the groups of zooplankton and species of copepods in Appendix 8, Tables 8-1 and 8-2. Copepods were the dominant organisms during all cruises except during December when tornaria larvae dominated (Table 6-1). Other numerically abundant groups included bivalve larvae, chaetognaths, larvacea, and barnacle cypris larvae.

Copepod densities showed a monthly pattern similar to that of the zooplankton as a whole (Figure 6-3). Calanoids were the most abundant group (always over 60%) and cyclopoids became relatively abundant in October and January (Figure 6-4). Harpacticoids were rarely abundant. When the percentages of adult females, adult males, and immature forms were compared (Figure 6-5) adult males generally had the lowest percentages. Immature forms (copepodids) were abundant in September, November, and January. They were also abundant at Station A in July. Little consistent pattern, however, was apparent from these data.

Tornaria larvae occurred in significant numbers only during December and January (Figure 6-6). The variability between the stations during these cruises appeared high with the greatest mean densities of larvae occurring at Station B. Perhaps information on the spatial distribution of mature hemichordates from the benthic study could explain this distribution of larvae.

Bivalve larvae were present in the samples mostly from October through December (Figure 6-7). Mean densities reached over 2000/m^3 at

Table 6-1. Dominant zooplankton groups in the predisposal study. Percentages are based on total mean densities from tows covering the entire water column.

Cruises 1-7 combined

Group	% of zooplankton	cum. %
Copepods	81.4	81.4
Tornaria larvae	5.3	86.7
Bivalve larvae	3.2	89.9
Chaetognaths	1.9	91.8
Larvacea	1.9	93.7
Barnacle cypris larvae	1.5	95.2
Other crustacean larvae (OCL)	0.9	96.1
Doliolida	0.9	97.0

Cruise	Group	%	cum. %
1 JUN	Copepods	96.5	96.5
	Doliolida	0.7	97.3
	OCL	0.7	97.9
	Penilia	0.5	98.4
	Larvacea	0.4	98.8
2 JUL	Copepods	52.8	52.8
	Doliolida	16.4	69.2
	Chaetognaths	10.4	79.6
	Euconchoecia	4.5	84.1
	Penilia	4.1	88.2
3 SEP	Copepods	74.9	74.9
	Larvacea	8.3	83.2
	Chaetognaths	7.2	90.4
	OCL	5.9	96.3
	Lucifer	1.3	97.6
4 OCT	Copepods	65.2	65.2
	Chaetognaths	13.6	78.8
	Bivalve larvae	10.6	89.4
	OCL	7.2	96.6
	Larvacea	1.1	97.7

Cruise	Group	%	cum. %
5 NOV	Copepods	74.7	74.7
	Bivalve larvae	15.4	90.1
	Larvacea	4.2	94.3
	Chaetognaths	4.2	98.5
	OCL	0.5	99.0
6 DEC	Tornaria larvae	37.9	37.9
	Copepods	28.0	65.9
	Bivalve larvae	21.9	87.8
	Chaetognaths	3.9	91.7
	Larvacea	3.5	95.2
7 JAN	Copepods	57.0	57.0
	Tornaria larvae	14.8	71.8
	Barnacle cypris	11.4	83.2
	others	5.5	88.7
	Larvacea	5.1	93.8

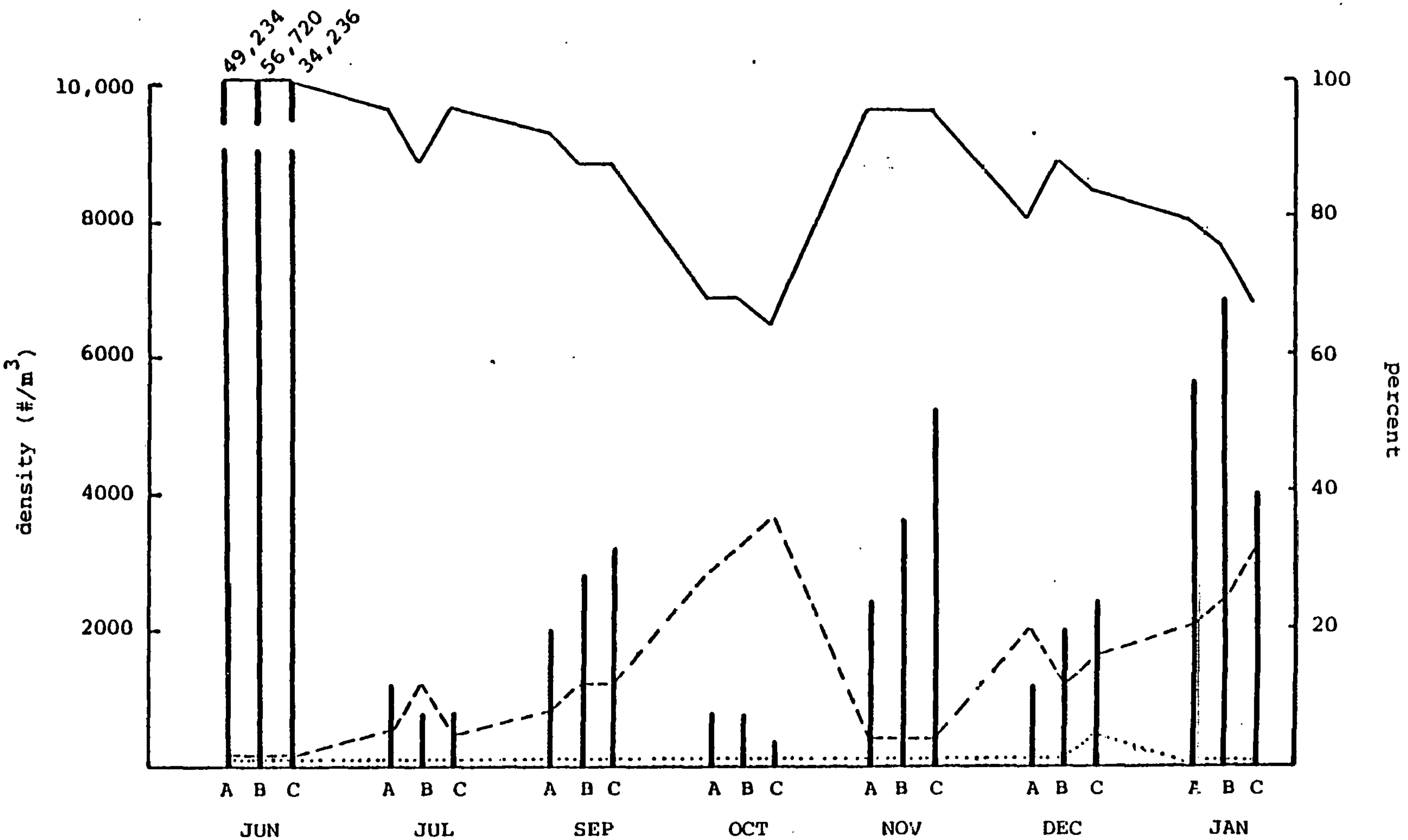

Figure 6-4. The percentage of calanoids (solid line), cyclopoids (dashed line), and harpacticoids (dotted line) within the copepods at each station on the seven predisposal cruises. The vertical bars represent mean copepod densities at each station. All values are based on tows over the entire water column.

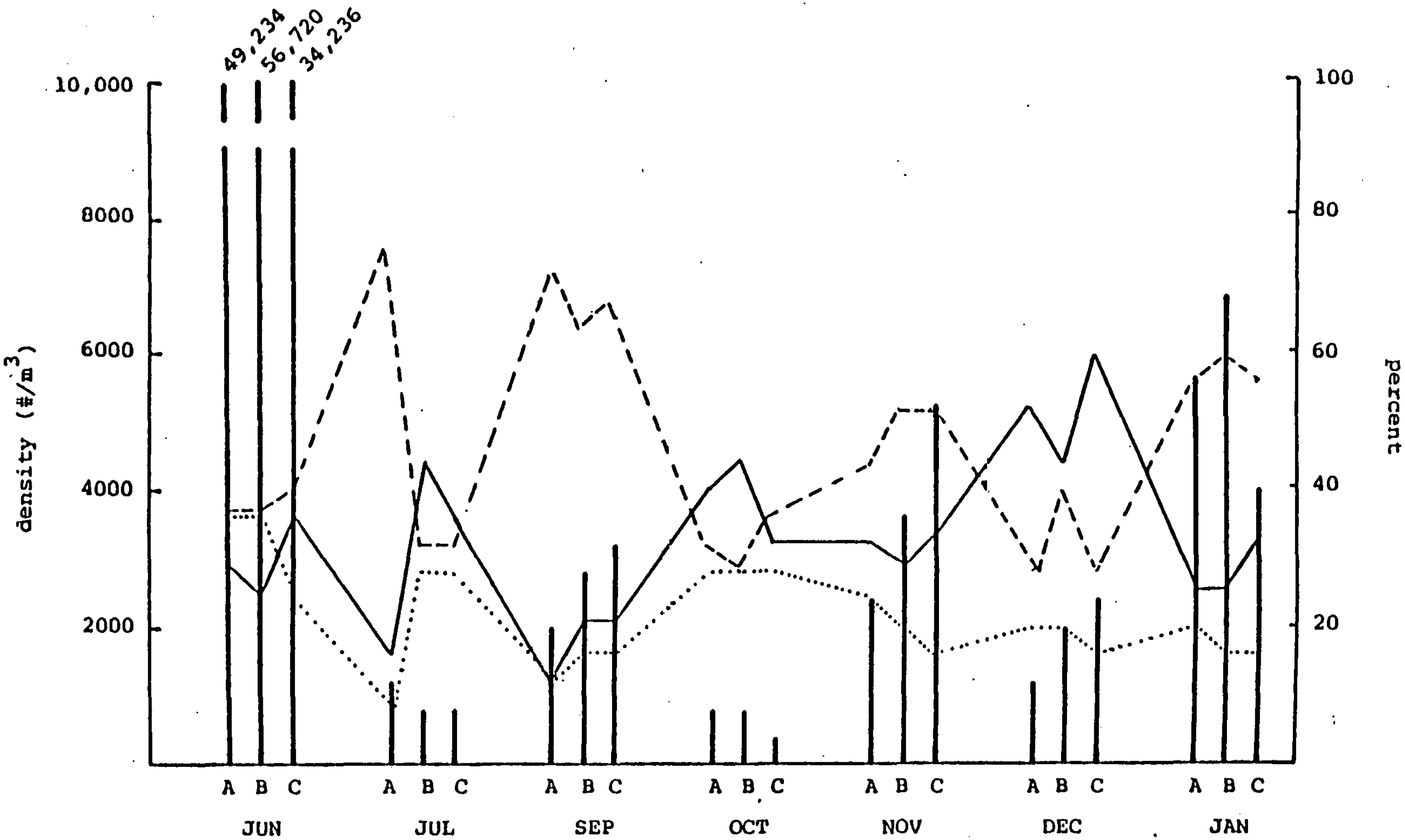

Figure 6-5. The percentage of adult females (solid line), copepodids (dashed line), and adult males (dotted line) within the copepods at each station on the seven predisposal cruises. The vertical bars represent mean copepod densities at each station. All values are based on tows over the entire water column.

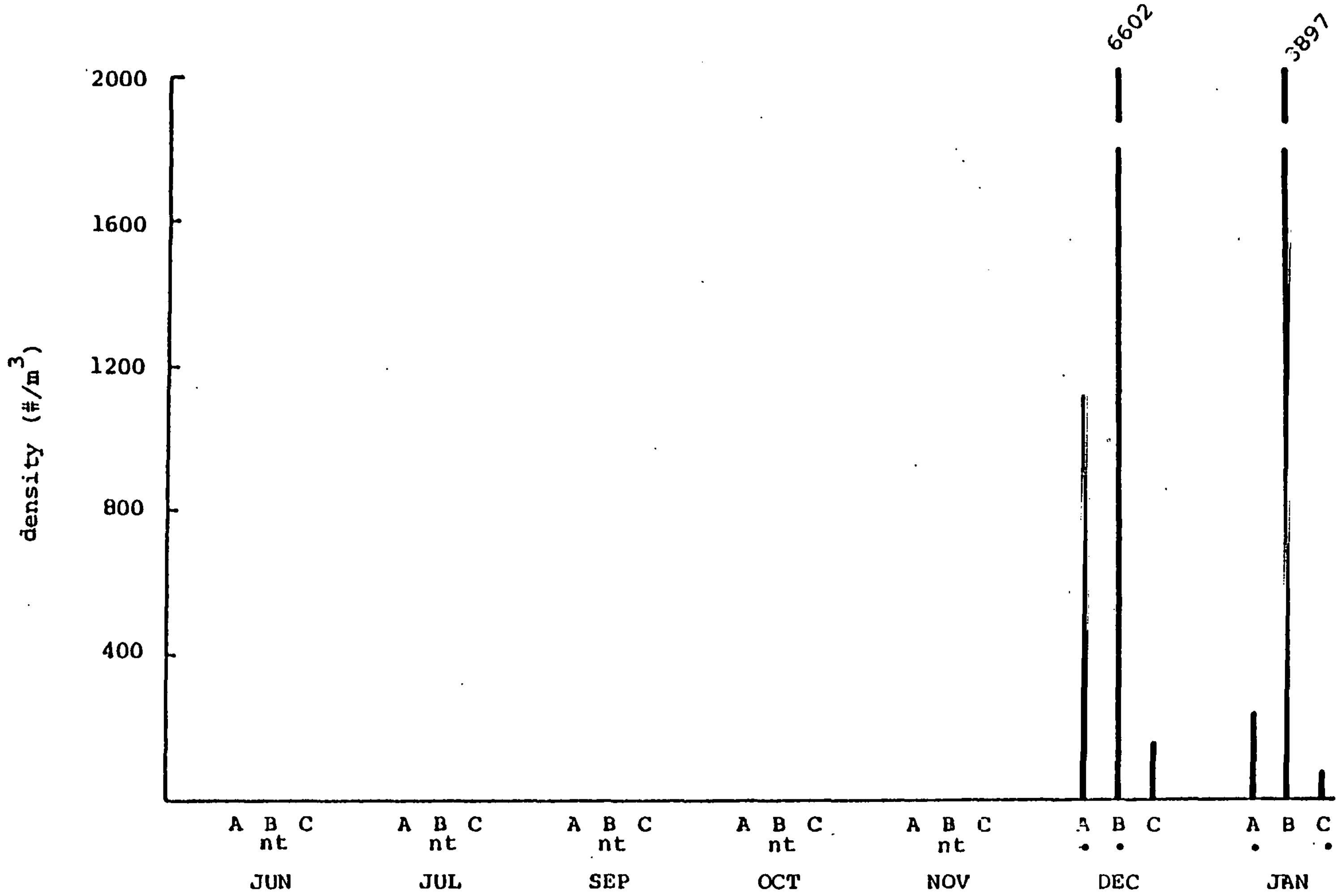

Figure 6-6. Mean densities of tornaria larvae at each station for the seven predisposal cruises. Bars represent mean values from three replicate tows taken over the entire water column. Stations with the same symbols (• or *) were similar at the 1% significance level based on Duncan's multiple range test performed on log transformed densities. nt = no test performed.

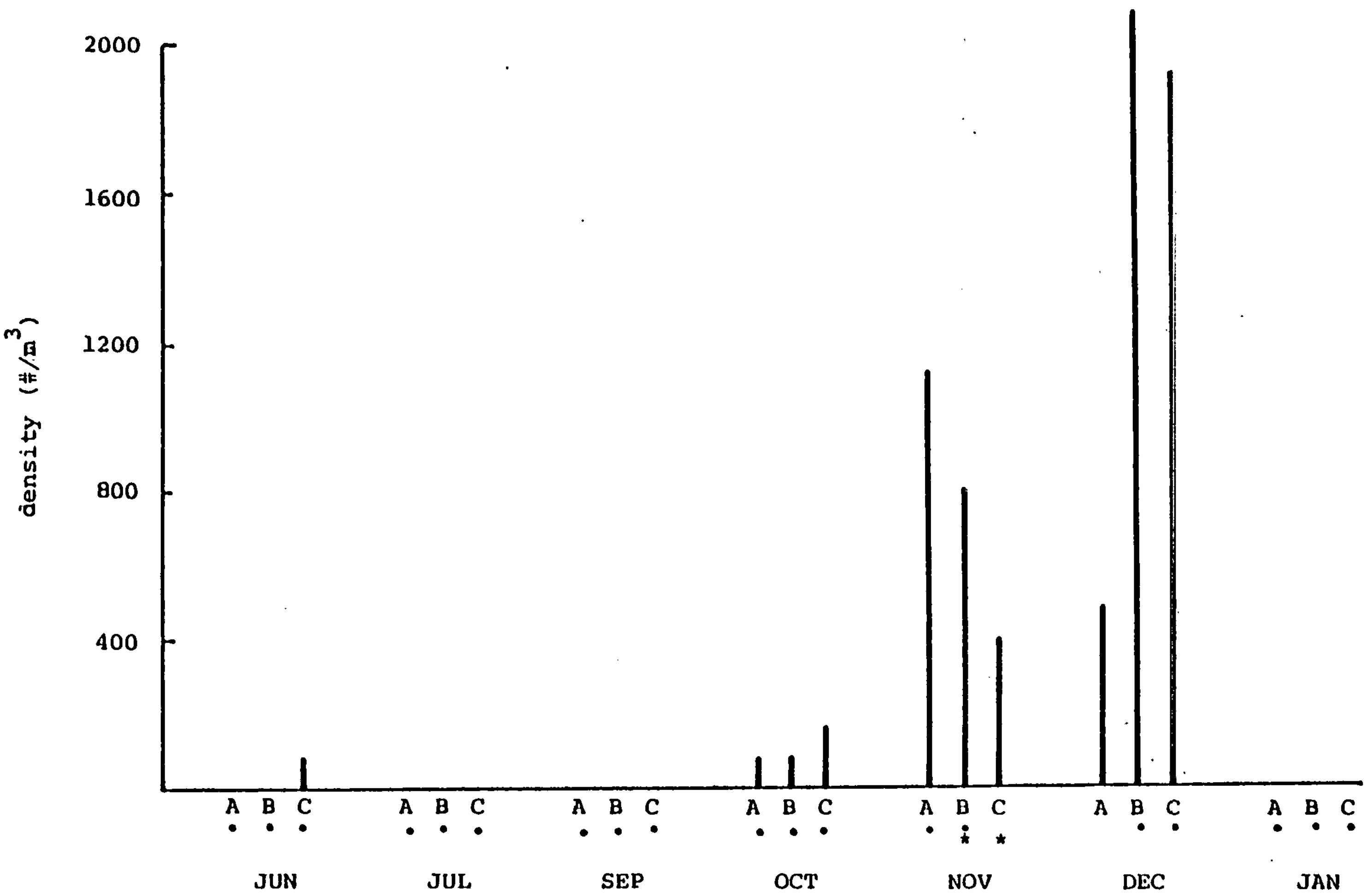

Figure 6-7. Mean densities of bivalve larvae at each station for the seven predisposal cruises. Graphed as in Figure 6-6 (pg. 6-14).

Station B in December. The density of bivalve larvae was positively correlated ($r = +0.32$, $P = 1.2\%$) with the density of tornaria larvae.

Chaetognaths and larvacea occurred more consistently throughout the seven cruises (Figures 6-8 and 6-9). Maximum mean densities of chaetognaths occurred during December and January and high densities of larvacea were also present in January. Densities of larvacea were very low in July and October. Differences between the three stations appeared minimal for both of these groups.

Barnacle cypris larvae were absent or found in low numbers during the first six cruises (Figure 6-10). Densities were high during January however when the mean density at Station B reached $2577/m^3$.

The dominant species of copepods based on the percentages of adult females from all cruises were *Acartia tonsa* and *Paracalanus quasimodo*. These two species made up 87% of the adult female copepods (Table 6-2). *Acartia tonsa* made up over 50% of the adult female copepods during June, November, and January. *Paracalanus quasimodo* was dominant in December (71.5%). During the July, September, and October cruises several species were found in similar numbers with no clear dominant form. The most abundant species found during these months in addition to *A. tonsa* and *P. quasimodo* were *Centropages velificatus, Temora turbinata, Eucalanus pileatus, Corycaeus amazonicus, Corycaeus giesbrechti,* and *Oncaea venusta*. Monthly density distributions for the ten most abundant species of copepods are shown in Figures 6-11 through 6-20.

Species diversity was measured as the total number of species of adult female copepods identified at a station during a particular cruise. The changes in species diversity over the seven cruise period are shown in Figure 6-21. Although no strong trend was apparent, the highest di-

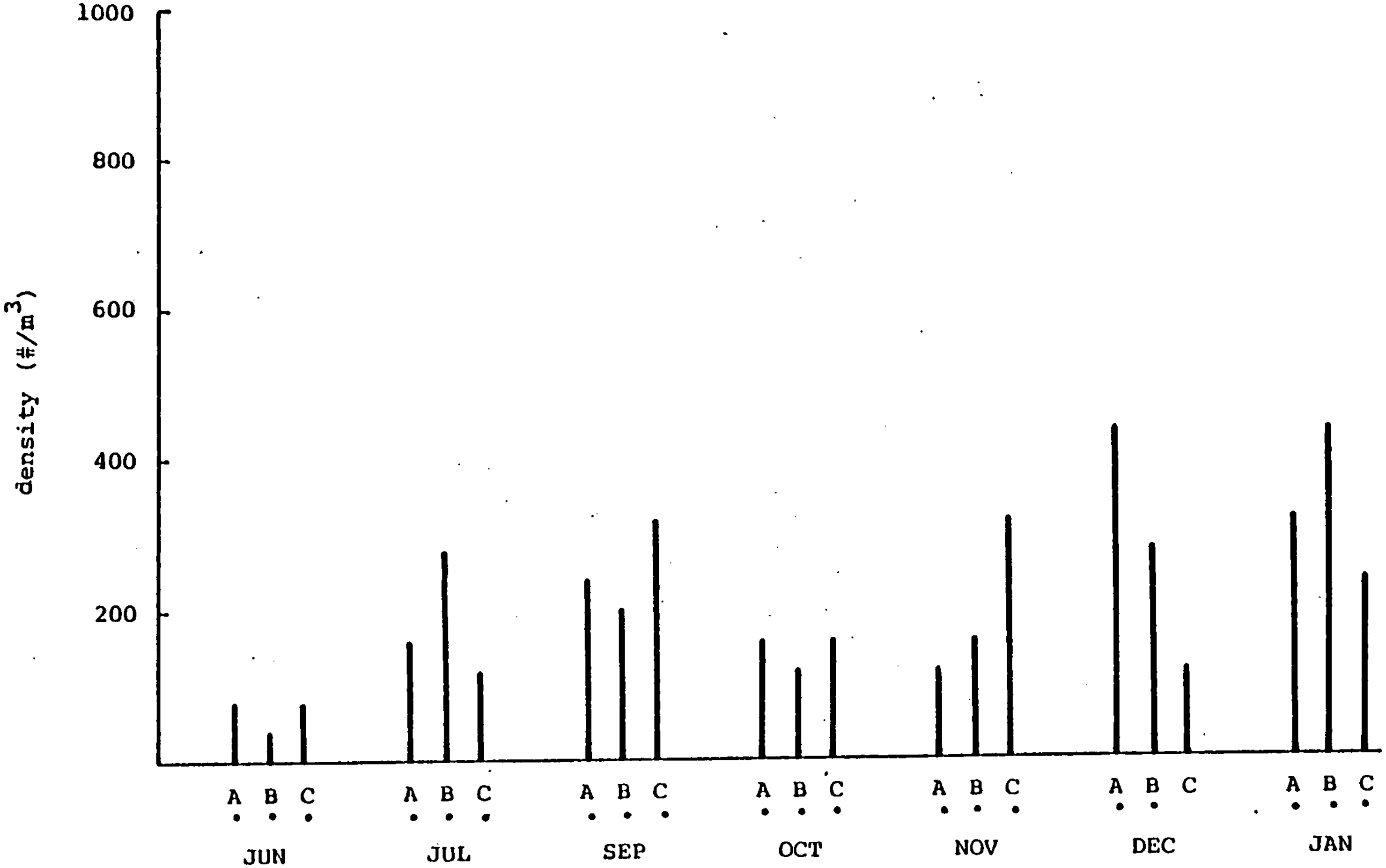

Figure 6-8. Mean densities of chaetognaths at each station for the seven predisposal cruises. Graphed as in Figure 6-6 (pg. 6-14).

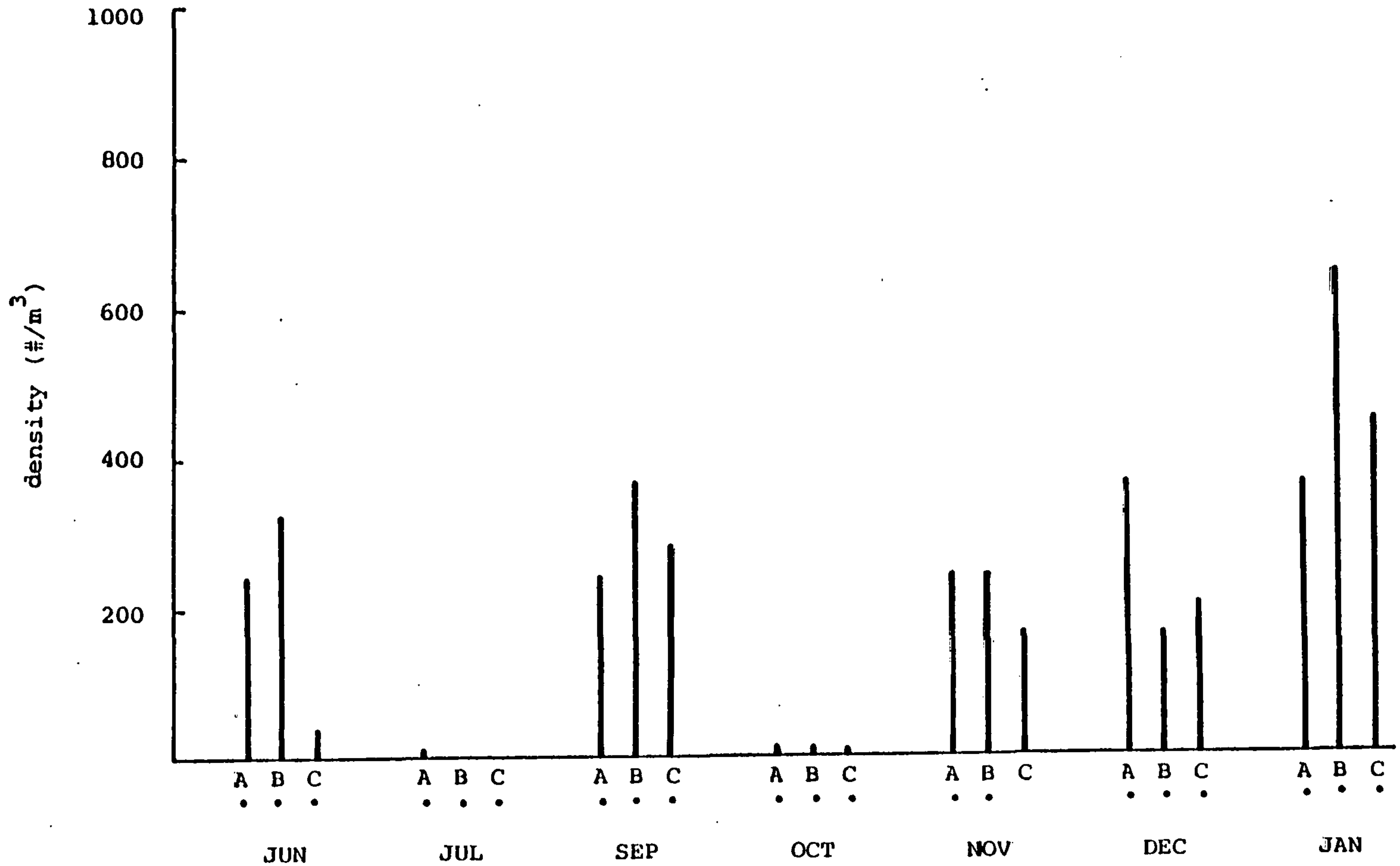

Figure 6-9. Mean densities of larvacea at each station for the seven predisposal cruises. Graphed as in Figure 6-6 (pg. 6-14).

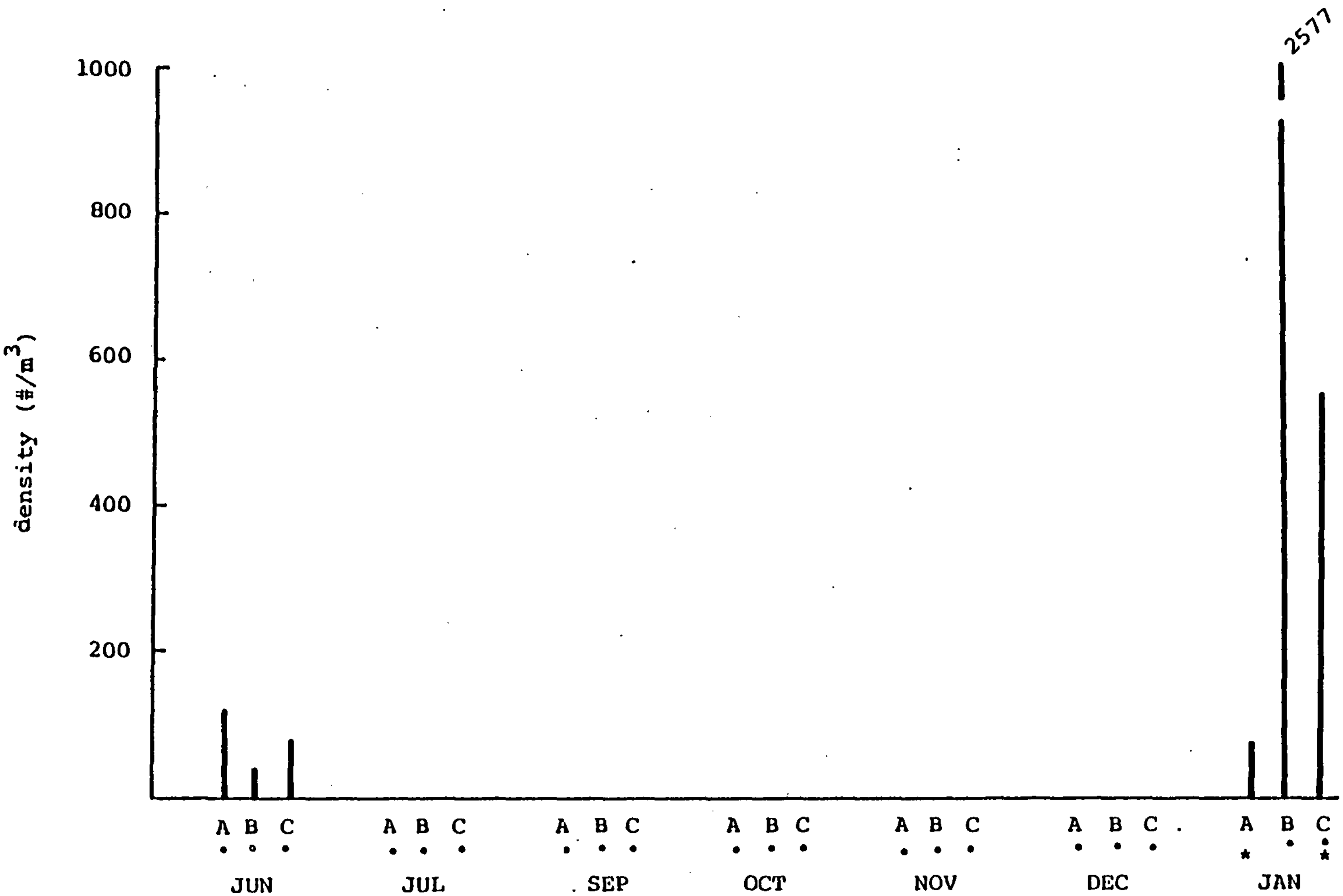

Figure 6-10. Mean densities of barnacle cypris larvae at each station for the seven predisposal cruises. Graphed as in Figure 6-6 (pg. 6-14).

Table 6-2. Dominant species of copepods in the predisposal study. Percentages are based on total mean densities of adult females from tows covering the entire water column.

