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Marine Studies of San Pedro Bay, California

PART 15

THE IMPACT OF THE *SANSINENA* EXPLOSION AND BUNKERS C SPILL ON THE MARINE ENVIRONMENT OF OUTER LOS ANGELES HARBOR

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Edited by
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Harbors Environmental Projects
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Institute of Marine and Coastal Studies
University of Southern California
Los Angeles, California 90007

December, 1978

This volume incorporates
the final report to the Union Oil Company
and to the USC-Sea Grant Program

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and
Harbors Environmental Projects
of the
Institute for Marine and Coastal Studies

The Principal Investigator

Marine Studies of San Pedro Bay, California, Part 15

ERRATUM

Page 66, second paragraph should read:

Weighted discriminant analysis showed the interactions of the parameters and gives coefficients of separate determination for each parameter. Thus the higher the coefficient for a parameter the more important that parameter is as a variable interacting with all the other biotic and abiotic variables. Bar graph data, presented at the end of this section, show the separate parameters (Figures 58-67), but they will generally not show the same ranking of means and extremes as the weighted means used to calculate the coefficients. Weighting compensates for patchiness and statistical errors in sampling, population dominance and the like.

Marine Studies of San Pedro Bay, California
Part 15

THE IMPACT OF THE *SANSINENA* EXPLOSION AND BUNKER C SPILL ON THE MARINE ENVIRONMENT OF OUTER LOS ANGELES HARBOR

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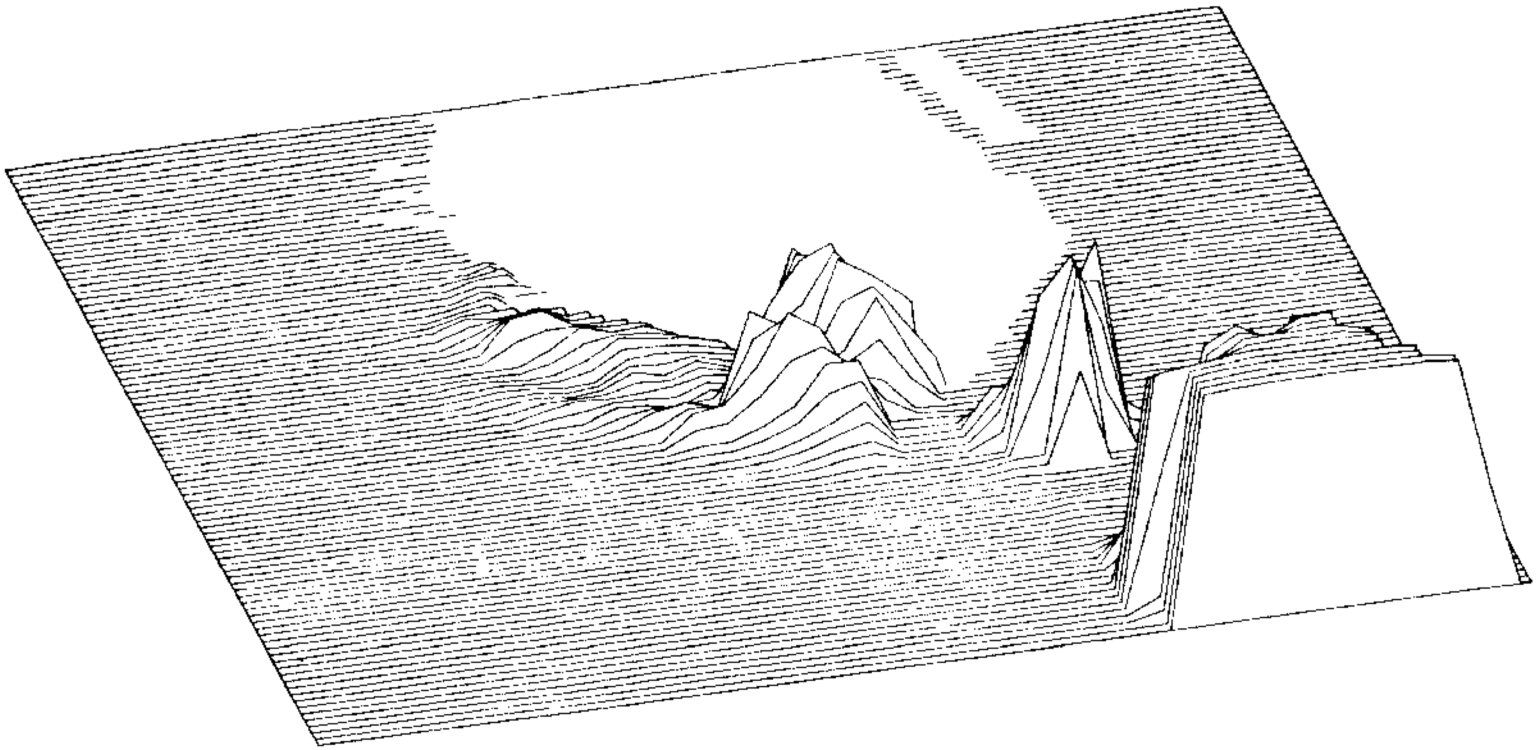
Cover photo, courtesy of Los Angeles Fire Department



SANSINENA EXPLOSION - BOTTOM DISTRIBUTION OF OIL, DECEMBER 1977

Stereogram (vertical profile exaggerated).
Courtesy of John W. McDonald.

SUMMARY OF IMPACTS

PHYSICAL EFFECTS OF THE SANSINENA BUNKER C SPILL

1. The residual oil in the tanker Sansinena spread over the southwest basin of outer Los Angeles Harbor, coating the San Pedro breakwater and inner Cabrillo Beach.

2. Some of the Bunker C fuel on the surface burned and residue sank, while ruptured lines beneath the dock flowed for several days, creating a deep pool of Bunker C fuel on the bottom. The fuel spread in the ship channel and surfaced through the water column as blobs and slicks.

3. Concentrations in the water column and nearby sediments decreased through the spring and summer but increased in the fall when pile driving and storms uncovered and stirred up bottom residues. An estimated 3000-4500 barrels that could not be salvaged remained in the outer harbor area one year later.

BIOLOGICAL EFFECTS OF THE SANSINENA INCIDENT

A. Phytoplankton Productivity

1. The data indicate that a distinct stimulation in the activity of the phytoplankton occurred immediately following the explosion and oil spill. There was not a concurrent increase in population size, indicating that the activity was possibly related to the trauma of the incident rather than to the presence of oil in the water.

2. An unusual red tide bloom occurred in the area in July, while phytoplankton was inhibited in November rather than stimulated. Both conditions may have been due to natural events, but a return to high oil levels in the water in November may have been inhibitory.

3. Nutrient levels in the area also peaked above nearby ambient levels in the two weeks following the spill. In January, nitrite rose and then dropped below ambient, while nitrate remained high at the spill site but dropped nearby; ammonia rose above ambient and remained high throughout the early spring.

B. Benthic Biology

1. Weighted discriminant computer analysis indicated that December 1976 distribution patterns (site groupings) of benthic species were strongly influenced by salinity, pH and turbidity, but less so by oil and grease in the sediments and dissolved oxygen in areas not directly beneath the oil pool.

2. In January 1977 the benthic patterns appeared to be much more strongly influenced by oil and grease, although counts per square meter had not dropped radically.

3. By April, instead of the spring increases normally expected, populations dropped radically, even though oil and grease levels had also dropped greatly. It should be noted that more than one month elapsed before large mortalities occurred. Bioassay tests for toxicity generally are not carried out for the 2-4 months that would have simulated this cumulative impact.

4. By November, numbers of species or other taxa were near normal, but population counts did not approach those of the 1974 survey. Analysis suggested that oil and grease levels were no longer strongly influencing distribution in spite of the fact that reconstruction activities at the dock and storms had increased levels in the water column and surface sediments greatly. This does not mean, however, that there were no further influences from the oil residues, but that other factors such as temperature, dissolved oxygen and salinity played important roles in species distribution and population.

C. Zooplankton Investigations

1. Species diversity remained high for several weeks after the explosion, with increases in copepod and cladoceran taxa, but total members per cubic meter were reduced. *Paracalanus parvus* and *Acartia tonsa* showed increases in January.

2. In April numbers of species dropped, but counts rose greatly in the Sansinena area, although they did not rise outside the area. Literature surveyed suggested that copepods may feed on oil without harm.

3. Data analysis showed that oil and grease levels far outweighed other parameters in December-January in determining species distribution (site groupings). Phytoplankton parameters were next in importance.

4. By April phytoplankton parameters, dissolved oxygen, salinity and pH were major determinants. Oil and grease levels were also important even though levels were low. July data analysis again showed phytoplankton parameters to be the most important parameters. Mid- and bottom water oil and grease levels had lesser effect than did surface levels.

5. November distribution patterns (site groupings) were determined largely by phytoplankton parameters and temperature. In spite of large increases in oil and grease levels, those parameters did not appear to define the site groups. The hypothesis was advanced that the residual oil was no longer toxic to zooplankton or to benthic organisms.

D. Meroplankton

1. The number of species or other taxa did not show the usual spring increase near the Sansinena; increases did occur by June and July, however.

2. Numbers of species and individuals were similar in the site area and outside it in February, but by April the numbers were nearly double away from the site as compared with the highest in the site area. That study was terminated in July.

E. Breakwater Biota

1. The breakwater rocks were heavily coated with tar at the higher high tide marks. Animal species abundance was generally better in the January survey than it was in March, the reverse of the usual pattern, with some recovery by June, 1977. Algal species returned earlier, with increases in March, which may in turn have provided food for the subsequent animal recolonization. A kelp bed built on the breakwater in June subsequently attracted good diverse populations to the area.

F. Fish Fauna

1. No differences were observed in limited surveys of fish populations that could be attributed to the spill. Fish were recruited to the breakwater kelp bed beginning in June 1977 and a resident population was apparently established without regard to oil in the area.

G. The Cabrillo Beach Area

1. The most serious impact on the beach community may have resulted from excessive sand removal in cleaning up the initial oil spill. Animals that were physically coated with the tarry material died. Intertidal and subtidal rocks were coated and killed barnacles, limpets, mussels and the algae-eating isopod *Ligia*. *Ligia* did not return. The beach and cobble area were barren until March, with gradual increases in species through November-December of 1977.

2. No dead birds were observed by the research team, although a few were reported by word of mouth, and some gulls had tarred feet. A variety of birds continued to feed in the shallows throughout the study.

H. Diver Surveys

1. Impact on invertebrates covered by the oil was total. Outside the area covered by the residual oil those benthic invertebrates that could be observed by divers did not seem to be affected by the spill. Cerianthid anemones, sea pens, geoducks and *Cancer* crabs were found adjacent to globs of oil on the bottom throughout the study. Poor visibility in the water in the spring precluded accurate comparative counts. The area in the ship channel was frequently disturbed by ship traffic prior to the spill, so would have been depauperate initially.

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Helicopter view of the Sansinena incident, December 1976

Note oil slicks and boom in upper center; bulk loading facility to lower left, boat yard to lower right.

Helicopter view of the Sansinena at Berth 46 following explosion, fire and Bunker C spill, December 1976.

MARINE STUDIES OF SAN PEDRO BAY, CALIFORNIA. PART 15. DECEMBER 1978

THE IMPACT OF THE *SANSINENA* EXPLOSION AND BUNKER C SPILL ON THE MARINE ENVIRONMENT OF OUTER LOS ANGELES HARBOR

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ABSTRACT. On December 17, 1976 the 70,000 ton tanker *Sansinena* exploded and burned in Los Angeles Harbor while refueling. The explosion and fire resulted in an estimated spill of 32,000 barrels of Bunker C fuel. Harbors Environmental Projects initiated studies on December 20 on the spread of the oil and its impact on biology and water quality at 24 stations. Prior studies by HEP at the site provided a baseline from 1972 to December 1976. Intertidal areas evidenced the greatest impact. Benthic population decreased greatly through April but returned to normal by November 1, 1977. Benthic organisms correlated best with oil and grease concentrations in bottom waters rather than in surface sediments, until November when hydrocarbons rose but no longer were correlated (toxic). Phytoplankton productivity dropped during the first two weeks but appeared to be recovered by January 1977. Zooplankton were affected by oil and grease in the water in April and July, but did not appear to be closely related in November 1977.

ACKNOWLEDGMENTS. Investigations were funded in part by a contract between Harbors Environmental Projects and the Union Oil Company, with assistance from rapid-response funds of the USC Sea Grant Program and HEP, both of the Institute for Marine and Coastal Studies, University of Southern California. Portions of this study are being published by the American Institute of Biological Science as Proceedings of the Conference on The Assessment of Ecological Impacts of Oil Spills, at Keystone, Colorado, June 14-17, 1978.

I. INTRODUCTION

The Sansinena Incident

The Sansinena, an 850 foot, 70,000 ton tanker of Liberian registry under charter to the Union Oil Company, exploded and burned at the dock at Berth 46 in outer Los Angeles Harbor at 19:40 hours on December 17, 1976 (Figure 1). The ship had apparently completed unloading 500,000 barrels of Indonesian light crude oil and had taken on 22,000 barrels of Bunker C fuel while ballasting under low clouds and foggy conditions, when an unknown incident caused the entire midship section to explode. The superstructure was hurled high into the air and crashed on the dock, behind the chicksans, rupturing valves and lines. An unknown quantity of crude and Bunker C flowed into the harbor beneath the dock and wreckage for several days. This caused intermittent backfiring on the dock, blazing up periodically (U.S. Coast Guard, 1977) after containment. An estimated 400 barrels of crude which had been residual in the cargo holds burned, along with that which leaked from the dock pipelines (Los Angeles Times, December 18, 1976; December 19, 1976). Flames shot 1,000 feet into the air at one time. The oil spread over the water and the Coast Guard estimated that most of the crude and some of the light fractions of Bunker C burned. However, the realization that the Bunker C would sink, especially if lighter fractions burned, caused revision of estimates of the amount of oil on the bottom. Oil that leaked under the dock and did not burn was trapped by the wreckage and pooled on the bottom 8-10 feet deep. Final estimates were a loss of from 20,000 to 32,000 barrels, but the actual amount will never be known. Diver and grab sampler surveys of the bottom led to the conclusion that globs of oil had also been blown laterally through the air and/or water to lie widely splattered across the soft silty bottom.

When the fire erupted at 19:40 hours, it was just past high tide (18:56 hours) and ebb tide would normally have carried the oil through the outer harbor and outside the breakwater. However, a southeast wind of 5-8 knots later helped to keep much of the floating oil in the southwest basin area. Low tide was at 23:54 hours on December 17, and booms were deployed by 02:00 hours on December 18. The next high tide was a maximum 6.6 feet at 6:21 hours, which tarred breakwaters, beaches and pilings up to 1.5 feet above higher high tide marks. There followed a week of extreme tides,with lows of minus 1.6 ft on December 20 and 21, and highs of 7.1 and 7.0 feet respectively, which coated intertidal areas severely.

The importance of having oil delivery systems located in well developed harbors was displayed in the Sansinena incident. The first Coast Guard boat arrived within five minutes, as did the first Los Angeles City Fire Department boat (U.S. Coast Guard, 1977). The powerful blast knocked in windows and doors of residences on the hillside behind Cabrillo Beach and in San Pedro, and the blast was heard more than 40 miles away. More than sixty fire units provided backup nearby in the harbor, where many oil and chemical tanks and lines are located.

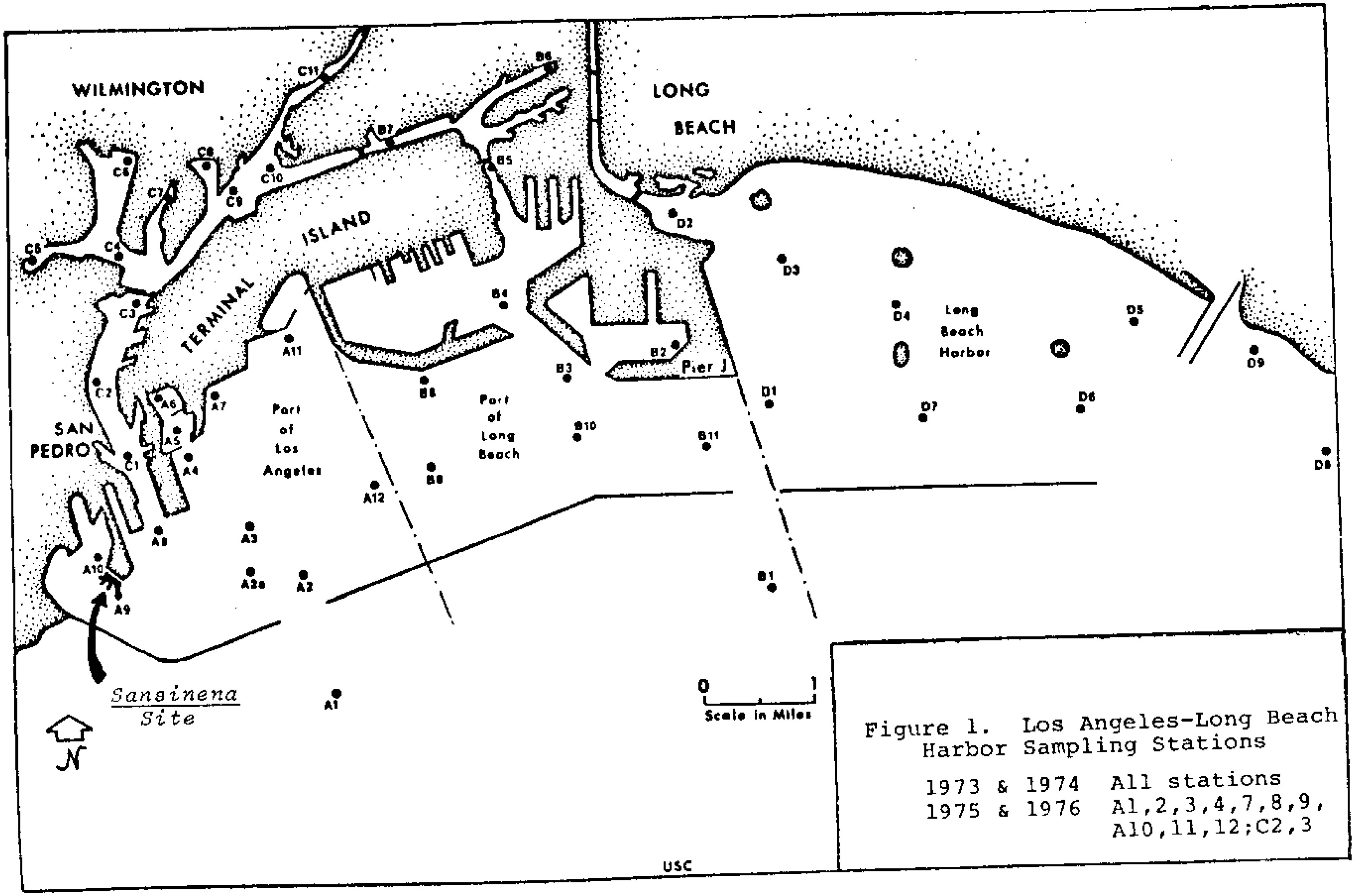


Figure 1. Los Angeles-Long Beach Harbor Sampling Stations

1973 & 1974 All stations
1975 & 1976 A1,2,3,4,7,8,9,
A10,11,12;C2,3

Prior Baseline Studies

Harbors Environmental Projects at the University of Southern California had carried out monitoring studies at a station (A9=U09) on the site of the explosion for six years prior to the Sansinena incident. The most recent samples had been taken on December 1, 1976, sixteen days before the explosion. Past biological studies in the area have included monthly primary productivity, chlorophyll *a* and assimilation ratios, microbials, zooplankton species and numbers, meroplankton/fouling fauna and sea birds. Benthic organisms were sampled quarterly; fish trawls were done occasionally. Monthly measurements also included physical parameters such as temperature, salinity, oxygen, pH and turbidity throughout the depth of the water column; nutrients were sampled at the surface. Sediment chemistry and grain size analyses were carried out. Table 1 summarizes the methods and references to techniques used.

Multivariate analysis (Smith, 1976) had been carried out on data from 1973 and 1974 (Allan Hancock Foundation, 1976) for the U.S. Army Corps of Engineers. Cooperative funding for the studies included the Corps of Engineers, the Pacific Lighting Corporation (Southern California Gas Company), the Port of Los Angeles and Port of Long Beach, the USC Sea Grant Program (NOAA, Department of Commerce), the Tuna Research Foundation, and others.

This data base appeared to offer the first opportunity to study the impact of Bunker C on the marine environment where prior conditions were known and the impact was confined to a reasonably well defined area. Although it would have been preferable to duplicate all procedures at the proposed impact stations, sufficient funds were not available. The study of the impact of the Sansinena on the marine environment was funded by the Union Oil Company, with assistance from the USC Sea Grant Program and Harbors Environmental Projects, of the Institute for Marine and Coastal Studies, University of Southern California. Preliminary results were presented at the Conference on Assessment of Ecological Impacts of Oil Spills, Keystone, Colorado in June 1978 (in press, American Institute of Biological Sciences).

Analytical Methods

Hierarchical classification was used to study patterns in the biological data. Groups of biologically similar sampling sites were defined, and these groups were then compared with the patterns in the measured environmental parameters. From this, hypotheses concerning the relationships between the biota and the environment were suggested. Of particular interest, of course, was whether parameters that were possibly related to the ship incident were actually correlated with the pattern or sample-site groupings.

Specifically, flexible sorting (B=-.25) strategy (Lance and Williams, 1967) and the Bray-Curtis distance index (Bray and Curtis, 1957; Clifford and Stephenson, 1975) were used to classify the sampling sites. The species counts in each sample were first transformed by a square root and standardized by a weighted species mean (Smith, 1976). The plankton counts were transformed by a square root and standardized by a species maximum.

Table 1. PARAMETERS MEASURED, LOS ANGELES-LONG BEACH HARBORS

A. MONTHLY MONITORING	METHOD
1. Abiotic Parameters	
a. Temperature b. Salinity c. Dissolved Oxygen d. pH	Martek electronic remote probe, at 1m intervals through the water column
e. Light transmittance	Hydroproducts Transmissometer, remote probe with self-contained light path, at 1m intervals through depth
f. Ammonia	Solorzano (1969)
g. Nitrite	Strickland and Parsons (1968)
h. Nitrate i. Phosphate	Modified Strickland and Parsons (AHF, 1976)
2. Biotic Parameters	
a. Biological Oxygen Demand (BOD)	Standard Methods (American Public Health, 1971) modified by Juge and Greist (1975), surface samples
b. Total Coliforms c. Fecal Coliforms d. Fecal Streptococcus	Millepore (1972), AHF (1976)
e. Bacterial Standard Plate Count	Amer. Soc. Microbiol. (1957); AHF (1976)
f. Primary Productivity, Phytoplankton	Modified Steeman-Neilsen (1952) ^{14}C light and dark bottles, standard light source incubator with ambient water temperature
g. Chlorophyll	Spectrophotometry, Strickland and Parsons (1968) equations
h. Assimilation ratio	
i. Zooplankton species	253u net surface tow with flow meter
j. Water column fouling fauna, larvae and juveniles	Glass microscope slides in wood frame rack, plastic screened, suspended at 3m depth

B. QUARTERLY MONITORING	METHOD
1. Abiotic Parameters	
a. Sediment grain size	Pettijohn (1957), Felix (1969), Gibbs (1971), AHF (1976)
b. Trace metals pesticides	Amer. Publ. Health (1971); AHF (1976)
2. Biotic Parameters	
a. Benthic Fauna	Campbell grab or Reinecke box corer, 0.5mm screen
b. Fish species	Otter trawl, gill netting
C. BIWEEKLY MONITORING (OUTER LOS ANGELES HARBOR ONLY)	
1. Abiotic Parameters	
a. Temperature b. Salinity c. Dissolved Oxygen d. pH	Martek electronic remote probe, at 1m intervals through the water column
e. Oil and Grease	Amer. Publ. Health (1971)
2. Biotic Parameters	
a. BOD	Standard Methods (Amer. Publ. Health, 1971) modified by Juge and Greist (1975), surface samples
D. WEEKLY (OUTER LOS ANGELES-LONG BEACH HARBORS) 1973-1974	
1. Biotic Parameters	
a. Bird census	Observations of nesting, resting, feeding and transit

To elucidate the relationships between the species and the sampling site groups defined in the classification, two-way coincidence tables were constructed (Kikkawa, 1968; Clifford and Stephenson, 1975). The numbers in the body of the table were 1) transformed and standardized as in the site classification analysis, and 2) converted to symbols, which are as follows:

*	> .75 to 1
+	> .5 to .75
-	> .25 to .50
.	> 0 to .25
blank	0

To study the relationships between the classification results and the measured environmental variables, bar graphs were constructed for each group on each variable. This showed the levels and variability of each environmental variable in the site groups. This technique has the weakness that it will not show the more complex multivariate (biotic-environmental) relationships. To test for the presence of such relationships, the groups were analyzed for correspondence with the environmental data using multiple discriminant analysis (Smith, 1976). Shannon-Weiner diversity indices were also calculated. Bar graphs presented show considerable overlap in some parameters; the multivariate method assigns coefficients to the parameters but does not imply statistical significances to them.

II. PHYSICAL EFFECTS OF THE SANSINENA BUNKER C SPILL

Oil and Grease Distribution

December, 1976. Surface sediment samples were taken in locations requested by the Union Oil Company in December, 1976 on the 22nd, 23rd, 24th, 27th, 28th, 29th and 30th of the month. Sampling was limited, and was hampered by the placement of booms and clean-up efforts. A small snapper grab on a hand line was used from a Boston Whaler. Analysis for total oil and grease was made in the USC Environmental Engineering Laboratory, directed by Dr. K.Y. Chen.

The measurements on December 22 and 23 showed little difference from expected normal levels in the sediment except where the oil pool near the stern yielded 665,000 ppm. A high reading of 7460 ppm beyond the bow section on December 24 indicated an unexpected spread in that direction, and on December 27 increases in the fairway channel to the east were found up to 6360 ppm.

A rapid increase in oil and grease levels was shown a few days later (Figure 2) in the area sampled, where values from 5,000 to above 7,000 ppm were found, particularly in depressions on the irregular bottom over a wider area. Readings in the area closer to the booms or "sea curtain" were actually lower than those in areas somewhat farther away. Oil and grease at the water surface ranged from 4.20 ppm at the innermost slip down to 0.10 near the main channel at the end of December (Figures 3-5).

January, 1977. In the water surface by mid-January, 1977 (Figures 6-8) some readings increased, with a high of 6.26 ppm at station U03. Bottom water concentrations were also higher in a number of locations. A Nauman sampler was used for taking water. Computer mapping of results is courtesy of John W. McDonald of the USC Geography Department. Values were rounded to the tenth ppm for computer analysis purposes. The oil and grease levels decreased in the sediments at most stations. Figure 9 offers a comparison, bearing in mind that sampling within the oil pool itself was not carried out. Sediment samples were taken as subcores from the benthic boxcores used to sample the fauna.

April, 1977. The stormy weather of the spring months and salvage of bow and stern sections of the tanker apparently combined to distribute oil anew throughout the area. The bow was towed to the scrap yard on February 18, 1977 and the stern was towed away April 18, 1977. Hull debris was subsequently cleaned up at the site. Oil and grease concentrations in the water column decreased greatly (Figures 10-12). This might represent a decline in leaching of residual oil into the water column, or it might reflect the tidal phase at the time of sampling. There were tidal highs of +5.4 ft on the 17th and 18th, the latter at the time of sampling. Efforts to vacuum up the pool of oil at the site continued throughout the summer of 1977.

Sediment oil and grease levels continued to increase at station U01, a dead end slip, and values were considerably higher at most sampling locations (Figure 13) than they had been in January. Rain fell throughout the first week of January and near the end of March; air temperature ranges were 79-90F (26-32C) during mid-January, for several days in February, and in March and April. This may also have affected the oil distribution patterns.

July, 1977. Concentrations of oil and grease in the water column (Figures 14-16) increased, however, and this could not readily be explained by tides. Inner harbor surface temperatures had risen about 1.5C, but temperatures at other stations were generally similar for April and July. Increased recreational boating could be responsible, and an upswing in bunkering operations in the outer harbor could also have increased the incidence of slicks. Certainly all of the oil cannot be attributed to the Sansinena. Analysis of some of the "chocolate mousse" on the beach indicated that it was probably not Sansinena oil (R.J. King, pers. comm.; Table 2).

Boxcore samples taken July 18, 1977 were sampled at the top, middle, and bottom of the sediment cores to obtain information on the depth of penetration of oil and grease into the sediment. Surface sediment levels had dropped from the April readings at most of the stations sampled. Penetration varied considerably, ranging from being almost uniform at station U01 to dropping by more than 50 percent from top to bottom of the cores at U019 and U021 (Figures 17-19). This might be related to grain size of sediment, which tends to be finest in the innermost slip areas (AHF, 1976) and is easily transported.

November, 1977. Harbors Environmental Projects sampled the stations again on November 1, 1977 after the conclusion on the Union Oil Company study. Concentrations in the top, middle, and bottom of the water column were higher at most stations (Figures 20-22). Oil and grease measurements were also made at the top, middle, and bottom of the boxcore samples (Figures 23-25). Increases in oil and grease levels occurred at all of the stations over the July readings, except for the shallow stations nearest the breakwater.

Figures 26 and 27 plot the ranges of oil and grease concentrations in the water column and sediment over the year's study. Although tidal action may affect concentrations in the water column during sampling, the rise in November parallels the increase in the sediment, apparently due to reconstruction activities.

Reconstruction of the pier involved pile driving and barge operations at the site. In spite of the clean-up efforts to remove the pool, it was impossible to remove all of the residue.

The jelly-like blobs that were initially scattered across the bottom weathered to some extent. However, on warm days tiny blobs would rise to the surface, where they dissolved in the sunlight into flat slicks. The vibration of the pile driver also caused blobs to rise to the surface. Weather in the 80-90°F range occurred into December, 1977.

April, 1978. The first ship to stop at the reconstructed dock did so as a test, with the U.S. Coast Guard and Los Angeles Harbor Department as observers. Due to propeller wash, an estimated two barrels of oil rose to the surface, which was boomed off for recovery. Since the pier is a public facility some 30 years old, under lease by the Harbor Department to Union Oil, it cannot be stated unequivocally that all oil accumulated in the vicinity of the pier was a result of the Sansinena incident. Oil slicks are not uncommon near Navy facilities (near station UO2), around the marinas (UO3), and at the boat launching ramp at Cabrillo Beach. However, the rising of small slicks strongly indicates that Bunker C residues are still mixed in the sediments in the area. This will remain a problem, for dredging the ship channel is planned, and any dredging method will resuspend and distribute residual oil.

Previous Data. Previous published records for the area are limited; no analyses had been done in the areas very close to Cabrillo Beach, so it is not possible to state that higher values did not occur in sediments deposited there prior to the blast. That is unlikely, however, since the highest values found in the harbor in 1973-1974 during a survey by Harbors Environmental Projects were in the 4000 ppm range found in the inner harbor blind-end slips and near an oil island in Long Beach. Values in the outer harbor vicinity of Berth 46 ranged from about 1800 to 2100 at the time (Figure 28).

More intensive sampling in Cerritos Channel (Long Beach) in March 1976 showed a few depositional areas with higher readings at the end of slips. This might be expected in areas of low flushing that have not been dredged for some years. Cerritos Channel values ranged from 660 to 4300 ppm. In Channel Two, the range was from 4370 to 6670 ppm (Figure 29).

In San Pedro Channel, the oil and grease levels recorded by Chen and Lu (1974) in the Channel and around Santa Catalina Island are of interest. Many of these were higher than harbor levels, even at boxcore depths of 30 cm. Levels increased with water depth, suggesting a downward movement along with the finer sediments to the 450m contour north of the island (Figure 30).

Final Survey of Sansinena Oil

During the year that elapsed after the Sansinena exploded, releasing quantities of Bunker C fuel and crude residue, cleanup operations were carried out. Information on the quantity of oil lost and the quantity recovered had not been released as of November, 1977. However, residual oil on the bottom was observed by various divers. A cooperative survey of the site was carried out on December 2, 1977, coordinated by Harbors Environmental Projects (HEP) of the University of Southern California, to determine the extent of bottom covered by the oil. Agencies which participated included the U.S. Coast Guard, U.S. Army Corps of Engineers, U.S. National Marine Fisheries Service, California Department of Fish and Game, Port of Los Angeles, Claremont Colleges, and the Institute of Marine and Coastal Studies of the University of Southern California.

Prior to the dive a series of eleven ¼ inch polypropropylene braided lines 800 ft long were prepared with buoys at either end to be anchored to the bottom by weights at 100 ft intervals. Forty numbered markers were placed at 20 ft. These were deployed on the morning of the dive to serve as markers for the transects the divers would follow. A few of the buoy lines on some of the transect lines could not be secured at the point nearest the pier. This resulted in some question as to the exact orientation of the ends of lines 7 through 11, nearest the dock, although the positions of buoys, as observed from the surface, were not considered to be excessively in error (Figure 31).

Despite the problems associated with the presence of a barge being used for construction at the site, all transects were occupied as indicated on the map and the work was successfully completed. Teams of two divers each were deployed by tender boats on the odd-numbered lines while two diver teams remained on board as observers. When the first teams completed their transects, the second teams surveyed the even-numbered transects while the first teams observed. Coast Guard patrol vessels protected divers and lines by intercepting boats that ignored dive flags and red buoys. Without this protection such a large-scale dive operation would have been impossible.

The data on oil distribution in the area and, where noted, the thickness of the oil layer are presented in Table 3. No oil was observed along transects 7, 10 and 11, and no oil was found in the shallow areas around the ship channel.

The most extensive bottom coverage was in the channel adjacent to the pier, in the area formerly occupied by the ship. Except on transect 5 the oil layer in this area seldom exceeded 1 inch in thickness. In the deep channel fairway southeast of the pier site, oil was spotty along transect 8, except for a deeper patch at the end of the transect farthest from the pier. Along transect 9, oil was found at most positions from 1 through 14, up to 10 inches in thickness. Construction activities had apparently caused oil globs to surface and spread. While the area was boomed, the boom was opened for barge changes. The tidal extremes in the first 10 days of December, 1977 may also have contributed to deposition of new oil on Cabrillo Beach and the breakwater. Information on the occurrence of animals at each transect was recorded for four transects, numbers 1, 3, 5, and 7. The data are summarized in Table 4.

The occurrence of benthic animals along these transects appeared to be inversely correlated with distance from the pier and, therefore, with the presence of oil on the bottom, although this trend was least apparent in the data for transect 1. It was not clear, however, if this trend was due to the presence of fewer animals or to the poorer visibility for diver observation which was found in the waters nearest the pier. The latter was the case for transect 5, according to the dive team. (For earlier diver observations, see Feldmeth in this volume).

Calculations were made on the amount of oil remaining on the bottom on the basis of the data obtained by the divers, as shown in Table 3. Assuming an area 1000 ft. long (the length of the pier) and 400 ft. wide (half of a transect) covered uniformly with 3/4 in. of oil (actual range 0 to 10") one could estimate that nearly 4500 barrels of oil remained on the sediments. This is considerably in excess of the 100 barrels or less estimated by the salvage operator at the conclusion of vacuum pumping.

Heavy rain during the last two weeks of December and minus low tides from December 8th to the 14th and the 24th to the 26th created a great deal of sediment redistribution in the harbor. Nearby Cabrillo Beach is known to lose several feet of sand in a single storm, which may in turn be re-deposited at a later date.

Attempts to resurvey the oil could not be completed until January, 1978. At that time HEP personnel made repeated dives near the end of transect 8, but were unable to find any trace of oil. Presumably the oil was buried or carried to deeper water. Department of Fish and Game personnel made 14 diver transects on January 25 and 26, 1978 in the area thought to be at the end of transect 8, where the pooled oil had been on December 2, 1977. They were unable to locate any oil and remarked that the area looked as though it had never been oiled.

The effects of residual Bunker C buried in the sediments made future harbor improvement difficult. An unnumbered drawing entitled "BERTH 45-47; MAINTENANCE DREDGING. DREDGING PLAN, PORT OF LOS ANGELES" included soundings on a 20' X 50' grid in the waters adjacent to the pier. Many of the soundings, extending southeast from the midpoint of the pier, showed depths in excess of -50 feet. That was the area that was most extensively covered with oil. It appeared that proposed maintenance dredging to -51 feet would not remove much of the oil adjacent to the pier and probably none of the deeper patches in the Deep Channel Fairway. However, hydraulic dredging would undoubtedly disturb some of the oil, possibly fouling the gear, the dredge material and the water.

Hydrocarbon Analysis

It was not within the scope of this study to carry out hydrocarbon chemistry analysis of the Bunker C fuel as it weathered on the harbor bottom, or coated organisms or was deposited on the beach.

However, a few specimens of organisms were assembled in pooled tissue samples and gas chromatographs were run at Analytical Research Laboratories, Inc. in Monrovia, California. The samples were not all processed at the same time on the same machine, but the method gives a precision of ± 5 units on the Kovats scale, according to Zsolnay, Maynard and Gebelein (1977).

Text Table 1 shows data on the fraction recovery for the various species. The *Mytilus* collected in December 1976 had the highest aromatics content, followed by mixed crabs collected in June, and mixed clams and mussels collected in November. These data are compared with analysis of Bunker C residue weathered for nearly one year. The gas chromatogram of *Mytilus* appeared almost identical to the Bunker C residue pattern.

Text Table 1. Hydrocarbons in Invertebrate Tissues.

Date	Fraction Recovery: Sample	Paraffin Hexane	Aromatic Benzene
12/31/76 Cabrillo Beach	Octopus	0.0005	0.0009
	Mussels *(Mytilus)*	0.0014	0.0054
	Mixed clams	0.0004	0.0007
	Tivela stultorum	0.0003	0.0000
6/29/77 Cabrillo Fishing pier	Mixed crabs	0.0006	0.0031
	Scallops *(Hinnites multirugosus)*	0.0006	0.0004
10/13/77 Cabrillo Beach	Dying *Ulva* (seaweed)	-0-	-0-
	Healthy *Ulva*	-0-	0.0001
11/15/77 Cabrillo Beach	Mixed Clams and Mussels	0.0007	0.0025
12/2/77 55 ft. depth Ship Channel	Bunker C residue	0.0021	0.0072

Experimental Hydrocarbon Study

A supplementary field study was carried out to determine what the interaction of the sediment-water interface might be, if circulation was restricted. Three hemi-cylindrical chambers of plexiglass (Text Figure 1) with sampling ports, commonly used to determine sediment oxygen demand, were placed at three locations beside the ship channel at the Sansinena site (Figure 32).

On June 8, 1977 Dissolved Oxygen (DO) as determined by Martek remote probe analyzer, was 8.40 ppm at the surface and 6.70 ppm at 1m above the bottom when the chambers were placed on sites A (U09), B, and C (U06).

After 16 days the DO was measured in two chambers by taking samples through the ports for Winkler titration. Unfortunately the sampler at C had been overturned. Surface and bottom water was also sampled for Winkler titrations of dissolved oxygen, and for total oil and grease concentrations.

The dissolved oxygen occurring within the two chambers was 69% and 52% respectively of that in the water column at one meter above the bottom. This could be caused by chemical oxygen demand (COD) or biological oxygen demand (BOD) due to microbial breakdown of the organics (Text Table 2).

Oil and grease apparently was still leaching from the sediment in June as indicated by concentrations of about 2.5 times those in the water column at one meter above the bottom at sites A and B.

Repetition of this experiment in August showed almost 2 times the concentration in the chamber at site A (U09) as in the water column, but site C showed almost no difference; B chamber had been overturned. This study was discontinued, due to the disturbances by ship traffic.

Physical Parameters

Data on salinity, temperature, dissolved oxygen, pH and turbidity (as percent light transmittance) were collected monthly at the stations where oil and grease and biological samples were taken. Use of remote probe-packs allows for profiling the water column to note variations both horizontally and vertically. The data are presented in Appendix A.

To gain some perspective on the water column conditions during the Sansinena study, from December 1976 to November 1977, data from December 1975 and January 1976 can be examined (Table 5).

It is important to note that the water temperatures were considerably cooler in December 1975 (13C surface to 12.8C bottom) and January 1976 (11.7C surface to 10.2C bottom) than they were after the spill on December 29, 1976 (17C to 16.6C at A9). Temperatures rose slightly in January, 1977 (18.2C), and remained relatively warm through April. Thus the 1976-1977 thermal regime can be considered warmer than usual for the winter period. It is more normal to find temperatures of 11-13C in January, followed by a gradual spring rise. Sometimes a sharp drop will also occur in April or May due to marine overcast, and then a rise to summer temperatures follows. (See Soule and Oguri 1974 and 1976 for comparisons, and Appendix A, this volume.)

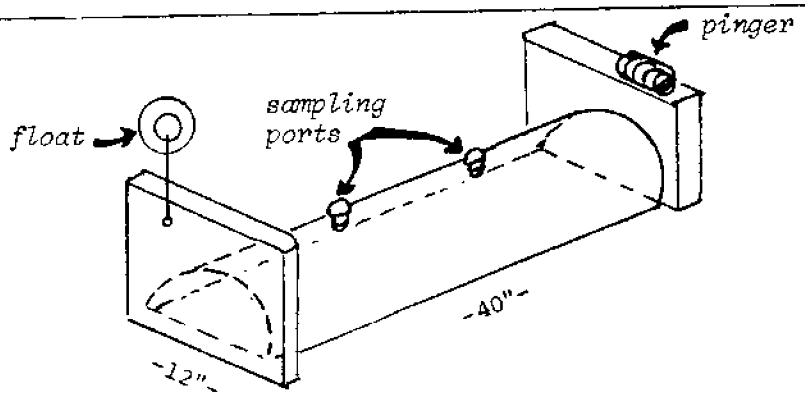
Text Table 2. UNION OIL - Benthic Oxygen Chamber Study

Chambers set: 8 June 1977;
Retrieved: 26 June 1977; 24 August 1977

Location: (see Figure 32)

CHAMBER LOCATION		DISSOLVED OXYGEN*		OIL AND GREASE**	
		6/8/77		6/26/77	8/24/77
	Study Site	surface	8.40#		
		1M above bottom	6.70#		
		6/26/77			
A	L.A. Harbor Sta. A9	surface	6.50	0.78	1.21
		1M above bottom	6.20	0.88	0.33
		inside chamber	4.30	1.98	0.65
B	Mid-point between A9 and Black buoy #3	surface	6.60	1.07	
		1M above bottom	6.50	0.48	
		inside chamber	3.40	1.18	
C	Black buoy #3	surface	6.70	0.45	0.67
		1M above bottom	6.30	0.63	0.11
		inside chamber	no data ##		0.12

Legend, Text Table 2.
* Dissolved Oxygen determined by Winkler titration, except as marked #
\# D.O.s determined by Martek Water Quality Analyser
\#\# Chamber found overturned



TEXT FIGURE 1. BENTHIC CHAMBER

Table 2. Hydrocarbons present in Cabrillo Beach "Brown Scum."

Identification	Total Alkanes	Pristane C17	Pristane Phytane	Normal Branched
Water-Seawater Cabrillo Beach 4-21	<1	-	-	-
Water-Seawater Cabrillo Beach 4-21	<1	-	-	-
Sand-Cabrillo Beach 4-21	3520	2.13	5.0	0.8
Sand-Cabrillo Beach 4-21	92	0.5	1.6	0.26

Identification	Aromatic Total	Phenan-threne	Naph-thalene	Methyl Naph-thalene	Dimethyl Naph-thalene	Naph-thalene Phenan-threne
Water-Seawater Cabrillo Beach 4-21	<1	-	-	-	-	-
Water-Seawater Cabrillo Beach 4-21	<1	-	-	-	-	-
Sand-Cabrillo Beach 4-21	266	12	4.5	73	177	0.38
Sand-Cabrillo Beach 4-21	0.42	0.02	0.11	0.19	0.1	5.5

* Infinite
water -µg/l
soil - sediment - µg/g

Table 3. Oil distribution and thickness near Berths 45-47, Port of Los Angeles. December 2, 1977.

Tr.	1	2	3	4	5	6	7	8	9	10	11
1	+	+	++	0	+++ 2	++ 1	None	+	0	None	None
2	+	+	++	0	+++ 2	++ 1		+	+		
3	0	+	++	++++ 1	+++ 4	++ 1		0	+		
4	0	+	++	++++ 1	+++ 6	++ 1		0	++ 6		
5	0	+++ 1"	0	0	+++ 3	++ 1		0	+		
6	0	+	+++ 3	0	++ 1½	++ 1		0	+		
7	0	0	++	++++ 1	++ 1½	0		+	++ 1		
8	0	0	++	++++ 1	+++ 1	0		0	+++ 6		
9	0	0	0	0	++ ½	0		0	+++ 6		
10	0	0	0	0	++ 1½	0		+	+++ 6		
11	0	0	0	++++ 1½	++ 3	0		+	+ ½		
12	0	0	0	++++ 1	++ 3	0		+	0		
13	0	0	0	0	++ 3	0		0	+++ 10		
14	0	0	0	0	++ 2	0		0	+++ 9		
15	0	0	++	++++ ½	++ ½	0		0	0		
16	0	0	0	++++ ½	++ ½	0		0	0		
17	0	0	0	0	++ ½	0		0	0		
18	0	0	++	+++ 2	+	0		0	0		
19	0	0	0	0	+	0		0	0		
20	0	0	0	0	0	0		+	0		
21	0	0	0	0	0	0		0	0		
22	0	0	0	0	0	0		0	0		
23	0	0	0	0	0	0		+	0		
24	0	0	0	0	0	0		0	0		
25	0	0	0	0	0	0		0	0		
26	0	0	0	0	0	0		+	0		
27	0	0	0	0	0	0		0	0		
28	0	0	0	0	0	0		0	0		
29	0	0	0	0	0	0		0	0		
30	0	0	0	0	0	0		0	0		
31	0	0	0	0	0	0		0	0		
32	0	0	0	0	0	0		+	0		
33	0	0	0	0	0	0		+ 6	0		
34	0	0	0	0	0	0		0	0		
35	0	0	0	0	0	0		0	0		
36	0	0	0	0	0	0		0	0		
37	0	0	0	0	0	0		+	0		
38	0	0	0	0	0	0		+++ 6	0		
39	0	0	0	0	0	0		++++	0		
40	0	0	0	0	0	0		++++	0		

Legend:		
0 or no entry	-	no oil reported
+	-	trace or splotch
++	-	globule
+++	-	patch or pool
++++	-	extensive cover

Number following is the thickness of the oil in inches, where noted.

Table 4. Animals observed along transects 1, 3, 5 and 7. The identities reported are those of the divers. The number following is the number of observations in the inclusive positions.

Positions	Transect			
	1	3	5	7
1-10	*Cancer*-1 *Cerianthus*-2 *Mytilus*-2	*Cerianthus*-1	(poor visibility)	*Cancer*-1
11-20	*Cerianthus*-1 *Gorgonian*-1 *Pisaster*-1 Sea pen-2	*Cerianthus*-4	(poor visibility)	*Cancer*-1
21-30	*Cerianthus*-2 Sea pen-10	*Cerianthus*-5 Piddock-7	Bacterial patches-7 Cerianthidae-4 Clams-4 Sea pen-4 On rock pile 27-29 Barred sand bass Bryozoa (2 spp) *Lophogorgia chilensis* *Muricea californica*	*Cerianthus*-2 *Panope*-1
31-40	Sea pen-10	*Cerianthus*-10 *Gorgonian*-1 Ponnatalid-2 Piddock-10	Barred sand bass-1 Cerianthidae-10 Clams-10 Sea pen-10	*Cerianthus*-4 *Panope*-2

TABLE 5. PRE-EXPLOSION FIELD DATA

DATE: DECEMBER 09, 1975 TIME: 0959

STATION: A9 CABRILLO BEACH 525Y SSW BERTH 47

DEPTH		TEMPERATURE		SALINITY	D.02	PH	TURBIDITY
METERS/FEET		°C	°F	0/00	PPM	H ION CONC	% TRANS
00	0.0	13.00	55.40	33.80	2.60	8.44	72.00
01	3.28	13.00	55.40	33.75	2.20	8.45	73.00
02	6.56	13.00	55.40	33.75	2.60	8.49	78.50
03	9.84	13.00	55.40	33.75	2.50	8.55	81.00
04	13.12	13.00	55.40	33.75	2.70	8.57	82.00
05	16.40	12.90	55.22	33.75	2.80	8.55	80.00
06	19.68	12.90	55.22	33.75	2.80	8.55	72.00
07	22.96	12.80	55.04	33.80	2.50	8.55	75.00
08	26.24	12.80	55.04	33.80	2.60	8.61	80.00

DATE: JANUARY 07, 1976 TIME: 0909

STATION: A9 CABRILLO BEACH 525Y SSW BERTH 47

DEPTH		TEMPERATURE		SALINITY	D.02	PH	TURBIDITY
METERS/FEET		°C	°F	0/00	PPM	H ION CONC	% TRANS
00	0.0	11.70	53.06	32.40	7.60	7.94	87.50
01	3.28	11.60	52.88	32.40	7.40	7.94	87.50
02	6.56	11.40	52.52	32.40	7.30	7.95	88.00
03	9.84	11.30	52.34	32.40	7.40	7.95	88.00
04	13.12	10.80	51.44	32.40	7.30	7.95	87.50
05	16.40	10.60	51.08	32.40	7.30	7.95	87.50
06	19.68	10.60	51.08	32.35	7.30	7.95	87.50
07	22.96	10.30	50.54	32.35	7.30	7.95	87.50
08	26.24	10.20	50.36	32.30	7.30	7.95	87.50
09	29.52	10.20	50.36	32.30	7.30	7.95	87.50
10	36.80	10.20	50.36	32.30	7.30	7.95	87.50
11	36.08	10.20	50.36	32.30	7.30	7.95	87.50
12	39.36	10.20	50.36	32.30	7.10	7.93	87.00

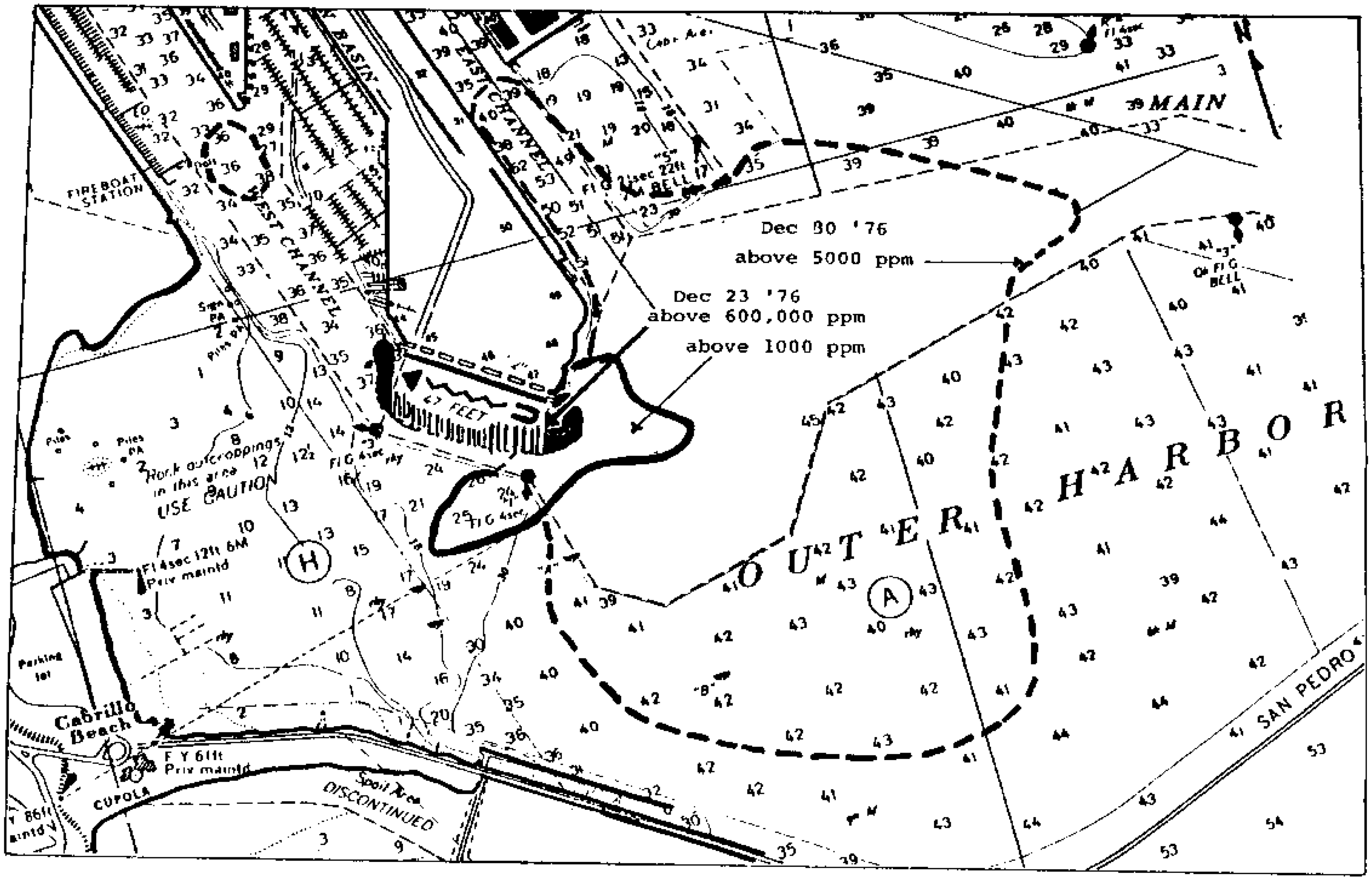


Figure 2. Spread of Oil and Grease in Sediment (sample area restricted by booms).

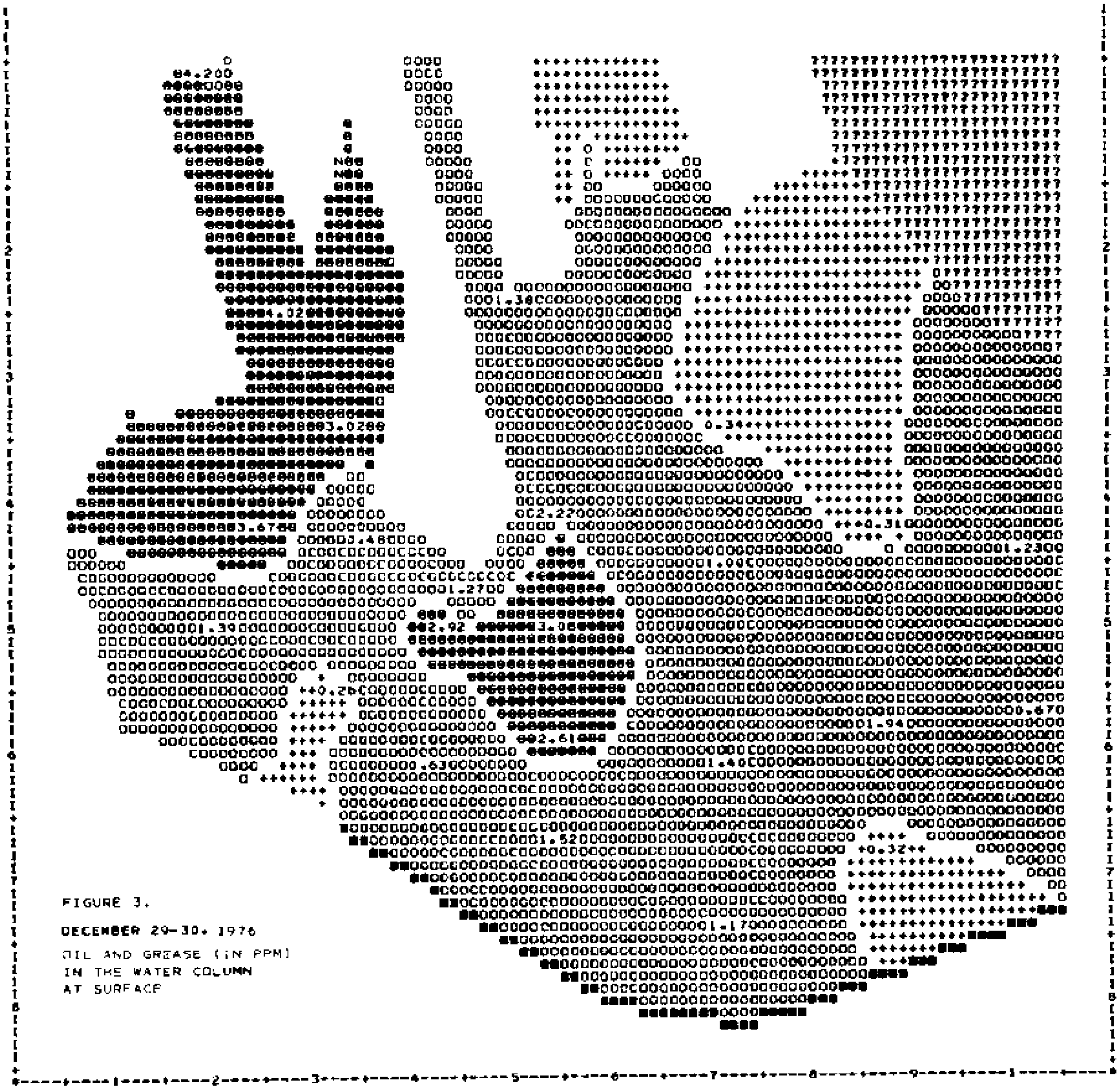


FIGURE 3.

DECEMBER 29-30, 1976

OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
AT SURFACE

```
 SYMAP
10.931195 MINUTES FOR MAP


DECEMBER 29-30, 1976
NUMBERS EXPRESSED IN PPM--WATER SURFACE
    3            10.0



DATA VALUE EXTREMES ARE          0.26          4.20



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
        ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

   MINIMUM        0.0        0.04       0.45       2.23       4.47
   MAXIMUM        0.04       0.45       2.23       4.47       6.70


PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

                  0.67       6.00      26.67      33.33      33.33


FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
   LEVEL             1          2          3          4          5
              ========================================================
               .........  +++++++++ OOOOOOOOO ●●●●●●●●● ■■■■■■■■■
               .........  +++++++++ OOOOOOOOO ●●●●●●●●● ■■■■■■■■■
   SYMBOLS     ....1....  ++++2++++ OOOO3OOOO ●●●●4●●●● ■■■■5■■■■
               .........  +++++++++ OOOOOOOOO ●●●●●●●●● ■■■■■■■■■
               .........  +++++++++ OOOOOOOOO ●●●●●●●●● ■■■■■■■■■
              ========================================================
   FREQ.             0          4         13          7          0
         1                  I++2++I    IOO3OOI    I●●4●●I
         2                  I++2++I    IOO3OOI    I●●4●●I
         3                  I++2++I    IOO3OOI    I●●4●●I
         4                  I++2++I    IOO3OOI    I●●4●●I
         5                             IOO3OOI    I●●4●●I
         6                             IOO3OOI    I●●4●●I
         7                             IOO3OOI    I●●4●●I
         8                             IOO3OOI
         9                             IOO3OOI
        10                             IOO3OOI
        11                             IOO3OOI
        12                             IOO3OOI
```

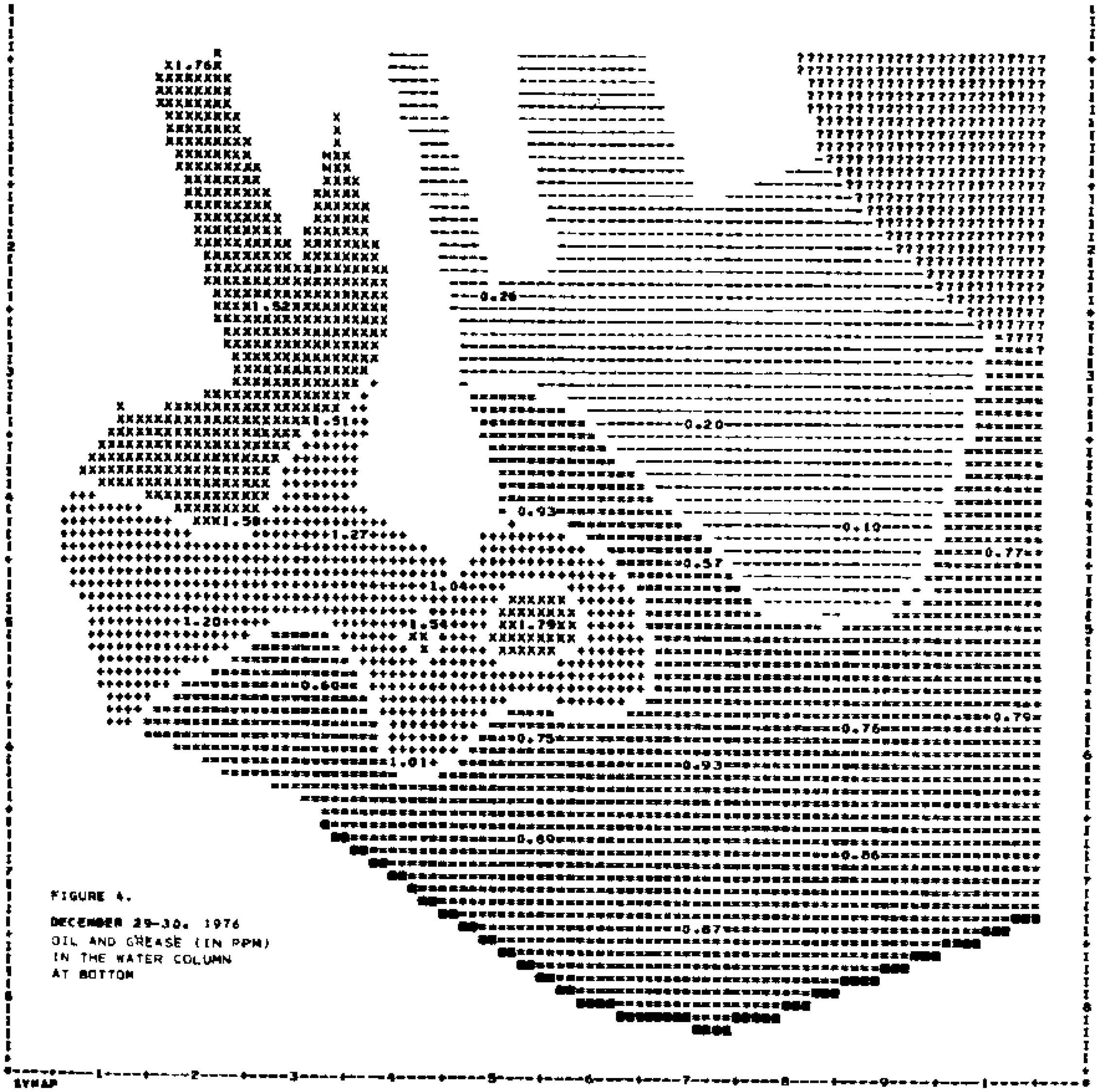
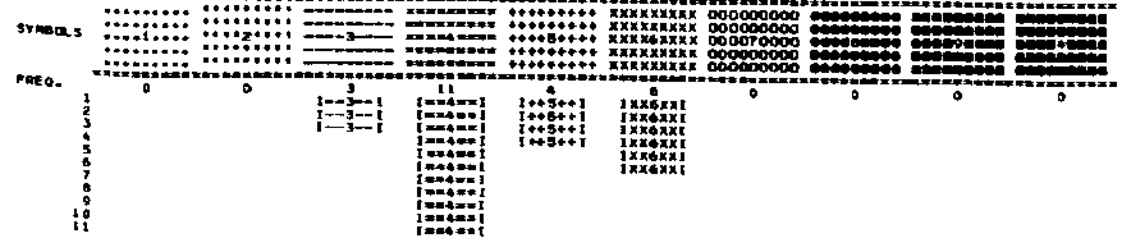


FIGURE 4.

DECEMBER 29-30, 1976
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
AT BOTTOM

```
10.841864 MINUTES FOR MAP


DECEMBER 29-30, 1976
OIL AND GREASE

NUMBERS EXPRESSED IN PPM -- IN WATER COLUMN AT BOTTOM


DATA VALUE EXTREMES ARE          0.10        1.79


ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM      0.0      0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00
  MAXIMUM      0.01     0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00      6.70

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

               0.15     1.34      5.97      7.46      7.46      7.46     14.93     14.93     14.93     25.37
```

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL



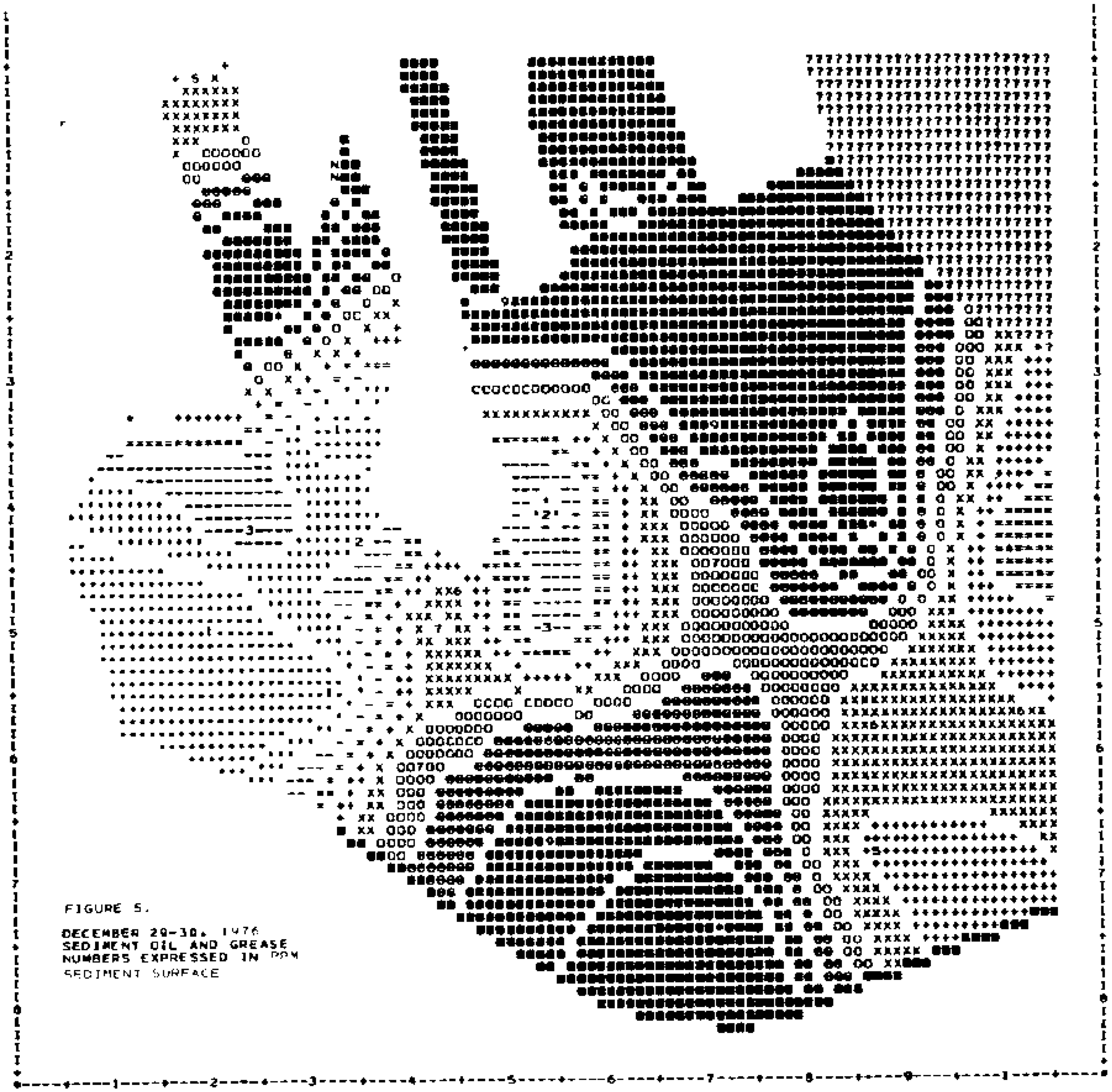


FIGURE 5.

DECEMBER 29-30, 1976
SEDIMENT OIL AND GREASE
NUMBERS EXPRESSED IN PPM
SEDIMENT SURFACE

```
SYMAP
12.024994 MINUTES FOR MAP


DECEMBER 29-30, 1976
SEDIMENT OIL AND GREASE
NUMBERS EXPRESSED IN PPM SEDIMENT SURFACE


DATA VALUE EXTREMES ARE        325.00      7290.00


ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
       ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

 MINIMUM    325.00   1021.50   1718.00   2414.50   3111.00   3807.50   4504.00   5200.50   5897.00   6593.50
 MAXIMUM   1021.50   1718.00   2414.50   3111.00   3807.50   4504.00   5200.50   5897.00   6593.50   7290.00


PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

             10.00     10.00     10.00     10.00     10.00     10.00     10.00     10.00     10.00     10.00


FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL        1         2         3         4         5         6         7         8         9        10
          ==========================================================================================================
            .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ■■■■■■■■■  ■■■■■■■■■  ■■■■■■■■■
            .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ■■■■■■■■■  ■■■■■■■■■  ■■■■■■■■■
 SYMBOLS    ....1....  ''''2''''  ----3----  ====4====  ++++5++++  XXXX6XXXX  OOOO7OOOO  ■■■■8■■■■  ■■■■9■■■■  ■■■■+■■■■
            .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ■■■■■■■■■  ■■■■■■■■■  ■■■■■■■■■
            .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ■■■■■■■■■  ■■■■■■■■■  ■■■■■■■■■
          ==========================================================================================================
 FREQ.         3         2         2         1         2         3         3         2         3         3
          1  I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   IOO7OOI   I■■8■■I   I■■9■■I   I■■+■■I
          2  I..I..I   I''2''I   I--3--I             I++5++I   IXX6XXI   IOO7OOI   I■■8■■I   I■■9■■I   I■■+■■I
          3  I..I..I                                           IXX6XXI   IOO7OOI             I■■9■■I   I■■+■■I
```

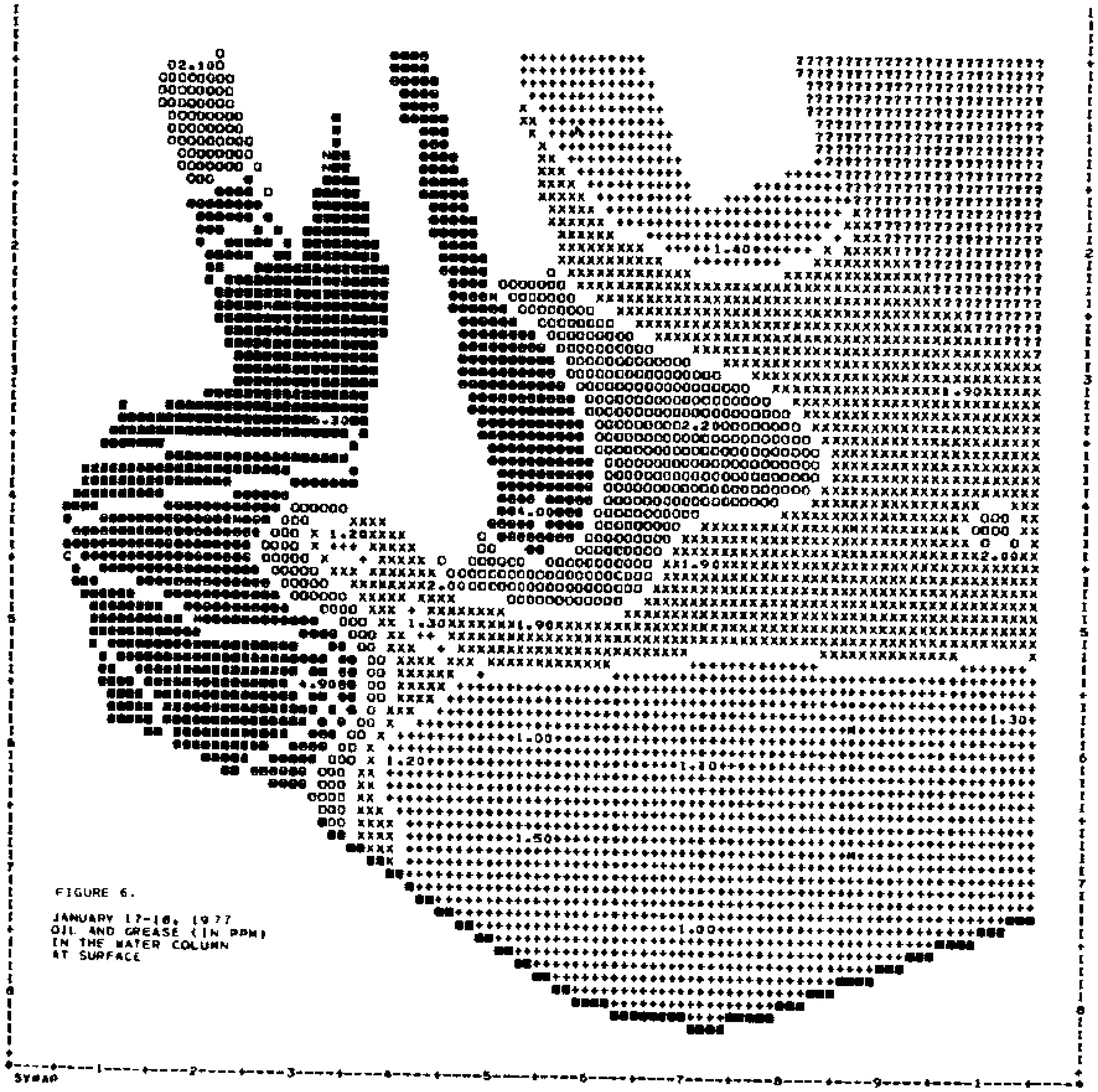


FIGURE 6.

JANUARY 17-18, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
AT SURFACE

```
11.794060 MINUTES FOR MAP


JANUARY 17-18, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN (SURFACE)


DATA VALUE EXTREMES ARE          1.00        6.30


TOTAL MISSING DATA POINTS IS          7


ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

 MINIMUM     0.0       0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00
 MAXIMUM     0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00      6.70

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

             0.15      1.34      5.97      7.46      7.46      7.46      14.93     14.93     14.93     25.37

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL         1         2         3         4         5         6         7         8         9         10
          ************************************************************************************************
 SYMBOLS  .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000  @@@@@@@@@  █████████  █████████
          .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000  @@@@@@@@@  █████████  █████████
          ....1....  ''''2''''  ----3----  ====4====  ++++5++++  XXXX6XXXX  000070000  @@@@8@@@@  ████9████  ████+████
          .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000  @@@@@@@@@  █████████  █████████
          .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000  @@@@@@@@@  █████████  █████████
 FREQ.    ************************************************************************************************
    1          0         0         0         0         8         4         4         0         2         1
    2                                               I++5++I   IXX6XXI   I00700I             I██9██I   I██+██I
    3                                               I++5++I   IXX6XXI   I00700I             I██9██I
    4                                               I++5++I   IXX6XXI   I00700I
    5                                               I++5++I   IXX6XXI   I00700I
    6                                               I++5++I
    7                                               I++5++I
    8                                               I++5++I
                                                    *******
```

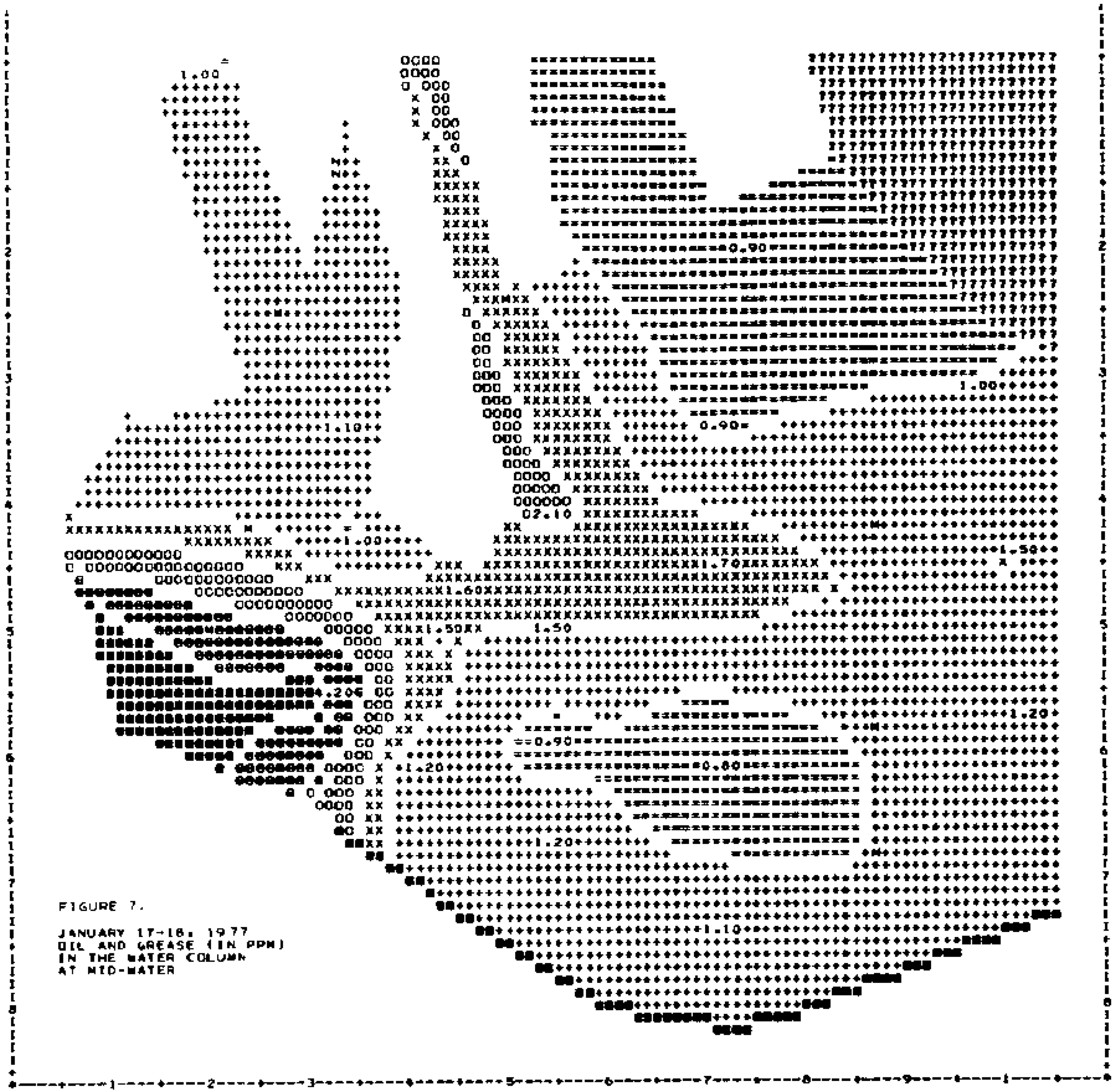


FIGURE 7.

JANUARY 17-18, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
AT MID-WATER

```
 SYMAP

10.850690 MINUTES FOR MAP


JANUARY 17-18, 1977

OIL AND GREASE (IN PPM)

IN THE WATER COLUMN (MID-WATER)



DATA VALUE EXTREMES ARE          0.80         4.20



TOTAL MISSING DATA POINTS IS          7



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM       0.0        0.01       0.10       0.50       1.00       1.50       2.00       3.00       4.00       5.00
  MAXIMUM       0.01       0.10       0.50       1.00       1.50       2.00       3.00       4.00       5.00       6.70


PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

                0.15       1.34       5.97       7.46       7.46       7.46      14.93      14.93      14.93      25.37


FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL            1          2          3          4          5          6          7          8          9         10
           ==========================================================================================================
            .........  ''''''''' ---------  ========= +++++++++ XXXXXXXXX 000000000 ████████ █████████ █████████
            .........  ''''''''' ---------  ========= +++++++++ XXXXXXXXX 000000000 ████████ █████████ █████████
  SYMBOLS   ....1....  ''''2'''' ----3----  ====4==== ++++5++++ XXXX6XXXX 000070000 ████8████ ████9████ ████10███
            .........  ''''''''' ---------  ========= +++++++++ XXXXXXXXX 000000000 ████████ █████████ █████████
            .........  ''''''''' ---------  ========= +++++++++ XXXXXXXXX 000000000 ████████ █████████ █████████
           ==========================================================================================================

  FREQ.            0          0          0          4          8          5          1          0          1          0
         1                              I==4==I    I++5++I    IXX6XXI    I0070OI              I██9██I
         2                              I==4==I    I++5++I    IXX6XXI
         3                              I==4==I    I++5++I    IXX6XXI
         4                              I==4==I    I++5++I    IXX6XXI
         5                                         I++5++I    IXX6XXI
         6                                         I++5++I
         7                                         I++5++I
```

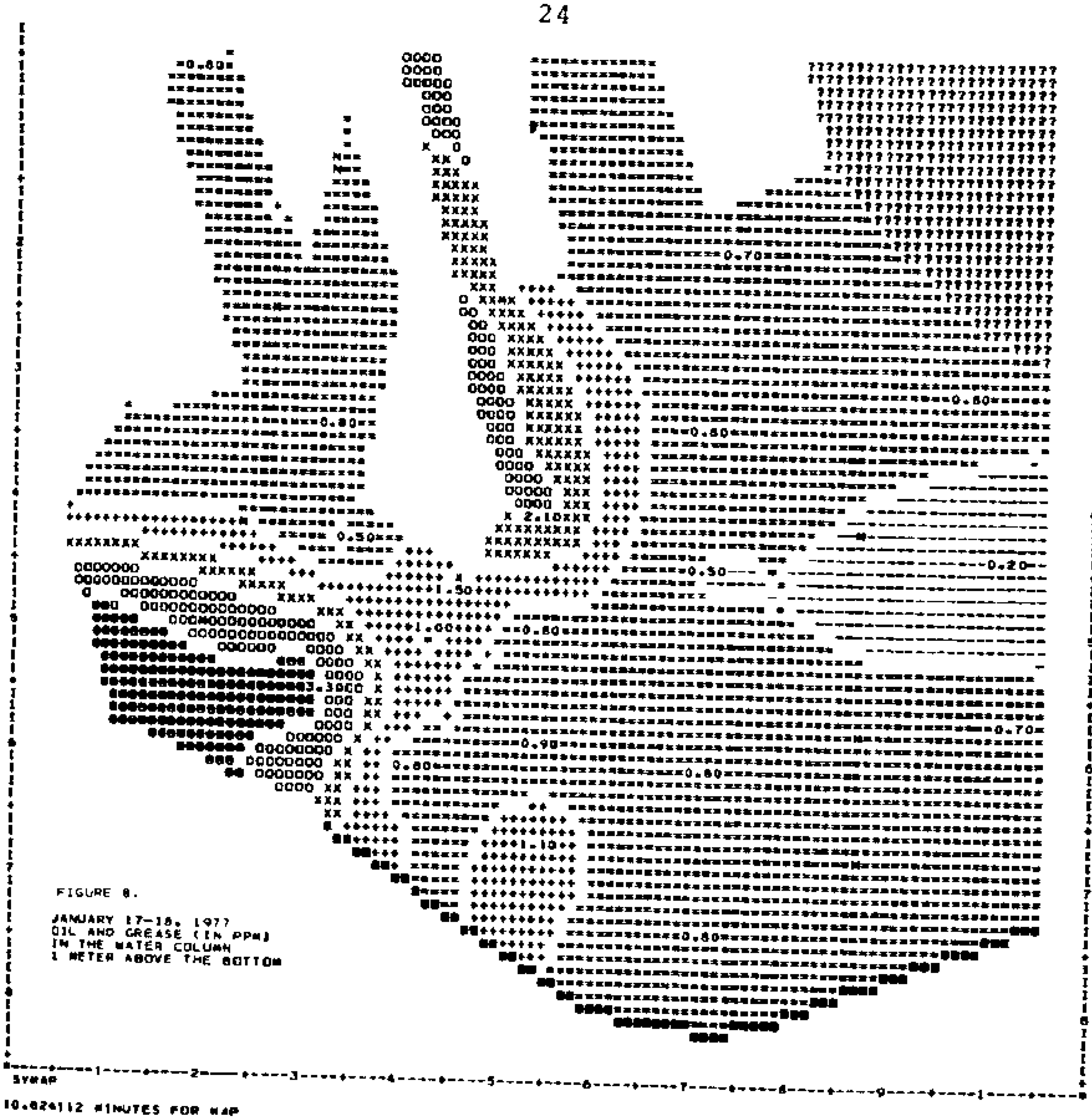


FIGURE 8.

JANUARY 17-18, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
1 METER ABOVE THE BOTTOM

```
10.824112 MINUTES FOR MAP


JANUARY 17-18, 1977

OIL AND GREASE (IN PPM) IN THE WATER COLUMN

1 METER ABOVE THE BOTTOM



DATA VALUE EXTREMES ARE          0.20         3.30



TOTAL MISSING DATA POINTS IS          7



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
        ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM      0.0      0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00
  MAXIMUM      0.01     0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00      6.70

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

               0.15     1.34      5.97      7.46      7.46      7.46     14.93     14.93     14.93     25.37

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL        1         2         3         4         5         6         7         8         9         10
          ************************************************************************************************
           .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO
  SYMBOLS  .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO
           ....1....  ''''2''''  ----3----  ====4====  ++++5++++  XXXX6XXXX  OOOO7OOOO
           .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO
           .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO
  FREQ.   ************************************************************************************************
               0         0         1         13        2         1         1         1         0         0
      1                          I--3--I   I==4==I   I++5++I   IXX6XXI   IOO7OOI   I●●●●●I
      2                                    I==4==I   I++5++I
      3                                    I==4==I
      4                                    I==4==I
      5                                    I==4==I
      6                                    I==4==I
      7                                    I==4==I
      8                                    I==4==I
      9                                    I==4==I
     10                                    I==4==I
     11                                    I==4==I
     12                                    I==4==I
     13                                    I==4==I
```

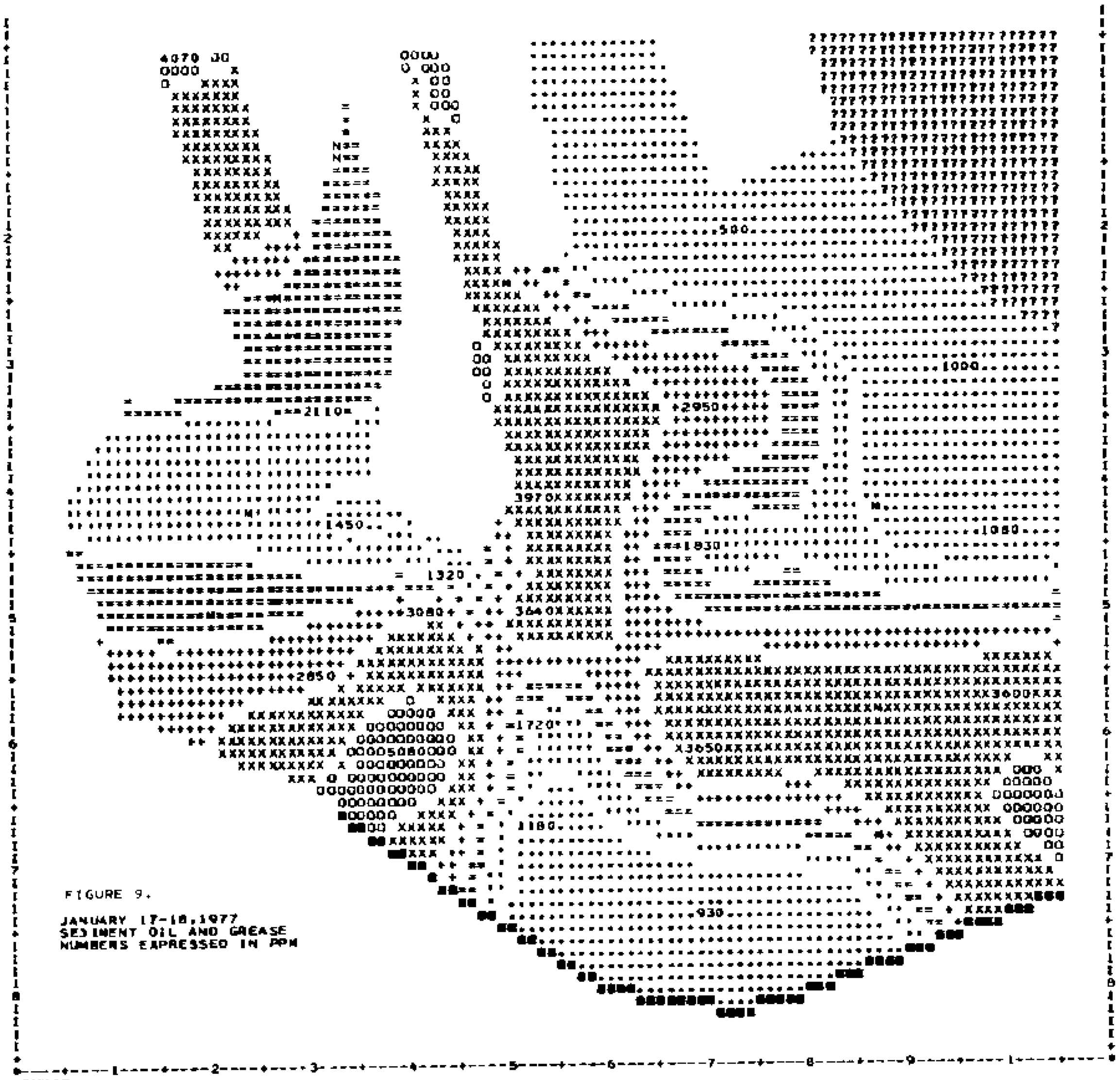


FIGURE 9.

JANUARY 17-18,1977
SEDIMENT OIL AND GREASE
NUMBERS EXPRESSED IN PPM

```
(0.22885) MINUTES FOR MAP


JANUARY 17-18,1977

SEDIMENT OIL AND GREASE

NUMBERS EXPRESSED IN PPM



DATA VALUE EXTREMES ARE        500.00      5080.00




TOTAL MISSING DATA POINTS IS          7




ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
       ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM       0.0     1600.00    2000.00    2500.00    3000.00    4000.00    6000.00    8000.00   10000.00
  MAXIMUM   1600.00     2000.00    2500.00    3000.00    4000.00    6000.00    8000.00   10000.00   11027.00


PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

             14.51       3.63       4.53       4.53       9.07      18.14      18.14      18.14       9.31


FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL         1          2          3          4          5          6          7          8          9
            ==========================================================================================
             .........  '''''''''  ========= +++++++++ XXXXXXXXX 000000000 @@@@@@@@@ ######### ▉▉▉▉▉▉▉▉▉
             .........  '''''''''  ========= +++++++++ XXXXXXXXX 000000000 @@@@@@@@@ ######### ▉▉▉▉▉▉▉▉▉
             .........  ''''2''''  ====3==== ++++4++++ XXXX5XXXX 000060000 @@@@7@@@@ ####8#### ▉▉▉▉9▉▉▉▉
  SYMBOLS    ....1....  '''''''''  ========= +++++++++ XXXXXXXXX 000000000 @@@@@@@@@ ######### ▉▉▉▉▉▉▉▉▉
             .........  '''''''''  ========= +++++++++ XXXXXXXXX 000000000 @@@@@@@@@ ######### ▉▉▉▉▉▉▉▉▉
             .........
            ==========================================================================================
  FREQ.         7          2          1          2          5          2          0          0          0
          1  I..I..I    I''2''I    I==3==I    I++4++I    IXX5XXI    I00600I
          2  I..I..I    I''2''I               I++4++I    IXX5XXI    I00600I
          3  I..I..I                                     IXX5XXI
          4  I..I..I                                     IXX5XXI
          5  I..I..I                                     IXX5XXI
          6  I..I..I
          7  I..I..I
```

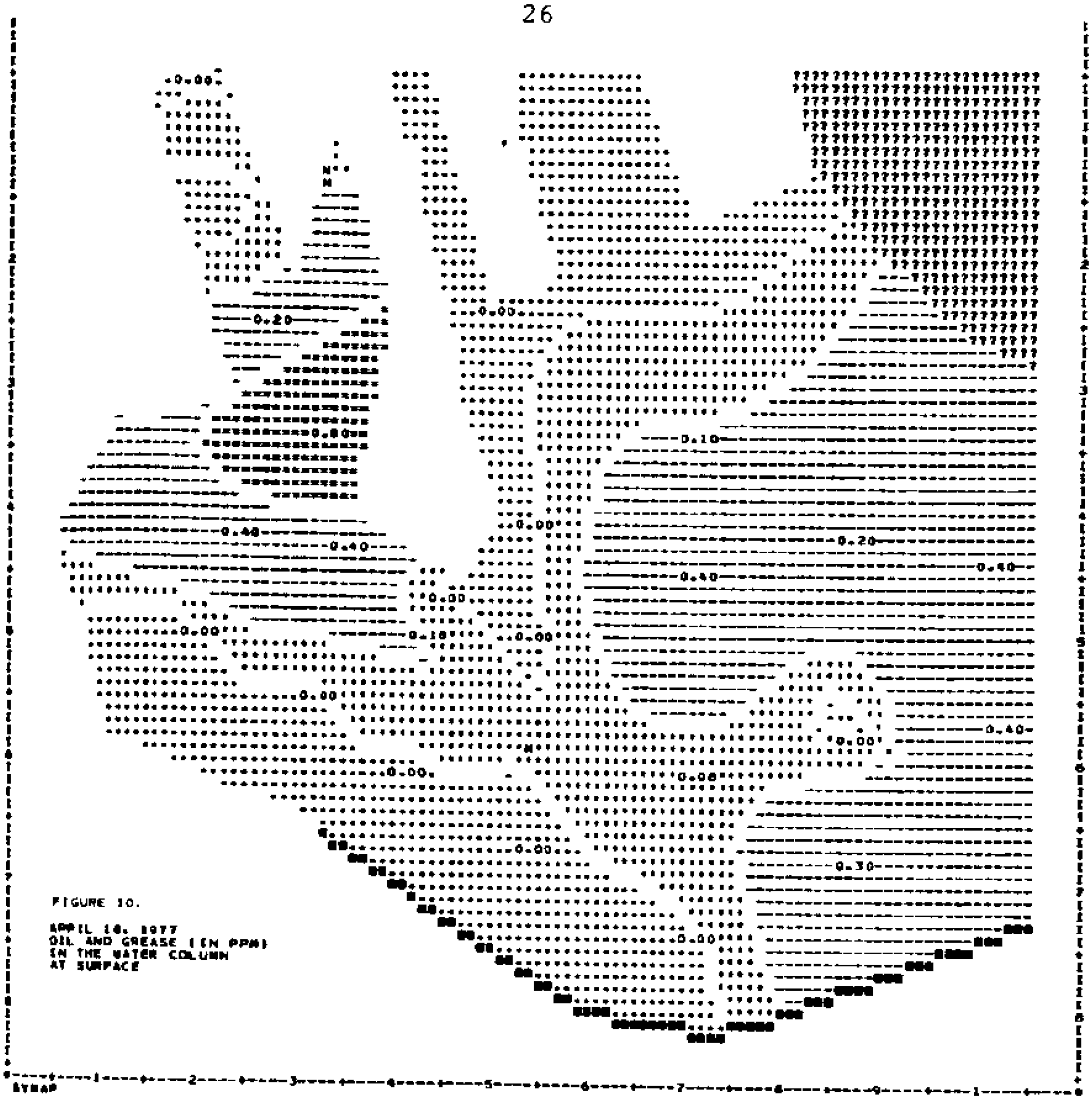


FIGURE 10.

APRIL 18, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
AT SURFACE

```
SYMAP

10.462758 MINUTES FOR MAP


APRIL 18, 1977

OIL AND GREASE (IN PPM)

IN THE WATER COLUMN (SURFACE)


DATA VALUE EXTREMES ARE          0.0          0.80


TOTAL MISSING DATA POINTS IS          1


ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM      0.0       0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00
  MAXIMUM      0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00      6.70

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

               0.15      1.34      5.97      7.46      7.46      7.46     14.93     14.93     14.93     25.37

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL        1          2          3          4          5          6          7          8          9         10
          ************************************************************************************************************
          .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ■■■■■■■■■  ■■■■■■■■■  ■■■■■■■■■
          .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ■■■■■■■■■  ■■■■■■■■■  ■■■■■■■■■
 SYMBOLS  ....1....  ''''2''''  ----3----  ====4====  ++++5++++  XXXX6XXXX  OOOO7OOOO  ■■■■■■■■■  ■■■■■■■■■  ■■■■■■■■■
          .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ■■■■■■■■■  ■■■■■■■■■  ■■■■■■■■■
          .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ■■■■■■■■■  ■■■■■■■■■  ■■■■■■■■■
 FREQ.    ************************************************************************************************************
               11         1          10         1          0          0          0          0          0          0
      1    I..1..I    I''2''I    I--3--I    I==4==I
      2    I..1..I               I--3--I
      3    I..1..I               I--3--I
      4    I..1..I               I--3--I
      5    I..1..I               I--3--I
      6    I..1..I               I--3--I
      7    I..1..I               I--3--I
      8    I..1..I               I--3--I
      9    I..1..I               I--3--I
     10    I..1..I               I--3--I
     11    I..1..I
```

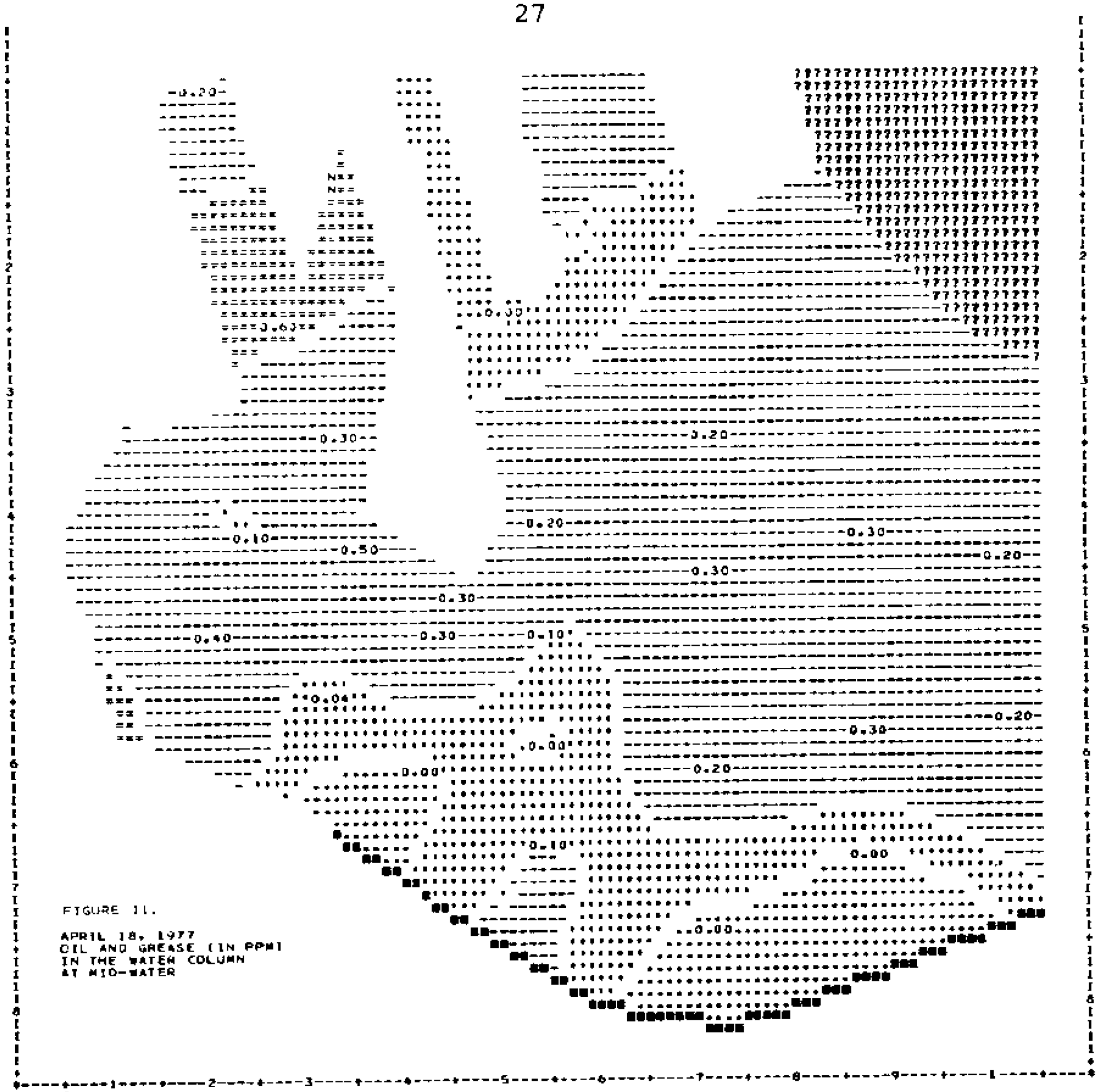


FIGURE 11.

APRIL 18, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
AT MID-WATER

```
 SYMAP

10.834833 MINUTES FOR MAP


APRIL 18, 1977

OIL AND GREASE (IN PPM)

IN THE WATER COLUMN (MID-WATER)


DATA VALUE EXTREMES ARE          0.0          0.60


ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM      0.0       0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00
  MAXIMUM      0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00      6.73


PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

               0.15      1.34      5.97      7.46      7.46      7.46     14.93     14.93     14.93     25.37


FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL          1         2         3         4         5         6         7         8         9        10
            ====================================================================================================
             .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  █████████  █████████
             .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  █████████  █████████
  SYMBOLS    ....1....  ''''2''''  ----3----  ====4====  ++++5++++  XXXX6XXXX  OOOO7OOOO  ØØØØ8ØØØØ  ████9████  ████10███
             .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  █████████  █████████
             .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  █████████  █████████
            ====================================================================================================
  FREQ.          5         1         16        2         0         0         0         0         0         0
          1  I..I..I   I''2''I   I--3--I   I==4==I
          2  I..I..I             I--3--I   I==4==I
          3  I..I..I             I--3--I
          4  I..I..I             I--3--I
          5  I..I..I             I--3--I
          6                      I--3--I
          7                      I--3--I
          8                      I--3--I
          9                      I--3--I
         10                      I--3--I
         11                      I--3--I
         12                      I--3--I
         13                      I--3--I
         14                      I--3--I
         15                      I--3--I
         16                      I--3--I
```

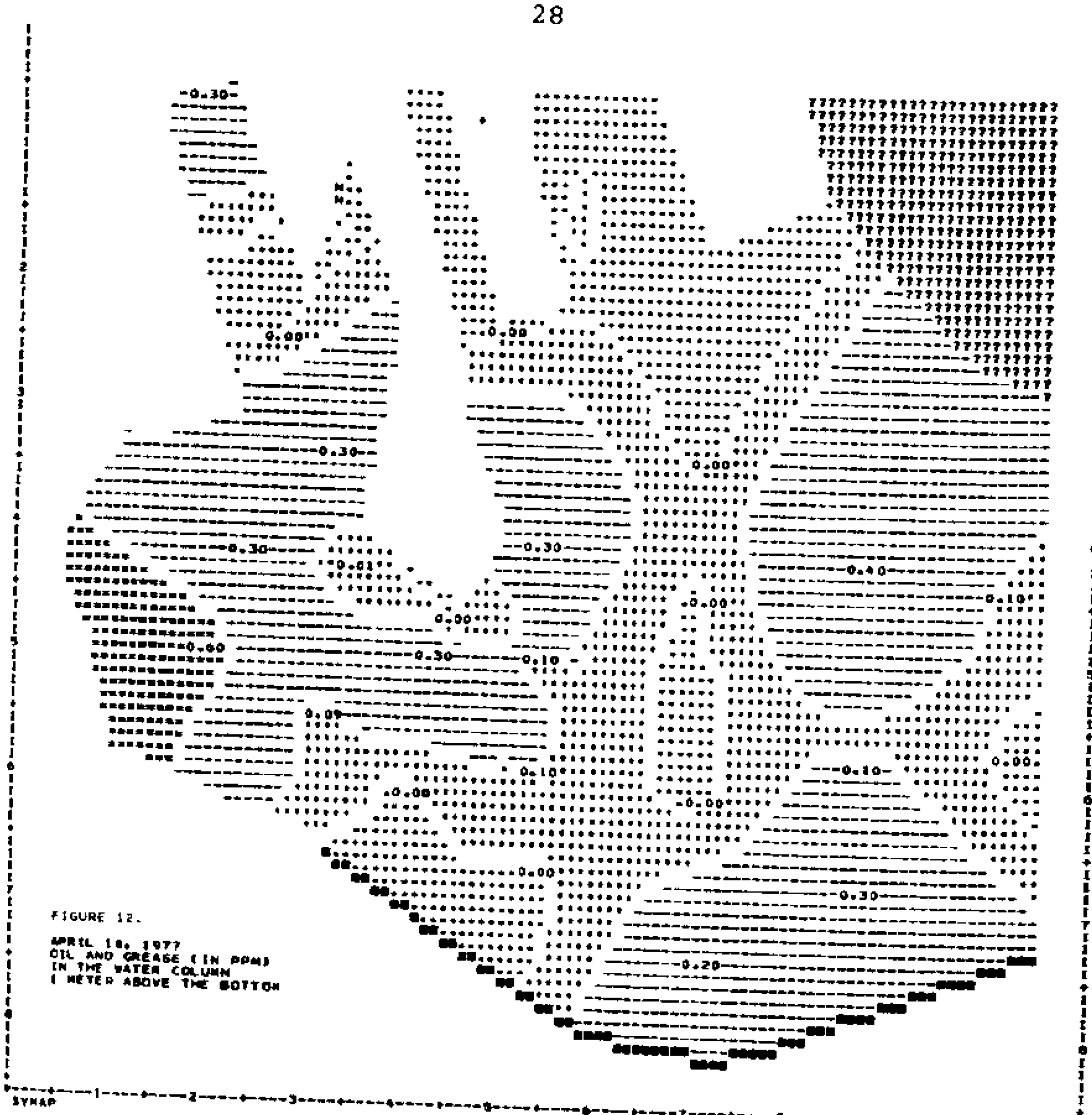


FIGURE 12.

APRIL 18, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
1 METER ABOVE THE BOTTOM

```
10.434952 MINUTES FOR MAP


APRIL 18, 1977

OIL AND GREASE (IN PPM) IN THE WATER COLUMN

1 METER ABOVE THE BOTTOM



DATA VALUE EXTREMES ARE            0.0          0.60



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

 MINIMUM     0.0       0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00
 MAXIMUM     0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00      6.70

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

             0.15      1.34      5.97      7.46      7.46      7.46     14.93     14.93     14.93     25.37

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL          1          2          3          4          5          6          7          8          9         10
         ******************************************************************************************************
         .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000
 SYMBOLS .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000
         ....1....  ''''2''''  ----3----  =========  ++++5++++  XXXX6XXXX  000070000
         .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000
         .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000
 FREQ.   ******************************************************************************************************
             9          2         12          1          0          0          0          0          0          0
     1   I..1..I    I''2''I    I--3--I    I==4==I
     2   I..1..I    I''2''I    I--3--I
     3   I..1..I               I--3--I
     4   I..1..I               I--3--I
     5   I..1..I               I--3--I
     6   I..1..I               I--3--I
     7   I..1..I               I--3--I
     8   I..1..I               I--3--I
     9   I..1..I               I--3--I
    10                         I--3--I
    11                         I--3--I
    12                         I--3--I
```

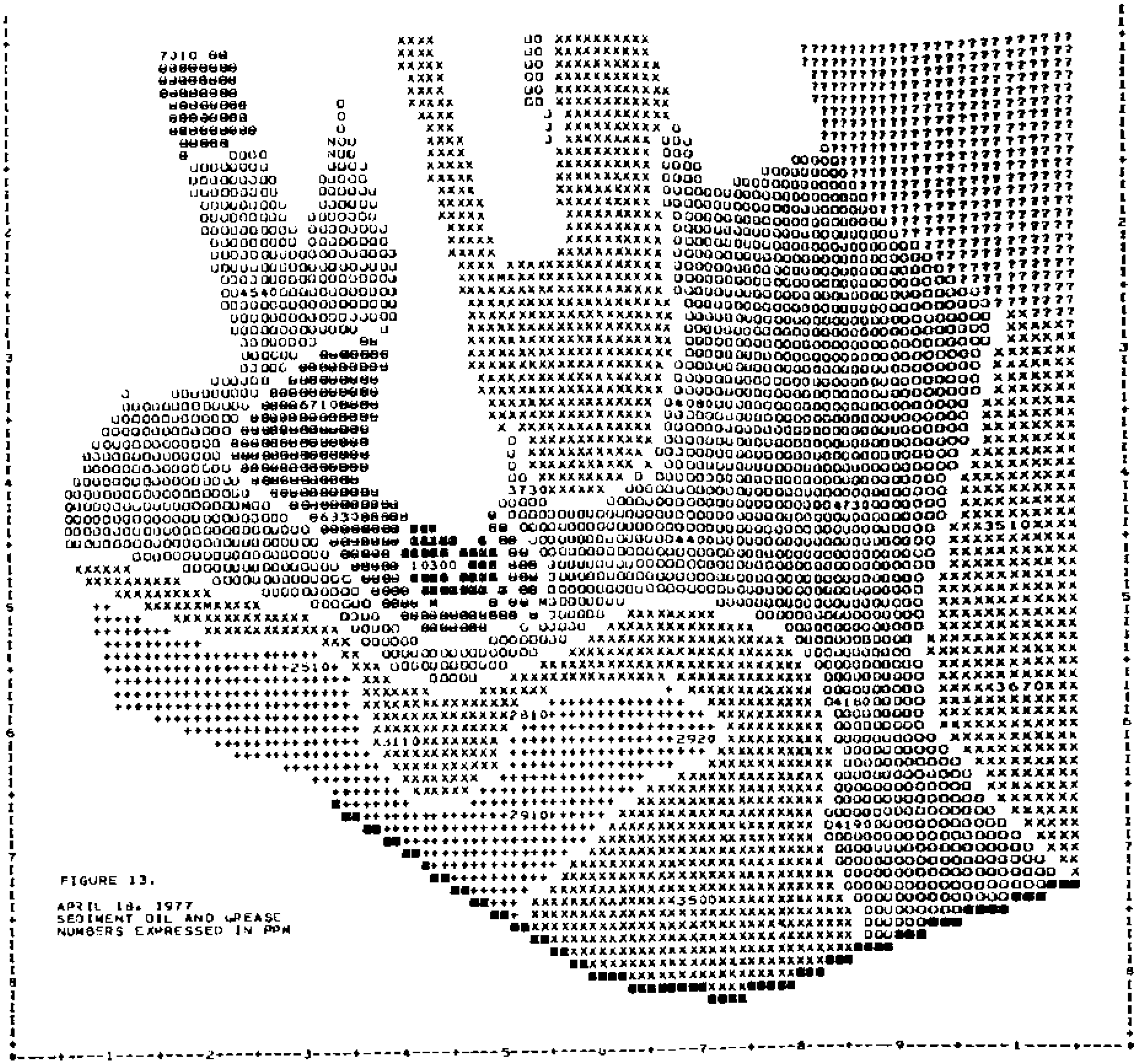


FIGURE 13.

APRIL 18, 1977
SEDIMENT OIL AND GREASE
NUMBERS EXPRESSED IN PPM

```
 SYMAP

14.322556 MINUTES FOR MAP


APRIL 18, 1977

SEDIMENT OIL AND GREASE

NUMBERS EXPRESSED IN PPM



DATA VALUE EXTREMES ARE       2510.00    10310.00



TOTAL MISSING DATA POINTS IS          5



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

                                                                       6000.00   8000.00  10000.00
  MINIMUM      0.0     1600.00   2000.00   2500.00   3000.00   4000.00 8000.00  10000.00  11027.00
  MAXIMUM   1600.00    2000.00   2500.00   3000.00   4000.00   6000.00


PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

                                                                       18.14     18.14      9.31
            14.51      3.63      4.53      4.53      9.07     18.14


FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL         1         2         3         4         5         6         7         8         9
         ==========================================================================================
          .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  @@@@@@@@@
          .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  @@@@@@@@@
 SYMBOLS  ....1....  ''''2''''  ====3====  ++++4++++  XXXX5XXXX  OOOO6OOOO  @@@@7@@@@
          .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  @@@@@@@@@
          .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  @@@@@@@@@
         ==========================================================================================
 FREQ.          0         0         0         4         5         6         3         0         1
      1                              I++++++I   IXX5XXI   IOO6OOI   I@@7@@I              I@@9@@I
      2                              I++++++I   IXX5XXI   IOO6OOI   I@@7@@I
      3                              I++++++I   IXX5XXI   IOO6OOI   I@@7@@I
      4                              I++++++I   IXX5XXI   IOO6OOI
      5                                         IXX5XXI   IOO6OOI
      6                                                   IOO6OOI
```

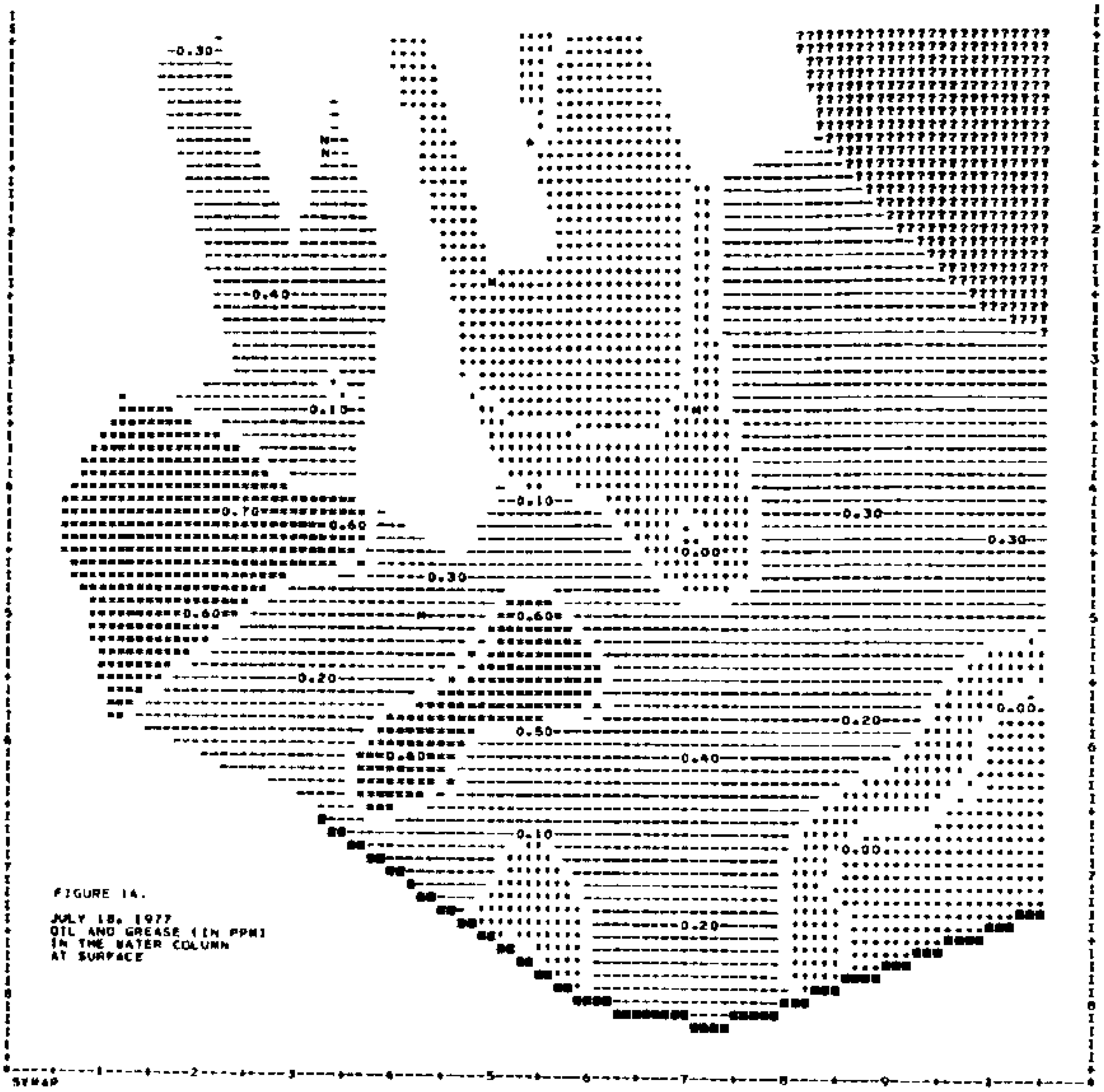


FIGURE 14.

JULY 18, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
AT SURFACE

```
10.30F0PL MINUTES FOR MAP


JULY 18, 1977

OIL AND GREASE (IN PPM)

IN THE WATER COLUMN (SURFACE)



DATA VALUE EXTREMES ARE           0.0           0.70




TOTAL MISSING DATA POINTS IS          3



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
       ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

 MINIMUM      0.0        0.01       0.10       0.50       1.00       1.50       2.00       3.00       4.00       5.00
 MAXIMUM      0.01       0.10       0.50       1.00       1.50       2.00       3.00       4.00       5.00       6.70

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

              0.15       1.34       5.97       7.46       7.46       7.46      14.93      14.93      14.93      25.37

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL           1          2          3          4          5          6          7          8          9         10
         ****************************************************************************************************
          .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  █████████  █████████  █████████
 SYMBOLS  .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  █████████  █████████  █████████
          ....1....  ''''2''''  ----3----  ====4====  ++++5++++  XXXX6XXXX  OOOO7OOOO  ████8████  ████9████  ████10███
          .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  █████████  █████████  █████████
          .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  █████████  █████████  █████████
         ****************************************************************************************************
 FREQ.           3          0         12          6          0          0          0          0          0          0
      1     I..1..I              I--3--I    I==4==I
      2     I..1..I              I--3--I    I==4==I
      3     I..1..I              I--3--I    I==4==I
      4                          I--3--I    I==4==I
      5                          I--3--I    I==4==I
      6                          I--3--I    I==4==I
      7                          I--3--I
      8                          I--3--I
      9                          I--3--I
     10                          I--3--I
     11                          I--3--I
     12                          I--3--I
```

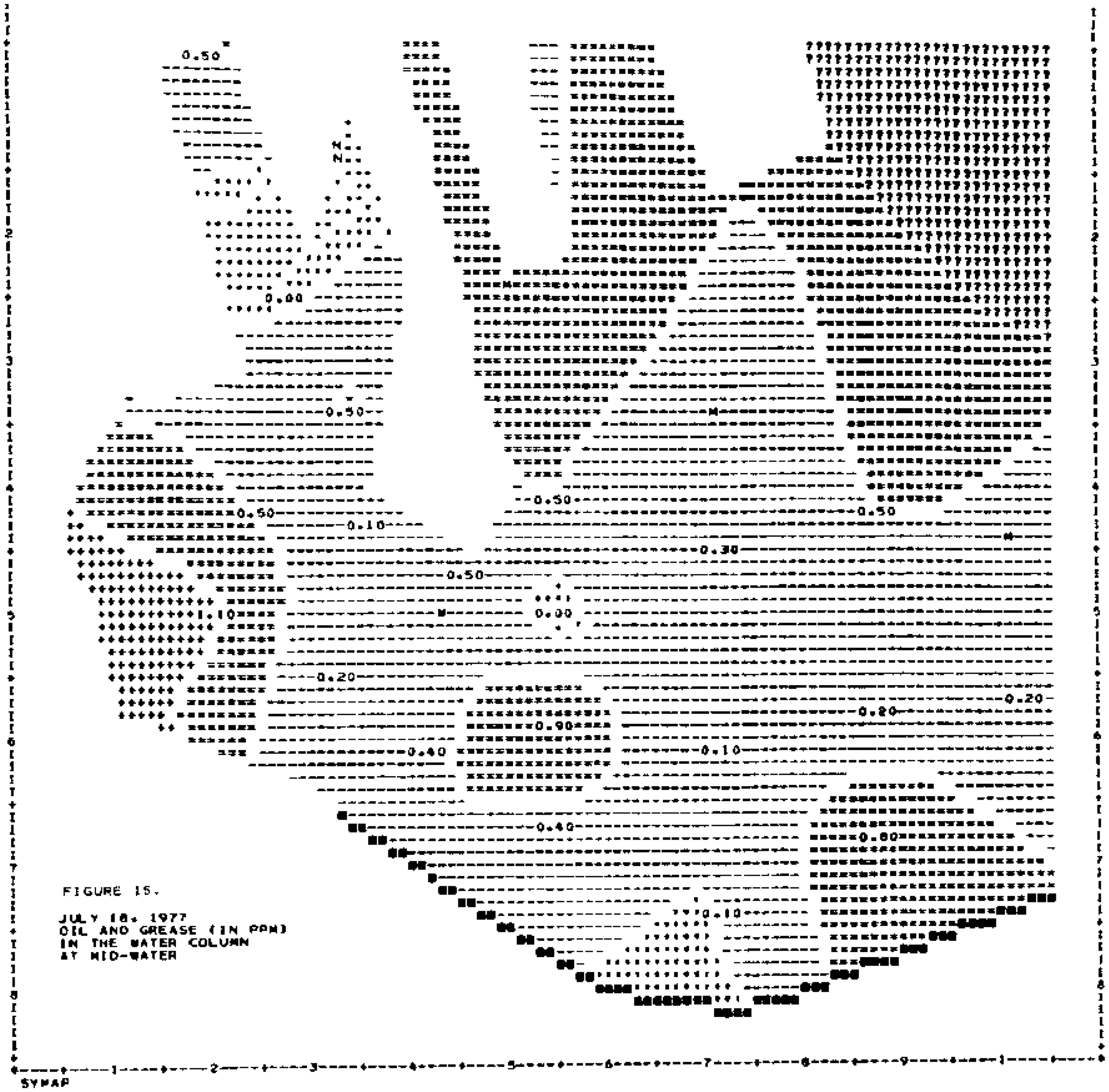


FIGURE 15.

JULY 18, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
AT MID-WATER

```
SYMAP
10.249101 MINUTES FOR MAP


JULY 18, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN (MID-WATER)



DATA VALUE EXTREMES ARE          0.0          1.10




TOTAL MISSING DATA POINTS IS          4




ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

   MINIMUM      0.0        0.01       0.10       0.50       1.00       1.50       2.00       3.00       4.00       5.00
   MAXIMUM      0.01       0.10       0.50       1.00       1.50       2.00       3.00       4.00       5.00       6.70


PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

                0.15       1.34       5.97       7.46       7.46       7.46      14.93      14.93      14.93      25.37


FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
   LEVEL          1         2          3          4          5          6          7          8          9         10
             ==================================================================================================================
              .........  ''''''''' ---------  =========  +++++++++  XXXXXXXXX  000000000  @@@@@@@@@  ■■■■■■■■■  ■■■■■■■■■
              .........  ''''''''' ---------  =========  +++++++++  XXXXXXXXX  000000000  @@@@@@@@@  ■■■■■■■■■  ■■■■■■■■■
   SYMBOLS    ....1....  ''''2'''' ----3----  ====4====  ++++5++++  XXXX6XXXX  000070000  @@@@8@@@@  ■■■■9■■■■  ■■■■10■■■
              .........  ''''''''' ---------  =========  +++++++++  XXXXXXXXX  000000000  @@@@@@@@@  ■■■■■■■■■  ■■■■■■■■■
              .........  ''''''''' ---------  =========  +++++++++  XXXXXXXXX  000000000  @@@@@@@@@  ■■■■■■■■■  ■■■■■■■■■
             ==================================================================================================================
   FREQ.          2         0          9          8          1          0          0          0          0          0
        1     [..1..]              [--3--]    [==4==]    [++5++]
        2     [..1..]              [--3--]    [==4==]
        3                          [--3--]    [==4==]
        4                          [--3--]    [==4==]
        5                          [--3--]    [==4==]
        6                          [--3--]    [==4==]
        7                          [--3--]    [==4==]
        8                          [--3--]    [==4==]
        9                          [--3--]
```

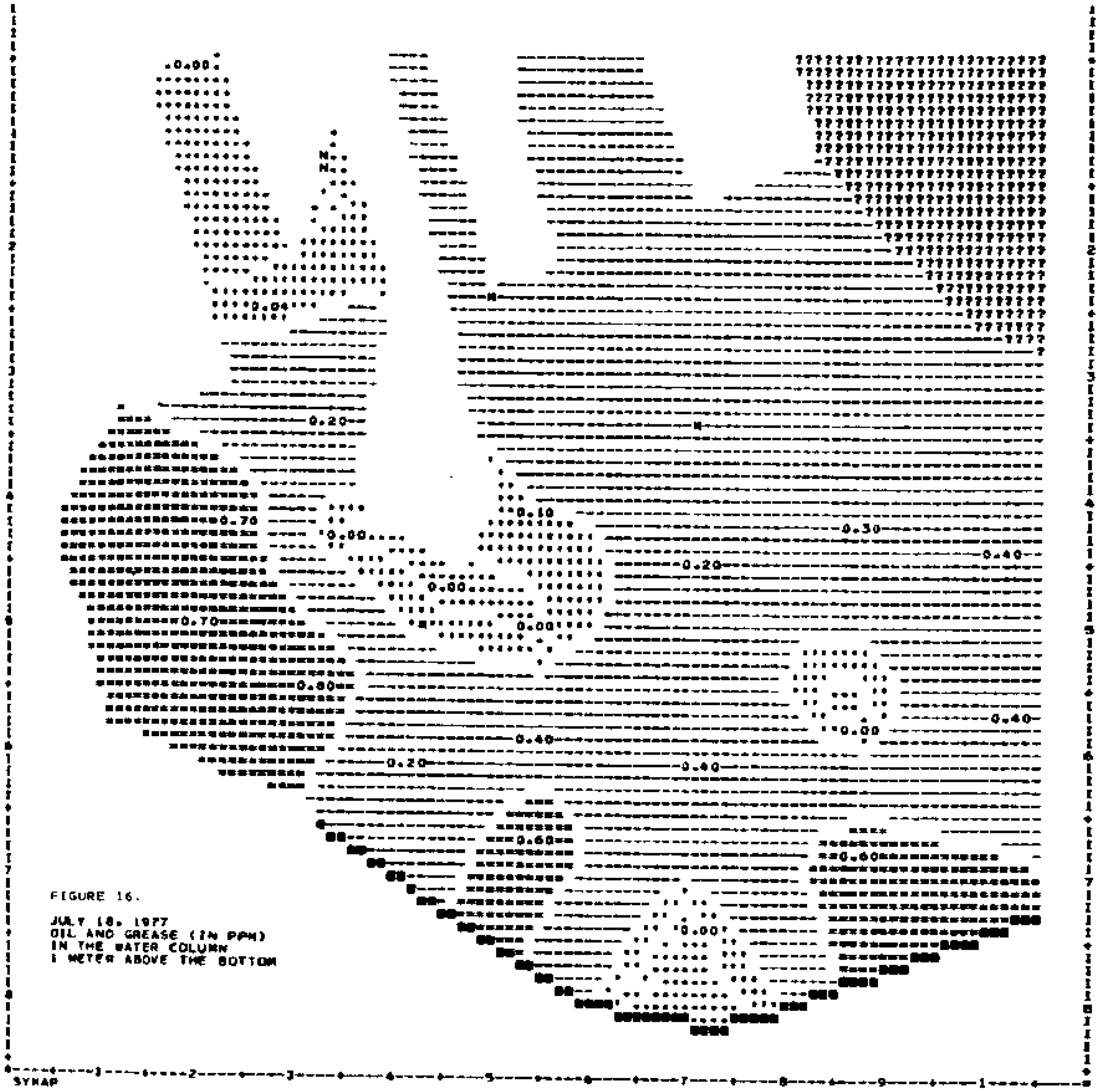


FIGURE 16.

JULY 18, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
1 METER ABOVE THE BOTTOM

```
10.219833 MINUTES FOR MAP


JULY 18, 1977
OIL AND GREASE (IN PPM) IN THE WATER COLUMN
1 METER ABOVE THE BOTTOM



DATA VALUE EXTREMES ARE          0.0          0.80



TOTAL MISSING DATA POINTS IS          3



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM     0.0       0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00
  MAXIMUM     0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00      6.70

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

              0.15      1.34      5.97      7.46      7.46      7.46     14.93     14.93     14.93     25.37

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL         1         2         3         4         5         6         7         8         9        10
         ****************************************************************************************************
          .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  █████████  █████████  █████████
 SYMBOLS  .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  █████████  █████████  █████████
          ....1....  ''''2''''  ----3----  ====4====  ++++5++++  XXXX6XXXX  OOOO7OOOO  ████8████  ████9████  ████10███
          .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  █████████  █████████  █████████
          .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  █████████  █████████  █████████
         ****************************************************************************************************
 FREQ.          6         1         9         5         0         0         0         0         0         0
      1    I..1..I   I''2''I   I--3--I   I==4==I
      2    I..1..I             I--3--I   I==4==I
      3    I..1..I             I--3--I   I==4==I
      4    I..1..I             I--3--I   I==4==I
      5    I..1..I             I--3--I   I==4==I
      6    I..1..I             I--3--I
      7                        I--3--I
      8                        I--3--I
      9                        I--3--I
```

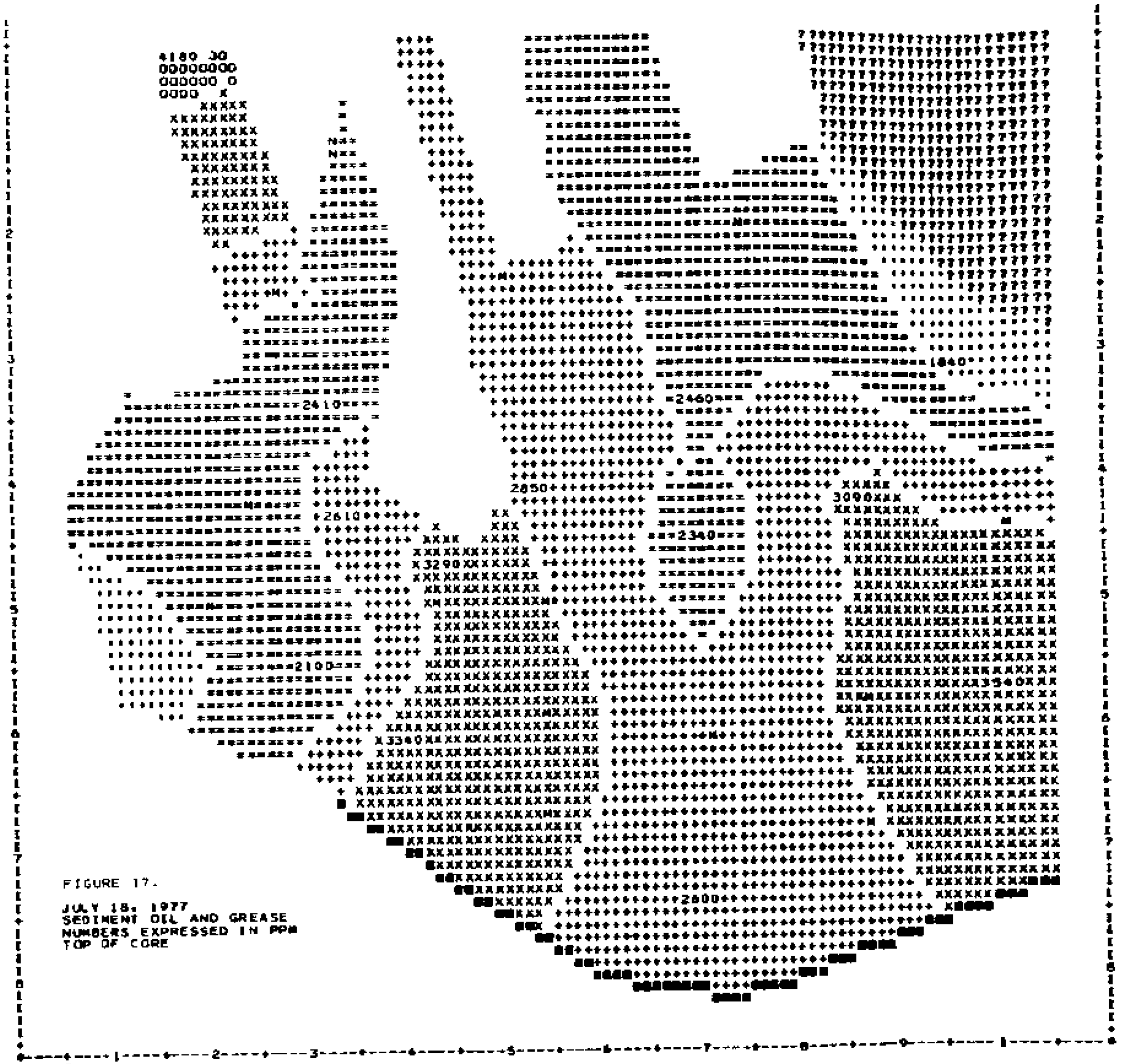


FIGURE 17.

JULY 18, 1977
SEDIMENT OIL AND GREASE
NUMBERS EXPRESSED IN PPM
TOP OF CORE

```
SYMAP

10.144113 MINUTES FOR MAP


JULY 18, 1977

SEDIMENT OIL AND GREASE

NUMBERS EXPRESSED IN PPM--TOP OF CORE



DATA VALUE EXTREMES ARE        1840.00       4180.00



TOTAL MISSING DATA POINTS IS          13



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
       ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM       0.0     1600.00    2000.00    2500.00    3000.00    4000.00    6000.00    8000.00   10000.00
  MAXIMUM   1600.00     2000.00    2500.00    3000.00    4000.00    6000.00    8000.00   10000.00   11027.00


PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

               14.51      3.63       4.53       4.53       9.07      18.14      18.14      18.14       9.31


FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL          1          2          3          4          5          6          7          8          9
          **********************************************************************************************
            .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  █████████  █████████
            .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  █████████  █████████
  SYMBOLS   ....1....  ''''2''''  ====3====  ++++4++++  XXXX5XXXX  OOOO6OOOO  ØØØØ7ØØØØ  █████████  █████████
            .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  █████████  █████████
            .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  █████████  █████████
          **********************************************************************************************
  FREQ.          0          1          4          3          4          1          0          0          0
     1                  I''2''I    I==3==I    I++4++I    IXX5XXI    IOO6OOI
     2                             I==3==I    I++4++I    IXX5XXI
     3                             I==3==I    I++4++I    IXX5XXI
     4                             I==3==I               IXX5XXI
```

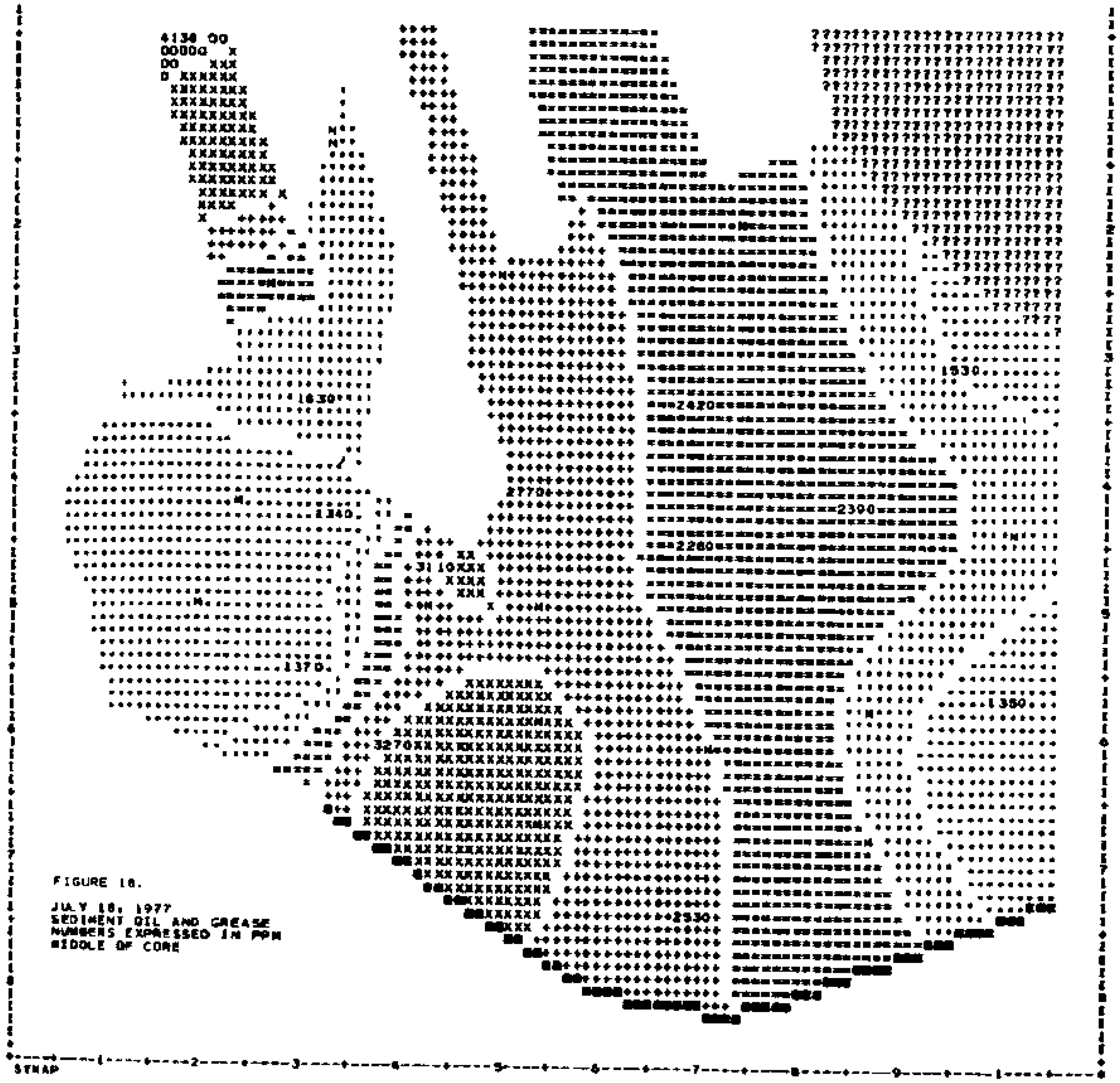


FIGURE 18.

JULY 18, 1977
SEDIMENT OIL AND GREASE
NUMBERS EXPRESSED IN PPM
MIDDLE OF CORE

```
10.194051 MINUTES FOR MAP


JULY 18, 1977

SEDIMENT OIL AND GREASE

NUMBERS EXPRESSED IN PPM -- MIDDLE OF CORE


DATA VALUE EXTREMES ARE       1340.00     4130.00


TOTAL MISSING DATA POINTS IS        13


ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

 MINIMUM        0.0     1600.00    2000.00    2500.00    3000.00    4000.00    6000.00    8000.00   10000.00
 MAXIMUM    1600.00     2000.00    2500.00    3000.00    4000.00    6000.00    8000.00   10000.00   11027.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

             14.51       3.63       4.53       4.53       9.07      18.14      18.14      18.14       9.31

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL          1          2          3          4          5          6          7          8          9
          ********************************************************************************************
           .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  █████████  █████████  █████████
 SYMBOLS   .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  █████████  █████████  █████████
           ....1....  ''''2''''  ====3====  ++++4++++  XXXX5XXXX  OOOO6OOOO  ████7████  ████8████  ████9████
           .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  █████████  █████████  █████████
           .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  █████████  █████████  █████████
 FREQ.    ********************************************************************************************
                4          1          3          2          2          1          0          0          0
      1      I..1..I    I''2''I    I==3==I    I++4++I    IXX5XXI    IOO6OOI
      2      I..1..I               I==3==I    I++4++I    IXX5XXI
      3      I..1..I               I==3==I
      4      I..1..I
```

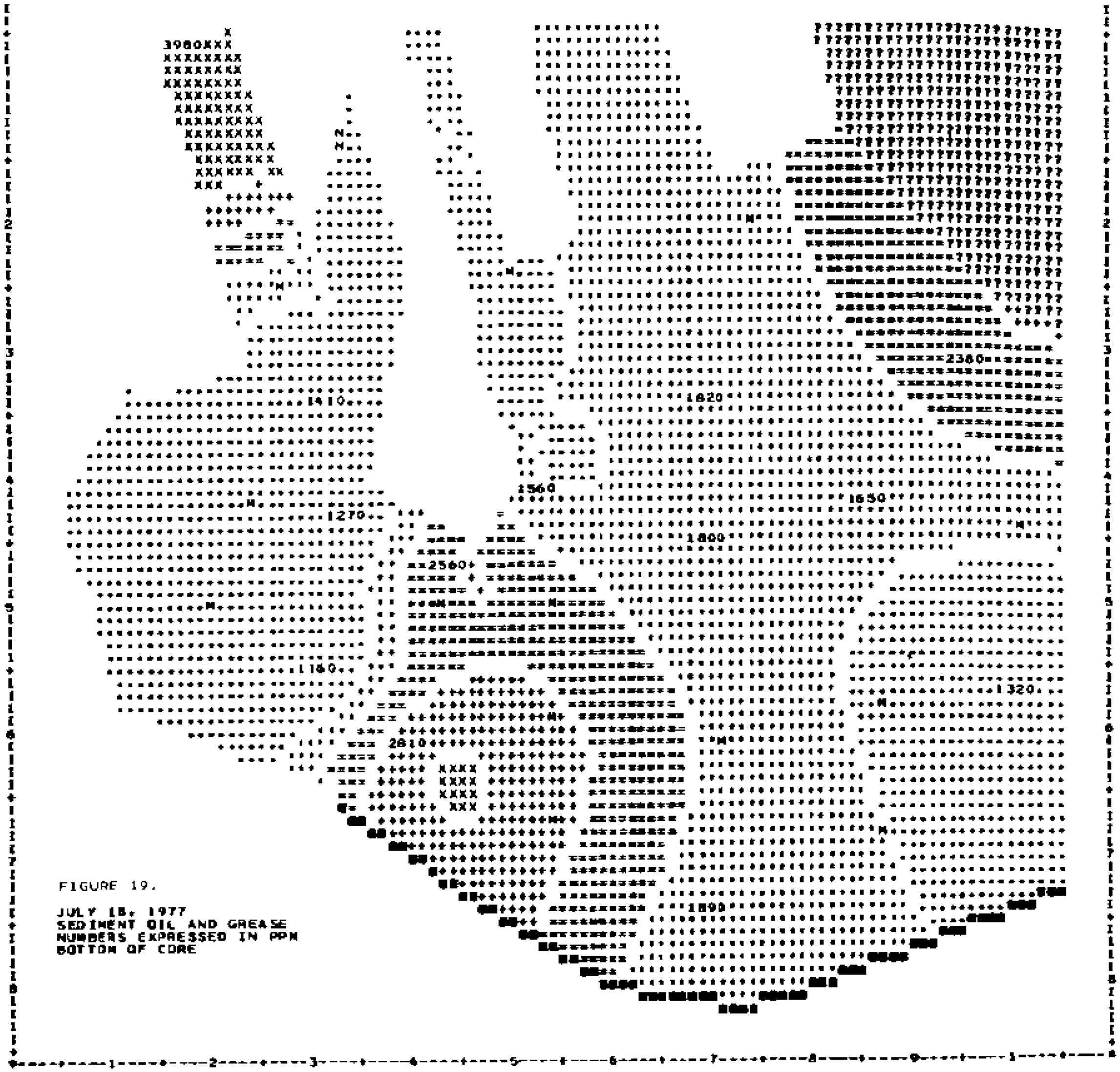
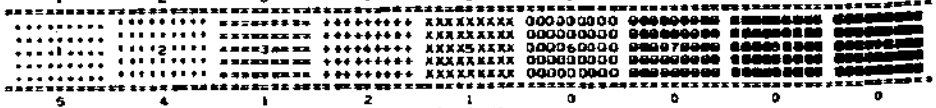


FIGURE 19.