Cruises 1-7 combined

Species	% of adult females	cum. %
Acartia tonsa (AT)	74.7	74.7
Paracalanus quasimodo (PQ)	12.3	87.0
Temora turbinata (TT)	3.3	90.3
Centropages velificatus (CV)	2.1	92.4
Corycaeus americanus (CA)	1.2	93.6
Corycaeus amazonicus (CAZ)	1.0	94.6
Oncaea venusta (OV)	1.0	95.6
Eucalanus pileatus (EP)	1.0	96.6
Paracalanus crassirostris (PC)	0.8	97.4
Clausocalanus furcatus (CF)	0.5	97.9
Corycaeus giesbrechti (CG)	0.4	98.3
Oithona nana (ON)	0.3	98.6
Paracalanus indicus (PI)	0.2	98.8
Oithona colcarva (OC)	0.2	99.0
Temora stylifera (TS)	0.1	99.1

Cruise	Species	%	cum. %
1 JUN	*A. tonsa*	87.4	87.4
	P. quasimodo	6.1	93.5
	T. turbinata	2.7	96.2
	C. velificatus	1.2	97.4
	P. crassirostris	0.9	98.3
2 JUL	*C. velificatus*	40.9	40.9
	P. quasimodo	26.9	67.8
	T. turbinata	12.0	79.8
	A. tonsa	5.4	85.2
	E. pileatus	4.2	89.4
3 SEP	*A. tonsa*	22.1	22.1
	P. quasimodo	16.2	38.3
	T. turbinata	14.5	52.8
	E. pileatus	13.0	65.8
	C. amazonicus	10.9	76.7
4 OCT	*P. quasimodo*	26.0	26.0
	A. tonsa	18.7	44.7
	O. venusta	18.3	63.0
	C. giesbrechti	11.2	74.2
	C. velificatus	9.1	83.3
5 NOV	*A. tonsa*	65.7	65.7
	P. quasimodo	15.5	81.2
	E. pileatus	4.3	85.5
	T. turbinata	3.1	88.6
	Labidocera aestiva	1.9	90.5
6 DEC	*P. quasimodo*	71.5	71.5
	O. venusta	5.5	77.0
	T. turbinata	4.3	81.3
	A. tonsa	4.0	85.3
	C. americanus	3.2	88.5
7 JAN	*A. tonsa*	51.2	51.2
	P. quasimodo	21.0	72.2
	C. americanus	11.3	83.5
	T. turbinata	2.9	86.4
	C. amazonicus	2.9	89.3

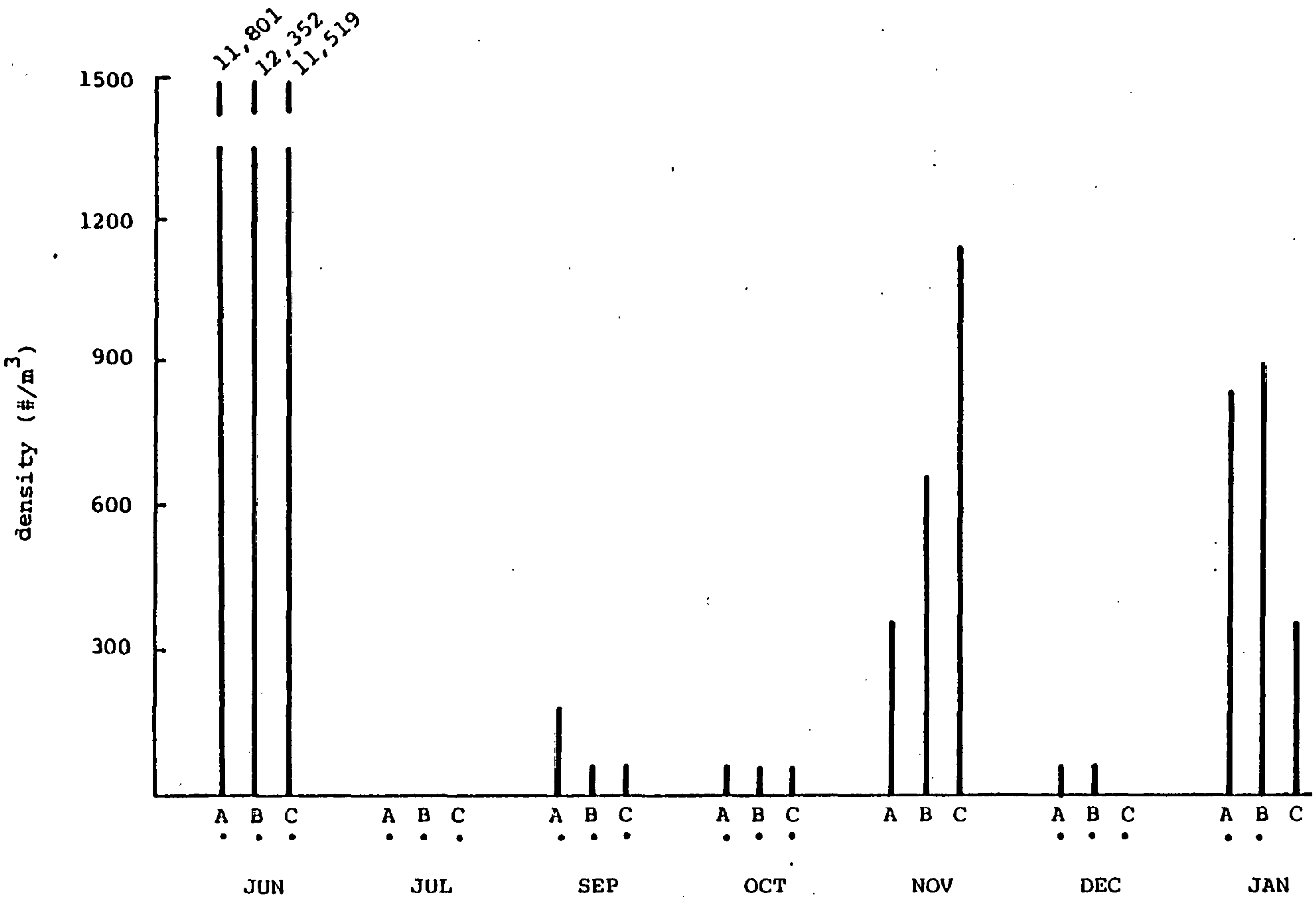

Figure 6-11. Mean densities of *Acartia tonsa* at each station for the seven predisposal cruises. Bars represent mean densities of adult females from the three replicate tows taken over the entire water column. Stations with the same symbols (• or *) were similar at the 1% significance level based on Duncan's multiple range test performed on log transformed densities. nt = no test performed.

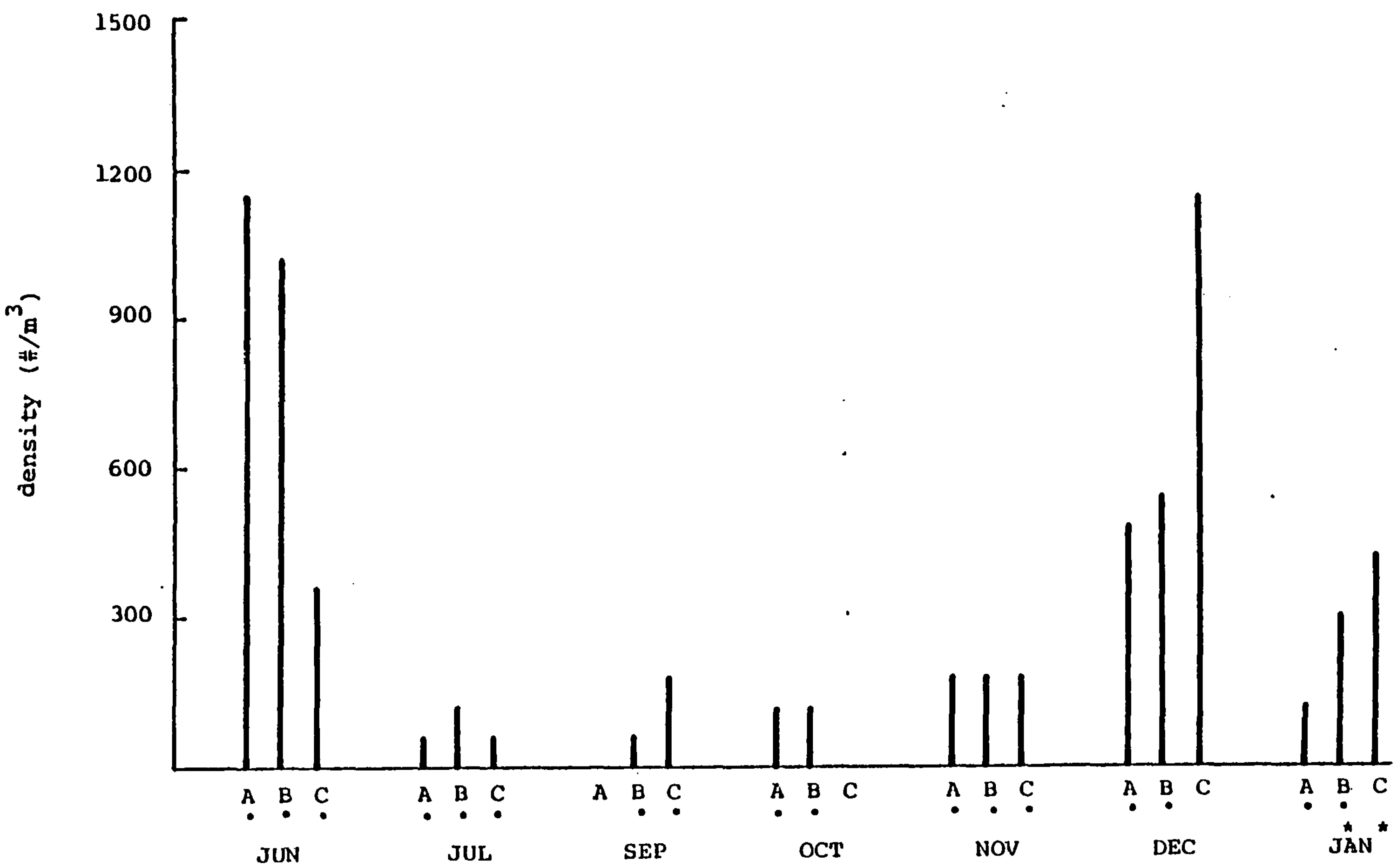

Figure 6-12. Mean densities of *Paracalanus quasimodo* at each station for the seven predisposal cruises. See legend of Figure 6-11 (pg. 6-21).

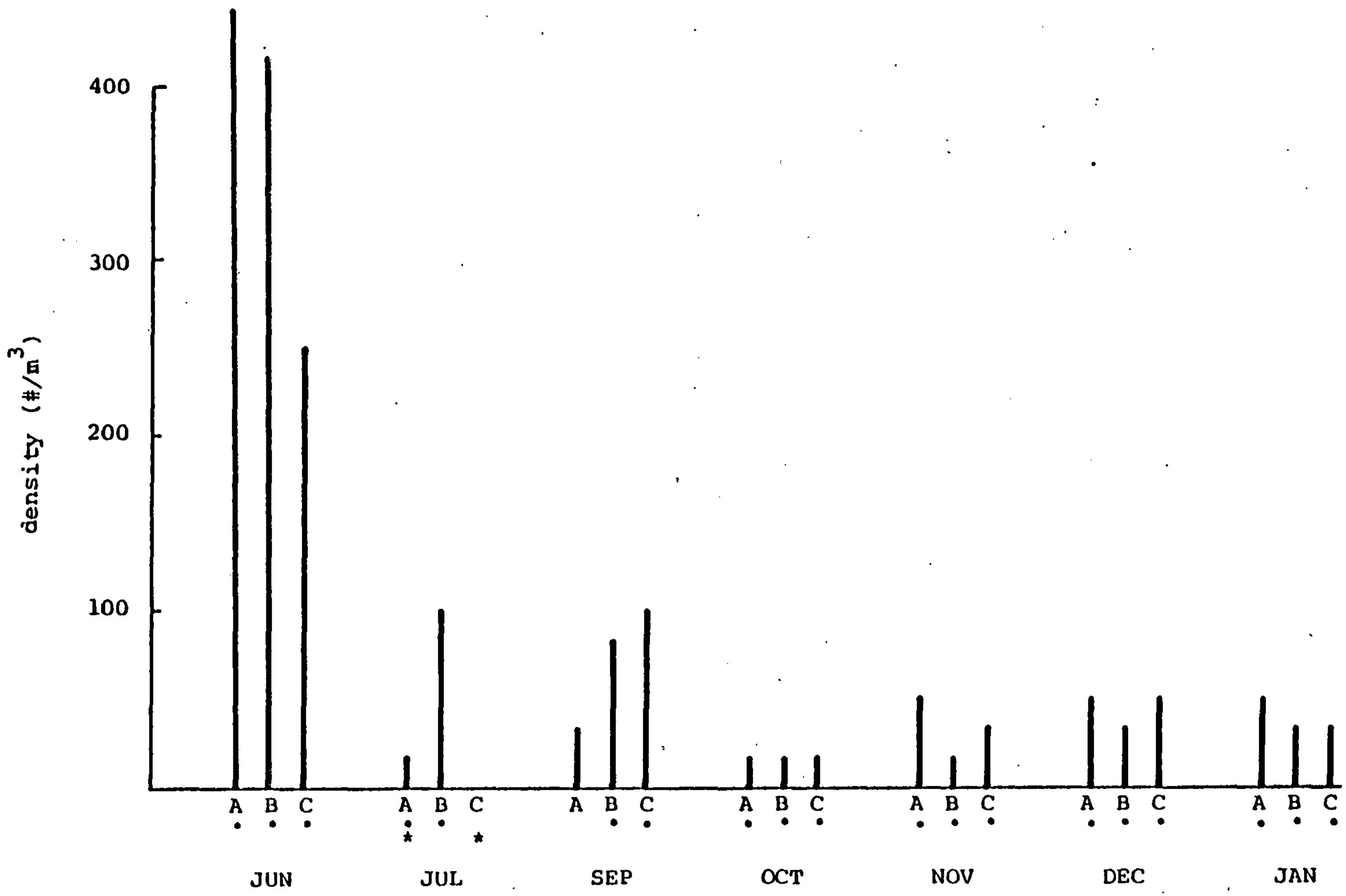

Figure 6-13. Mean densities of *Temora turbinata* at each station for the seven predisposal cruises. See legend of Figure 6-11 (pg. 6-21).

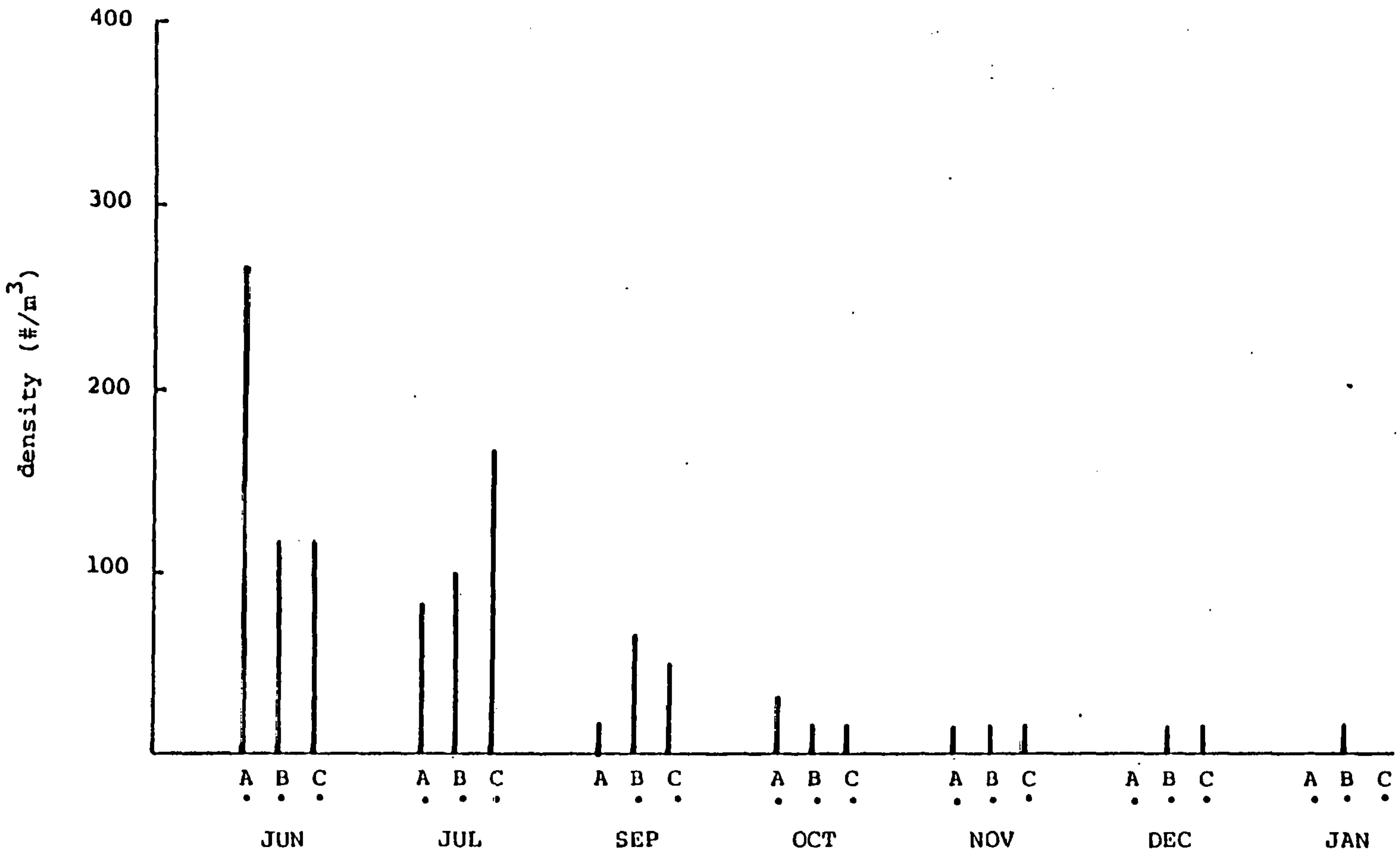

Figure 6-14. Mean densities of *Centropages velificatus* at each station for the seven predisposal cruises. See legend of Figure 6-11 (pg. 6-21).

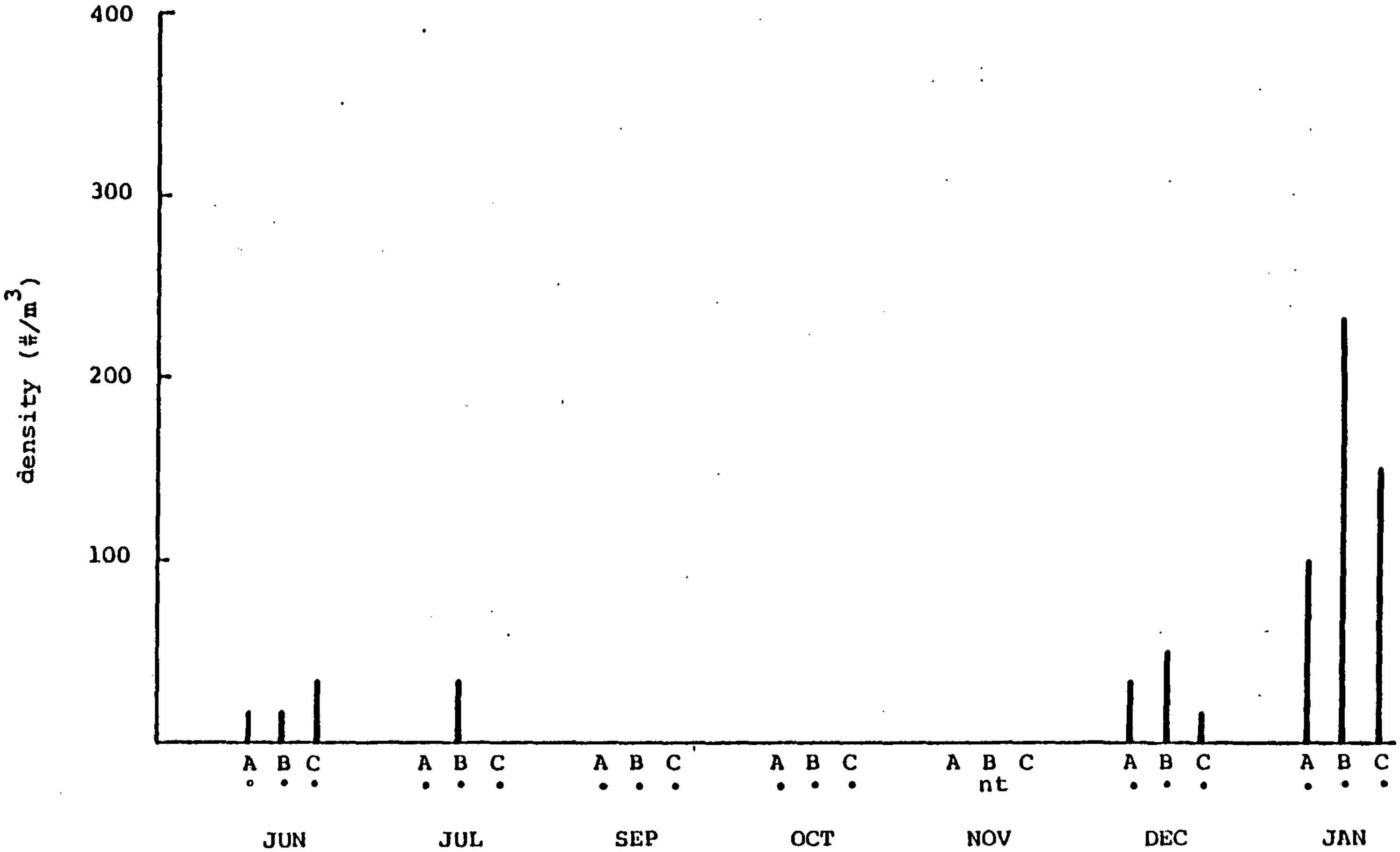

Figure 6-15. Mean densities of *Corycaeus americanus* at each station for the seven predisposal cruises. See legend of Figure 6-11 (pg. 6-21).

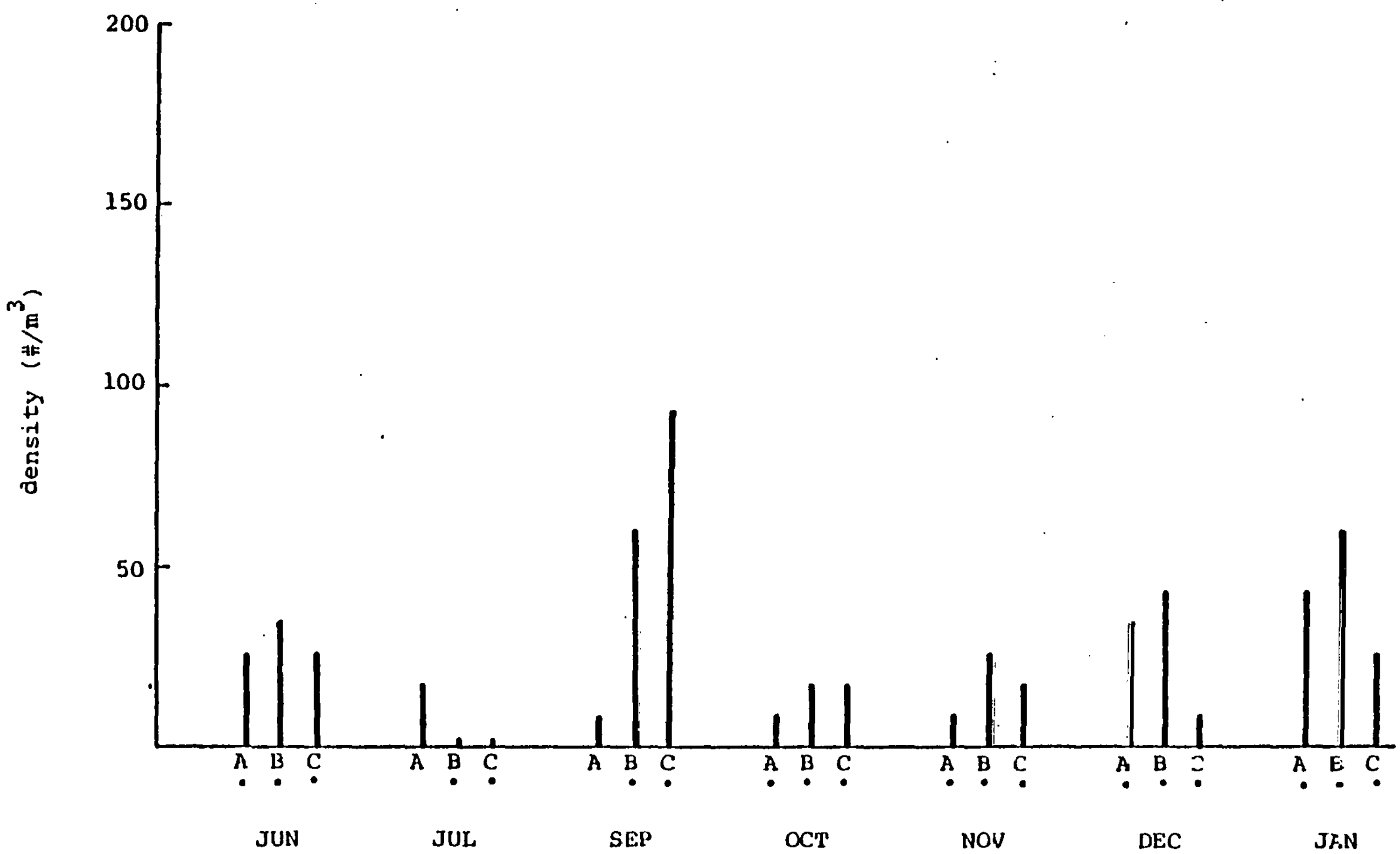

Figure 6-16. Mean densities of *Corycaeus amazonicus* at each station for the seven predisposal cruises. See legend of Figure 6-11 (pg. 6-21).

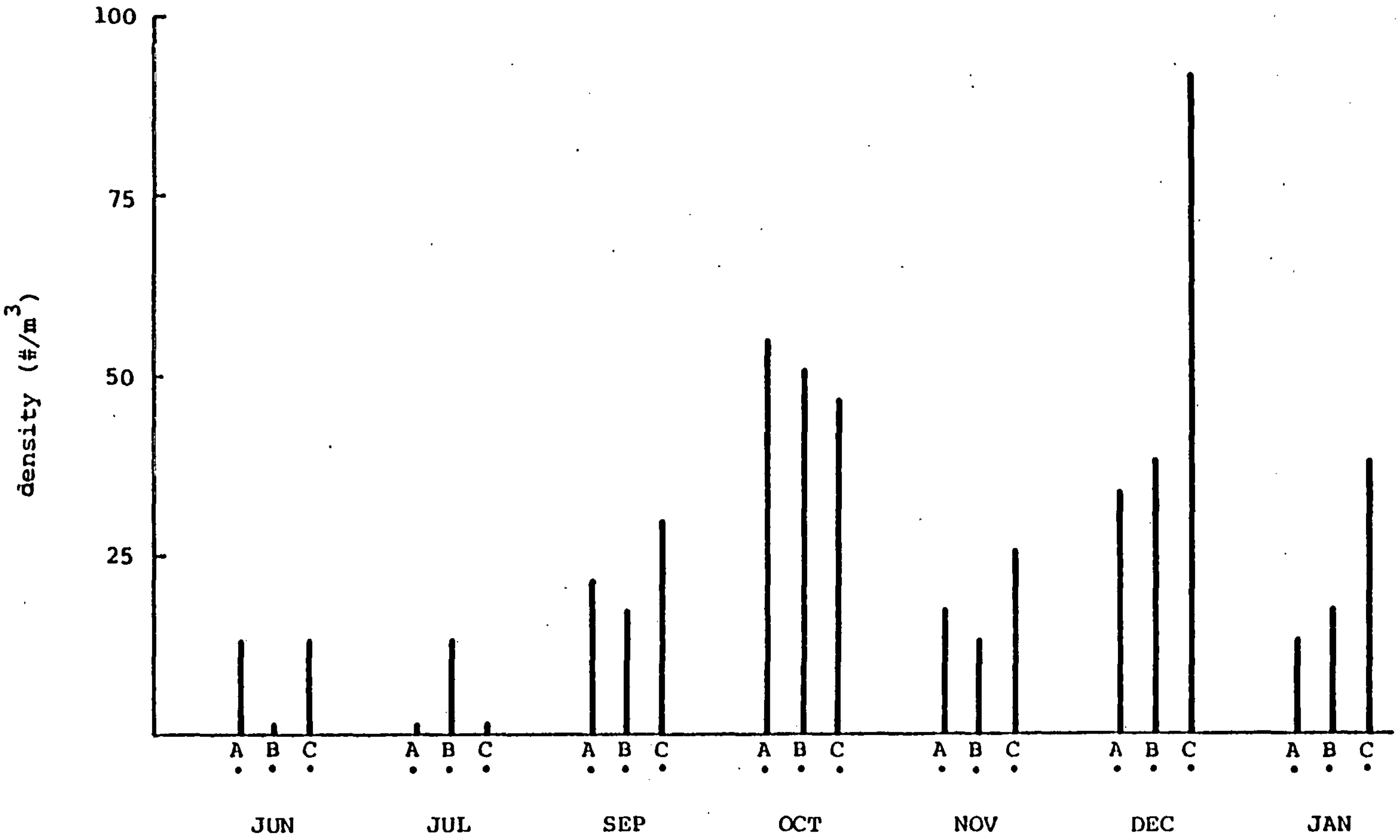

Figure 6-17. Mean densities of *Oncaea venusta* at each station for the seven predisposal cruises. See legend of Figure 6-11 (pg. 6-21).

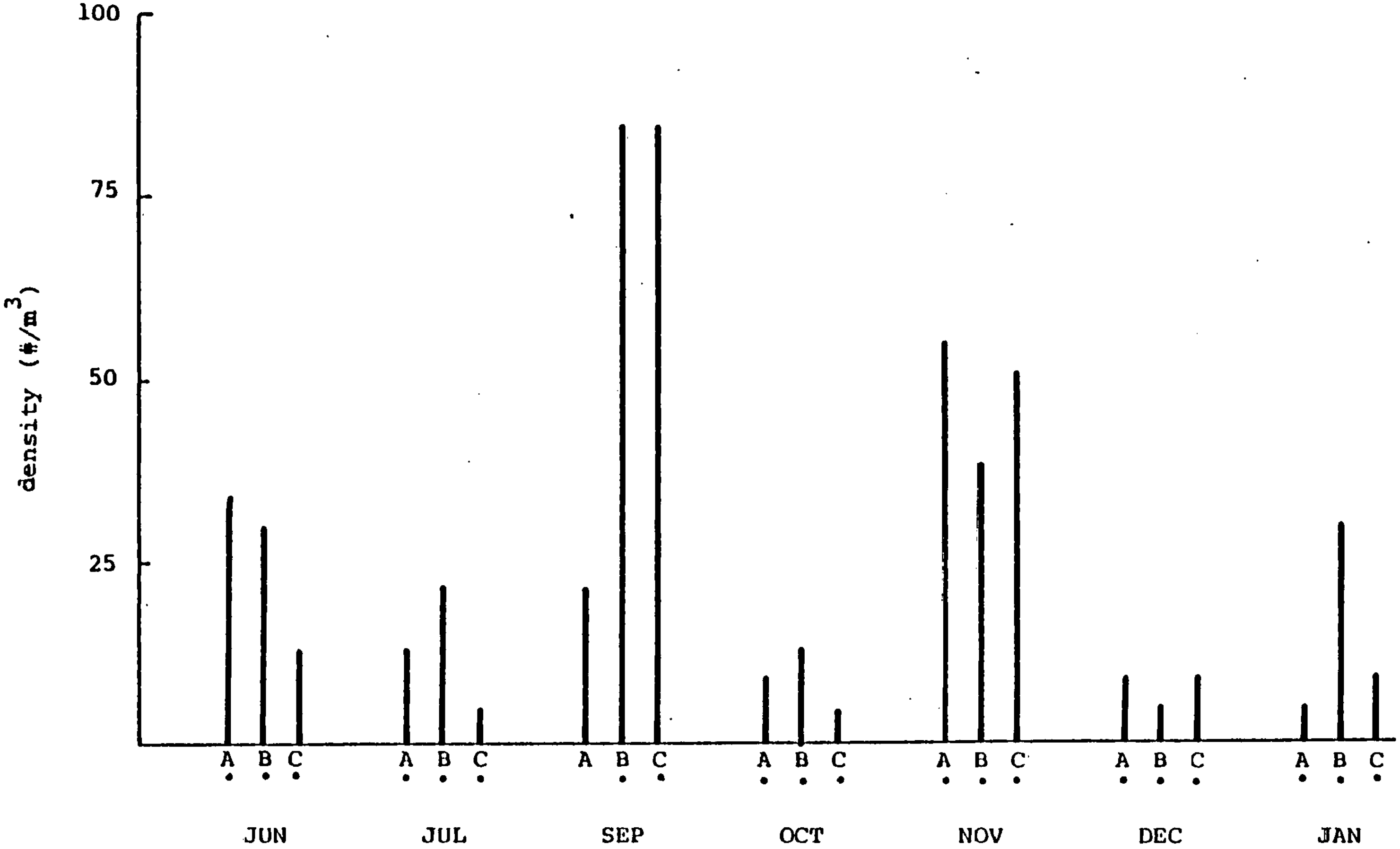

Figure 6-18. Mean densities of *Eucalanus pileatus* at each station for the seven predisposal cruises. See legend of Figure 6-11 (pg. 6-21).