JULY 18, 1977
SEDIMENT OIL AND GREASE
NUMBERS EXPRESSED IN PPM
BOTTOM OF CORE

```
 SYMAP

10.193787 MINUTES FOR MAP


JULY 18, 1977

SEDIMENT OIL AND GREASE

NUMBERS EXPRESSED IN PPM BOTTOM OF CORE



DATA VALUE EXTREMES ARE       1160.00     3980.00




TOTAL MISSING DATA POINTS IS        13



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
       ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

   MINIMUM       0.0     1600.00   2000.00   2500.00   3000.00   4000.00   6000.00   8000.00  10000.00
   MAXIMUM   1600.00     2000.00   2500.00   3000.00   4000.00   6000.00   8000.00  10000.00  11027.00


PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

              14.51       3.63      4.53      4.53      9.07     18.14     18.14     18.14      9.31


FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
   LEVEL          1         2         3         4         5         6         7         8         9
```



```
   FREQ.          5         4         1         2         1         0         0         0         0
          1   I..I..I   I''2''I   I==3==I   I++4++I   IXX5XXI
          2   I..I..I   I''2''I             I++4++I
          3   I..I..I   I''2''I
          4   I..I..I   I''2''I
          5   I..I..I
```

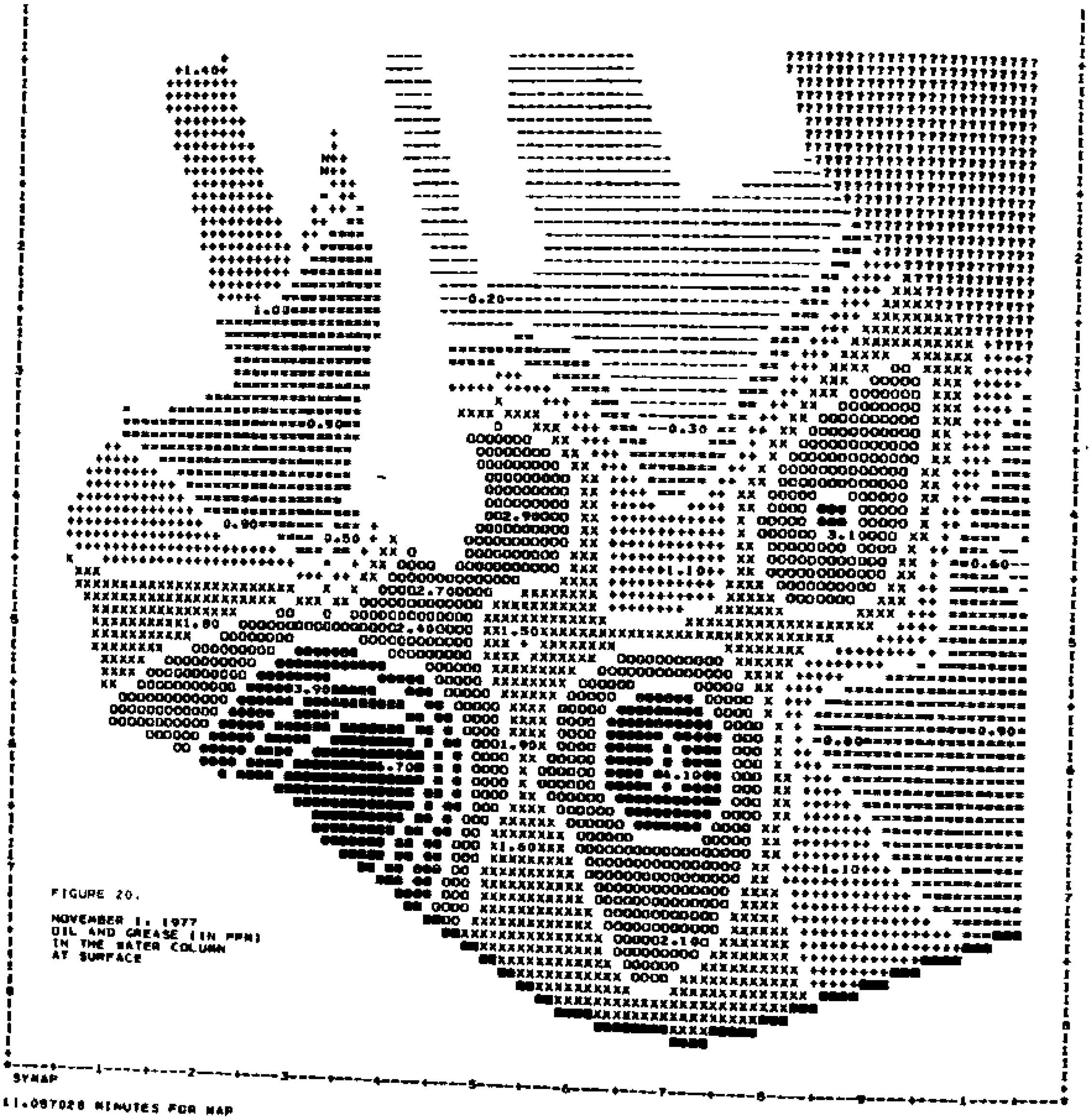
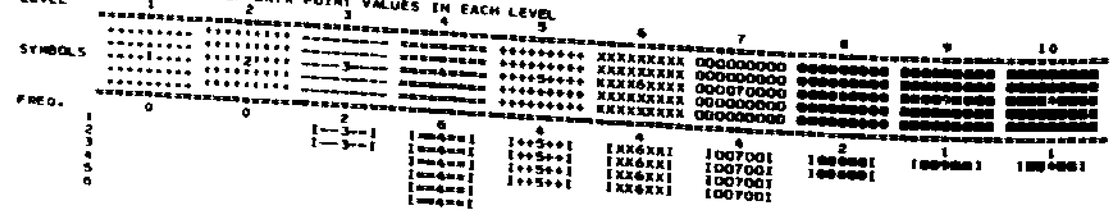


FIGURE 20.

NOVEMBER 1, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
AT SURFACE

```
11.097028 MINUTES FOR MAP


NOVEMBER 1, 1977

OIL AND GREASE (IN PPM) IN THE WATER COLUMN

AT SURFACE



DATA VALUE EXTREMES ARE             0.20          6.70


ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
       ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

 MINIMUM      0.0      0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00
 MAXIMUM      0.01     0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00      6.70

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

              0.15     1.34      5.97      7.46      7.46      7.46     14.93     14.93     14.93     25.37

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
```



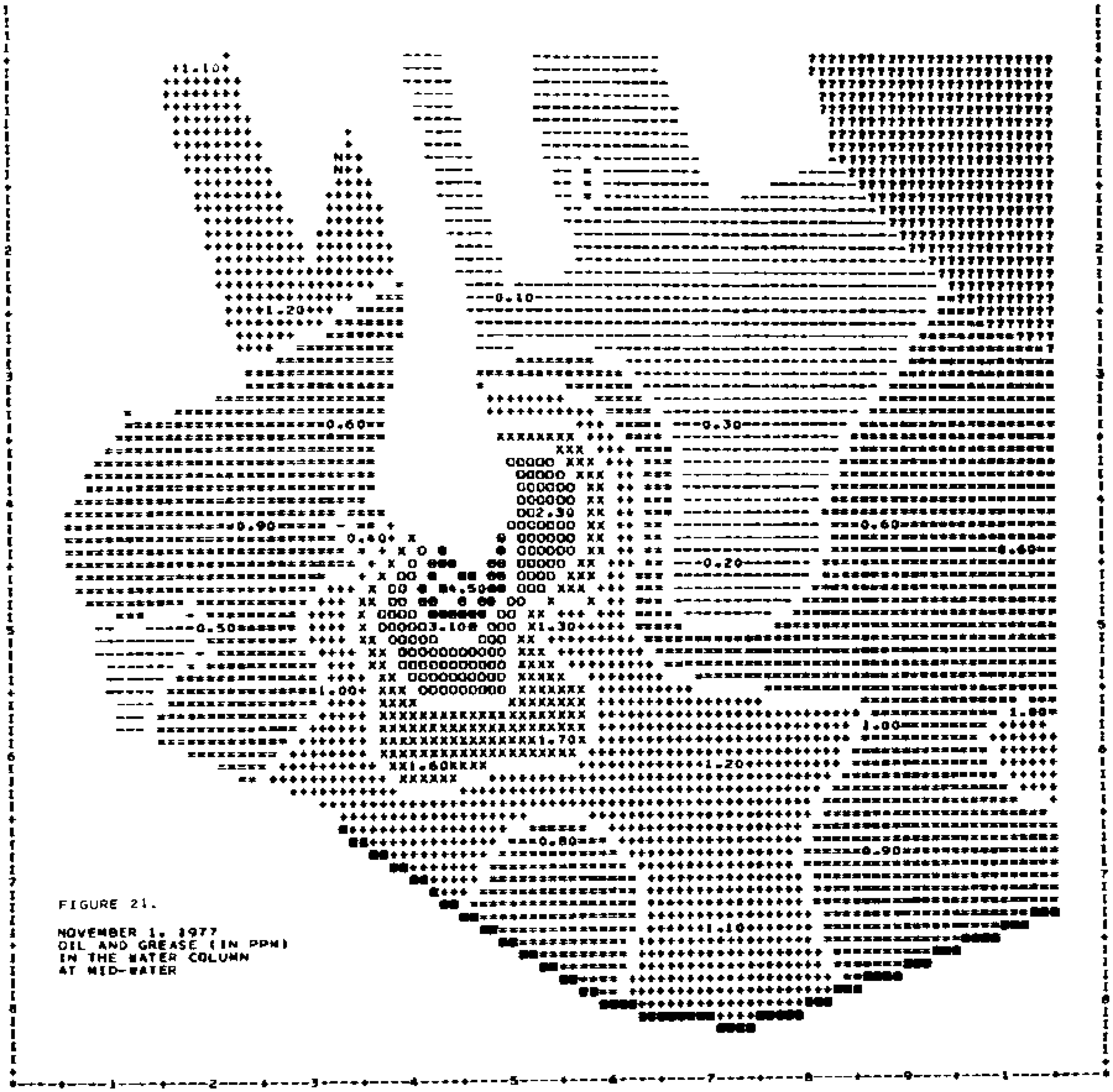


FIGURE 21.

NOVEMBER 1, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
AT MID-WATER

```
SYMAP

11.024318 MINUTES FOR MAP


NOVEMBER 1, 1977

OIL AND GREASE (IN PPM) IN THE WATER COLUMN

AT MID-WATER



DATA VALUE EXTREMES ARE          0.10         4.50



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
       ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM      0.0       0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00
  MAXIMUM      0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00      4.70


PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

               0.15      1.34      5.97      7.46      7.46      7.46     14.93     14.93     14.93     25.37


FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL         1         2         3         4         5         6         7         8         9        10
           ==========================================================================================================
            .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000  ■■■■■■■■■  ■■■■■■■■■  ■■■■■■■■■
            .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000  ■■■■■■■■■  ■■■■■■■■■  ■■■■■■■■■
 SYMBOLS    ....1....  ''''2''''  ----3----  ====4====  ++++5++++  XXXX6XXXX  000070000  ■■■■8■■■■  ■■■■9■■■■  ■■■10■■■■
            .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000  ■■■■■■■■■  ■■■■■■■■■  ■■■■■■■■■
            .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000  ■■■■■■■■■  ■■■■■■■■■  ■■■■■■■■■
           ==========================================================================================================
 FREQ.          0         0         4         7         8         2         1         1         1         0
       1                        I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I■■8■■I   I■■9■■I
       2                        I--3--I   I==4==I   I++5++I   IXX6XXI
       3                        I--3--I   I==4==I   I++5++I
       4                        I--3--I   I==4==I   I++5++I
       5                                  I==4==I   I++5++I
       6                                  I==4==I   I++5++I
       7                                  I==4==I   I++5++I
       8                                            I++5++I
```

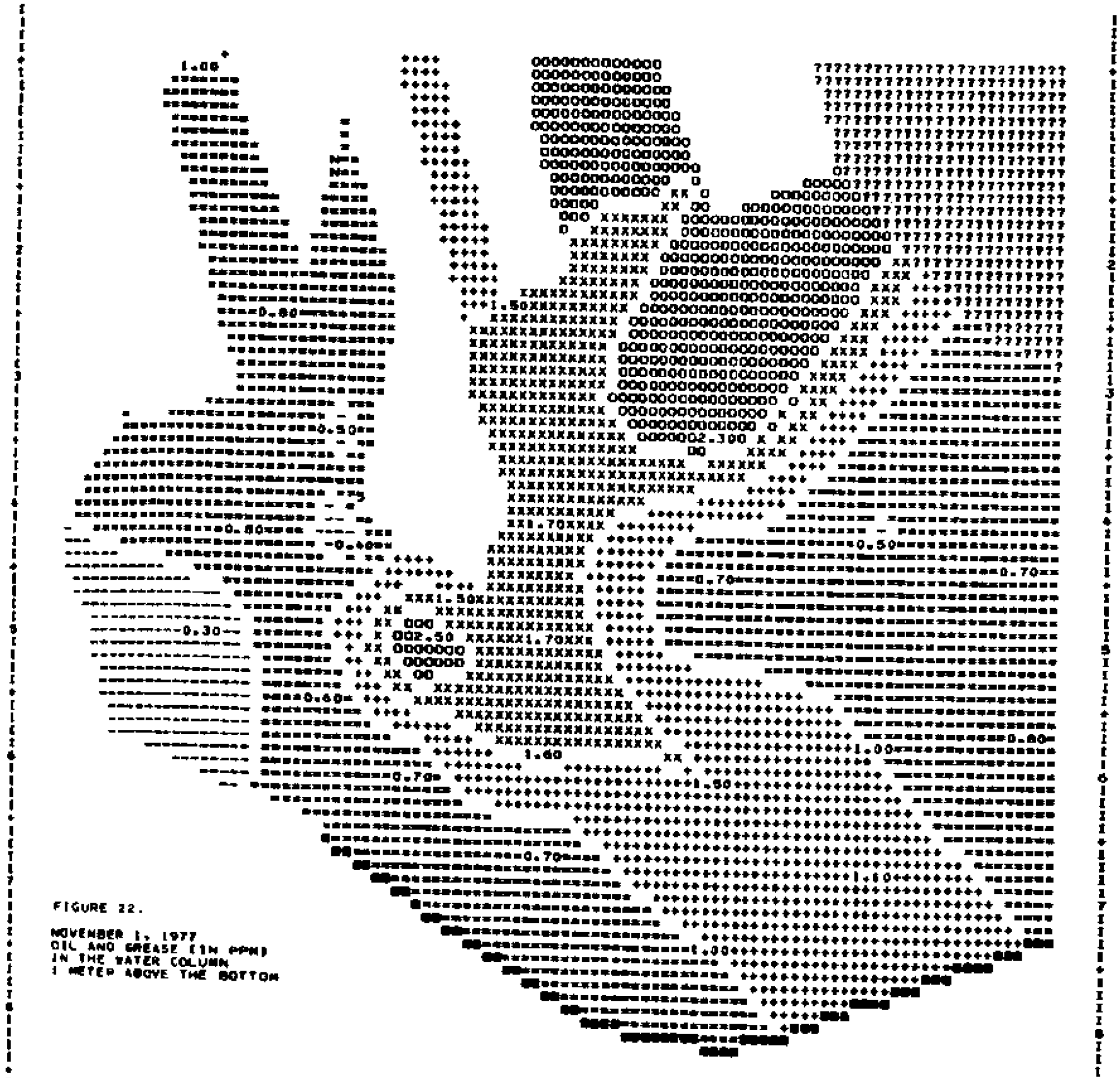


FIGURE 22.

NOVEMBER 1, 1977
OIL AND GREASE (IN PPM)
IN THE WATER COLUMN
1 METER ABOVE THE BOTTOM

```
10.753540 MINUTES FOR MAP


NOVEMBER 1, 1977

OIL AND GREASE (IN PPM) IN THE WATER COLUMN

1 METER ABOVE THE BOTTOM



DATA VALUE EXTREMES ARE            0.30          2.50



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM        0.0       0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00
  MAXIMUM        0.01      0.10      0.50      1.00      1.50      2.00      3.00      4.00      5.00      6.70

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

                 0.15      1.34      5.97      7.46      7.46      7.46     14.93     14.93     14.93     25.37

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL           1         2         3         4         5         6         7         8         9         10

 FREQ.           0         0         2         10        4         6         2         0         0         0
   1                                I---3---I I===4===I I+++5+++I IXXX6XXXI IOOO7OOOI
   2                                I---3---I I===4===I I+++5+++I IXXX6XXXI IOOO7OOOI
   3                                          I===4===I I+++5+++I IXXX6XXXI
   4                                          I===4===I I+++5+++I IXXX6XXXI
   5                                          I===4===I           IXXX6XXXI
   6                                          I===4===I           IXXX6XXXI
   7                                          I===4===I
   8                                          I===4===I
   9                                          I===4===I
  10                                          I===4===I
```

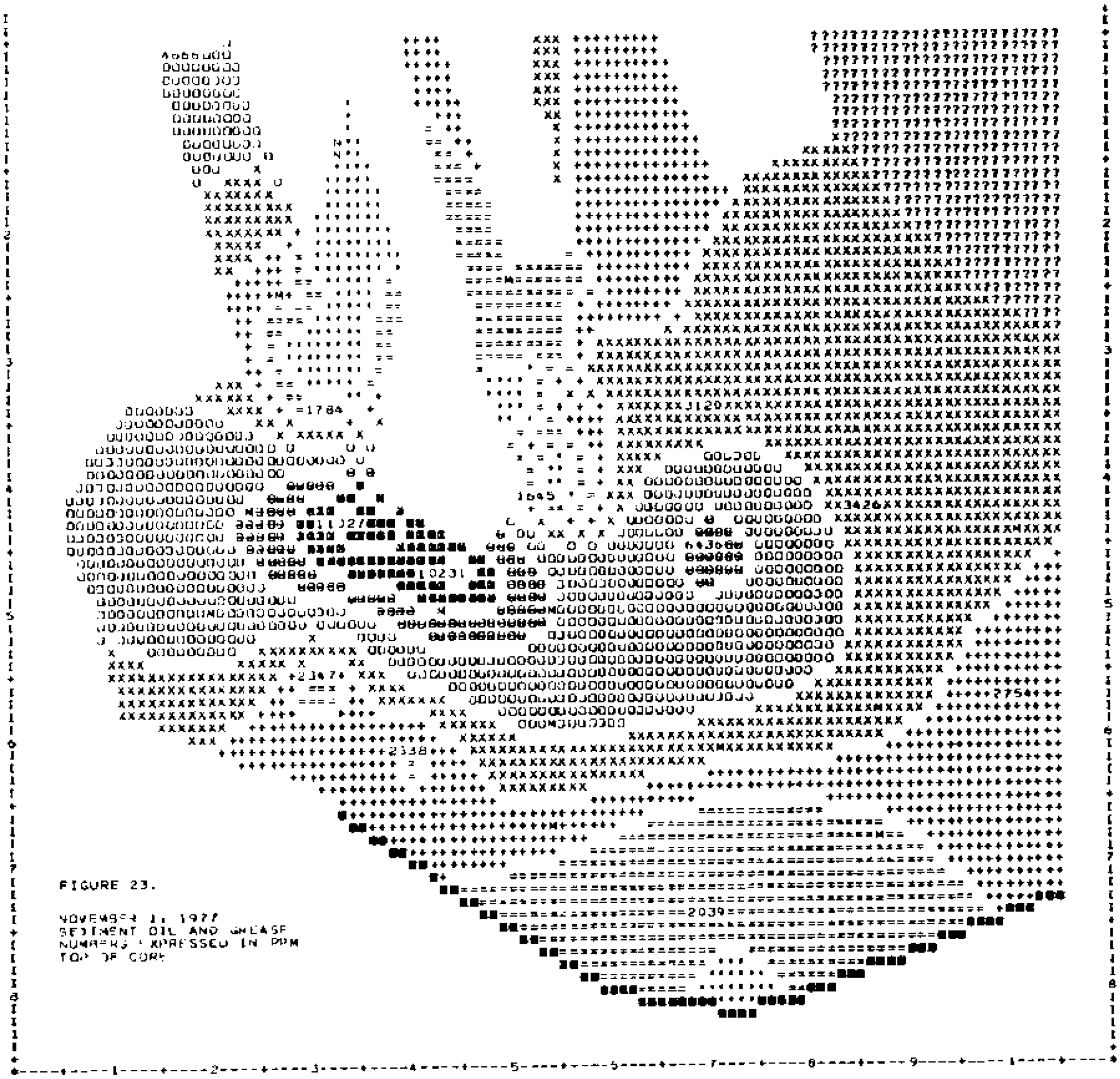


FIGURE 23.

NOVEMBER 1, 1977
SEDIMENT OIL AND GREASE
NUMBERS EXPRESSED IN PPM
TOP OF CORE

```
13.912249 MINUTES FOR MAP


NOVEMBER 1, 1977

SEDIMENT OIL AND GREASE

NUMBERS EXPRESSED IN PPM--TOP OF CORE



DATA VALUE EXTREMES ARE        1645.00     11027.00



TOTAL MISSING DATA POINTS IS          12



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
       ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

  MINIMUM        0.0    1600.00   2000.00   2500.00   3000.00   4000.00   6000.00   8000.00  10000.00
  MAXIMUM    1600.00    2000.00   2500.00   3000.00   4000.00   6000.00   8000.00  10000.00  11027.00


PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

               14.51      3.63      4.53      4.53      9.07     18.14     18.14     18.14      9.31


FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL         1         2         3         4         5         6         7         8         9
          ==========================================================================================
           .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  ■■■■■■■■■  ■■■■■■■■■
           .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  ■■■■■■■■■  ■■■■■■■■■
  SYMBOLS  ....1....  ''''2''''  ====3====  ++++4++++  XXXX5XXXX  OOOO6OOOO  ØØØØ7ØØØØ  ■■■■8■■■■  ■■■■9■■■■
           .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  ■■■■■■■■■  ■■■■■■■■■
           .........  '''''''''  =========  +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  ■■■■■■■■■  ■■■■■■■■■
          ==========================================================================================
  FREQ.         0         2         2         2         2         1         1         0         2
                      I''2''I   I==3==I   I++4++I   IXX5XXI   IOO6OOI   IØØ7ØØI             I■■9■■I
                      I''2''I   I==3==I   I++4++I   IXX5XXI                                 I■■9■■I
```

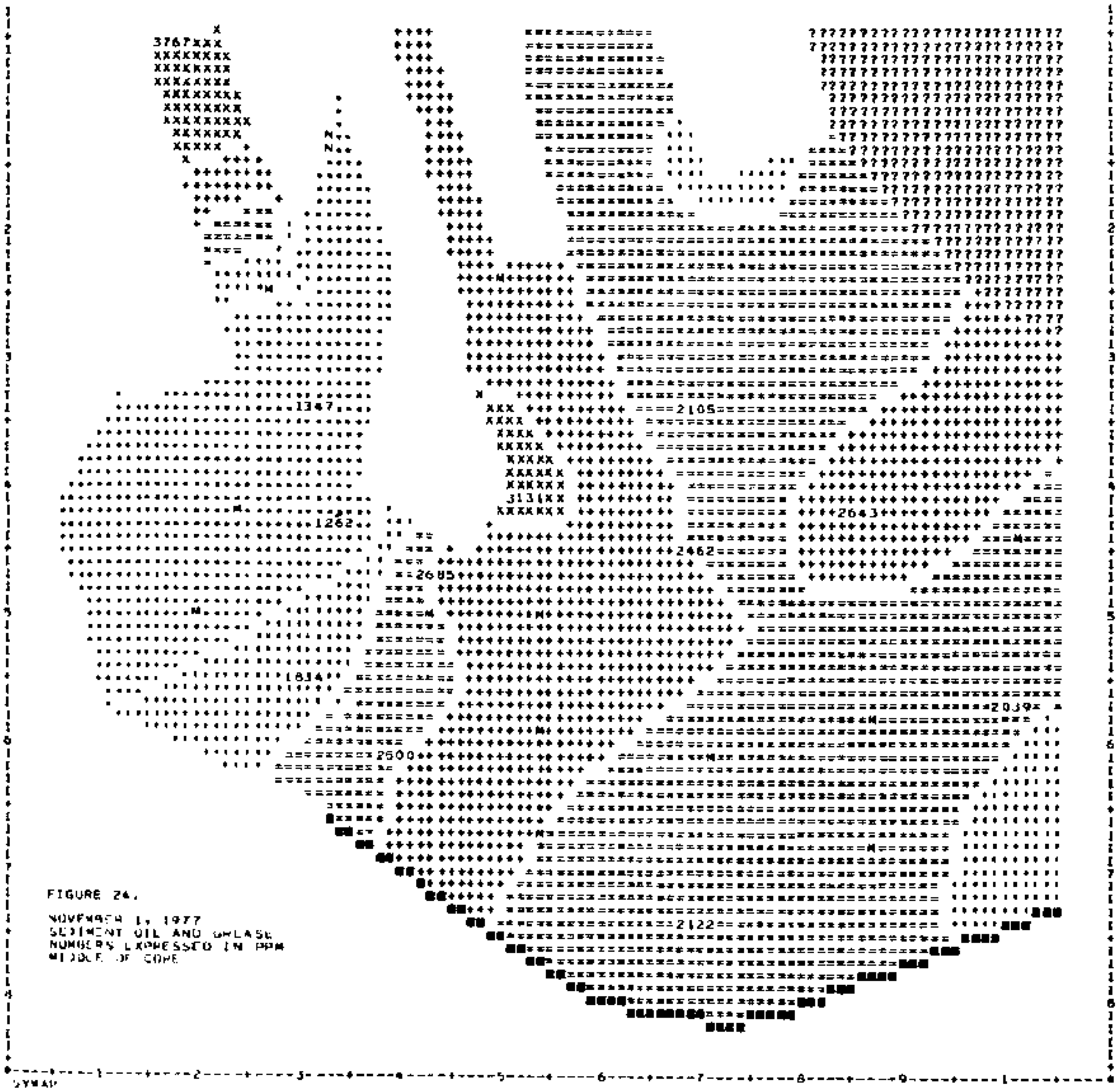


FIGURE 24.

NOVEMBER 1, 1977
SEDIMENT OIL AND GREASE
NUMBERS EXPRESSED IN PPM
MIDDLE OF CORE

```
13.370041 MINUTES FOR MAP


NOVEMBER 1, 1977

SEDIMENT OIL AND GREASE

NUMBERS EXPRESSED IN PPM -- MIDDLE OF CORE



DATA VALUE EXTREMES ARE        1262.00       3767.00



TOTAL MISSING DATA POINTS IS          12



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

 MINIMUM        0.0     1600.00    2000.00    2500.00    3000.00    4000.00    6000.00    8000.00   10000.00
 MAXIMUM    1600.00    2000.00    2500.00    3000.00    4000.00    6000.00    8000.00   10000.00   11027.00


PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

             14.51       3.63       4.53       4.53       9.07      18.14      18.14      18.14       9.31


FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL          1          2          3          4          5          6          7          8          9
          ==========================================================================================
          .........  '''''''''  =========  +++++++++  XXXXXXXXX  000000000  @@@@@@@@@  ■■■■■■■■■  ■■■■■■■■■
          .........  '''''''''  =========  +++++++++  XXXXXXXXX  000000000  @@@@@@@@@  ■■■■■■■■■  ■■■■■■■■■
 SYMBOLS  ....1....  ''''2''''  ====3====  ++++4++++  XXXX5XXXX  0000600000  @@@@7@@@@  ■■■■8■■■■  ■■■■9■■■■
          .........  '''''''''  =========  +++++++++  XXXXXXXXX  000000000  @@@@@@@@@  ■■■■■■■■■  ■■■■■■■■■
          .........  '''''''''  =========  +++++++++  XXXXXXXXX  000000000  @@@@@@@@@  ■■■■■■■■■  ■■■■■■■■■
          ==========================================================================================
 FREQ.          2          1          4          3          2          0          0          0          0
      1     I..1..I    I''2''I    I==3==I    I++4++I    IXX5XXI
      2     I..1..I               I==3==I    I++4++I    IXX5XXI
      3                           I==3==I    I++4++I
      4                           I==3==I
```

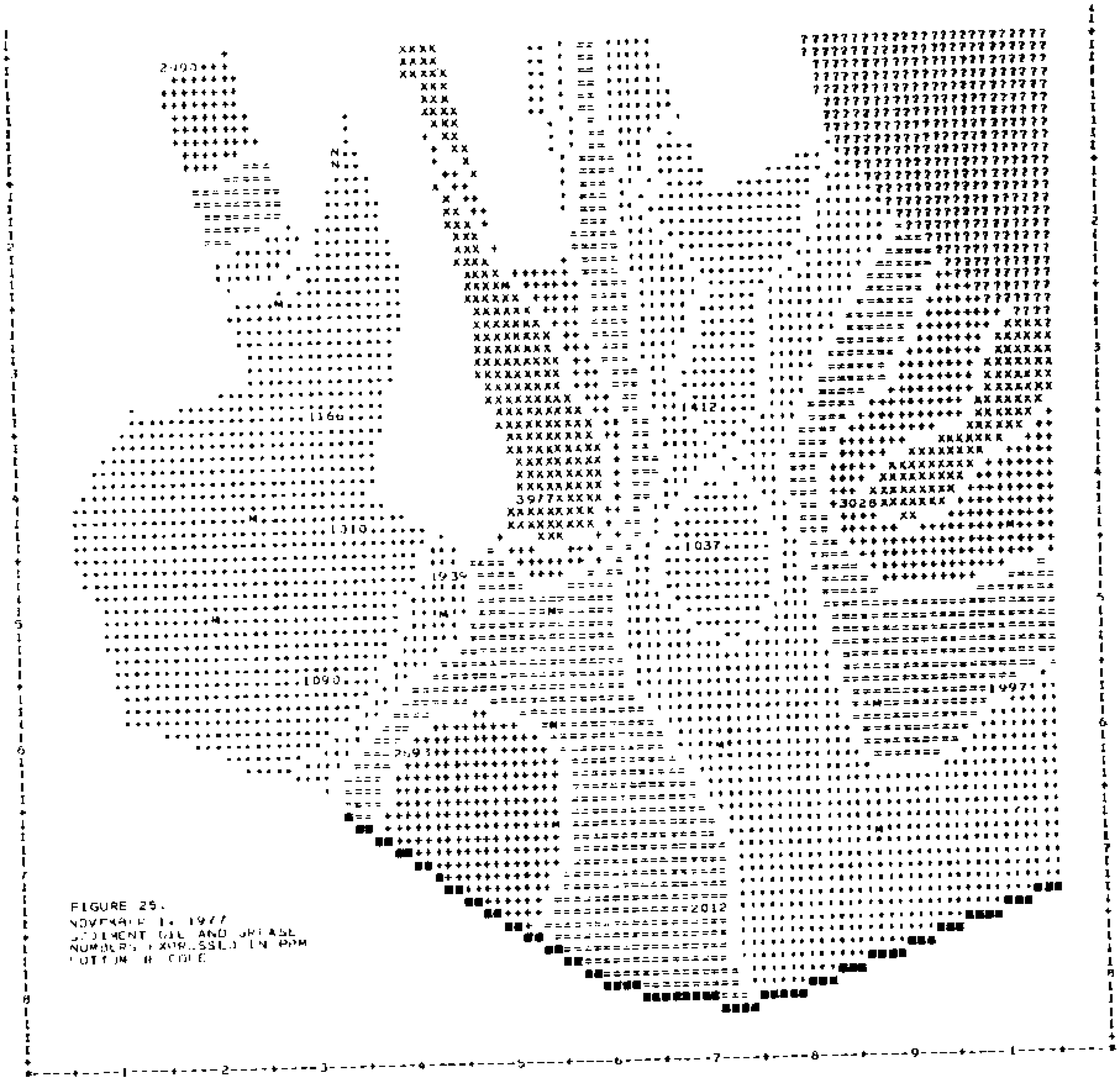
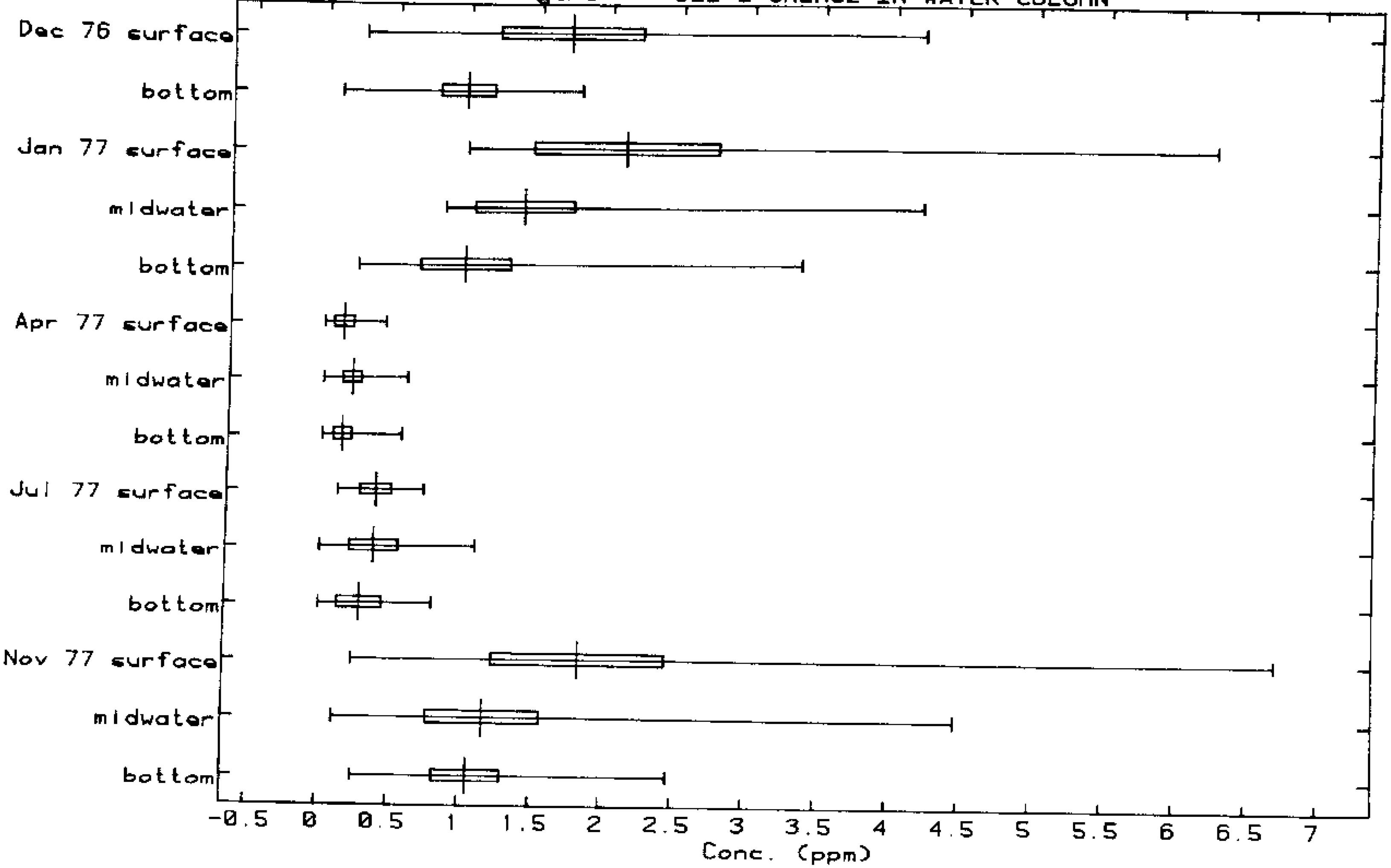


FIGURE 25.
NOVEMBER 1, 1977
SEDIMENT OIL AND GREASE
NUMBERS EXPRESSED IN PPM
BOTTOM OF CORE

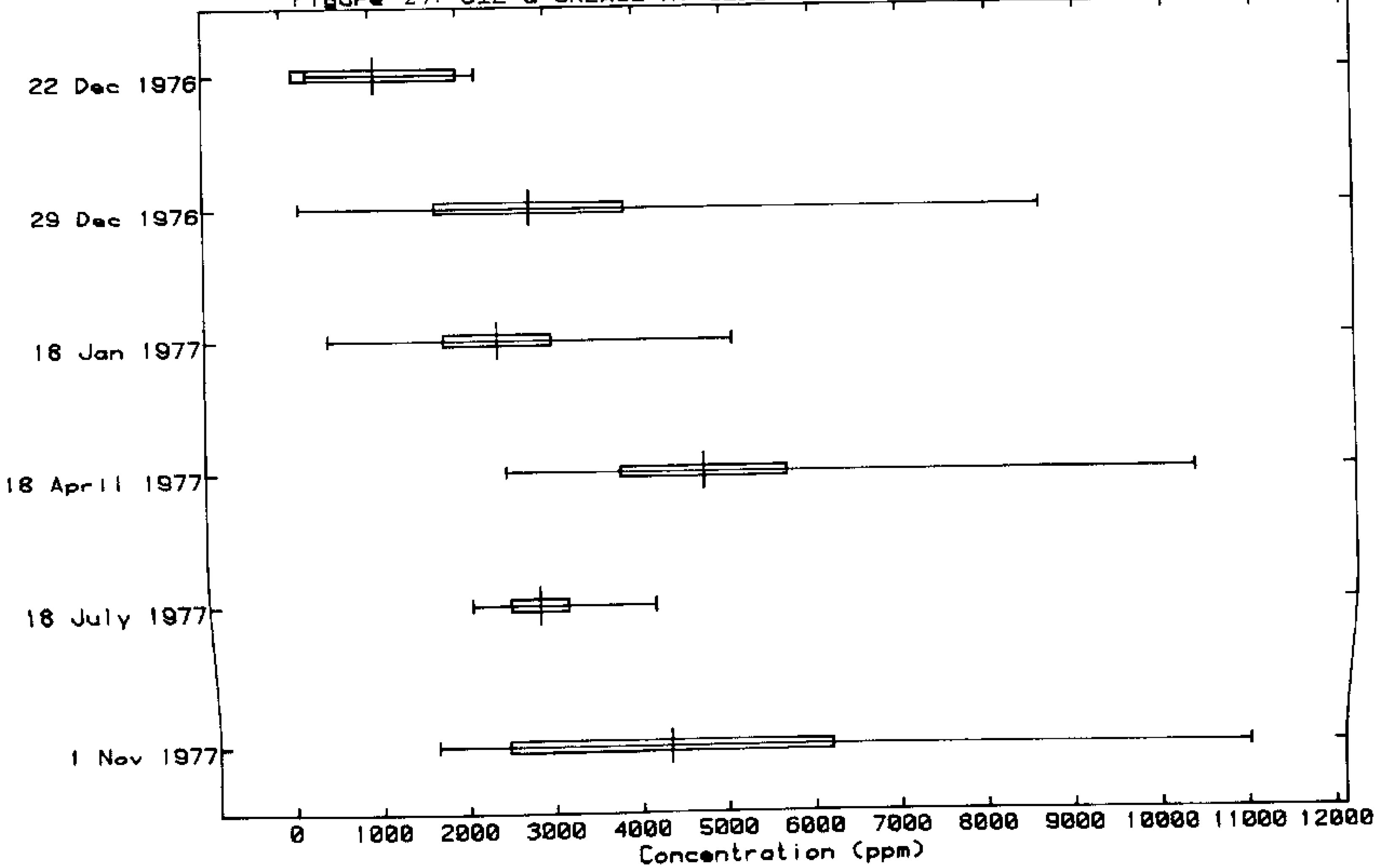
```
SYMAP

13.143996 MINUTES FOR MAP


NOVEMBER 1, 1977

SEDIMENT OIL AND GREASE

NUMBERS EXPRESSED IN PPM BOTTOM OF CORE



DATA VALUE EXTREMES ARE        1010.00        3977.00



TOTAL MISSING DATA POINTS IS          12



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
        (MAXIMUM INCLUDED IN HIGHEST LEVEL ONLY)

                                                                       4000.00     6000.00     9000.00    10000.00
 MINIMUM        5.0     1600.00     2000.00     2500.00     3000.00     6000.00     8000.00    10000.00    11027.00
 MAXIMUM    1500.00     2000.00     2500.00     3000.00     4000.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

                                                                                                          9.31
             14.51       3.63        4.53        4.53        9.07       18.14       18.14       18.14


FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
 LEVEL        1           2           3           4           5           6           7           8           9
          ==========================================================================================================
                                                    +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  ■■■■■■■■■  ■■■■■■■■■
           .........   '''''''''   =========   +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  ■■■■■■■■■  ■■■■■■■■■
           .........   ''''''''''  =========   +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  ■■■■■■■■■  ■■■■■■■■■
 SYMBOLS   ....1....   ''''2''''   ====3====   ++++4++++  XXXX5XXXX  OOOO6OOOO  ØØØØ7ØØØØ  ■■■■8■■■■  ■■■■9■■■■
           .........   '''''''''   =========   +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  ■■■■■■■■■  ■■■■■■■■■
           .........   '''''''''   =========   +++++++++  XXXXXXXXX  OOOOOOOOO  ØØØØØØØØØ  ■■■■■■■■■  ■■■■■■■■■
           .........
          ==========================================================================================================
              5           2           1           2           2           0           0           0           0
 FREQ.
       1   I..1..I     I''2''I     I==3==I     I++4++I     IXX5XXI
       2   I..1..I     I''2''I                 I++4++I     IXX5XXI
       3   I..1..I
       4   I..1..I
       5   I..1..I
```

Figure 26 : OIL & GREASE IN WATER COLUMN



* The difference is significant (by anova, P= 0.001); Range & mean ± 2 S.E. are shown.

Figure 27: OIL & GREASE AT SEDIMENT SURFACE (OUTSIDE OIL POOL)



* The difference is significant (by anova, P= 0.002); Range & mean ± 2 S.E. are shown.

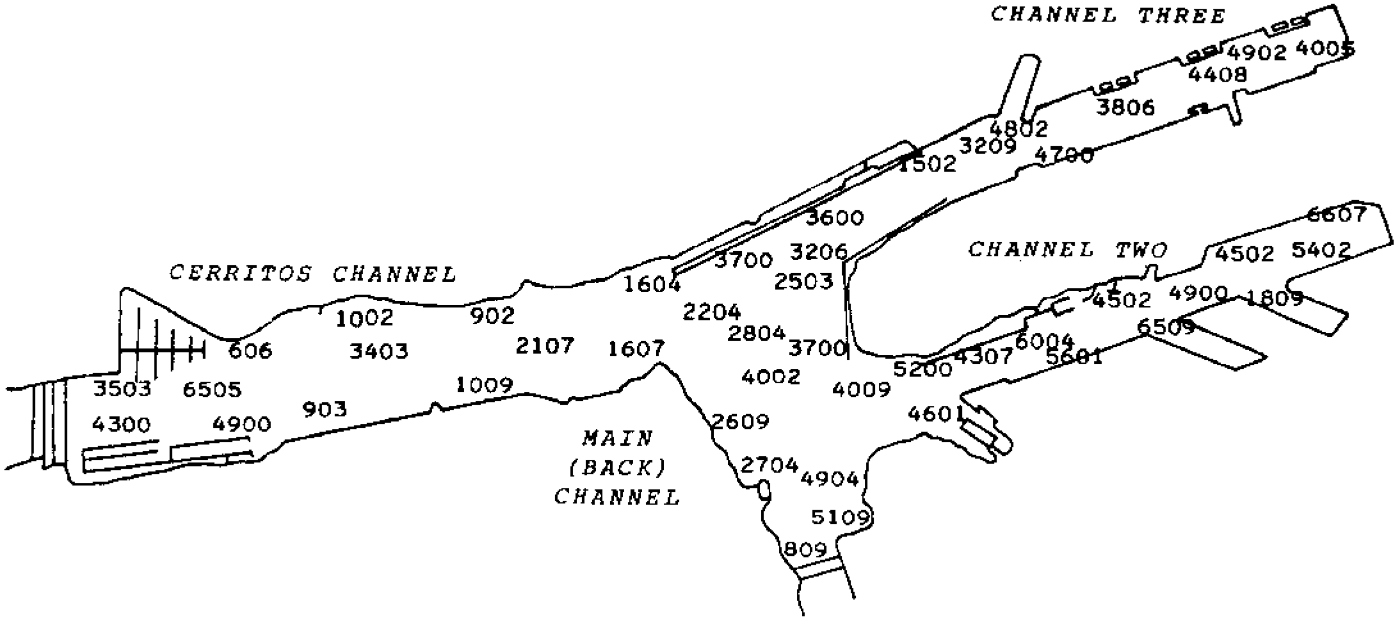


Figure 28. Oil and Grease, Sediment Samples, 1976. (x 100 = ppm)

Source: SOHIO EIR. By HEP.

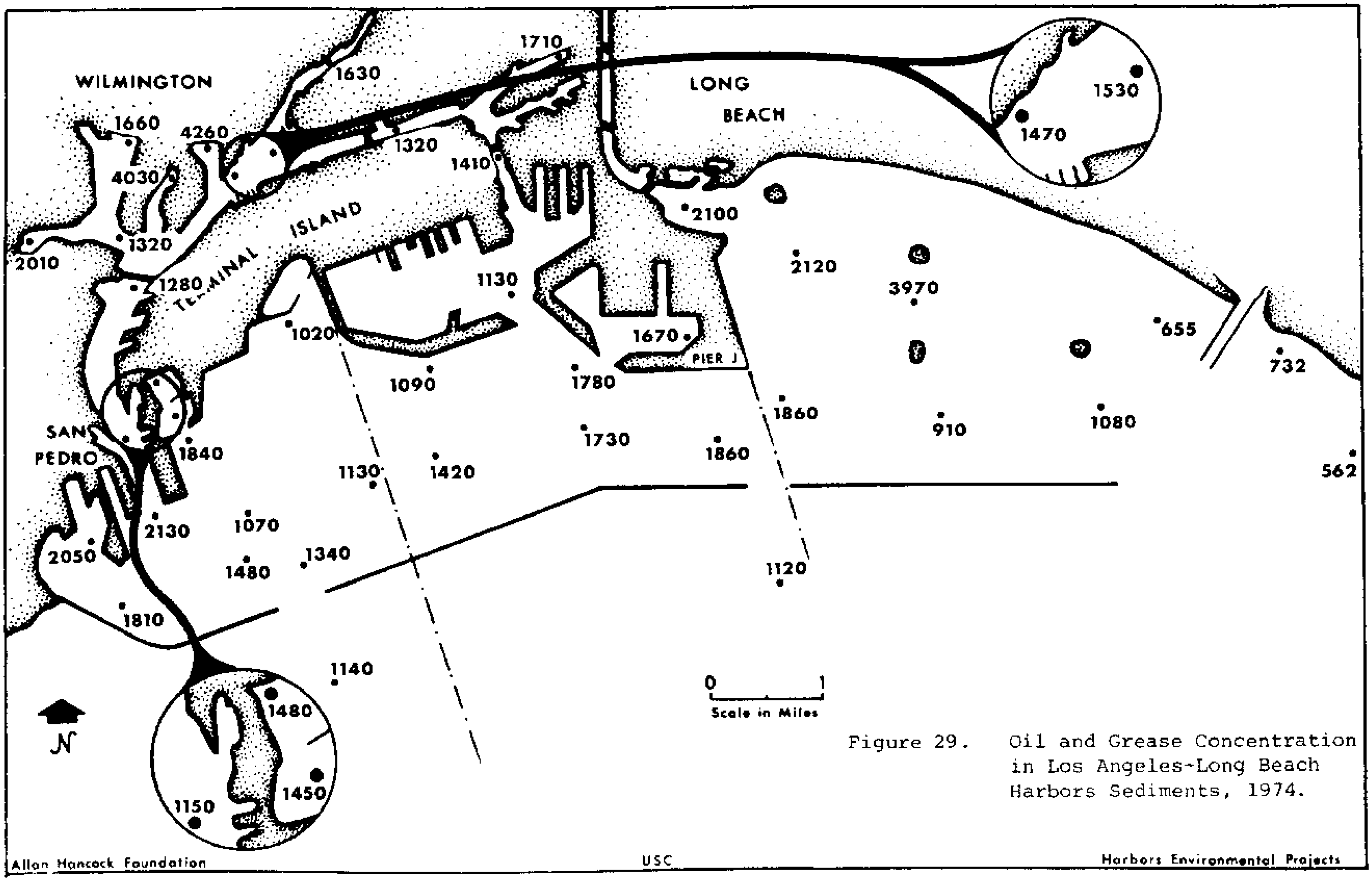


Figure 29. Oil and Grease Concentration in Los Angeles-Long Beach Harbors Sediments, 1974.

Allan Hancock Foundation USC Harbors Environmental Projects

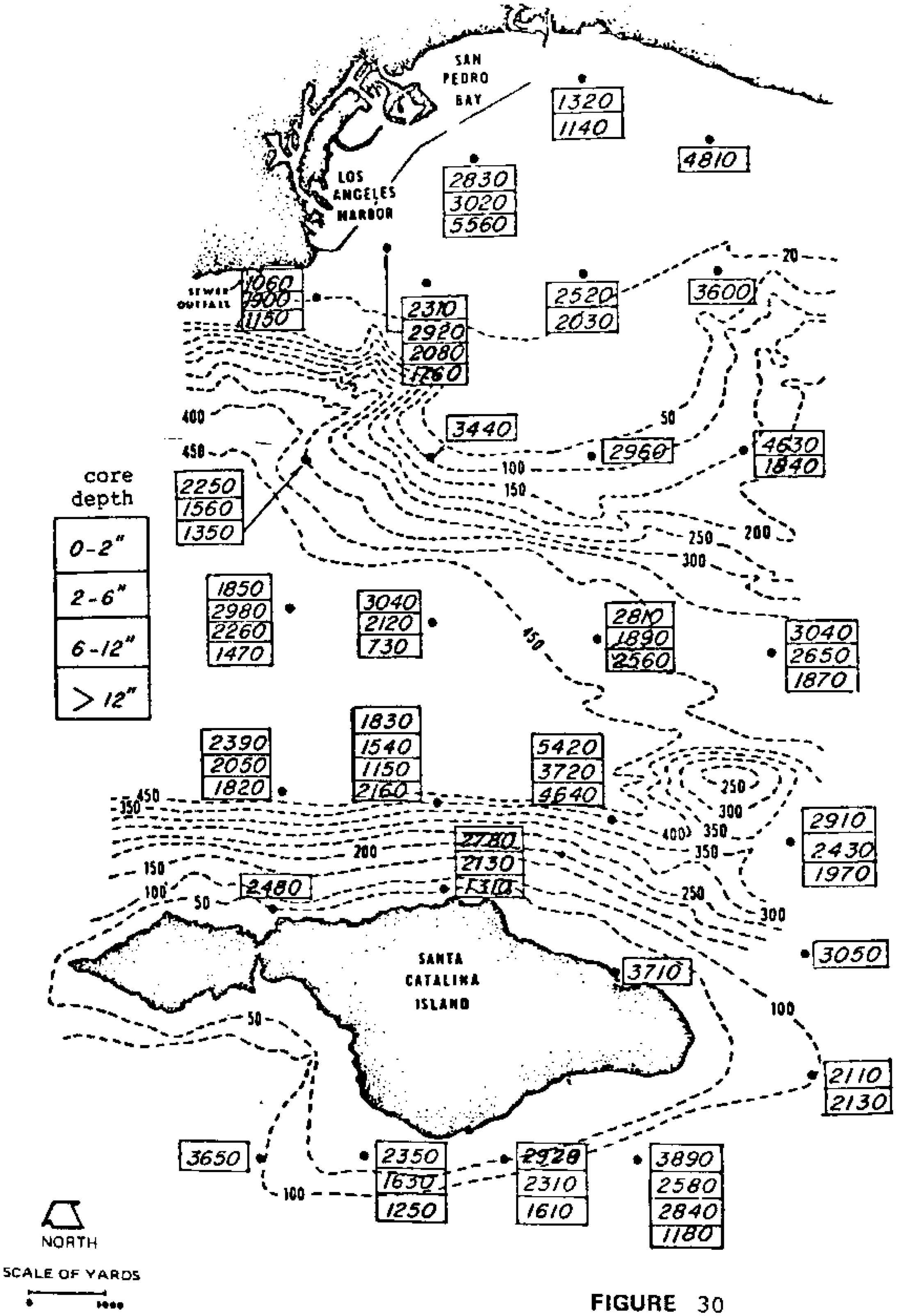


FIGURE 30

OIL AND GREASE IN THE SEDIMENT OF SAN PEDRO CHANNEL (ppm)

Source: Chen and Lu, 1974
Marine Studies of San
Pedro Bay, Calif. Part 7.

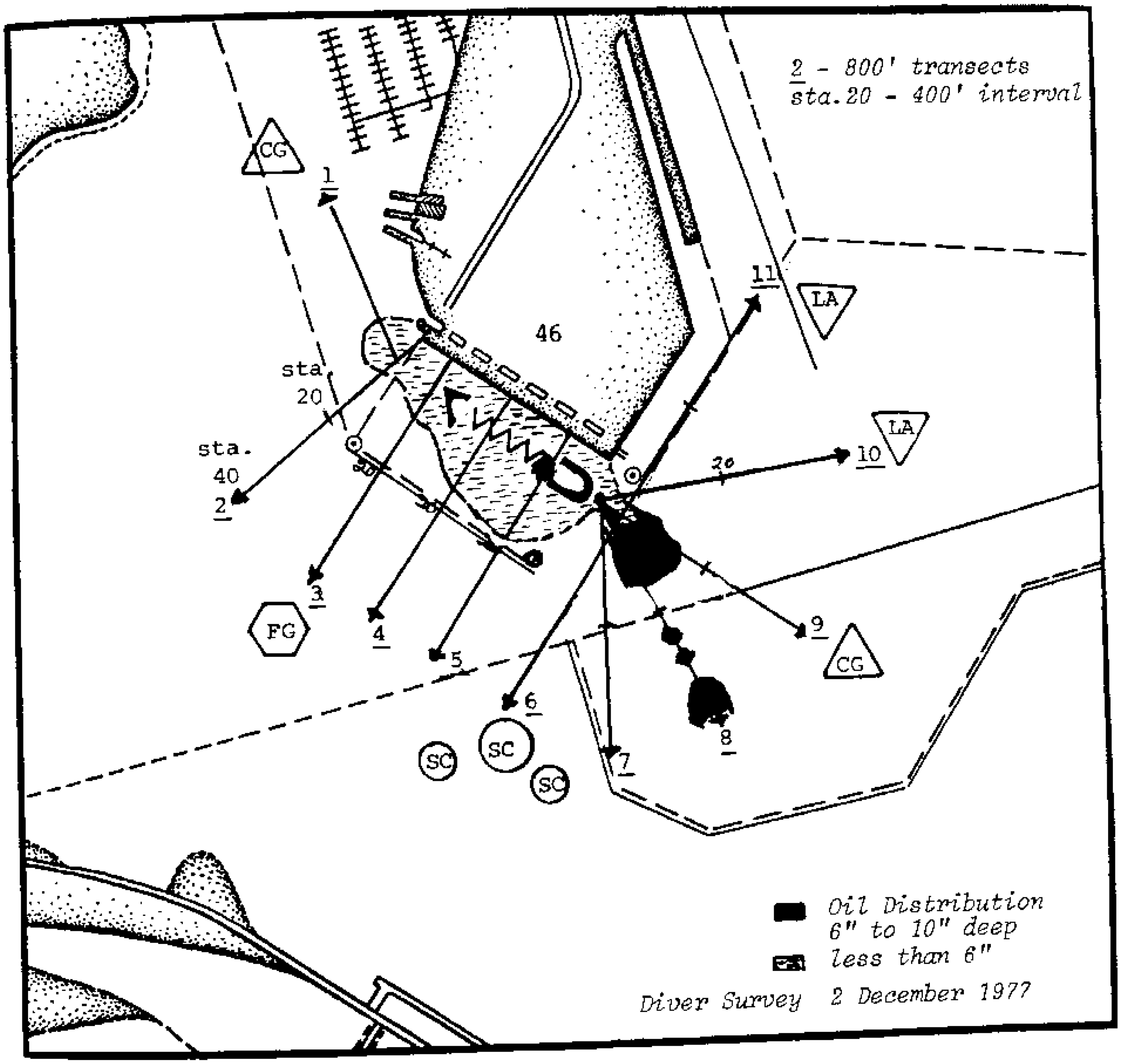


Figure 31. Diver Survey of Residual Oil from the Sansinena, December 2, 1977.

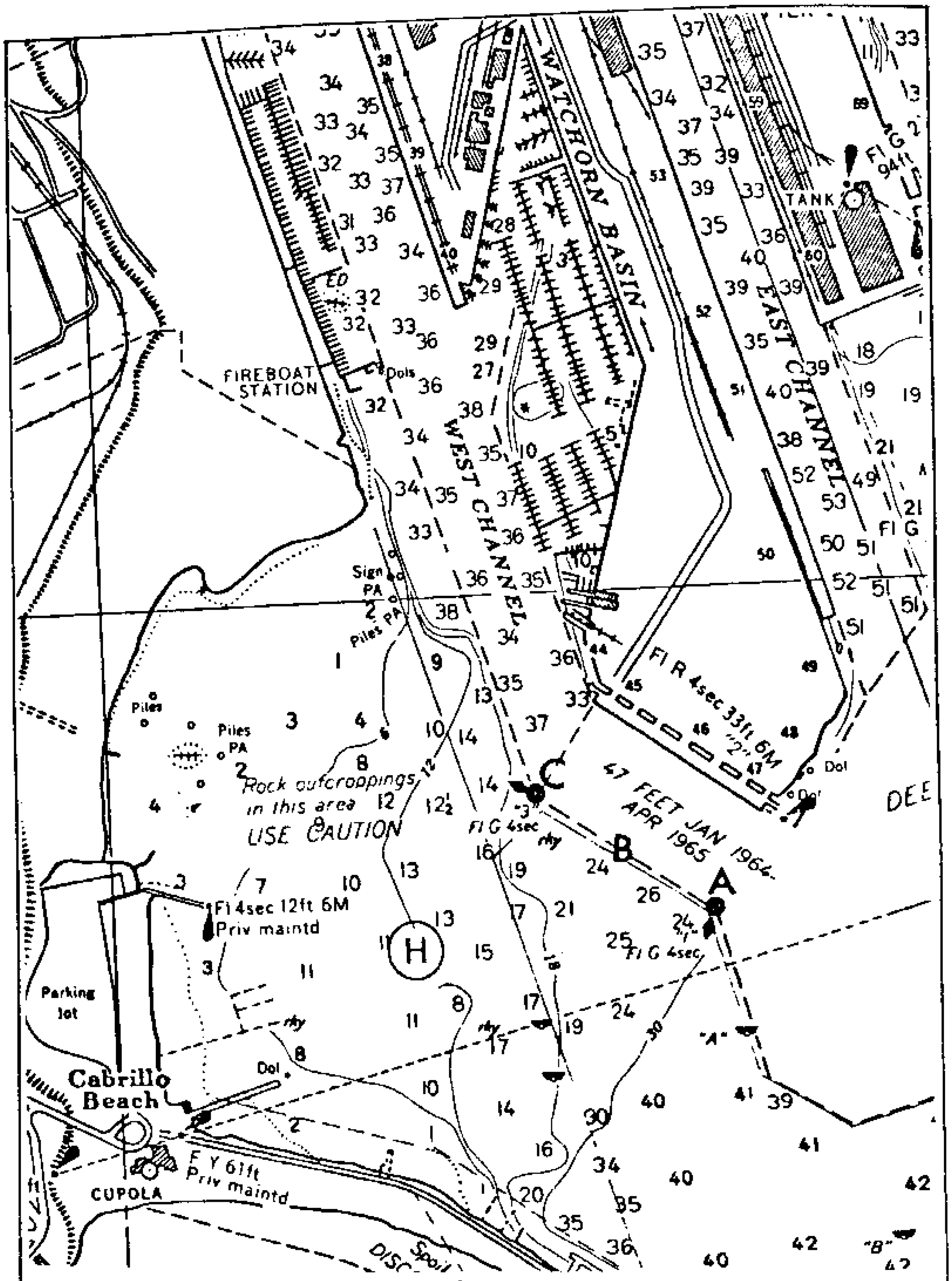


Figure 32
Chamber Locations, Benthic Holding Chamber Study.

III. BIOLOGICAL EFFECTS OF THE SANSINENA INCIDENT

INTRODUCTION

The effects on the marine biota of the Sansinena explosion of December 17, 1976, and the consequent spillage of Bunker C fuel, were evaluated in several ways. The groups of organisms that make up the food web were examined as part of the trophic structure, from nutrients and primary productivity to primary and secondary consumer organisms. Habitats were examined for impacts on the species present, or expected to be present, and on their populations. These factors were then compared with conditions prior to the incident within the harbor, and with ambient conditions outside the harbor. Harbors Environmental Projects has monthly and quarterly sampling records from 1972 to 1978 at a station (A1) outside the entrance to Los Angeles Harbor at the sea buoy (Part I, Figure 1). plus eight other A stations in the outer Los Angeles Harbor. These data were used for comparison. Ambient conditions were warmer than usual during the preceding year and the study period. Therefore, efforts were made to examine the role of temperature as it compared to the impacts of the spill.

A series of 24 stations was established in the vicinity of the Sansinena for sampling on December 29 and 30, 1976. The number of stations occupied quarterly was reduced subsequently because of the time and effort involved. However, the analytical results seen in the plankton and benthos nevertheless indicated instability and variation between stations throughout most of the year that justified an extensive station pattern.

A. PRIMARY PRODUCTIVITY AND NUTRIENTS

Samples for measurement of phytoplankton productivity, chlorophyll *a* and assimilation ratio were collected at five stations near the Sansinena on December 23, 1976. While sampling was very difficult for the first month because of containment and cleanup efforts, it was important to obtain productivity measurements as close as possible to the site initially to look for micro-effects. The station pattern was expanded to the newly established UO1 to UO24 station series on December 29-30, 1976, so the stations are not directly comparable.

Sampling had been carried out at the regular HEP stations in the vicinity on December 1, 1976 as part of the monthly program, supported at that time partially by the Southern California Gas Company and the Sea Grant Program. The stations of this series that are near the site of the incident are stations A2, A8 and A9. Station A10 was not sampled on the date. These stations are shown in Figure 33, along with stations established to monitor the effects of the Sansinena incident.

Station A9 is beside the channel marker buoy where the Sansinena docked; this station became identified as UO9 for the oil study. It was not possible to get to the buoy itself, so samples were taken just outside the boom ("sea curtain") to the east of A9. Station A10 is at the entry of the Holiday

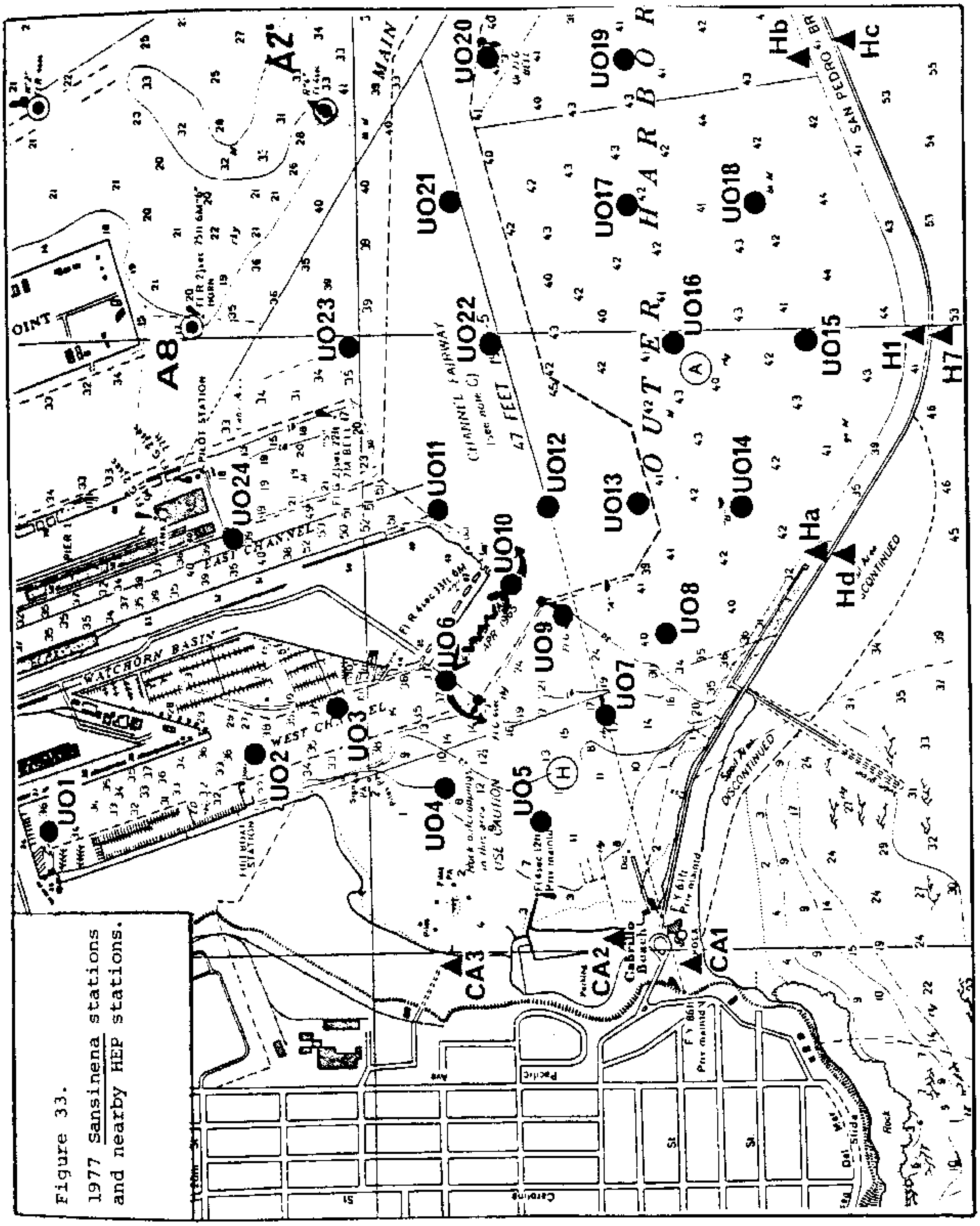


Figure 33.
1977 Sansinena stations
and nearby HEP stations.

Harbor Marina, and was close to U03, which was located in the center of the West Channel rather than to the side of the marina. Routine measurements had not been carried out at A10 since the 1973-1974 studies, but it had been used intermittently for a phytoplankton sampling site for another research study.

Stations A8 and A2 are located across the Los Angeles Main Channel and thus should have escaped the flow of Bunker C on the bottom. These two stations have constituted comparative locations for examining possible effects from the oil nearer the site of the spill.

Samples for productivity measurements were taken with a well-rinsed plastic bucket at the surface of the water at each station. Subsamples for each parameter are taken from that sample to insure homogeneity.

Primary productivity measurements were carried out using a modification of the method of Steeman Nielsen (1952) (Table 1, Section I). In this method radiocarbon ^{14}C as a carbonate is used as a tracer in the photosynthetic conversion of nutrient salts to living material by phytoplankton. Productivity values are expressed as $mgC/hr/m^3$. These values represent the ability of the phytoplankton present, regardless of population size, to synthesize organic material under the conditions prevalent in the waters sampled. The time factor indicates that this is a measurement of a rate at which a biological process is carried out, unlike most values which represent standing crop or the amount of material present at a given time.

The photosynthetic pigments, the chlorophylls, were assessed by spectrophotometric measurement of acetone extracts of the phytoplankton following the method and formulae described by Strickland and Parsons (1968). Chlorophyll values are a measure of the standing crop of the phytoplankton population present at the time and place of sampling. The determination is made on the basis of pigment analysis; the quantity varies among species and cells but is an acceptable measure of the material available to catalyze conversion of non-living material to phytoplankton.

Productivity Results

December, 1976. The time of year when the Sansinena incident occurred coincided with the season that is generally lowest in phytoplankton productivity and standing crop. The data from samples collected on December 23, 1976 (Table 6) do not compare directly with subsequent samples because they were collected in a relatively small area, just outside the containment boom. Because of the proximity of the stations and the overall similarity of the data, the values have been averaged for December 23.

Table 7 presents the data for samples collected at the newly established regular stations on December 29-30, 1976. These data show that there were moderately higher productivities at stations U02 through U06, and at U09 to U011, on December 29-30, as compared with values at the other stations at that time, and with the December 23 values. Also, more moderate increases in the chlorophyll *a* concentrations resulted in higher assimilation values at those stations than generally were found at the other stations.

April, 1977. Values found in April at the regular UO stations were relatively uniform for productivity, chlorophyll and assimilation ratios (Table 8). The values in April were somewhat higher for productivity and chlorophyll, apparently reflecting a vernal bloom that normally occurs in harbor and other local waters.

July, 1977. The productivity was high in July and, with the chlorophyll data, indicated that the population was probably undergoing a bloom (Table 9). The harbor is generally subject to phytoplankton blooms in the spring and again in the summer months; the so-called red tide blooms of dinoflagellate species usually occur in late summer or in the fall. Patches of red tide may occur in limited areas of the harbors almost year around.

The July bloom may have been indicative of an early appearance of the red tide.

Oguri (1976) presented tables of the primary productivity values for Los Angeles and Long Beach Harbors for 1973 and 1974, which can be used to compare the values. The July 1973 values were lower, but August 1974 values were much higher than those seen at the July 1977 UO stations.

It is possible that some effect may have been exerted by the conversion of the Terminal Island treatment plant to secondary waste effluent in June 1977. Higher levels of nitrite and nitrate, which are readily assimilated by phytoplankton, are expected with secondary treatment. The productivity data (Table 11) showed that higher productivity was found in the vicinity of the Sansinena site (at A9) on December 1, 1976 than was occurring at other stations away from the area (Figure 34). The high productivity at A9 at that time suggests that it was due to some other, unknown cause. There was, however, a rise after the explosion, which did not occur away from the site, followed by a drop in January at all the stations sampled.