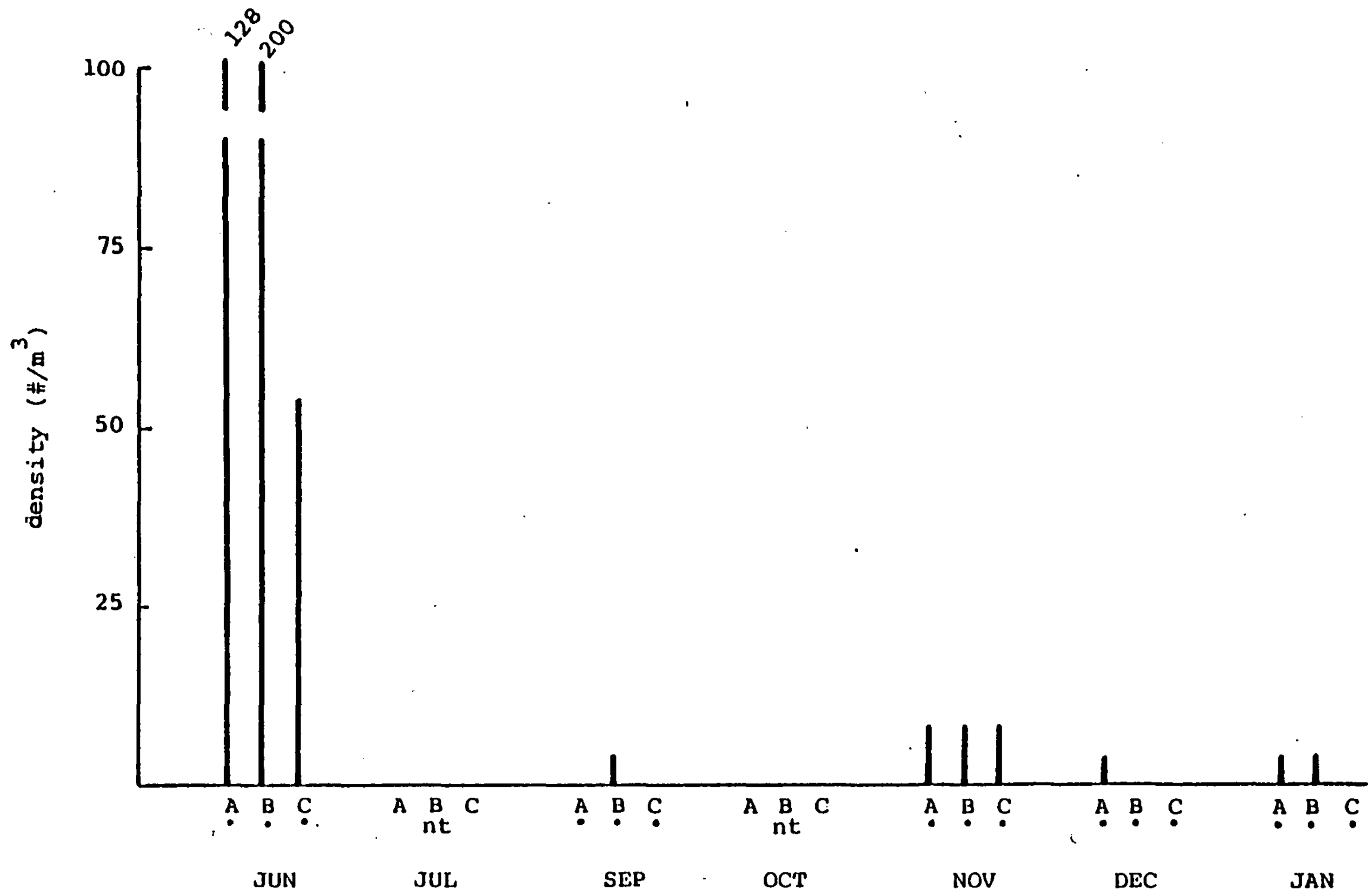

Figure 6-19. Mean densities of *Paracalanus crassirostris* at each station for the seven predisposal cruises. See legend of Figure 6-11 (pg. 6-21).

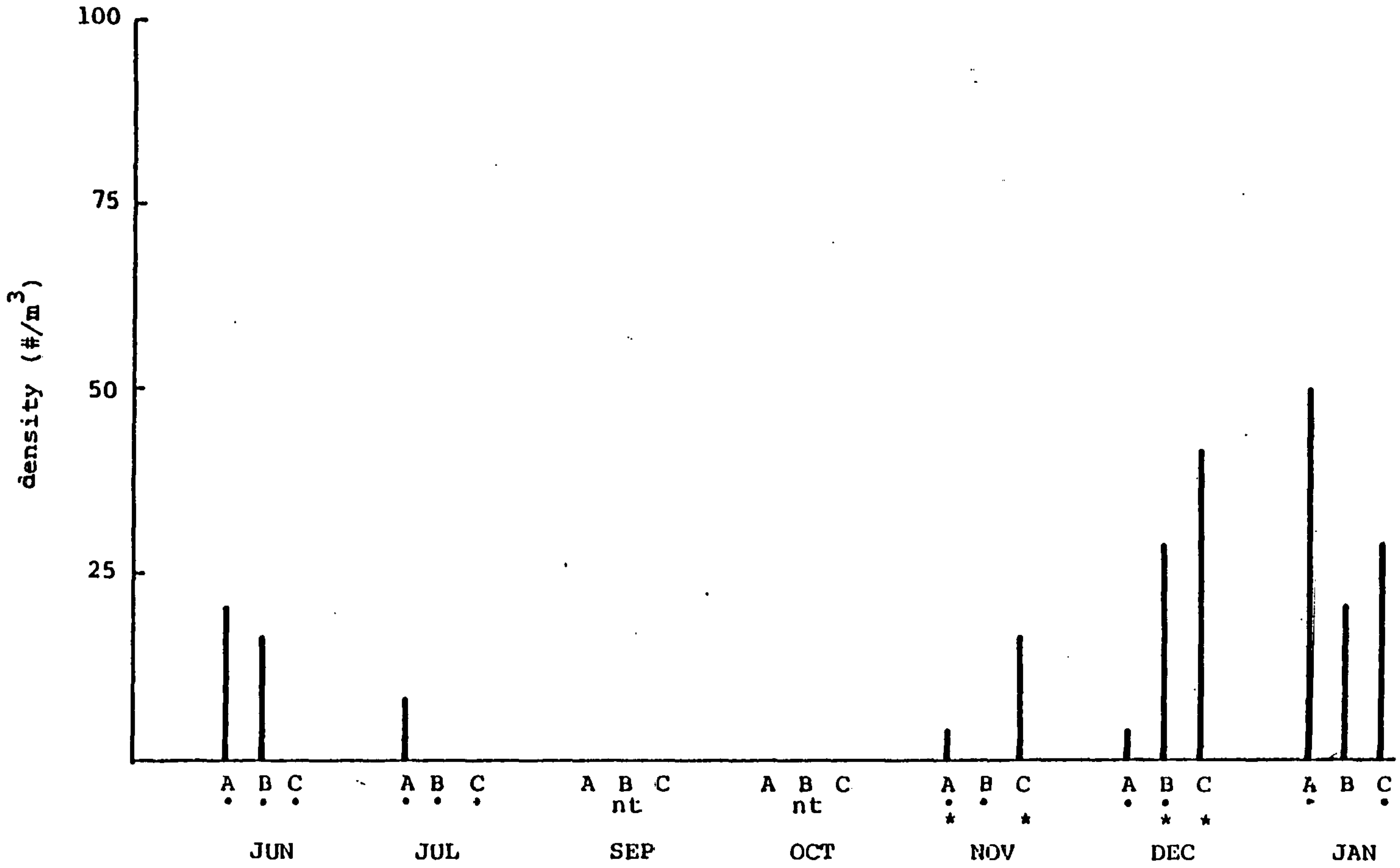

Figure 6-20. Mean densities of *Clausocalanus furcatus* at each station for the seven predisposal cruises. See legend of Figure 6-11 (pg. 6-21).

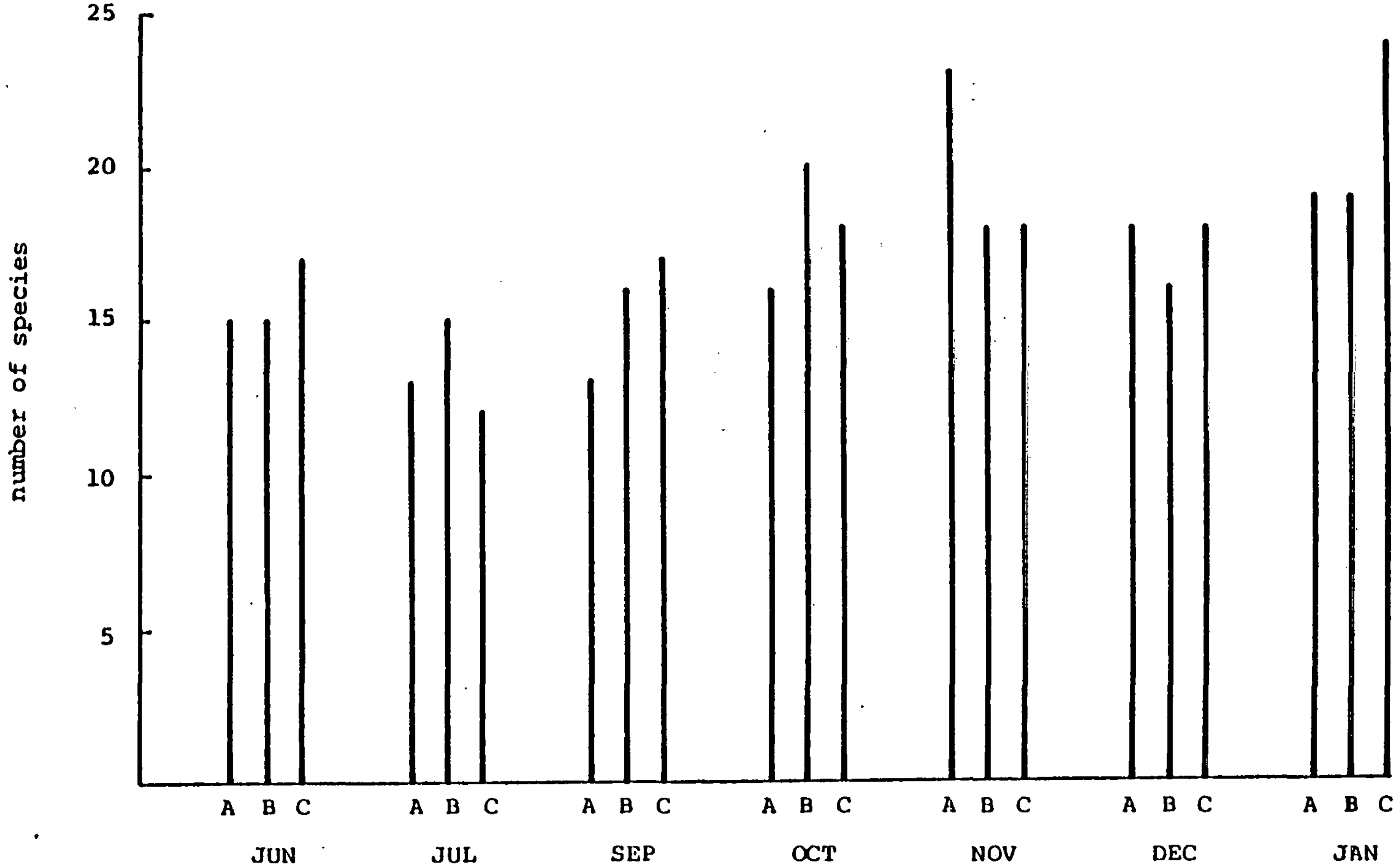

Figure 6-21. The number of species of adult female copepods at each station for the seven predisposal cruises. Values represent the total number of species identified from all tows taken at each station.

versities generally appeared in the November through January cruises. When the number of species identified was plotted against the number of specimens examined at a station, no distinct relationship was present. In most cases, 600 to 1500 specimens of adult female copepods were examined at each station during a cruise.

6.3.1.3 The Analysis of Variance

An analysis of variance was used on log transformed densities to determine whether the three stations sampled were similar during each of the seven cruises. A separate analysis was performed on total zooplankton, the dominant groups and the abundant species of copepods. The error term used to test for station variability was a pooled variance based on the replicate tow error during each cruise. For total zooplankton densities, significant differences (at the 1% level) between the three stations were found during Cruises 2, 5, 6, and 7 (Table 6-3). Data for the copepods as a group were similar but the results differed within the other major groups. In general, however, the three stations appeared to be most dissimilar during Cruises 5-7. Since the F test is a variance ratio, these data indicate that compared to the replicate tow variability, station variability was high from November through January.

When the analysis was run on the densities of the ten dominant species of copepods, five out of the ten showed significant differences at the 1% level between stations during the September cruise. During the other 6 months, the three stations appeared similar based on the analysis of seven out of ten of these dominant species. The stations appeared dissimilar on Cruises 5-7 based on the analysis of *Acartia tonsa, Paracalanus quasimodo,* and *Clausocalanus furcatus.*

Table 6-3. Analysis of variance results for total zooplankton, dominant zooplankton groups, and dominant copepod species. Probability values are listed for each cruise. Values below 0.050 indicate that there was a significant difference between the three stations during that cruise at the 5% level. All analyses were based on log transformed densities.

Group/Species	Cruise						
	JUN	JUL	SEP	OCT	NOV	DEC	JAN
Total Zooplankton	0.065	0.004	0.186	0.622	0.008	0.008	0.001
Copepods	0.057	0.015	0.152	0.083	0.000	0.000	0.010
Tornaria larvae	..	..	..	..	..	0.000	0.001
Bivalve larvae	0.632	0.577	0.325	0.451	0.011	0.010	0.800
Chaetognaths	0.376	0.190	0.453	0.951	0.027	0.000	0.493
Larvacea	0.159	0.223	0.652	0.150	0.011	0.033	0.200
Barnacle cypris larvae	0.532	0.454	0.228	0.422	0.422	0.629	0.008
Adult female copepods							
Acartia tonsa	0.902	0.031	0.140	0.354	0.000	0.111	0.009
Paracalanus quasimodo	0.052	0.376	0.001	0.004	0.999	0.002	0.021
Temora turbinata	0.648	0.011	0.007	0.328	0.582	0.111	0.080
Centropages velificatus	0.300	0.116	0.001	0.148	0.970	0.171	0.297
Corycaeus americanus	0.560	0.025	0.455	0.290	..	0.019	0.065
Corycaeus amazonicus	0.906	0.010	0.001	0.156	0.475	0.235	0.836
Oncaea venusta	0.630	0.017	0.660	0.614	0.668	0.236	0.194
Eucalanus pileatus	0.980	0.046	0.010	0.079	0.503	0.649	0.044
Paracalanus crassirostris	0.107	..	0.155	..	0.492	0.253	0.868
Clausocalanus furcatus	0.629	0.422	..	..	0.008	0.016	0.006

6.3.1.4 Correlation Analysis

Temperature and salinity profiles measured at each station during five of the seven cruises are shown in Figures 6-22 and 6-23. Surface and bottom temperatures for June and November were obtained from the phytoplankton cruises during these months. Pearson correlation coefficients were calculated between the log densities of each major group and species and the surface and bottom temperature and salinity values (Table 6-4). Total zooplankton and copepod densities were highly correlated with low surface salinities. The densities of *Acartia tonsa* and *Paracalanus crassirostris* were also highly negatively correlated with surface salinity. Densities of bivalve larvae, chaetognaths, and *Oncaea venusta* were positively correlated with surface salinity. Many of the major groups of zooplankton which occurred in large numbers during the winter months showed high positive correlations with surface and bottom temperatures.

Group by group and species by species correlation matrices were constructed based on the logs of the mean densities for each tow. In the group by group analysis (Table 6-5), the highest positive correlations appeared between the copepods and the barnacle cypris larvae ($r = + 0.53$) and the copepods and larvaceans ($r = + 0.40$). Copepod densities were negatively correlated with the density of chaetognaths. A high negative correlation between cypris larvae and bivalve larvae was also present.

Figure 6-24 is a graphical summary of the species by species correlation matrix constructed from the densities of the 15 most abundant adult female copepods. A line is used to connect species positively correlated at decreasing levels of r. The length of the line is insignificant. This method often reveals species groups which change in density

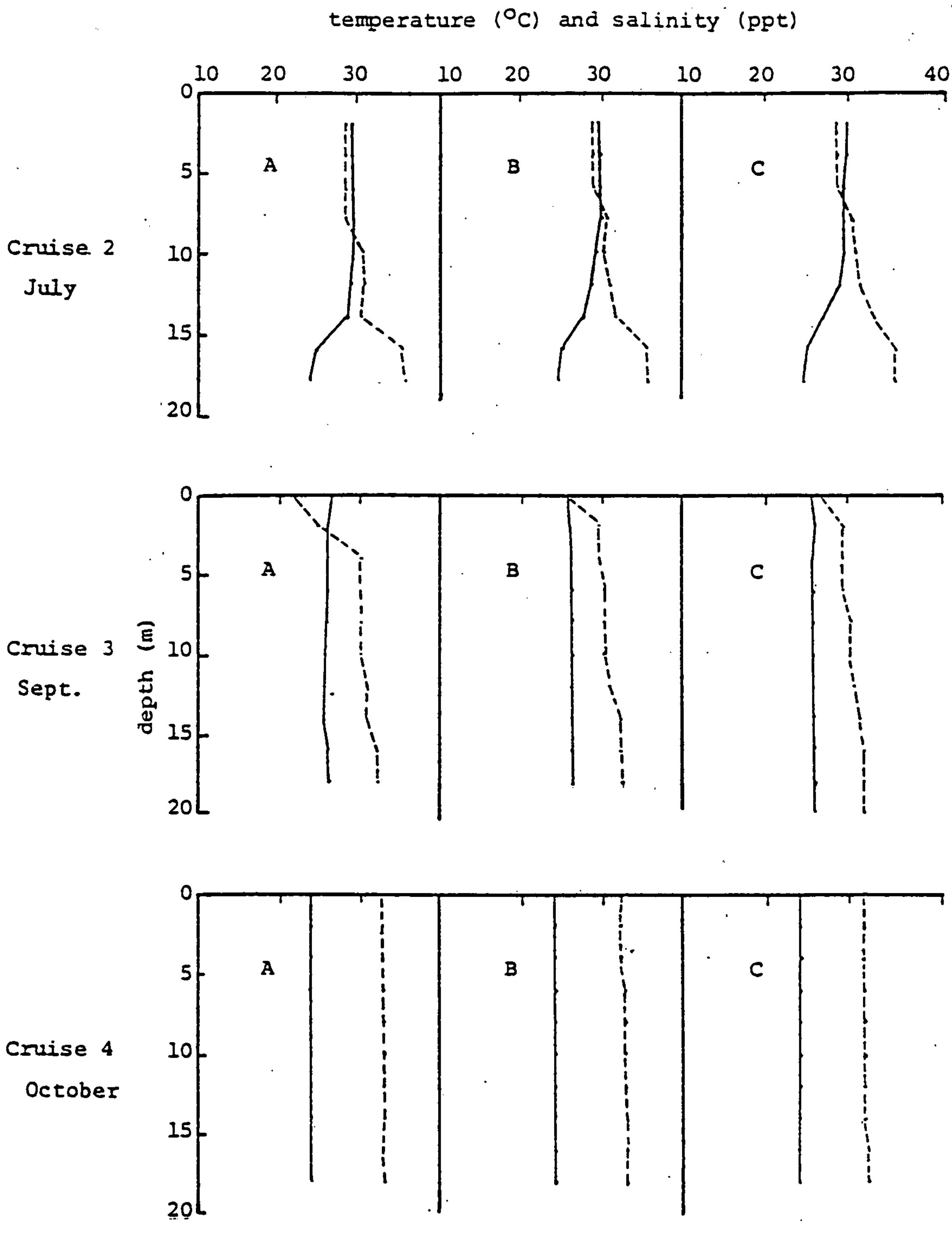

Figure 6-22. Temperature (solid line) and salinity (dashed line) profiles measured at each station (A,B,C) for Cruises 2, 3, and 4.

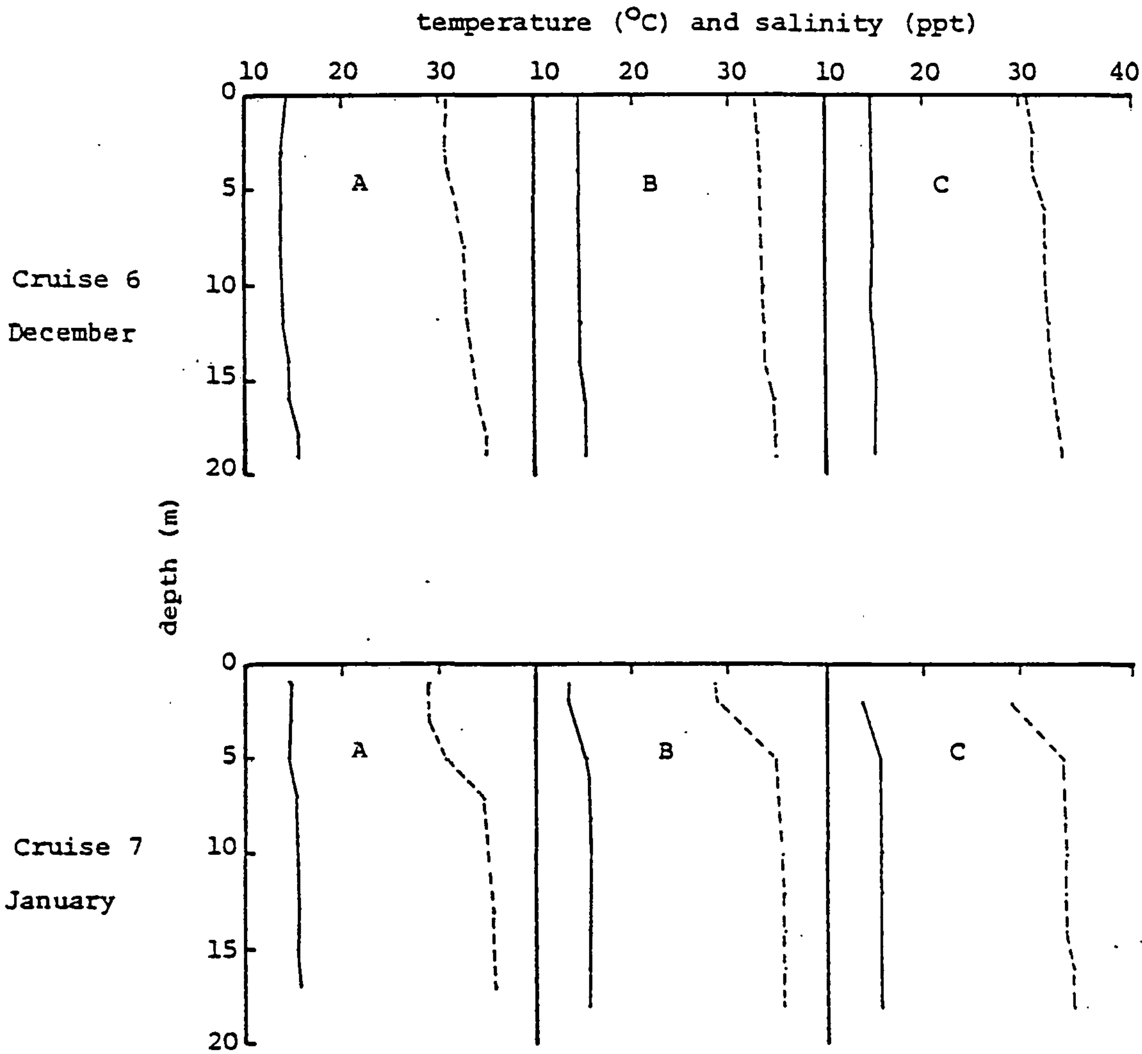

Figure 6-23. Temperature (solid line) and salinity (dashed line) profiles measured at each station (A,B,C) for Cruises 6 and 7.

Table 6-4. Pearson correlation coefficients calculated between zooplankton groups and surface and bottom temperatures and salinities. Values are based on log transformed densities from each tow covering the entire water column (n=63). ns = not significant at the 5% level, # - P between 1% and 5%, * - P less than 1%

	Temperature		Salinity	
Group/Species	Surface	Bottom	Surface	Bottom
Total Zooplankton	ns	ns	-0.66/*	+0.36/*
Copepods	ns	ns	-0.76/*	+0.25/#
Tornaria larvae	-0.71/*	-0.74/*	+0.26/#	+0.39/*
Bivalve larvae	-0.56/*	-0.53/*	+0.60/*	ns
Chaetognaths	-0.40/*	-0.29/#	+0.44/*	ns
Larvacea	-0.57/*	-0.46/*	ns	ns
Barnacle cypris larvae	ns	-0.30/#	-0.37/*	+0.63/*
Adult female copepods				
Acartia tonsa	ns	ns	-0.61/*	ns
Paracalanus quasimodo	-0.38/*	-0.51/*	ns	+0.43/*
Temora turbinata	ns	ns	-0.59/*	ns
Centropages velificatus	+0.65/*	+0.55/*	-0.34/*	ns
Corycaeus americanus	-0.56/*	-0.68/*	ns	+0.68/*
Corycaeus amazonicus	-0.33/*	ns	ns	ns
Oncaea venusta	-0.44/*	-0.25/#	+0.47/*	-0.44/*
Eucalanus pileatus	ns	+0.26/#	ns	-0.41/*
Paracalanus crassirostris	ns	ns	-0.68/*	ns
Clausocalanus furcatus	-0.67/*	-0.75/*	ns	+0.40/*

Table 6-5. Group by group correlation matrix for dominant zooplankton groups. Pearson correlation coefficients were based on log transformed mean densities from each tow covering the entire water column (n=63). ns = not significant at the 5% level, # - P between 1% and 5%, * - P less than 1%

	Copepods	Tornaria larvae	Bivalve larvae	Chaetognaths	Larvacea	Barnacle cypris larvae
Copepods	1	ns	ns	-0.39/*	+0.40/*	+0.53/*
Tornaria larvae		1	+0.32/#	+0.31/#	+0.38/*	+0.26/#
Bivalve larvae			1	+0.29/#	+0.25/#	-0.31/#
Chaetognaths				1	ns	ns
Larvacea					1	ns
Barnacle cypris larvae						1

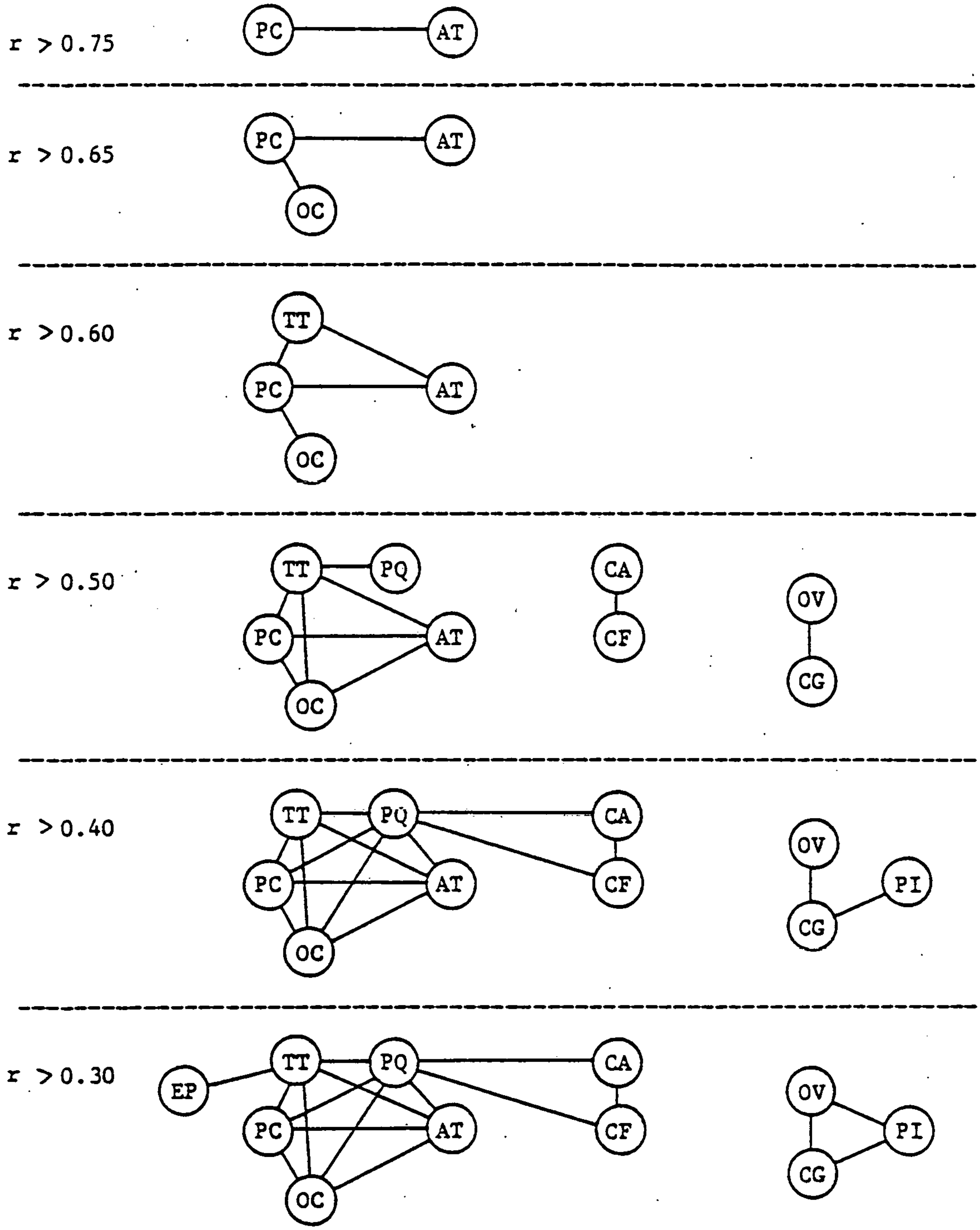

Figure 6-24. Graphical summary of positive Pearson correlation coefficients from a species x species correlation matrix constructed for the 15 most abundant adult female copepods. Species codes are identified in Table 6-2 (pg. 6-20). Species correlated at each level of r are connected with a solid line. Correlations are based on log transformed mean densities from each tow covering the entire water column (n=63). All correlations shown were significant at the 5% level.

together.

Densities of *Acartia tonsa* and *Paracalanus crassirostris* were highly correlated in this analysis. These estuarine or inshore species both peaked in the June samples when salinities were low. *Temora turbinata* and *Oithona colcarva* were also closely linked to this estuarine group. The densities of the members of this group were negatively correlated with surface salinity.

At lower levels of r, *Paracalanus quasimodo* became linked to the estuarine group and other linkages appeared between *Corycaeus americanus* and *Clausocalanus furcatus* and between *Oncaea venusta, Corycaeus giesbrechti,* and *Paracalanus indicus*.

This analysis therefore revealed three groups of correlated species from the seven cruises.

1. An inshore or estuarine group was present which was negatively correlated with surface salinity. These species occurred in greatest numbers in June and also were fairly abundant from November through January.

2. A small group consisting of *Corycaeus americanus* and *Clausocalanus furcatus* was also present. Densities of these species were positively correlated with bottom salinities and negatively correlated with surface temperatures. They also appeared in June and from November through January but their highest densities occurred in the winter months. This group was linked to the estuarine group through *Paracalanus quasimodo*.

3. The third group consisted of *Oncaea venusta, Corycaeus giesbrechti,* and *Paracalanus indicus*. The members of this group occurred in greatest numbers from September through January. Few specimens were found in the summer samples.

6.3.2 Half Depth Samples

In an attempt to roughly examine the vertical distribution of the zooplankton, a one half depth tow was taken at every station. When displacement volumes, densities of total zooplankton, and densities of copepods as a group were compared between the entire water column and the upper one half of the water column, little consistent pattern was apparent. In some of the other major zooplankton groups and species of copepods, however, some evidence for vertical stratification could be seen. Tornaria larvae and barnacle cypris larvae were apparently present in greater numbers in the lower one half of the water column. *Acartia tonsa* however appeared to generally be present in greater densities in the upper one half of the water column.