Data for chlorophyll concentrations (Table 12) showed fairly good agreement with the productivity data through December 1976. Assimilation ratio data (Table 13) emphasized the differences between the stations close to the site and those farther away. Assimilation was higher close to the site through December; the pattern was atypical as compared with the data at the end of 1977 and January of 1978, shown on the table.

November, 1977. Data for November 1, 1977 (Table 10)showed a pattern of moderate productivity, high chlorophyll values, and low assimilation ratios. This suggests that the phytoplankton population, although it remained relatively high, was either limited or inhibited. This might suggest a declining bloom that occurred with normal seasonal changes. However, this coincided with a return of very high levels of oil and grease in the water column and the sediments so that it appears possible that phytoplankton activity was inhibited. Higher than normal temperatures for the period would normally have been expected to produce a fall bloom, such as was shown in November, 1974 data.

The concurrent monitoring program at regular HEP stations included a few sites in the Sansinena area, as well as other locations in the outer Los Angeles Harbor (Figure 1, Section I). Those stations were monitored monthly and were in close enough proximity to permit some direct comparison. Station U03 is at the same site as A10, U09 and A9 were the same site, except that both were deflected to the south by the oil containment boom or curtain. Stations U03, U06, U09, U010 and U011 could be considered directly comparable with A9 and A10. These stations as a group were close to the Sansinena site and would be expected to show the most pronounced impact. Stations U020 and U021 were farther removed from the site, and might show less impact. They are most directly comparable to stations A2, across the Los Angeles main channel (east of station U019, off the map, Figure 33). Comparing the data in such a grouping of stations close to the site and farther away from the site permits some extrapolation of finer detail from monthly A station sampling than did the quarterly Union Oil sampling.

Tables 11, 12 and 13 show the combined data for the stations discussed for the period of December 1, 1976 to January 4, 1978. The tables also include the averaged data from the special stations occupied close to the Sansinena on December 23, 1976.

Conclusions

The data indicate that there was a significant stimulation in the activity of the phytoplankton in the aftermath of the explosion and oil spill. However, this did not result in a significant increase in the size of the population. The shortness of the period during which this occurred indicates that this was possibly related to the immediate trauma of the incident, rather than the presence of oil in the environment. A small amount of oil in the water is not an uncommon occurrence in the area.

Nutrients

Nutrient levels in the entire harbor were measured in 1973 and 1974 (AHF, 1976). Nitrite, nitrate and ammonia values were determined for regular A stations on December 1, 1976 prior to the explosion, and at the Union Oil stations shortly afterward (Table 14).

Nitrite. Nitrite levels generally are at maximum in June-September, and the minimum falls in January-February. The mean concentration in 1973-1974 was 0.19, with a range of from 0.0 to 1.02 μg-atoms N/l.

Nitrite levels were below 0.20 at A2 and A8, and at 0.21 at A9 before the spill. Nitrite levels dropped slightly by the end of December and then rose gradually in January at A9 (U09). Levels at A8 were stable and below those of A9, throughout the period. A2 had the lowest readings throughout December, but rose steeply between the 5th and 18th of January to be among the highest (Figure 34).

At station A10 (U03) the value on December 23rd was close to A8, but it rose somewhat by December 30, and peaked by January 5. It then dropped steeply to a level below all other stations in the area by January 18, 1977.

Nitrate. Nitrate is always the most abundant chemical in the harbor of those measured. The mean concentration for 1973-1974 was 3.42 µg-atoms N/1, with a range of 0.0 to 10.06 µg-atoms N/1. There is usually a winter maximum, followed by spring and summer lows which build up gradually after August (Raymont, 1963).

Values at A2 were low, while those at A8 were just above average and at A9 were slightly higher. Values at A8 and A2 stayed relatively stable through January 5th with A2 rising somewhat; A2 then rose steeply by January 18 but remained well below A9 values.

Following the spill, values at A9 rose and stayed fairly high, above 6 µg-atoms N/1. Values at U03 (A10) were initially higher than at A9 after the spill, but fell at the end of December. The U03 value returned to the earlier high by January 18, 1977 (Figure 34).

Ammonia. The mean for ammonia in the entire harbor in 1973-1974 was 0.41 µg-atoms N/1 with a range from 0.0 to 26.11 and 12.85 µg-atoms N/1 respectively (AHF, 1976). There were no seasonal extremes during that period, but intermittent peaks occurred.

Ammonia levels were above average at A2 and A9, and highest at A8 before the spill. A8 is closest to the sewer outfall and cannery waste areas. These values gradually rose from December 1, 1976 to January 5, 1977.

At station U03 (A10) the reading was in the range with A8 and A9 on December 23 but rose above them, lying between values for U020 (above U03) and U021 (below U03). At U020, the high value decreased, as did the U03 value by January 18.

Nutrient Results

Nutrient levels peaked well above ambient in the two weeks after the spill in the vicinity. Nitrite rose near the spill and then dropped below ambient by January 18 except at A9. Nitrate remained high closest to the spill site but dropped in the fairway. Ammonia rose and remained high; it was highest nearest the spill. This may reflect the reduced utilization by stressed phytoplankton. Although data points were limited prior to the spill and restricted by cleanup operations afterward, the trends appear to be valid.

Table 6. Dec. 23, 1976. Phytoplankton Productivity, Chlorophyll a and Assimilation Ratio at 5 Special Stations in the Vicinity of the *Sansinena*. Station SPI was nearest to the bow and station SPV nearest to the stern.

Station	Productivity mgC/hr/m^3	Chlorophyll a mg/l	Assimilation Ratio
SPI	2.97	0.81	3.67
SPII	3.39	0.92	3.68
SPIII	5.92	0.54	10.96
SPIV	3.62	0.88	4.11
SPV	3.16	0.73	4.33
mean values $\bar{X}$	3.81	0.78	5.35

Special Station Locations

SPI - near U03
SPII - near U06
SPIII - between U06 and U07
SPIV - south of U09
SPV - at U013

Table 7. Dec. 29-30, 1976. Phytoplankton Productivity, Chlorophyll a and Assimilation Ratio at a Series of Stations in Outer Los Angeles Harbor. Stations are shown in Figure

Station	Productivity mgC/hr/m^3	Chlorophyll a mg/l	Assimilation Ratio
UO1	2.95	1.13	2.61
UO2	5.70	1.08	5.28
UO3	7.24	0.95	7.62
UO4	5.40	0.84	6.43
UO5	5.30	1.12	4.73
UO6	7.67	1.18	6.50
UO7	3.79	0.99	3.83
UO8	3.26	0.77	4.23
UO9	4.66	0.95	4.91
UO10	4.95	1.15	4.30
UO11	4.72	0.93	5.08
UO12	3.48	0.75	4.64
UO13	3.09	1.29	2.39
UO14	4.00	0.99	4.04
UO15	3.04	0.80	3.82
UO16	3.84	0.98	3.92
UO17	3.73	0.98	3.82
UO18	4.49	1.15	3.90
UO19	2.81	0.66	4.24
UO20	2.64	0.75	3.52
UO21	1.95	----	----
UO22	4.04	1.19	3.41
UO23	4.26	----	----
UO24	1.52	0.75	2.02

Table 8. April 15, 1977. Phytoplankton Productivity, Chlorophyll a and Assimilation Ratio at a Series of Stations in Outer Los Angeles Harbor.

Station	Productivity mgC/hr/m^3	Chlorophyll a mg/l	Assimilation Ratio
UO3	7.25	2.70	2.69
UO6	5.19	2.36	2.20
UO7	7.75	1.49	5.20
UO8	5.51	1.63	3.38
UO10	3.28	1.24	2.65
UO11	8.89	----	----
UO13	5.71	2.37	2.41
UO15	8.07	2.15	3.75
UO19	8.77	1.88	4.66
UO21	8.22	1.31	6.27
UO22	8.91	2.19	4.07
UO23	8.69	2.23	3.90

Table 9. July 18, 1977. Phytoplankton Productivity, Chlorophyll *a* and Assimilation Ratio at a Series of Stations in Outer Los Angeles Harbor.

Station	Productivity mgC/hr/m^3	Chlorophyll *a* mg/l	Assimilation Ratio
UO3	9.72	2.21	4.40
UO6	16.26	3.80	4.28
UO7	12.48	3.18	3.92
UO8	9.69	2.28	4.25
UO10	12.87	2.31	5.57
UO11	7.73	2.33	3.32
UO13	20.27	2.39	8.48
UO15	24.38	3.22	7.57
UO19	26.47	1.94	13.64
UO 21	18.42	1.54	11.96
UO22	20.12	2.25	8.94
UO23	14.34	3.07	4.67

Table 10. Nov. 1, 1977. Phytoplankton Productivity, Chlorophyll a and Assimilation Ratio at a Series of Stations in Outer Los Angeles Harbor.

Station	Productivity mgC/hr/m^3	Chlorophyll a mg/l	Assimilation Ratio
UO3	4.33	6.21	0.70
UO6	4.56	5.99	0.76
UO7	3.78	6.00	0.63
UO8	4.20	3.30	1.27
UO10	4.01	3.17	1.09
UO11	3.77	4.07	0.93
UO13	7.50	5.00	1.50
UO15	10.76	8.94	1.20
UO19	3.95	3.24	1.22
UO21	5.70	2.90	1.97
UO22	7.74	4.44	1.74
UO23	5.93	3.16	1.88

Table 11. Comparison of productivity data at selected Union Oil stations and "A" stations in outer Los Angeles Harbor, 1 December 1976 to 4 January 1978.

Date	Stations Nearest The Sansinena Site					Stations Away From Site		
	UO3	UO6	UO10	A9	A10	UO20	UO21	A2
1 Dec '76				3.46				1.42
23 Dec		$\bar{X} = 3.81$						
29 Dec	7.24	7.67	4.95	4.66		2.64	1.95	
5 Jan '77				1.92	1.29			0.96
2 Feb				3.05	3.42			2.27
9 Mar				6.04	16.15			14.66
6 Apr				10.09	7.99			22.36
18 Apr	7.25	5.19	3.28				8.22	
4 May				4.16	3.39			4.59
8 June				9.56	12.95			14.23
6 July				18.38	13.81			30.52
18 July	9.72	16.26	12.87				18.42	
3 Aug				39.11	35.73			51.50
14 Sept				0.45	0.20			0.67
28 Sept				1.92				4.95
5 Oct				4.23				7.60
12 Oct				3.77				3.93
1 Nov	4.33	4.56	4.01				5.70	
2 Nov				3.65				4.49
6 Dec				0.62				1.17
4 Jan '78				1.40				1.98

Table 12. Comparison of chlorophyll *a* concentrations at selected Union Oil stations and "A" stations in outer Los Angeles Harbor, 1 December 1976 to 4 January 1978. Data are expressed as mg/l.

Date	Stations Nearest the Sansinena Site					Stations Away From Site		
	U03	U06	U010	A9	A10	U020	U021	A2
1 Dec '76				1.54				0.85
23 Dec		$\bar{X}$ = 0.78						
29 Dec	0.95	1.18	1.15	0.95		0.75		
5 Jan '77				1.59	0.66			0.36
2 Feb				1.32	1.33			1.13
9 Mar				1.64	5.11			8.19
6 Apr				5.84	4.06			6.22
18 Apr	2.70	2.36	1.24				1.31	
4 May				2.22	2.75			1.59
8 June				2.40	3.15			2.67
6 July				3.56	4.19			4.23
18 July	2.21	3.80	2.31				1.54	
3 Aug				1.45	2.77			5.43
14 Sept				3.28	4.03			3.91
28 Sept				2.20				1.85
5 Oct				4.97				4.31
12 Oct				5.31				2.03
1 Nov	6.21	5.99	3.17				2.90	
2 Nov				3.46				3.14
6 Dec				1.01				0.52
4 Jan '78				1.21				1.17

Table 13. Comparison of assimilation ratios at selected Union Oil stations and "A" stations in outer Los Angeles Harbor, 1 December 1976 to 4 January 1978.

Date	Stations Nearest the Sansinena Site					Stations Away From Site		
	UO3	UO6	UO10	A9	A10	UO20	UO21	A2
1 Dec '76				2.25				1.67
23 Dec	$\overline{X} = 5.35$							
29-30 Dec	7.62	6.50	4.30	4.91		3.52		
5 Jan '77				1.21	1.95			2.67
2 Feb				2.31	2.56			2.45
9 Mar				3.68	3.16			1.79
6 Apr				1.73	1.97			3.59
18 Apr	2.69	2.20	2.65				6.27	
4 May				1.87	1.23			2.89
8 June				3.98	4.11			5.33
6 July				5.16	3.30			7.22
18 July	4.40	4.28	5.57				11.96	
3 Aug				26.97	12.90			9.48
14 Sept				0.14	0.05			0.17
28 Sept				0.87				2.68
5 Oct				0.85				1.76
12 Oct				0.71				1.94
1 Nov	0.70	0.76	1.28				1.97	
2 Nov				1.05				1.43
6 Dec				0.61				2.25
4 Jan '78				1.16				1.69

Table 14. Comparison of Nutrients Before and After Bunker C Spill, on December 17, 1976 (in μg-atoms N/l).

	1 Dec	23 Dec	30 Dec	5 Jan	18 Jan
NITRITE					
nearest Sansinena					
A9 =UO9	0.21		0.19	0.22	0.23
A10=				0.28	
near UO3		0.20	0.22		0.13
across main channel					
A8	0.19			0.18	
A2	0.16			0.11	0.26
n. side of fairway					
UO23			0.20		0.15
s. side of fairway					
UO21			0.14		
UO20			0.14		0.14
NITRATE					
nearest Sansinena					
A9=UO9	4.65		6.42	6.14	6.30
A10=				5.45	
near UO3		6.82	5.18		6.71
across main channel					
A8	3.98			4.20	
A2	2.02			3.29	5.11
n. side of fairway					
UO23			5.42		4.85
s. side of fairway					
UO21			5.70		
UO20			5.87		4.50
AMMONIA					
nearest Sansinena					
A9=UO9	1.93		4.86	7.23	
A10=				8.34	
near UO3		2.93	7.24		
across main channel					
A8	2.87			6.57	
A2	1.16			2.76	
n. side of fairway					
UO23			5.41		
s. side of fairway					
UO21			6.63		
UO20			8.78		

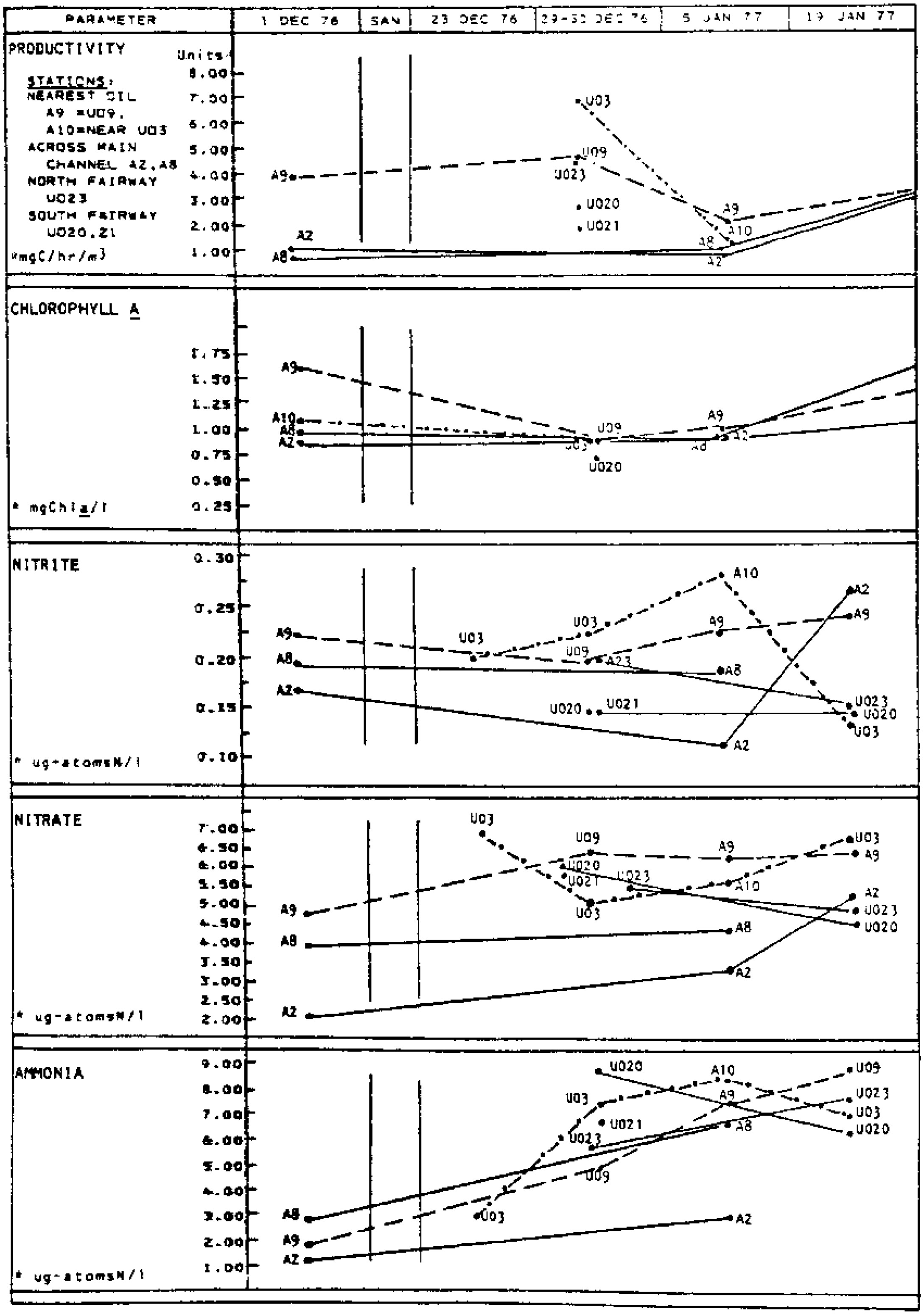


FIGURE 34. COMPARISON OF PHYTOPLANKTON AND NUTRIENTS BEFORE AND AFTER THE SANSINENA SPILL.

B. BENTHIC BIOLOGY

The first major study of the marine benthic ecology of Los Angeles-Long Beach Harbors was conducted in the early 1950's (Reish, 1959). Reish found that some portions of the Harbor benthos, such as inner slips, were devoid of macroscopic animal life. Because of the high organic load, the low dissolved oxygen (DO), and the presence of hydrogen sulfide (H_2S), these areas were characterized as very polluted. Areas that were less polluted supported more diverse assemblages of benthic species.

More recently a number of surveys of limited areas have been conducted in the harbor for private industry. Results of these studies suggest a general improvement of benthic conditions, with more species and less pollution in some areas. Such improvement probably resulted from pollution abatement measures enacted circa 1969, although differences in sampling techniques do not permit exact comparison.

Since 1971 Harbors Environmental Projects (HEP), University of Southern California, has maintained an extensive monitoring program and also conducted a number of small-scale studies in the harbor complex. Data for 1973 and 1974 were analyzed using multivariate techniques as reported in Allan Hancock Foundation (AHF), 1976 and Smith, 1976.

By 1973-1974, the Los Angeles-Long Beach Harbors had one of the richest soft-bottomed communities in southern California. A number of stations in the outer harbor supported 40-75 species and 40,000 to 77,000 individuals per square meter of benthic surface. This can be compared with inner slip areas with 3-20 species and 2,000-10,000 individuals. In Santa Monica Bay, California, an area that is considered to be enhanced by the Hyperion sewage outfall plume, supported 24 species and 16,000 individuals/m^2.

The harbor area not far from the Sansinena site supported about 40 species and 40,000 individuals/m^2 in 1974 but there is little information on populations since that time.

The effects of seasonal change on benthic invertebrates is probably less severe than it is on planktonic organisms. Effects of changes in annual temperature cycles such as took place in 1976 and 1977 are not known, and the analysis of data available is still in process. Apparently, benthic populations were reduced generally after 1974.

Figures 35 and 36 show a comparison between the annual surface temperature curve and the incidence of three common benthic species for station A1, which is at the sea buoy outside the main channel entry of the Port of Los Angeles, and A9, located by the Sansinena site. Note that one of the species, *Haploscoloplos elongatus*, showed a small rise in April 1977, at the sea buoy (A1), but otherwise counts were low during 1977. At A9, counts of all three species dropped in April from December-January levels, the reverse of expected spring increases in populations.

The Sansinena data were analyzed by computer programs similar to those used in the 1976 reports. Results were transformed from dendrograms of stations and two-way tables (TWT) of species information into maps showing site (station) groupings. The groupings are based on the biological data (the occurrences of species and populations) and the abiotic parameters measured (see Section I, this volume, for methods).

Weighted discriminant analysis showed the interactions of the parameters and gives coefficients of separate determination for each parameter. Thus the higher the coefficient for a parameter the more important that parameter is as a variable interacting with all the other biotic and abiotic variables. Bar graph data, presented at the end of this section, shows the separate parameters (Figures 58-67), but the coefficients will generally not show the same ranking of means and extremes as the bar compensates for patchiness and statistical errors in sampling, population dominance and the like.

December 29-30, 1976. The site group separations produced by the dendrograms and two-way tables at first glance appeared to be typical of usual harbor conditions for the season, separating inner slips and outer shallow areas from deeper channels. In general, the inner slips may be warmer, with less circulation (Groups 4 and 5), while outer harbor areas are more influenced by oceanic conditions (Groups 1, 2 and 3). Shallow areas are quicker to warm and to cool, but the usual seasonal drop in ocean temperatures did not occur; rather, temperatures increased toward the end of December and in January 1977 and so the temperatures did not produce separations. Examination of the TWT (Figure 38) showed differences among the site groups based on fairly large gaps in the fauna. The benthic species in the harbor are mostly polychaete worms because of the soft unconsolidated sediments composing the bottom; stirring is common because of shallowness and ship traffic. Some benthic molluscs and crustaceans occur in certain areas, however.

Coefficients of separate determination indicated that salinity, pH, turbidity and depth were important natural variables. The oil and grease levels in the surface sediments were highest for Group 2 stations, as shown by the bar graph data (Figure 67), followed by Group 3 and Group 1 stations, in descending order. It must be noted that the station sampling pattern did not include sites beneath the pool of oil, since all fauna there would have been killed when covered by the thick layer of spilled Bunker fuel. There was little difference between the means of Groups 1 and 4 with regard to surface sediment oil and grease, so that other factors must have influenced the separation as well. Station U04, in very shallow water, stood alone (Group 5); it is a population feeding area for birds and the benthic fauna might reflect this as well as physical parameters.

Concentrations in sediments for the December 30, 1976 benthic sampling ranged as follows:

Group	Minimum	Maximum	Mean
1	1525	4765	2628
2	3925	7290	5850
3	2815	6890	4820
4	410	5035	2426
5	2155	2155	2155

Surface and bottom waters were sampled for oil and grease in December. The groups defined by the benthic species did not seem to be correlated with the surface measurements, which is not surprising for benthic species. The range was from 4.2 ppm at station U01, down to 0.1 ppm at station 21, on the channel fairway. Later analyses indicated that levels in the bottom water may be more important than in the sediment itself. Group 5 was a single station (U04) isolated in a shallow area of the harbor that is a popular site for wading birds and gulls. It was isolated, using weighted means, by higher salinity and by lower pH, dissolved oxygen and light transmittance.

While Group 5 had the lowest sediment oil and grease levels, it had the highest level among the bottom water means (Figures 66, 67). This was no doubt responsible for the large gaps in species occurrences shown in the TWT (Figure 38). Only the polychaetes generally found in polluted areas were prominent, along with the clam *Macoma*.

Group 4 stations included inner channel and shallows areas. They were closely related to Group 5 in low temperature, dissolved oxygen, pH and light transmittance and probably separated from Group 5 by reason of lower salinity in Group 4. Sediment oil and grease means were next lowest in Group 4 and second highest in bottom water. There were gaps in the Group 4 species shown in the TWT, but not as extreme as in Group 5, and the species really determine the site groupings.

Site groups 1, 2, and 3 were in deeper water, but had higher weighted means for temperature, dissolved oxygen and pH. Groups 1, 2 and 3 had higher oil and grease levels in the sediment and lower levels in the bottom water than Groups 4 and 5, although Group 1 means were closer to those of Groups 2 and 3 than the others. Groups 1 and 2 were quite close to each other in the dendrogram (Figure 39) as well as overlapping geographically. The species shown in the TWT indicated the differences that created the separations of Groups 1, 2 and 3; otherwise they might have fallen into one large outer harbor group, based only on natural physical parameters.

Figure 40 gives the numbers of species and individuals per square meter of surface, as well as the Shannon-Weiner Diversity Index. Shannon-Weiner values should be viewed with consideration of the restrictions in normal soft-bottom species numbers; the trends in the subsequent quarters are of interest for comparison, however.

January, 1977. At first glance, examination of January data also appeared to show inner slip-outer harbor divisions, with Groups 3 and 5 representing the inner area (Figure 71).

Based on the bar graph data, sediment of oil and grease levels were similar in Groups 1, 2 and 3, whereas the oil and grease levels in surface, midwater , bottom water and sediments were much higher at the single station U07 in Group 5 (Figure 66). U07 is in shallower water near Cabrillo Beach; depth was an important factor in separating Groups 3 and 5 from the deeper stations Groups 1, 2 and 4.

The January range for all stations in surface sediment oil and grease was from 930 ppm to 5080 ppm, a considerable drop from the December range (Figure 67; Figures 5 and 9, in Section II).

Group 5 had the highest weighted means for temperature and for all the oil and grease measurements in the water column and sediment. It had the lowest weighted mean salinity, dissolved oxygen, pH, and light transmittance as well. Group 3, while close to Group 5 in depth, had the lowest weighted mean temperature and much lower oil and grease levels than Group 5.

Group 1, composed of outer harbor stations, had the highest weighted means for salinity, dissolved oxygen, and pH, the deepest waters, and the lowest oil and grease levels in all measurements. Groups 2 and 4 assumed intermediate positions in the weighted means. Bar graph data (Figures 58-61) showed a wider range for oil and grease values for Group 2 stations than the other site groups. Salinity differences were probably transitory and not significant to the benthic animals.

The most important natural variables for the distribution of benthic organisms in January were temperature, dissolved oxygen, and depth. Bottom water (1m above the sediment) levels of oil and grease were more important than any of the natural variables, according to the coefficients of separate determination.

The two-way table (Figure 42) illustrates the biological data that gave the five groupings. The number of species dropped greatly in January, from about 60 in December to about 40. The dendrogram (Figure 43) could have been divided into 4 major groups instead of 5, merging groups 2 and 3, but the TWT showed clear differences in species composition between the two groups. Although the number of species (taxa) dropped, the average number of organisms per taxon, per square meter (Figure 44) rose. This suggests a biostimulation effect of removal of competitors for the animals able to survive stressed conditions. If bacteria multiply rapidly following a spill, as has been suggested, the benthic filter feeders not affected by toxicity may have found more to eat in the usually lean month of January.

Population Trends. The April sampling showed a large drop in average numbers of individuals per species or taxon, from 1256 in January to 252! At station U023 near the main channel the drop was from 1865 in January to 341. At U06, near the *Sansinena*, December showed an average of 1582; this dropped to 1016 in January, to 361 in April, to 228 in July, and rose to 488 in November.

In contrast U010 showed an average number of individuals per taxon of 757 in December, 824 in January, and 248 in April. In July, however, the number soared to 2836 and remained up in November. The average number for all taxa rose from the low of 252 in April to 719 in July and back to normal at 1213 in November (Figure 45).

April generally shows an increase in harbor fauna so that the drop was impressive. Unfortunately, no *Sansinena* studies were possible after

November, 1977, so that the trends in 1978 could not be observed over the UO station pattern. Records for the regular A stations are being taken under contract with the City of Los Angeles during 1978.

April 1977. Classification produced five groups (Figures 46-48), with Group 1 fairly typical of outer harbor stations and with comparatively good diversity and numbers. Station UO15 (Group 5) stood alone in the TWT, with low species and abundance (Figure 47). Along with station UO21 (Group 2) these two sites had fewer species and lower abundance. Identification of the benthic groups according to the species, as shown in the TWT, created some overlap in the groupings according to abiotic parameters, as shown in the bar graphs. The bar graphs and weighted discriminant analysis coefficients indicated the importance of oil and grease levels in bottom waters, which were highest and next highest for groups 2 and 5, respectively (Figure 66). Groups 2 and 5 also had the lowest and next lowest mean pH and dissolved oxygen, respectively. Group 5 had the lowest percent light transmittance; otherwise the two groups were separated only by depth and salinity. Note that neither of these two stations is near the pier.

Important separations in the other groups were found based on depth, salinity, dissolved oxygen, turbidity, and temperature in spite of overlapping of the groups to some extent for most of these. This demonstrates the usefulness of multivariate analysis, when ranges as seen on bar graphs do not provide definitive separation. Figures 58 to 67 show the ranges of physical parameters for the benthic groups and seasons. The Shannon-Weiner Index (Figure 49) ranged from 1.80 to 2.43 and averaged 2.17 in April when total numbers were low. The average SWDI was 1.71 at the end of December and averaged 1.66 in January, 1977.

July 1977. Four groups of sites were identified, somewhat patterned along the lines of inner slip and shoals (Group 1) and outer harbor (Group 3) separations (Figures 50-52). However, the overlapping of groups may serve to indicate that abnormal, stressed patterns existed. Station UO22 (Group 2) was low in species, and station UO7 (Group 4) was particularly low in clam species (Figure 51). In July the average SWDI had dropped back to 1.93, from 2.17 in April (Figure 53).

Separations based on weighted discriminant analysis were more clear in July. Oil and grease levels were distinctive: Oil and grease levels in the water column were higher than in April, but lower than in January. Group 4 (UO7) which was depauperate, was the shallowest and warmest, with the lowest sediment oil and grease, but with the highest oil and grease concentration in the bottom water. There was no overlap with other groups and the difference was clear cut. Group 2 (UO22), also species poor, was the deepest, with surface oil and grease, high bottom water oil and grease, and low sediment oil and grease (Figures 66 and 67).

Coefficients for depth, temperature and pH were important but were dominated by oil and grease levels in water and sediments. Separations of Groups 1 and 3 were less distinctive, based partly on higher mean salinity, dissolved oxygen, pH and lower mean transparency in Group 3 (Figures 59-61).

November 1977. Classification patterns were more definitively separated into outer harbor (Groups 1 and 2) and inner slip (Group 3) stations. There were no really extreme isolates (Figures 54-56), and the species groups in the TWT appeared to be somewhat more balanced (Figure 55). The SWDI (Figure 56) dropped to 1.83, but there are no 1978 data as yet analyzed for the area to extend the comparisons further. Numbers of species or taxa were nearly normal, but populations were nowhere near 1974 levels (AHF, 1976).

Oil and grease levels increased markedly in sediments during the November sampling and showed penetration throughout the 45 cm cores, but in spite of this populations appeared almost recovered to 1976 levels. Analysis in July showed that the benthic populations were correlated with oil and grease levels in the water column at one meter above the sediment rather than the oil and grease in the sediment itself. Group 1 stations had higher oil and grease levels in surface and mid-water, but the ranges in bottom water were overlapped by Group 2, which had a higher mean as well. Group 2 had a lower mean for sediment surface oil and grease, but the ranges were overlapped completely by Groups 1 and 3. This indicates that group separations on the basis of oil and grease alone were not possible. Temperature, dissolved oxygen and salinity exerted as much or more influence.

Group 3 had the lowest mean and range for bottom water oil and grease. However, it also had the lowest temperatures, dissolved oxygen and pH, and poorest light transmittance, but was not depauperate. Groups 1 and 2 were separated by higher salinity in the latter, but shared higher temperatures, dissolved oxygen and pH than Group 3.

Conclusion

By November 1977 the spill had been cleaned up except for amounts variously estimated at 200 to 4000 barrels. The residual tarry material may well have migrated to the main channel or become covered by storm-shifted silt. However, oil and grease levels in the water and sediments rose greatly and were as high as they had been the previous December, perhaps due to storms.

The benthic community appeared to have recovered by November, 1977, at least to the level of December 29-30, 1976, which was after the explosion but prior to the large drops in numbers of species seen in January (Figure 42) and drops in counts seen in April (Figure 45). Prior to the spill, on December 2, 1976, there had been 76 species or taxa at A9 with average counts of 365 per m^2. These trends are difficult to interpret, however, and long term data analysis is still in progress.

In spite of the return of high levels of total oil and grease in the water in November, toxic fractions presumably had been largely reduced or dissipated from the residual material or the benthic fauna would not have approached normal numbers. Oil and grease in bottom water still had a high coefficient, but this was exceeded considerably by coefficients for salinity and temperature and approached by dissolved oxygen, so that natural variables appeared to be most important in determining species patterns.

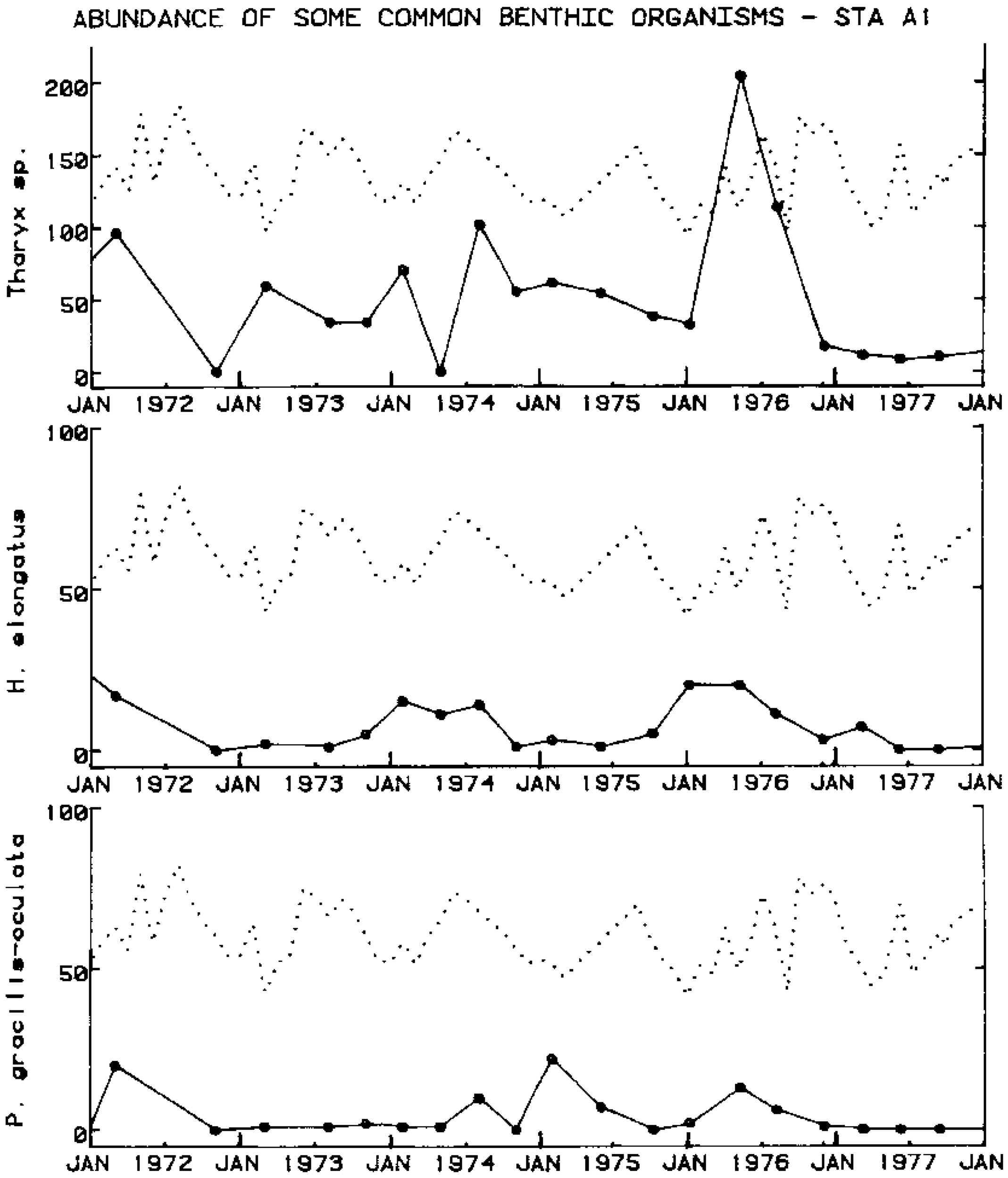


FIGURE 35. ANNUAL SURFACE TEMPERATURE (TOP CURVE) AND ABUNDANCES 1972-1977 AT STATION A1.

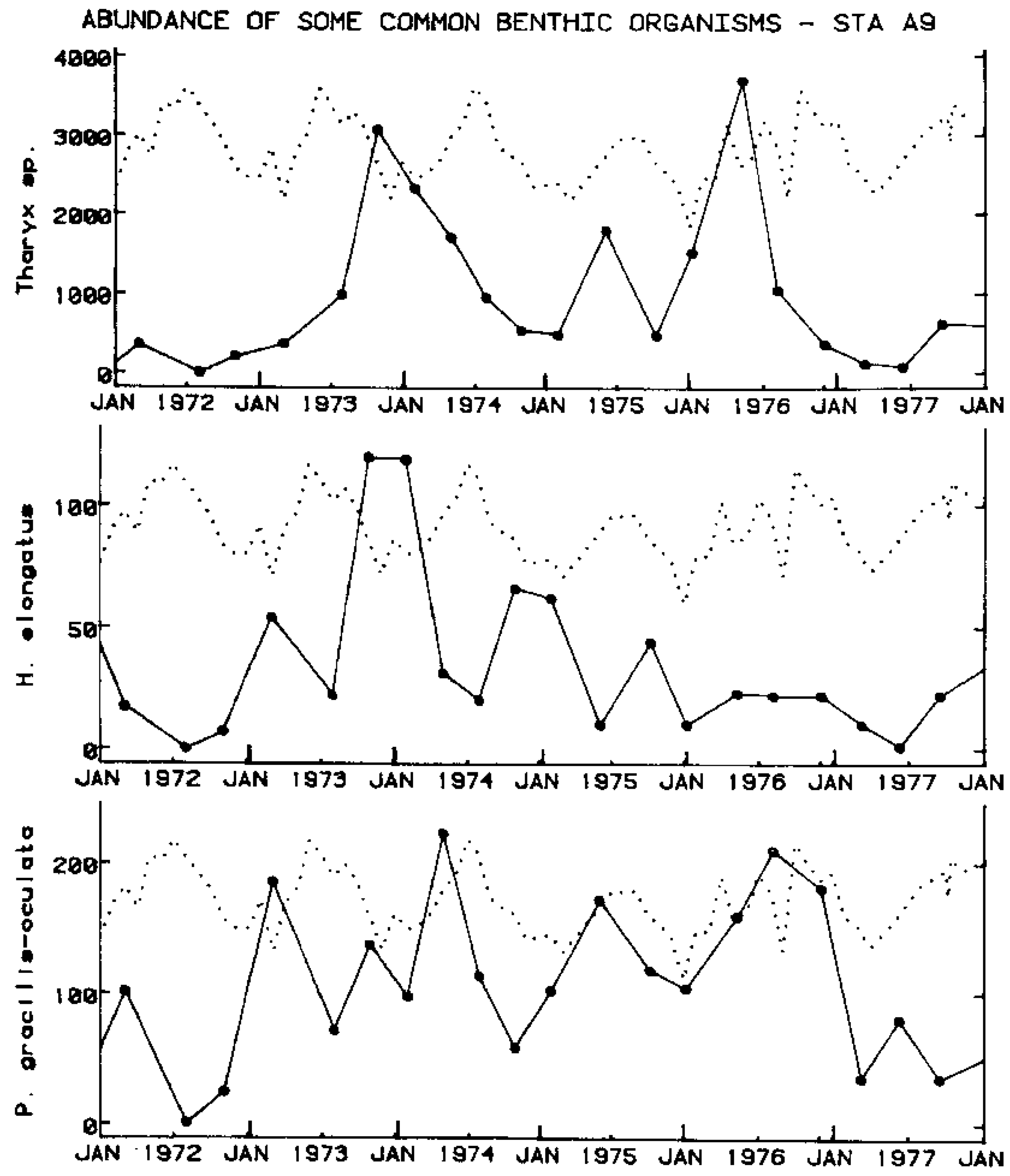


FIGURE 36. ANNUAL SURFACE TEMPERATURE (TOP CURVE) AND ABUNDANCES 1972-1977 AT SANSINENA SITE A9.

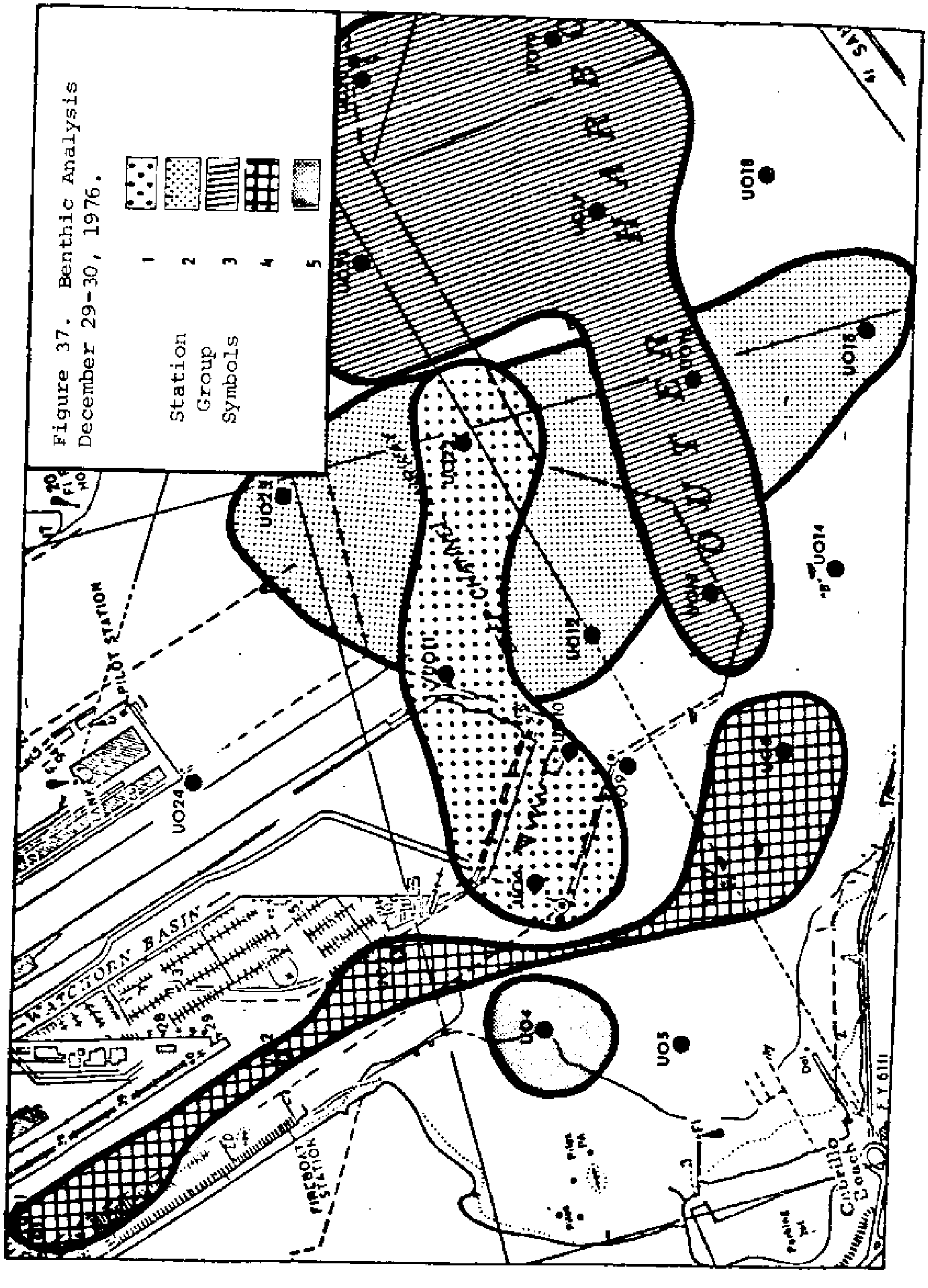


Figure 37. Benthic Analysis December 29-30, 1976.

Figure 38

Union Oil Benthic Data, December 29-30, 1976.

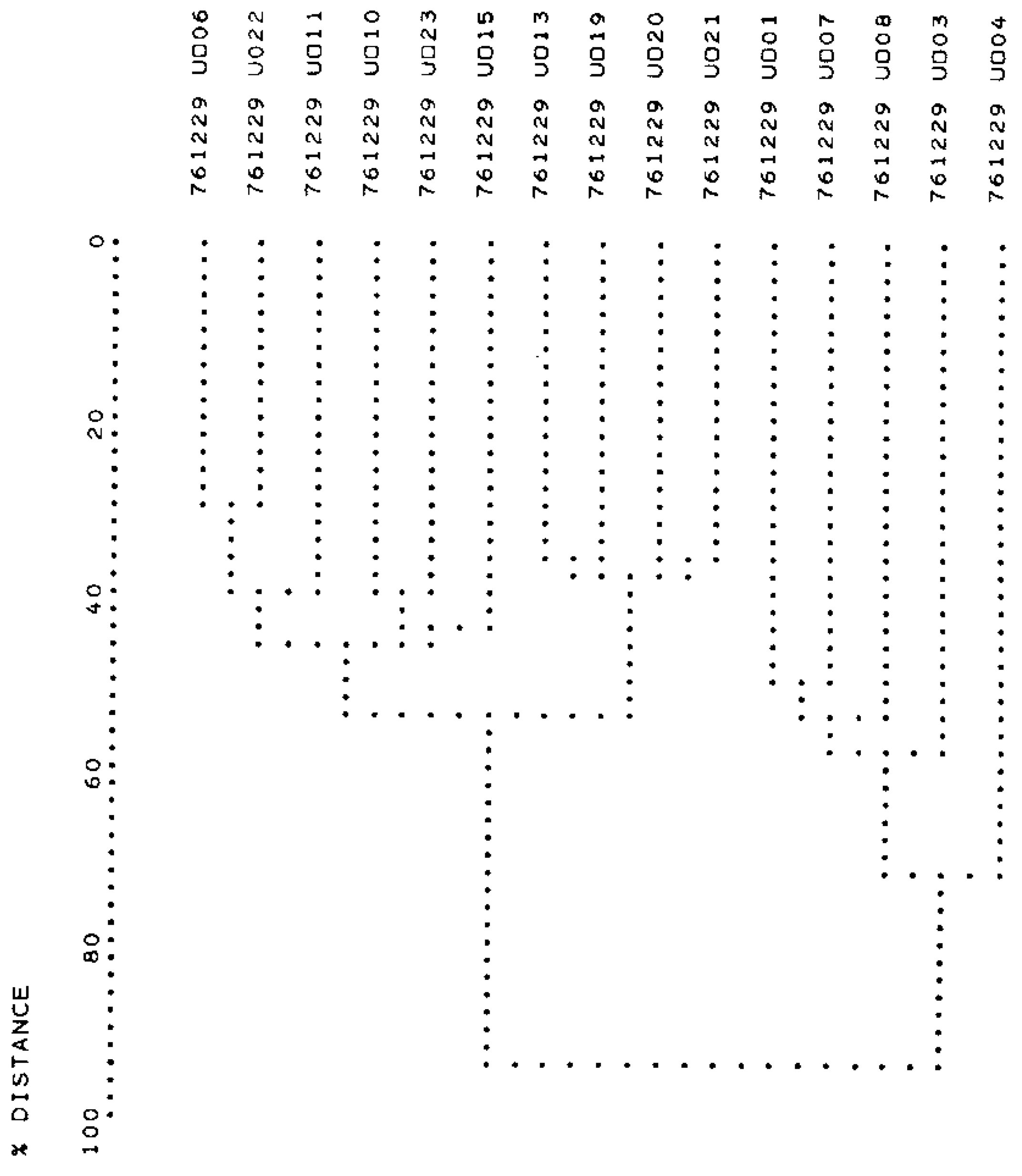
Coincidence numbers, transformed and standardized

* > .75 to 1
\+ > .5 to .75
\- > .25 to .50
. > 0 to .25
blank 0

STATION GROUPS	1			2			3				4				5
	U0061	U0022	U0011	U0110	U0023	U0115	U0130	U0119	U0120	U0121	U0001	U0007	U0008	U0003	U0004
	761229		761229		761229		761229		761229		761229		761229		761229
CHAETOZONE CORONA	+	*	+	+	*	-	+	*	-	*	.	-	+		-
CIRRATULIDAE THARYX	*	*	+	+	*	-	-	+	*	*	-	.	+	-	-
PARAPRIONOSPIO PINNATA	*	*	+	*	*	+	-	*	+	*			*	*	-
COMPSOMYAX SUBDIAPHANA	-	*	+			*	+	-	+	*	-	-	-	-	
NEPHTYS CORNUTA-FRANCISCANA	*	*	-	-	*	*	-	-	+	+	-	-	-	-	.
GLYCERA AMERICANA	*	*	+	*	*		-	*	*	*	-	-	+		
PARAONIS GRACILIS-OCULATA	*	*	.	-	*	+	+	*	-	*	+	-	-	.	
COSSURA CANDIDA	+	-	-	-	+	-	-	-	-	-	*	+	-	.	+
HAPLOSCOLOPLOS ELONGATUS	*	+	-	-	-	-	-	-	-	-	*	+	+	+	.
THYASIRA FLEXUOSA	*	-	-	-	-		*	-		*	*	+	*		
GYPTIS BREVIPALPA (ARENICOLA-G	*	*	-	*	+	*	*	+	*		*	*			
NEREIS PROCERA	+	+	-	*			*	+	+	+	*		-	-	
EUCHONE LIMNICOLA	*	-	-	.	-	+	-		.	+	+		-	*	.
THEORA LUBRICA	-	.	.		+		.	.	-	.	*		-	*	-
MARPHYSA DISJUNCTA		+	*	+	+	+	*		+	+				+	
NOTOMASTUS TENUIS	+	*	+		*	*	*		*	*	*			+	
LAONICE CIRRATA	+	*	-	-	-	-	-		+	-			-	-	
OXYUROSTYLIS PACIFICA	.	-	.	.	+	*			.	-			.	-	
SIGAMBRA TENTACULATA	-	-	+	*	.	*	-	-	*	+	+				
STREBLOSOMA CRASSIBRANCHIA	-	.	-	.	*	-	+	+	*	*	-			.	
ETEONE DILATAE			+				+				*				
OPHIODROMUS PUGETTENSIS	*	*									*				
PSEUDOPOLYDORA PAUCIBRANCHIATA	.		.		.						*	.	.	.	.
ACTEOCINA CULCITELLA		+				+				*	+				
ACESTA CATHERINAE	*	*			+								+		
PHOLOE GLABRA	*	*								+			*		
MEGALOMMA PIGMENTUM		*	*										*		
THRACIA CURTA	*	*	+									+	+		
EUCHONE INCOLOR	*		+											+	
TELLINA MODESTA	+	+	*	+		+								+	
ARMANDIA BIOCULATA								*				*		*	
SCHISTOMERINGOS LONGICORNIS	-	-		+							+	-		*	
HARMOTHOE PRIOPS	*		*						*	*		*			
AMPHICTEIS SCAPHOBRANCHIATA		*	+		*		-	+	*						
PRIONOSPIO MALMGRENI	-	-		-	+		-	*	+						
EUPHILOMEDES CARCHARODONTA	+	*	-		.	*	-	.	-				.		
MYSELLA PEDROANA	+	+			*	*	-	*	-	*					
MACOMA ACOLASTA	-	-	-			*		*	-			-			
SPIOPHANES BERKELEYORUM						+	+	*	*						
AMPHARETE LABROPS							*	+		+					
GLYCERA CAPITATA								+	*	+					
AMAEANA OCCIDENTALIS		*							*	*				*	
PECTINARIA CALIFORNIENSIS-NEWP	-	*	-					-	*	+				-	
HARMOTHOE IMBRICATA		*		+			+	+		*				+	+
ACTEOCINA HARPA		*	+		*		+			+					
SPIOCHAETOPTERUS COSTARUM		*	+					+		+					
CIRRATULUS CIRRATUS	.	*		-	.	.	.	.		.					
AXINOPSIDA SERRICATA	+	*	+	+	+	+									
GYPTIS BRUNNEA	+			+	*	+									
ACESTA HORIKOSHII				+	*				+						
POLYDORA SOCIALIS		+		+	*										
PEISIDICE ASPERA				*											
CAPITELLA CAPITATA		.										.		.	*
TAGELUS SUBTERES			+	+											*
PRIONOSPIO PYGMAEUS	+	-	-					*		+					*
SPIOPHANES MISSIONENSIS			-		-			-	-		-			-	*
PRIONOSPIO CIRRIFERA	.	.	.	.	-	.					*	+			*
PRIONOSPIO HETEROBRANCHIA-NEWP											*				*
CAPITITA AMBISETA	+	-	.	-	+	-	-	-	.	-	+	.	.	-	*
MACOMA NASUTA		+		+			+	+			*	+		+	*

FIGURE 39

UNION OIL BENTHIC DATA, DECEMBER 1976



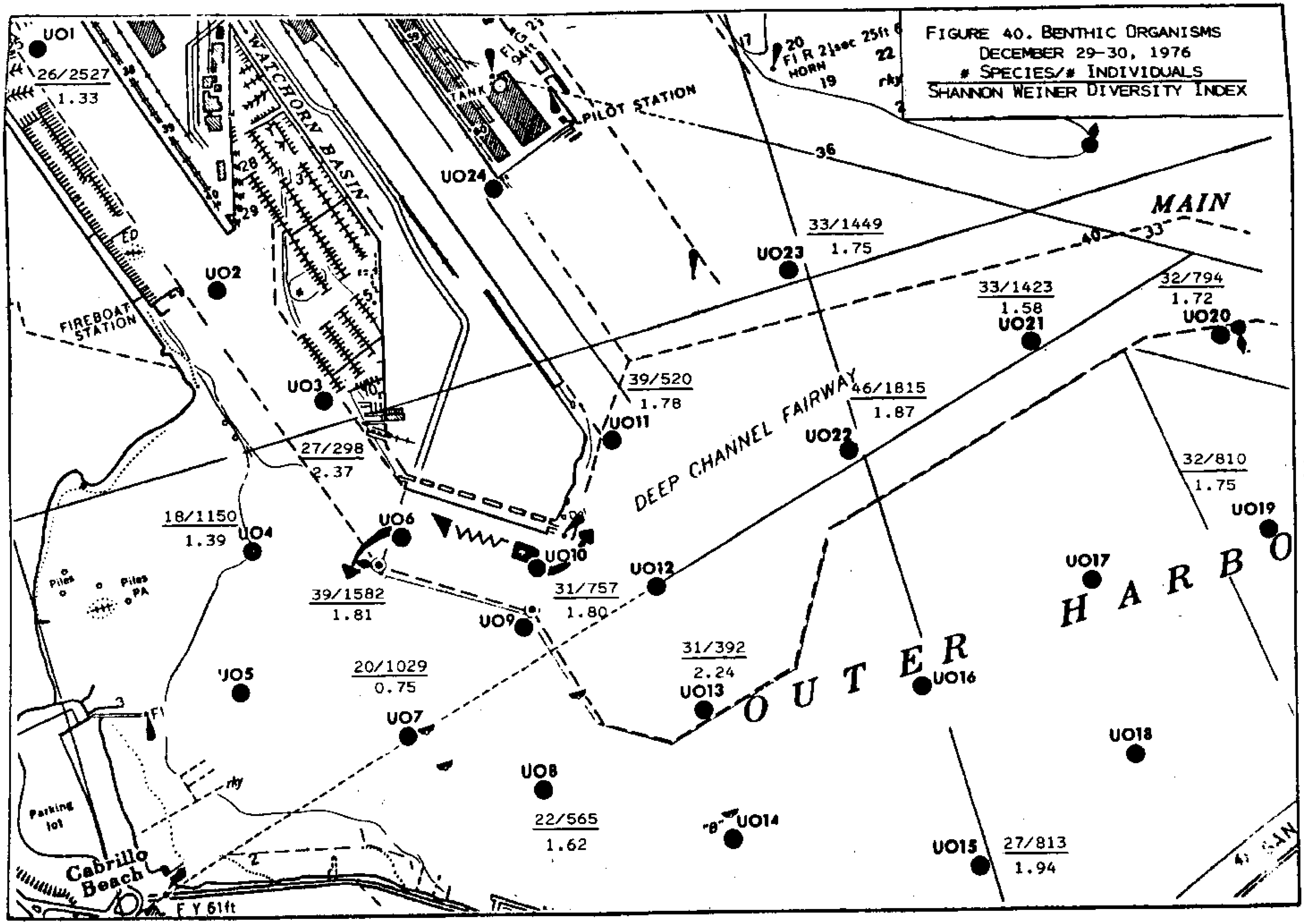


FIGURE 40. BENTHIC ORGANISMS
DECEMBER 29-30, 1976
SPECIES/# INDIVIDUALS
SHANNON WEINER DIVERSITY INDEX

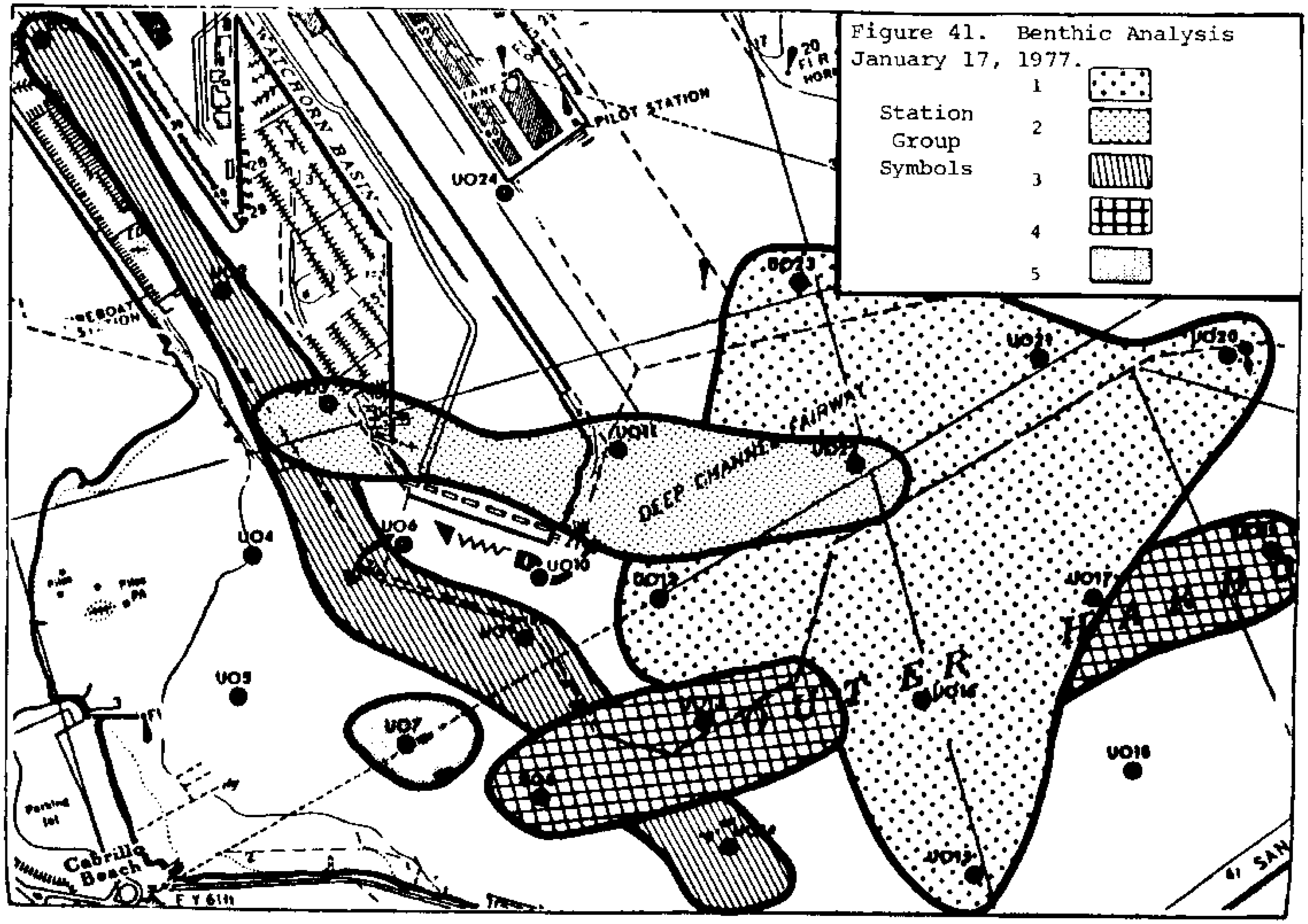


Figure 41. Benthic Analysis January 17, 1977.

Figure 42

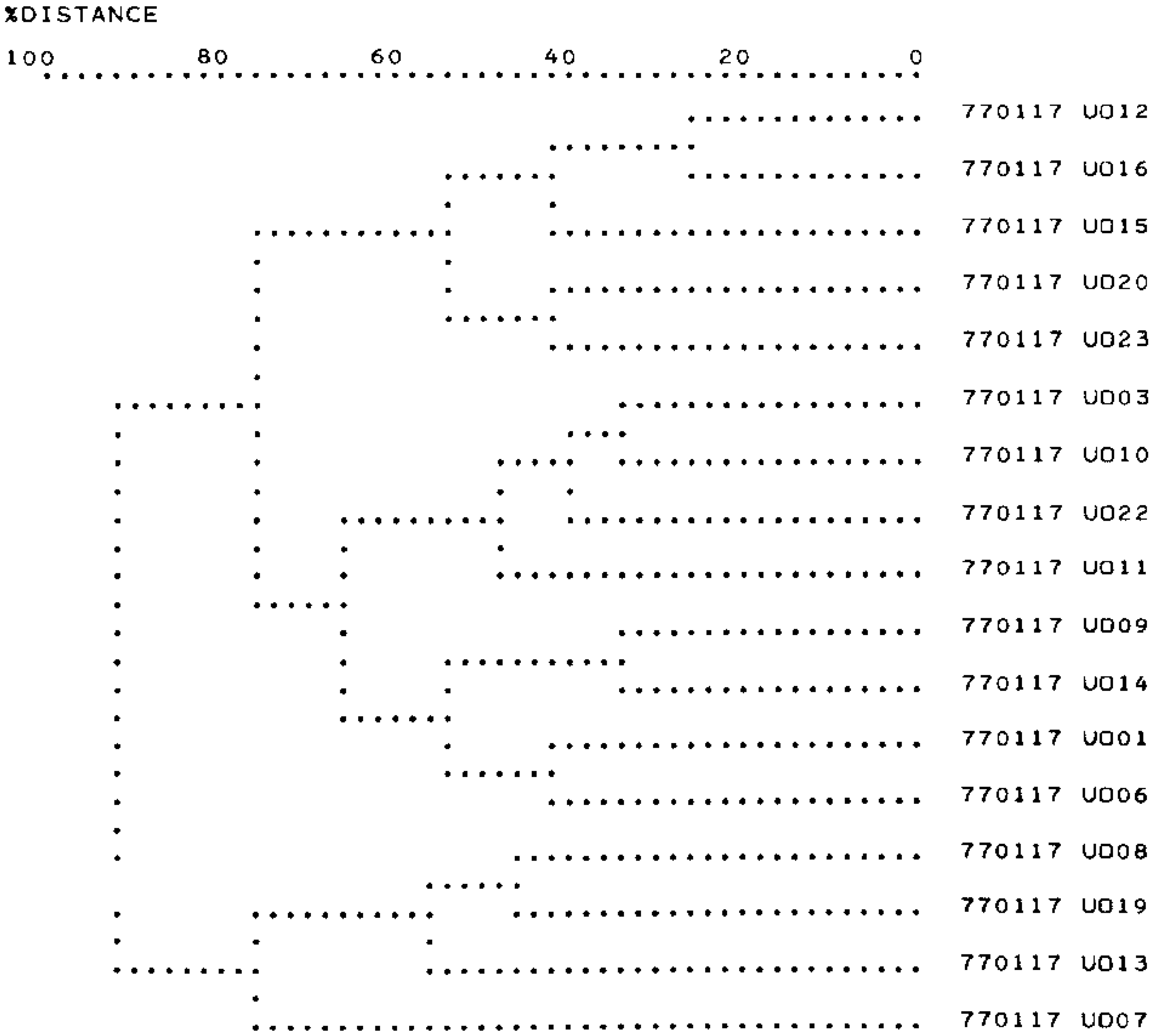
Union Oil Benthic Data, January 17, 1977.

Coincidence numbers,
transformed and standardized

* > .75 to 1
\+ > .5 to .75
\- > .25 to .50
. > 0 to .25
blank 0

STATION GROUPS	1					2				3				4			5
	770117 U012	770117 U016	770117 U015	770117 U020	770117 U023	770117 U003	770117 U010	770117 U022	770117 U011	770117 U009	770117 U014	770117 U001	770117 U006	770117 U008	770117 U019	770117 U013	770117 U007
AMPHICTEIS SCAPHOBRANCHIATA				*							*						
NOTOMASTUS TENUIS				*							*						
OXYUROSTYLIS PACIFICA				*	-						*						
GYPTIS BREVIPALPA (ARENICOLA-G	-			-	-					-	*						
MARPHYSA DISJUNCTA	*	*	+	+				+	+		*						
GLYCERA CAPITATA						*					*						
HARMOTHOE PRIOPS		*									*						
PARAPRIONOSPIO PINNATA							*	*			*						
PRIONOSPIO MALMGRENI					*						*					*	
COMPSOMYAX SUBDIAPHANA				*	*	*											
OLIVELLA BAETICA				*	*												
LASAEA SUBVIRIDIS		+		-	*												
THRACIA CURTA		*			*												
LAONICE CIRRATA			+		*												
PECTINARIA CALIFORNIENSIS-NEWP				*				*									
PISTA FASCIATA				*													
ACESTA HORIKOSHII			*	*													
GLYCERA AMERICANA	+	+		*										+			
LUCINA NUTTALLI				*								*					
NEREIS PROCERA				*		+	+	*				+					
MYSELLA PEDROANA				*									+				
EUPHILOMEDES CARCHARODONTA		+		*		*	*							+	+		
NEPHTYS CORNUTA-FRANCISCANA	*	*	+	*	*	-	*	*	+	.	*	.		+	.	-	
STREBLOSOMA CRASSIBRANCHIA	-	+	*	*	*	-	-	-				-		-	-	-	
SIGAMBRA TENTACULATA	+	+	*	*	*			*	+	-	+	-				-	
PARAONIS GRACILIS-OCULATA	+	*	*	*	-	+	-	*		*	+	+	.	-	.	-	
CIRRATULIDAE THARYX ^	+	+	*	*	*	+	-	*	*	+	*	+	-	-	-	-	-
HAPLOSCOLOPLOS ELONGATUS			+	*	-	+		-	*	*	*	+	-	*		-	+
COSSURA CANDIDA	+	*	*		+	*	+	+	+	*	*	*	*	+	.	-	+
CAPITITA AMBISETA	-	+	-	+	*					*	*	-	-	-			.
CHAETOZONE CORONA	-	*	*	-	+	-	+	+	-	+	+		-	*	-		
PRIONOSPIO CIRRIFERA	-							-		-	*	-	*	-			
THEORA LUBRICA										+	-	-	*				
MACOMA NASUTA					-								*				
PSEUDOPOLYDORA PAUCIBRANCHIATA										-		*	*			-	
EUCHONE LIMNICOLA						*	+	*	+	*	+	-	+				
ETEONE DILATAE			*						*								*
PRIONOSPIO PYGMAEUS			+							+							*
CIRRATULUS CIRRATUS	-	+	*					-		-	.						
PHOLOE GLABRA			*														

FIGURE 43
UNION OIL BENTHIC DATA, JANUARY 1977



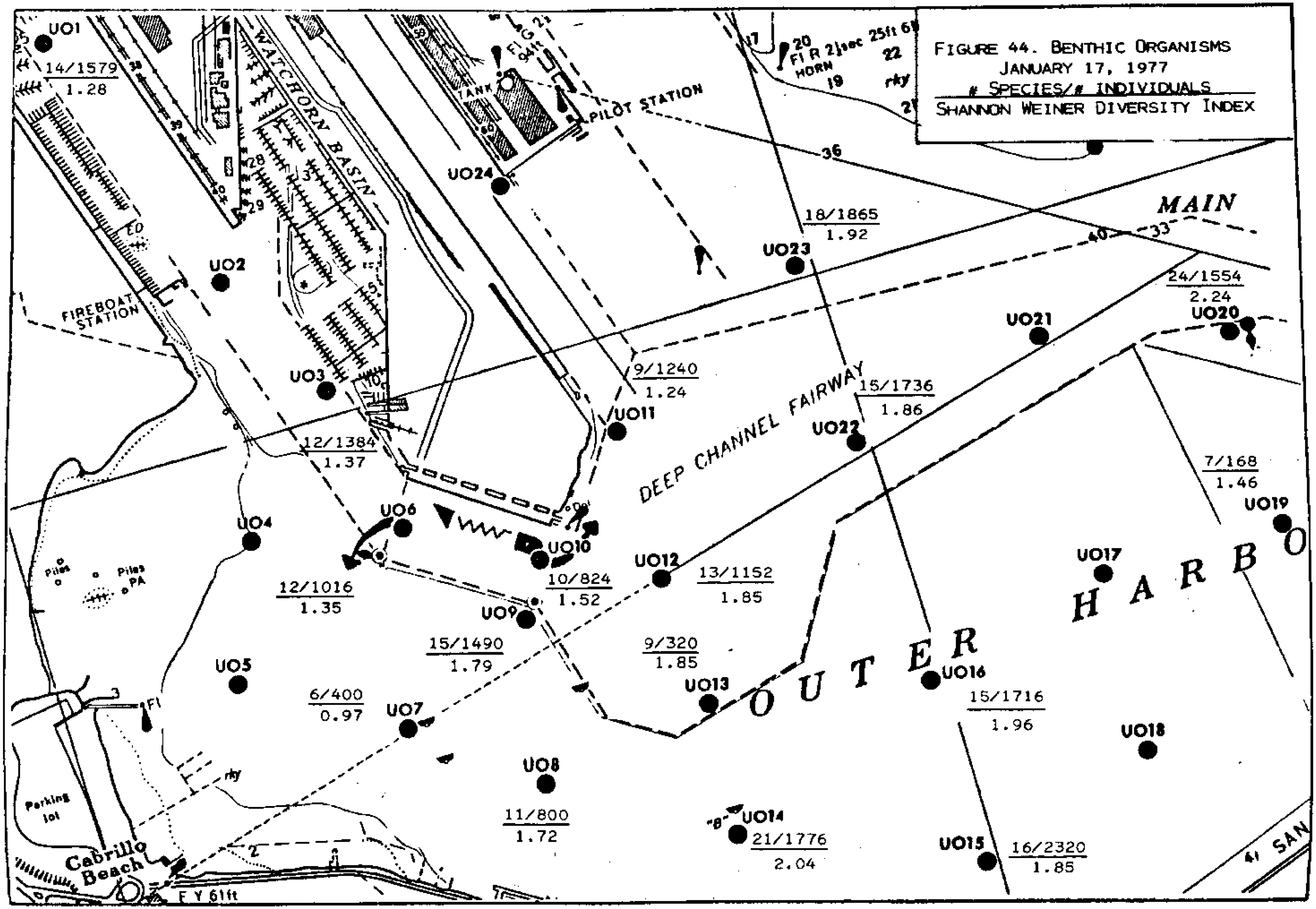


FIGURE 44. BENTHIC ORGANISMS
JANUARY 17, 1977
SPECIES/# INDIVIDUALS
SHANNON WEINER DIVERSITY INDEX

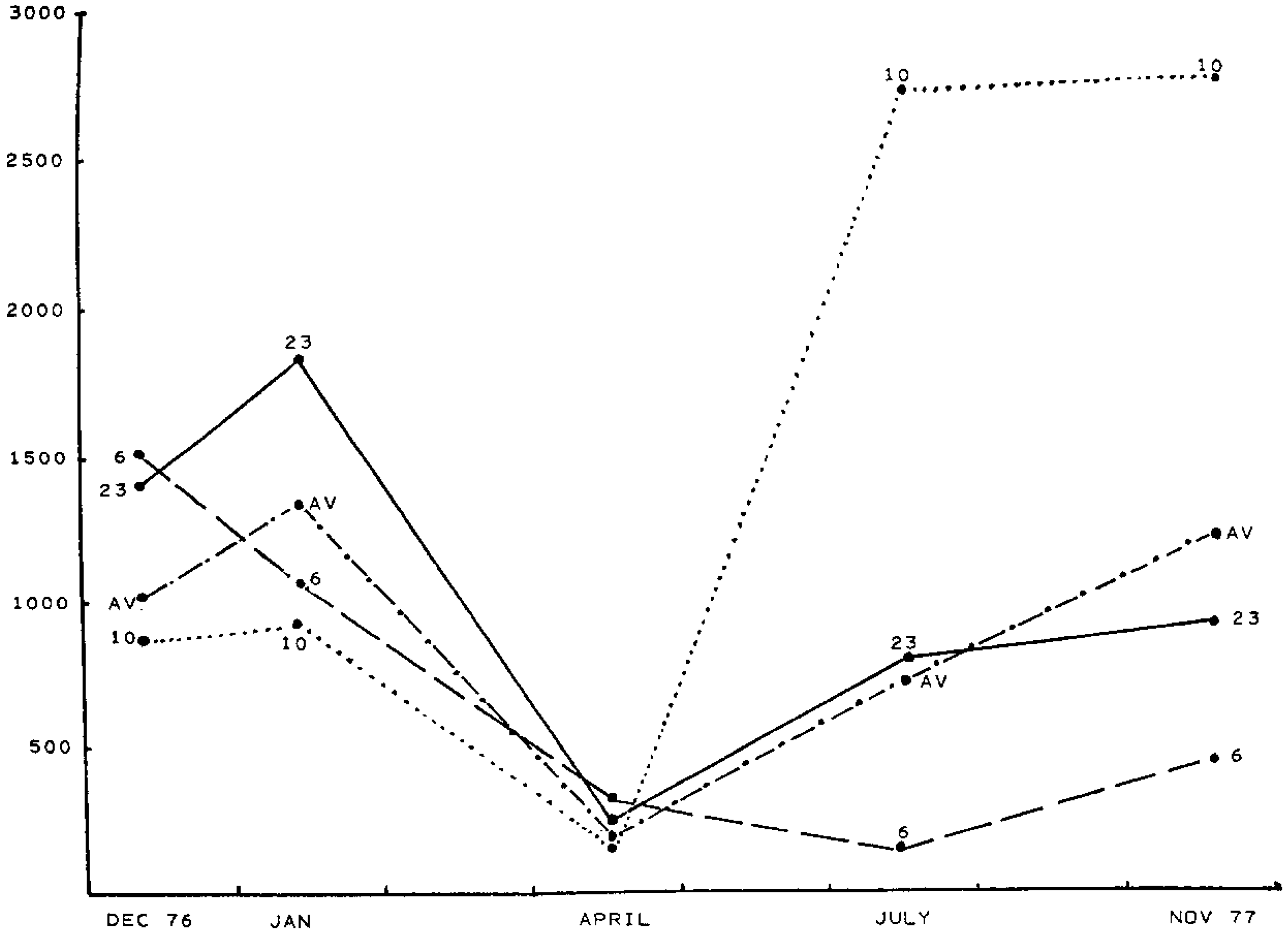


FIGURE 45. NUMBER OF INDIVIDUALS ÷ NUMBER OF BENTHIC SPECIES AT STATIONS U06, U010 AND U023, PLUS TOTALS AVERAGED (AV)

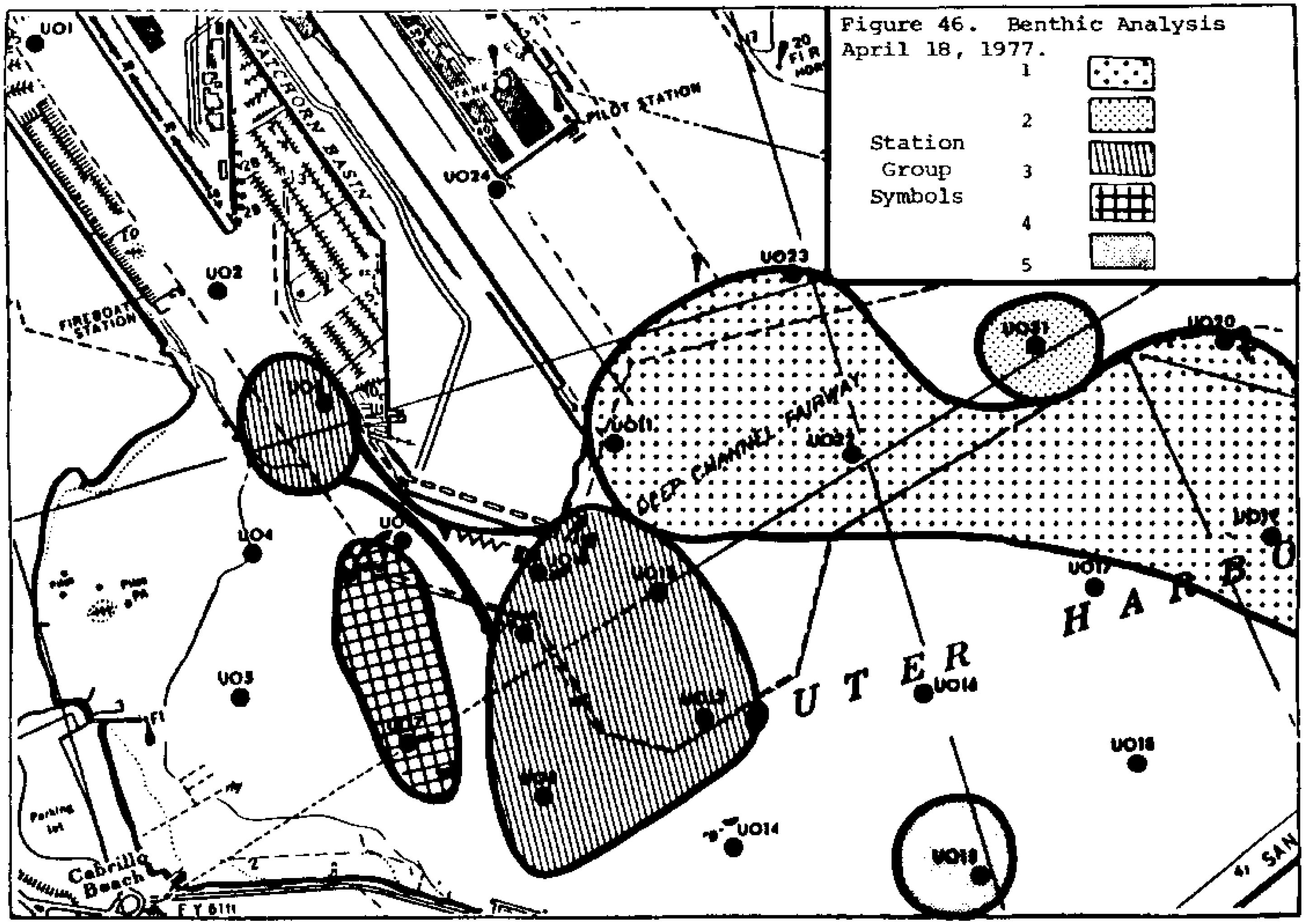


Figure 46. Benthic Analysis April 18, 1977.

Figure 47

Union Oil Benthic Data, April 18, 1977.

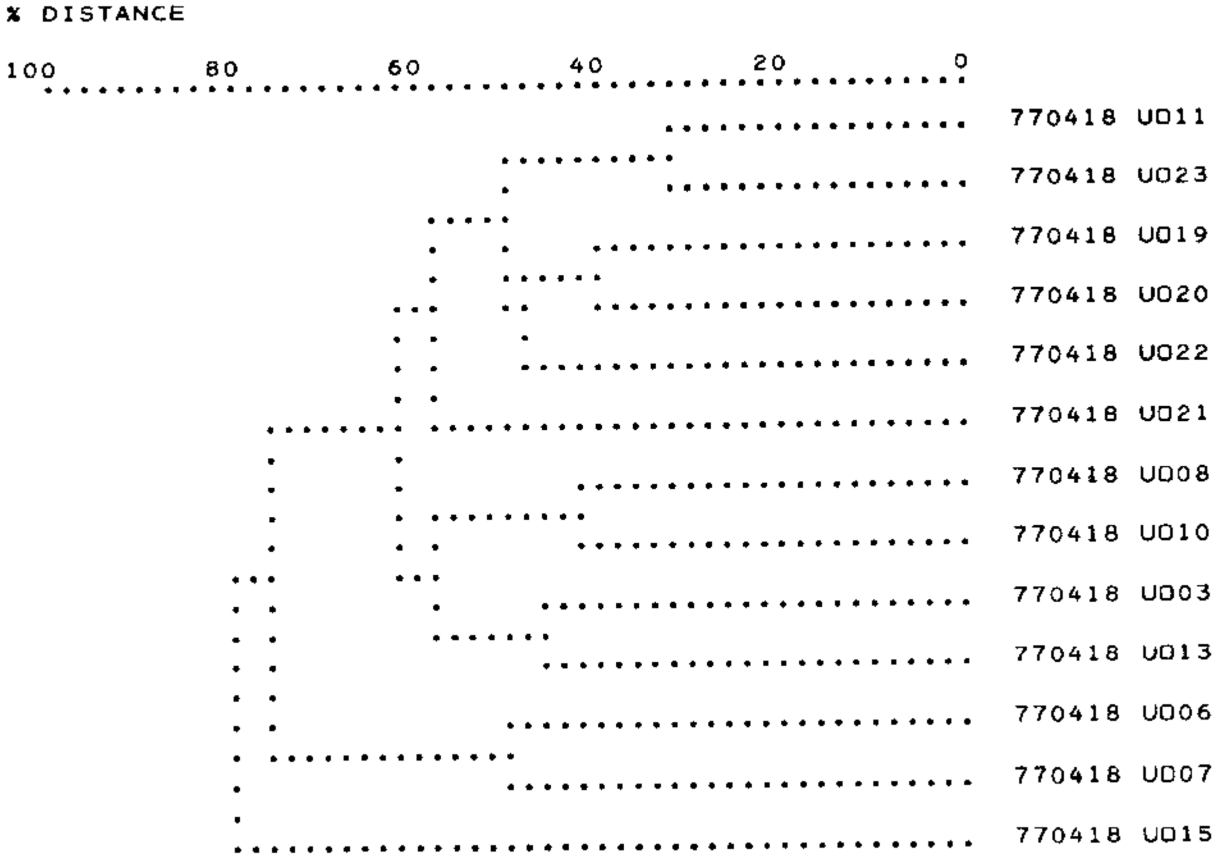
Coincidence numbers,
transformed and standardized

* > .75 to 1
\+ > .5 to .75
\- > .25 to .50
. > 0 to .25
blank 0

STATION GROUPS	1					2	3				4		5
	770418 U011	U023	770418 U019	U020	770418 U022	U021	770418 U008	U010	770418 U003	U013	770418 U006	U007	770418 U015
EUMIDA SANGUINEA							*				*		
THRACIA CURTA							+				*		
PRIONOSPIO HETEROBRANCHIA-NEWP	-										*		
EXOGONE VERUGERA		*									*		
NEREIS PROCERA	+	+		+	*						*		
OXYUROSTYLIS PACIFICA			*	+	+					*	*		
PRIONOSPIO PYGMAEUS			*								*		
HARMOTHOE PRIOPS						*				*	*		
SPIOPHANES MISSIONENSIS					*	*					*		
SCHISTOMERINGOS LONGICORNIS									+	*	+		
STHENELAIS VERRUCULOSA	+			+					*		+		
AXINOPSIDA SERRICATA								*			+		
CUMINGIA CALIFORNICA											*	*	
PSEUDOPOLYDORA PAUCIBRANCHIATA							.	.	-		*	+	
POLYDORA CAULLERYI (BRACHYCEPH		*	+						+		*	*	
HARMOTHOE IMBRICATA				*							+	+	
PRIONOSPIO CIRRIFERA		-	+	*		-					-	-	
CAPITITA AMBISETA	+	+	+	*	-	.	*	-	+	-	*	*	
COSSURA CANDIDA	-	*	-	*	+	-	+	+	-	+	*	*	.
STHENELANELLA UNIFORMIS			-	-			+	-	-		*	-	
EUCHONE LIMNICOLA			.	.	.		+	.	*	.	+	.	.
HAPLOSCOLOPLOS ELONGATUS	-	-		-	-	-	*	.	*		+	*	.
EUPHILOMEDES CARCHARODONTA	-			+	-	+	*	+	*	*	*		-
GLYCERA AMERICANA	*	*	+	*	*	+			*	+	+	+	
THEORA LUBRICA		*		-	-	*		+	+	-	+	*	
CIRRATULIDAE THARYX	*	*	+	*	*	+	+	*	+	-	-	.	-
NEPHTYS CORNUTA-FRANCISCANA	+	-	-	+	-	*	+	*	+	-	-	.	-
CHAETOZONE CORONA	+	*	-	.	*		+	*	.	-	.		-
SIGAMBRA TENTACULATA	*		*	*		+	-	*		-			-
STREBLOSOMA CRASSIBRANCHIA	*	*	+	*	-			-	-	+	.		
PARAONIS GRACILIS-OCULATA	+	-	+	*	*	-	+	+	-	+		+	-
PARAPRIONOSPIO PINNATA		+	-	-	*		-		*	-		+	-
GYPTIS BREVIPALPA (ARENICOLA-G	-	-	+	-	+	+	-					-	-
CIRRATULUS CIRRATUS					*					*			-
MARPHYSA DISJUNCTA	*				*			+					+
COMPSOMYAX SUBDIAPHANA	+	*	-			+	-	-	-	+			
PECTINARIA CALIFORNIENSIS-NEWP	+	+	+	*	+	*	+		-	+			
NOTOMASTUS TENUIS	+	+				+			+	*			
ACESTA CATHERINAE	*									*			
THYASIRA FLEXUOSA			*							*			
AMPHICTEIS SCAPHOBRANCHIATA	-	+	-	-		-	*	*				-	
LAONICE CIRRATA		*		+		+	*	*					
MACOMA NASUTA							*	*	+			*	
BOCCARDIA BASILARIA	*	*						*					
SPIOCHAETOPTERUS COSTARUM	*	*	*				*	*					
MEGALOMMA PIGMENTUM								*	*				
CAPITELLA CAPITATA	*											*	
AMPHARETE LABROPS			+	+	*								
MAGELONA PITELKAI			*	*									
STYLATULA ELONGATA		*		+									
MACOMA ACOLASTA			+				*						
POLYDORA SOCIALIS				-			*				-		
PHOLOE GLABRA	.	.				*							
PRIONOSPIO MALMGRENI	+	+		+		*							
MYSELLA PEDROANA	+	-		*		+		-					
PISTA FASCIATA						*		*					
ARMANDIA BIOCULATA						*					*		*
SPIOPHANES BERKELEYORUM		*				*							*

FIGURE 48

UNION OIL BENTHIC DATA, APRIL 1977



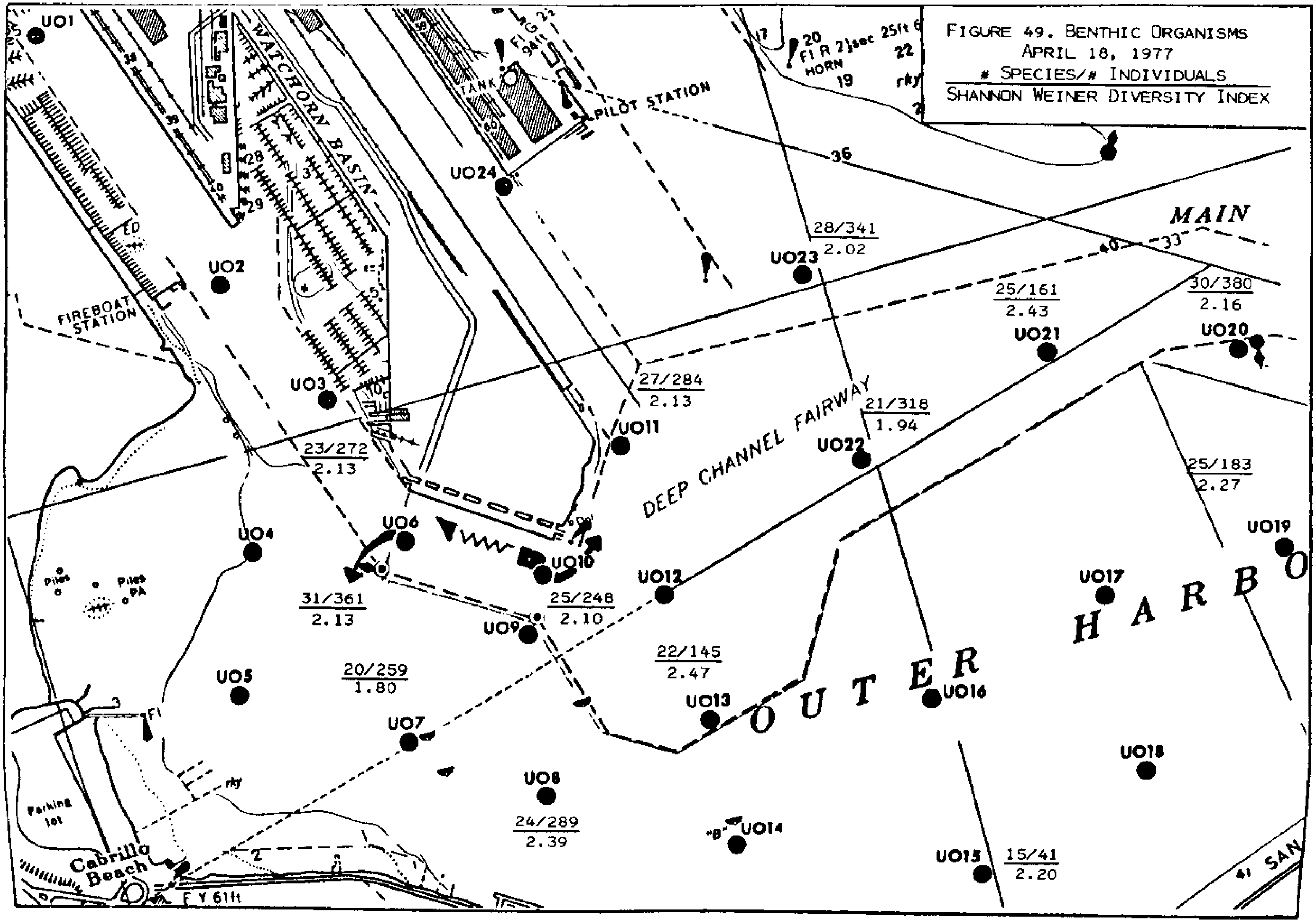


FIGURE 49. BENTHIC ORGANISMS
APRIL 18, 1977
SPECIES/# INDIVIDUALS
SHANNON WEINER DIVERSITY INDEX

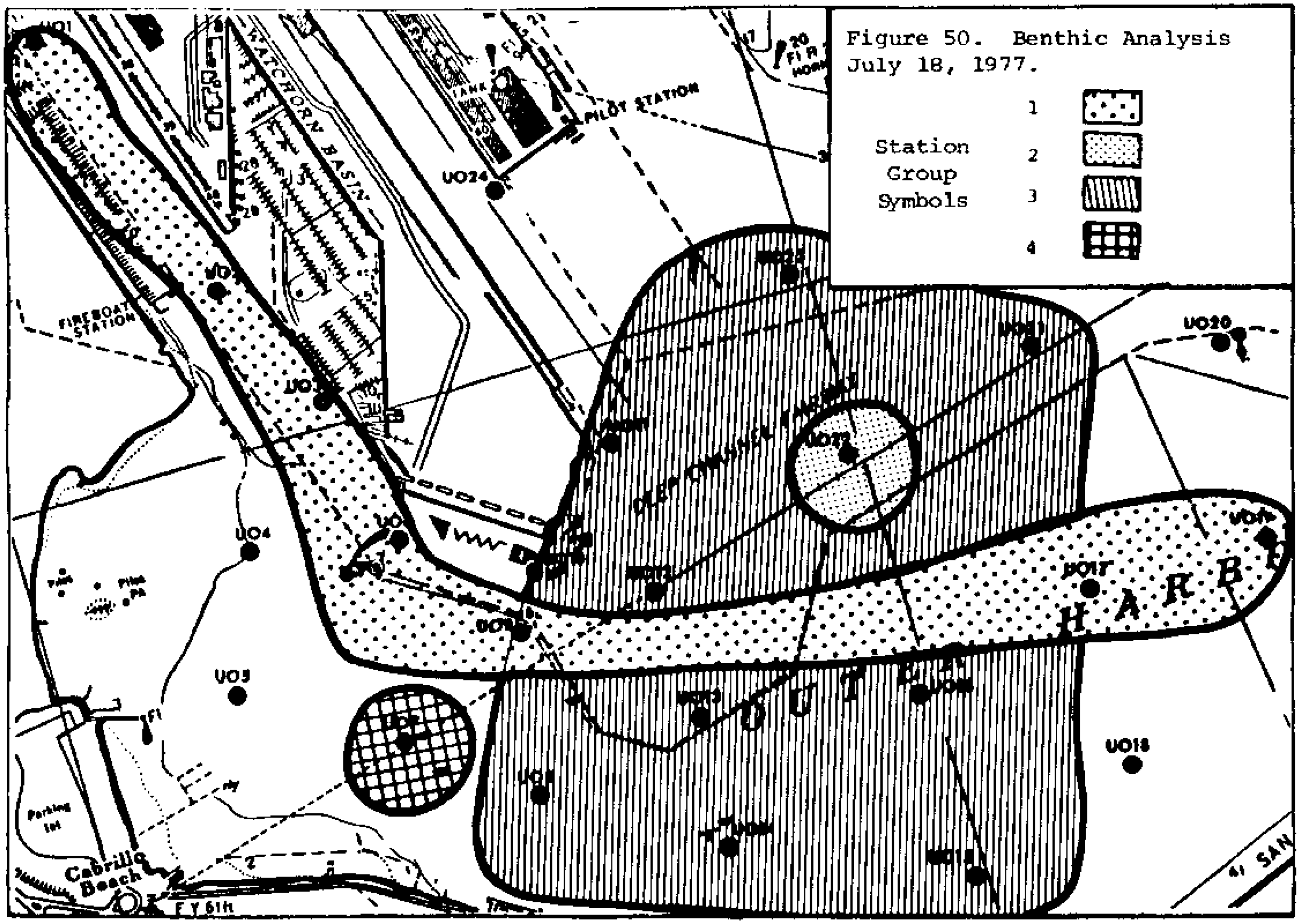
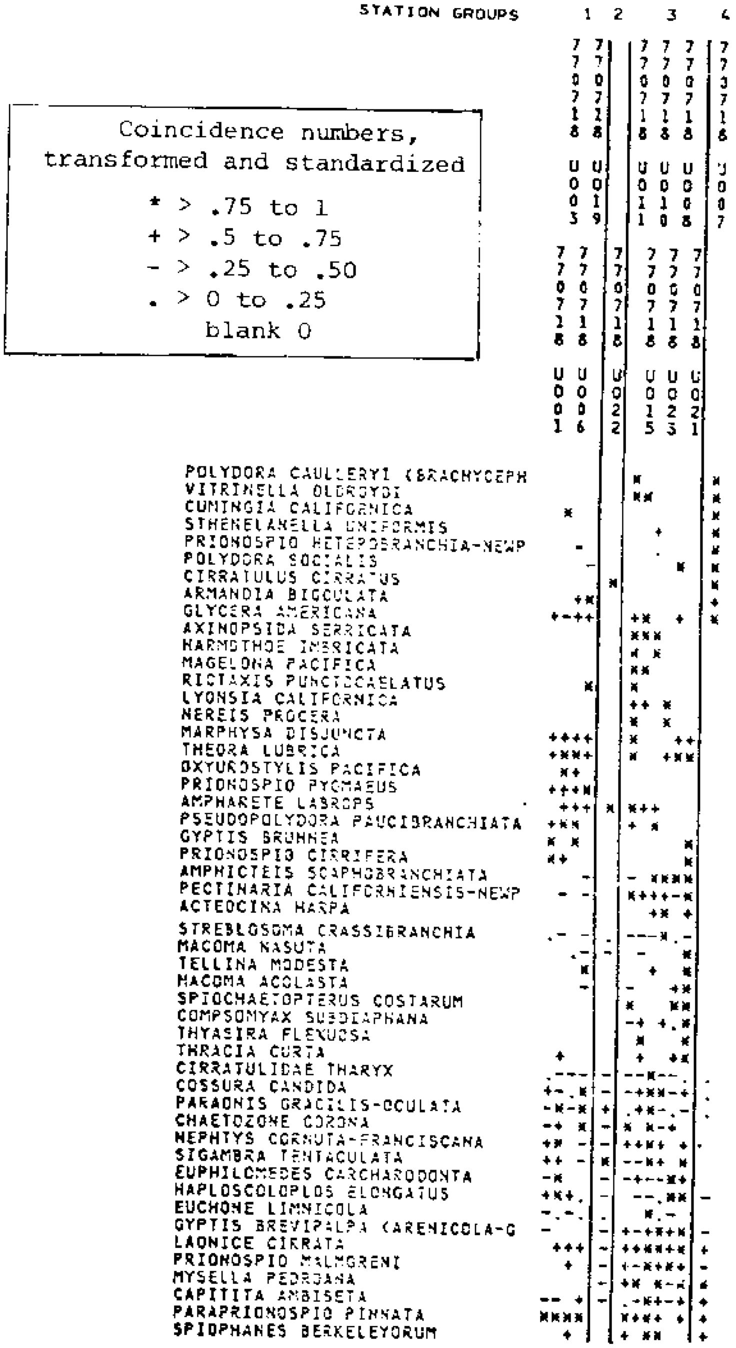


Figure 50. Benthic Analysis
July 18, 1977.

Figure 51

Union Oil Benthic Data, July 18, 1977.

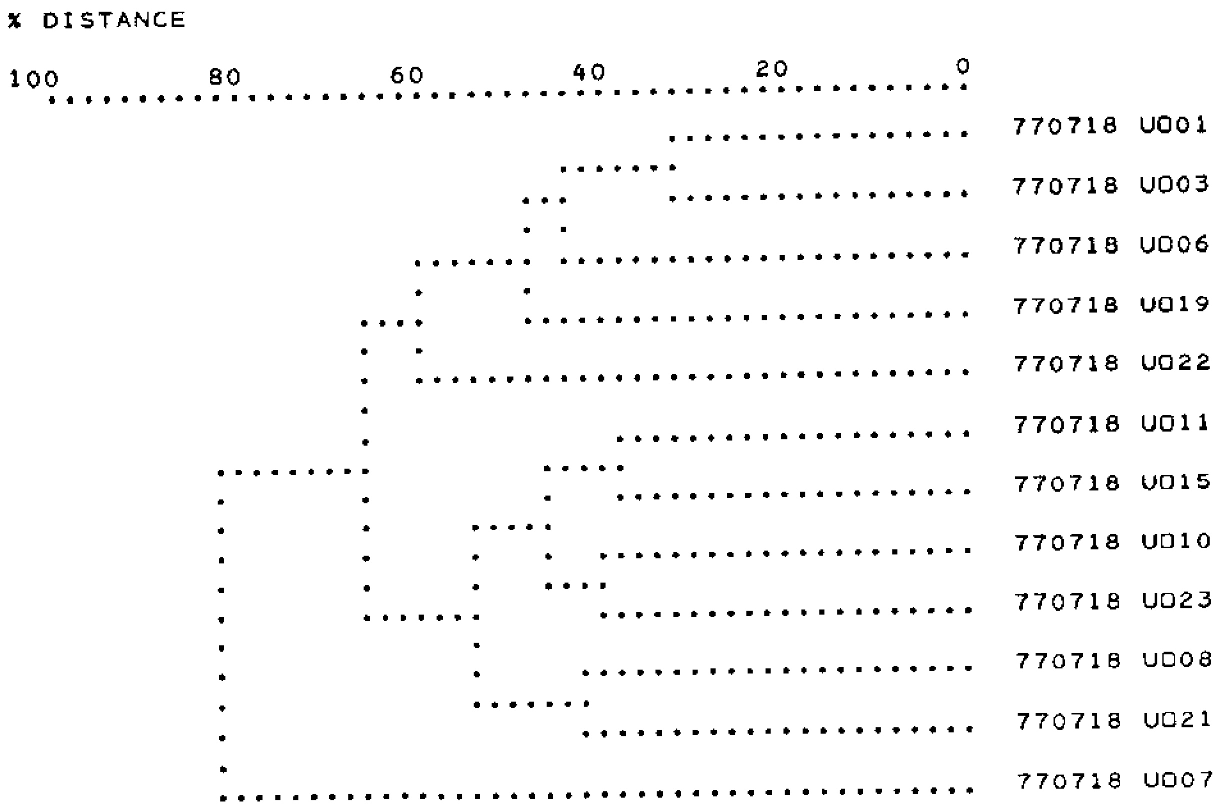


Coincidence numbers, transformed and standardized

- * > .75 to 1
- \+ > .5 to .75
- \- > .25 to .50
- . > 0 to .25
- blank 0

FIGURE 52

UNION OIL BENTHIC DATA, JULY 1977



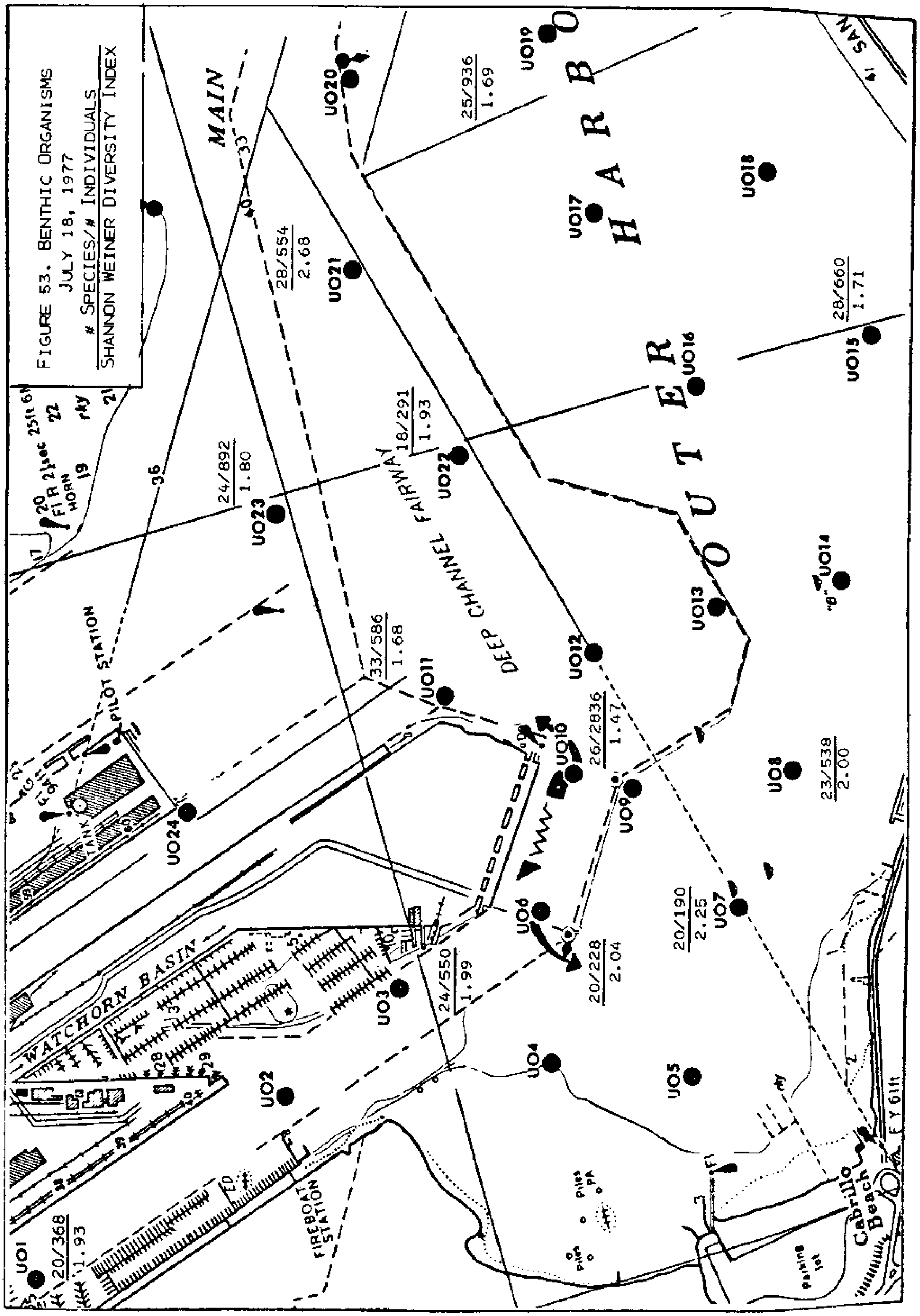


Figure 53. Benthic Organisms
July 18, 1977
Species/# Individuals
Shannon Weiner Diversity Index

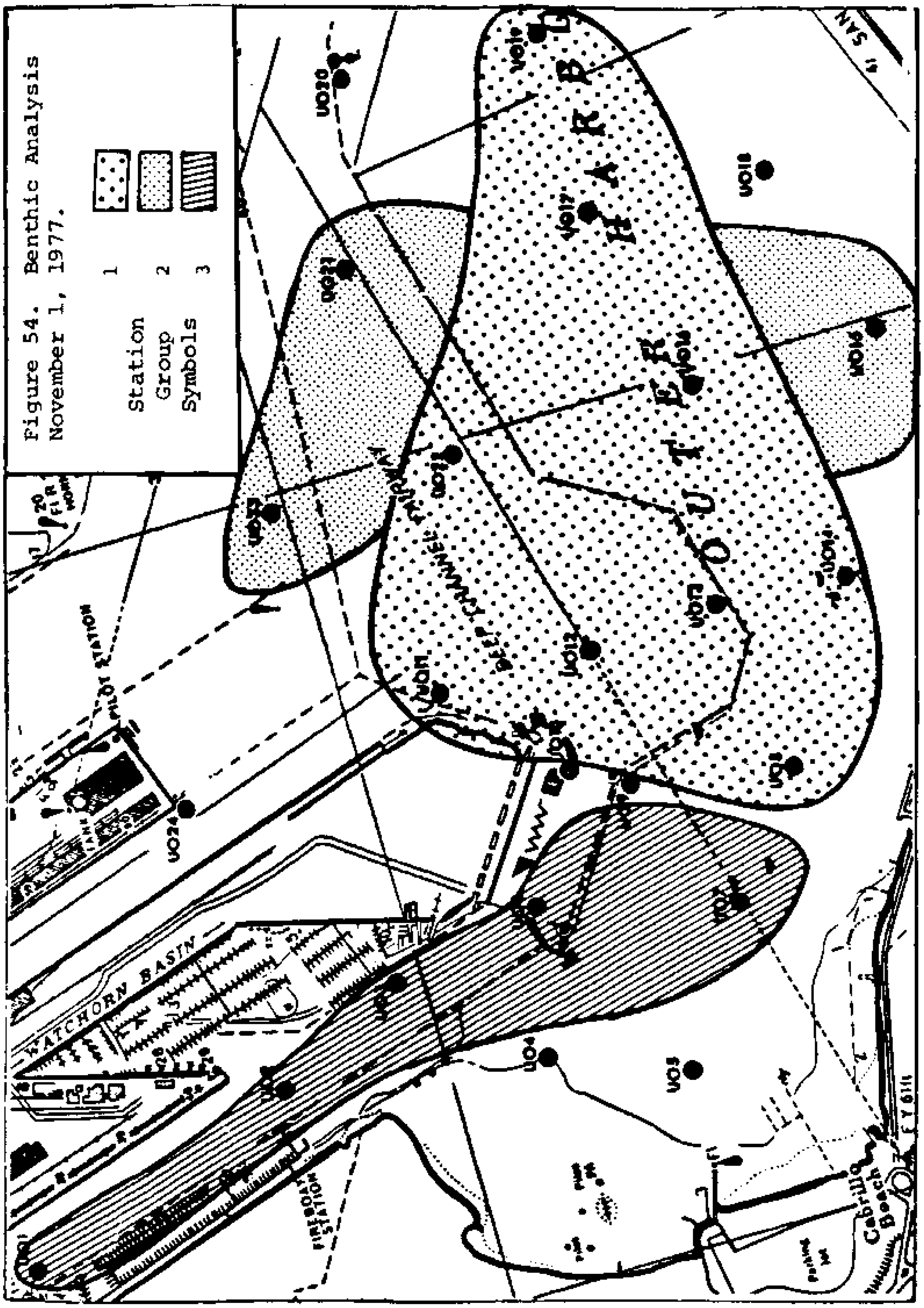


Figure 54. Benthic Analysis
November 1, 1977.

Station Group Symbols
1 ⬚
2 ▒
3 ▨

Figure 55

Union Oil Benthic Data, November 1, 1977.

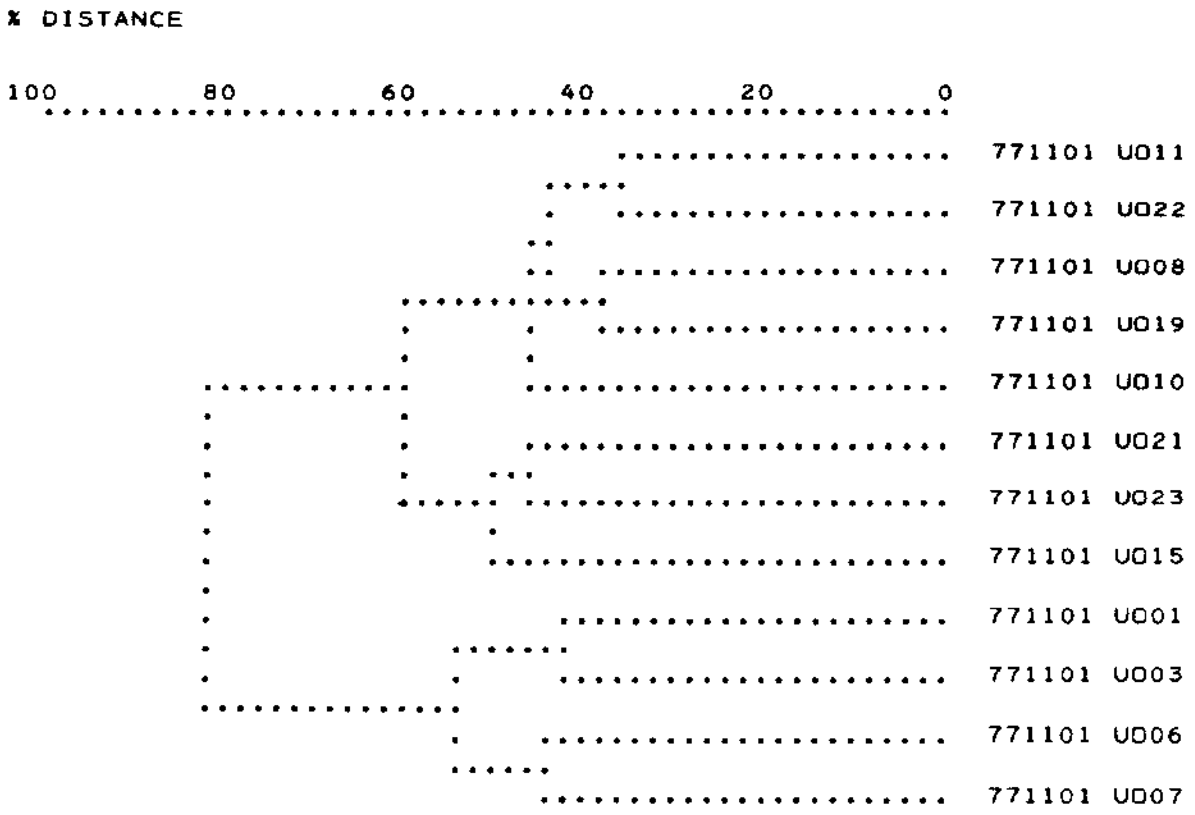
Coincidence numbers, transformed and standardized

* > .75 to 1
\+ > .5 to .75
\- > .25 to .50
. > 0 to .25
blank 0

STATION GROUPS	1					2			3			
	771101 U0111	U0229	771101 U0180	U0219	771101 U0110	U0221	771101 U0223	U0215	771101 U0001	U0003	771101 U0006	U0007
PRIONOSPIO HETEROBRANCHIA-NEWP										-	*	-
TAGELUS SUBTERES										.	*	-
PISTA DISJUNCTA			-								*	-
ARMANDIA BIOCULATA									+		*	-
CUMINGIA CALIFORNICA									+		*	
AXINOPSIDA SERRICATA						+			*	+	*	+
SCHISTOMERINGOS LONGICORNIS					*					+	*	+
THRACIA CURTA					-	-		-			*	-
EUCHONE LIMNICOLA		-		-					+	*	*	
SPIOPHANES MISSIONENSIS					+				+	+	*	
CAMPYLASPIS HARTAE										*	*	
MACOMA ACOLASTA		+	+	+				+			*	
OPHIODROMUS PUGETTENSIS	*										*	
HAPLOSCOLOPLOS ELONGATUS	+	-	*	-	*	+		+	*	*	-	*
NEPHTYS CORNUTA-FRANCISCANA	*	-	-	-	*	*		+	*	*	*	-
COSSURA CANDIDA	*	*	+	+	+	-	+	+	*	*	.	+
EUPHILOMEDES CARCHARODONTA	*	-	-	.	-			.	*	-	.	*
MYSELLA PEDROANA	+	*	-			-	-	-	-		*	+
PRIONOSPIO CIRRIFERA	+	-		-		+	+		-		*	+
MACOMA NASUTA	.	-				.		+	.	.	*	*
TELLINA MODESTA				-				-			+	*
OXYUROSTYLIS PACIFICA							+			*	+	+
PSEUDOPOLYDORA PAUCIBRANCHIATA	-		.				.		*	+	-	-
CAPITITA AMBISETA	*	+	.	-	*	-	-	-	-	-	-	-
CIRRATULIDAE THARYX	*	+	+	+	*	-	+	+	-	+	.	.
CHAETOZONE CORONA	*	*	*	+	*		+	-	-	+		
NEREIS PROCERA	*	+		+	*	-	+	-		-		
AMPHICTEIS SCAPHOBRANCHIATA	-	-	.	-	*	-	-		.	-	.	.
MARPHYSA DISJUNCTA		-	+	-	*	-			-	-	-	-
PARAONIS GRACILIS-OCULATA	.	*	-	+	+	.	.	-	-	-	.	.
PARAPRIONOSPIO PINNATA	+	*	+	*	*	-	-			-		-
PECTINARIA CALIFORNIENSIS-NEWP	-	*	-	-	*	*				-		+
PRIONOSPIO MALMGRENI	*	+	-		*				-	-		-
COMPSOMYAX SUBDIAPHANA	*	*	+		+	+				+		
SIGAMBRA TENTACULATA	*	+	-	-	+	*	-			.		
AMPHARETE LABROPS	*	+	-	*	*	-			-			
ACTEOCINA HARPA					*		+					
ETEONE DILATAE	+				+		*					
COOPERELLA SUBDIAPHANA	+		+	-	*		-				*	-
STHENELANELLA UNIFORMIS					*		+				+	
ACESTA CATHERINAE					*	*						
MEGALOMMA PIGMENTUM	*				*							
SPIOCHAETOPTERUS COSTARUM				*	*							+
LEPTON MEROEUM				+		*	+					
MAGELONA PACIFICA			+	*		*	+					
GLYCERA AMERICANA	*		+	+		+	+	+	+			
NOTOMASTUS TENUIS	+	*				*	*	+	+			
GYPTIS BREVIPALPA (ARENICOLA-G	+	*	+	+	-	+	+	+				
STREBLOSOMA CRASSIBRANCHIA	*	+	.		.		+	+	-	*		
AMAEANA OCCIDENTALIS		+		+			*				+	
PRIONOSPIO PYGMAEUS		+		*	-	.	*	-		.	-	
THEORA LUBRICA	-	+	*	+	*	+	-	*	-		-	
THYASIRA FLEXUOSA		+	*		*			-			-	
LAONICE CIRRATA		+	+				-	*		-	-	
CIRRATULUS CIRRATUS					-			*				
ACTEOCINA CULCITELLA		*								*		
ANCISTROSYLLIS HAMATA	*								*			

FIGURE 56

UNION OIL BENTHIC DATA, NOVEMBER 1977



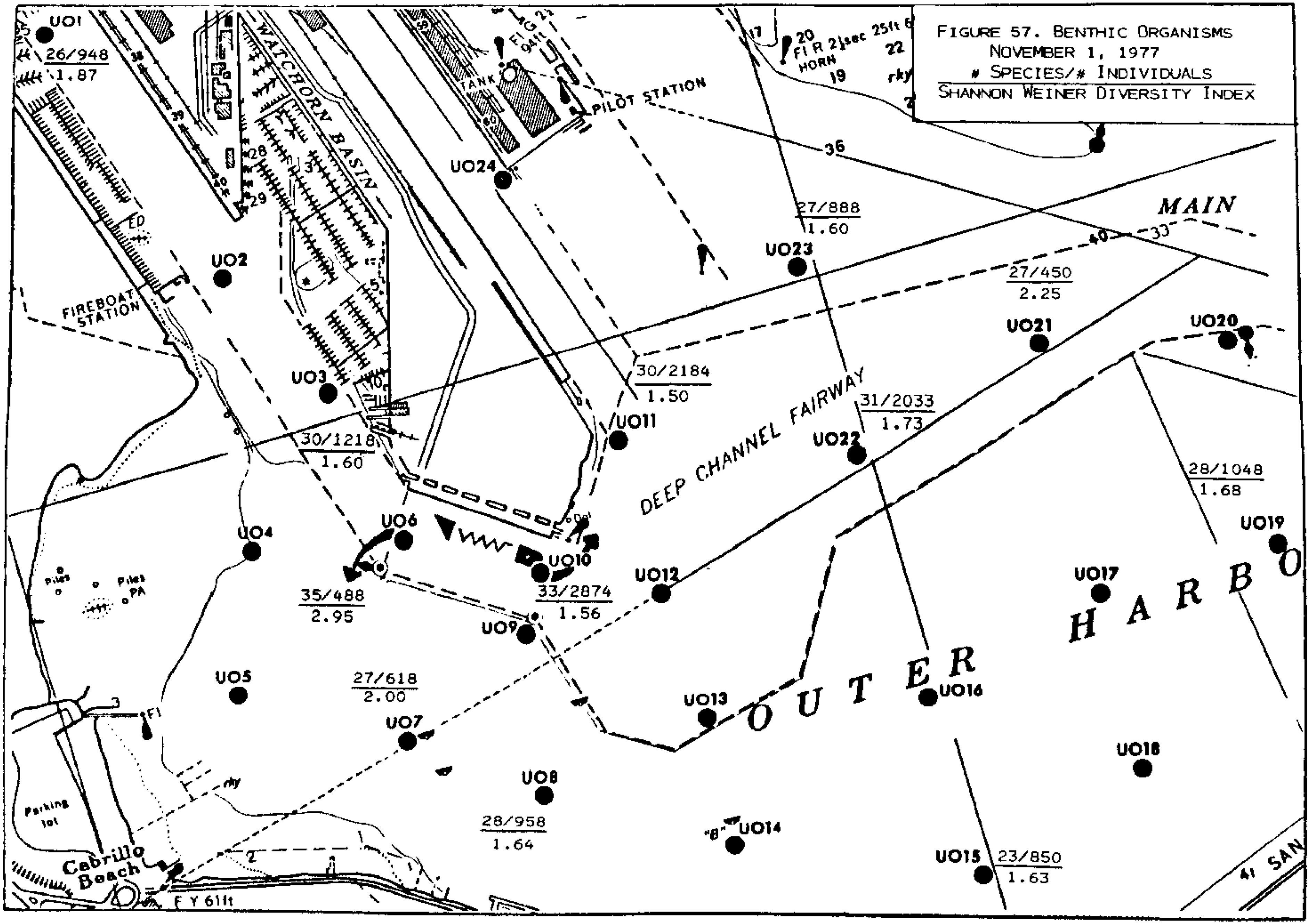


FIGURE 57. BENTHIC ORGANISMS
NOVEMBER 1, 1977
SPECIES/# INDIVIDUALS
SHANNON WEINER DIVERSITY INDEX

ABIOTIC PARAMETERS

by

BENTHIC GROUPINGS

FIGURE 58
BENTHIC GROUPINGS
TEMPERATURE (Benthic)
(RANGE & MEAN ± 2 S.E.)

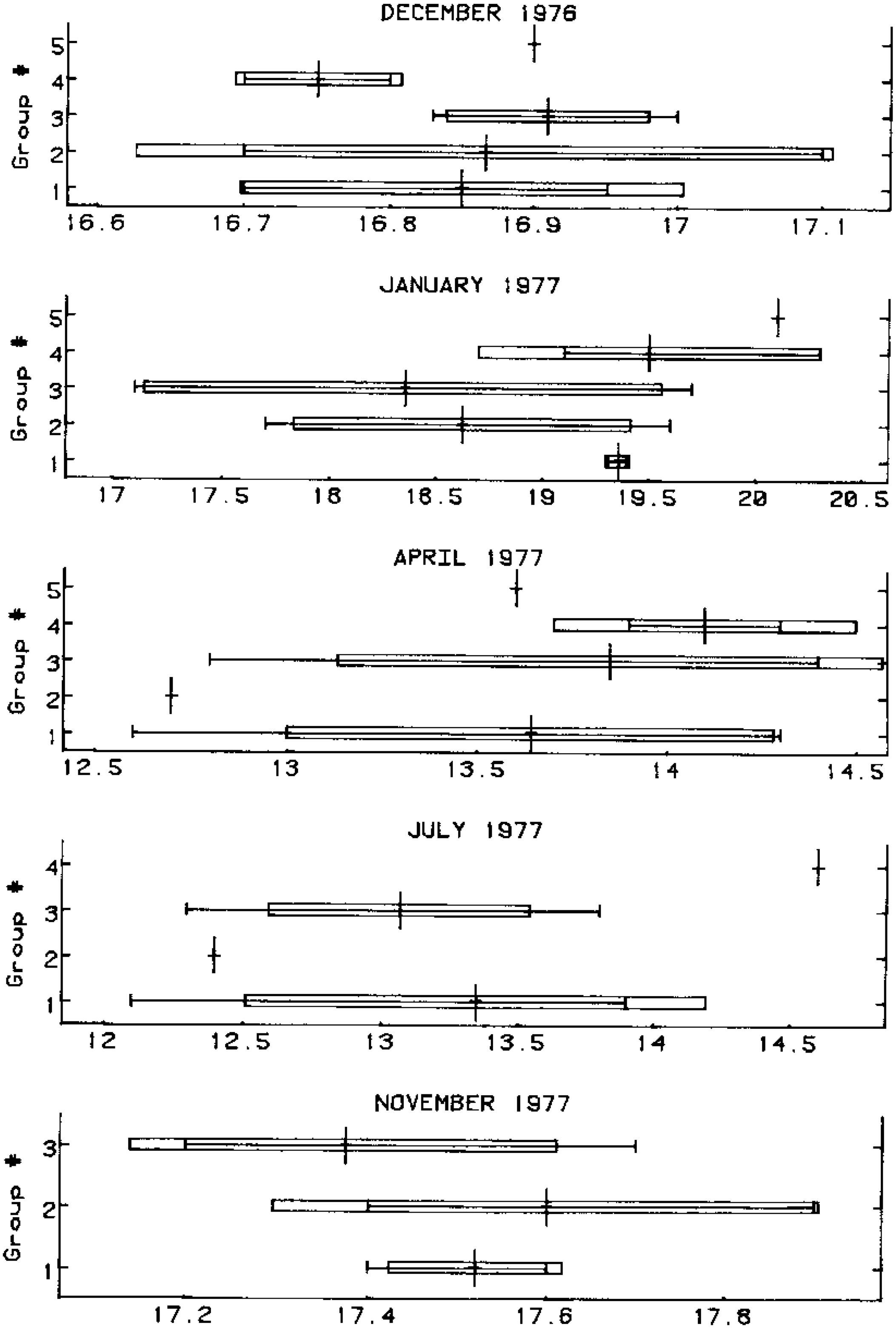


FIGURE 59
BENTHIC GROUPINGS

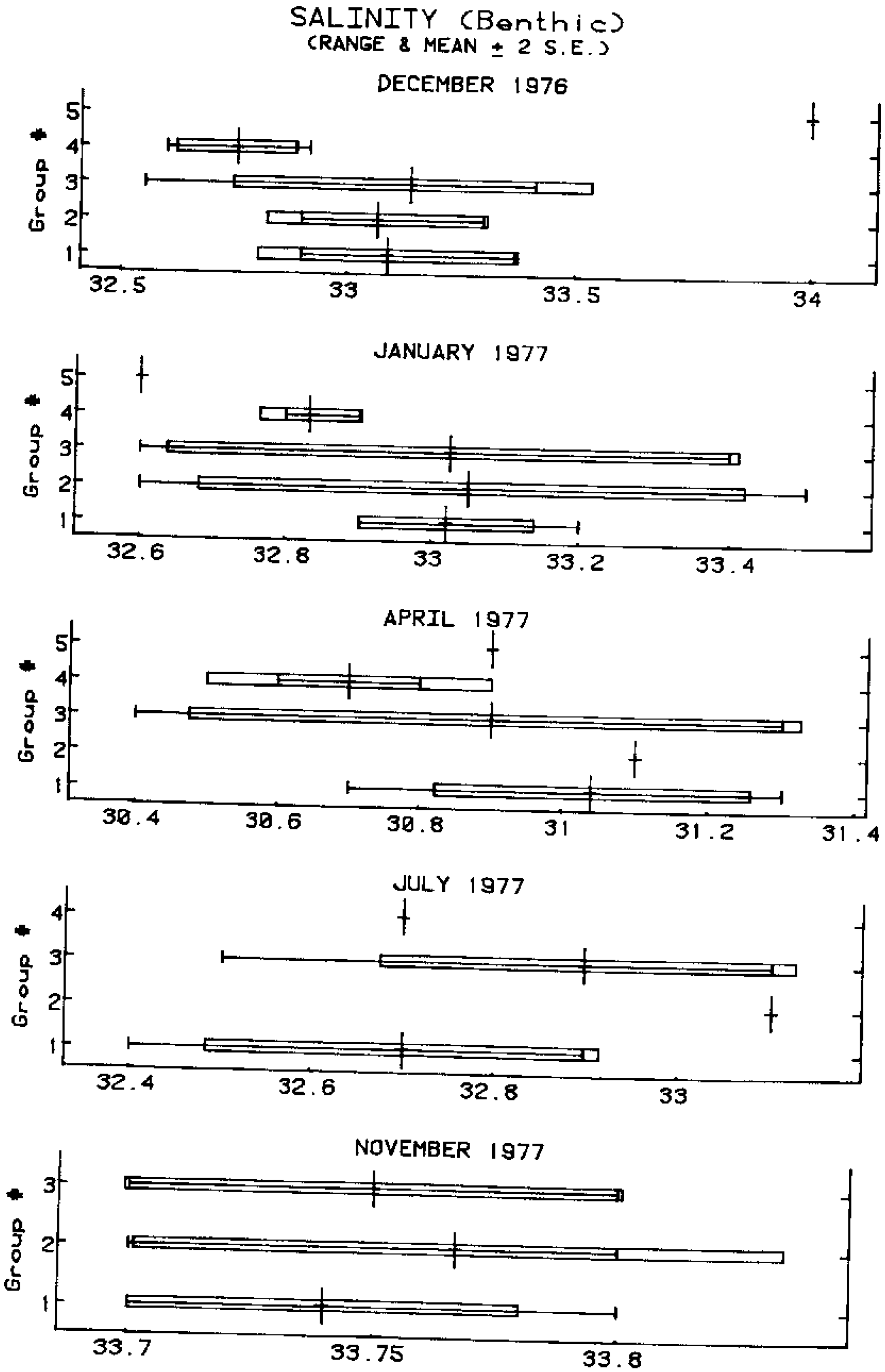


FIGURE 60
BENTHIC GROUPINGS

DISSOLVED OXYGEN (Benthic)
(RANGE & MEAN ± 2 S.E.)

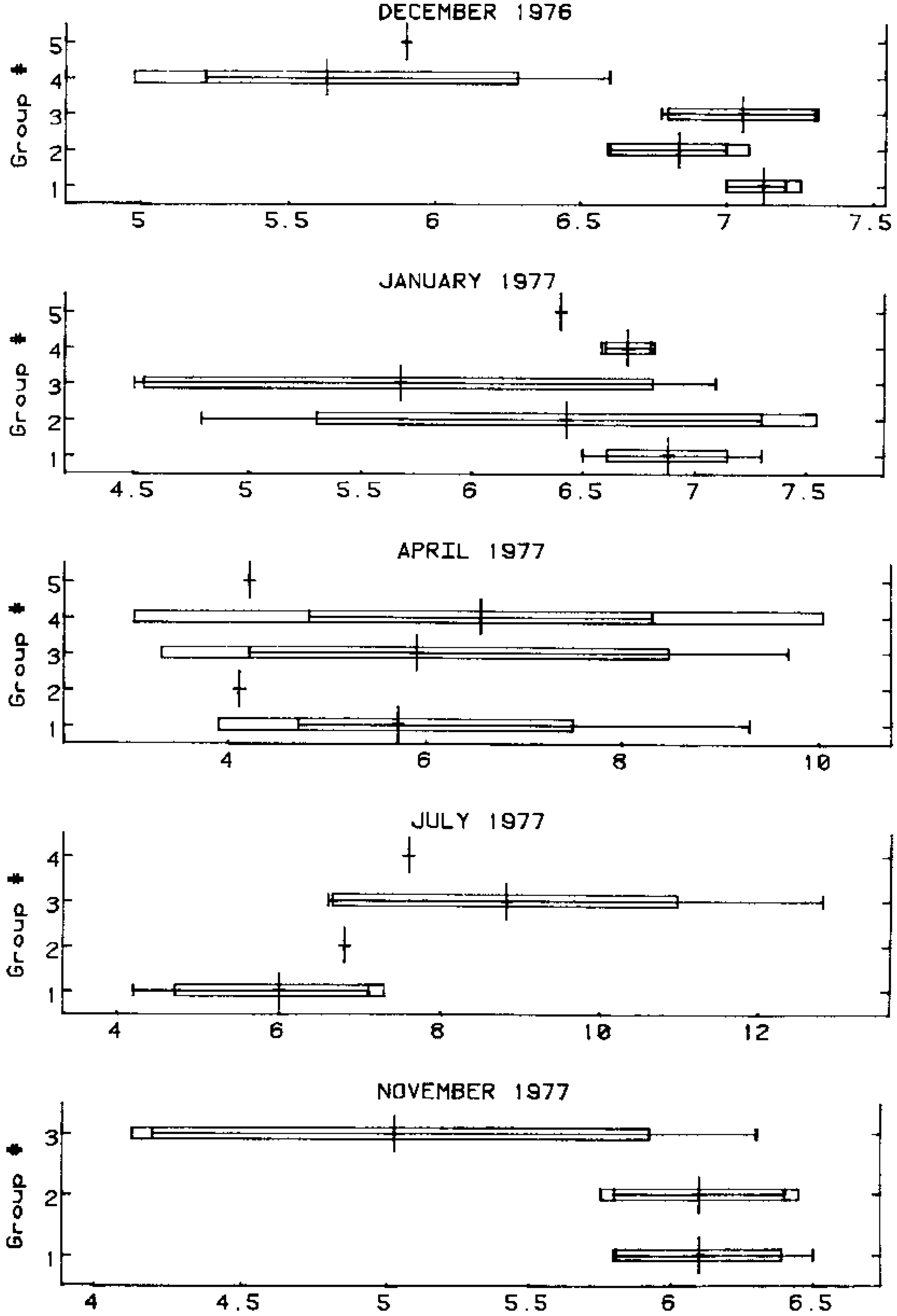
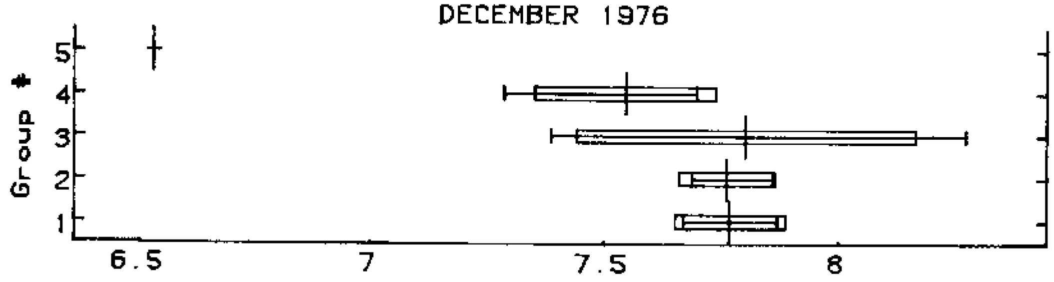


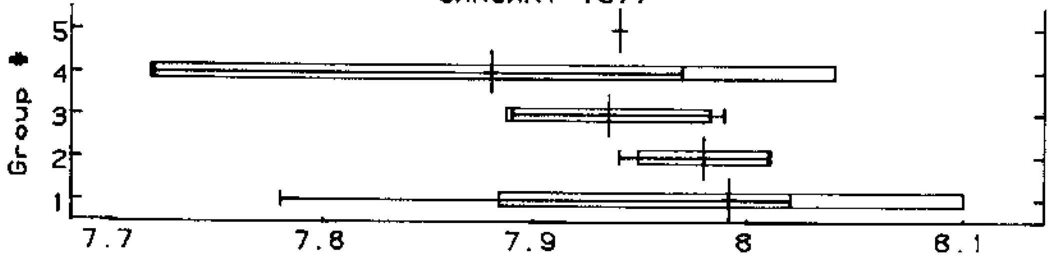
FIGURE 61
BENTHIC GROUPINGS

pH (Benthic)
(RANGE & MEAN ± 2 S.E.)

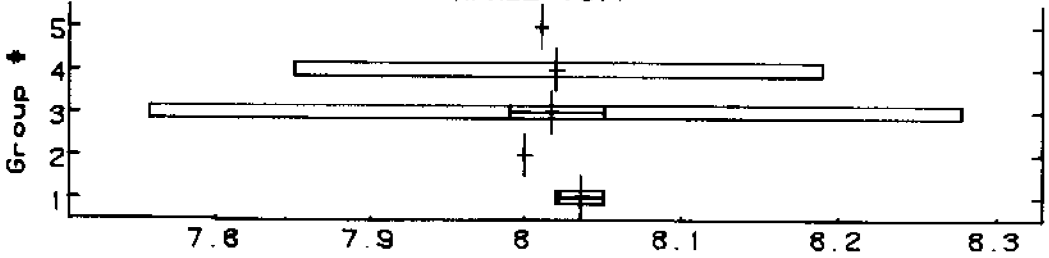
DECEMBER 1976



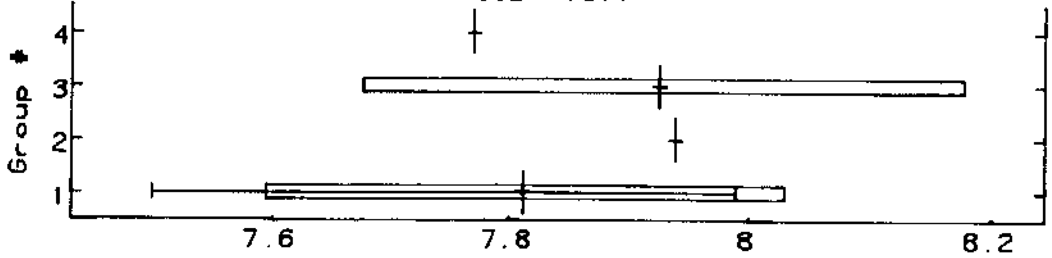
JANUARY 1977



APRIL 1977



JULY 1977



NOVEMBER 1977

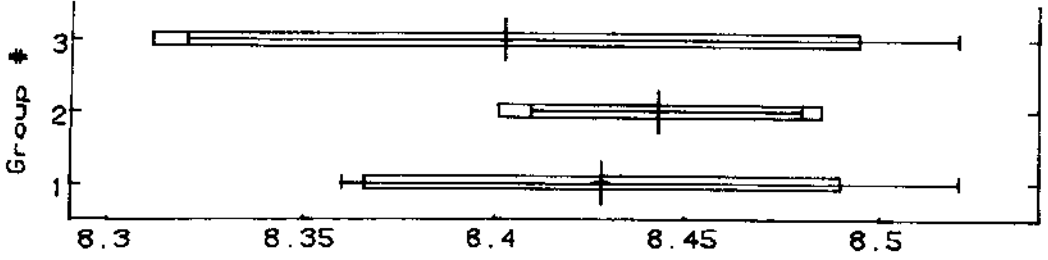


FIGURE 62

DEPTH (Benthic groupings)
(RANGE & MEAN ± 2 S.E.)

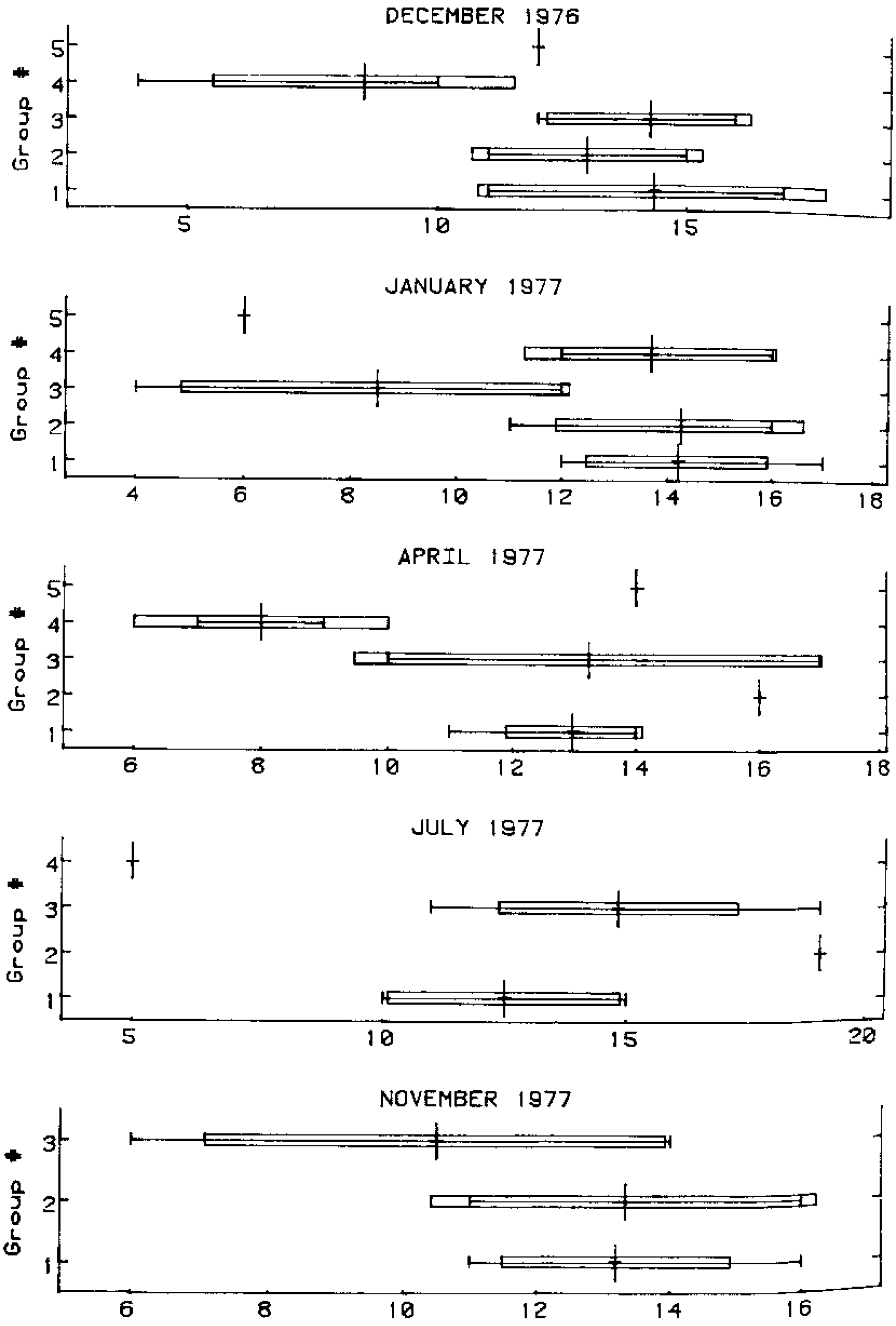


FIGURE 63
PERCENT LIGHT TRANSMITTANCE
TURBIDITY (Benthic groupings)
(RANGE & MEAN ± 2 S.E.)