6.3.3 Historical Data

Monthly densities for total zooplankton at Stations W2 and W3 for the years 1963 and 1964 indicated a definite seasonal pattern (Figure 6-25 and 6-26). Densities were high in the spring and fall months. Overall densities were higher at Station W2 where they reached almost 6000 organisms/m^3 in May and November of 1964. The trend of decreasing zooplankton densities with the distance from shore exhibited in these two stations has repeatedly been seen in studies of the neritic zooplankton of the northwestern Gulf of Mexico (Park, 1979; Park and Turk, 1980; Minello, 1980).

Densities of major groups of zooplankton and all species of copepods are listed for each station in Appendix 8, Tables 8-3 through 806. The percentage of copepods in the samples was variable and showed no distinct seasonal trend (Figures 6-25 and 6-26). This percentage generally ranged

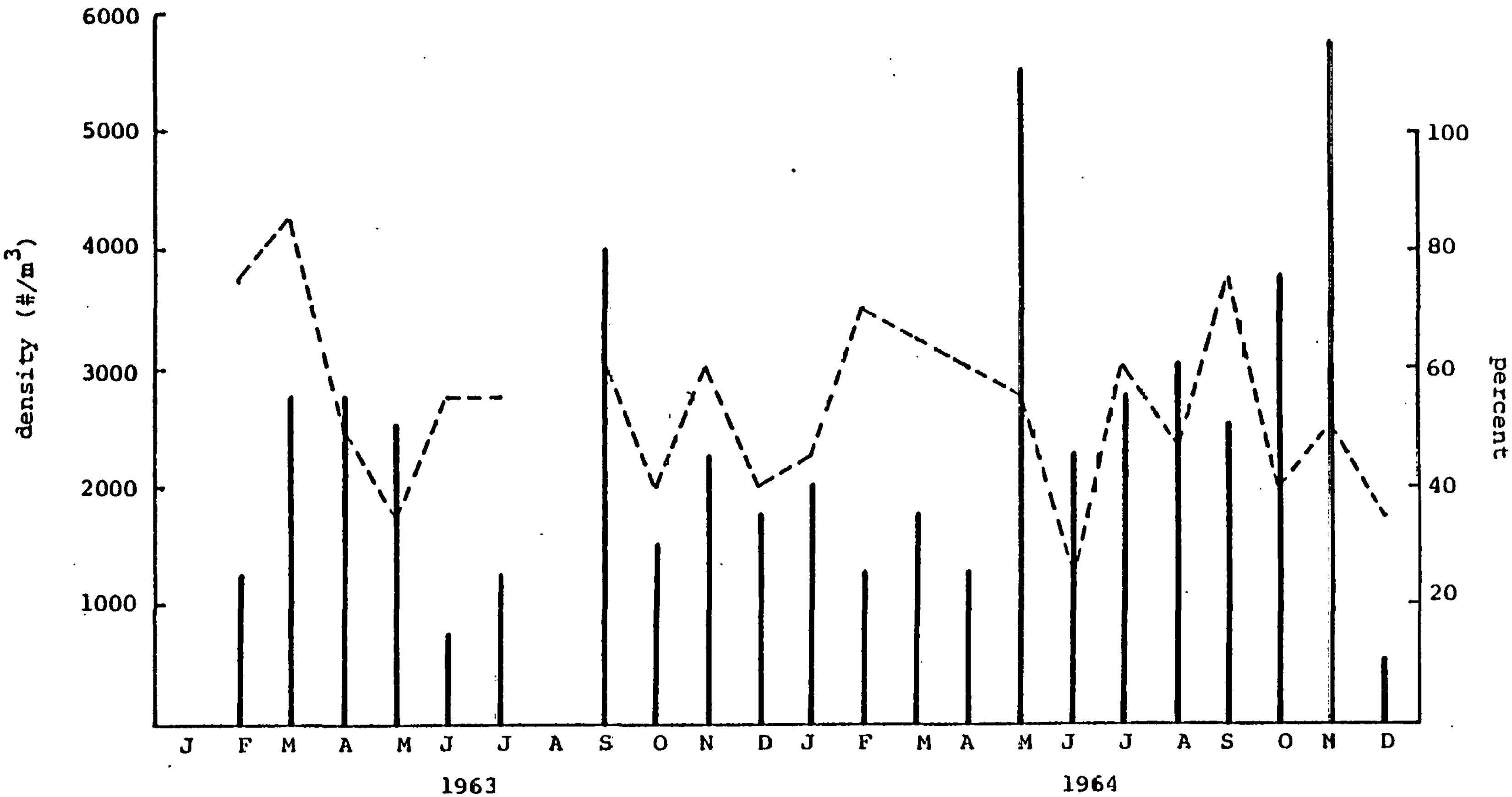

Figure 6-25. Monthly densities of zooplankton (vertical bars) and percentages of copepods (dashed line) from 1963 to 1964 at Station W2.

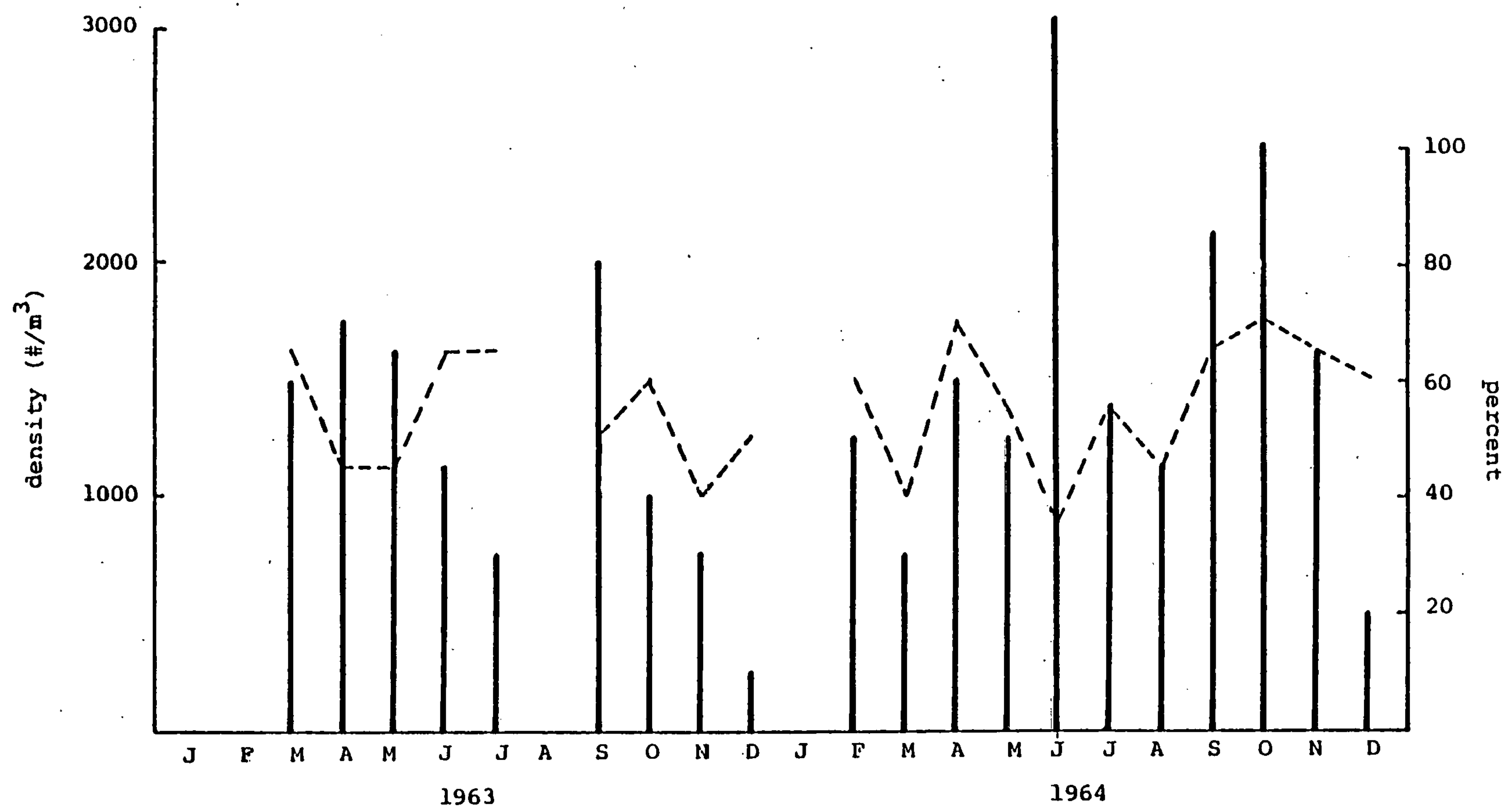

Figure 6-26. Monthly densities of zooplankton (vertical bars) and percentages of copepods (dashed line) from 1963 to 1964 at Station W3.

between 40 and 70% and the mean values were 53.4% at Station W2 and 55.3% at Station W3. Other dominant groups include the larvacea, chaetognaths, the cladocera *Penilia,* the ostracod *Euconchoecia,* and mollusc larvae (Table 6-6).

The seasonal density distribution of the copepods was similar to that of the zooplankton as a whole. Calanoids were the most abundant copepods at both stations (Figures 6-27 and 6-28). The highest percentages of cyclopoids were present at Station W3. Harpacticoids were relatively rare at both stations. The percentages of adult females and copepodids appeared to fluctuate around 40% at both stations (Figures 6-29 and 6-30). Copepodids were relatively more abundant at Station W2 where they reached their highest percentages (60 to 70%) in the spring of the year. The percentage of adult males was relatively stable and remained around 20% at both stations.

Seasonal changes in density for the other major groups of zooplankton are shown in Figures 6-31 through 6-34. Larvacea occurred sporadically with major density peaks in the summer and fall of 1964. *Penilia* occurred in large numbers only during a few months of the year with density peaks in the summers of 1963 and 1964. At Station W2, the ostracod *Euconchoecia* appeared only during the winter months. At W3 this group was present in smaller numbers throughout most of the year and had a density peak in April of 1963. The other major groups examined were not as abundant, especially at the offshore station (W3). At Station W2 densities of gastropod larvae peaked during September of 1963 and March of 1964. Bivalve larvae were generally present in highest densities in the late fall and winter months of both years.

Paracalanus indicus and *Paracalanus quasimodo* were the dominant

Table 6-6. Dominant groups of zooplankton at Stations W2 and W3. Percentages are based on total mean densities over the 2 year sampling period (1963-1964).

Station W2

Group	% of zooplankton	cum. %
Copepods	53.4	53.4
Larvacea	10.5	63.9
Chaetognaths	5.3	69.2
Penilia	4.9	74.1
Gastropod larvae	4.5	78.6
Euconchoecia	4.5	83.1
Bivalve larvae	4.3	87.4
Medusae	2.5	89.9
Doliolida	0.8	90.7

Station W3

Group	% of zooplankton	cum. %
Copepods	55.3	55.3
Euconchoecia	12.0	67.3
Larvacea	8.8	76.1
Chaetognaths	6.4	82.5
Penilia	4.4	86.9
Gastropod larvae	2.6	89.5
Medusae	1.8	91.3
Bivalve larvae	1.6	92.9
Doliolida	0.8	93.7

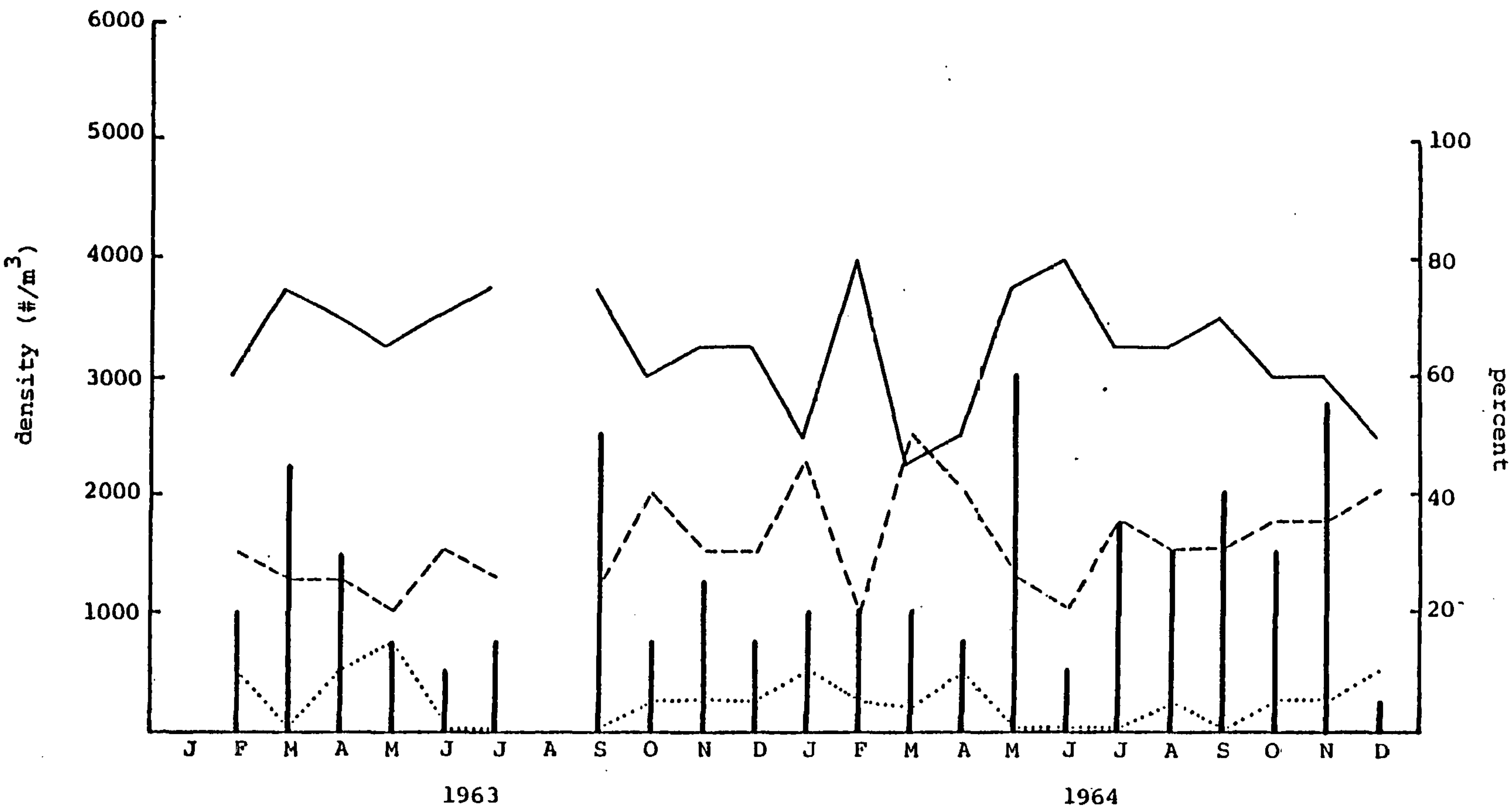

Figure 6-27. Monthly percentages of calanoids (solid line), cyclopoids (dashed line), and harpacticoids (dotted line) within the copepods at Station W2. Densities of copepods are represented by the vertical bars.

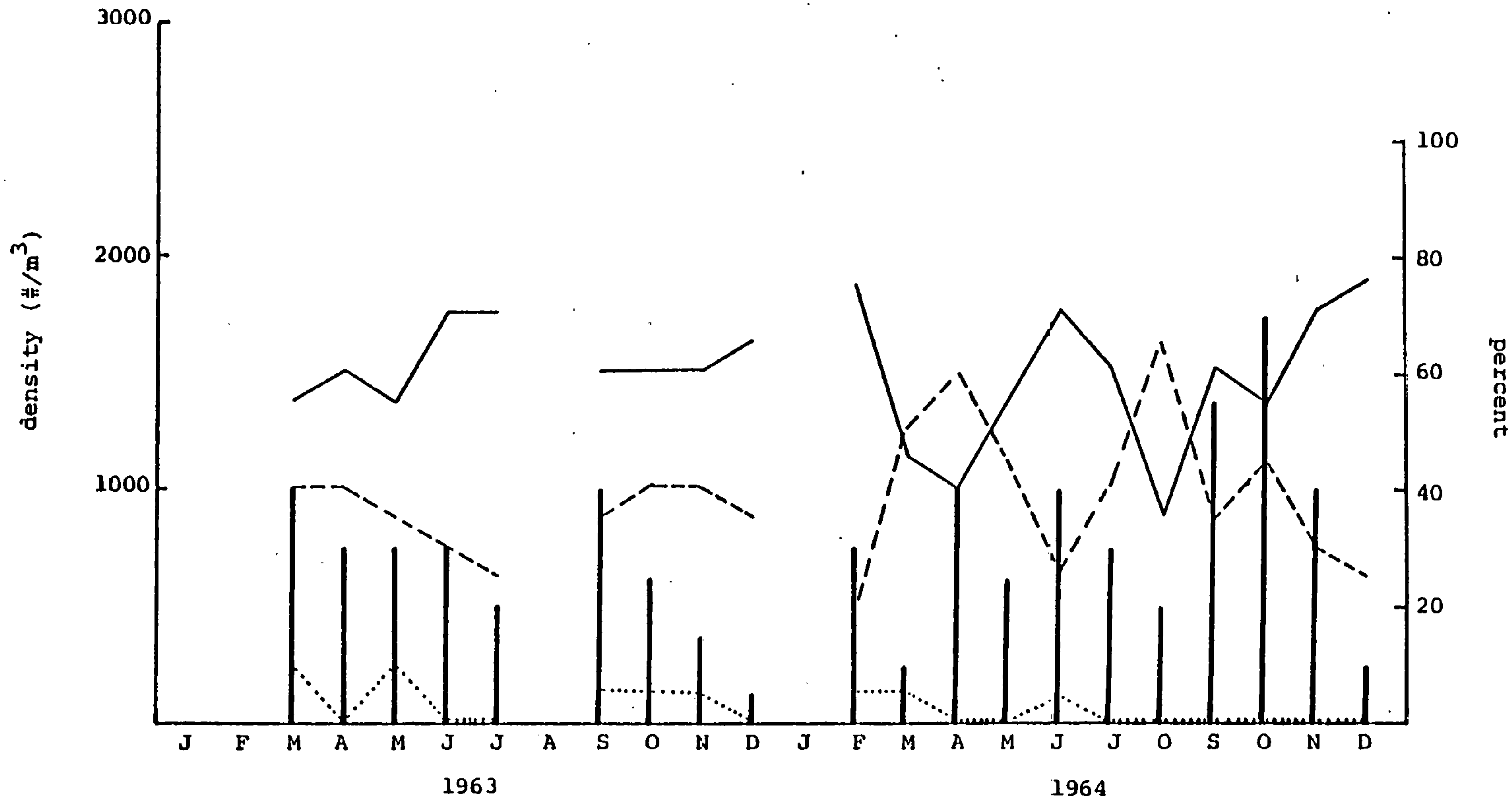

Figure 6-28. Monthly percentages of calanoids (solid line), cyclopoids (dashed line), and harpacticoids (dotted line) within the copepods at Station W3. Densities of copepods are represented by the vertical bars.

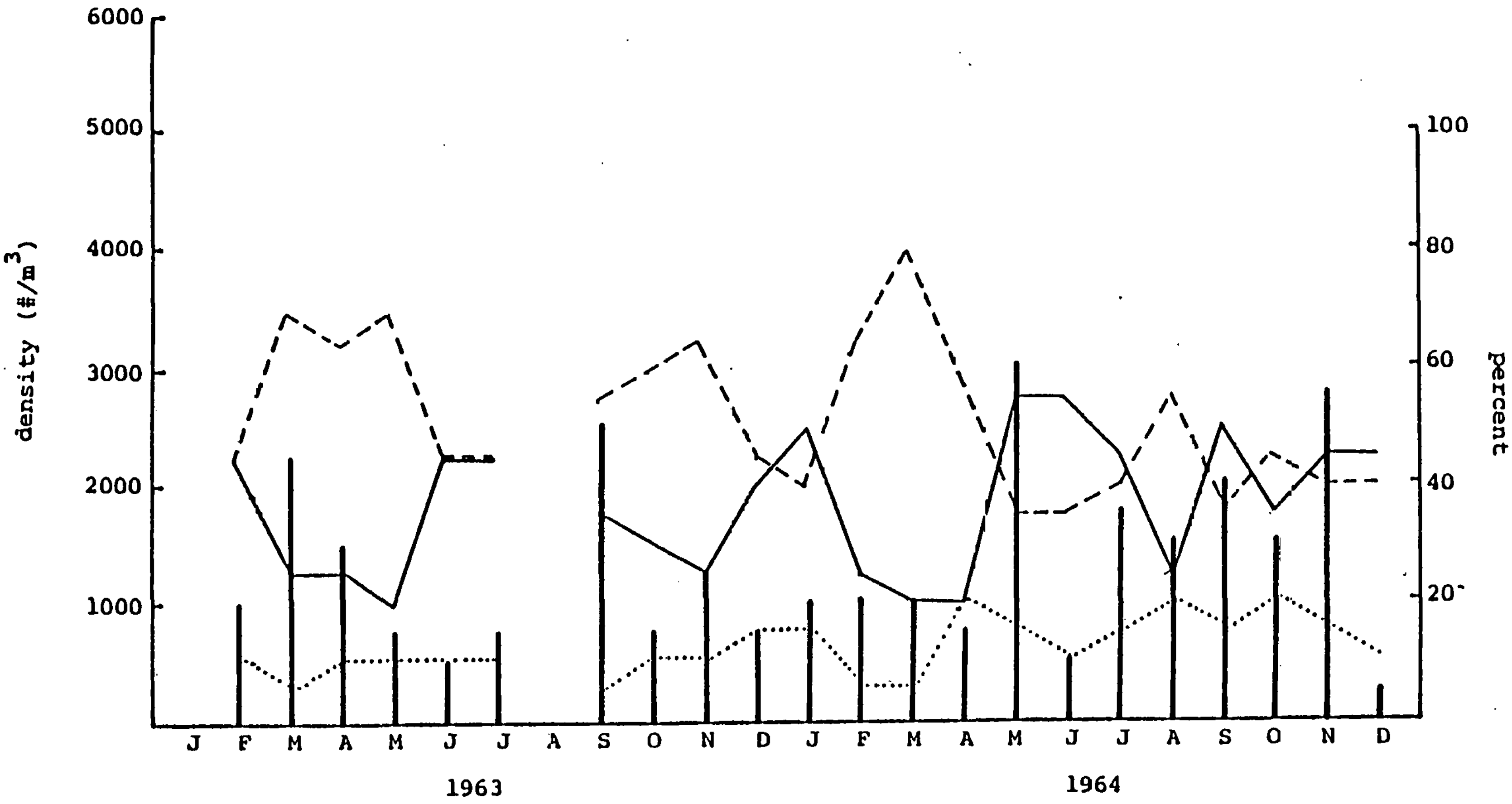

Figure 6-29. Monthly percentages of adult females (solid line), copepodids (dashed line), and adult males (dotted line) within the copepods at Station W2. Densities of copepods are represented by the vertical bars.

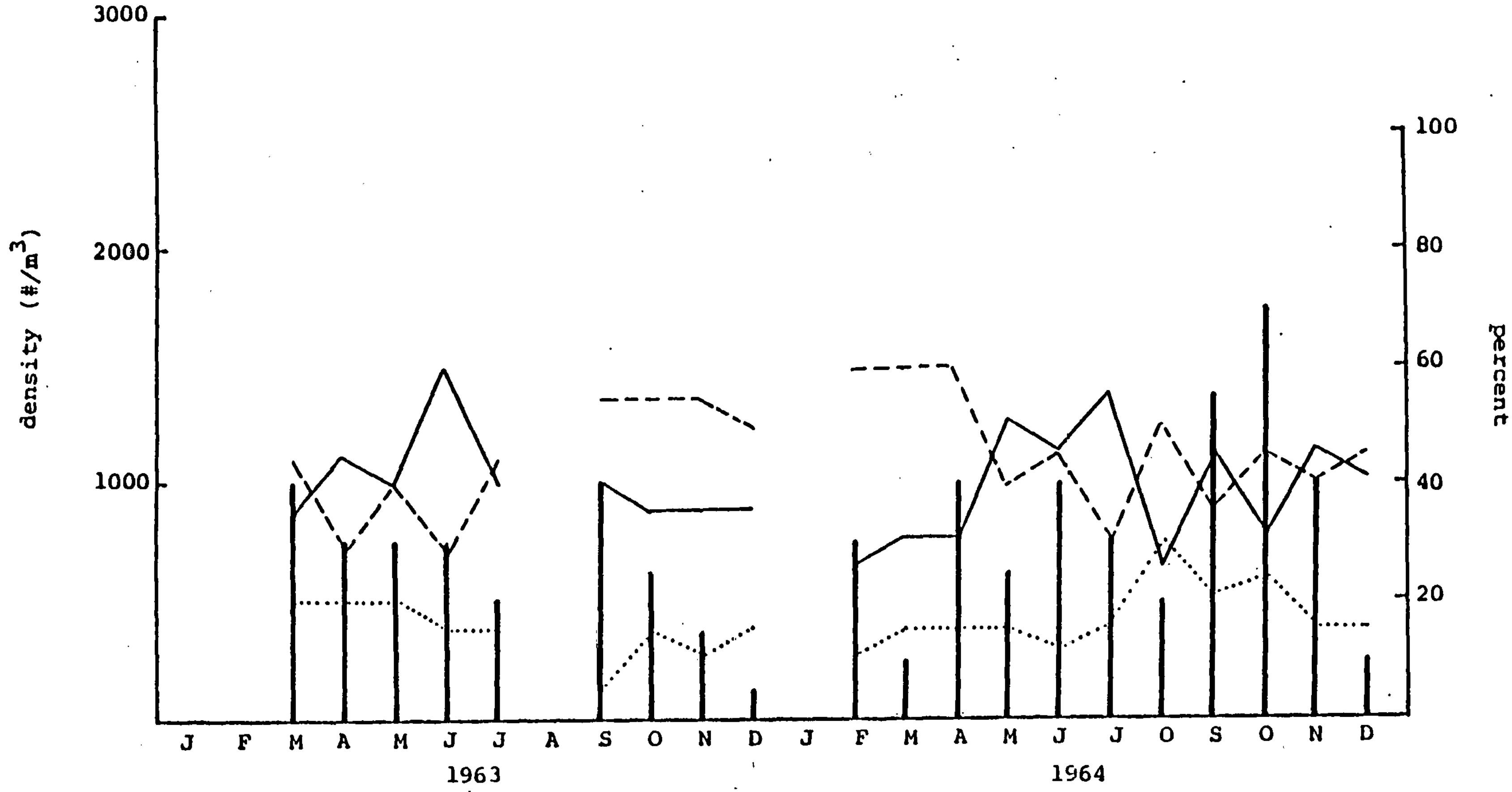

Figure 6-30. Monthly percentages of adult females (solid line), copepodids (dashed line), and adult males (dotted line) within the copepods at Station W3. Densities of copepods are represented by the vertical bars.

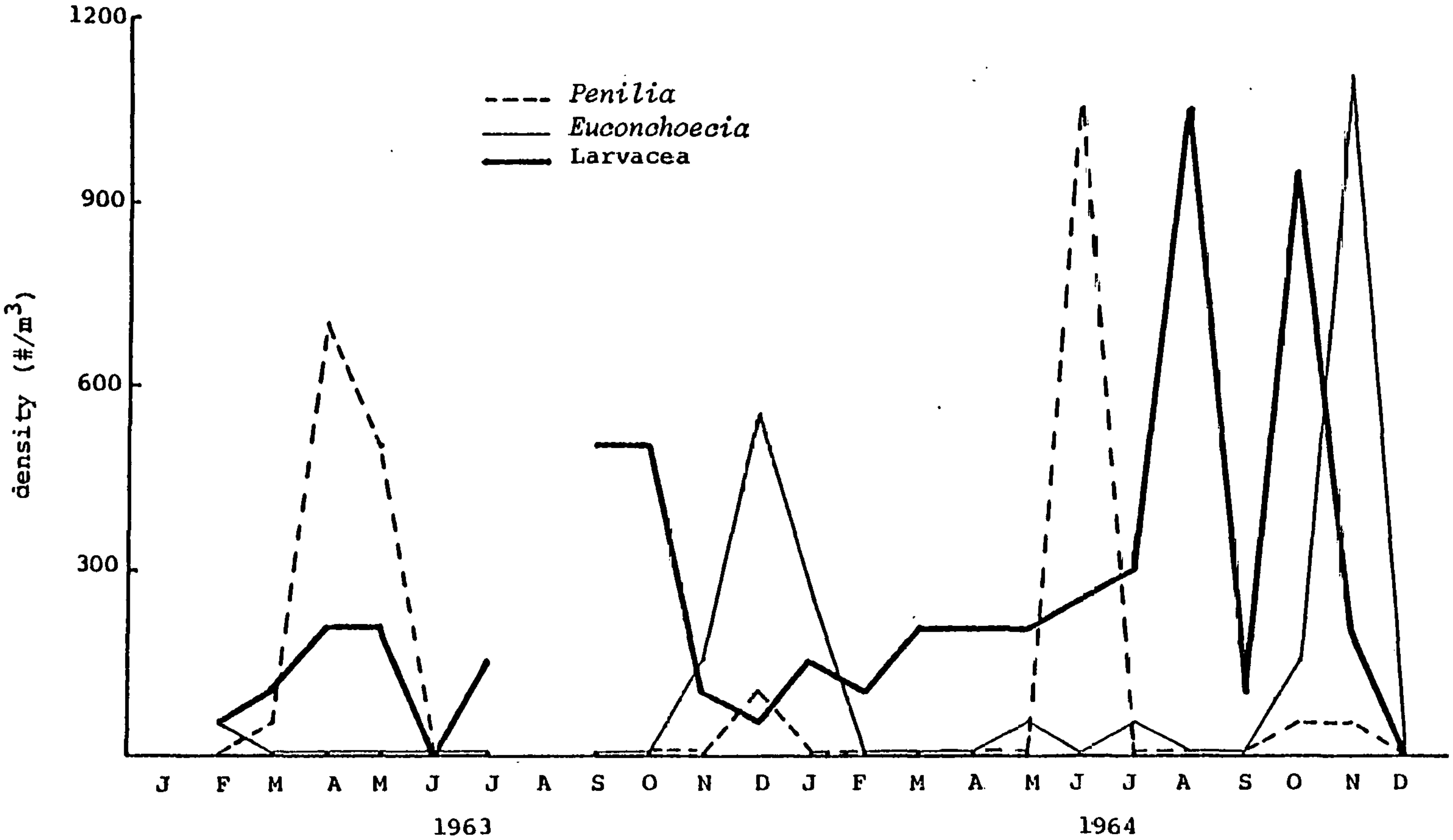

Figure 6-31. Monthly densities of *Penilia*, *Euconchoecia*, and larvacea at Station W2 in 1963 and 1964.

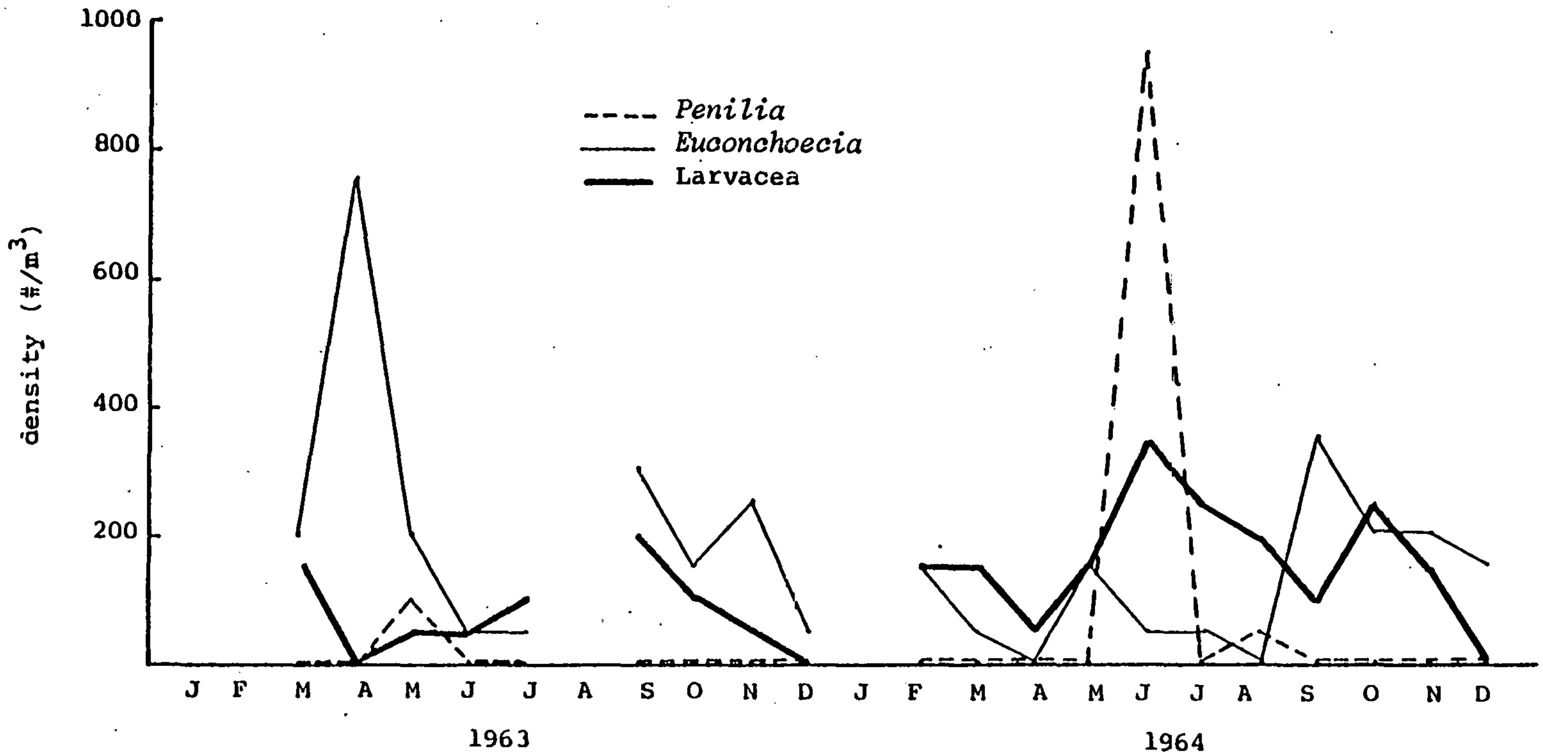

Figure 6-32. Monthly densities of *Penilia*, *Euconchoecia*, and larvacea at Station W3 in 1963 and 1964.