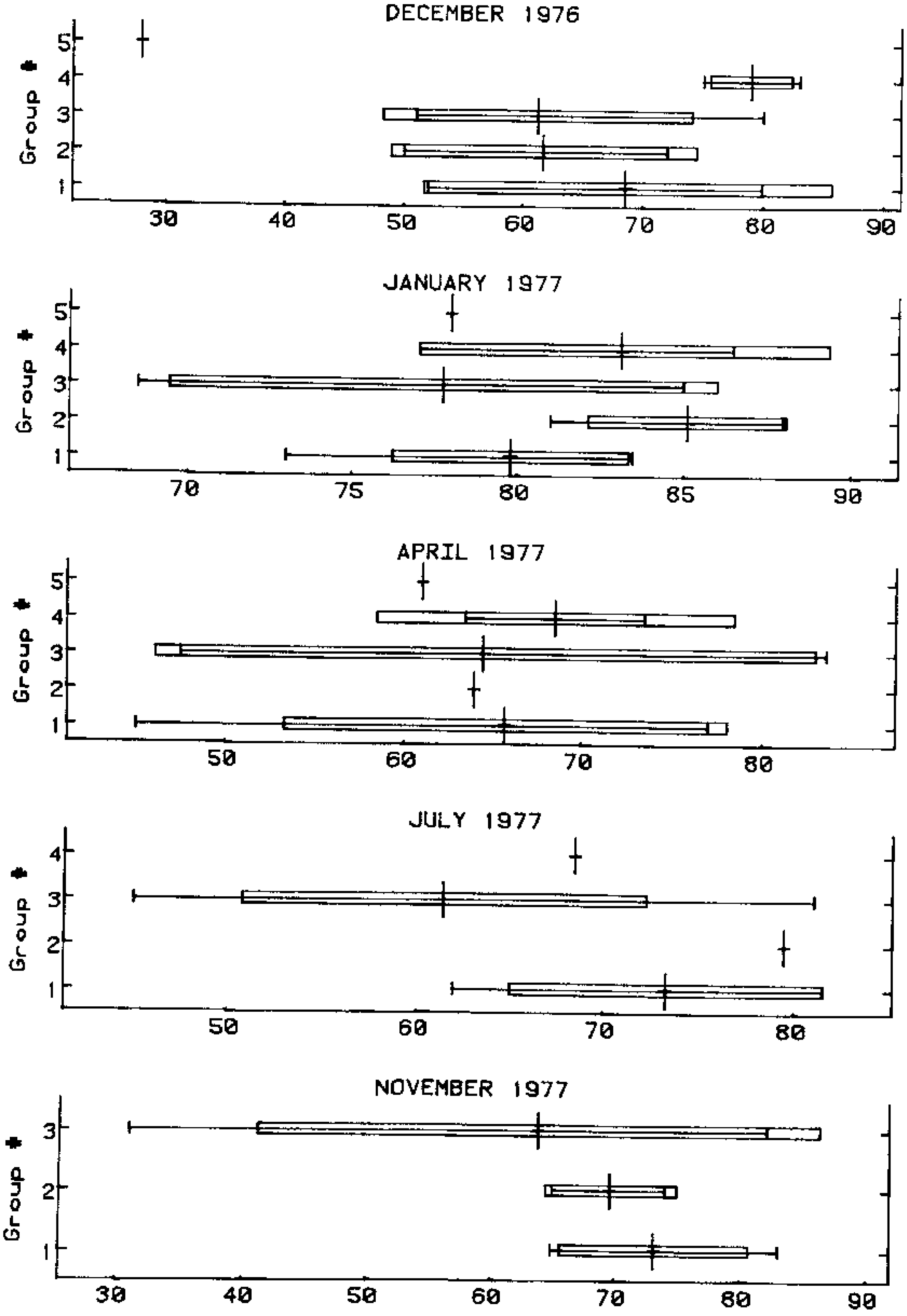
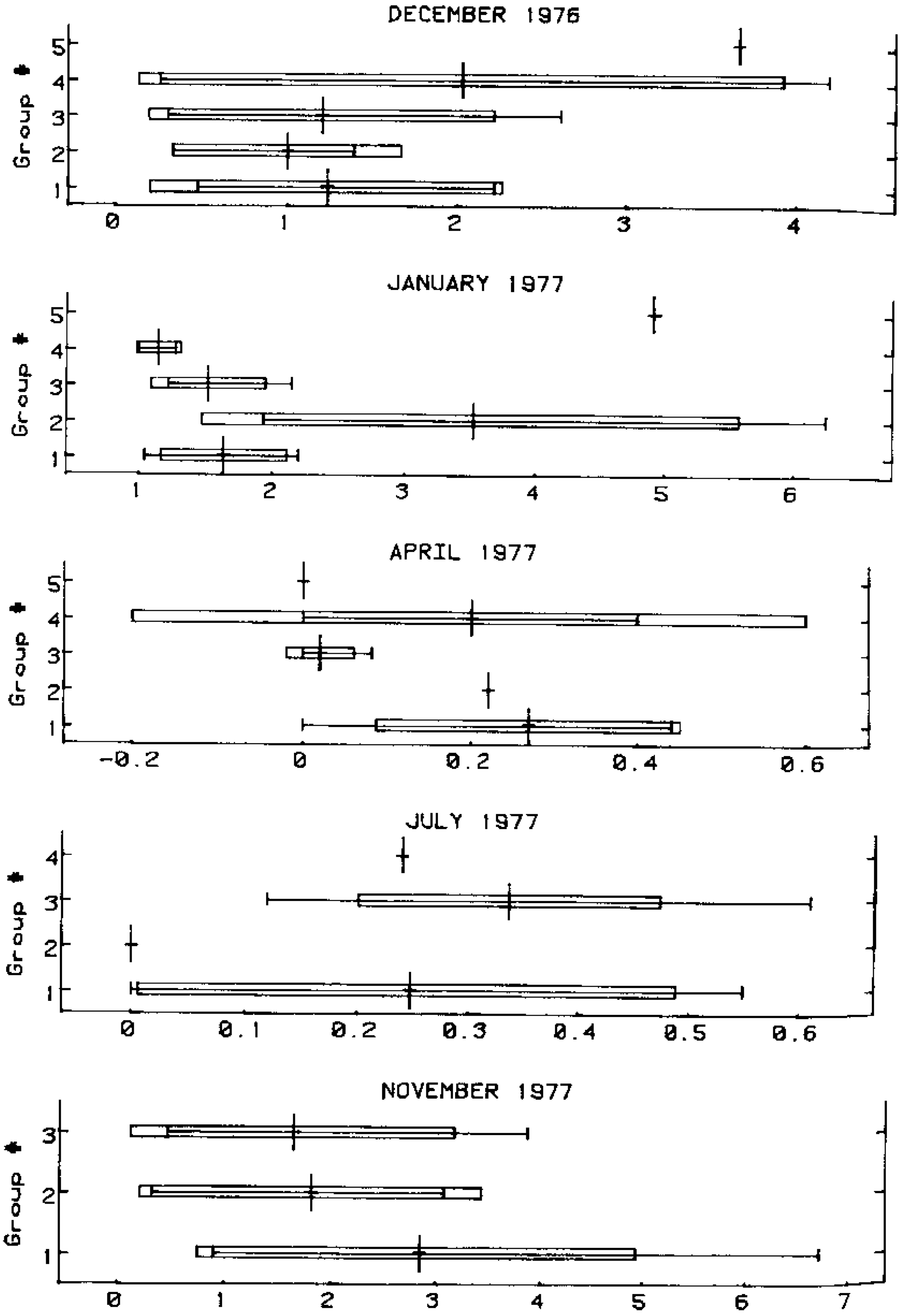


FIGURE 64
BENTHIC GROUPINGS

OIL & GREASE (water surface)
(RANGE & MEAN ± 2 S.E.)


DECEMBER 1976

JANUARY 1977

APRIL 1977

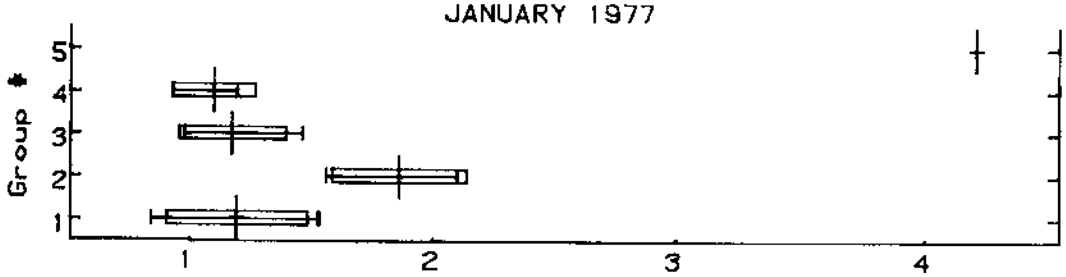
JULY 1977

NOVEMBER 1977

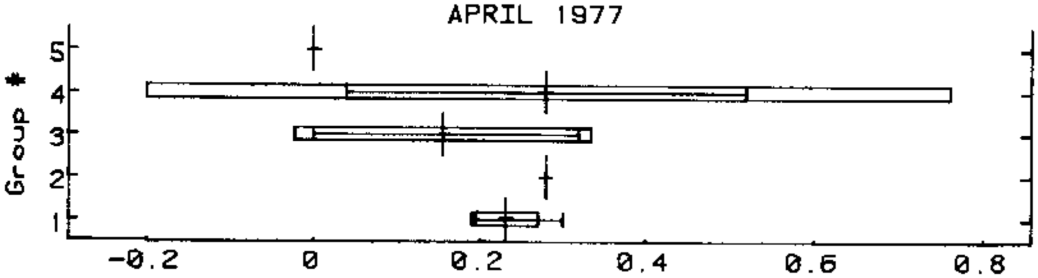
FIGURE 65
BENTHIC GROUPINGS

OIL & GREASE (water mid-depth)
(RANGE & MEAN ± 2 S.E.)

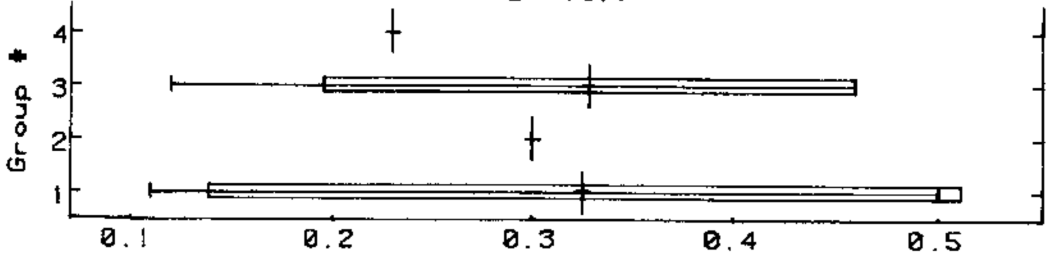
JANUARY 1977



APRIL 1977



JULY 1977



NOVEMBER 1977

FIGURE 66

BENTHIC GROUPINGS

OIL & GREASE (water bottom)

(RANGE & MEAN ± 2 S.E.)

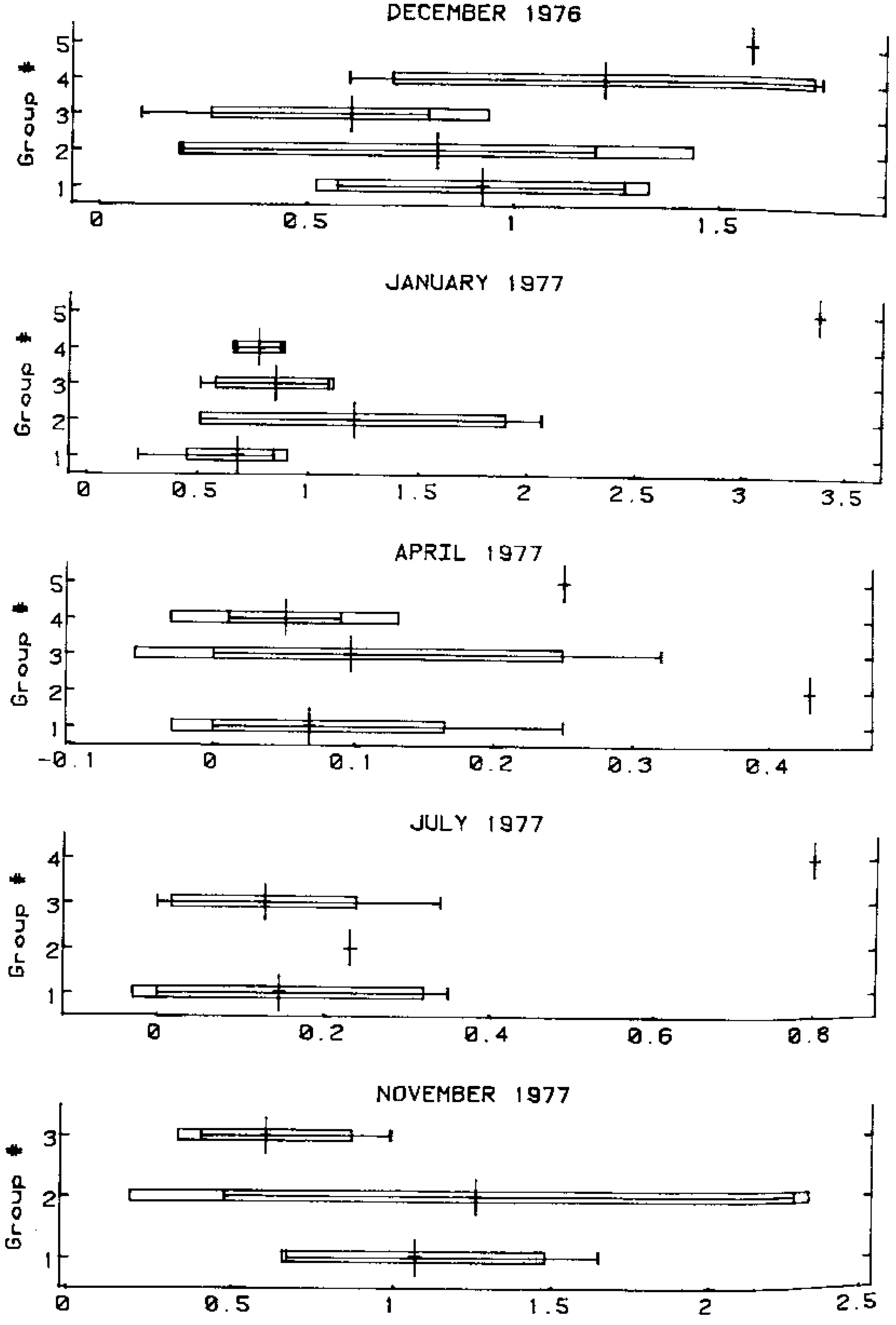
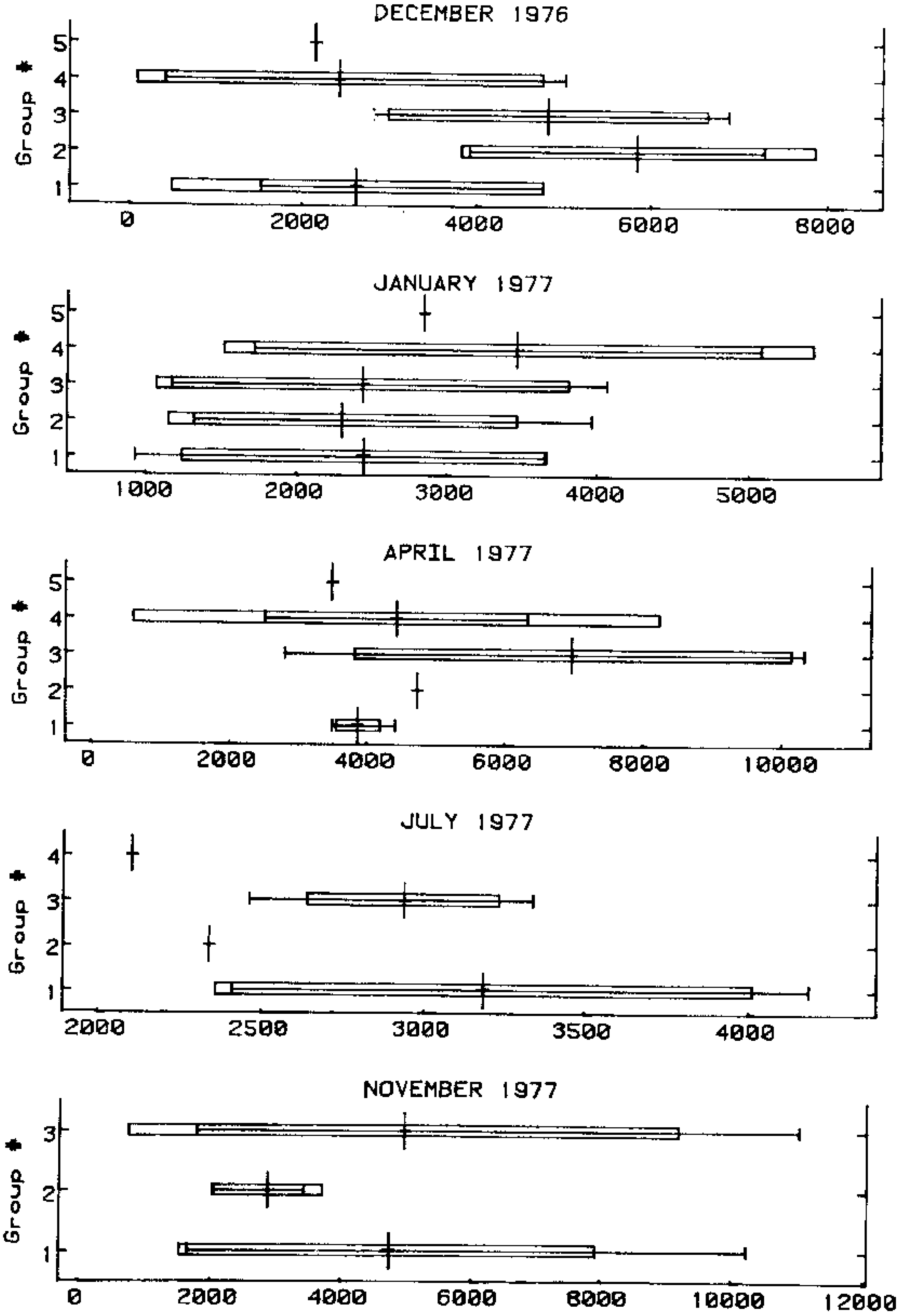


FIGURE 67
BENTHIC GROUPINGS

OIL & GREASE (sediment surface)
(RANGE & MEAN ± 2 S.E.)



C. ZOOPLANKTON INVESTIGATIONS

Introduction

Planktonic organisms are those that are permanently or temporarily suspended in a water mass and subject to transport by circulation patterns. Although some are able to swim, the organisms generally are not large enough or strong enough to swim any significant distance. Included in the zooplankton are numerous tiny crustaceans called copepods, which furnish food for many fish and invertebrates, plus the eggs, larvae and some juveniles of other crustaceans, molluscs, polychaete worms, ectoprocts, hydroids and fish.

An extensive zooplankton survey of the Los Angeles-Long Beach Harbors was carried out during 1973 and 1974 for the U.S. Army Corps of Engineers (AHF, 1976) by the Harbors Environmental Projects of USC. In this study distribution and diversity of zooplanktonic organisms were studied for the many geographic localities of the harbors and related to seasonal variations as well as points of particular interest, such as areas of chemical pollution or eutrophication. Survey data for Pacific Lighting Corporation cover a five-year period prior to the Sansinena explosion on 17 December 1976.

The objective of the present study of zooplankton was to determine what impact the oil spilled by the Sansinena had upon the zooplankton communities of the harbors. Zooplankton were thus collected for a number of localities throughout 1977 so that a comparison could be made with existing data from past years. Alteration in numbers of animals or species diversity could thus be noted by comparison with these data.

The presence of Bunker C fuel in a marine harbor habitat would be expected to have a considerable impact on any organism living on or in a surface with which the oil makes contact. Benthic epifauna and infauna such as worms, anemones, crabs or sea pens would all be affected by contact with oil. Oil washed ashore or picked up at the air-water interface would also have an impact on marine invertebrates and plants. Zooplankton, because they live within the harbor water column, are likely to show less impact because they are constantly being exchanged by tidal flushing. Oil rising from the bottom or washed by currents, tide or wind-produced turbulence, may have a transient impact on the biota in the water column at any given time.

Methods

Surface zooplankton collections were taken aboard the research vessel Golden West, using a half-meter, 253μm nylon, conical plankton net. The net was towed at about one knot for five minutes, with a flow meter of water positioned between the center and the rim of the mouth to record the volume of water flowing through the net. Plankton samples were placed in liter jars and preserved in formalin.

Identification and counting of the samples was preceded by subsampling with a Folsom plankton splitter such that the aliquots contained approximately 500 to 1,000 organisms.

Within a week after the spill sampling was begun on December 23, 1976 at special stations I to V and expanded to ten stations on December 29-30, 1976. The special sampling near A9 (=U09) outside the booms provided data for the area close to the *Sansinena*.

Results

The numbers of species found on December 23 were unusually high. The following species were found that are rarely present in the harbor:

Eucalanus crassus
Eucalanus elongatus
Centropages sp.
Rhincalanus nasutus
Mecynocera clausi
Lucicutia flavicornis
Temora discaudata
Candacea sp.
Corycaeus geisbrechti
Corycaeus flaccus
Farranula curta
Ischnocalanus tenuis

The weather and oceanographic conditions for the fall of 1976 and for 1977 were unusually warm, and this may account for differences in the species present. Increased diversity was also found in samples taken on December 1, 1976, outside the harbor. The very high tides of November and December (7 ft+) may have brought into the harbor species that normally occur offshore.

Concentrations of zooplankton at regular Harbors Projects stations sampled on December 1, 1976 prior to the explosion are given in Text Table 3. Station A9 (=U09) is at the channel marker buoy nearest to the *Sansinena* site. Other stations (A2, A3 and A8) are on the east side of the Los Angeles Main Channel. These data, compared with concentrations found on December 23 and December 29-30, after the spill, show a decrease in concentrations after the explosion.

Text Table 3. Concentrations of Zooplankton, 1976 (number/meter^3)

December 1	December 23		December 29-30	
A2: 2774	SPI-II	757	U01:	232
A3: 1063	SPIII-IV	593	U03:	656
A8: 1098	SP V	431	U05:	192
A9: 829			U07:	414
			U011:	787
			U013:	568
			U015:	776
			U017:	637
			U019:	807
			U021:	430
			U023:	463

Dec. 23 special stations

SP I - near U03
SP II - near U06
SP III - between U06 and U07
SP IV - south of U09
SP V - from U013 to north

The most notable feature following the explosion and spill was the persistence of high diversity, for at least a few weeks, with an increase in copepod and cladoceran species, even though the concentrations were reduced. Numbers of individuals of a few species actually increased.

Previously the two most numerous harbor copepods had been *Acartia tonsa* and *Paracalanus parvus* (AHF, 1976). Following the spill *Acartia tonsa* appeared to have increased in concentration from December 1, 1976 to the post-spill sampling. Mean *Acartia tonsa* was about 1100/m^3 at stations A2, A8 and A9 prior to the spill, increasing to about 1400/m^3 after the spill. This may not be significant, however, due to the generally patchy distribution of zooplankton because of winds, tides and proabaly food supply. Similarly, most *Paracalanus parvus* concentrations in the post-spill December 29-30 samples were unusually high, particularly at stations U07 through U023. Concentrations after the spill were about 275/m^3, much higher than they had been since July, 1976.

During 1973-1974 the ranges of mean *Acartia tonsa* concentrations at A2 were 1800-2400/m^3, 1200-1800 at A9, 600-1200 at A10, and about 600 at A8. During that period mean concentrations of *Paracalanus parvus* were between 200 and 300/m^3 at A2, A8 and A9, and below 100 at A10.

The abundances of four common species of zooplankton at station A1 (the sea buoy outside Los Angeles Harbor) and at A9 (beside the Sansinena site) are plotted in Figures 68 and 69 for the period 1972-1977. A surface temperature curve is superimposed, for comparing the variation in temperature seasonally and annually with the zooplankton. Figures 70 and 71 give the data on an expanded scale for the year 1977 alone.

No peaks were apparent at the sea buoy (station A1) during the winter of 1976 and early spring, prior to April or May of 1977 in the four species graphed (Figure 70). In contrast, some distinct peaks occurred near A9 (the Sansinena site) in December/January (Figure 71), particularly for *Paracalanus parvus*. However, fall peaks occurred both inside and outside the harbor in September-November 1977. This is not an uncommon phenomenon in the harbor (AHF, 1976) and may be related to seasonal temperature changes.

The numbers of individuals per cubic meter continued to be low outside the harbor from December 1976 through the spring of 1977, but counts in the spill area rose greatly in April as compared to the other area. The numbers of species of copepods and cladocerans dropped in the site area from December / January levels through April and July, and rose again by the November 1977 sampling.

The numbers alone cannot be compared absolutely, because the effects of wind and tide on distribution (patchiness) are difficult to assess. Certainly the data seem to show consistent trends, even though the trends may not be precisely quantifiable.

It is typical of a stressed environment that many species will be eliminated from an area, and a relatively few hardy or opportunistic species will "bloom". The initial surge in numbers is later followed generally by an increase in numbers of species and a decrease in numbers of individuals, due in part to growth and competition. Certain species may not be very tolerant of environmental stress but do not compete well with other species in a normal environment. Conversely some species cannot tolerate the varied environment of a natural estuary and would not survive long there even if they were reintroduced frequently by tidal exchanges.

Conover (1971) found that two species of copepods, *Calanus finmarchicus* and *Temora longicornis*, fed on weathered Bunker C oil particles and that this was a natural factor in the immobilization of an oil spill, without apparent toxic effects on the ingesting copepods. It is not known whether recruitment is possible to any extent, since zooplankton have limited ability to move independently of tidal or other water movements.

With regard to transitory effects of oil on zooplankton, it must be noted that at the time of the collection of the first samples subsequent to the spill (special stations I-V) the technicians observed that the copepods showed no activity and appeared dead. Upon sorting these samples there was no evidence of their death prior to collection, such as the presence of broken or decomposing bodies. It is possible that the zooplankton were in a state of torpor caused by the presence of the oil spill. While this observation is very subjective, it may be significant nevertheless.

Discriminant Analysis

Because there are synergistic effects of the physical and chemical parameters exerted on the biota, experimental or observational information on the impact of a particular parameter such as Bunker C fuel may differ from field information. Computer analysis (Section I, this publication) offers a method for calculating and plotting the interactions and indicating the relative importance of each parameter measured. This is not to say that the methods are necessarily statistically significant, or that some unmeasured parameters might not exert an influence that was not recognized.

Temperature ranges were unusual in 1977 and therefore might have exerted an influence that would exceed or mask the impacts of the oil spill. In order to test whether temperature exerted an overriding impact, multiple indiscriminant analysis was first carried out without temperature data intput, and then repeated with temperatures included. Similarly, analysis was carried out with, and without, the input of phytoplankton data to examine the differences in the importance of the oil and grease content of the water column.

A variety of treatments of the data can produce different species and site groupings, so that the importance of different parameters can be examined. The analytical programs were run first, using all the entities (species and higher categories) reported and then using only the most common copepod and cladoceran species. Therefore it must be recognized that the station groupings, the Two-Way-Tables and the dendrograms are not fixed and might be different in each case. Also, weighting of variables is used to minimize particular problems, as for example to reduce extreme ranges of counts of dominant species. The important factors under each set of inputs can thus be identified. If certain factors are identified as important under each of the analyses tested then it can be assumed that the parameters so identified are strongly related to the faunal distribution of that period.

Weighting of variables is accomplished by using calculations of biological "distance" between sites by constructing similarity matrices based on groupings determined by the dendrogram calculations. The complex equations used in these analyses are not the subject of this paper and are discussed in depth in Smith, 1976.

Means and extremes of the data for each variable are presented as bar graphs at the end of this section (Figures 88-99). However, in discriminant analysis the means are weighted by using the similarity matrices, so that the values in the tables of weighted group means will not be the same as the values for raw data shown in the bar graphs.

December 1976-January 1977. Because of difficulties in making horizontal plankton tows around booms and cleanup crews, the December 29-30 and January data were combined for multiple discriminant analysis and classification. It is an accepted procedure to combine data for analysis on a seasonal basis in any cast. Figure 72 shows the five groups for the post-spill month which were delineated by classification of all the biological entities listed in the Two-Way-Table (TWT, Figure 73) and the dendrogram (Figure 74).

When another analysis was made using only the 18 most common copepod and cladoceran species and recalculated counts, five groupings still were seen, but slightly different site group separations were created, which isolated station U01 from U07 and station U03 from U023.

The important result, regardless of the various analyses performed, was that the oil and grease levels in the water column far outweighed any other physical parameters in determining the distribution of zooplankton in the winter period. Interestingly, midwater concentrations of oil and grease were more important than surface water concentrations. Chlorophyll *a* was the most important natural variable. Temperature and salinity were less important variables, along with dissolved oxygen; pH and light transmittance were of marginal importance under the various analyses.

The weighted group means of the variables for December-January are shown in Table 15. Site group 1 was characterized by having the lowest weighted means in primary productivity and chlorophyll *a* but the second highest assimilation ratio, all phytoplankton parameters. Group 1 also had the highest weighted means for temperature and salinity as well as the lowest weighted water means for oil and grease in surface, mid- and bottom water and sediment.

Table 16 shows one of the sets of coefficients of separate determination developed for the winter data. The numbers for each parameter are expressed as percentages of the "influence" among all parameters measured. The axes (columns) represent hypothetical plots in space, on which the combined values of interacting parameters would be located as new values. Generally, most of the significant values fall within the first two or three axes developed.

The coefficients in the first two axes in Table 16 show the importance of chlorophyll *a* and of oil and grease in the water column and sediment.

Group 5 in this analysis included the inner channel stations, which were clearly separated on the basis of the highest weighted means for productivity and chlorophyll *a* and the lowest assimilation ratio, as well as the lowest salinity and dissolved oxygen and lowest temperature. Group 5 also had the highest oil and grease in surface and bottom water and second highest mean content in mid-water and sediment.

The Two Way Table showed distinct gaps in the species composition in Group 5.

Group 3 sites were clearly isolated in this analysis only on the basis of the highest weighted means for mid-water and sediments for oil and grease, and the lowest pH.

Group 2 overlapped Group 1 spatially and in parameter means and ranges. Group 2 had the highest mean dissolved oxygen and lowest pH and light transmittance. Group 4 sites also were not clearly separated. They were distinguished only by having the highest assimilation ratio and percent of light transmittance.

It must be emphasized that there is always the possibility that some parameters not measured in the present analyses could alter these groupings and achieve further separations or characterizations if they were included. The station groupings remained generally similar in the various analyses tested, with only minor shifts of single sites from one group to another. The important coefficients were the same, although the values were adjusted according to the number of variables included.

Figure 75 presents the data on the number of species and number of individuals per cubic meter at each station, as well as the Shannon-Weiner Diversity Index calculation for the period.

<u>April, 1977</u>. Classification of species groups showed four site groupings in the area (Figures 76-78) in April, three of which had considerable overlap. The TWT showed distinct gaps in the species composition of each group. Tables 17 and 18 present the weighted means for the site groups and the coefficients of separate determination, respectively. Based on the coefficients (Table 18), primary productivity, dissolved oxygen and salinity were the most important natural parameters; oil and grease in the water surface was also important, even though levels were low. Temperature and pH were apparently of lesser importance.

Group 2, isolated as station U023, had the highest weighted means for primary productivity, salinity and pH, and the lowest mean dissolved oxygen (perhaps associated with the productivity). It also had the second lowest weighted mean for water surface oil and grease and the lowest temperature.

Groups 3 and 4 were composed of stations close to the <u>Sansinena</u> site, and probably the zooplankton reflect changes in the bottom oil residue associated with salvage operations. Group 3 had the second lowest weighted means for salinity, dissolved oxygen and pH, and the lowest weighted mean light transmittance and productivity. However, Group 3 had the highest mean surface water oil and grease levels and highest temperature.

July, 1977. Classification techniques resulted in four groupings (Figures 80-82). The TWT shows the reduced numbers of species and gaps in distribution.

In July the zooplankton was clearly dominated by productivity, chlorophyll *a* and assimilation ratios. Turbidity may have been due to phytoplankton. The weighted means for one analysis are shown in Table 19.

Group 1 stations were intermediate, having second highest weighted means for salinity, pH, light transmittance and oil and grease in surface waters. It was, however, lowest in dissolved oxygen, and next lowest in temperature, and was median in phytoplankton parameter means as well.

Group 2 stations were highest in weighted means for dissolved oxygen, perhaps indicating a phytoplankton bloom, and in salinity, and second highest in temperature. They were second lowest in pH, light transmittance and surface water oil and grease. However, they were first in productivity and assimilaion ratio, probably the determining factors.

Group 3 had the lowest weighted means for salinity and temperature and highest for pH, light, and surface water oil and grease. It was second lowest in dissolved oxygen. The three stations in Group 3 were clustered next to the pier. In July, differences in oil and grease in the water column were small and bar graph data showed extensive overlap. Once again phytoplankton clarified this group, with the lowest productivity and assimilation ratio, and the highest chlorophyll *a* and light transmittance. While surface water oil and grease showed no importance, when the analyses were re-run with mid- and bottom water concentrations included those coefficients showed some importance. They were still outweighed by the phytoplankton characters. The coefficients for two analyses are compared in Table 20.

Group 4 stations were physically isolated. They shared lowest chlorophyll *a* values and second highest productivity and assimilation ratio. They were also separated slightly by the highest temperature, the second lowest salinity, lowest pH, and lowest light transmittance. The lowest surface oil and grease apparently was not an important factor, since differences were so small in the physical variables. Interestingly, the map of groupings resembles the distribution of oil and grease shown in Chapter II (Figures 14 to 17). The number of species and counts are presented in Figure 81, along with the Shannon-Weiner Diversity Index. Counts were up in a few locations, as was diversity.

November, 1977. In November, as in previous months, phytoplankton parameters of productivity, chlorophyll *a*, and assimilation ratio dominated group separations of zooplankton that otherwise could not be clearly made. When temperature and phytoplankton measurements were all omitted from the data, weighted discriminant analysis produced weak separations, with overlapping bar graph data, based on salinity, dissolved oxygen and pH. Overlap was extensive in all oil and grease data, except for surface water where Groups 2 and 3 were separated by that factor, but Group 1 overlapped both in range.

When phytoplankton parameters alone were eliminated from the analysis, temperatures appeared to be much more definitive in separating the groups in November. Air temperature had extreme ranges inland - 10C(50F) to 32C(90F). Water temperatures were unusually high for the period - 17C(63F) to 19C(66F). Generally water temperatures have dropped below that level into the 14-15C range by November. This, along with some rainfall, could affect the diversity as well as total numbers; certainly the combination of temperature extremes with pollutants would affect plankton populations. Groupings were typical of inner slip-deep channel-shoaling area divisions, without the anomalous patterns previously observed which probably were indications of the impact of the spill, however.

In the analysis presented, Figure 84 shows one set of site groupings developed, along with the Two Way Table (Figure 85) and dendrogram of sites (Figure 86). The weighted means used in these figures are in Table 21.

Site group 1 was characterized by highest weighted mean productivity and assimilation ratio and highest pH, with the lowest weighted mean light transmittance and temperature. Site group 2 had highest weighted means for salinity, dissolved oxygen, light transmittance and oil and grease in surface waters. However, the most important parameters were probably the low weighted means for productivity and chlorophyll *a*.

Group 3, the inner channel stations, had the highest weighted mean temperature values but lowest weighted means for salinity, dissolved oxygen, pH and surface oil and grease. Species diversity did not change appreciably in November (Figure 87) but the counts per cubic meter appeared to have increased, especially at the inner slip stations.

Table 22 gives comparisons of two different sets of coefficients of separate determination for November, based on changing the parameters selected for the weighted discriminant analysis. In most cases it can be seen that the important coefficients (higher values) remain important (above 5.0, perhaps). However, the comparative values change as more parameters are introduced. Salinity, temperature and dissolved oxygen in particular dropped when phytoplankton parameters were introduced.

The site groups could be altered by various adjustments in the species included and the counts. However, in each case tested the inner stations U01 and U02 were together, the sites U010 and U011 at the Sansinena dock remained together, and the shoaling area of the outer harbor clustered into one or more site groups. Certain stations changed groups more readily. Stations U03, U06, U07, U08 and U021 shifted about; one might assume that less definitive relationships occurred at these stations. Certainly the testing carried out indicated that, while flexibility was seen, the trends were consistent.

Summary. In examining the multivariate analyses, it must be remembered that the significance is not validated for the weighted discriminant method. Comparison of bar graph data for each separate parameter with the weighted discriminant analysis plots gives a good indication of interactions among the parameters. There is always the possibility that factors other than those measured are responsible, at least in part, for the results.

In December and January, unusually high numbers of rare species occurred in the harbor but low total numbers of zooplankton were seen. Phytoplankton parameters were the most important factors, followed by oil and grease in the water column. For the rest of 1977 species diversity was low but numbers of individuals rose well above usual counts in the outer harbor.

In April and July, phytoplankton furnished the dominant parameters, with oil and grease and temperature also showing lesser separations.

November groupings were largely determined by phytoplankton and temperature; lower coefficients and overlap led to the hypothesis and tentative conclusion that oil was no longer toxic to the zooplankton.

Bar graph data of abiotic variables and nutrients are presented, according to the plankton station groupings by season at the end of this section (Figures 88 to 99). If separations were made with bar graphs on the basis of individual parameters rather than by coefficients, each might show some means and ranges that would separate one group from another. In many instances, however, there was considerable overlapping. The multiple discriminant techniques using weighted variables show the interactions or interrelationships among the physical and biological parameters.

TABLE 15

WEIGHTED GROUP MEANS

DISCRIMINANT ANALYSIS * JANUARY 1977
UNION OIL PLANKTON DATA

	SITE GROUPS				
	1	2	3	4	5
1. PRODUCTIVITY	3.7060	3.7345	3.7560	3.8029	3.8032
2. CHLOROPHYLL A	0.8469	0.6594	0.8706	0.8627	0.8835
3. ASSIMILATION RATIO (A)	5.0877	5.0220	5.0158	5.1009	4.9361
4. OIL + GREASE (WATER SURFACE)	1.1764	1.1859	1.2095	1.2115	1.2270
5. OIL + GREASE (WATER MID-DEPTH)	0.9281	0.9379	0.9588	0.9358	0.9542
6. OIL + GREASE (WATER BOTTOM)	0.7054	0.7174	0.7315	0.7174	0.7342
7. OIL + GREASE (SED SURFACE)	2589.0408	2631.4275	2722.8613	2654.0935	2721.9185
8. TEMPERATURE	16.7309	16.7251	16.6888	16.7094	16.6552
9. SALINITY	33.0141	33.0135	32.9865	32.9729	32.9451
10. DISSOLVED OXYGEN	7.2936	7.3064	7.2958	7.2413	7.2297
11. PH	7.6878	7.6859	7.7009	7.6868	7.6948
12. TRANSMITTANCE	71.8427	71.2326	71.5979	72.1221	72.0549

TABLE 16

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE)) ** (AXES IN COLUMNS)

DISCRIMINANT ANALYSIS * JANUARY 1977
UNION OIL PLANKTON DATA

	AXES		
	1	2	3
1. PRODUCTIVITY	3.3	0.7	1.7
2. CHLOROPHYLL A	20.7	2.6	1.6
3. ASSIMILATION RATIO (A)	6.2	3.3	8.2
4. OIL + GREASE (WATER SURFACE)	5.9	0.3	8.5
5. OIL + GREASE (WATER MID-DEPTH)	3.6	35.7	3.2
6. OIL + GREASE (WATER BOTTOM)	6.7	7.9	0.0
7. OIL + GREASE (SED SURFACE)	12.9	11.3	9.0
8. TEMPERATURE	7.5	17.9	3.0
9. SALINITY	13.9	0.2	12.1
10. DISSOLVED OXYGEN	9.5	5.2	12.2
11. PH	1.4	11.6	24.2
12. TRANSMITTANCE	8.5	3.2	16.3

TABLE 17

WEIGHTED GROUP MEANS

WEIGHTED DISCRIMINANT ANALYSIS * UNION OIL * APRIL, 1977

	SITE GROUPS			
	1	2	3	4
1. SALINITY	30.8251	30.8779	30.8057	30.8037
2. DISSOLVED OXYGEN	5.2790	5.0919	5.2529	5.4721
3. PH	8.0101	8.0116	8.0097	8.0093
4. TURBIDITY	62.5462	62.7082	61.8597	63.0707
5. PRODUCTIVITY	6.5477	6.8599	6.4235	6.5325
6. CHLOROPHYLL A	0.0119	0.0108	0.0131	0.0142
7. OIL + GREASE (WATER SURFACE)	0.1525	0.1436	0.1596	0.1434
8. TEMPERATURE	15.8282	15.8209	15.8339	15.8231

TABLE 18

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE)) ** (AXES IN COLUMNS)

WEIGHTED DISCRIMINANT ANALYSIS * UNION OIL * APRIL, 1977

	AXES	
	1	2
1. SALINITY	19.0	4.6
2. DISSOLVED OXYGEN	21.2	43.4
3. PH	11.2	1.1
4. TURBIDITY	0.5	12.2
5. PRODUCTIVITY	34.9	6.7
6. CHLOROPHYLL A	9.0	2.8
7. OIL + GREASE (WATER SURFACE)	0.6	20.2
8. TEMPERATURE	3.4	9.1

TABLE 19

WEIGHTED GROUP MEANS

DISCRIMINANT ANALYSIS * JULY 1977
UNION OIL PLANKTON DATA

	SITE GROUPS			
	1	2	3	4
1. PRODUCTIVITY	16.2113	16.5545	15.7533	16.2461
2. CHLOROPHYLL A	2.5432	2.5301	2.6037	2.5217
3. ASSIMILATION RATIO (A)	1.9939	2.0144	1.9470	2.0038
4. SALINITY	32.9451	32.9569	32.9315	32.9400
5. DISSOLVED OXYGEN	6.9424	7.0708	6.9634	7.0014
6. PH	7.7955	7.7918	7.8154	7.8022
7. TURBIDITY	63.5289	62.6251	63.8017	62.5388
8. OIL + GREASE (WATER SURFACE)	0.2938	0.2893	0.2972	0.2901
9. TEMPERATURE	16.6616	16.6622	16.6545	16.7148

TABLE 20

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE)) ** (AXES IN COLUMNS)

DISCRIMINANT ANALYSIS * JULY 1977
UNION OIL PLANKTON DATA

	AXES		
	1	2	3
1. PRODUCTIVITY	29.8	17.3	43.1
2. CHLOROPHYLL A	19.5	21.9	5.7
3. ASSIMILATION RATIO (A)	39.7	39.4	24.5
4. SALINITY	0.6	0.0	0.1
5. DISSOLVED OXYGEN	0.4	0.9	3.2
6. PH	2.9	0.2	0.2
7. TURBIDITY	5.6	19.4	13.6
8. OIL + GREASE (WATER SURFACE)	0.6	0.9	1.0
9. TEMPERATURE	0.8	0.1	8.7

WEIGHTED DISCRIMINANT ANALYSIS * UNION OIL PLANKTON DATA * JULY, 1977

1. PRODUCTIVITY	22.8	13.7	0.2
2. CHLOROPHYLL A	15.3	22.9	2.2
3. ASSIMILATION RATIO (A)	1.2	36.0	6.0
4. SALINITY	2.5	0.1	0.2
5. DISSOLVED OXYGEN	2.8	0.1	13.4
6. PH	26.5	0.2	42.9
7. TURBIDITY	1.1	1.8	3.4
8. TEMPERATURE	8.4	1.8	10.6
9. OIL + GREASE (WATER SURFACE)	1.0	0.6	4.4
10. OIL + GREASE (WATER MID-DEPTH)	5.6	16.1	15.0
11. OIL + GREASE (WATER BOTTOM)	12.7	6.6	1.8

TABLE 21

WEIGHTED GROUP MEANS

DISCRIMINANT ANALYSIS * NOVEMBER 1977
UNION OIL PLANKTON DATA

	1	2	3
1. PRODUCTIVITY	1.8344	1.8194	1.8319
2. CHLOROPHYLL A	4.9866	4.8763	5.0806
3. ASSIMILATION RATIO (A)	1.1383	1.1310	1.1042
4. SALINITY	3.5480	3.5481	3.5478
5. DISSOLVED OXYGEN	5.3566	5.3689	5.2188
6. PH	8.3996	8.3984	8.3917
7. TRANSMITTANCE	50.9983	52.2848	51.1873
8. OIL + GREASE (WATER SURFACE)	2.3795	2.3931	2.0455
9. TEMPERATURE	18.3402	18.3796	18.4512

TABLE 22A

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE)) ** (AXES IN COLUMNS)

** UNION OIL PLANKTON DATA * NOVEMBER 1977 **
** WEIGHTED DISCRIMINANT ANALYSIS * GROUPS FROM DENDROGRAM **

	1	2
1. SALINITY	16.1	3.2
2. DISSOLVED OXYGEN	31.2	4.6
3. PH	21.6	60.4
4. TURBIDITY	1.4	23.2
5. OIL + GREASE (WATER SURFACE)	29.8	8.7

TABLE 22B

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE)) ** (AXES IN COLUMNS)

WEIGHTED DISCRIMINANT ANALYSIS * UNION OIL * NOVEMBER, 1977

	1	2
1. SALINITY	14.1	0.0
2. DISSOLVED OXYGEN	26.7	13.3
3. PH	20.7	17.6
4. TURBIDITY	0.5	10.9
5. OIL + GREASE (WATER SURFACE)	27.4	1.9
6. TEMPERATURE	10.6	56.4

TABLE 22C

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE)) ** (AXES IN COLUMNS)

DISCRIMINANT ANALYSIS * NOVEMBER 1977
UNION OIL PLANKTON DATA

	AXES	
	1	2
1. PRODUCTIVITY	3.5	37.5
2. CHLOROPHYLL A	19.0	42.9
3. ASSIMILATION RATIO (A)	22.4	12.0
4. SALINITY	6.2	0.5
5. DISSOLVED OXYGEN	14.7	0.0
6. PH	15.9	0.7
7. TURBIDITY	0.3	2.7
8. OIL + GREASE (WATER SURFACE)	14.8	0.4
9. TEMPERATURE	3.2	3.3

TABLE 22D

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE)) ** (AXES IN COLUMNS)
WEIGHTED DISCRIMINANT ANALYSIS * UNION OIL PLANKTON DATA * NOVEMBER, 19,77

	1	2	3
1. PRODUCTIVITY	11.6	39.6	42.2
2. CHLOROPHYLL A	9.9	3.5	26.0
3. ASSIMILATION RATIO (A)	33.4	32.3	21.7
4. SALINITY	5.3	5.0	2.4
5. DISSOLVED OXYGEN	16.8	2.8	0.7
6. PH	17.6	3.3	0.2
7. TURBIDITY	0.0	0.1	3.1
8. TEMPERATURE	0.7	0.3	1.0
9. OIL + GREASE (WATER SURFACE)	3.0	3.1	1.9
10. OIL + GREASE (WATER MID-DEPTH)	0.9	9.7	0.7
11. OIL + GREASE (WATER BOTTOM)	0.8	0.3	0.0

FIGURE 68. ZOOPLANKTON 1972-1977

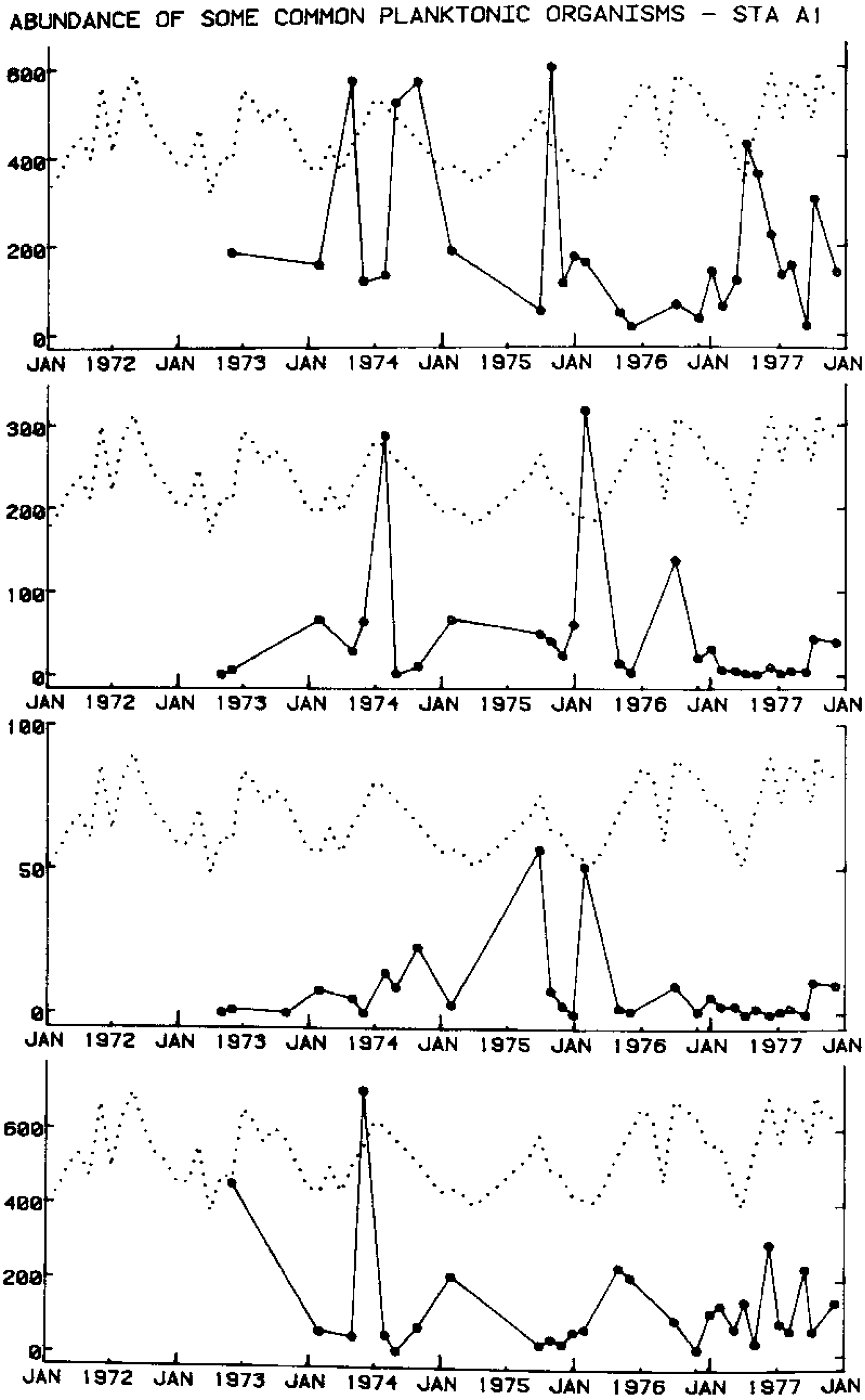


FIGURE 69. ZOOPLANKTON 1972-1977

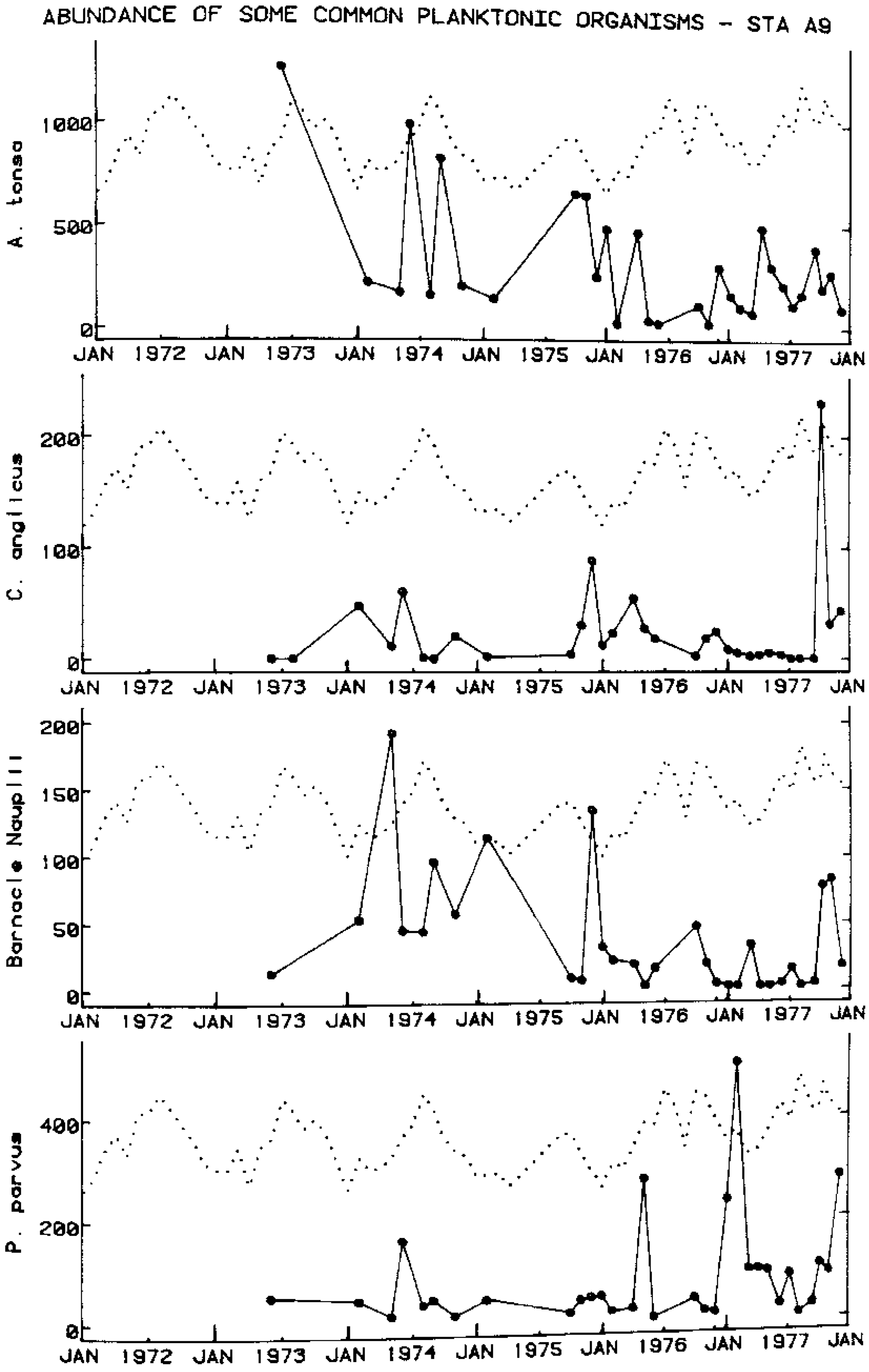


FIGURE 70. ZOOPLANKTON 1977

ABUNDANCE OF SOME COMMON PLANKTONIC ORGANISMS - STA A1

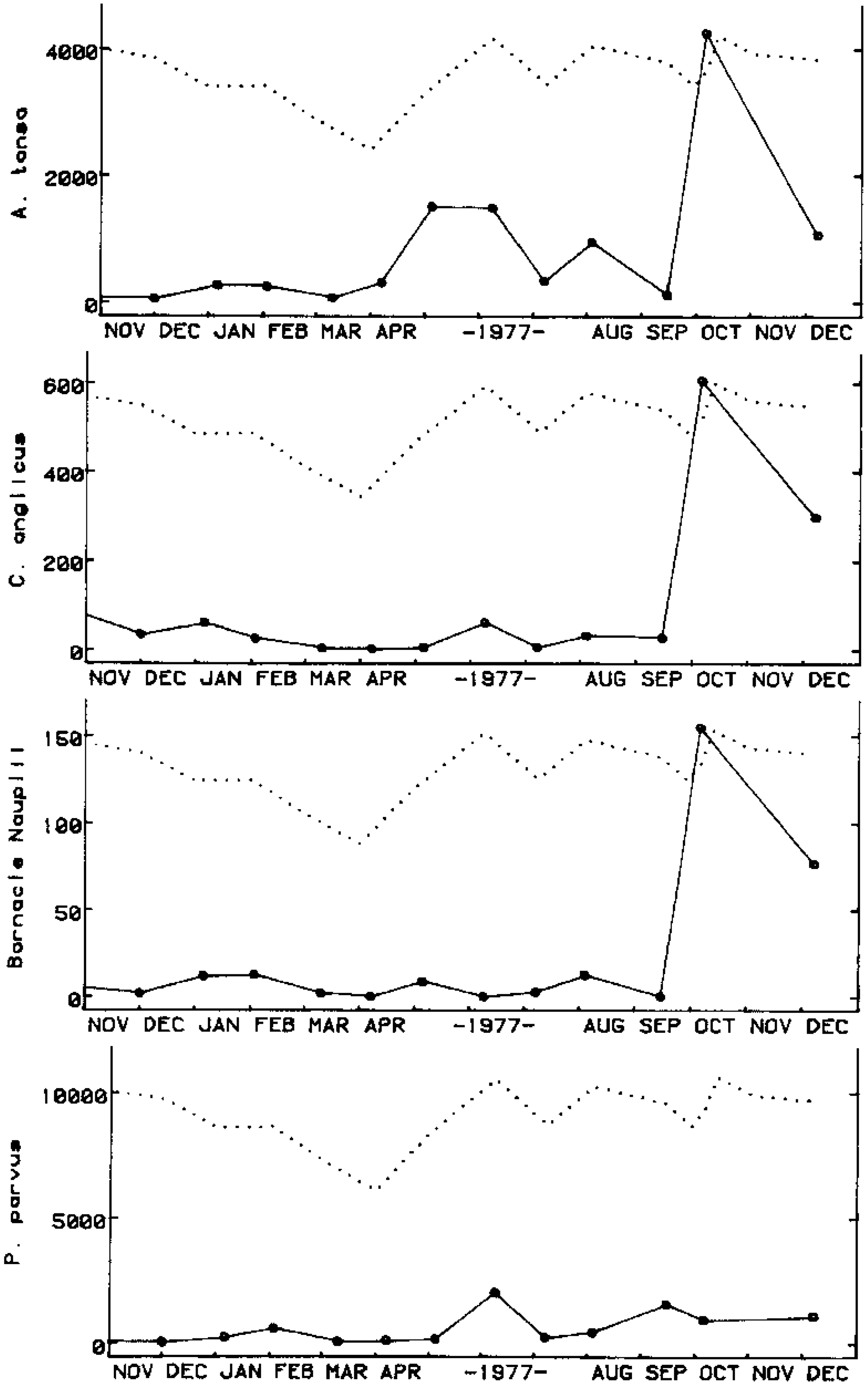
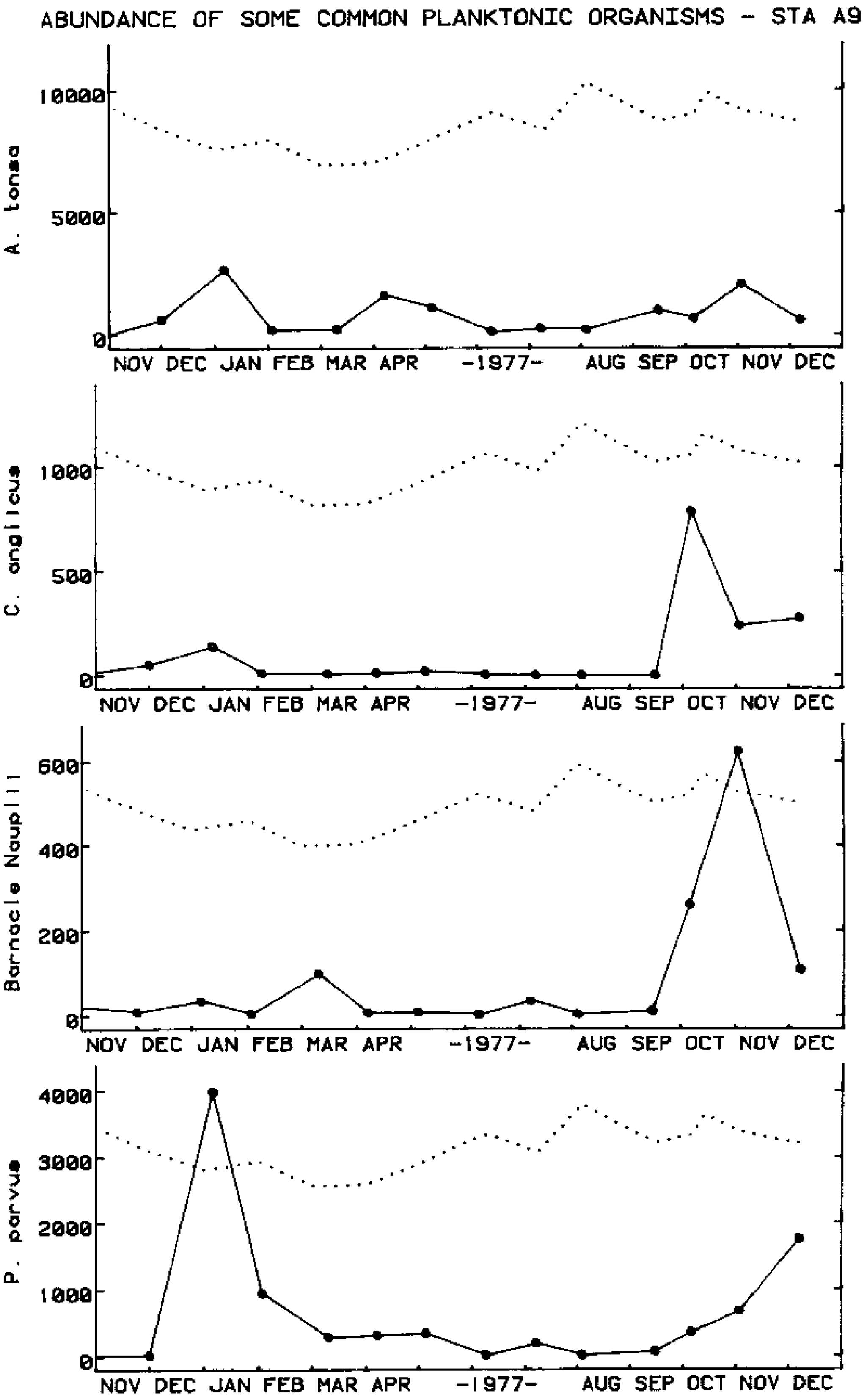


FIGURE 71. ZOOPLANKTON 1977



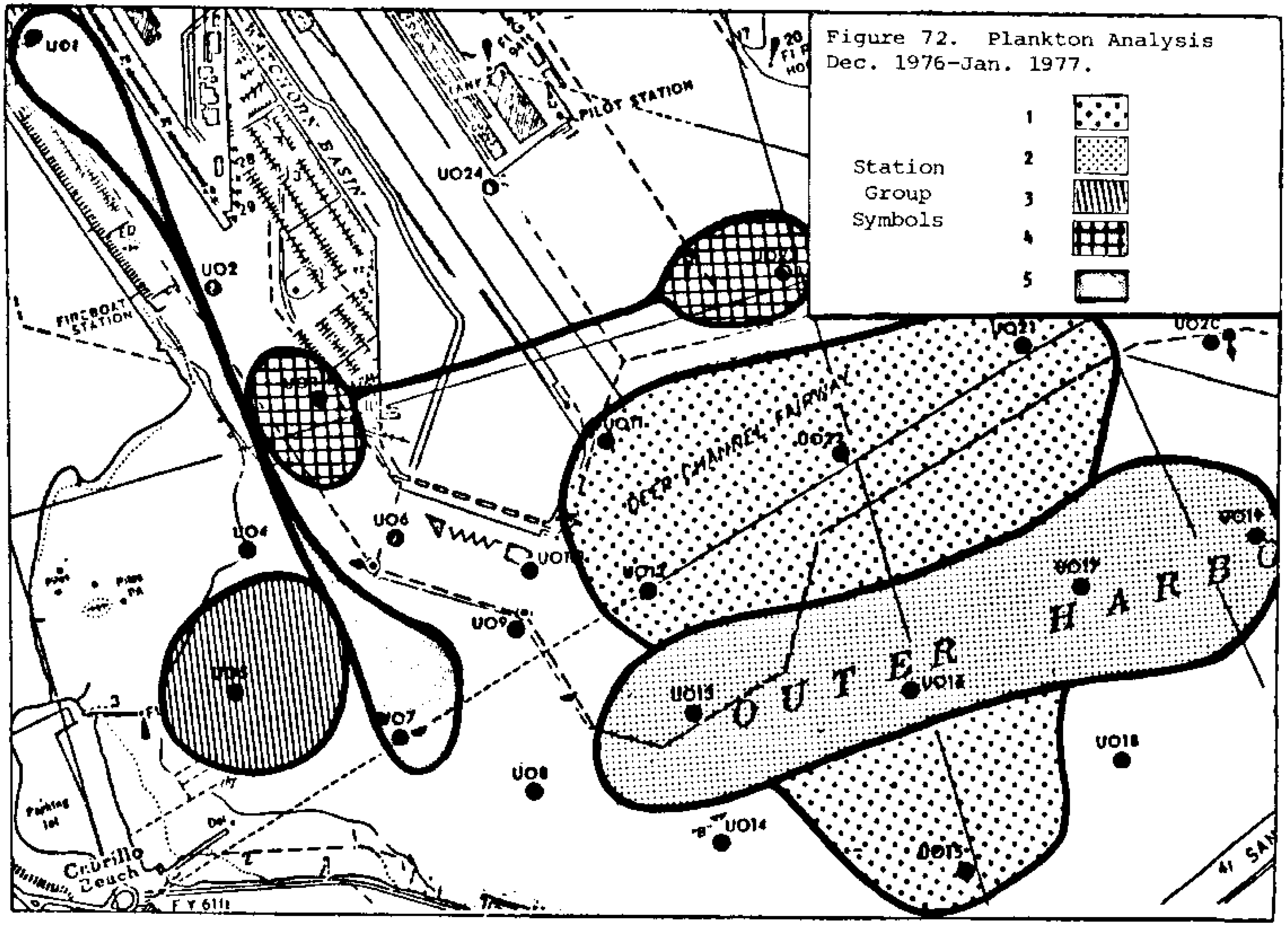


Figure 72. Plankton Analysis
Dec. 1976-Jan. 1977.

FIGURE 73
UNION OIL PLANKTON DATA, JANUARY 1977.

Coincidence numbers,
transformed and standardized

* > .75 to 1
\+ > .5 to .75
\- > .25 to .50
. > 0 to .25
blank 0

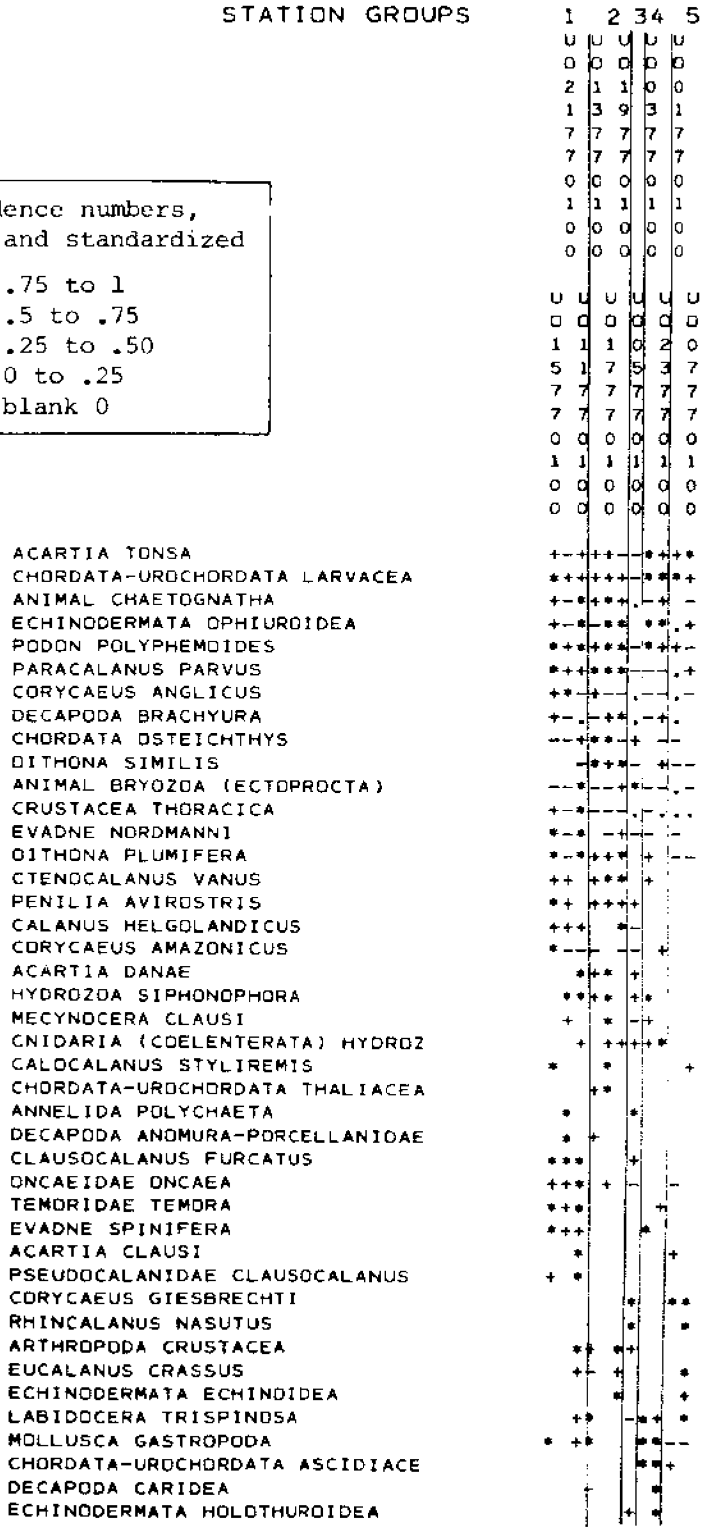
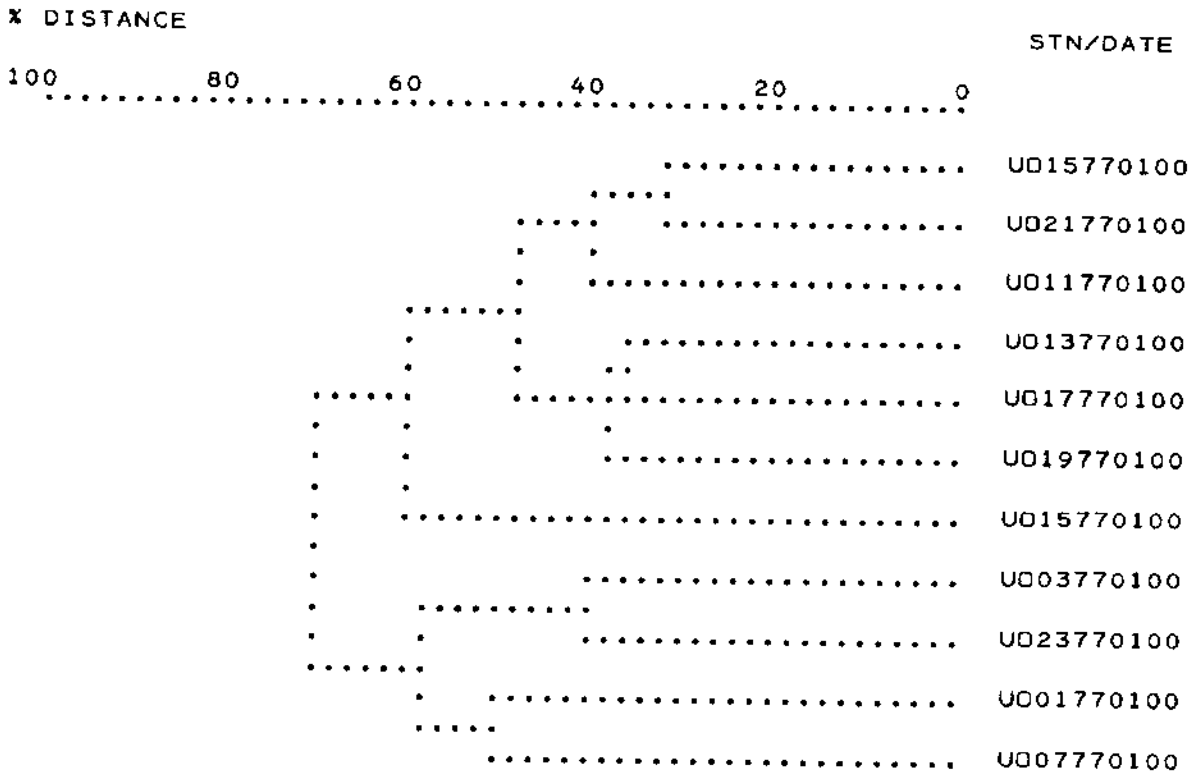


FIGURE 74

UNION OIL PLANKTON DATA NORMAL ANALYSIS, JANUARY 17, 1977.