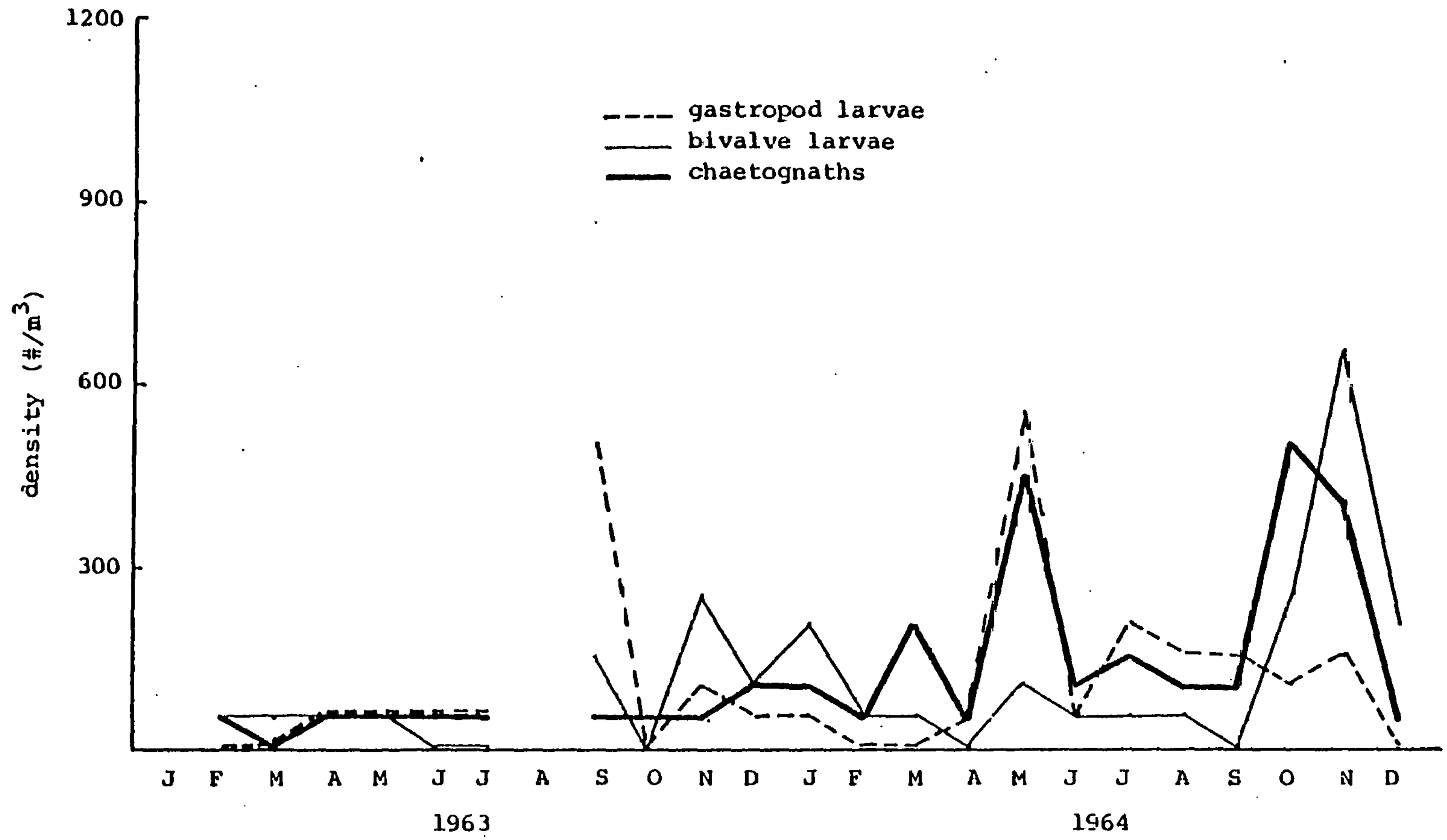

Figure 6-33. Monthly densities of gastropod larvae, bivalve larvae, and chaetognaths at Station W2 in 1963 and 1964.

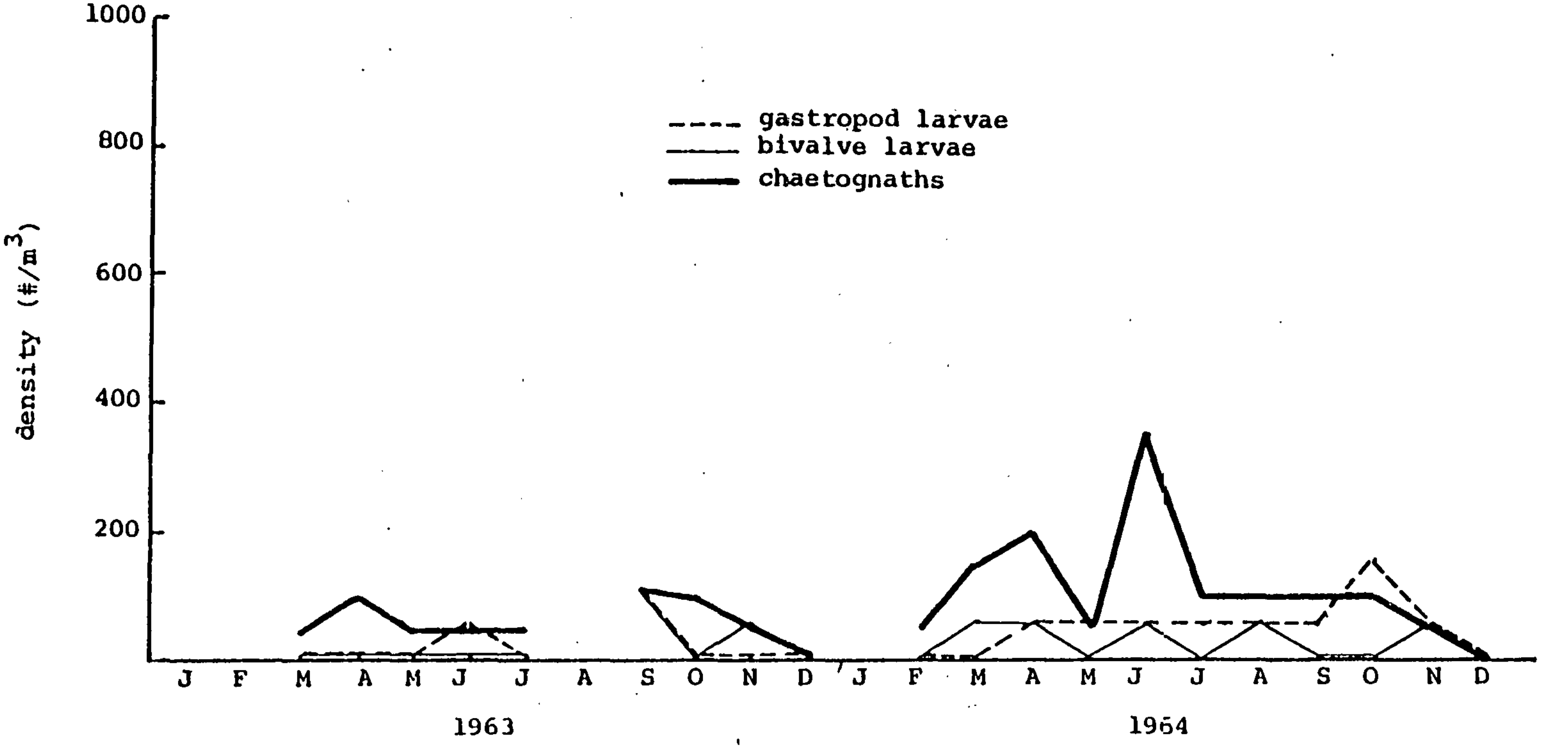

Figure 6-34. Monthly densities of gastropod larvae, bivalve larvae, and chaetognaths at Station W3 in 1963 and 1964.

species of copepods at both stations (Table 6-7). Other abundant species at both stations included *Clausocalanus furcatus* and *Oncaea media*. *Acartia tonsa* was abundant only at Station W2.

When the monthly densities of the five most abundant species were plotted on the same graph for each station (Figures 6-35 and 6-36), the highest values appeared in 1964 from April through December. Monthly variability was high for all species. *Paracalanus indicus* and *P. quasimodo* generally had density peaks in the spring to early summer and in the fall. *Acartia tonsa* was found in relatively large numbers at Station W2. Peak densities of this species occurred in April and May.

Monthly densities for the other abundant species are shown in Figures 6-37 and 6-38. *Oithona plumifera* consistently had peak densities in September. Densities of *Oithona nana*, an inshore form, peaked in the spring and fall. *Paracalanus crassirostris* was abundant only at Station W2 where a high density was recorded during March of 1963.

Seasonal trends in species diversity, which was measured as the number of species of adult females identified from each sample, are shown in Figure 6-39. At both stations the lowest number of species generally occurred during the spring months. The greatest number of species was found in December 1963 at Station W3. Diversity was generally greater at Station W3.

6.3.4 Comparison of the Recently Collected Data with the Historical Data

Data from the recently collected (RC) samples near the diffuser appeared to be more similar to the data from Station W2 than the data from Station W3. If the anomalously high densities in the June 1979 samples

Table 6-7. Dominant species of copepods at Stations W2 and W3. Percentages are based on total mean densities of adult female copepods over the 2 year period.

Station W2

Species	% of adult females	cum. %
Paracalanus indicus	18.2	18.2
Paracalanus quasimodo	13.8	32.0
Oncaea media	11.1	43.1
Clausocalanus furcatus	9.5	52.6
Acartia tonsa	5.8	58.4
Oithona nana	5.5	63.9
Paracalanus aculeatus	4.7	68.6
Oithona plumifera	4.6	73.2
Paracalanus crassirostris	4.5	77.7
Farranula gracilis	3.5	81.2

Station W3

Species	% of adult females	cum. %
Clausocalanus furcatus	17.2	17.2
Paracalanus indicus	13.2	30.4
Paracalanus quasimodo	11.5	41.9
Oithona plumifera	9.6	51.5
Oncaea venusta	9.4	60.9
Oncaea media	9.3	70.2
Farranula gracilis	4.6	74.8
Paracalanus aculeatus	4.0	78.8
Corycaeus amazonicus	2.3	81.1
Oithona nana	1.9	83.0

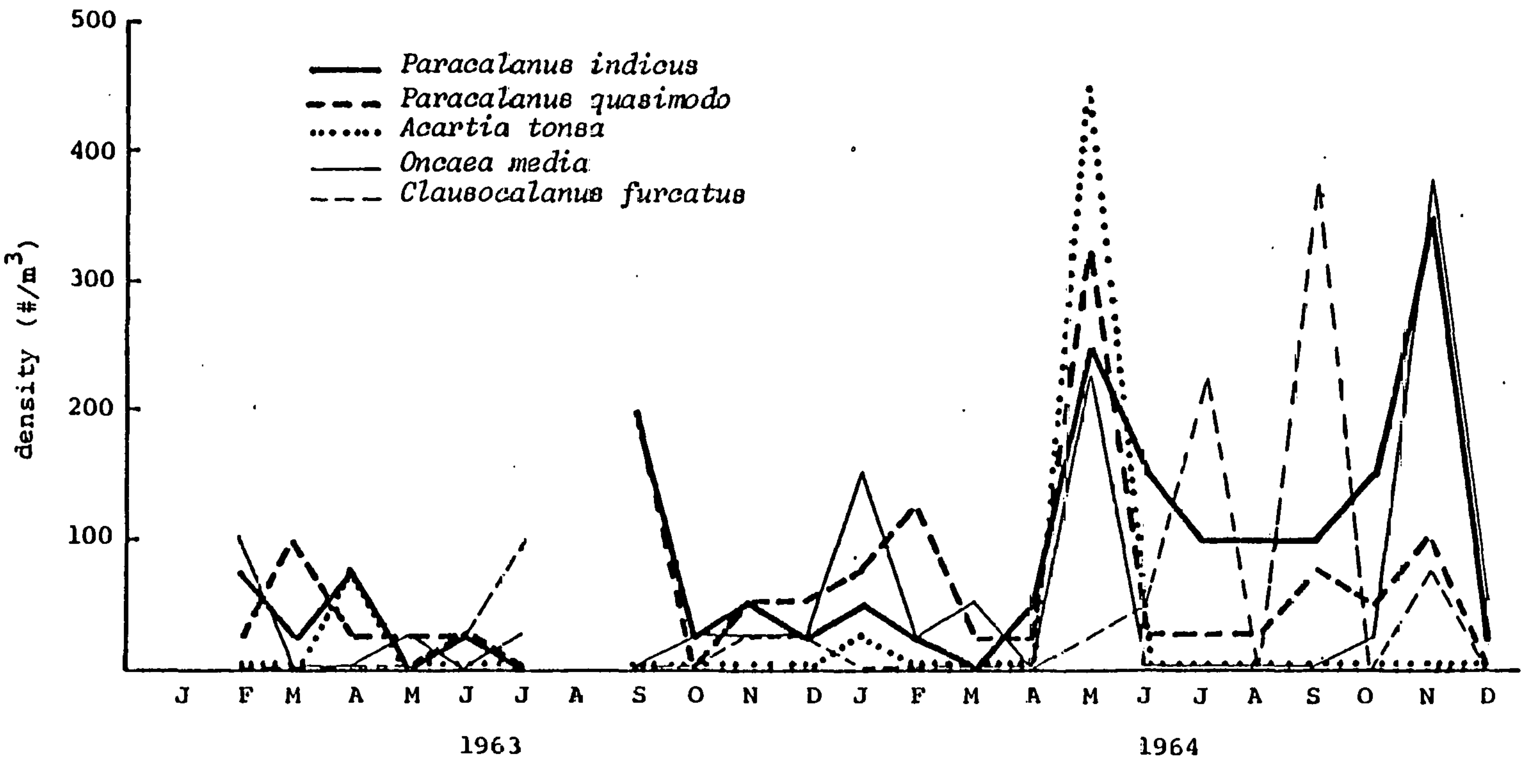

Figure 6-35. Monthly densities of the five dominant species of adult female copepods at Station W2.

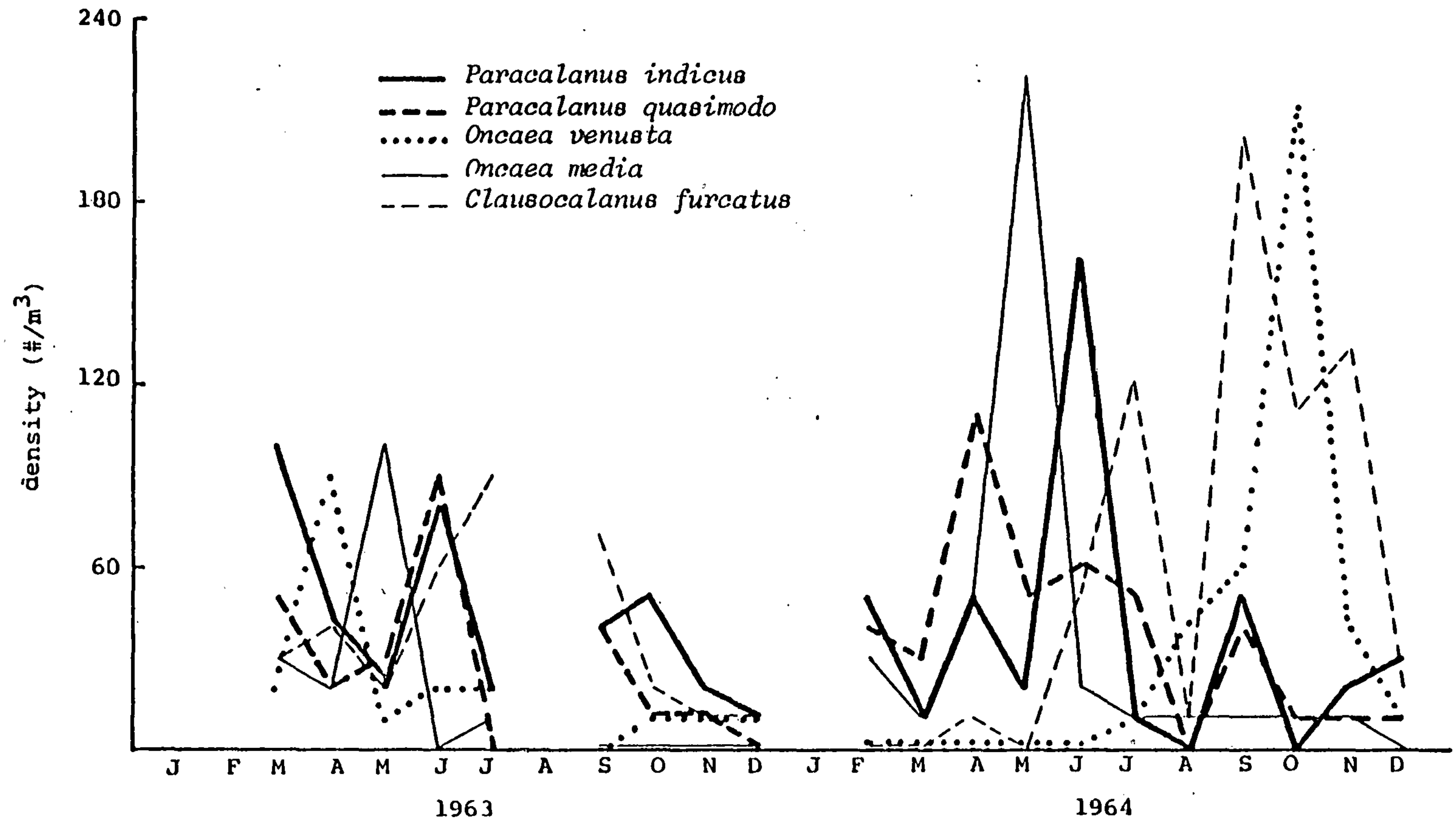

Figure 6-36. Monthly densities of the five dominant species of adult female copepods at Station W3.

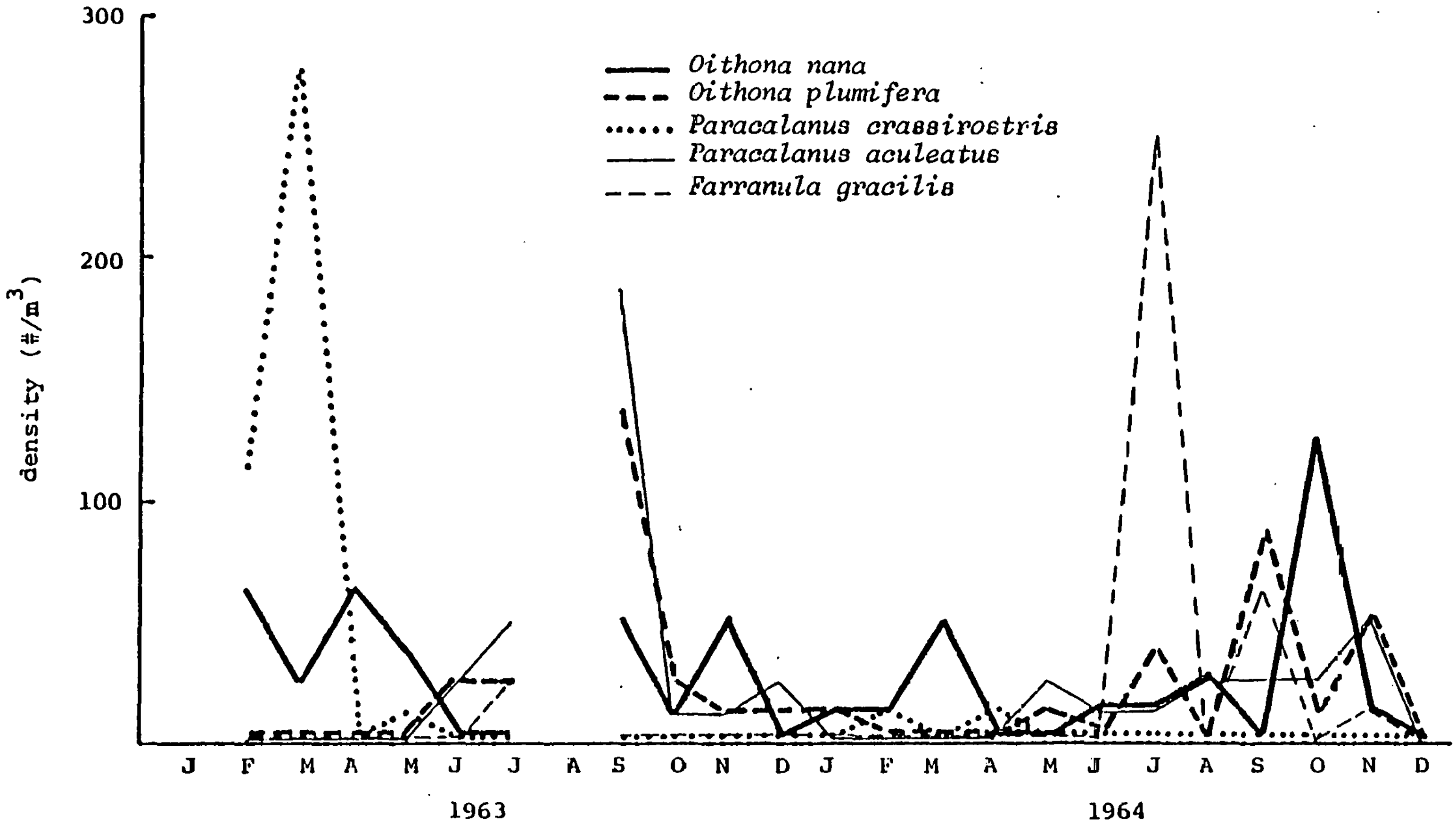

Figure 6-37. Monthly densities of abundant species of adult female copepods at Station W2.

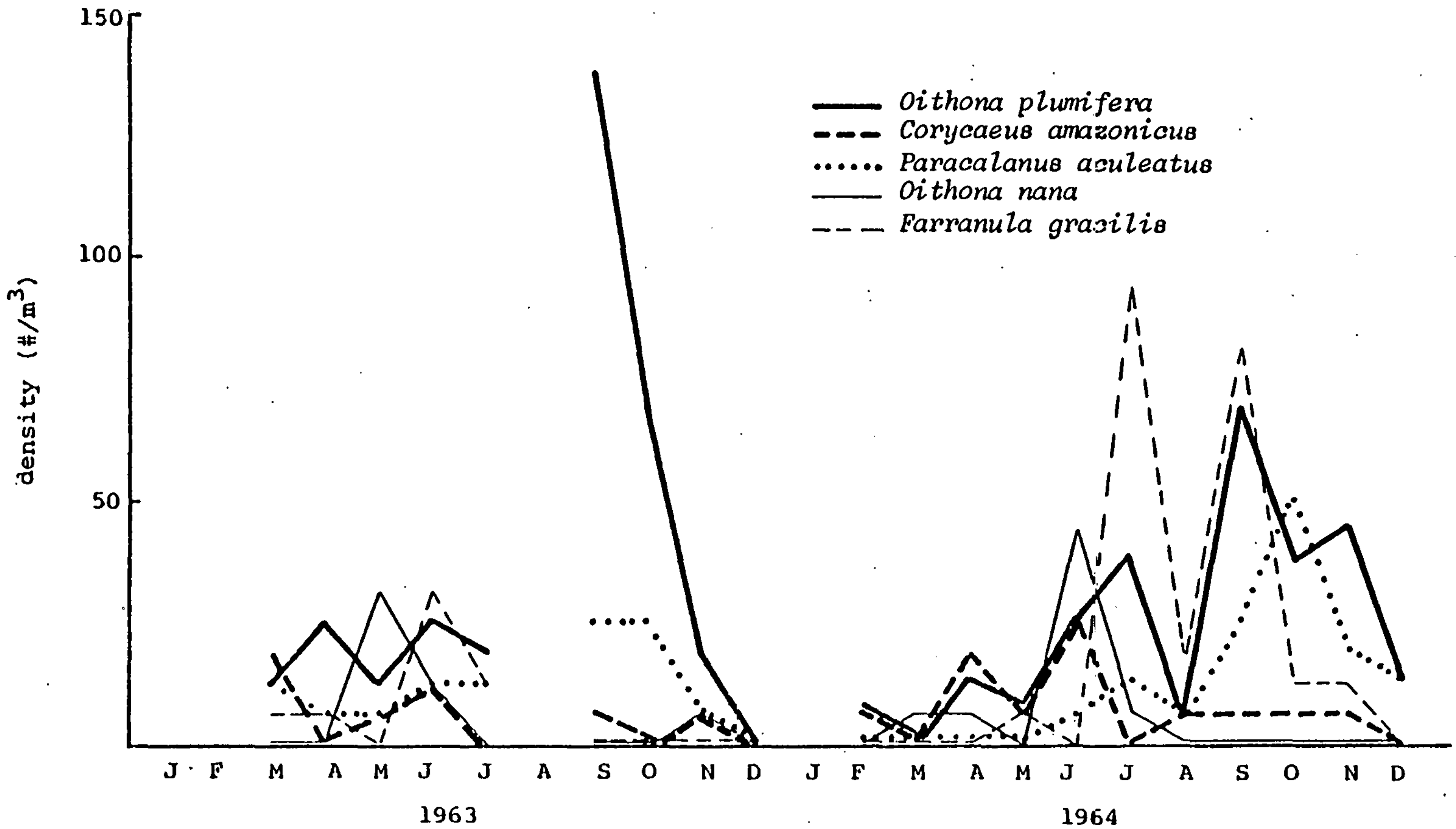

Figure 6-38. Monthly densities of abundant species of adult female copepods at Station W3.

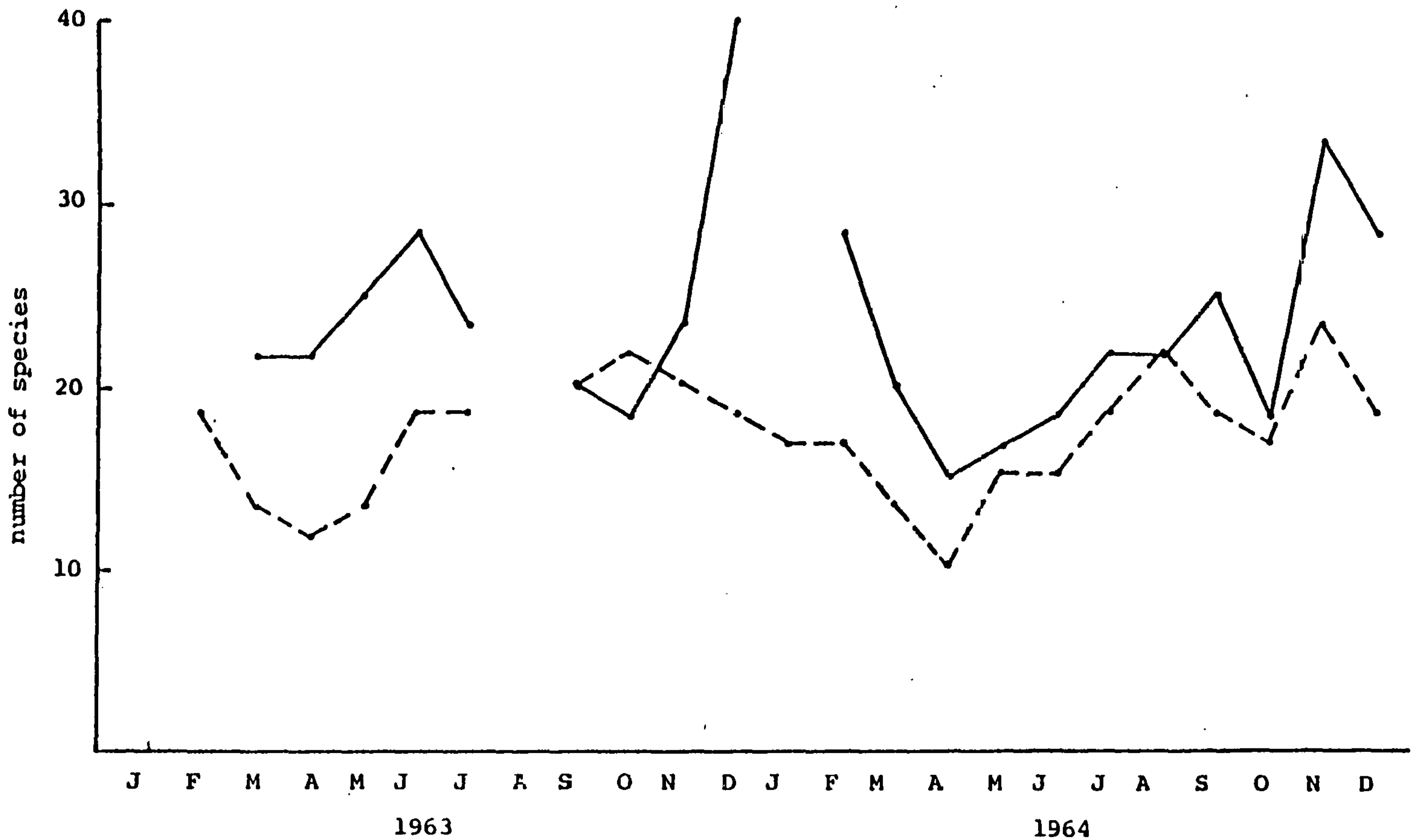

Figure 6-39. The number of species of adult female copepods identified from samples taken in 1963 and 1964 at Stations W2 (solid line) and W3 (dashed line).

were eliminated, total zooplankton densities appeared to be only slightly higher in the 1979-1980 samples when compared to the historical samples taken at Station W2. The density peaks which occurred in September and October in 1963 and 1964, however, were not present in the RC samples. The percentages of copepods and the percentages of calanoids were also higher in the RC samples. These differences were mostly due to the relatively high densities of *Acartia tonsa* present in the samples collected near the diffuser. Meroplanktonic forms such as tornaria larvae and barnacle cypris larvae were also more abundant in the RC samples compared to the historical samples.

The species of copepods present in the recently collected samples were generally similar to those found in the historical samples although more inshore forms appeared to be abundant in the RC samples. The low densities of *Paracalanus indicus* in the recently collected samples however was puzzling. At Stations W2 and W3, *P. indicus* and *P. quasimodo* occurred in similar abundances. Other work in coastal areas off Texas and Louisiana also indicate that there is generally a high correlation between the densities of these two congeners (Park, 1979; Minello, 1980).

The number of species of adult female copepods found at Station W2 and in the 1979-1980 samples was similar although the values may have been slightly lower in the recently collected samples. The seasonal trend of highest diversities in the fall and winter months seen in the historical samples also appeared in the RC samples to some extent.

Most of the differences between the historical samples and the recently collected samples can probably be attributed to the proximity to shore and the shallower water depth at the diffuser site. Seasonal fluctuations in the very nearshore areas where the influence of river runoff is highest probably tend to be larger than in coastal areas farther offshore. The influence of river flow seems especially important since the estuarine copepod *Acartia tonsa* contributed greatly to the high zooplankton densities near the diffuser which occurred during a period of low surface salinity. Common coastal water trends of decreasing zooplankton densities and increasing diversity away from the shore could also explain some of the differences between the historical samples and the recently collected samples.

6.4 Conclusions and Summary

Seasonal variability in zooplankton biomass and density near the diffuser area appears to be very high. This variability is probably due to the periodic influx of nutrients and estuarine species into the area during times of high river flow. Copepods dominated the zooplankton and populations of *Acartia tonsa*, a typical estuarine species, reached extremely high densities near the diffuser in June 1979. Copepod densities (mostly *Acartia*) during this June sampling period ranged between approximately 35,000 to 55,000 organisms/m^3. Densities dropped dramatically by July and density values for total zooplankton and copepods appeared to be typical for this coastal area during the other six cruises. Elevated densities of total zooplankton in December and January were largely due to high densities of tornaria larvae (hemichordates). Meroplanktonic forms in general (including bivalve larvae and barnacle cypris larvae) were abundant from November through January.

A graphical analysis of a species by species correlation matrix revealed three fairly distinct groups of copepod species. The species in these groups generally varied in density together.

1. The largest group was an inshore or estuarine group of species which included *Acartia tonsa, Paracalanus crassirostris, Oithona colcarva,* and *Temora turbinata*. These species occurred in greatest numbers during June and also were fairly abundant from November through January. Their densities were negatively correlated with surface salinity.

2. A group of two species including *Corycaeus americanus* and *Clausocalanus furcatus* was also present. These species also appeared in June and from November through January but their highest densities were found in the winter months.

3. The third group consisted of *Oncaea venusta, Corycaeus giesbrechti,* and *Paracalanus indicus*. These species were most abundant from September through January and were rarely found in summer samples.

Although a number of interesting trends were exhibited in the zooplankton populations examined from the predisposal samples, a major characteristic appeared to be a high monthly variability. This temporal variability will make it difficult to detect any effect of brine diffusion in the sampling area based on comparisons with previous sampling periods unless the effect is catastrophic. For this reason an analysis of variance (AOV) was used to measure spatial variability during each cruise. In this AOV, the variability among stations was compared to the pooled variability from the replicate tows taken at each station.

Although patchiness in plankton populations is well documented (Wiebe, 1970; Haury, 1976), the three stations were closely spaced (approximately 2 nautical miles apart) and the population densities at each station were expected to be similar. The analysis of variance which was based on total zooplankton densities, however, indicated that on four out of the seven cruises, the stations were not similar. When the AOV was based on densities of the dominant groups of zooplankton and abundant species of copepods, the results varied. Some groups and species (Larvacea, *Corycaeus americanus, Oncaea venusta, Paracalanus crassirostris*) however showed few significant differences among the stations. An examination of the spatial variability of these groups in the postdisposal samples should be of interest in determining possible effects of the brine.

For all groups, including total zooplankton, multiple range tests based on the AOV results were used to determine which of the three stations were similar. In very few cases were all three stations dissimilar. The location of dissimilar stations in relation to the brine plume in the post-disposal samples may also provide information on possible effects of disposal on zooplankton population.

CHAPTER 7

PHYTOPLANKTON

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7.1 Introduction

The term phytoplankton is collectively applied to the assemblage of the many varied microscopic species of algae which float and drift in the water. These tiny individuals are usually unicellular, and in the marine environment are mainly diatoms, dinoflagellates, silicoflagellates, and coccolithophorids. Many have limited powers of locomotion, but such powers are negligible compared with the water currents.

Although small in size, the phytoplankton represent vast numbers of individuals so that their importance as the base of the food chain in marine and freshwater environments cannot be overstressed. They are the primary producers which convert sunlight and nutrients into organic compounds needed by the consumers. Production by phytoplankton is influenced mainly by the availability of light and nutrients, and to a lesser extent by temperature. Seasonal changes in these factors often cause changes in species composition and numerical abundance of the phytoplankton, and these changes may be rapid and pronounced in neritic waters.

Objectives: This study concerns the phytoplankton in a small area of the northwest Gulf of Mexico which will receive discharged brine from the

Bryan Mound salt dome located near Freeport, Texas. Our overall objectives are: 1) to characterize the existing phytoplankton in this area with regard to composition and abundance, 2) to determine spatial differences in composition and abundance within a limited area of about 10 square miles (26 km^2), 3) to identify differences, if any, between the top and bottom water phytoplankton composition and abundance, and 4) to examine the effects of brine discharge (when it is initiated) on phytoplankton composition and abundance. This report includes data from June 1979 through February 1980; this is the period of study prior to the discharge of brine in the area. March 1980 data is not included because the monthly samples were taken after discharge had begun.

Review of pertinent literature: Few phytoplankton studies have been made of the neritic Gulf waters off the Texas coast. A significant contribution in this area was recently made by the South Texas Outer Continental Shelf study funded by the U.S. Bureau of Land Management (Kamykowski et al., 1977; Kamykowski & Milton, 1980; van Baalen, 1976). Although most of their sampling stations were located much further from shore than our stations, their shallowest stations were in comparable depths as ours and should provide comparative and informative data concerning species composition, abundances, and chlorophyll a concentrations. Information on species and indicator assemblages of phytoplankton for the Gulf of Mexico is available in the Serial Atlas of the Marine Environment (Folio 22) produced by the American Geographical Society (El-Sayed et al., 1972). Many important phytoplankton studies have been conducted in neritic Gulf waters off the Florida coast (Saunders, et al., 1967; Saunders & Glen, 1969; Steidinger et al., 1967a). Great concern over "red tides" in that area stimulated extensive work on dinoflagellates in particular. Some of these works will prove useful to our study (Steidinger et al., 1967b; Steidinger & Williams, 1970).

7.2 Materials and Methods

Sampling procedures: The study area (Fig. 7-1) is located 16 km south of the Freeport jetties in about 22 m of water. Thirteen total stations were established in the study area (Fig. 7-2). The nine stations approximately 150 m apart in the vicinity of the diffuser are collectively referred to as the experimental stations, and the four stations approximately 7.5 km from the diffuser area are referred to as control stations in anticipation of future discharging of brine. Stations MM and D2 through D9 were sampled from June 1979 through January 1980. These stations were southwest of the diffuser area, and the grid was shifted in February 1980 to center the grid along the diffuser line. The new stations were designated D10 through D 18. The changes involved a shift of only 450 m (center to center). Table 7-1 gives the coordinants of the sampling stations used June 1979 to February 1980.

Samples are taken monthly between 0830 and 1800 hours. At each station a water sample is collected from one meter below the surface and one meter above the bottom using van Dorn water samplers. Temperature was measured using a glass-mercury immersion thermometer immediately upon bringing the samples onboard. A 1-liter cubitainer was filled with water from each sampler and stored in an insulated cooler to insure minimum temperature change before analyses could be made in the laboratory.

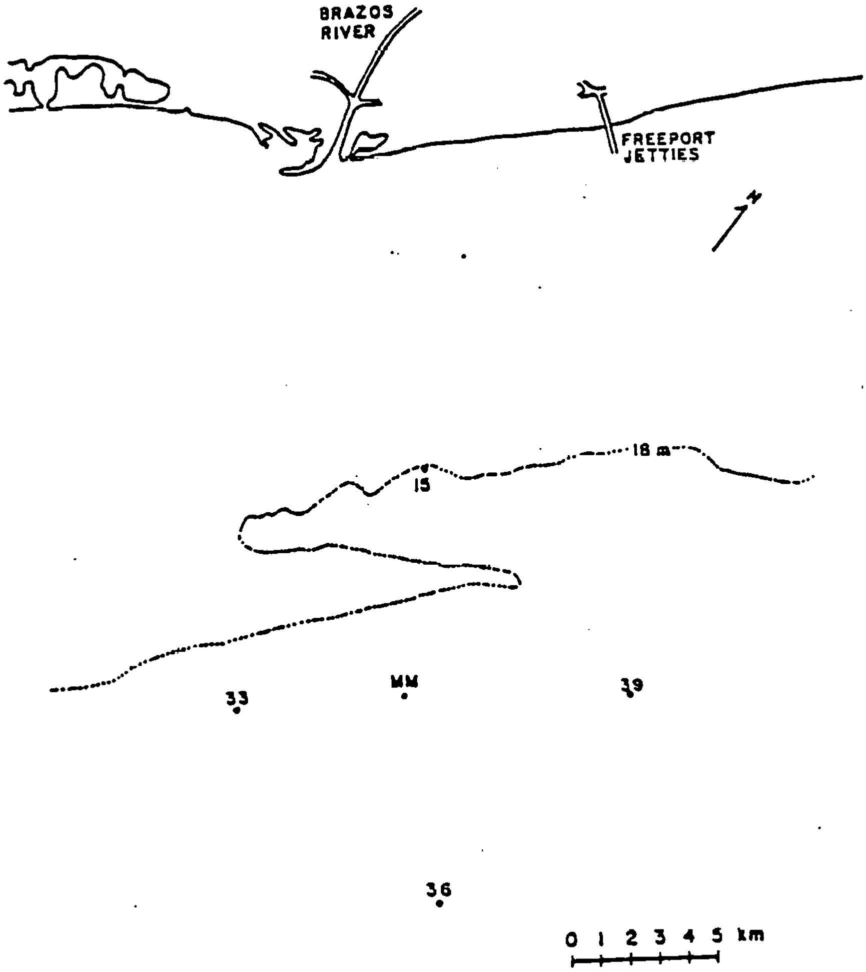


Fig. 7-1. Location of the phytoplankton control stations around the diffuser. Refer to Fig. 7-2 for location of the diffuser relative to station MM.

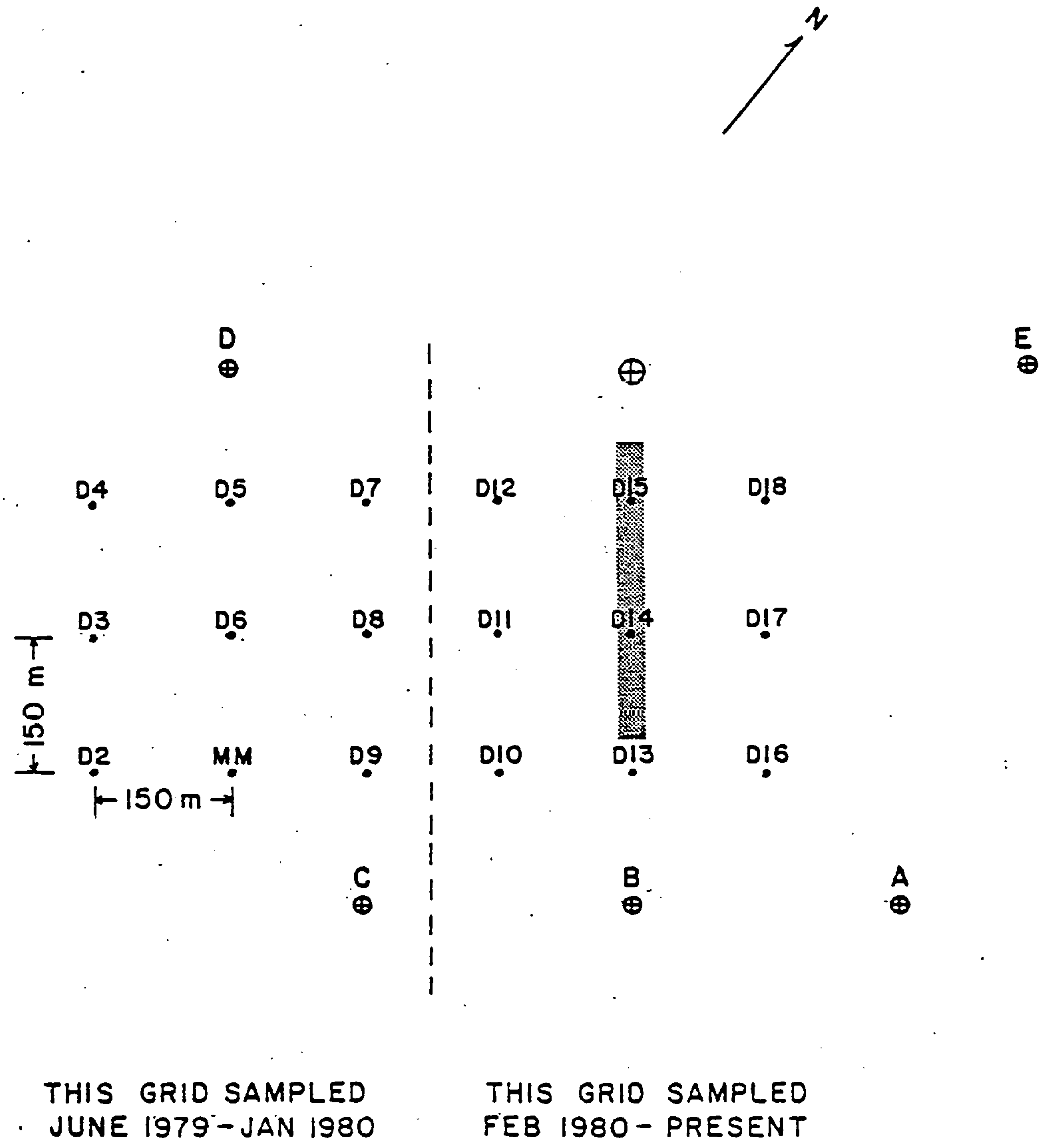


Fig. 7-2. Location of sample stations with regard to the diffuser in the experimental stations. ⊕ = NORDA buoy, located at shoreward end of diffuser trench. Buoy B is located at other end of diffuser trench. Buoys A, C, D, and E mark the outside corners of the study area. Diffuser shown in stippled region. All stations 150 m apart.

Table 7-1. Coordinates for the phytoplankton sampling stations in the Bryan Mound brine discharge study area off Freeport, Texas.

Station Number	Latitude (North)	Longitude (West)
Experimental- June 1979 to Jan 1980		
MM	28°44.50'	95°14.67'
D2	28°48.51'	95°14.61'
D3	28°48.45'	95°14.54'
D4	28°48.39'	95°14.46'
D5	28°48.33'	95°14.53'
D6	28°48.39'	95°14.60'
D7	28°48.27'	95°14.59'
D8	28°48.32'	95°14.66'
D9	28°48.38'	95°14.73'
Experimental - February 1980		
D10	28°44.06'	95°14.56'
D11	28°44.11'	95°14.61'
D12	28°44.18'	95°14.67'
D13	28°44.08'	95°14.49'
D14	28°44.17'	95°14.55'
D15	28°44.22'	95°14.59'
D16	28°44.13'	95°14.41'
D17	28°44.20'	95°14.46'
D18	28°44.27'	95°14.51'
Control		
15	28°48.44'	95°17.11'
33	28°42.30'	95°17.70'
36	28°41.40'	95°11.45'
39	28°47.00'	95°10.40'

Laboratory analyses: Upon return to the laboratory, each sample's salinity was measured using a direct-reading American Optical refractometer.

In vivo chlorophyll *a* fluorescence was measured using a Turner Model 110 fluorometer following a procedure similar to that of Lorenzen (1966).

An archive for possible future reference was established by preserving a 10 ml subsample of each water sample in 5% buffered formalin (Throndsen, 1978).

The remainder of each sample was stored in a constant temperature room overnight. Within 24 hours of collection, live cell counts and identification of the phytoplankton in each sample were made. Triplicate subsamples were analyzed for each sample. An analysis (one of the triplicates consisted of mixing the sample, withdrawing roughly 1 ml and filling a Palmer-Maloney counting chamber (0.1 ml). All phytoplankton in an area crossing the central portion of the chamber (0.014 ml; refer to Fig. 7-3) were identified and counted live at 100X. Each individual in the phytoplankton was identified to genus or to the lowest taxon possible. Cupp, 1943; Freese, 1952 and Wood and Ferguson, 1963, were used to assist in identification of diatoms; Steidinger *et al.*, 1967b and Steidinger & Williams, 1970 were used to assist in identification of dinoflagellates. Also, Campbell, 1973 and Curl, 1959 are good as general references in identification.

Computer and statistical procedures: All data from the analyses of chlorophyll *a* and phytoplankton cell counts (numerical abundance) were entered on cards and stored in the Amdahl computer at Texas A&M University in College Station. Each month's data file was verified prior to transmittal to E.T.I.S. Data files were then used for correlation analyses among chemical, physical and biological parameters. Graphical means of analysis and data presentation were also available through the computer system, and were used.

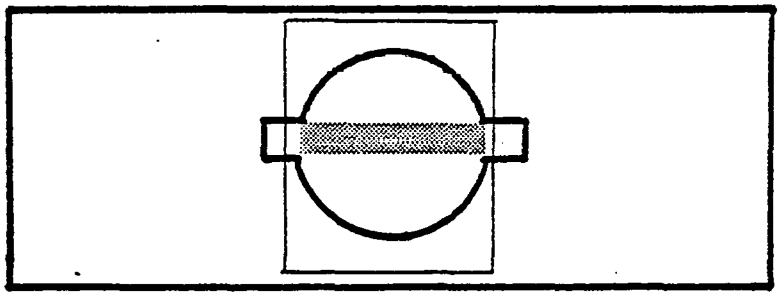


Fig. 7-3. Representation of a Palmer-Maloney counting chamber. The stippled region represents 0.014 ml or the area in which the phytoplankton are counted.

7.3 Results

Composition: The phytoplankton assemblage was found to be characterized mainly by diatoms and also by some dinoflagellates. The diatoms by far dominated the phytoplankton in this area. There were 36 taxa identified during the predischarge study period (Table 7-2), and they belonged to four major plant divisions: the Bacillariophyceae or diatoms of the Chrysophyta (25 taxa), the Pyrrhophyta or dinoflagellates (7 taxa), the Chlorophyta or green algae (2 taxa), and the Cyanophyta or bluegreen algae (2 taxa). The most frequently occurring taxa during the study period included the diatoms *Chaetoceros*, *Coscinodiscus*, *Navicula*, *Nitzschia*, *Rhizosolenia*, and *Thalassiosira*, the dinoflagellate *Prorocentrum*, and some small unidentified dinoflagellates. This group of the dominant taxa was frequently enriched with several of the following taxa: the diatoms *Biddulphia*, *Cyclotella*, *Diploneis*, *Ditylum*, *Hemiaulus*, *Pleurosigma*, *Skeletonema*, *Thalassionema* and *Thalassiothrix*, the dinoflagellate *Gymnodinium* and some very small unidentified flagellates.

At times the dominant species complex showed some seasonality, as in January 1980 when the dominant genera were *Skeletonema*, *Chaetoceros*, and *Nitzschia*. This assemblage is indicative of winter Gulf waters. At other times the genera complex was simply more typical of year-round common Gulf phytoplankton. An assemblage indicative of river outflow (*Cyclotella*, *Melosira* and *Navicula*) was never dominant, although there was sporadic occurrence of some of these genera (as in June, 1979).

Diversity: Although 36 taxa were identified in the study period, 31 of these were identified to genus only. Presumeably the diversity would be about twice as great had the phytoplankton been identified to species,

Table 7-2 Occurrence of phytoplankton taxa collected from June 1979 through February 1980. Taxa Code numbers: 1 - Chrysophyta and 2 - Pyrrophyta

TAXON	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
BLUE-GREENS, Unk.				X	X	X			
SPIRULINA				X	X				
FLAGELLATE [1]					X	X	X	X	X
GREEN ALGAE, Unk.			X		X				
ASTERIONELLA [1]				X		X			X
BACTERIASTRUM [1]				X	X		X	X	
BIDDULPHIA [1]	X	X	X	X	X	X			X
CHAETOCEROS [1]	X	X	X	X	X		X	X	X
CORETHRON [1]						X	X		
COSCINODISCUS [1]	X	X	X	X	X	X	X	X	X
COSCINOSIRA [1]			X						
CYCLOTELLA [1]		X	X	X				X	X
DIATOM [1], Unk.	X				X				X
DIPLONEIS [1]			X	X	X	X	X		
DITYLUM [1]		X		X		X	X	X	
GRAMMATOPHORA						X			
HEMIAULUS [1]	X	X		X	X		X		
HEMIDISCUS [1]	X								
LITHODESMIUM [1]	X								
NAVICULA [1]	X	X	X	X	X	X	X	X	X
NITZSCHIA [1]	X	X	X	X	X	X	X	X	X
PLEUROSIGMA [1]				X	X	X		X	X
RHIZOSOLENIA [1]	X	X	X	X	X	X	X	X	X
SKELETONEMA [1]	X			X	X	X		X	X
SURIRELLA				X					
THALASSIONEMA [1]	X	X	X	X				X	
THALASSIOSIRA [1]	X	X	X	X	X	X		X	X
THALASSIOTHRIX [1]	X			X		X	X	X	
TRACHYNEIS [1]					X	X			X
DINOFLAGELLATE [2], Unk.		X	X	X	X	X	X	X	X
DINOPHYSIS [2]								X	
GONYAULAX [2]	X	X	X						
GYMNODINIUM [2]		X	X	X	X	X	X		
GYRODINIUM [2]		X	X						
PERIDINIUM [2]	X								
PROROCENTRUM [2]	X	X	X	X	X	X		X	
TOTAL	17	16	17	23	21	20	14	17	15

since there are several genera identified which have several species normally present in neritic Gulf waters. The observed diversity or total number of taxa was slightly higher in the surface water than in the bottom water and was slightly higher in the experimental area than in the control area although the differences are so small as to probably be meaningless (Table 7-3). The higher diversity in the experimental area is probably due to the fact that more samples were taken and analyzed in the experimental area.

The phytoplankton diversity was at its peak during the autumn months of September through November (Table 7-3). The grand total diversity (or total number of taxa identified in one month's samples) was about the same for the summer and winter months.

Density: At the start of the study in June 1979 the phytoplankton densities were high in the surface water of both control and diffuser areas, averaging 1202 and 1509 cells/ml resepctively (Fig. 7-4 and Table 7-4). In June bottom waters contained significantly less phytoplankton than surface waters, averaging only 140 and 132 cells/ml in the control and diffuser areas, respectively. Densities were lower in July in the surface waters and not greatly changed for bottom waters, but in August the densities in the entire study area were very low and at a minimum for the study period--between 13 and 40 cells/ml. During these first three months of the study period the surface water was distinctly lower in salinity (Fig. 7-5 and Table 7-5) and higher in temperature (Fig. 7-6 and Table 7-6) than the bottom water.

In September, the phytoplankton densities were similar to those of July and in October another peak in densities occurred (Fig. 7-4). This time the densities ranged from 572 to 1010 cells/ml with perhaps the surface water's densities being slightly higher than the bottom water's (Table 7-4).

Table 7-3 Diversity or total number of taxa tabulated for each monthly sample in the control and diffuser areas, surface and bottom waters.

	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.
Grand Total	17	16	17	23	21	20	14	17	15
Control Area Total	11	9	13	19	16	11	11	9	12
Diffuser Area Total	15	15	17	20	20	18	12	16	11
Surface Water Total	14	12	11	19	21	16	11	14	12
Bottom Water Total	11	12	17	20	15	14	12	14	11
Control Area									
Surface Total	9	6	6	15	13	8	8	6	8
Bottom Total	8	5	11	14	12	6	9	9	11
Diffuser Area									
Surface Total	13	11	11	18	18	15	11	14	10
Bottom Total	8	11	16	17	14	13	9	13	7

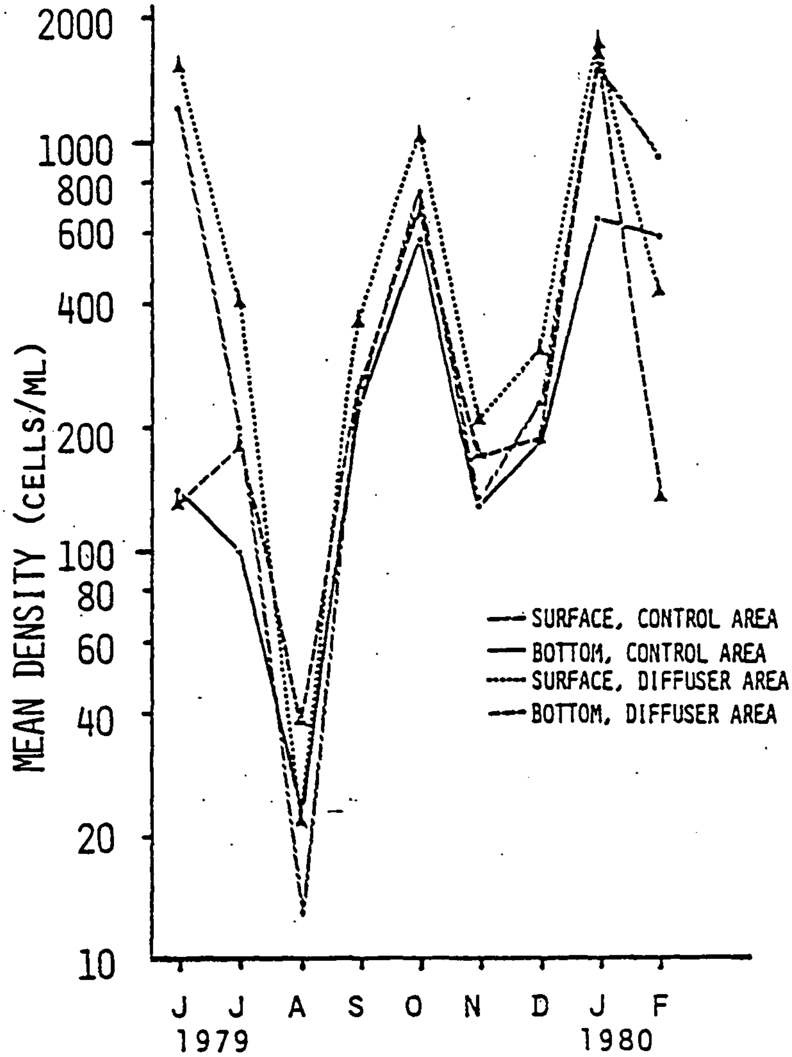
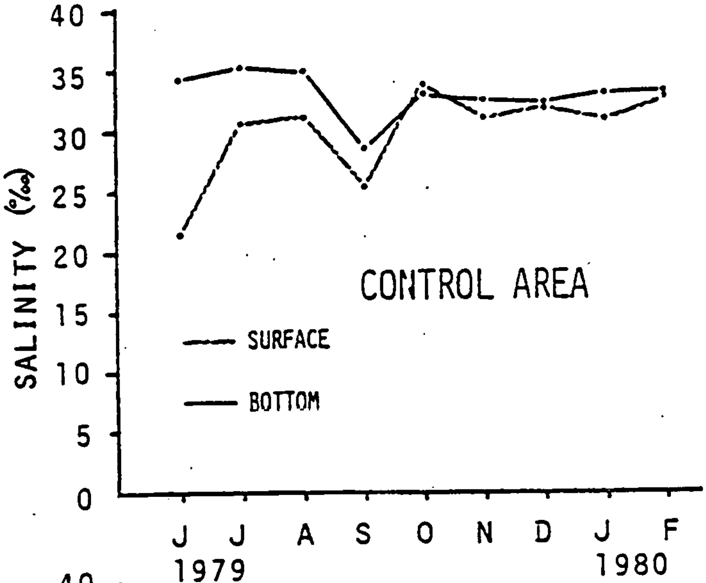


Fig. 7-4. Mean density in cells/ml of phytoplankton in samples taken from off Freeport, Texas, from June 1979 to February 1980.

Table 7-4 Mean density of phytoplankton cells expressed in cells/ml for surface and bottom waters, control and experimental areas off Freeport, Texas, during June 1979 to February 1980. The grand mean values at the bottom were calculated using the means of all 26 samples (13 surface and 13 bottom samples).

	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.
CONTROL AREA									
Surface Mean	1202	198	13	252	752	134	228	1493	904
" Min.	840	23	6	78	280	70	117	93	70
" Max.	1417	700	17	470	1353	187	443	3640	2753
Bottom Mean	140	99	23	230	572	128	181	642	578
" Min.	0	0	6	97	93	23	47	210	23
" Max.	210	140	49	426	1027	233	280	1563	1867
Combined (Surface and Bottom)									
Mean	671	149	18	241	662	131	204	1068	741
Min.	0	0	6	78	93	23	47	93	23
Max.	1517	700	49	470	1353	233	443	3640	2753
DIFFUSER (=EXPERIMENTAL AREA)									
Surface Mean	1509	410	22	354	1010	207	311	1703	425
" Min.	1190	0	12	141	51	70	93	747	47
" Max.	1703	2707	33	766	4387	490	1073	4060	770
Bottom Mean	132	179	39	254	664	174	187	1563	135
" Min.	23	0	26	71	23	47	0	490	23
" Max.	397	933	54	496	980	537	1027	3733	303
Combined (Surface and Bottom)									
Mean	821	294	30	312	685	191	249	1633	280
Min.	23	0	12	71	23	47	0	490	23
Max.	1703	2707	54	766	4387	537	1073	4060	770
Grand Mean	775	249	26	289	678	173	235	1459	422



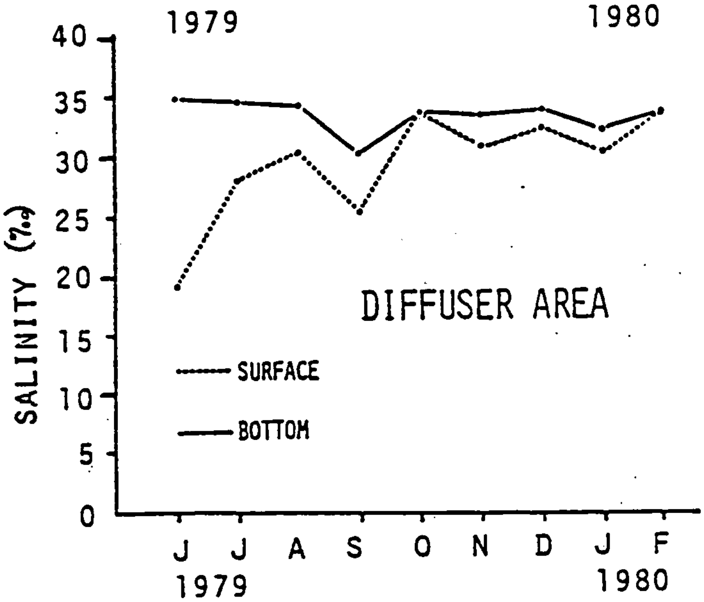


Fig. 7-5. Salinity of surface and bottom waters in study area off Freeport, Texas, from June 1979 to February 1980. Salinity expressed in ppt.

Table 7-5. Mean, minimum and maximum salinity in parts per thousand for each monthly sample in the control and diffuser areas, surface and bottom waters.

CONTROL AREA

Surface	Mean	21.5	30.8	31.0	25.2	33.8	31.0	31.8	30.8	33.2
"	Min.	19.0	27.0	30.0	25.0	33.0	29.0	32.0	30.0	33.0
"	Max.	25.0	35.0	32.0	28.0	36.0	33.0	33.0	32.0	34.0
Bottom	Mean	34.2	34.2	34.0	28.5	33.0	32.5	32.5	33.0	33.0
"	Min.	32.0	34.0	33.0	26.0	33.0	30.0	30.0	32.0	31.0
"	Max.	35.0	35.0	35.0	30.0	33.0	34.0	34.0	34.0	34.0

DIFFUSER AREA

Surface	Mean	19.3	28.0	30.0	25.3	33.3	30.7	32.0	30.0	33.2
"	Min.	19.0	27.0	30.0	25.0	33.0	29.0	32.0	30.0	33.0
"	Max.	20.0	29.0	32.0	26.0	34.0	32.0	32.0	30.0	34.0
Bottom	Mean	34.8	34.4	34.0	30.0	33.3	33.1	33.6	31.8	33.3
"	Min.	34.0	34.0	34.0	30.0	32.0	32.0	33.0	30.0	33.0
"	Max.	35.0	35.0	34.0	30.0	34.0	34.0	34.0	32.0	34.0

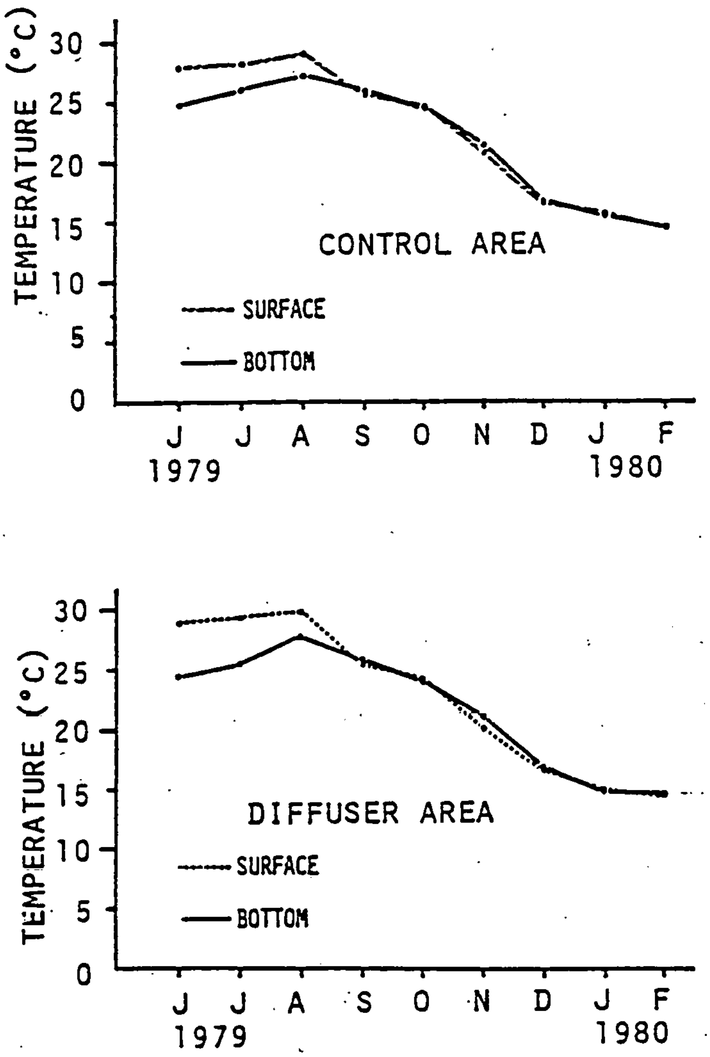


Fig. 7-6. Temperature (in °C) of water 1 meter from the surface and 1 meter from the bottom in study area off Freeport, Texas from June 1979 to February 1980.