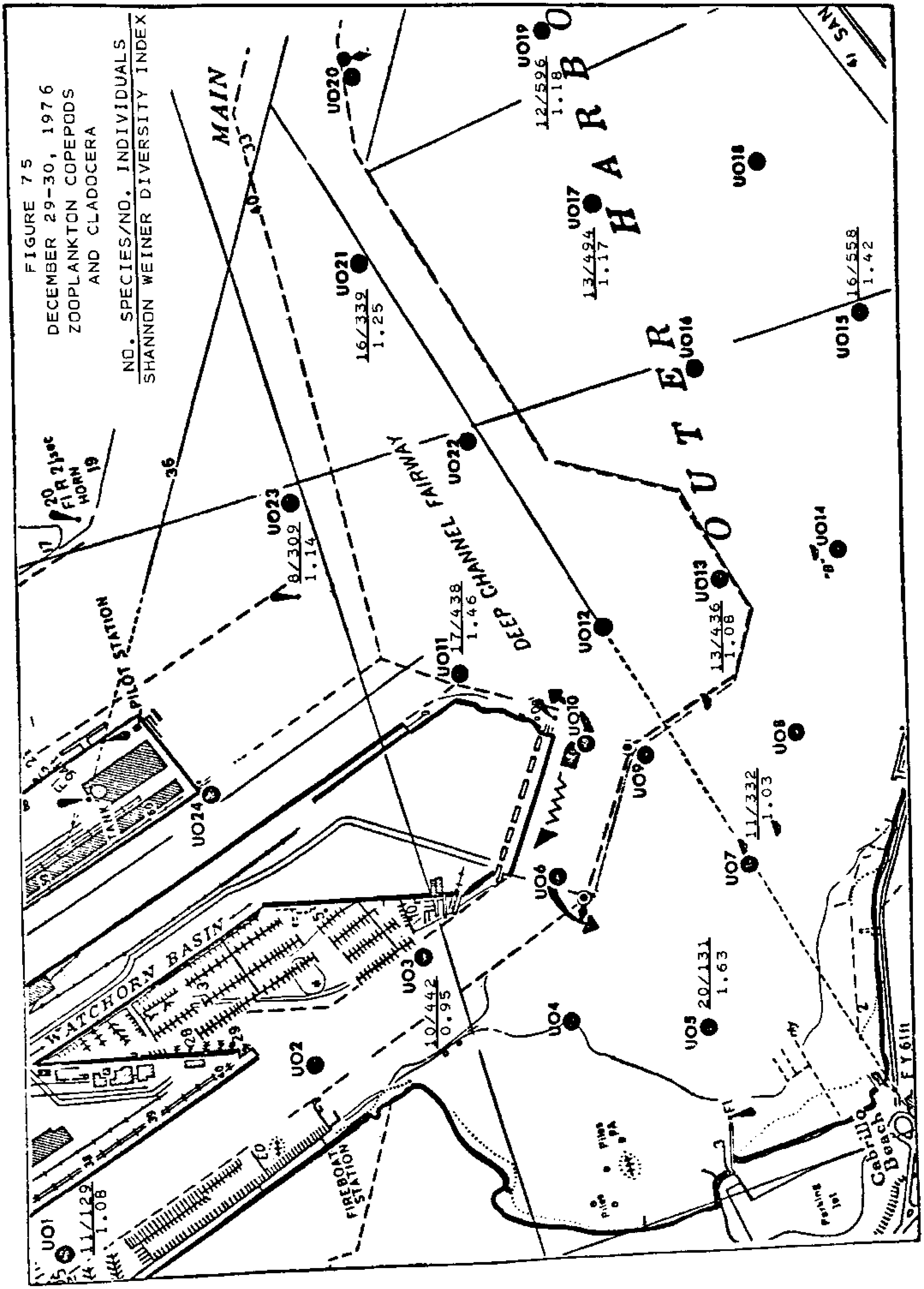


FIGURE 75
DECEMBER 29-30, 1976
ZOOPLANKTON COPEPODS
AND CLADOCERA

NO. SPECIES/NO. INDIVIDUALS
SHANNON WEINER DIVERSITY INDEX

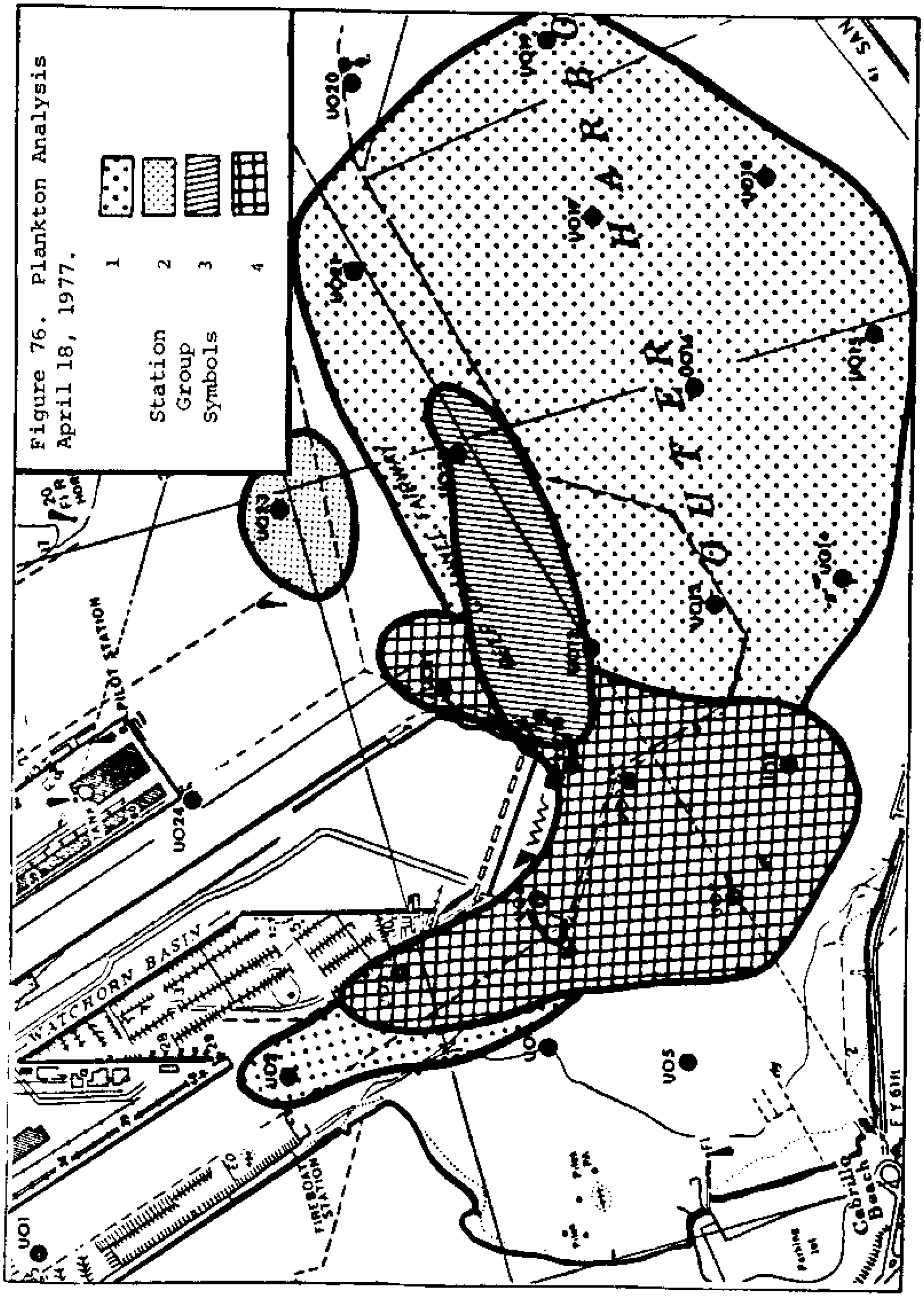


Figure 76. Plankton Analysis
April 18, 1977.

FIGURE 77

UNION OIL PLANKTON DATA, APRIL 18, 1977.

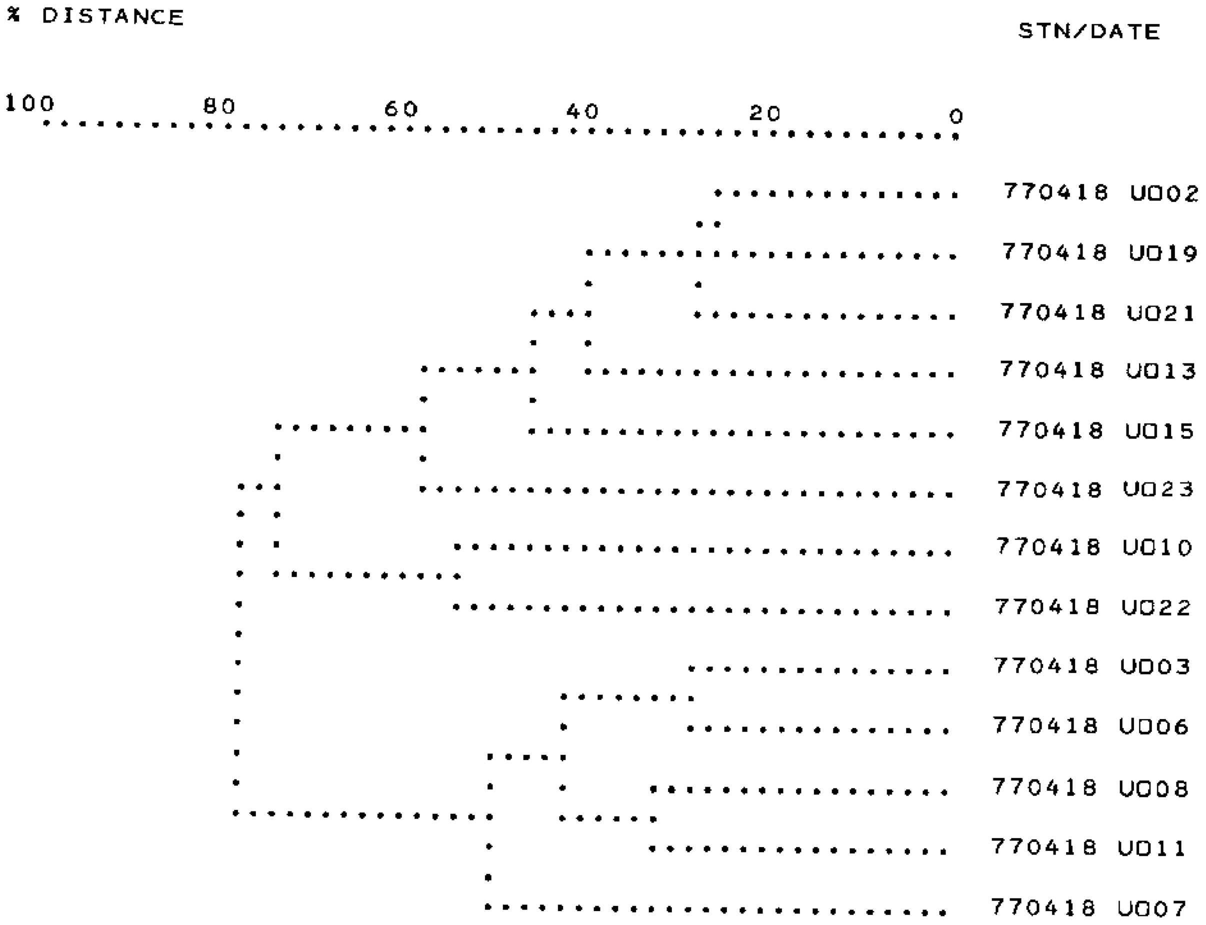
Coincidence numbers,
transformed and standardized

* > .75 to 1
+ > .5 to .75
- > .25 to .50
. > 0 to .25
blank 0

STATION GROUPS	1					2	3		4				
	770418 U002	770418 U019	770418 U021	770418 U013	770418 U015	770418 U023	770418 U010	770418 U022	770418 U003	770418 U006	770418 U008	770418 U011	770418 U007
ACARTIA TONSA	+	+	*	+	*	*	-	+	+	-	+	+	*
LABIDOCERA TRISPINOSA	+	+	-	+	*	*	-	+	-	-	.	+	
CHORDATA OSTEICHTHYS	-	-	+	-	*	-			-	*	-	-	
EVADNE NORDMANNI		+	-	+	-		+		+	*	+		+
PARACALANUS PARVUS	-	+	-	*	-	-	-	*	-	+	*	*	-
PODON POLYPHEMOIDES	.	-	.	.	-	.	.	.	-	+	+	-	*
CALANUS HELGOLANDICUS				+	*				+				
CLAUSOCALANUS FURCATUS					*				*			*	
CORYCAEUS AMAZONICUS									*	*	*	*	*
MICROSETELLA ROSEA									*	*			
OITHONA SIMILIS								*					
RHINCALANUS NASUTUS											*		
CORYCAEUS ANGLICUS		.	.		-	*		-	.		+	-	.
OITHONA OCULATA	.	.	-	.		*						.	.
TORTANUS DISCAUDATUS		-			-	*							
EUTERPINA ACUTIFRONS				*		*							
OITHONA PLUMIFERA						*							+

FIGURE 78.

UNION OIL PLANKTON DATA NORMAL ANALYSIS, APRIL 18, 1977.



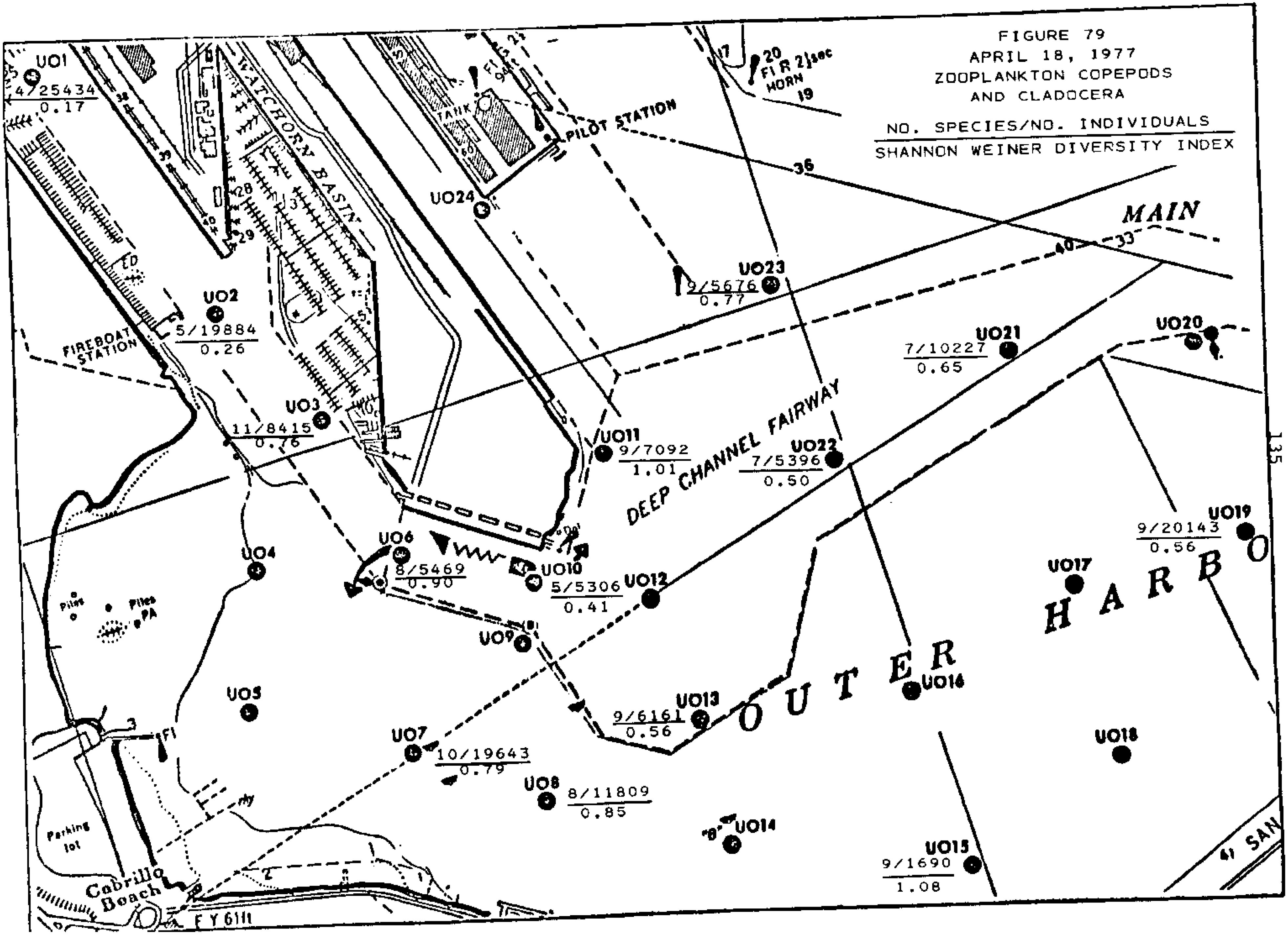


FIGURE 79
APRIL 18, 1977
ZOOPLANKTON COPEPODS
AND CLADOCERA

NO. SPECIES/NO. INDIVIDUALS
SHANNON WEINER DIVERSITY INDEX

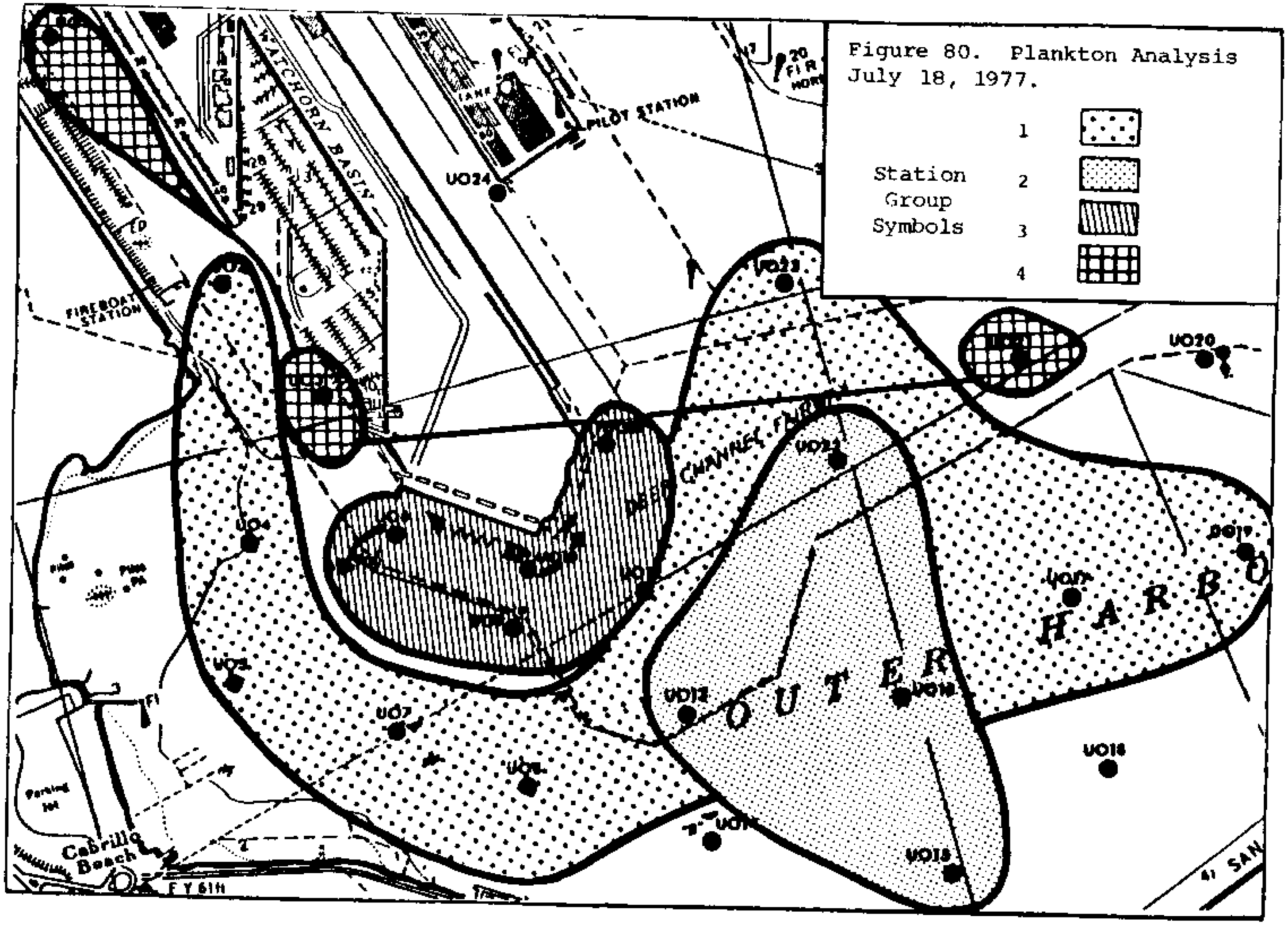


Figure 80. Plankton Analysis July 18, 1977.

FIGURE 81
UNION OIL PLANKTON DATA, JULY 18, 1977.

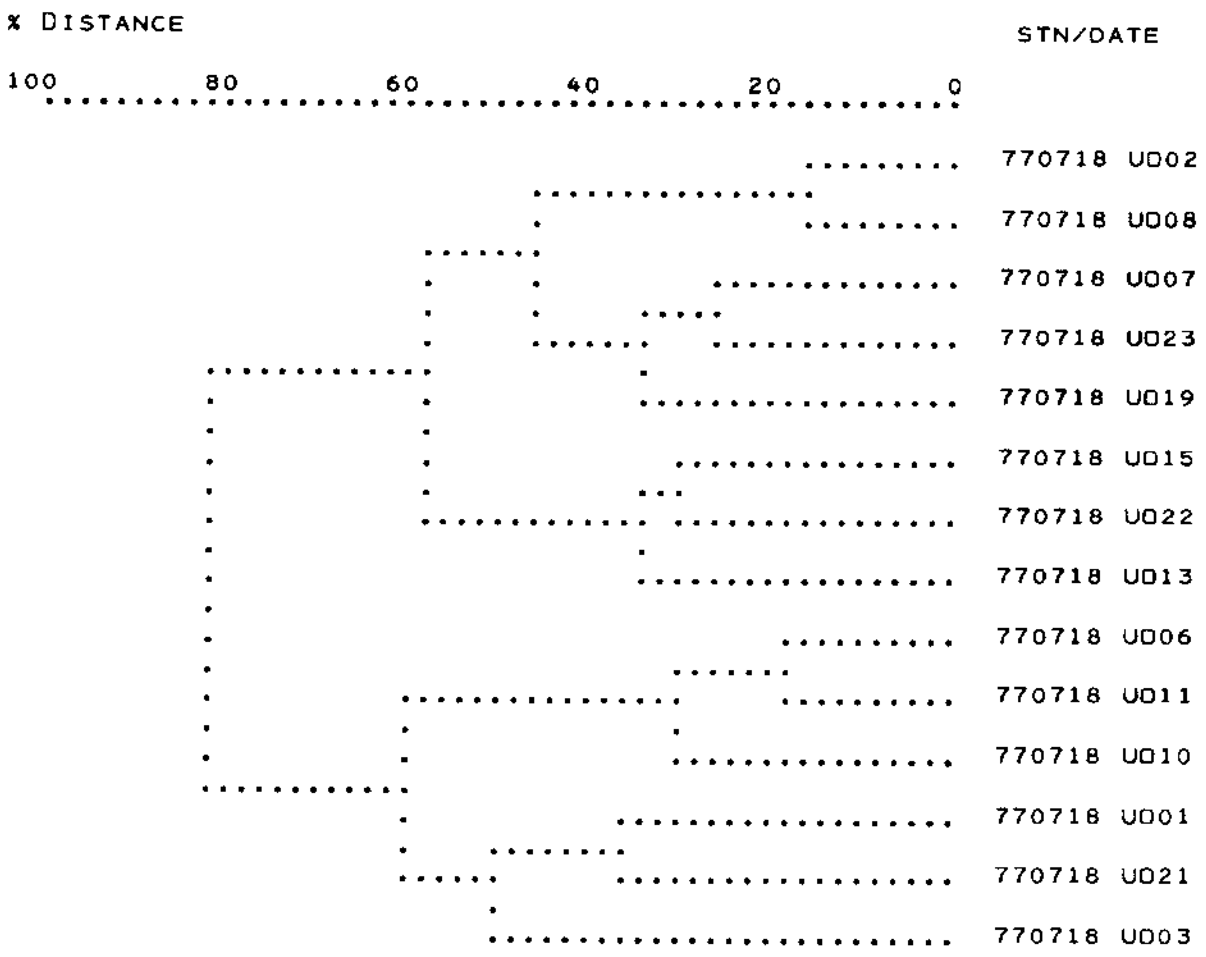
Coincidence numbers, transformed and standardized

* > .75 to 1
+ > .5 to .75
- > .25 to .50
. > 0 to .25
blank 0

STATION GROUPS	1					2			3			4		
	770718 U002	770718 U008	770718 U007	770718 U023	770718 U019	770718 U015	770718 U022	770718 U013	770718 U006	770718 U011	770718 U010	770718 U001	770718 U021	770718 U003
ACARTIA TONSA	+	.	*	*	+	.	.	.	+	+	*	+	*	*
PARACALANUS PARVUS	-	-	-	-	-	+	-	*	+	*	*	-	.	*
EVADNE NORDMANNI	.	-	-	+	*	-	-	-	-	-	+	.	-	.
PODON POLYPHEMOIDES	-	*	-	*	+	-	*	-	-	-	+	*	-	.
CORYCAEUS ANGLICUS	*	*	+	+	+	+	*	*					+	
OITHONA SIMILIS	*	*	*	*	+	-	-	-		+		-	-	+
CALOCALANUS STYLIREMIS	*	*			*									
CHORDATA OSTEICHTHYS				*				*						
ISCHNOCALANUS TENUIS								*						*
LABIDOCERA TRISPINOSA			+	+	*		*	+						
OITHONA PLUMIFERA				*	+									+
ACARTIA CLAUSI	-											*	-	-
OITHONA OCULATA					+	+	+	+			+	*	*	+
EUTERPINA ACUTIFRONS													*	

FIGURE 82

UNION OIL PLANKTON DATA NORMAL ANALYSIS, JULY 18, 1977.



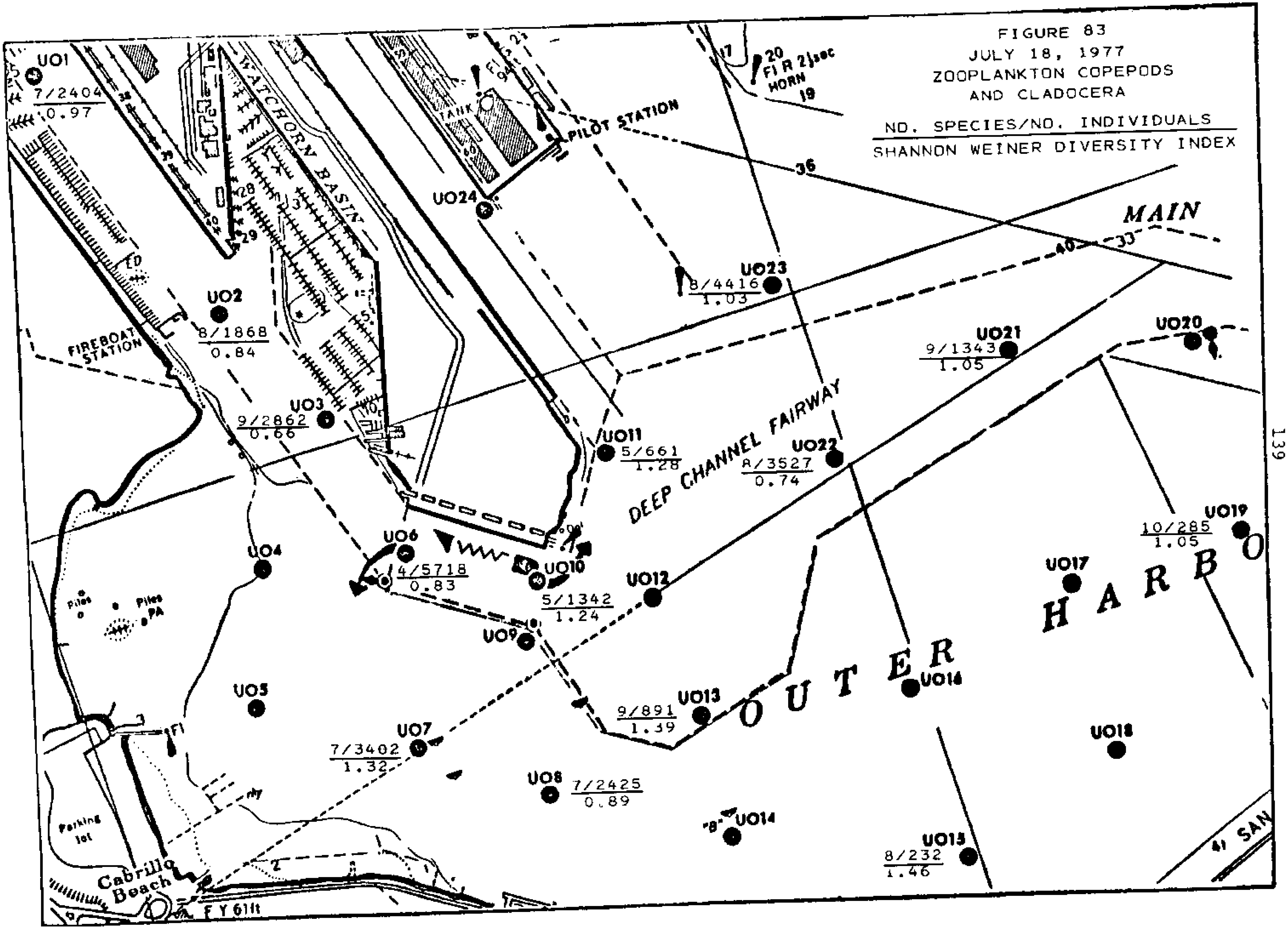


FIGURE 83
JULY 18, 1977
ZOOPLANKTON COPEPODS
AND CLADOCERA

NO. SPECIES/NO. INDIVIDUALS
SHANNON WEINER DIVERSITY INDEX

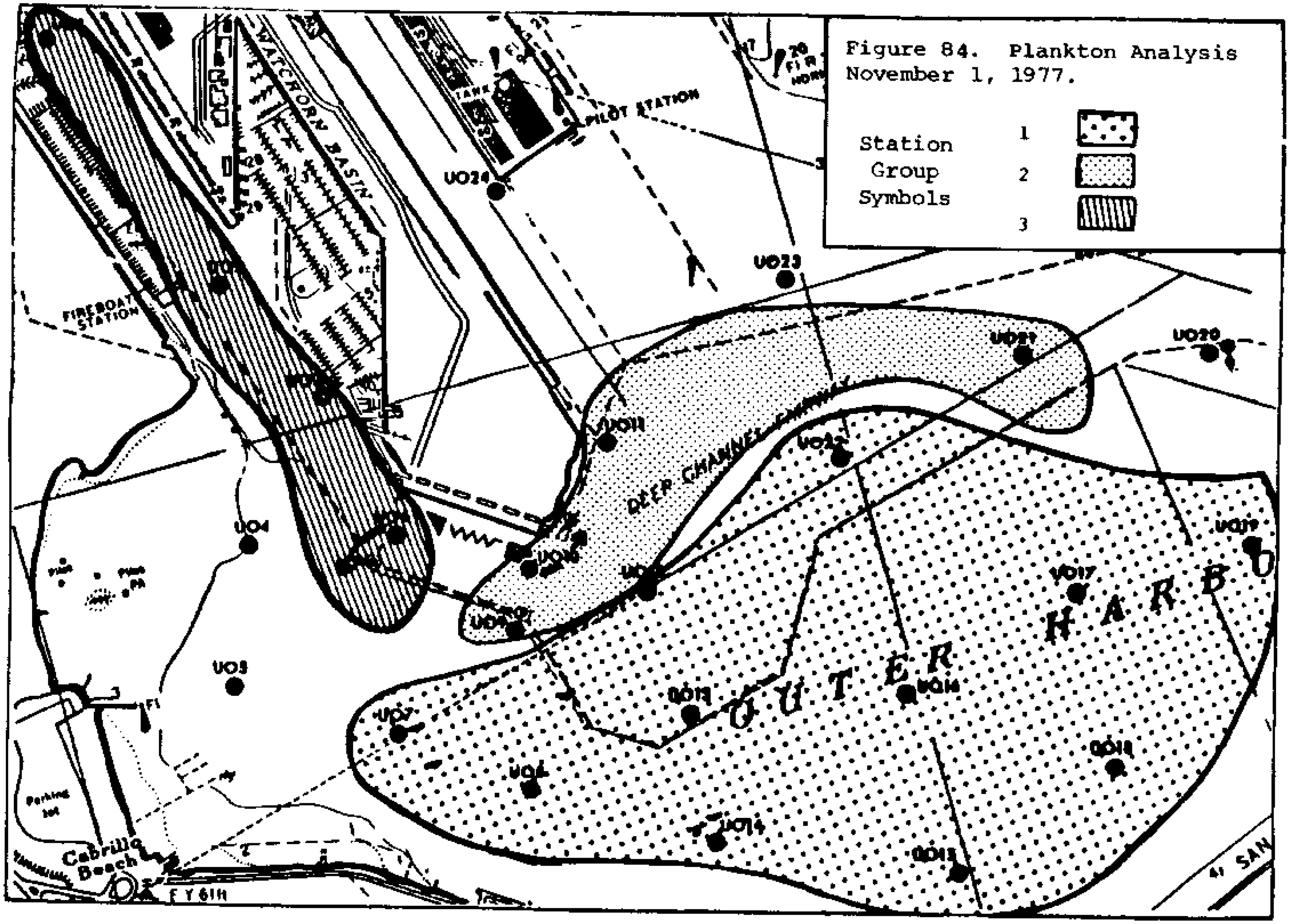


Figure 84. Plankton Analysis November 1, 1977.

Station Group Symbols	
1	⁘
2	▒
3	▥

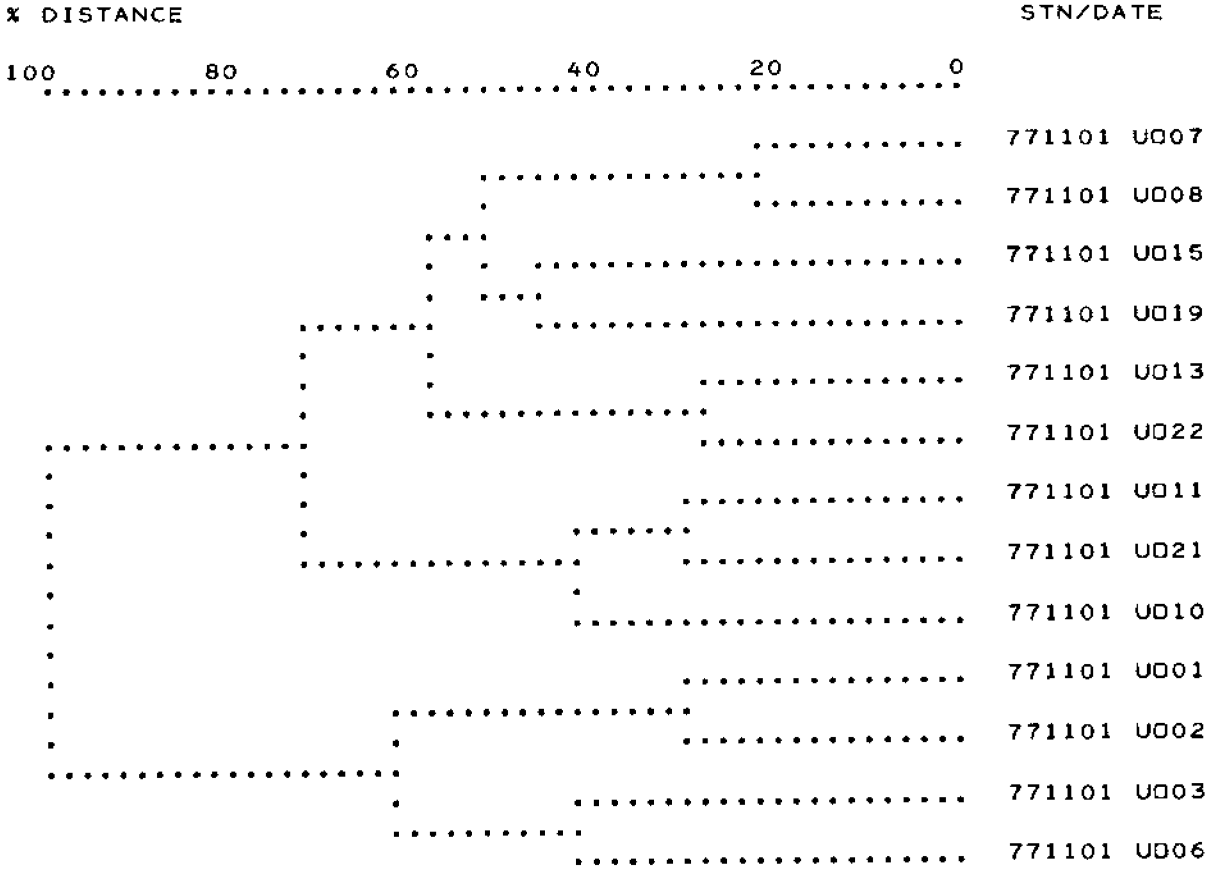
FIGURE 85
UNION OIL PLANKTON DATA, NOVEMBER 1, 1977.

Coincidence numbers, transformed and standardized

* > .75 to 1
+ > .5 to .75
- > .25 to .50
. > 0 to .25
blank 0

STATION GROUPS	1						2			3			
	771101 U007	771101 U008	771101 U015	771101 U019	771101 U013	771101 U022	771101 U011	771101 U021	771101 U010	771101 U001	771101 U002	771101 U003	771101 U006
EUTERPINA ACUTIFRONS			*									*	
OITHONA SIMILIS			*									*	
CORYCAEIDAE CORYCAEUS												*	
ACARTIA CLAUSI										+	+	*	*
ACARTIA TONSA	.	+	*	+	*	*	*	-	+	*	*	+	*
PARACALANUS PARVUS	-	*	+	*	+	*	-	*	+	.		-	+
PENILIA AVIROSTRIS	.	.	-	+	-	+	+	*	.	.	.	.	.
CORYCAEUS ANGLICUS	-	*	*	*	.	+	.	-	.				.
LABIDOCERA TRISPINOSA	-	+	*	-	+	+	-	.				-	-
EVADNE NORDMANNI	+	.	*	-	.	-	.	.	.			.	.
PODON POLYPHEMOIDES	*	+	*	-	-	-	.	.	-		-	+	-
CHORDATA OSTEICHTHYS							*	+	+				
OITHONA OCULATA			+				+	*	+	+			
PSEUDODIATOMUS EURYHALINUS							*						
CALANUS HELGOLANDICUS	+	+							*				
CALOCALANUS STYLIREMIS				*									
OITHONA SPINIROSTRIS				*			+	+					
CORYCAEUS AMAZONICUS						*							*
OITHONA PLUMIFERA						*							
EVADNE SPINIFERA					*	*							

FIGURE 86
UNION OIL PLANKTON DATA NORMAL ANALYSIS, NOVEMBER 1, 1977.



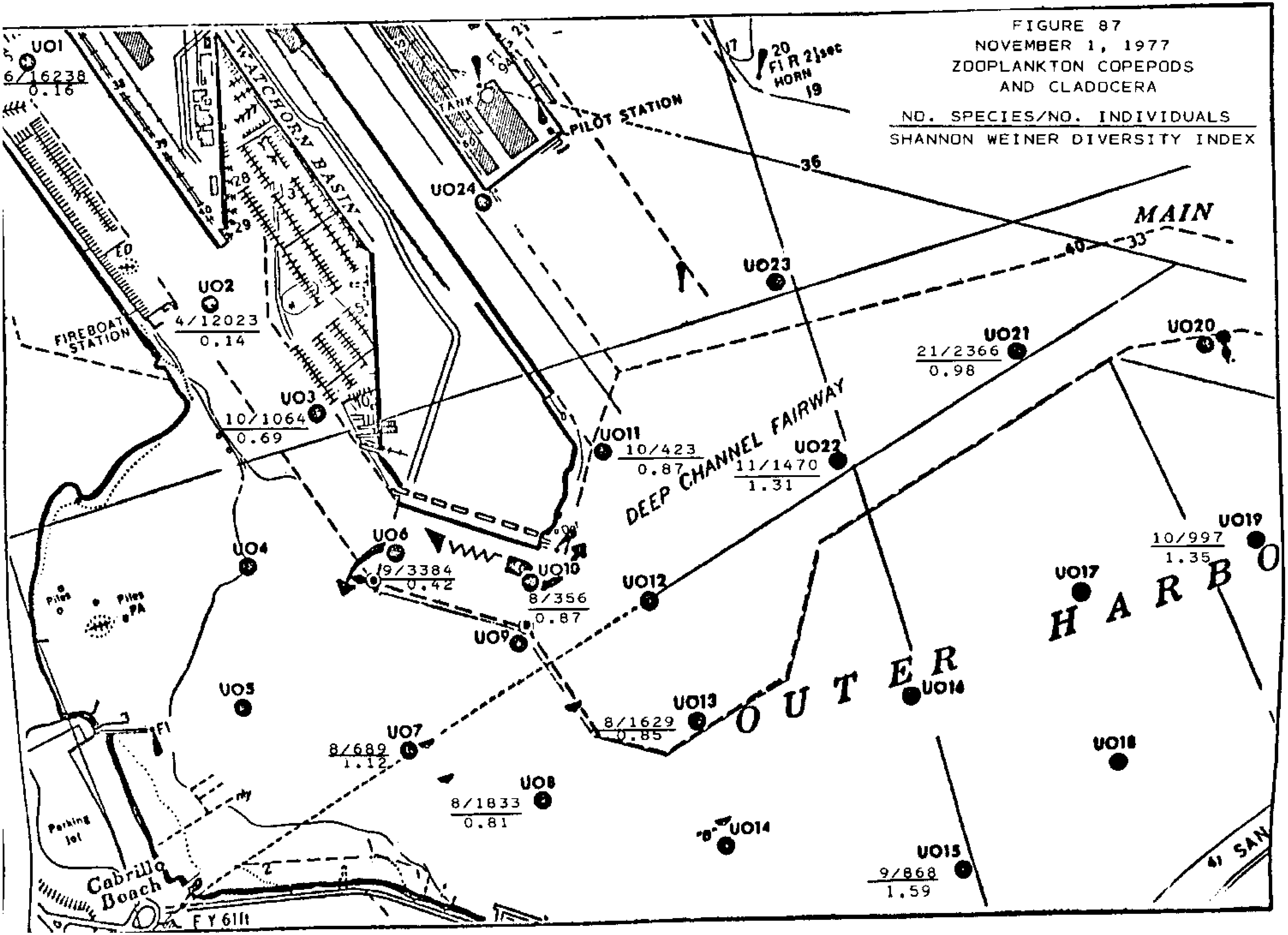


FIGURE 87
NOVEMBER 1, 1977
ZOOPLANKTON COPEPODS
AND CLADOCERA

NO. SPECIES/NO. INDIVIDUALS
SHANNON WEINER DIVERSITY INDEX

ABIOTIC PARAMETERS
by
PLANKTON GROUPINGS

FIGURE 88

TEMPERATURE (plankton groupings)
(RANGE & MEAN ± 2 S.E.)

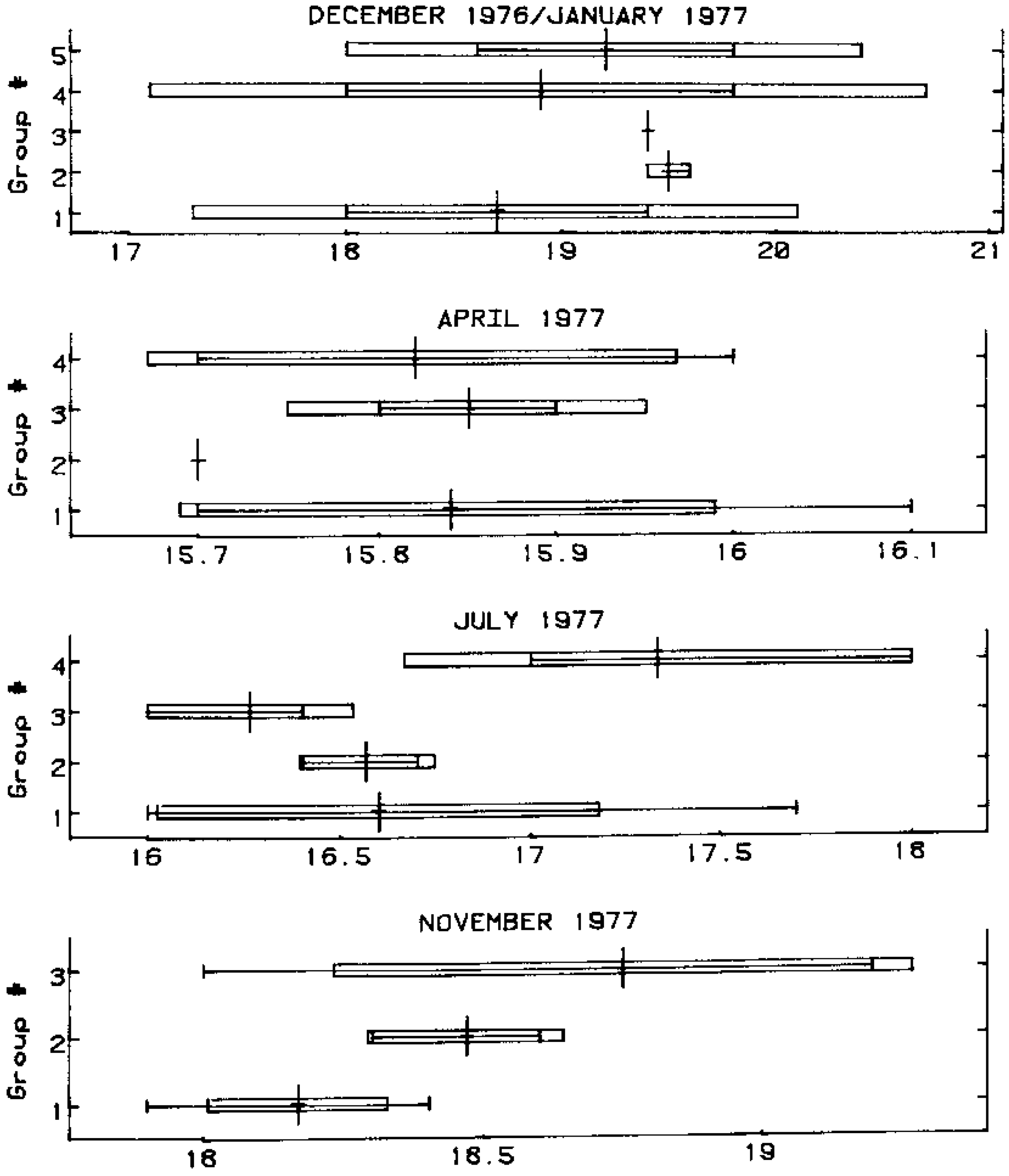
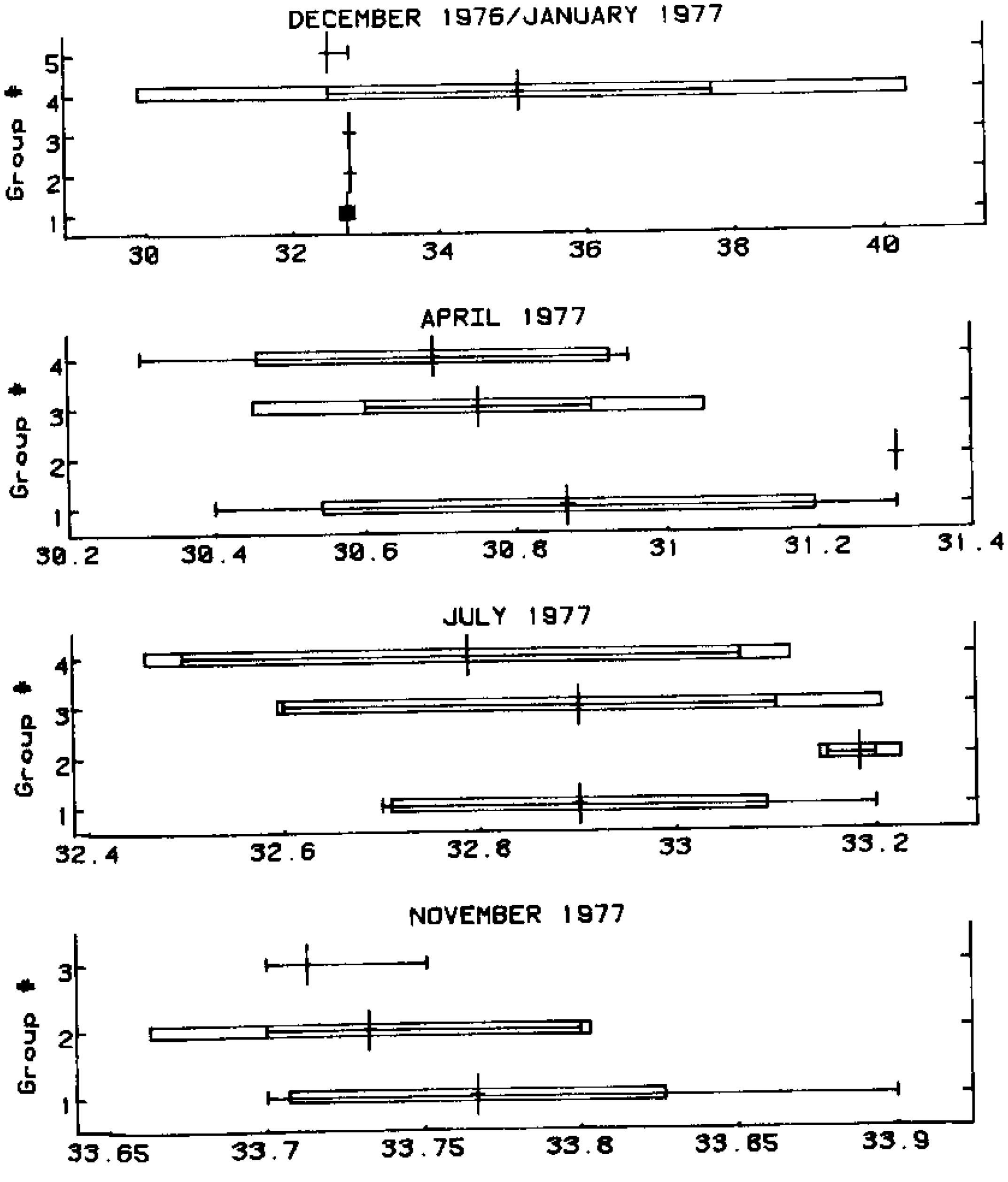


FIGURE 89

SALINITY (plankton groupings)
(RANGE & MEAN ± 2 S.E.)


DECEMBER 1976/JANUARY 1977

APRIL 1977

JULY 1977

NOVEMBER 1977

FIGURE 90

DISSOLVED OXYGEN (plankton groupings)
(RANGE & MEAN ± 2 S.E.)

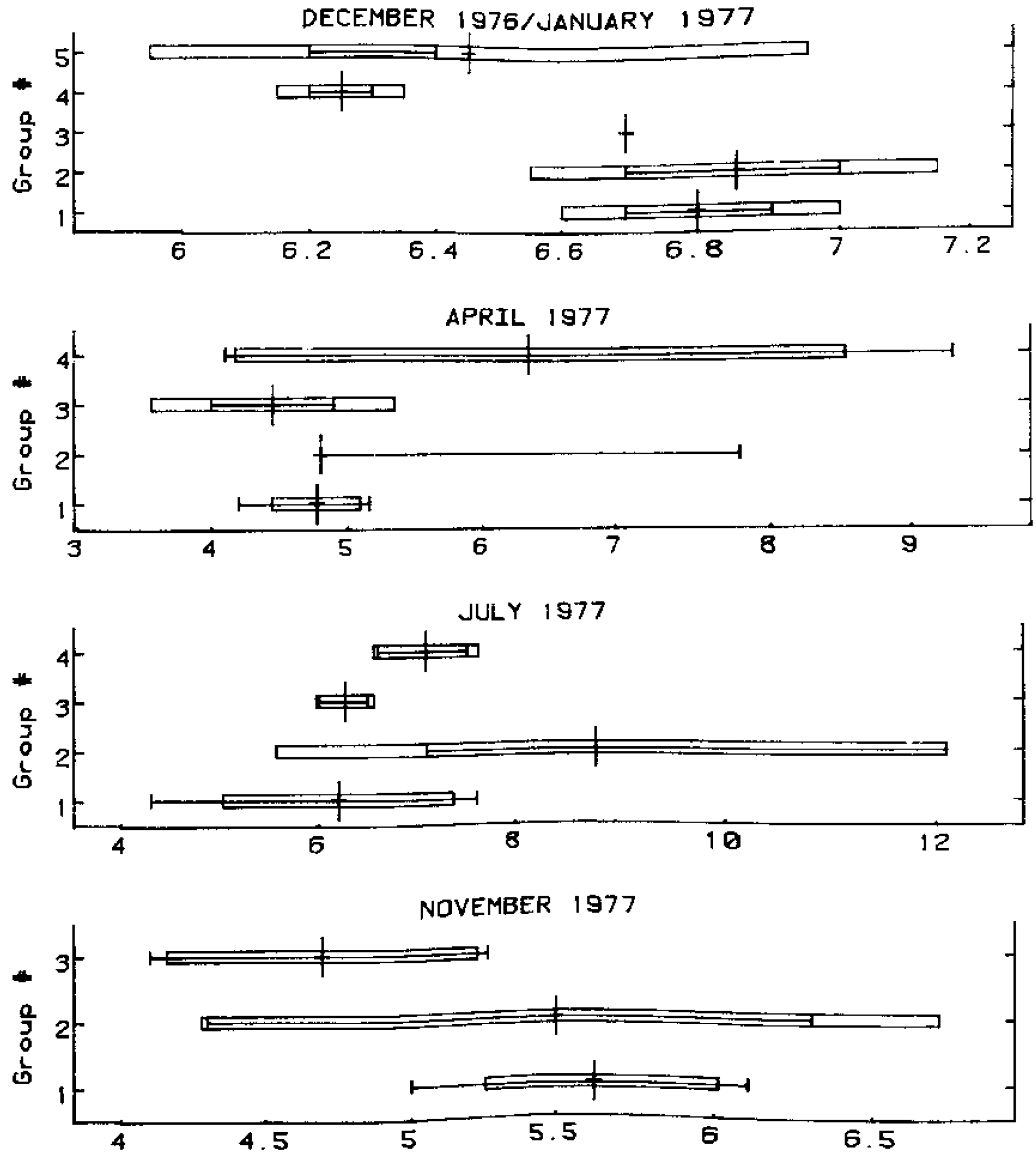
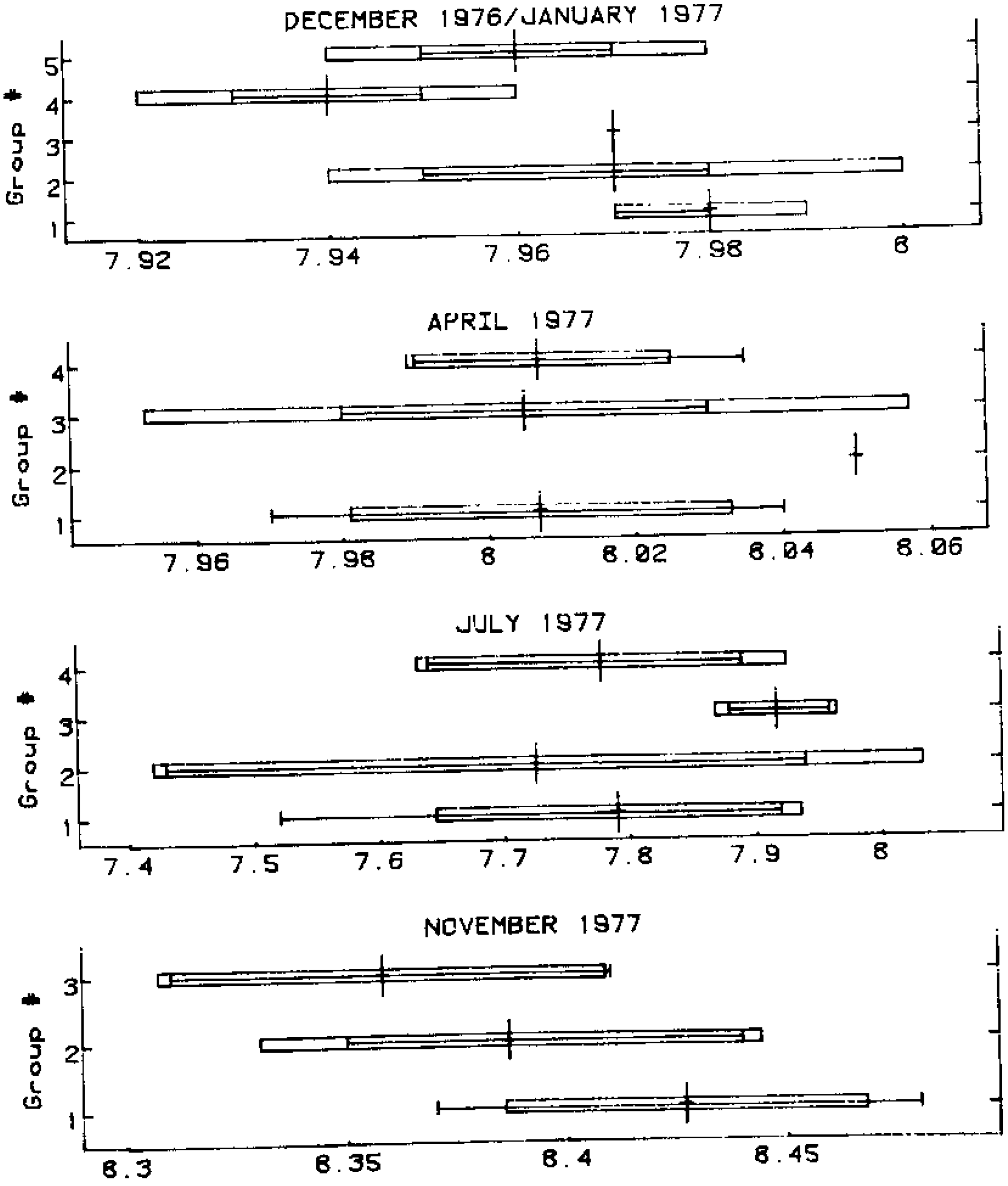


FIGURE 91

pH (plankton groupings)
(RANGE & MEAN ± 2 S.E.)



]

FIGURE 92

PERCENT LIGHT TRANSMITTANCE

TURBIDITY (plankton groupings)

(RANGE & MEAN ± 2 S.E.)

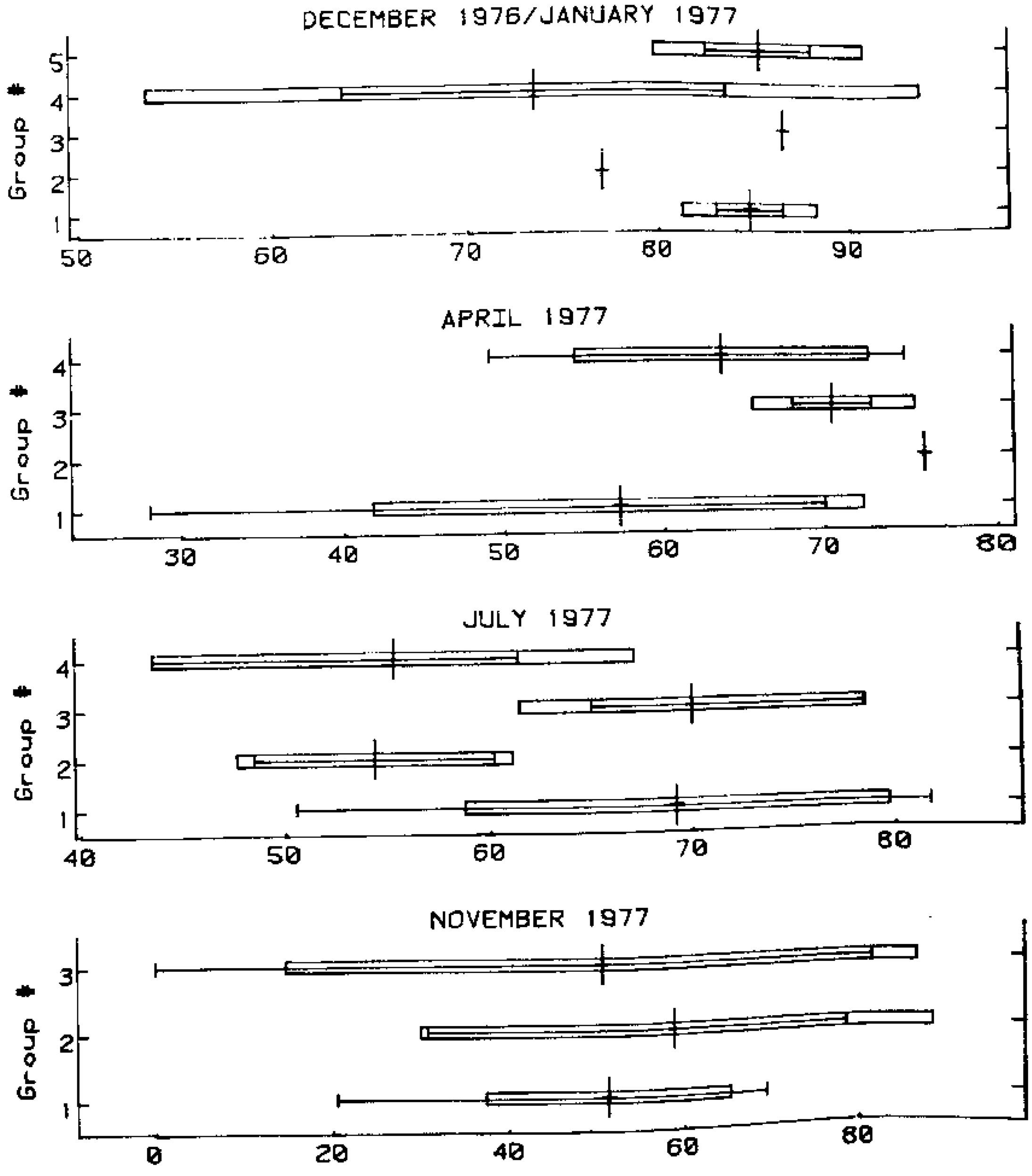


FIGURE 93

PRODUCTIVITY (plankton groupings)
(RANGE & MEAN ± 2 S.E.)

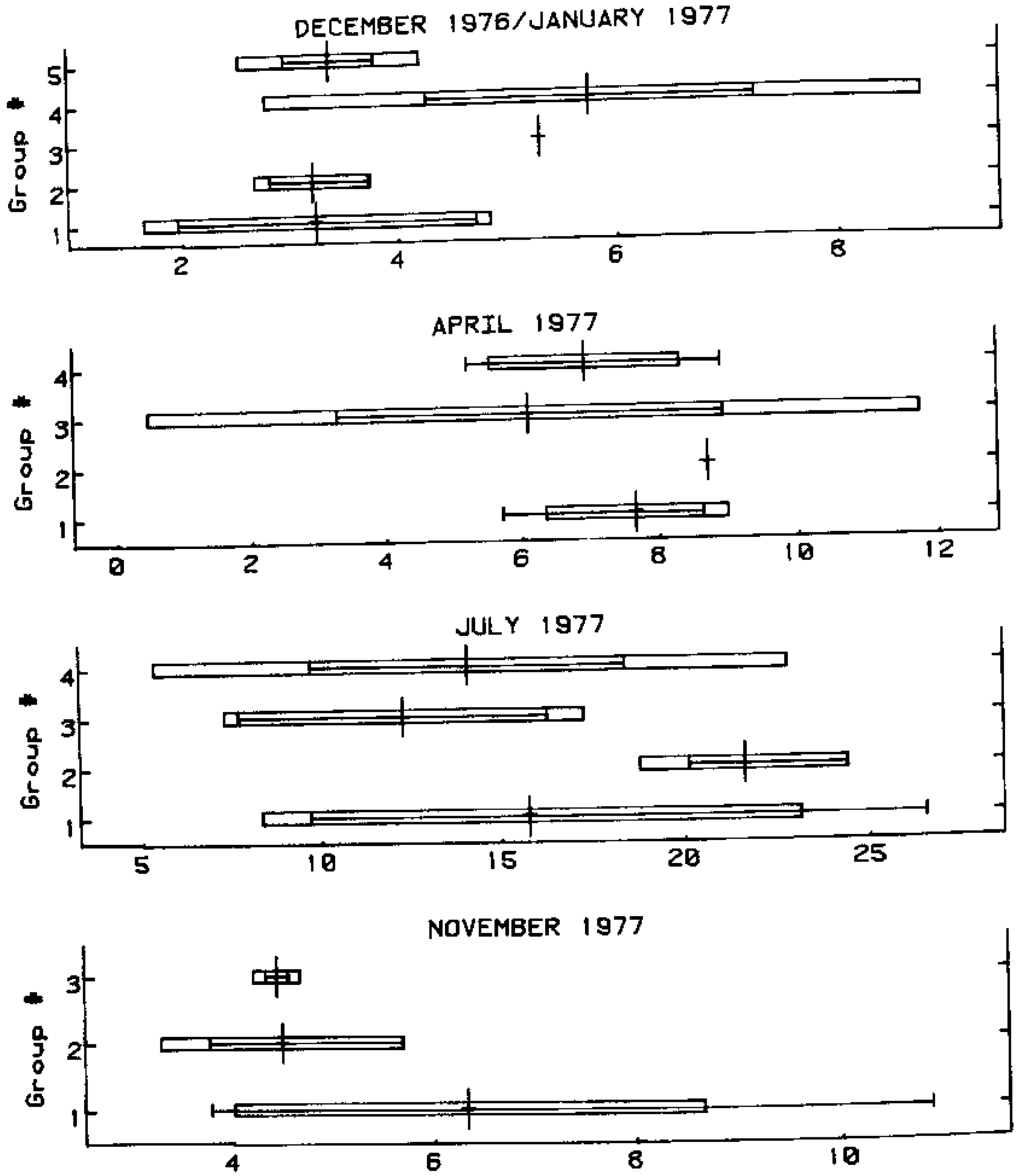


FIGURE 94

CHLOROPHYLL a (Plankton groupings)
(RANGE & MEAN ± 2 S.E.)

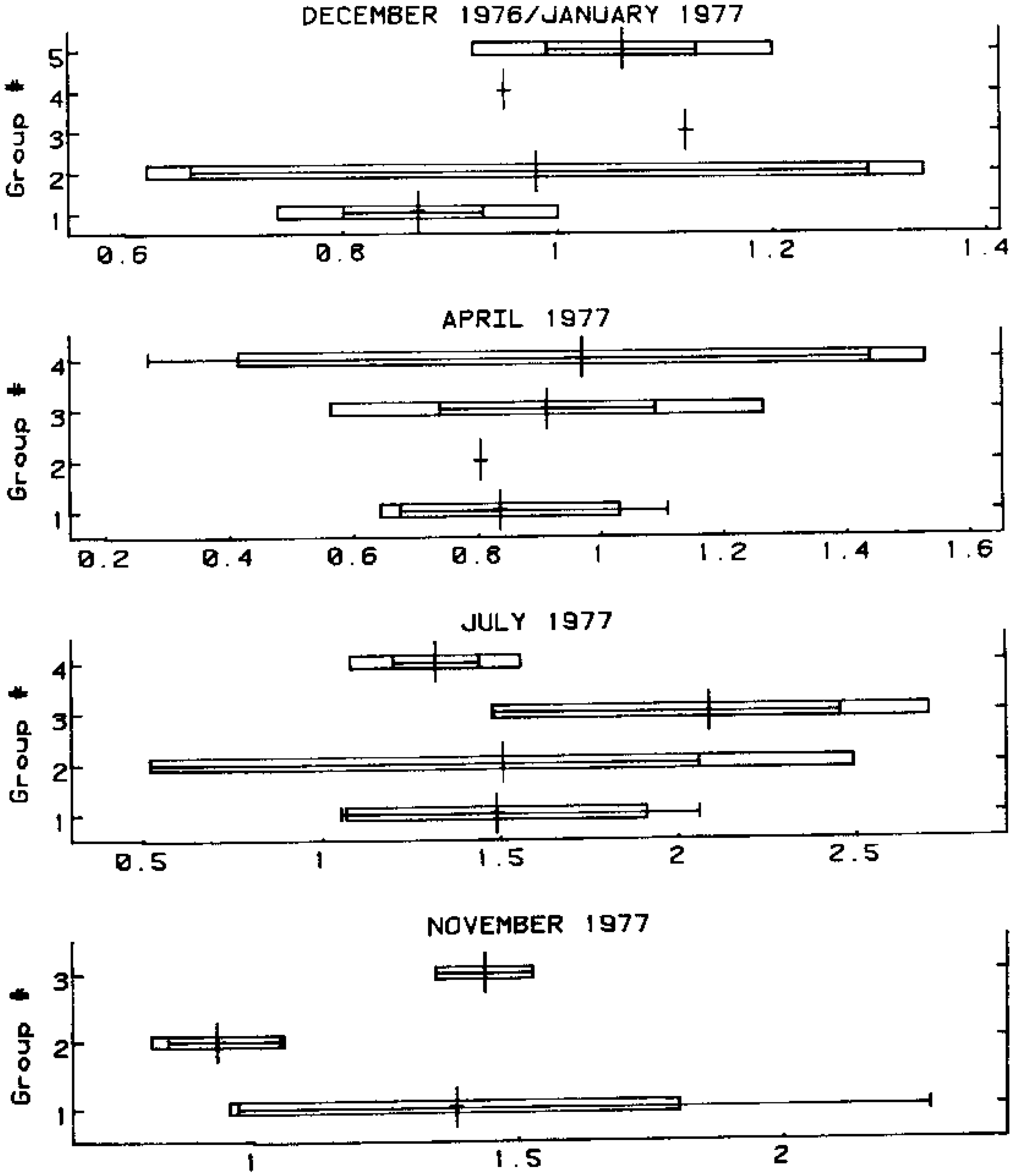


FIGURE 95
PLANKTON GROUPINGS

AMMONIA - NITROGEN
(RANGE & MEAN ± 2 S.E.)