Table 7-6. Mean, minimum and maximum temperatures in °C for each monthly sample in the control and diffuser areas, surface and bottom waters.

CONTROL AREA

		JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.
Surface	Mean	27.9	28.3	29.0	25.4	24.4	20.6	16.4	15.7	14.4
"	Min.	27.2	28.3	28.9	24.4	24.4	20.0	16.1	15.0	13.3
"	Max.	28.9	28.3	29.4	26.7	24.4	21.1	17.2	16.1	15.0
Bottom	Mean	24.9	26.1	27.2	25.7	24.3	21.2	16.6	15.4	14.6
"	Min.	24.4	26.1	25.6	25.0	23.3	20.0	15.6	15.0	13.9
"	Max.	26.1	26.1	29.4	26.7	25.0	22.2	17.2	16.1	15.0

DIFFUSER AREA

		JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.
Surface	Mean	27.9	29.4	29.9	25.6	24.3	20.1	16.6	14.9	14.5
"	Min.	28.9	28.3	29.4	24.4	23.9	20.0	16.1	14.4	14.4
"	Max.	28.9	30.0	30.0	26.1	24.4	20.6	16.7	15.0	15.0
Bottom	Mean	24.7	25.7	27.8	25.9	24.1	21.1	16.8	14.7	14.6
"	Min.	24.4	25.6	27.8	24.4	23.9	20.6	16.7	14.4	14.4
"	Max.	25.6	26.1	27.8	26.7	24.4	21.1	17.2	15.0	15.0

From September 1979 through February 1980 the surface and bottom water temperatures decreased gradually and together (Fig. 7-6). Phytoplankton densities of all four water areas were similar for each month and changes paralled each other in the period from September 1979 through January 1980. Densities were significantly lower in November, averaging only 128 to 207 cells/ml, and they rose only slightly in December.

In January 1980 the densities reached a maximum during the study period and averaged between 642 and 1703 cells/ml (Table 7-4). The mean densities were slightly higher in the diffuser area than in the control area, the lowest densities occurring in the control area bottom waters.

In vivo fluorescence: The *in vivo* fluorescence of chlorophyll was found to vary from 0 to 10.7 relative fluorescence units (RFU) during the nine months of the study (Table 7-7, Fig. 7-7). This corresponds to extremely low values of chlorophyll. With the possible exception of the RFU peak in June 1979, we feel the *in vivo* chlorophyll fluorescence data is meaningless. (Refer to sections in the Discussion and Recommendations for further information.)

7.4 Discussion

Composition and species-complexes: Kamykowski *et al.*, 1977, state that diatoms usually accounted for more than 90% of the populations they studied at various sites in the South Texas outer continental shelf area. We find a similar predominance of diatoms.

Our dominant taxa, *Chaetoceros*, *Coscinodiscus*, dinoflagellates, *Navicula*, *Nitzschia*, *Rhizosolenia* and *Thalassiosira* correspond to the May to November assemblage identified in Gulf waters by Kamykowski & van Baalen,

Table 7-7. *In vivo* fluorescence (in seawater) of chlorophyll expressed as mean, maximum and minimum relative fluorescence units (RFU) for each monthly collection in the control and diffuser areas, surface and bottom waters.

CONTROL AREA

		JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.
Surface	Mean	8.4	2.3	1.3	4.5	4.4	2.6	5.6	2.9	3.6
"	Min.	6.0	2.0	1.0	3.7	2.0	2.8	3.3	1.0	1.7
"	Max.	10.7	2.8	1.7	5.3	9.0	3.5	8.0	4.7	8.9
Bottom	Mean	0	2.2	2.1	2.4	2.1	2.1	4.6	3.3	2.7
"	Min.	0	1.7	1.5	2.0	0.5	1.3	3.5	2.2	1.3
"	Max.	0	2.5	2.3	3.2	4.5	2.5	6.5	4.3	5.5

DIFFUSER AREA

		JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.
Surface	Mean	8.7	2.4	0.4	6.0	2.8	2.8	4.3	1.1	3.5
"	Min.	6.3	1.7	0.0	5.0	2.0	2.5	3.7	0.3	2.0
"	Max.	10.0	2.8	1.0	7.7	4.0	3.5	5.5	1.7	5.0
Bottom	Mean	0	2.4	6.0	2.8	2.1	2.8	2.8	1.4	2.0
"	Min.	0	1.7	2.5	2.2	1.5	2.0	2.2	0.2	0.7
"	Max.	0	2.8	10.3	5.3	3.0	4.0	3.2	3.2	2.8

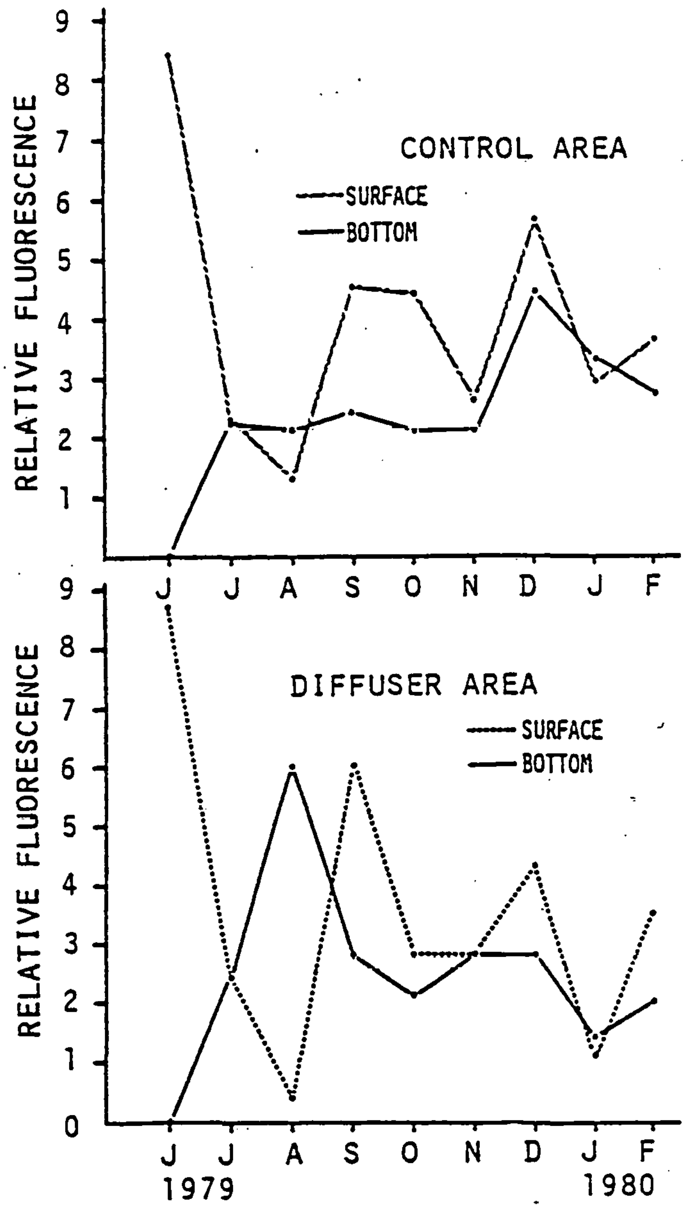


Fig. 7-7. Relative *in vivo* fluorescence (mean values) of surface and bottom waters off Freeport, Texas, from June 1979 to February 1980.

1976. Our second most abundant taxa, Skeletonema, Thalassiosira and flagellates would correspond to part of the December to April assemblage identified in the Gulf by Kamykowski et al., 1977.

Our results (Table 7-2) agree with those of van Baalen, 1979, in that we find the genera Thalassiosira, Rhizosolenia, Bacteriastrum, Chaetoceros and Nitzschia are common all year round. Fucik & El-Sayed, 1979, state that the most dominant dinoflagellate in their samples from Timbalier Bay, Louisiana, is Exuviaella compressa. We have found Prorocentrum, a closely related genus, in all but two of our monthly collections.

The phytoplankton we have identified are composed of typical Gulf neritic, coastal taxa. The assemblages we find are similar to those published by van Baalen, 1976; Kamykowski & Milton, 1980; Kamykowski et al., 1977; Kamykowski & van Baalen, 1979; Simmons & Thomas (working near the Mississippi Delta), 1962; Fucik & El-Sayed, 1979, and El-Sayed, 1972.

The Asterionella-Skeletonema-Thalassiosira assemblage, which is typical of low salinity (20-30‰), and winter Gulf waters, according to Saunders et al., 1967, was found by us in several winter months. We especially have noticed the predominance of Skeletonema in some of our winter samples. The Nitzschia closterium, N. seriata, Rhizosolenia, Chaetoceros assemblage defined by Saunders et al., 1967, as being indicative of high salinity waters (30-35‰), has not been a dominant assemblage in our samples, but the various taxa have occurred sporadically. The species complex identified by Simmons and Thomas (1962) as indicative of a river or estuarine assemblage, namely Melosira-Cyclotella-Navicula, were found in our July, August and September samples, but were never the dominant assemblage. El-Sayed et al., 1972, have reported Gulf assemblages that were dominated by Chaetoceros. Our June 1979 phytoplankton community was dominated by Chaetoceros, but the other species present do not seem to show any strong seasonal influence.

Density: Densities ranging from about 10 to 4000 cells/ml were found in the Bryan Mound discharge study area (Table 7-4). These results are certainly in the range of those reported by various authors in the South Texas outer continental shelf studies conducted from 1974 to 1978 Kamykowski & van Baalen, 1979; Kamykowski et al., 1977; van Baalen, 1975; van Baalen, 1976. These densities are also similar to those found in the nearshore Gulf waters off Louisiana (Simmons & Thomas, 1962) and off the coast of Florida (Saunders et al., 1967).

Phytoplankton populations were severely depressed during the August collection which coincided with the end of an extensive period of stratification. A well established thermocline (at about 10 m depth) was evident during June and July (Table 7-6, Fig. 7-6). The extent and characterization of this stratification is discussed in the benthic section of this report. All phytoplankton densities were quite low both above and below the thermocline during August and it was then that bottom densities in the control and diffuser areas slightly exceeded their respective surface numbers. A number of factors may have contributed to this event. First, the intense stratification tended to reduce mixing and this isolated surface and bottom phytoplankters. The more intense biological activity in the surface waters probably used up available nutrients thus placing surface populations under stress. It has been noted by Lännergren (1979) that many diatoms sink as a result of reduced nutrients. This response may have been a factor in August. Another factor, reduced surface salinities and increased bottom salinities, would also stress and benefit their respective communities. Low population densities can generally be expected during such periods of summer stratification (Raymont, 1980). The conditions during the summer of 1979, however, may have been more severe than normal. Unfortunately, the phytoplankton study began in June and so information prior to this period is available.

The high densities of phytoplankton seen in June, October and January are referred to as "blooms". They are well known in coastal waters and may occur as a result of geometric increases in the number of individuals belonging to a single species when conditions become optimum for growth of that species (Medlin & Wilson, 1979). Algal blooms typically occur when nutrients are plentiful (as after runoff from land or after upwelling or mixing of ocean waters), and when the physical environment is optimum (as when there is lots of sunlight or long days, warm weather, calm, stratified water column). Many algal blooms are beneficial and provide food for small grazing zooplankton (Raymont, 1980) which are at the base of the food web from which man ultimately benefits.

During the nine months of this study, three diatom blooms occurred in the study area. The first bloom occurred in June and was confined to the upper part of the water column. Chaetoceros was the single dominant taxon of this bloom and it accounted for 46% of the total density. Thalassionema and Coscinodiscus also contributed heavily, 14 and 10% respectively. Rhizosolenia, Skeletonema, Prorocentrum and Thalassiosira contributed to the bloom to a lesser but notable extent. The June bloom possibly is attributable to spring river runoff bringing in nutrients, followed by warm, calm, sunny weather allowing the phytoplankton to maintain themselves at the surface. Migration of dinoflagellates such as Prorocentrum into surface waters is also suggested in this case (Heaney & Talling, 1980; Staker and Bruno, 1980).

Densities during the second bloom in October, 1979, were slightly lower than those of the June bloom, but the bloom encompassed the entire water column. This time the phytoplankton assemblage was dominated by Thalassiosira, but not to the same extent that Chaetoceros dominated the phytoplankton population in June. Thalassiosira accounted for 20% of the population and was strongly supported by populations of Navicula, Skeletonema, and Nitzschia. Thalassiosira has been reported as a dominant taxon in Louisiana waters at some times by Fucik & El-Sayed, 1979. Also in October, a single, large occurrence of an unidentified green alga accounted for almost 20% of the population.

The third phytoplankton bloom occurred in January, 1980, and was dominated by Skeletonema which contributed about 46% of the total density. Densities of Skeletonema alone surpassed 2000 cells/ml in several samples, however, the mean density was about 800 cells/ml. Similar densities of Skeletonema have been reported for Skeletonema blooms in Florida (Saunders et al., 1967), Louisiana (Simmons & THomas, 1963), and the Texas coast just off Port Aransas (van Baalen, 1976). Both Chaetoceros and Cyclotella contributed significantly to the January bloom, and notable additions were also made by Nitzschia, Rhizosolenia, Thalassiosira and small dinoflagellates. A similar assemblage was found by Kamykowski et al., 1977, to be characteristic of nearshore Texas waters from December through April.

It appears that the study area possesses typical nearshore Gulf phytoplankton assemblaged as found by several others for the Northwestern Gulf of Mexico. The assemblages are similar to those noted for Florida nearshore Gulf waters and are most likely common in Mexico also. The three blooms observed in the 9 month study period correspond in time within a month or two to those of reported blooms. The typical spring and fall algal blooms are not necessarily the only ones to be expected in the nearshore Gulf environment, especially along the Texas and Louisiana coasts where changes in the timing and quantity of freshwater runoff appear to have a significant impact on shallow Gulf water production (Kamykowski et al., 1977; Kamykowski & Milton 1980).

Diversity: Within the nine months of this study, roughly 70% of the phytoplankton genera which have been reported for the Texas and Louisiana coastal waters have been found in the study area. These genera appear to be well scattered over the study area in such a way that diversity in the diffuser area is about the same as that in the control area. Site 15, the control station nearest to shore, with densities and frequently species differences from other stations, may prove to be a singular site as to diversity, but it will necessitate cluster analysis to bring this out. The slightly higher diversity values for the diffuser area probably are due to the fact that more samples were taken and analyzed from that area each month.

In vivo fluorescence: We feel that the in vivo fluorescence data obtained during the predischarge period is meaningless for the following reasons: 1) When the RFUs of 0 to 10.7 are converted to mg chlorophyll a/m^3, values of 0 to 0.014 mg chlorophyll a/m^3 are obtained. These values are absurd in light of values reported by others, for example, El-Sayed et al., 1972, who reported chlorophyll a values of 0.01 to 2.35 mg chlorophyll a/m^3 with a mean of 0.20. for 435 observations. 2) The observed RFUs do not correlate with observed densities of phytoplankton. 3) The in vivo fluorescence method does not allow for correction of the fluorescence due to interfering or contributing compounds, such as degraded chlorophyll or phaeopigments. The correction for excess fluorescence due to phaeophytin, for example, can only be made by addition of acid to a chlorophyll extract in 90% acetone. The *in vivo* method, however, detects chlorophyll fluorescence in seawater. For this reason Yentsch, 1974, has cautioned against the use of *in vivo* fluorescence because of interfering phaeopigments. 4) In May, 1980, it was discovered that an adapter making the fluorometer extra sensitive was intended to be used with these *in vivo* RFU readings. Without the adaptor, the readings are too low to be significant. The RFUs typically were between 0 and 3.5 on a scale of 100, and the machine wavers ± 1.0. Much of the variability seen in the data is probably due to machine fluctuations.

7.5 Conclusions

The phytoplankton population in the study area in general show effects of some nutrient deficiencies or mesotrophic conditions. Even when algal blooms occur, the numbers of phytoplankton individuals that can be supported is relatively low. The phytoplankton population is dominated by diatoms practically to the exclusion of other groups of algae. The assemblages of phytoplankton communities that were found compatible with those of other workers in the Gulf; they are typical of Gulf, neritic, coastal waters. At times the dominant species complex shows some seasonality, as in January, 1980, when the dominant genera were *Skeletonema*, *Chaetoceros* and *Nitzschia*. This assemblage is indicative of winter Gulf waters. At other times the genera complex was simply more typical of year-round, common Gulf phytoplankton.

Of a total of 36 taxa we have identified 7 as dominant: *Chaetoceros*, *Coscinodiscus*, *dinoflagellates*, *Navicula*, *Nitzschia*, *Rhizosolenia* and *Thalassiosira*.

The phytoplankton densities found during this study period were typical for nearshore Gulf waters. They showed the typical seasonal changes including the end of a spring bloom followed by low densities in the summer, followed by another bloom in the fall. The winter peak is variable; it may or may not appear. Just as the neritic environment undergoes rapid physical and chemical changes, so, too, do phytoplankton densities which may rise or fall two orders of magnitude between monthly samplings.

7.6. Recommendations

1) The in vivo fluorescence method for chlorophyll analysis should be dropped in favor of fluorometric procedures outlined by Yentsch & Menzel (1963) and Strickland and Parsons (1968). Extraction of the chlorophylls into acetone allows concentration of the chlorophyll so that greater RFUs can be obtained and lower concentrations of chlorophyll can be detected accurately. Although this new procedure will require an increase in man-hours, we feel it is believed to be necessary to obtain meaningful data.

2) Identification of the phytoplankton should be made to species whenever possible. A consultant has been hired to assist us in species identification of diatoms and other phytoplankton. In addition, it is planned to use the scanning electron microscope for identification of some of the smaller flagellates.

3) It is planned to concentrate phytoplankton samples by killing with Lugol's iodine and allowing the cells to settle, then counting a precise dilution. The activity is intended to be carried out in addition to the usual live counts and enumeration of phytoplankton from fresh samples.

CHAPTER 8

DATA MANAGEMENT

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8.1 Introduction

The project data management office was established to provide a central location to meet the data processing needs of the other principal investigators and to forward data to the Environmental Data and Information Service (EDIS) in Washington, D. C. in compliance with the Data Management Plan developed by the SPR Program Data Manager dated July 6, 1978.

Data Processing activities include the maintenance of a centralized data storage and retrieval system based on file processing techniques and the provision of statistical and programming support for project scientists and engineers. Each phase of the project lends itself to one or more separate data sets, each which is maintained on computer disk files safeguarded with weekly tape backups. Data sets are being maintained in the areas of physical oceanography, water and sediment quality, benthos, nekton, phytoplankton, and zooplankton. Physical oceanographic data includes both current meter measurements and over-the-side current measurements. Data for each area is entered onto on-line computer storage from either cards, computer terminal, or, in the case of the Type 105 Endeco data, from magnetic tape. Type 174 Endeco data which is collected on a magnetic tape cassette is entered onto computer disk files through an Endeco Data Translator. Copies of the data are returned to the respective investigators for validation. Processing of the physical oceanography and water and sediment quality data sets is being done by the respective investigators. However, nearly all the software used in the processing of the biological data has been written by the data management staff.

8.2 Data Processing

In general, data collected on this project is generated and processed as shown in Figure 8-1. After the sample is collected, it is analyzed in the laboratory, compiled on coding forms, and sent to the data management staff where it is digitized and entered onto computer storage. The data then undergoes one or more cycles of validation processing. During each cycle, the data is processed by the respective validation program and forwarded to the principal investigator for error checking. Errors are corrected and the process is repeated until the data is error free. The data is then available for forwarding to EDIS, statistical analysis, and report generation. Security of the data sets is, of course, maintained at all times.

8.3 Software Development

Specifications for the development of a computer program are forwarded from a principal investigator to the data management staff. At that time the feasibility of developing the program is considered

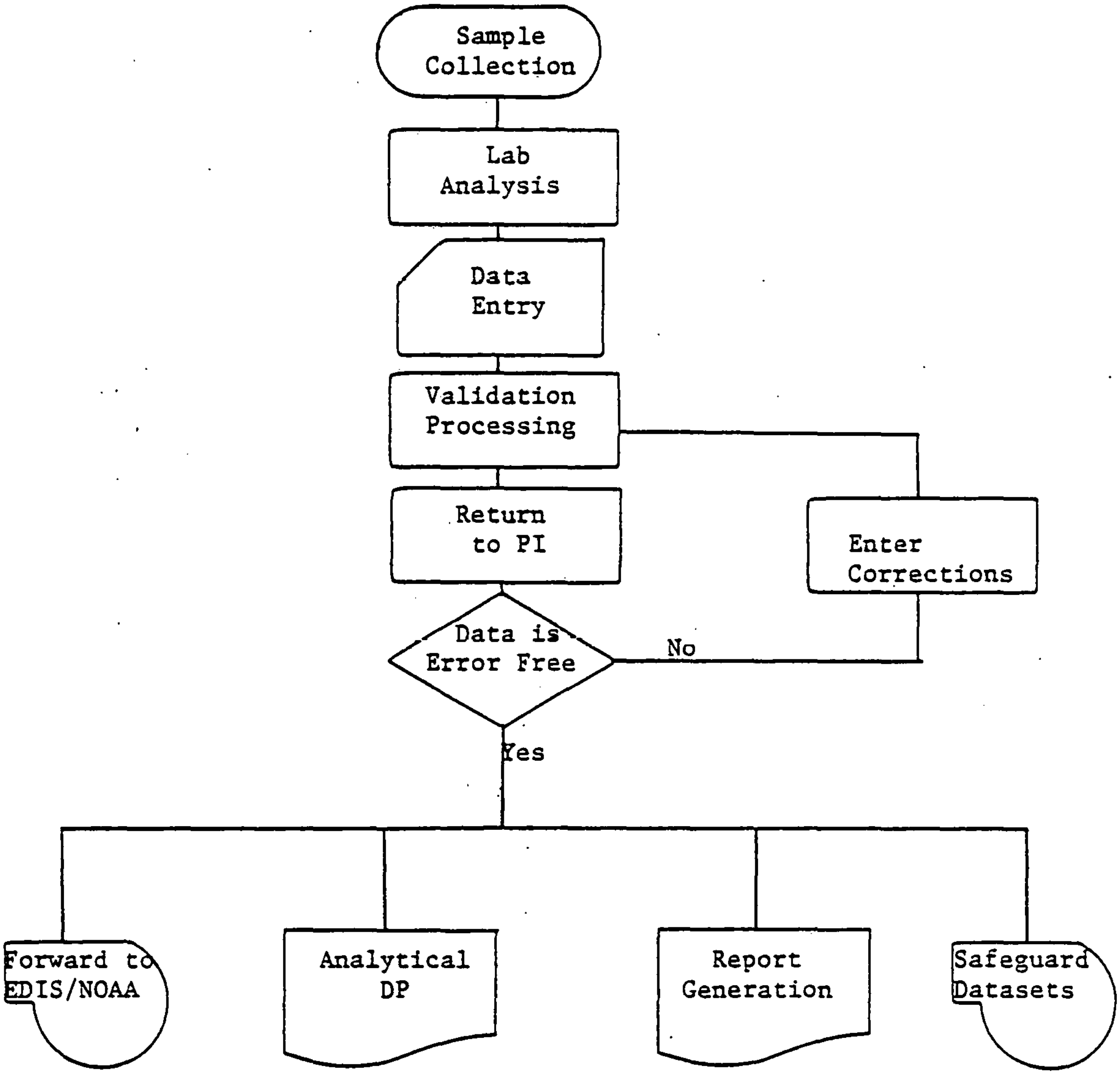

Figure 8-1. Flow chart of data processing activity.

and recommendations are made to the requestor as shown in Figure 8-2. After discrepancies are resolved, a chief programmer is assigned to the project. His responsibilities are to design the program, draw a flow chart, and code and test the program. At that point he may request additional programmers to continue the development process. After the program is flow charted, a structured walk through is conducted in the presence of a programmer who is not involved with the program. The purpose of this phase is to make sure that the program requested is indeed the program undergoing development. Major design flaws can also be detected. The program is then coded and tested. If the program constitutes part of a system of programs, a system test is then performed. At this point the capabilities and output generated by the program are presented to the requestor for his review. Changes are then incorporated, if necessary. After the program is accepted by the requestor, it is compiled into the job library and a procedure is stored on line which will use the stored load module during production processing. The program is then maintained throughout the life of the project.

8.4 Benthic Data

Two data sets are being maintained, one on the old five-mile station and the other on the twelve-mile station. All of the processing for these two data sets is done by the data management staff. After the data is entered to on-line storage from the raw data sheets, it is processed by a data checking program as an aid in debugging the data Corrections are then made and this process repeated until the data can

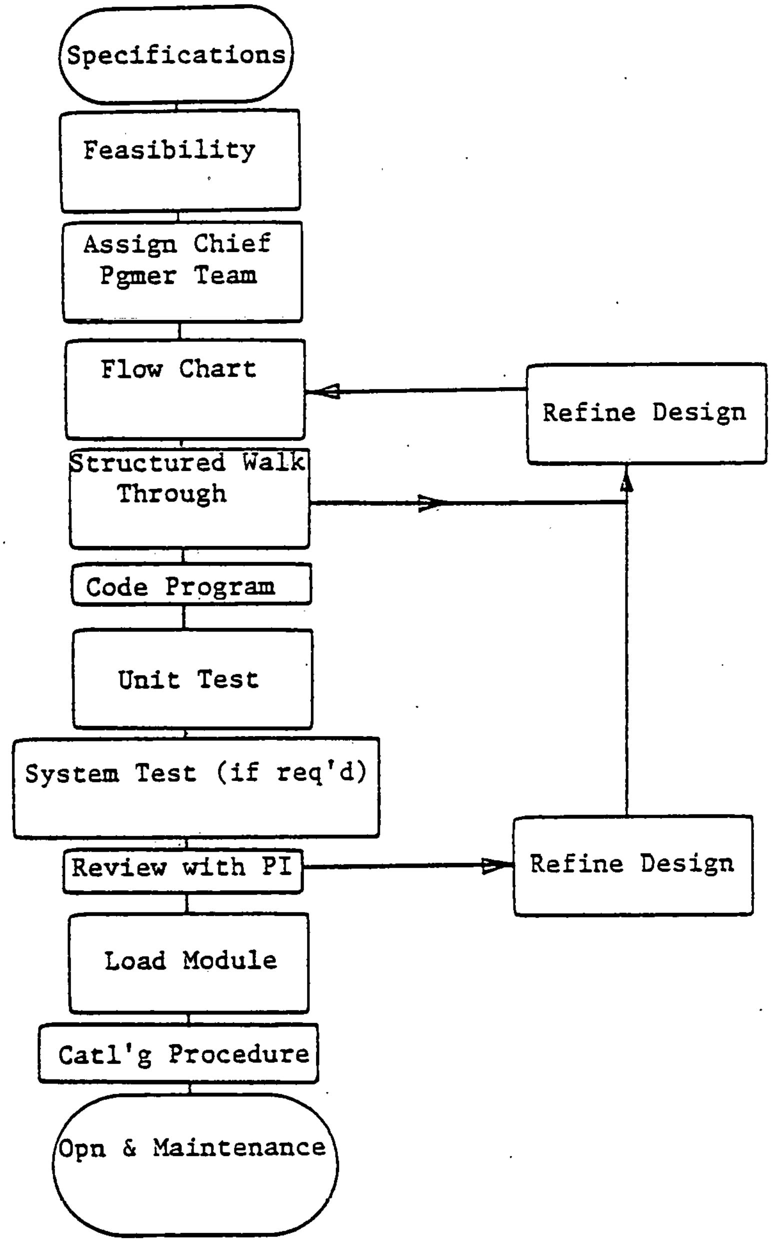

Figure 8-2. Flow chart of software development.

be read by machine without error. The data are then processed into format that resembles the raw data coding form and returned to the investigator for validation. Once these corrections are entered, then process is repeated to insure that the data is being maintained to the satisfaction of the investigator. These data sets are used as input to several different programs. One program rearranges the data into two-dimensional matrix of species versus sites summed over all collection periods or species versus time summed over all stations. The species are sorted in descending numerical order. The matrix is saved for later use as input to cluster analysis. Several programs have been written to convert the raw data into a suitable input format for use in commercial statistical packages such as SAS (Statistical Analysis System). In order to conserve space in the raw data code numbers are used to represent the various species collected. These numbers refer to the corresponding line in the benthic species list which is maintained in a separate file. The species list contains names from benthic studies conducted along the Gulf coast since 1970. Also contained in the species list is a code number that relates the project code numbers to the NOAA/EDIS numbers. A higher taxon code is also maintained in the species list. This latter number along with the species code is used to print the species list in numerical order by species code, alphabetical order, and alphabetical order by higher taxon. The printout is useful in coding the data. A separate program converts the species code in the raw data to the next higher taxon code from the species and uses this to arrange the data into a two-dimensional matrix of taxon versus station over all collection periods. The abundance of each element in the matrix is expressed as a percentage of all individuals collected at that station.

8.5 Nekton Data

After the data have been entered on-line, a data checking program is used to debug the data as explained in the benthic data section. The data is then processed into a format resembling the raw data sheets for validation by the investigator. A species list is maintained in the same manner as the benthic species list. The data is also processed by a program that plots the natural logarithm of abundance plus one versus the average of replicates of a particular species at each station per collection period. Another program is used to arrange the data into matrices of stations versus species along with summary statistics for each collection period. All of these programs are being modified to facilitate use by others.

8.6 Plankton Data

Phytoplankton and zooplankton data are maintained separately and processed in essentially the same meanner as the benthic data. Each data set consists of a number of cruises. The station codes are decoded by a file containing the station names. Likewise, the species and cruise codes are decoded by the respective files containing the species names and collection dates. After validation, the data is processed into reports and formats suitable for statistical analysis using SAS.

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BIBLIOGRAPHY

Adams, E.E., K.D. Stolzenbach and D.R.F. Harleman. 1975. Near and Far Field analogies of Buoyant Surface Discharge into Large Bodies of Water. Cambridge, Mass: Report 205, Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics, Dept. of Civil Engineering, M.I.T.

Adelman, H.C. 1967. The taxonomy of summer and fall vertical distribution of the Chaetognaths off Galveston, Texas. Ph.D. Dissertation, Texas A&M University, College Station. 54 pp.

Allison, T.C. 1967. The diel vertical distribution of copepods off Galveston, Texas. Ph.D. Dissertation, Texas A&M University, College Station. 77pp.

Anonymous. 1978. Grunde Environmental Systems Model 6230N Laboratory Salinometer Instruction Manual, Grunde, Environmental Systems, Inc., March.

Anonymous. 1977. MS06 System Manual, Del Norte Technology, Inc., August.

Anonymous. 1964. Operational and Service Manual, Model III Flourometer, G.K. Turner Associates.

Anonymous. 1973. Operation and Service Manual For Model RM 25 Robot Monitor S/N 216, Schneider Instrument Company.

American Public Health Association. 1975. Standard Methods for the Examination of Water and Wastewater, 14th Edition, APHA-AWWA-WPCF, American Public Health Association, Washington, D.C.

Armstrong, H.W., K. Fucik, J.W. Anderson and J.M. Neff. 1979. Effects of oilfield brine effluent on sediments and benthic organisms in Trinity Bay, Texas. Mar. Environ. Res., 2:55-69.

Arnold, E.L., Jr. 1958. Gulf of Mexico plankton investigations: 1951-53. U.S. Fish Wildlife Serv., SSR-269, 53 pp.

Bailey, R.M., J.E. Fitch, E.S. Herald, E.A. Lachner, C.C. Lindsay, C.R. Robins, and W.B. Scott. 1970. A list of common and scientific names of fishes from the United States and Canada. Amer. Fish. Soc., Spec. Pub. No. 6, 149 pp.

Bishop, Joseph M. and James Overland. 1977. Seasonal drift on the Middle Atlantic shelf. Deep Sea Research, Vol. 24, pp. 161-169, Pergamon Press, Great Britain.

Bolen, Z.K. 1980. A Pumping System for Measuring Coastal Diffusion Coefficients, Master's Thesis, Texas A&M University, May.

Bowden, K.F. and R.E. Lewis. 1973. Dispersion in Flow from a Continuous Source at Sea, Water Research, vol. 7, pp. 1705-1728.

Bowden, K.F. 1965. Horizontal Mixing in the Sea due to a Shearing Current. Journal of Fluid Mechanics, Vol. 21, pp. 83-95.

Brannon, J.M., J.R. Rose, R.M. Engler, and I. Smith. 1977. The Distribution of Heavy Metals in Sediment Fractions From Mobile Bay, Alabama. Chemistry of Marine Sediments, T.F. Yen, ed., Ann Arbor Science Publishers, pp. 125-150.

Brongersma-Sanders, M. 1957. Mass Mortality in the Sea. In: Treatise on Marine Ecology and Paleoecology. Vol. 1. Ecology. Geol. Soc. Amer. Mem. 67: 951-960.

Brooks, D.A.. 1976. (editor), Fast and easy time series analysis at NCSU. Technical Report, Center for Marine and Coastal Studies, North Carolina State University, Raleigh.

Brooks, J.M.. 1979. Inorganic Nutrients at Proposed Brine Disposal Sites (Texoma and Capline Sectors) off Louisiana. Final report to NMFS by Texas A&M University, 31 pp.

Bumpus, D.F. 1972. A description of the circulation on the continental shelf of the east coast of the United States. Progr. Oceanography, in press.

Cairns, J., Jr., K.L. Dickson, P. Pryfogle, S.P. Almeida, S.K. Case, J.M. Fournier, and H. Fuji. 1979. Determining the accuracy of coherent optical identification of diatoms. Water Res. Bull. (15)6: 1770-1775.

Campbell, P.H. 1973. Studies on brackish water phytoplankton. University of North Carolin Sea Grant Program Publication UNC-SG-73-07, pp. i-xi, 1-403, pls. 1-3.

Chen, K.Y., et al. 1976. Research Study on the Effect of Dispersion, Settling, and Resedimentatin on Migration of Chemical Constituents During Open-Water Disposal of Dredged Materials. Contract Report D-76-1, U.S. Army Waterways Experiment Station, Vicksburg, Miss.

Chittenden, M.E., Jr. 1979. An evaluation of the relationships between catch tow duration for the brown shrimp (Penaeus aztecus), white shrimp (Penaeus setiferus), and pink shrimp (Penaeus duorarum). Final report, Predisposal studies. 122 pp.

Chittenden, M.E., Jr. and J.D. McEachran. 1976. Composition, ecology and dynamics of demersal fish communities on the northwestern Gulf of Mexico continental shelf, with a similar synopsis for the entire Gulf. Texas A&M Univ. Sea Grant Pub. No. TAMU-SC-76-208. 104 pp.

Chittenden, M.E., Jr. and D. Moore. 1977. Composition of the ichthyofauna inhabiting the 110 meter bathymetric contour of the Gulf of Mexico, Mississippi River to the Rio Grande, Northeast Gulf Sci. 1:106-114.

Chittenden, M.E., Jr. 1977. Simulatins of the effects of fishing on the Atlantic croaker. Proc. Gulf Carib. Fish Instit., Annual sess. 29:68-86.

Clark, R.C., Jr. 1966. Saturated Hydrocarbons in Marine Plant and Sediments. M.S. thesis, Department of Geology and Geophysics, MIT, Cambridge, Mass.

Clifford, H.T. and W. Stephenson. 1976. An introduction to numerical classification. Academic Press, N.Y.

Connell, J.H. 1978. Diversity in tropical rain forests and coral reefs. Science, 197: 1302-1310.

Crickmore, M.J. 1972. Tracer Tests of Eddy Diffusion in Field and Model. Journal of the Hydraulics Division, ASCE (HY 10), October, pp. 1737-1752.

Csanady, G.T. 1964. Turbulence and Diffusion in the Great Lakes. Publs. Great Lakes Res. Div. No. 11,. 326.

Csanady, G.T. 1963. Turbulent Diffusion in Lake Huron. Journal of Fluid Mechanics, Vol. 17, pp. 360-384.

Cupp, E.E. 1943. Marine plankton diatoms of the west coast of North America. Bull. Scripps Instn. Oceanogr. 5:1-238.

Curl, H. 1959. The phytoplankton of Apalachee Bay and the northeastern Gulf of Mexico. Publs. Inst. Mar. Sci. 6:277-320.

Cuthill, E.A. 1968. A Fortran IV Program for the Calculation of the Equilibrium Configuration of a Flexible Cable in a Uniform Stream, Naval Ship Research and Development Center, NSRDC Report 2531, February.

Daniel, R.A. and E.E. Collins. 1971. Inductive and conductivity probe calibration. Proceedings of 1971 IEEE International Conf. on Eng. in the Oceanographic Env., San Diego, California.

Dawson, C.E. 1967. Contributions to the biology of the cutlassfish (Trichiurus lepturus) in the northern Gulf of Mexico. Trans. Amer. Fish. Soc. 96:117-121.

DeVries, D.A. 1979. Aspects of the life history of the silver seatrout, Cynoscion nothus, in the Gulf of Mexico. M.S. thesis, Texas A&M Univ., 56 pp.

DeVries, D.A. and M.E. Chittenden, Jr. In preparation. Spawning, age determination, and population dynamics of the silver seatrout, Cynoscion nothus, in the Gulf of Mexico.

El-Sayed, S.Z., et al. 1972. Serial Atlas of the Marine Environment, Folio 22, Chemistry, Primary Productivity, and Benthic Algae of the Gulf of Mexico. American Geographical Society, New York, (V.C. Bushnell, ed.) pp. 1-29, pls. 1-6.

Endoh, Masahiro. 1977. Formation of thermohaline front by cooling of the sea surface and inflow of the fresh water. Journal of the Oceanographical Society of Japan, Vol. 33, pp. 6-15.

Environmental Protection Agency. 1979. Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, EMSL, EPA, Cinn. Ohio.

Farrell, D. 1974. Benthic ecology of Timbalier Bay, Louisiana, and adjacent offshore areas in relation to oil production. Ph.D. Thesis. Florida State University, 164 pp.

Farrington, J.W. and B.W. Tripp. 1977. Hydrocarbons in Western North Atlantic Surface Sediments. Geochim. Cosmochim. Acta., 41:1627-1641.

Feuerstein, D.L. and R.E. Selleck. 1963. Fluorescent Tracers for Dispersion Measurements. Journal of the Sanitary Division, ASCE (SA 4), August, pp. 1-21.

Filice, R.P. 1959. The effects of wastes on the distribution of bottom invertebrates in the San Francisco Bay estuary. Wismann J. Biol., 17:1-17.

Finucane, J.H. 1976. Baseline survey of ichthyoplankton. Pages 20-30 In: W.B. Jackson, ed. Environmental studies of the South Texas Outer Continental Shelf, 1975, Vol. 1 Plankton and fisheries. Report, Bur. Land Mgmt., Interagency Agreement 08550-125-19. 425 pp.

Fischer, H.B., E.J. List, R.C.Y. Koh, J. Imberger and N.H. Brooks. 1979. Mixing in Inland and Coastal Waters, Academic Press, New York.

Fischer, W. 1978. (editor) FAO species identification sheets for fishing purposes. Western Central Atlantic, Vol. I-VII. Food Agric. Organ. U.N. Rome.

Fish, A.G., L.L. Massey, J.R. Inabinet and P.L. Lewis. 1974. A study of the effects of environmental factors upon the distribution of the foraminifera, nematode and polychaetous annelid meiofauna of Timbalier Bay, Louisiana. GURC Offshore Ecological Investigation. Unpub. M.S.

Folk, R.L. 1974. Petrology of Sedimentary rocks. Hemphill, Texas. 182 pp.

Fotheringham, N. and G. Weissberg. 1979. Some causes, consequences and potential impacts of oxygen depletion in the northern Gulf of Mexico. Offshore Tech. Conf. Proc., OTC 3611:2205-2207.

Foxworthy, J.E. 1968. Eddy Diffusity and the Four-thirds Law In Near Shore Coastal Waters, Allan Hancock Foundation, Univ. of

So. Calif., Rep. 68-1.

Freese, L.R. 1952. Marine diatoms of the Rockport, Texas Bay area. Texas J. Sci. 4:331-386.

Fucik, K.W. and S.Z. El-Sayed. 1979. Effect of oil production and drilling operations on the ecology of phytoplankton in the OEI study area. In: The Offshore Ecology Investigation. Effects of oil drilling and production in a coastal environment. Eds. C.H. Ward, M.E. Bender and D.J. Reish, Rice Univ. Studies, 65(445): 325-353.

Gaboury, D.R. and K.D. Stolzenbach. 1979. Dispersion zone characteristics of ocean discharges, report no. 244, Ralph M. Parsons Lab. for Water Resources and Hydrodynamics, Dept. of Civil Eng., MIT.

Garlo, E.V., C.B. Milstein and A.E. Jahn. 1979. Impact of hypoxic conditions in the vicinity of Little Egg Inlet, New Jersey in summer 1976. Estuarine and Coastal Mar. Sci., 8:421-432.

Gearing, P., J.W. Gearing, T.F. Lytle and J.S. Lytle. 1976. Hydrocarbons in 60 northeast Gulf of Mexico Sediments: A Preliminary Survey Geochim, Cosmochim. Acta. 40: 1005-1017.

Grace, R.A. 1978. Marine Outfall Systems; Planning Design and Construction, Prentice-Hall Inc., Englewood Cliffs.

Gunter, G. 1958. Population Studies on the shallow water fishes of an outer beach in south Texas. Pub. Inst. Mar. Sci., Univ. Tex. 5:186-193.

Gunter, G. 1945. Studies on marine fishes. Pub. Inst. Mar. Sci., Univ. Tex., 1:1-190.

Gunter, G. 1979. The annual flows of the Mississippi River. Gulf Research Reports, Vol. 6, No. 3, pp. 283-290.

Hall, Clyde S. 1969. An investigation of the water balance of the basin of the Gulf of Mexico. M.S. thesis, Texas A&M Univ.

Hann, R.W., Jr., et al. 1978a. Evaluation of brine disposal from the Bryan Mound Site of the Strategic Petroleum Reserve Program. Texas A&M University, Progress Report, February.

Hann, R.W., Jr., et al. 1978b. Evaluation of brine disposal from the Bryan Mound Site of the Strategic Petroleum Reserve Program. Texas A&M University, Progress Report, July.

Hann, R.W., Jr., et al. 1979a. Evaluation of brine disposal from the Bryan Mound Site of the Strategic Petroleum Reserve Program. Texas A&M Univeristy, Progress Report, February.

Hann, R.W., Jr., et al. 1979b. Evaluation of brine disposal from the Bryan Mound Site of the Strategic Petroleum Reserve Program.

Texas A&M Univeristy, Progress Report, July.

Harper, D.E., Jr., R.J. Scrudato, and C.S. Giam. 1976. A preliminary environmental assessment of the Buccaneer Oil/Gas Field. Texas A&M Research Foundation project 3309 final report to National Marine Fisheries Service, Galveston, Texas.

Harper, D.E., Jr. 1977a. An investigation of the effects of dredging and dredged material dispoal on the offshore biota at Galveston, Texas. Texas A&M Research Foundation project 3347 final report to U.S. Army Corpsof Engineers, Waterways Experiment Station, Vicksburg, Miss.

Harper, D.E., Jr. 1978b. Distribution and abundance of macrobenthic and meiobenthic organisms in the vicinity of the Buccaneer Oil/Gas Field. Texas A&M Research Foundation project 3368 final reportto National Marine Fisheries Service, Galveston, Texas.

Harper, D.E., Jr. 1968. Distribution of Lucifer faxoni (Crustacea; Decapoda; Sergestidae) in neritic waters off the Texas coast, with a note on the occurrence of Lucifer typus. Contr. Mar. Sci. 13:1-16.

Harper, D.E., Jr. 1970. Ecological studies of selected level-bottom macroinvertebrates off Galveston, Texas. Ph.D. Thesis, Texas A&M University, 300 pp.

Harper, D.E., Jr. and R.J. Case. 1976. Numerical analysis of the benthic data. In: SEADOCK, Inc. Environmental Report: Texas Offshore Crude Oil Unloading Facility. Vol. 2. Chapt. 10, Sect 10.4. Texas A&M Research Foundation project 945 final report to SEADOCK, Inc. pp. 551-573.

Harrington, David L. Oceanographic observations on the Northwest continental shelf of the Gulf of Mexico, 1963-65, contribution no. 329, National Marine Fisheries Service Biological Lab., Galveston, Texas, unpublished manuscript.

Haury, L.R. 1976. Small-scale pattern of a California Current zooplankton assemblage. Mar. Biol. 37:137-157.

Haven, D.S. 1957. Distribution, growth and availability of juvenile croaker, Micropogon undulatus in Virginia. Ecology 38:88-97.

Heaney, S.I. and J.F. Talling. 1980. Dynamic aspects of dinoflagellate distribution patterns in a small productive lake. J. Ecol. 68:75-94.

Hedgepeth, J.W. 1953. An introduction to the zoogeography of the northwestern Gulf of Mexico with reference to the invertebrate fauna. Publs. Inst. Mar. Sci. Univ. of Texas, 3:109-224.

Hedgepeth, J.W. 1954. Bottom Communities in the Gulf of Mexico. In: The Gulf of Mexico, Its Origin, Waters and Marine Life. U.S. Fish and Wildlife Serv. Fish. Bull. 55(89): 203-214.

Henry, C.A. 1976. A study of offshore benthic communities in natural areas and areas affected by dredging and dredged material disposal M.S. thesis, Texas A&M University.

Hildebrand, H.H. 1954. A study of the fauna of the brown shrimp (Penaeus aztecus Ives) grounds in the western Gulf of Mexico. Publs. Inst. Mar. Sci., Univ. of Texas, 3:1-336.

Hulings, N.C. 1955. An investigation of the benthic invertebrate fauna from shallow waters of the Texas coast. M.S. thesis, Texas Christian University. 77 pp.

Hydes, D.J. 1980. Aluminum in Seawater: Control by Inorganic Processes. Science, 205:1260-1262.

Hydrolab. 1978. Hydrolab 8000 water quality system operation instructions. Hydrolab Corporation.

Ichiye, T. 1962. Studies of the Turbulent Diffusion of Dye Patches in the Ocean. Journal of Geophysical Research, vol. 67, pp. 3212-3216.

James, W.P., ed. 1977. Proceedings of Strategic Petroleum Reserve Workshop: Environment Considerations of Brine Disposal near Freeport, Texas, held at Houston, Texas, Feb. 17-18, 1977, Center for Marine Resources, Texas A&M University, College Station p. 75.

Jenne, E. A. and Luoma, S. N. 1975. Forms of Trace Elements in Soils, Sediments and Associated Waters: An Overview of Their Determinatin ad Biological Availability. Presented: Biological Implications of Metals in the Environment, 15th Life Sciences Symposium, Hanford, Sept. 29- Oct. 1, 1975.

Johnson, R. B. Jr., 1974. Ecological changes associated with the industrialization of Cedar Bayou and Trinity Bay, Texas. Texas Parks and Wild. Dept. Tech. Ser. 16. 79 pp.

Johnson, R. B. Jr. 1977. Fishery survey of Cedar Lakes and the Brazos and San Bernard River estuaries. Texas Parks and Wildl. Tech. Ser. 23. 65 pp.

Kamykowski, D. W. Pulich and C. van Baalen. 1977. Phytoplankton and productivity. In: Environmental Studies, South Texas Outer Continental Shelf, Biology and Chemistry. Final Report, Bureau Land Managem. Contract AA551-CT6-17, pp. 1 to 4-39.

Kamykowski, D. and C. van Baalen. 1979. Phytoplankton and and productivity. In: Environmental Studies, South Texas Outer Continental Shelf, Biology and Chemistry, Chapter 11, Final Report to Bureau of Land Managem. 57 pp.

Kamykowski, D. and S. Milton. 1980. Chapter 7. Phytoplankton and Productivity. In: Environmental Studis, South Texas Outer Continental Shelf, 1975-1977, vol. III, Study Area Final Reports, eds. Flint, R. W. and N. N. Rabalais. Bur. Land Managem. Contract AA551-CT8-51, pp. 231-284.

Kaplan, I. R., Mankiewicz, P., Reed, W. E., Ruth, E., Sandstrom, M., and Venkatesan, M. I., 1976. Final Report to SAI for Southern California Bight Program, Bureau of Land Management, Vol. III, Report 3.1, p. 105.

Karabashev, G. S. and Ozmidov, R. V. 1965. Investigation of Turbulent Diffusion in the Sea Using Fluorescent Tracers. American Geophysical Union, Vl. 1, 689-695.

Kritzler, H. 1974. Oil production and polychaetous annelids in a Louisiana estuary. GURC Offshore Ecological Investigation. Unpub. MS.

Kutkuhn, J. G. 1963. Expanded research on Gulf of Mexico shrimp resources. Proc. Gulf Caribb. Fish. Inst., 15th Ann. Sess., 1962. pp. 65-76.

Ladd, H. S. 1951. Brackish-water ad marine assemblages of the Texas coast, with special reference to mollusks. Publ. Inst. Sci., Univ. Texas, 2(1): 125-163.

Ladd, H. S., J. W. Hedgpeth ad R. Post. 1957. Environments and facies of existing bays on the Central Texas coast. In: Treatise on Marine Ecology and Paleoecology, Vol. 2, Paleoecology. Geol. Soc. Amer. Mem. 67: 599-640.

LaFond, E. C. 1951. Processing oceanographic data, U. S. Navy Hydrographic Office, H.O. Pub. No. 614, Washington, D. C.

Lane, E. D. 1967. A study of the Atlantic midshipmen, Porichthys porossissimus, in the vicinity of Port Aransas, Texas. Contrib. Mar. Sci., Univ. Texas. 12: 1-53.

Lannergren, C. 1979. Buoyancy of natural populations of marine phytoplankton. Mar. Biol. 54: 1-10.

Lee, G. F. 1970. Factors Affecting the Transfer of Materials Between Water ad Sediments. Literature Review, No. 1, Water Reources Center, University of Wisconsin.

Lorenzen, C. J. 1966. A method for the continuous measurement of in vivo chlorophyll concentration. Deep-Sea Res. 13: 223-227.

McFarland, W. N. 1963. Seasonal change in the number and the biomass of fishes from the surf at Mustang Island, Texas. Pub. Inst. Mar. Sci., Univ. Tex. 9:91-105.

Mackin, J. G. 1971. A study of the effects of oil field brine effluents on biotic communities in Texas estuaries. Texas A&M Research Foundation project 735 final report to Humble Oil and Refining Company.

Mackin, J. G. and S. H. Hopkins. 1962. Studies on oyster mortality in relation to natural environments and to oil fields in Louisiana. Publs. Ins. Mar. Sci., Texas, 7: 1-131.

Malone, T. C. 1971. The relative importance of nannoplankton and net plankton as primary producers in tropical oceanic and neritic phytoplankton communities. Limnol. & Oceanogr. 16: 633-639.

May, E. B. 1973. Extensive oxygen depletion in Mobile Bay, Alabama. Limnol., Oceanogr., 18: 353-366.

Medlin, L. K. and W. B. Wilson. 1979. Effects of temperature and salinity on the growth of the benthic diatom Nitzschia ovalis Arnott (Bacillariophyceae). Contrib. Mar. Sci. 22: 127-136.

Minello, T. J. 1980. The neritic zooplankton of the northwestern Gulf of Mexico. Ph.D. Dissertation, Texas A&M University.

Moffett, A. W. 1970. The shrimp fishery in Texas. Tex. Pks. Wild. L. Dept. Bull. No. 50. 38 pp.

Murthy, C. R. 1972. Complex Diffusion Processes in Coastal Currents of a Lake. Journal of Physical Oceanoraphy, Vol. 2(1), p. 80.

Murthy, C. R. and G. T. 1971. Experimental Studies of Relative Diffusion in Lake Huron. Journal of Physical Oceanography, Vol. 1 (1), p. 17.

National Academy of Sciences, 1975. Petroleum in the Environment, Workshop of Inputs, Fates and the Effects of Petroleum in the Marine Environment, May 21-25, 1973. National Academy of Sciences, Washington, D. C. 107 pp.

Neff, J. W., R. S., Foster and J. F. Slowey. 1978. Availability of Sediment adsorbed Heavy Metals to Benthos with Particular Emphasis on Deposit Feeding Infauna. Contract report DACW 39-57-C00096, U. S. Army Waterways Experiment Station, Vicksburg, Miss., 285 pp.

Nienaber, J. 1958. Shallow marine sediments offshore from the Brazos River. Ph.D. Thesis, University of Texas, Austin. 181 pp.

Neinaber, J. 1963. Shallow marine sediments offshore from the Brazos River. Texas. Publs. Inst. Mar. Sci., Univ. Texas, 9: 311-372.

NOAA, 1977. Analysis of Brine Disposal in the Gulf of Mexico. Bryan Mound, National Oceanic and Atmospherice Administration, February.

NOAA, 1979a. EDIS, National Climatic Center; Climatic Data; Texas.

NOAA, 1979a. EDIS, National Climatic Center, Local Climatological Data: Galveston.

Officer, C. B., 1976. Physical oceanography of estuaries, John Wiley and Sons, New York.

Okubo, A., Oceanic Diffusion Diagrams. Deep Sea Research, Vol. 18, 1971, pp. 789-803.

Owen, B. B., M Afzal and W. R. Cody, 1979. Distinguishing between live and dead diatoms in periphyton communities. In: American Society for Testing Material, Spec. Tech. Publ. 690, pp. 70-76.

Park, E. T. 1979. Zooplankton project, Chapter 14, Pages 14-1 to 14-58 in R. W. Flint and C. W. Griffin, eds. Environmental studies, South Texas Outer Continental Shelf, biology and chemistry, 1977. Final Report, Bur. Land Mgmt., Contract AA550-CT7-11.

Park, E. T. and P. Turk, 1980. Zooplankton project, Chapter 9 in R. W. Flint and N. Rabalais, eds. Environmental studies, South Texas Outer Continental Shelf, 1975-1977, Vol III. Study element reports. Report, Bur. Land Mgmt., Contract AA551-CT8-51.

Parker, R. H. 1960. Ecology and distributional pattern of marine invertebrates, northern Gulf of Mexico. In: Recent Sediments, Northwest Gulf of Mexico. F. P. Shepard, F. B. Phleger and T. H. vanAndel (eds). Amer. Assoc. Petrol. Geol. pp. 203-337.

Pearson, J. C. 1929. Natural history and conservation of the redfish and other commercial Sciaenids of the Texas coast. Bull. U.S. Bur. Fish. 44:129-214.

Pietrafesa, Leonard J., and Gerald S. Janowitz, 1979. On the effects of Buoyancy flux on continental shelf circulation. American Meteorological Society.

Pritchard, D. W., and Carpenter, J. H., 1960. Measurement of Turbulent Diffusion in Estuarine and Inshore Waters. International Association of Scientific Hydrology Bulletin, Vol. 20, pp. 37-50.

Raymont, J. G. 1980. Plankton and Productivity in the Oceans. vol. I, Phytoplankton, 2nd ed., Pergamon Press, Oxford, England, pp. i-xiv, 1-489.

Reinert, R. L., 1973. The Role of Shear in Oceanic Diffusion From a Continuous Point Source, New York University, School of Engineering and Science, Ph.D.

Riley, J. P. and Skirrow, G., 1965. Chemical Oceanography, Vol. 1, Academic Press, New York, 712 pp.

Sackett, W. M. and Brooks, J. M., 1978. Low-Molecular-Weight Hydrocarbons and Hydrographic Project, in Environmental Studies, South Texas Outer Continental Shelf, Biology and Chemistry, a report to the Bureau of Land Management from a consortium program conducted by Rice University and the University of Texas, Contract No. AA550-CT7-11.

Saunders, R. P. and D. A. Glenn. 1969. Diatoms. In: Memoirs of the Hourglass Cruises. Fla. Dept. Nat. Res. Lab., St. Petersburg 1(3): 1-119.

Saunders, R. P., B. L. Birnhak, J. T. Davis and C. L. Wahlquist. 1967. Seasonal distribution of diatoms in Florida inshore waters from Tampa Bay to Caxambas Pass, 1963-64. In: Red Tide Studies, Pinellas to Collier Counties. 1963-1966. A Symposium, Fla. Bd. Conserv. Mar. Lab., Prof. Pap. Ser. No. 9: 48-78.

Science Applications, Inc. 1978. Environmental Survey of Texoma Brine Diffuser Site, Report to Department of Energy, August 19.

Seadock, Inc. 1975. Environmental report: Texas offshore oil unloading facility. Texas A&M Res. Fdn. Proj. 945 Report.

Seadock, 1975. Seadock, Environmental Report, Vol. II, Houston, Texas.

Shlossmann, P. A. 1980. Aspects of the life history of the sand seatrout, Cynoscion arenarius, in the Gulf of Mexico. MS. Thesis, Texas A&M Univ.

Simmons, E. G. and J. P. Brewer. 1962. A study of redfish, Sciaenops cellata Linnaeus, and black drum, Pogonias cromis Linnaeus. Pub. Inst. Mar. Sci., Univ. Tex. 8: 184-211.

Simmons, E. G. ad W. H. Thomas. 1962. Phytoplankton of the Eastern Mississippi Delta. Contrib. Mar. Sci. 8: 269-288.

Slowey, J. F. and D. W. Hood. 1971. Copper, Manganese and zinc concentrations in Gulf of Mexico waters. Geochim. Acta., 35: 121-138.

Smith, R. L. 1974. Ecology and Field Biology. Harper and Row. New York. 850 pp.

Smith, N. P. 1979. Hydrography project. Environmental studies, South Texas outer continental shelf, biology and chemistry, R. D. Grover, Ed., pp.2-1 to 2-130. University of Texas Final Report to the Bureau of Land Management, Contract

AA550-CT7-11.

Smith, N. P. 1980. On the hydrography of shelf waters off the central Texas Gulf coast, Journal of Physical Oceanography, Vol. 10, pp. 806-813.

Staker, R. D. and S. F. Bruno. 1980. Diurnal vertical migration in marine phytoplankton. Botanica Marina 23: 167-172.

Steidinger, K. A., J. T. Davis and J. Williams. 1967b. A key to the marine dinoflagellate genera of the West coast of Florida. Fla. Bd. Conserv. Mar. Lab., Tech. Ser. No. 52: pp.1-42.

Steidinger, K. A., J. T. Davis and J. Williams. 1967a. Dinoflagellate studies on the inshore waters of the west coast of Florida. In: Red Tide Studies, Pinellas to Collier Counties, 1963-1966. Fla. Bd. Conserv. Mar. Lab., Prof. Pap. Ser. No. 9: 4-47.

Steidinger, K. A. and J. Williams. 1970. Dinoflagellates. In: Memoirs of the Hourglass Cruises. Mar. Res. Lab., Fla. Dept. Nat. Resources. vol. II, Contrib. 148, pp. 1-251.

Stommel, H. and A. Leetmaa. 1972. Circulation on the continental shelf. Proceedings National Academy of Science, Vol. 69, No. 11, pp. 3380-3384, November 1972.

Streeter, V. L. and Wylie, B. E. 1975. <u>Fluid Mechanics</u>, 6th Edition, McGraw-Hill Book Company, New York.

Strickland, J. D. H. and T. R. Parsons. 1972. A Practical Handbook of Seawater Analysis, Bulletin 167, Second Ed., Fisheries Research Board of Canada, Ottawa, Canada.

Strickland, J. D. H. 1968. Continuous measurement of in vivo chlorophyll; a precautionary note. Deep-Sea Res. 15: 225-227.

Sutton, O. G. 1953. <u>Micrometeorology</u>, McGraw-Hill Book Co., New York.

Talbot, J. W. 1975. Interpretation of Diffusion Data. <u>Discharge of Sewage Outfalls</u>, Proceedings, International Symposium, A. L. H. Gameson, Editor, Pergamon Press.

Temple, R. F. and D. L. Harrington and J. A. Martin. 1977. Monthly temperature and salinity measurements of continental shelf waters of the northwestern Gulf of Mexico, 1963-1965. NOAA Tech. Rept., SSRF-707. 26 pp.

Temple, R. F. 1976. Relative seasonal abundance and areal distribution of larval shrimp (<u>Penaeus spp</u>.). Pages 11-19 in W. Jackson, ed. Environmental studies of the South Texas Outer Continental Shelf, 1975. Vol. I. Plankton and

Fisheries. Report, Bur. Land Mgmt., Interagency Agreement 08550-125-19. 425 pp.

Temple, R. F. ad C. C. Fisher. 1967. Seasonal distribution and relative abundance of planktonic-stage shrimp (Penaeus spp.) in the northwestern Gulf of Mexico, 1961. U. S. Fish Wildl. Serv., Fish. Bull. 66(2):323-334.

Temple, R. F. and C. C. Fisher. 1965. Vertical distribution of the planktonic stages of penaeid shrimp. Publ. Inst. Mar. Sci. Univ. Texas. 10: 59-67.

Throndsen, N. 1978. Preservation and storage. In: Phytoplankton Manual. A. Sournia, ed., United Nations Ed., Sci and Cultural Org. (UNESCO). Page Brothers, Ltd., Norwich, U. K., pp. 69-74.

Trefry, J. H. 1977. The Transport of Heavy Metals by the Mississippi River and Their Fate in the Gulf of Mexico, Ph.D. dissertation, Texas A&M University, College Station, 223 pp.

U. S. Geological Survey 1977a. Water resources data for Louisiana water year 1977. U.S.G.S. Water Data Reports, LA-77-1,-2,-3, Vols. I, II, III.

U. S. Geological Survey 1978a. Water resources data for Louisiana water year 1978. U.S.G.S. Water Data Reports, LA-78-1,-2,-3, Vols. I, II, III.

U. S. Geological Survey, 1977a. Water resources data for Texas water year 1977. U.S.G.S. Water Data Reports, TX-77-1,-2,-3, Vols. I, II, III.

U. S. Geological Survey, 1978a. Water resources data for Texas water year 1978. U.S.G.S. Water Data Reports, TX-78-1,-2,-3, Vols. I, II, III.

van Baalen, Chase. 1976. Phytoplankton and phytoplankton biomass. In: Environmental Assessment of the South Texas Outer Continental Shelf, biology and chemistry, 1975, ed. P. L. Parker. Final Rept. submit. to Bur. Land Management. Wash., D. C., contract AA550-CT5-17, pp. 46-81.

van Baalen, Chase. 1975. Primary productivity. In: Environmental Studies of South Texas Outer Continental Shelf, 1975: An Atlas and Integrated Summary., ed. H. L. Berryhill, Jr., U. S. Bur. Land Managem. Report, pp. 129-149.

Waller, R. S. 1974. Effects of platforms on biota (invertebrates). GURC Offshore Ecological Investigation. Unpub. MS.

White, M. L. and M. E. Chittenden, Jr. 1977. Age determination, reproduction and population dynamics of the Atlantic croaker, Micropogonias undulatus. Fish. Bull. U. S. 75: 109-123.

Wiebe, P. H. 1970. Small scale spatial distribution in oceanic zooplankton. Limnol. Oceanogr. 15: 205-217.

Wilson, J. F. 1968. Fluorometer Procedures for Dye Tracing, Book 3, U. S. Department of the Interior.

Wilson, T. R. S. and A. J. Harrison, Submerged Pump System for Underway Monitoring at the Sea Surface, Using a Conventional STD or CTD Unit. Deep Sea Research, Vol. 22, 1975. pp. 571-574.

Weyl, P. K. 1964. On the changes in electrical conductance of seawater with temperature. Limnology and Oceanography, Vol. 9, pg. 75.

Wood, E. J. Ferguson. 1963. A study of the diatom flora of fresh sediments of the south Texas bays and adjacent waters.

Yentsch, C. S. and J. F. Hebard. 1957. A guage for determining plankton volume by the mercury immerion method. J. Cons. Int. Explor. Mer. 22: 184-190.

Yentsch, C. S. and D. W. Menzel. 1963. A method for the determination of phyotplankton chlorophyll and phaeophytin by flourescence. Deep-Sea Res. 10: 221-231.

Yentsch, C. S. 1974. Some aspects of the environmental physiology of marine phytoplankton: A second look. In: Oceanogr. Mar. Biol. Ann. Rev., ed. Harold Barnes, pp.41-45.