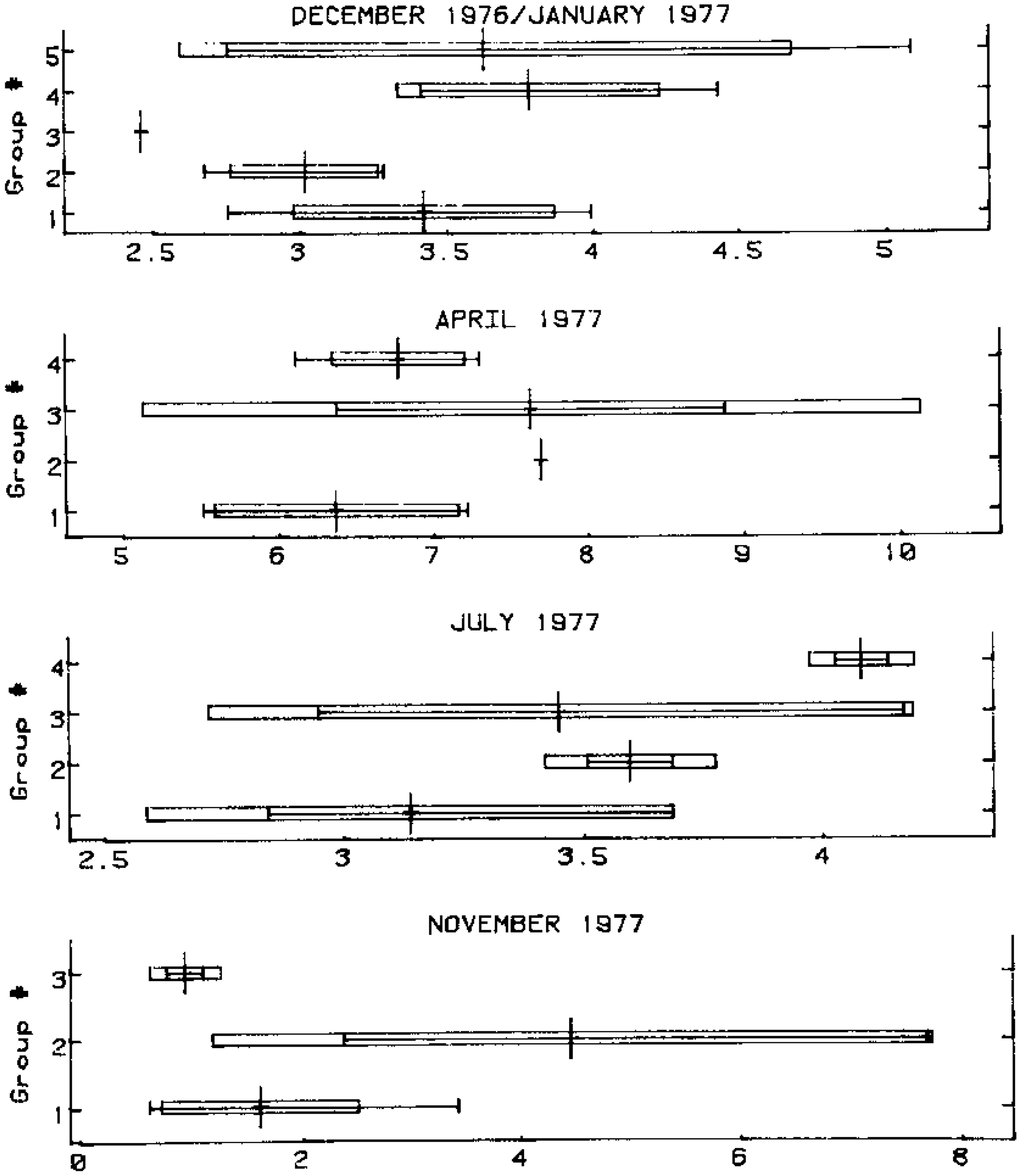


FIGURE 96
PLANKTON GROUPINGS

NITRITE
(RANGE & MEAN ± 2 S.E.)

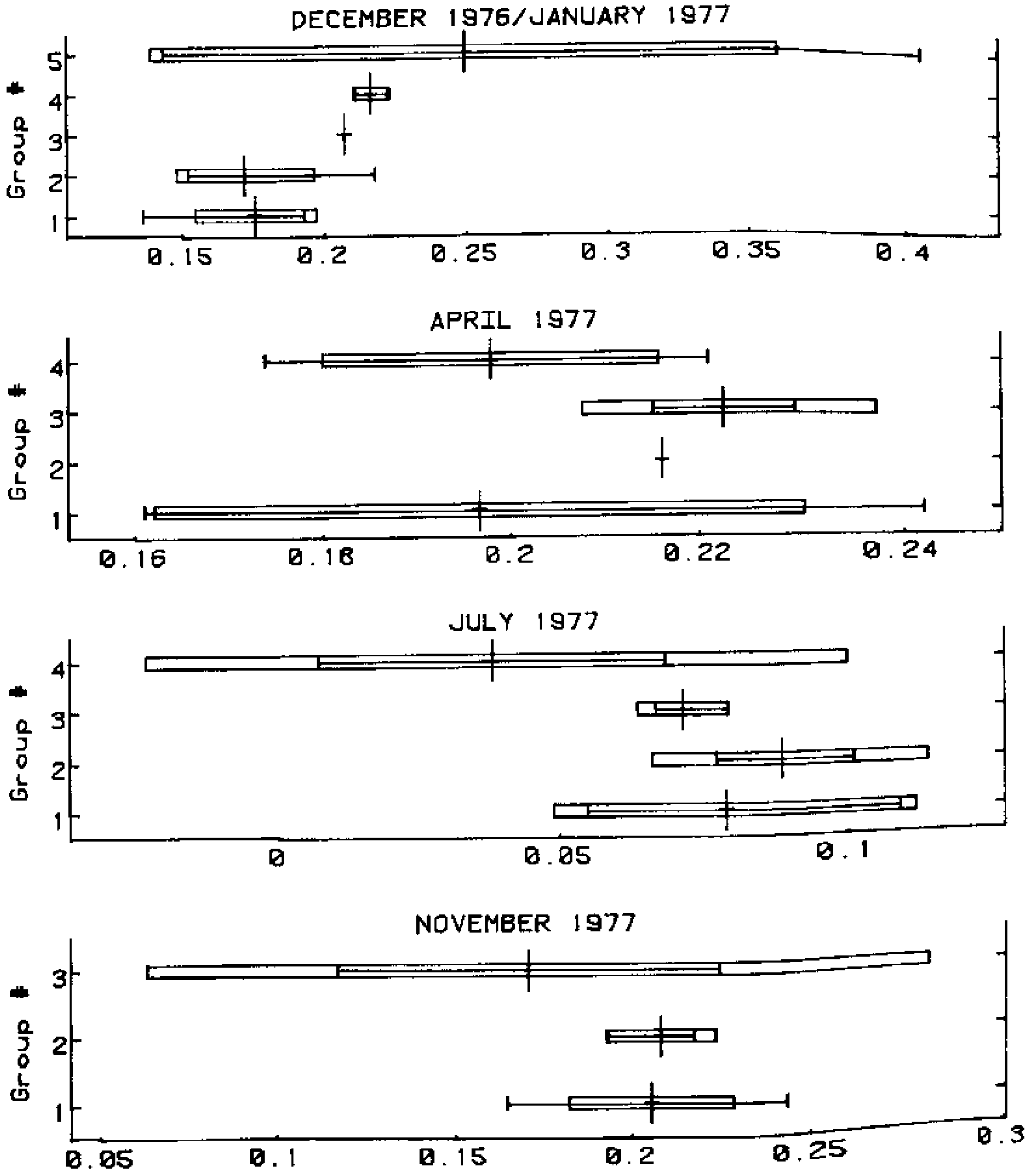


FIGURE 97
PLANKTON GROUPINGS

NITRATE
(RANGE & MEAN ± 2 S.E.)

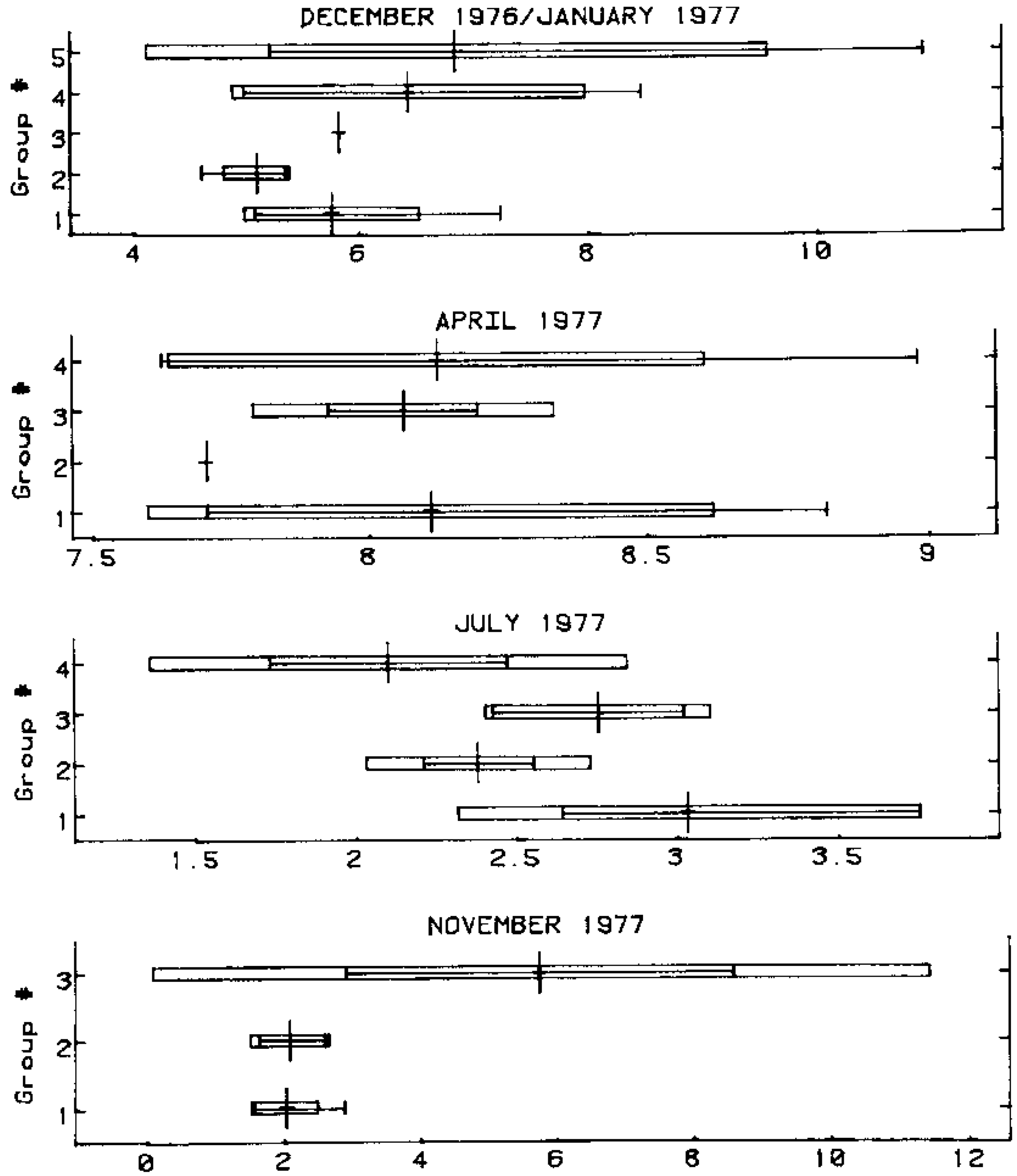


FIGURE 98
PLANKTON GROUPINGS

PHOSPHATE
(RANGE & MEAN ± 2 S.E.)

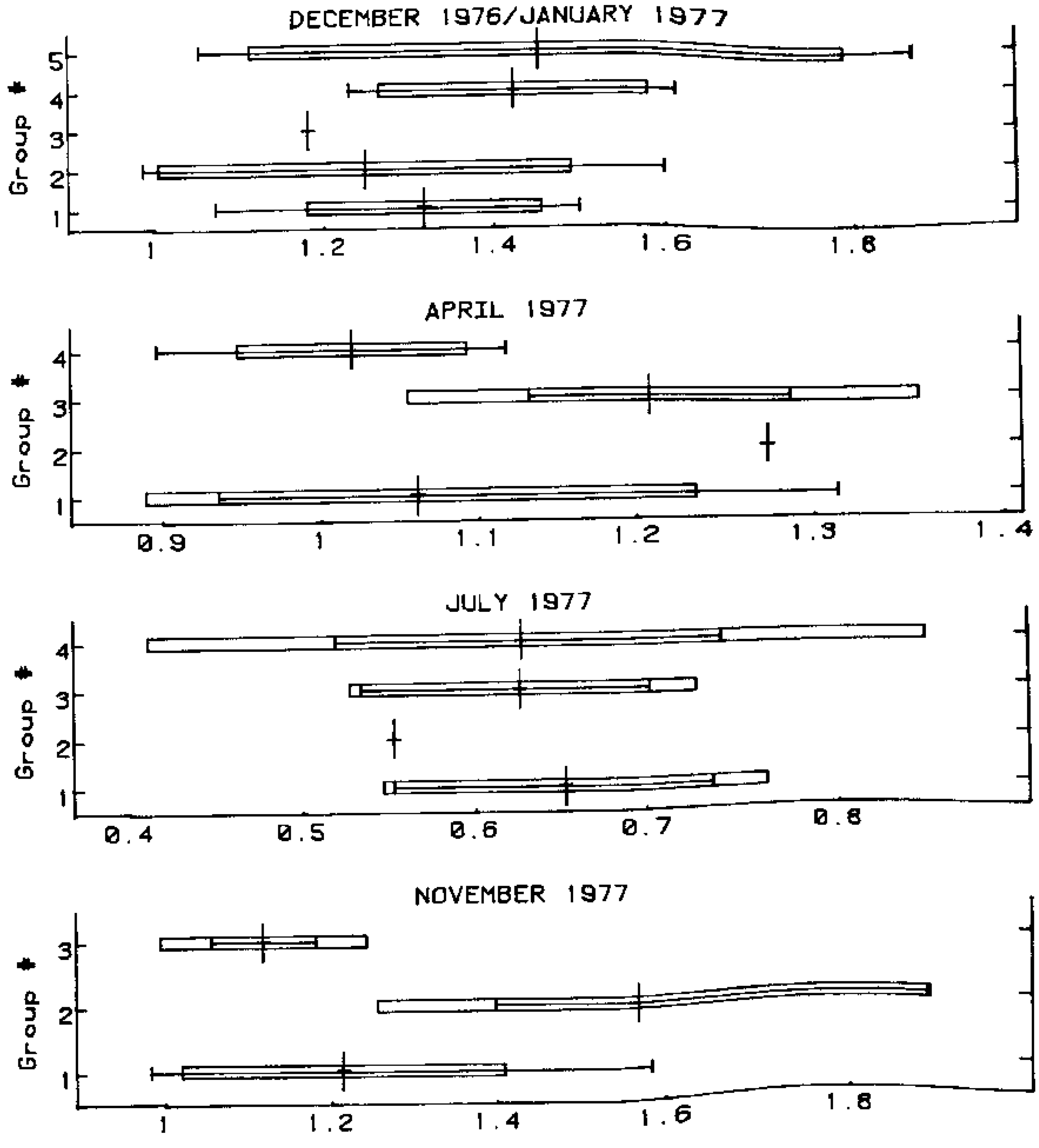
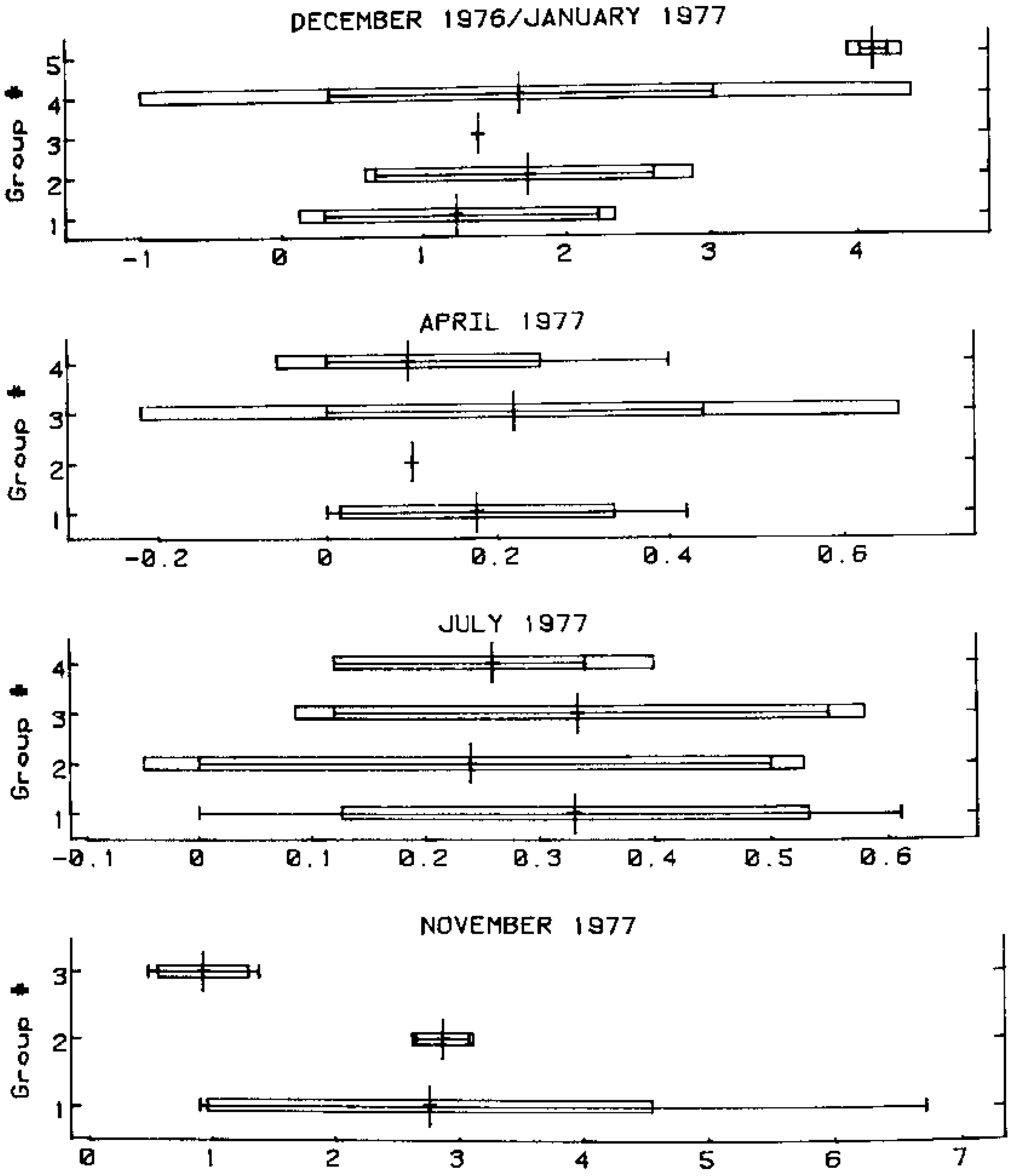


FIGURE 99
PLANKTON GROUPINGS

SURFACE OIL & GREASE (Plankton)
(RANGE & MEAN ± 2 S.E.)



D. MEROPLANKTON

Introduction

Studies of the environmental impact of the Sansinena incident on the biota were well quantified for phytoplankton, zooplankton and benthic organisms. In other cases it was not possible to collect sufficient samples for quantification and subsequent computer analysis, either because of disruptions due to cleanup operations or because of limitations in the scope of work. Sampling of meroplankton was one such study.

The meroplankton consist of eggs, larvae and adults of organisms that are temporarily suspended in the water column, but will settle out and become sessile or attached at some stage in their life cycle. The use of settling racks that can be suspended in the water column above possibly polluted bottoms gives an evaluation of those organisms being brought into an area during one month by tides or reproducing nearby on fixed surfaces. Many of these organisms would not survive on the bottom, either because of pollution or because the soft substrate is inappropriate to them.

For seven years small slide boxes containing 25 glass microscope slides and screened front and back with plastic screen have been used in harbor studies (Soule and Soule, 1971; AHF, 1976). Changed monthly, they give a picture of reproduction and recolonization as well as a faunal inventory. Eggs and larvae are carried through the screens and settle on the slides or frame. Some predation does occur in that microenvironment, but the collections have proved to be more diverse in major categories than either the benthic or zooplankton sampling.

Procedures

Following the Sansinena explosion settling racks were placed at four stations in the vicinity. Containment and cleanup activities caused considerable difficulty, however. Sometimes it was not possible to reach locations to place or retrieve racks, and a number of racks were destroyed by cleanup work or storms during the months surveyed. The effort was suspended in August 1977 because of continued problems with destruction and with funding limitations (Figure 100).

Discussion and Results

The irregularity of placement and retrieval due to salvage efforts made exact quantification impossible, since there were variations in time exposed (due to lack of access) and a lack of comparability, where racks at particular sites were lost. Counts of colonial animals are given in grams or as presence-absence, where it is not possible to count accurately the number of individuals in hydroid, bryozoan, or tunicate colonies, for example.

Prior Data. Analysis of settling rack data for 1973 and 1974 (AHF, 1976) showed that the numbers of species or other entities (taxa) were lowest in the winter period but varied from year to year. There were, for example, only 18 taxa found from all racks from the harbor in the December-February period in 1973, but 27 occurred in the same period in 1974. The summer period generally had the highest numbers of taxa, with a mean of 38 in both years for all stations. In some groups of organisms there are two periods of increase in species or in numbers, one in the spring around April, and another in the late summer -- early fall.

Examination of data at station A9 in 1976 prior to the Sansinena incident showed a low in March 1976 of 16 taxa, which increased to 22 in April but dropped back to 18 in August. October showed a considerable rise to 41 taxa, which dropped to 21 in November.

The occurrence of peak periods for reproduction is closely tied to temperature, and especially to temperature change rather than specific numbers. Apparently a rise (or fall) of several degrees in the water temperature serves as a reproductive "cue" to the metabolism to initiate maturing of eggs and sperm.

Post-Sansinena Data. In Table 23, data from some of the settling racks near the Sansinena are presented; the dates given are those at the end of an exposure period of approximately one month.

The total numbers of taxa showed an increase in April only at UO 3, whereas station UO10 showed a large increase in taxa in June and July, 1977. Station UO9 appeared to be reduced in species in comparison to UO10 in May and June.

Spirorbids dominated the racks in February 1977, along with copepods and, to some extent, *Mytilus*. Other polychaetes (*Ctenodrilus*) dominated in April, as well as increasing numbers of copepods. In May, the summer increase in numbers of individuals of copepods and amphipods began; large numbers of hydroids were present and *Mytilus* began to increase.

The June-July samples held large numbers of copepods and particularly amphipods; the amphipod *Jassa falcata* outnumbered all others. *Mytilus* was quite numerous in June but dropped considerably in July. Growth of the hydroid *Obelia* was very heavy in June, while the bryozoan *Bugula neritina* was present in some quantity in June and July and the tunicate *Ciona* was prominent in July.

Comparisons with data from station A2 across the main channel are of interest. In February fairly similar numbers of species and dominant organisms occurred at the UO stations and A2.

In April, A2 had nearly twice as many individuals as the maximum at the UO stations. *Jassa falcata*, which had been almost absent, returned to be the dominant arganism at A2, but remained scarce at UO stations.

In June, station A2 had over four times the number of organisms of any of the UO stations, but *Jessa falcata* had returned to UO stations as a dominant organism. The numbers at A2 remained much higher than at the UO stations throughout the sampling period through July, 1977.

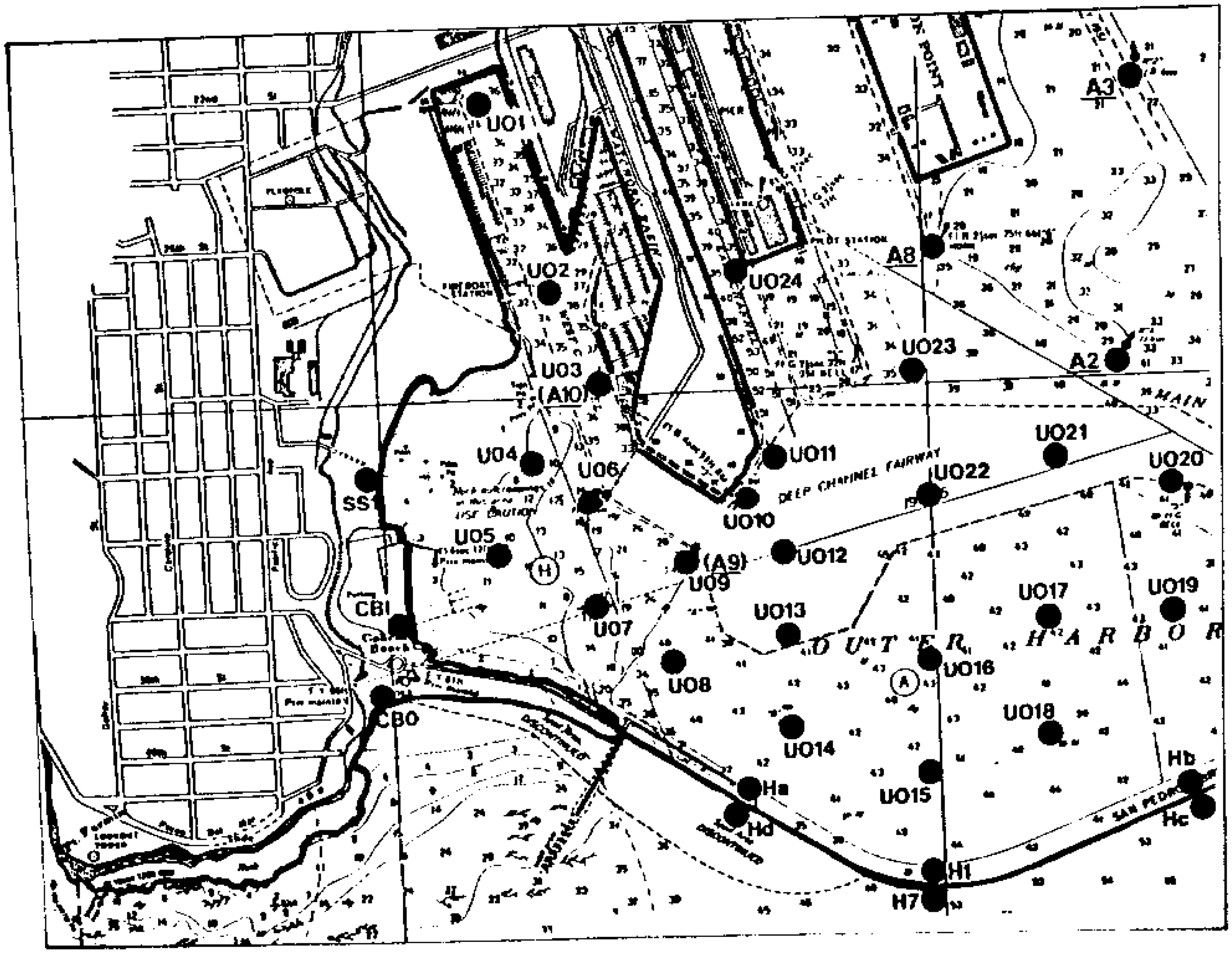


Figure 100. Meroplankton Studies of the Sansinena Settling Racks, placed at UO1, UO3(=A10), UO9(=A9) and UO10.

Table 23. **SANSINENA** SETTLING RACK DATA

	23 Feb. 77		1 Apr. 77			3 May 77	8 Jun. 77		25 Jul. 77
	UO Sta.		UO Sta.			UO Sta.	UO Sta.		UO Sta.
Organisms	01	03	01	03	10	09	09	10	10
ANNELIDA POLYCHAETA									
Capitellidae									
Capitella capitata	5	3	2	13		2		19	16
Chrysopetalidae									
Paleanotus bellis							48	12	10
Cirratulidae									
Chaetozone armata				1					
Chaetozone corona									1
Tharyx sp.									
Ctenodrilidae									
Ctenodrilus serratus	7	5	5	7	136	2		19	1
Dorvilleidae									
Ophryotrocha puerilis	2	2		1					4
Schistomeringos longicornis									
Hesionidae									
Ophiodromus pugettensis					4			1	
Nereidae									
Platynereis bicanaliculata	24	9	77	28	40		16	29	32
Opheliidae									
Armandia bioculata				2		2		68	29
Polyopthalmus pictus	5							5	3
Phyllodocidae									
Eulalia sp.								3	1
Eumida sp.									1
Eumida sanguinea									
Polynoidae				20		10		3	6
juvenile	1		15		20				
Halosydna brevisetosa								2	
Halosydna johnsoni									2
Harmothoe imbricata								3	1
Sabellidae									21
Chone sp.								3	
Chone ecaudata									
Chone mollis								1	
Serpulidae									
Hydroides pacificus								5	29
Spionidae									
Polydora ligni									432
Polydora limicola					8	4			
Polydora socialis		1	3	5					
Polydora sp.								94	
Boccardia proboscidea					4				
Laonice sp.									1
Spirorbidae	208	20		13					
Dexiospira sp.			107					25	35
Syllidae				9		4			
Autolytus sp.		2	1		4			29	17
Pionosyllis sp.	1						16		

Table 23 (continued)

	23 Feb. 77		1 Apr. 77			3 May 77	3 Jun. 77		25 Jul. 77
	UO Sta.		UO Sta.			UO Sta.	UO Sta.		UO Sta.
Organisms	01	03	01	03	10	09	09	10	10
ARTHROPODA CRUSTACEA									
Copepoda	364	144	501	383	804	648	848	602	526
Gammaridea (AMPHIPODA)									
Corophiidae									
Corophium acherusicum	35	28	49	65		102	288	1211	2425
Ericthonius brasiliensis	2	1	5			8	48	81	25
Gammaridae									
Elasmopus rapax	1	13	3	6				12	16
Isaeidae									
Gammaropsis thompsoni									
Ischyroceridae									
Jassa falcata			3	4		486	1728	380	2403
Microjassa litotes									
Podoceridae									
Podocerus brasiliensis	8	1	8	1	12	306	112	252	777
Stenothoidae									
Stenothoe valida				1		290	64	23	4
Caprellidea (AMPHIPODA)						236		94	59
Aeginellidae									
Deutella californica									
Caprellidae									
Caprella sp.				2	4		384		
Caprella californica	1	1					144		146
Caprella equilibra				5			384		84
Caprella verrucosa									
Isopoda									
Limnoridae									
Limnoria tripunctata		5		4				16	2
Munnidae									
Munna sp.									
Ianiridae									
Ianiropsis sp.				2					
Sphaeromatidae									
Paracerceis sculpta									1
ARTHROPODA									
Tanaidacea									
Anatanais normani	46		49	5	8	2		12	13
Thoracica									
Balanus amphitrite			1		12				
Pycnogonida		4		3	4	2	160	3	2
CHORDATA ASCIDIACEA									
Aplousobranchia									
Diplosoma macdonaldi (=*pizoni*)	0.12g			0.05g					0.01g
Phlebobranchia									
Ciona intestinalis	19	27	4	18		12	80	49	202
Stolidobranchia									
Botryllus sp.		0.03g	0.01g	0.02g	0.04g			0.04g	0.40g

Table 23 (continued)

	23 Feb. 77		1 Apr. 77			3 May 77	8 Jun. 77		25 Jul.77
	UO Sta.		UO Sta.			UO Sta.	UO Sta.		UO Sta.
Organisms	01	03	01	03	10	09	09	10	10
MOLLUSCA				23	32	6			
Gastropoda snail	1		7	30	4	86	160	59	4
Nudibranchia		3						67	1
Mitrella carinata		8	3	23		14	32	49	
Pelecypoda									
Hiatellidae							16	23	64
Hiatella arctica									
Mytilidae									
Mytilus edulis	11	38	4		16	40	400	479	78
Pectinidae									
Leptopecten latiauratus	1		1	6				3	2
NEMERTEA									1
ASCHELMINTHES									
Nematoda	7	2		2	4	8	16	12	89
PLATYHELMINTHES									
Turbellaria									
Polycladia			2	2		2	32	29	81
BRYOZOA CHEILOSTOMATA	0.04g	0.01g							
Bicelleriellidae									
Bugula californica								0.01g	
Bugula neritina	0.01g						0.16g	0.02g	0.42g
Membraniporidae									
Membranipora									
Cryptosula sp.			0.01g						
CNIDARIA HYDROZOA									
Campanulariidae									
Obelia sp.		0.11g		0.49g	0.04g	2.50g	16.64g	0.20g	0.95g
Tubilariidae									
Tubularia sp.		0.01g				0.16g			
OTHER ANIMALS									
Mysidacea Mysid			1	1					
Sea anemone									1
Sea urchin			1						
Foraminifera				3	32				
Oikopleura				4					
Larval crustacea				4					
Cumacea						2			
Thoracia				1					
Insecta						2			
Sabellaridae									
Sabellaria sp.								1	
Gastropoda									
Crepidula onyx								3	
Acmaeidae									1
Decapoda / Brachyura									
Loxorhynchus sp.								1	

Table 23 (continued)

	23 Feb. 77		1 Apr. 77			3 May 77	8 Jun. 77		25 Jul. 77
	UO Sta.		UO Sta.			UO Sta.	UO Sta.		UO Sta.
Organisms	01	03	01	03	10	09	09	10	10
OTHER ANIMALS									
Cheluridae									
Chelura terebrans								5	1
Ostracoda								18	
PLANTAE Algae	0.29g	0.28g	0.17g	0.43g					0.83g
CHLOROPHYCOPHYTA									
Chlorophyceae									
Uvales									
Enteromorpha sp.						0.16g	0.48g		
Ulva sp.					0.92g			0.03g	
CHRYSOPHYCOPHYTA									
Bacillariophyceae									
Filamentous diatoms									
PHAEOPHYCOPHYTA									
Phaeophyceae									
Ectocarpales									
Ectocarpus sp.					0.96g				
RHODOPHYCOPHYTA									
Florideophyceae									
Ceramiales									
Polysiphonia sp.					0.72g	0.28g	0.16g	0.10g	

E. BREAKWATER BIOTA

Algae. The breakwater rocks form a habitat for algae and incrusting, attached or sessile invertebrates. Samples taken from the breakwater by divers represent the growth and succession of biota of unknown size and duration, in contrast to settling racks which represent monthly changes in harbor species. The texture of the rocks and the differences in orientation, as well as the amount of exposure to air intertidally and exposure to wave action, give variety to the area and encourage species diversity.

The breakwater is really the only major habitat for algae in the harbor, except for limited numbers of species found on pilings and docks, and of course the newly planted kelp bed (HEP, 1978).

In July and August of 1973 and 1974, 12 stations on the breakwater were surveyed for algae and associated invertebrates, six on the inside of the three sections of breakwater and six on the outside. Station H1 was located at the bend in the San Pedro breakwater and H7 was on the outside at the same location. At that time a full square meter template was used for the area scraped, but subsequent sampling effort was reduced to 1/16 m^2 because of the irregularity of the substrate and the quantity of material obtained.

Station H1 was located near to station U015, established in December 1976 to study the Sansinena impacts. Two new stations were added; Ha was located at the outer end of the fishing pier near U014, and Hb was located about halfway from H1 to the Angels Gate end of the breakwater. The surf was too dangerous in January 1977 to scrape the outer breakwater, but there was no evidence of oil on the outer rocks. The 1973-1974 surveys had shown that, while there were about the same number of algae species on the inner and outer breakwaters, the species composition differed greatly.

The algal species found on January 4, 1977, two weeks after the Sansinena incident, are listed in Table 24. The breakwater had been heavily oiled by the tidal extremes, and oily debris was trapped at the bend; this is probably the reason for finding fewer species at H1, followed by Ha. Station Hb was the richest.

However, on March 29, 1977 station H1 was richer than either stations Ha or Hb, and it is possible that a die-off had permitted a broader range of species recolonizing. The increase in species was greatest among the phaeophycophytes in March (Table 25).

No further algal sampling was possible, but for purposes of comparison Table 26 gives species found in the summers of 1973 and 1974 (AHF, 1976). There was considerable difference in the species composition between the two years, as indicated by the symbols. This may have been due to the quite different temperature regimes in the five years (AHF, 1976). However, the possibilities for sampling limitations and patchiness preclude attaching undue importance to the data. Robert Setzer, who identified the 1973-74 algal collections, also identified the January and March 1977 samples.

Fauna. The animal species found in association with algae in the breakwater quadrat sampling were found to be much more abundant in species and numbers of individuals in the January 4, 1977 sampling than in March 1977 (Tables 27 and 28). Studies discussed later showed depauperate fauna in January and March at Cabrillo Beach, with some recovery by June. However, the abundance seen in the January samples at H1 was not found in June, although species diversity was good. Wicksten recorded the return of the isopod *Ligia occidentalis* to the beach in August as an indicator of more normal conditions.

A final survey in December 1977 (Table 30) showed considerable diversity. It should be roughly comparable to the January 4 sampling since the winter quarter is considered to consist of the months of December, January and February in this region.

Conclusion

Indications from the quadrat sampling were that there was a considerable impact on breakwater biota following the oil spill. Both numbers of species and individuals were greatly reduced in March and June, 1977.

The kelp bed transplant, begun in June 1977, indicated that numerous species and individuals were in the area or came to inhabit the kelp following that period (HEP, 1978).

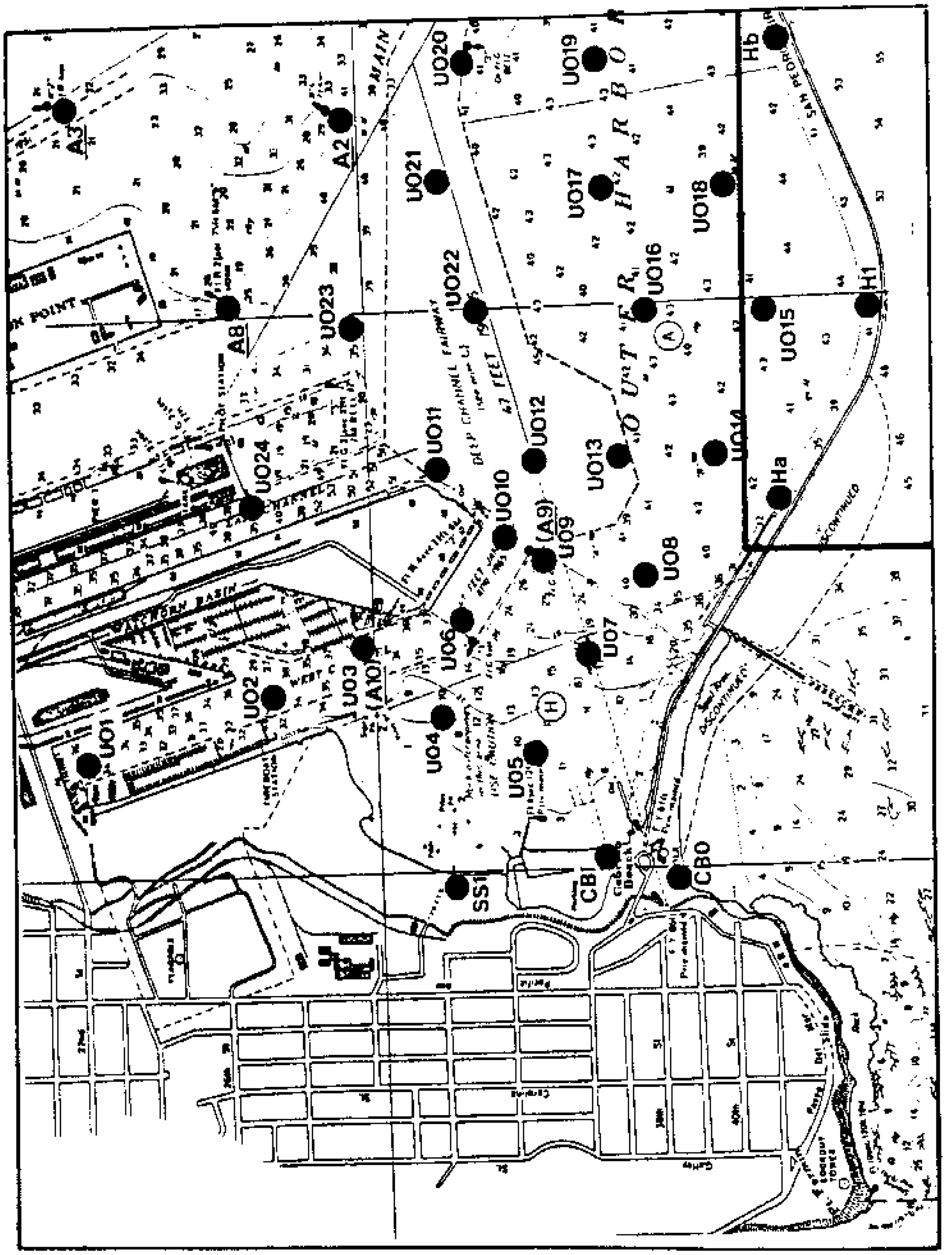


Figure 101. Los Angeles Harbor Breakwater Diver Survey Stations. January 4, 1977.

Table 24. Algae from Los Angeles Harbor Breakwater. January 4, 1977. (1/16 m. quadrat)

SPECIES	STATIONS		
	H1	Ha	Hb
Chlorophycophyta			
Chaetomorpha sp.			●
Cladophora sp.		●	●
Derbesia marina	●		●
Enteromorpha sp.			●
Ulothrix sp.		●	
Phaephycophyta			
Ectocarpus sp.			●
Feldmannia sp.	●		
Giffordia sp.		●	
Rhodophycophyta			
Antithamnionella breviramosa	●		●
Antithamnion defectum		●	
Champia parvula			●
Chondria arcuata			●
○ *Corallina officinalis chilensis*	●		
Corallina pinnatifolia	●		
Corallina vancouveriensis		●	●
Dasya sp.	●	●	●
Delesseriaceae (young)	●		
Erythrotrichia tetraseriata		●	●
Gigartina tepida		●	●
Goniotrichum alsidii		●	
Microcladia coulteri		●	●
Murrayellopsis dawsonii	●	●	●
Nienburgia andersoniana	●	●	
Pleonosporium vancouverianum	●		
Polysiphonia pacifica delicatula	●	●	●
Polysiphonia scopulorum var. *villum*			●
○ *Prionitis lanceolata*	●	●	●
Pterosiphonia dendroidea		●	●
Rhodymenia pacifica			●

○ Indicates dominant species

● Indicates presence

Table 25. Algae found along the Los Angeles Harbor Breakwater.
29 March, 1977.

SPECIES	H1	Ha	Hb
Chlorophycophyta			
Bryopsis sp.			●
Chaetomorpha linum	●		
Cladophora sp.	●	●	●
Derbesia sp.			●
Enteromorpha sp.	●	●	●
Ulva sp.	●	●	
Phaeophycophyta			
Dictyota sp.	●		
Ectocarpus sp.	●		●
Feldmannia cylindrica	●		
Giffordia granulosa	●		
Giffordia sp.	●	●	●
Laminarian (young)		●	
Sphacelaria furcigera	●		
Rhodophycophyta			
Acrochaetium sp.	●	●	●
Antithamnion defectum	●	●	●
Antithamnionella breviramosa	●		
Corallina vancouveriensis	●		●
Dasya sp.	●		
Erythrotrichia sp.	●	●	●
Fauchea laciniata f. *pygmaea?*		●	
Gigartina spinosa		●	
G. tepida	●		●
Goniotrichum sp.	●		●
Microcladia coulteri	●	●	●
Nienburgia andersoniana		●	
Pleonosporium vancouverianum		●	
Pleonosporium sp.	●		
Polysiphonia pacifica delicatula	●	●	●
P. scopulorum var. *villum*			●
Prionitis lanceolata	●	●	●
Pterosiphonia dendroidea	●	●	●
Pterosiphonia sp.		●	
Rhodymenia sp. *arborescens?*	●		
Tiffaniella snyderae		●	
Veleroa subulata	●		
Other			
Ulothrix sp.	●		
Diatoms		●	●

Table 26. Algae from Los Angeles Harbor **Breakwater** Summer,1973 and 1974. (Data from AHF, 1976).

SPECIES	Stations H1	 H7
Chlorophycophyta		
Chaetomorpha sp.	●	
Cladophora graminea	○	
Cladophora sp.	●	
Derbesia marina		○
Enteromorpha prolifera	○	
Enteromorpha sp.	●	
Ulva sp.	○	
Phaeophycophyta		
Colpomenia peregrina	●	
Dictyota flabellata	○	
Feldmannia sp.		○
Giffordia sp.	○●	
Rhodophycophyta		
Anisocladella pacifica	○	
Antithamnion defectum	○	○●
Antithamnion breviramosa	○●	
Corallina officinalis chilensis		○
Corallina pinnatifolia	●	●
Corallina vancouveriensis	○●	
Cryptopleura corallinara		○●
Dasya sinicola var. *abyssicola*	○●	
Erythrotrichia sp.	○	●
Fauchea laciniata var. *pygmaea*		○●
Gelidium robustum		○
Gigartina armata/spinosa complex		○
Gigartina spinosa		●
Gigartina tepida	●	○
Gonimophyllum skottsbergii		○
Goniotrichum elegans	○	○
Gymnogongrus platyphyllus		○
Lithothrix aspergillum	●	
Microcladia coulteri	○	○●
Nienburgia andersoniana	○●	○●
Pleonosporium abyssicola	○●	
Pogonophorella californica	○	
Polysiphonia pacifica var. *delicatula*	○●	○●
Prionotis lanceolata ◯	○●	○●
Pterosiphonia dendroidea	○●	○
Pterosiphonia pennata	●	
Rhodymenia californica	○	
Rhodymenia pacifica		○●
Sorella delicatula		○

○ 1973 ● 1974 ◯ Dominant species for each station

Table 27. Animals found along the Los Angeles Harbor Breakwater Diver Survey Stations. January 4, 1977.

SPECIES	Stations		
	H1	Ha	Hb
Protozoa			
Foraminifera	Abund.		
Porifera			
Demospongiae		Abund.	
Coelenterata			
Hydroidea	Common		P
Obelia sp. ?		Common	
Annelida			
Polychaeta	12		3
Serpulidae	27		
Mollusca			
?*Crenella* sp.			3
Crepipatella lingulata		3	1
Mitrella carinata	35	3	22
Nassarina penicillata	1		1
?*Nassarina* sp.			1
Arthropoda			
Gammarid amphipods	5		
Harpacticoida	4		
"*Dynamenella*" sp.	1		
Munna ubiquita	1		
Pagurus n. sp.?	1		
Pugettia dalli	1		
Tanaidacea	2		
Pycnogonida			
Anoplodactylus erectus			1
Tanystylum sp.	1		1
Bryozoa (Abundant)			
Amathia distans		P	
Thalamoporella californica			P
Holoporella brunnea	P		P
Membranipora tuberculata		P	
Bugula neritina	P		P
Scrupocellaria diegensis			P
Tricellaria occidentalis		P	
Diaperoecia californica	P		
Entoprocta			
Barentsia gracilis	4 cluster.		P
Echinodermata			
Strongylocentrotus purpuratus	3	1	
Chordata			
Ascidians	4		2

P = Present

Table 28. Animals from Los Angeles Breakwater Diver Survey - March 29, 1977.

Species	Stations		
	H1	Ha	Hb
PORIFERA			1
COELENTERATA			
Hydractinea, sp.		many	
Sertularella, sp.		7	
ANNELIDA			
Polychaeta, unid.		2	
Serpulidae, unid.	4		
ENTOPROCTA			
Barentsia discreta		abund.	
MOLLUSCA			
Chama pellucida	1		
Crepidula perforans	1+shell		
Crepipatella lingulata	2	1	
Hiatella arctica	1		
Mitrella carinata		8	
Mytilus edulis		2	
BRYOZOA			
Celleporaria (Holoporella) brunnea			abund.
Membranipora tuberculata			abund.
Thalamoporella californica			1
ARTHROPODA			
Gammaridea, unid.	4		
Ammothella tuberculata		1	
Cancer anthonyi		1	
Tanystylum intermedium		1	
CHORDATA	abund.	1	

Table 29. Animals from Los Angeles Breakwater Diver Survey - June 29, 1977.

Species	Stations H1	 Ha	 Hb
PORIFERA		5	
COELENTERATA			
Astrangia lajollaensis	6		
Clavularia?, sp.	4		
Sertularella, sp.		abund.	
ANNELIDA			
Polychaeta, unid.	1		1
Serpulidae, unid.	1		
Spirorbus?, sp.		6	
MOLLUSCA			
Aegires albopunctatus	1		
Crepidula onyx	1		
Crepipatella lingulata	1		
Mitrella carinata		9	3
Nasserina, sp.	1		
Tricolia pulloides			1
ARTHROPODA			
Gammaridea	1	9	11
Balanus tintinnabulum?		1	
Cancer anthonyi	1		
Cancer, sp.			1
Caprella verrucosa			3
Pugettia dalli	1		
Tetraclita squamosa	1		
CHORDATA			
Ascidacea	1		1
Ciona intestinalis	1		
BRYOZOA (unid.)	abund.	few	abund.
Scrupocellaria diegensis	abund.		

Table 30. Animals from Los Angeles Breakwater Diver Survey - December 22, 1977.

	Stations		
Species	H1	Ha	Hb
PORIFERA			1
?Haliclona, sp.	1		
ANNELIDA			
Polychaeta (unid.)			1
Serpulidae (unid.)			1
ENTOPROCTA			
Barentsia discreta		many	
MOLLUSCA			
Anomiidae			1
Crepipatella lingulata			2
Lacuna unifasciata		1	
Leptopecten latiauratus			1
Mitrella carinata	17	38	21
Mytilus edulis			2
Ocenebra poulsoni		1	
BRYOZOA			
Amathia distans	6 colonies	14 colonies	
Celleporaria brunnea			3 colonies
Crisulipora occidentalis			2 colonies
Membranipora tuberculata	17 colonies	8 colonies	127 colonies
Thalamoporella californica	105 colonies	52 colonies	18 colonies
ARTHROPODA			
Balanus tintinnabulum			1
"Dynamenella" sp.	1		
Gammaridea	18	3	14
Pugettia richi	1		
Taliepus nuttalli			1
Tantystylum intermedium			1
Tetraclita squamosa rubescens			2
ECHINODERMATA			
Strongylocentrotus purpuratus	5		

F. FISH FAUNA

Fish fauna of the Sansinena site area had not been surveyed systematically by trawling as had the fauna of other areas in outer Los Angeles and Long Beach Harbors in years previous to the explosion. Data from Chamberlain (1973, 1974 and 1976) and Stephens, Gardiner and Terry (1973) and Stephens, Terry and Allen (1974) were summarized in AHF (1976).

Numbers of fish in the outer harbor area reached higher than 3000 fish per trawl in the summer and fall of 1973 but dropped to below 200 by January 1974. The counts reached only about 700 per trawl in the fall of 1973 (AHF, 1976). After that counts dropped down to as low as 1-2 fish in 1975-76 (J.S. Stephens, pers. comm.).

On April 8 and 15, 1977 Dr. Stephens of Occidental College and his students made several trawls in the area from outside Fish Harbor toward Angels Gate (Figure 102) and parallel to the Sansinena site toward the southeast (Trawls 1 and 2). They also trawled off Whites Point, west of outer Cabrillo Beach on April 15 and the resulting data are presented in Table 32. Numbers of individuals per trawl and their average size in millimeters are given. The clear division in April 1977 was between harbor species and coastal Whites Point species, rather than any obvious differences between the in-harbor areas close to the Sansinena and away from it, or between the dates surveyed in April.

The most numerous species in the harbor in April 1977 was *Genyonemus lineatus*, the white croaker, which appears to flourish in the soft bottom, calmer water environment as an omnivore. In 1972-75 it composed 56% of the outer harbor fish (AHF, 1976). *Phanerodon furcatus* (white surfperch) was second in the April 1977 survey, whereas it had been fourth in the 1972-75 surveys, having 3.9% of the total during those years. *Symphurus atricauda* (California tonguefish) was third in the April 1977 survey, whereas it had been the second most common fish in the 1972-75 surveys, with 10.9% of the total during the earlier period.

Due to the limited access to the area more extensive surveys could not be carried out in the spring and funds were not available for summer or fall surveys.

Fishes were surveyed quarterly at the San Pedro Breakwater from June 1977 to June 1978 by Harbors Environmental Projects as part of a contract for construction and maintenance of a kelp bed for the Los Angeles Harbor Department. The project, created as a mitigation measure, attracted a variety of fish to the area. The complete study of the kelp bed (HEP, 1978) suggests that there was little or no inhibitory effect on its growth from the residual oil from the Sansinena.

The only prior records available to HEP for the breakwater area were qualitative, made by Mary K. Wicksten in the course of invertebrate research there. These data, previously unpublished, are presented in Table 32.

The kelp bed diver surveys were much more intensive and thus indicate the nature of the fish population more accurately. Comparison of species lists with the trawl data also reflects the difference in habitat sampled and the trawl method as compared with diver surveys of the breakwater-kelp habitat. Divers surveying the kelp included C.R. Feldmeth (HEP and Claremont Colleges), M.K. Wicksten (HEP), and G. Troyer (Pomona College). These data are presented in Table 33.

A check list of fishes from the harbor by Chamberlain (AHF, 1976) is presented for reference to names and ranges, as Table 34.

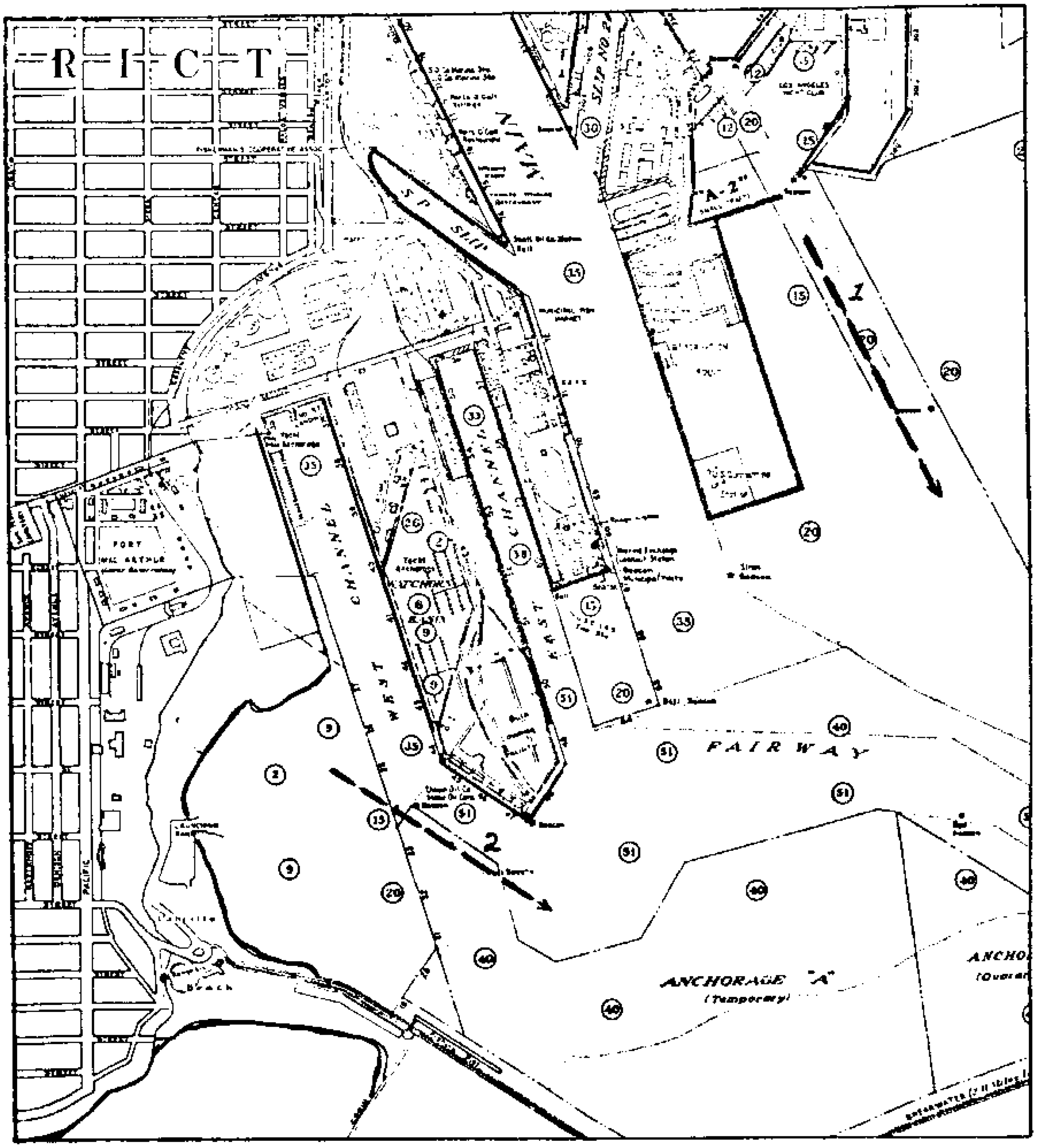


Figure 102. April Fish Trawls, 1977.

Table 31. Fish from the Sansinena area, San Pedro, compared with the White's Point area.

SPECIES	Stn. 1 Apr. 8 #I S	Stn. 2 Apr. 8 #I S	Stn. 1 Apr. 15 #I S	Stn. 2 Apr. 15 #I S	Wht.Pt. Apr. 15 #I S
Chilara taylori					2/225
Citharichthys sordidus					2/123
Cymatogaster aggregata		1/85			
Embiotoca jacksoni				1/120	
Genyonemus lineatus	80/155		29/143	1/210	
Glyptocephalus zachirus					2/170
Hippoglossina stomata					2/100
Hypsoblennius gilberti		1/55			
Microstomes pacificus					46/113
Odontopyxis trispinosa					1/100
Otophidium scrippsi					2/148
Paralabrax clathratus		1/60			
Paralabrax nebulifer		1/245			
Paralichthys californicus			1/90		
Phanerodon furcatus	1/170		4/128	13/129	
Sebastes dalli					15/86
Sebastes goodei					7/106
Sebastes saxicola		1/80			
Seriphus politus	1/135				
Symphurus atricauda		1/140	2/150	3/113	
Syngnathus sp.			1		
Xeneretmus latifrons					4/98

I = number of Individuals
S = Size (in millimeters) average

Station 1 (control) from Fish Harbor Breakwater toward Angels Gate.
Station 2 parallel to Sansinena south of channel marker buoys.

Table 32. Fishes Observed Along the San Pedro Breakwater and Fishing Pier, 1973-1974*

	1973			1974			1975						1976					1977	
	Apr	Sep	Oct	Mar	Sep	Oct	Jan	Feb	Apr	May	Oct	Nov	Jan	Mar	Apr	May	Nov	Feb	Aug
Amphistichus argenteus									F						F				
Brachyistius frenatus					NR								NR						NR
Citharichthys sp.																		S	
Clinocottus analis	AR																		R
Coryphopterus nicholsi					R	R		R					R					OS	R
Damalichthys vacca			NR		NR					NP			NR				NP	NP	NR
Embiotoca jacksoni													NR					NP	NP
Embiotocidae (unid.)		NR	NR	NR		NR		NP NR		NP	NP	NP		NP		NP			
Engraulis mordax																			S
Gibbonsia sp.					A			P		P	P	P		P			P	P	P
Girella nigricans																			NR
Gobiesox rhessodon																	C		
Heterostichus rostratus					A	A		A											A
Hypsoblennius gilberti		R				R			F			P			F			P	P
Hypsurus caryi			NR																NR
Leptocottus armatus										P				P				P	
Neoclinus stephensae										BC			BC	BC				BC	BC
Orthonopias triakis		R		R	R	R	R	R	P,R	P	P	P	R	P					R
Oxylebius pictus		R		R						P									
Paralabrax clathratus			NR	NR	NR	NR	NR	NR	NR	NP	NP		NR				NP	NP	NR
Paralabrax nebulifer			NS																NS
Phanerodon furcatus		NR								NP			NR						NP
Pleuronectidae (unid.)			SR				SR												SR
Pleuronichthys coenosus									SP	SP		SP			SP			SP	
Psettichthys melanostictus									SP	SP		SP			SP			SP	
Sciaenidae (unid.)		NS			NS												OS		
Scorpaena guttata		R	R		R			R			P			P		P		P	P,R
Scorpaenichthys marmoratus			R						P	P	P	P	R	P		P	P	P	P
Sebastes sp.										P									
Sebastes dalli																			NR
Sebastes mystinus		NR	NR	NR				NR					NR						NR
Sebastes serranoides														NP				NP	NR
Seriphus politus			NSn																

A = among algae
BC = in bottles/cans/shells
C = under cobble
F = caught by pier fishermen
P = on pilings
NP = near pilings

SP = sand below pilings
R = on rocks (breakwater)
AR = among rocks
NR = near rocks
S = on sand
SP = sand below pilings
OS = over sand

* Incidental fish data courtesy of Dr. Mary K. Wicksten; taken during SCUBA or snorkel observations of invertebrates.

Table 33. Fish Census for the San Pedro Breakwater, 1977-1978.
Los Angeles Harbor Department/Harbors Environmental Projects, Kelp Transplant Project.

SPECIES (Common name)*	Jul 15	Aug 19	Sep 21	Oct 28	Nov 30	Dec 19	Jan 24	Feb 21	Mar 29	Apr 27	May 18	Jun 13
Barred surfperch	6	6			7		2	1				
Black surfperch		10	5	11	7	10	7		13	9	22	14
Blackeye goby			1		3	1	1	1	1			1
Blacksmith	13	4		96	80	2	10	20	30		50	
Blue rockfish		5	6 juv	4	4	1	1	22	5			10
Calico rockfish			100's	12	3			13				
Cusk eel												
Diamond turbot												
Garibaldi				1	2			1				1
Giant kelpfish		2					1					
Halfmoon				1		1						
Kelp bass	9	16	14	4	9	5	5	8	15	3	27	45
Kelp greenling												
Kelp rockfish												
Kelp surfperch	6	12	25	9	14		58	60	19	44	200	8
Kelpfish				1	1							
Olive rockfish		3				7	12		6	1	2	
Opaleye			3		1							
Painted greenling									1			
Pile surfperch	1	3	7	6	2	5	4	4	3	5	5	7
Queenfish			10-15									8
Rainbow surfperch				6						1		
Rubberlip surfperch							1					
Sand bass												
Scorpionfish												
Senorita	1											
Sheephead		2							1			
Shiner surfperch						6	3				2	
Snubnose sculpin								3				
Topsmelt												
Treefish	1		1		5	6	1	2			5	
White surfperch	18	4		3	4	10	10	6	8	5	14	7
Yellowfin croaker												
Yellowfin fringehead	1						1		1			

* See Table 35 for scientific names.

TABLE 34. COMMON AND SCIENTIFIC NAMES OF FISH

PHYLUM CHORDATA

CLASS CHONDRICHTHYS - CARTILAGENOUS FISHES

Order Heterodontiformes

FAMILY HETERODONTIDAE - Bullhead Sharks

Hornshark . . . . *Heterodontus francisci* (Girard) Gulf of California to Monterey Bay. Shallow to 492 feet. Los Angeles-Long Beach Harbor: S3.

Order Squaliformes

FAMILY CARCHARHINIDAE - Requiem Sharks

Soupfin shark. . . *Galeorhinus zygopterus* Jordan & Gilbert Chile and Peru to Northern British Columbia, but not in the tropics. Near water surface. Los Angeles-Long Beach Harbor: S4.

Grey smoothhound. . . . . *Mustelus californicus* Gill Mazatlan, Mexico, to Cape Mendocino, California. Shallow to 150 feet. Los Angeles-Long Beach Harbor: BS, HLA, Common.

Brown smoothhound . . . . *Mustelus henlei* (Gill) Gulf of California to Humboldt Bay, California. Shallow. Los Angeles-Long Beach Harbor: HLA, S1.

Leopard shark. . . . .*Triakis semifasciata* Girard Mazatlan, Mexico, Gulf of California to Oregon. Bays and beaches. Los Angeles-Long Beach Harbor: BS, S3.

FAMILY SQUALIDAE - Dogfish Sharks

Spiny dogfish. . . . .*Squalus acanthias* Linnaeus Temperate and Subtropical Atlantic and Pacific, Chile, Baja California to Alaska, Japan. Shallow to 1200 feet. Los Angeles-Long Beach Harbor: T8, T11.

FAMILY SQUATINIDAE - Angel Sharks

Pacific angel shark . . . . . .*Squatina californica* Ayres Chile, Gulf of California to South East Alaska. Shallow water. Los Angeles-Long Beach Harbor: S4.

Order Rajiformes (Batoidei)

FAMILY PLATYRHINIDAE - Thornbacks*

Thornback. . *Platyrhinoidis triseriata* (Jordan & Gilbert) Baja California to San Francisco. Shallow to 150 feet. Los Angeles-Long Beach Harbor: BS, S1.

FAMILY RHINOBATIDAE - Guitarfishes

Shovelnose guitarfish . . . .*Rhinobatos productus* (Ayres) Gulf of California to San Francisco (recent records only to Capitola). Surface to 50 feet. Los Angeles-Long Beach Harbor: BS, S1.

FAMILY TORPEDINIDAE - Electric rays

Pacific electric ray . . . . . *Torpedo californica* Ayres Baja California to British Columbia. Shallow to 640 feet. Los Angeles-Long Beach Harbor: T7, T12, T13 (A number have been collected in other trawls but additional data is unavailable), Common.

FAMILY RAJIDAE - Skates

California skate . . . . . .*Raja inornata* Jordan & Gilbert Baja California to Strait of Juan de Fuca. 60 to 2200 feet. Los Angeles-Long Beach Harbor: S1.

FAMILY DASYATIDIDAE* - Stingrays

Diamond stingray. . *Dasyatis dipterura* (Jordan & Gilbert) Paita, Peru, to Kyuhuat, British Columbia. Shallow to 55 feet. Los Angeles-Long Beach Harbor: BS, S3, S4.

California butterfly ray. . . *Gymnura marmorata* (Cooper) Peru to Point Conception. Shallow bays and beaches. Los Angeles-Long Beach Harbor: BS, S4.

Round stingray. . . . .*Urolophus halleri* Cooper Panama Bay to Humboldt Bay. To 70 feet. Los Angeles-Long Beach Harbor: BS, S1, S3, S4.

FAMILY MYLIOBATIDAE - Eagle Rays

Bat ray . . . . *Myliobatis californica* Gill Gulf of California to Oregon. To 150 feet. Los Angeles-Long Beach Harbor: BS, HLD, S1, S3, T3, T6, Common.

Order Chimaeriformes

FAMILY CHIMAERIDAE - Chimaeras

Ratfish. . . . . *Hydrolagus colliei* (Lay & Bennett) Gulf of California to South East Alaska. Shallow to 1200 feet. Los Angeles-Long Beach Harbor: S4.

CLASS OSTEICHTHYS - BONY FISHES

Order Anguilliformes (Apodes & Lyomeri)

FAMILY MURAENIDAE - Morays

California moray. . . . .*Gymnothorax mordax* (Ayres) Baja California to Point Conception. Shallow reef areas. Los Angeles-Long Beach Harbor: S1, S4, Common along inside of outer breakwaters (Ron Williamson, Univ. So. Calif., pers. comm.).

Order Clupeiformes

FAMILY CLUPEIDAE - Herrings

Pacific sardine. . . . . . *Sardinops sagax caeruleus* Jenyns Guaymas, Mexico, to Kamchatka. Epipelagic. Los Angeles-Long Beach Harbor: BS, S3.

FAMILY ENGRAULIDIDAE - Anchovies

Deepbody anchovy. . . . . *Anchoa compressa* (Girard) Todos Santos Bay, Baja California to Morro Bay. Bays and estuaries. Los Angeles-Long Beach Harbor: BS, S3, T8, T13, T14, T17.

Anchoveta. . . . . *Centengraulis mysticetus* (Gunther) Sechura Bay, Peru, to Los Angeles Harbor. Los Angeles-Long Beach Harbor: Not taken, may be introduction (see Miller & Lea, 1972, p. 56).

Pacific Herring. . . .*Clupea harengus pallasi* Valenciennes Northern Baja California to Arctic Ocean and Japan. Inshore schooling fish. Los Angeles-Long Beach Harbor: BS.

Northern Anchovy . . . .*Engraulis mordax* Girard Cape San Lucas, Baja California to Queen Charlotte Island, British Columbia. Los Angeles-Long Beach Harbor: BS, S1, S3, T3-T16, Common.

Slough anchovy . . . . *Anchoa delicatissima* (Girard) Magdalena Bay, Baja California to Belmont Shores, Long Beach Harbors. Estuaries and bay backwaters. Los Angeles-Long Beach Harbor: BS, T6, T8, T13.

Order Salmoniformes

FAMILY SALMONIDAE - Salmons and Trouts

Coho (Silver) salmon . . . . *Oncorhynchus kisutch* (Walbaum) Chamalu Bay, Baja California to Bering Sea to Japan. Anadromous. Los Angeles-Long Beach Harbor: S1, Rare.

Order Myctophiformes

FAMILY SYNODONTIDAE - Lizardfishes

California lizardfish. . . . . . .*Synodus lucioceps* (Ayres) Guaymas, Mexico, to San Francisco. 5 to 150 feet. Los Angeles-Long Beach Harbor: S1, S4, T4-T7, T9, T11, T14, T16, U&G.

Order Batrachoidiformes

FAMILY BATRACHOIDIDAE - Toadfishes

Specklefin midshipman . . *Porichthys myriaster* Hubbs & Schultz Magdalena Bay, Baja California to Point Conception, California. Shallow to 414 feet. Los Angeles-Long Beach Harbor: BS, HLA, S1, S3, S4, T2-T17, Common.

Plainfin midshipman . . . .*Porichthys notatus* Girard Gulf of California Y Gorda Bank, Baja California to Sitka, Alaska. Surface to 1000 feet. Los Angeles-Long Beach Harbor: T5 (only one fish taken), Rare (may be seasonal), U&G.

Order Gadiformes (Anacanthini)

FAMILY GADIDAE - Codfishes

Pacific tomcod*. . . . . *Microgadus proximus* (Girard) Santa Monica Reef to Bering Sea. 40 to 1200 feet Los Angeles-Long Beach Harbor: S3.

FAMILY OPHIDIIDAE - Cusk-eels

Spotted cusk-eel . . . .*Chilara taylori* (Girard) San Cristobal Bay, Baja California to Northern Oregon. 4 to 800 feet. Los Angeles-Long Beach Harbor. T5, T7, T8, T13, G14.

Basketweave cusk-eel. . . . . . . *Otophidium scrippsi* Hubbs North of Guaymus, Mexico, to Point Arguello. Depth 9 to 230 feet. Los Angeles-Long Beach Harbor: BS.

Order Atheriniformes

FAMILY BELONIDAE - Needlefishes

California needlefish. . . . . *Strongylura exilis* (Girard) Peru to San Francisco. Shallow to about 300 feet Los Angeles-Long Beach Harbor: Belmont shore. Summer 1972, Beach Seine, Occidental College.

TABLE 34 (CONTINUED)

FAMILY CYPRINODONTIDAE

California killifish. . . . . *Fundulus parvipinnis* Girard
Common in Bays of Southern California. Los Angeles-Long Beach Harbor: BS, U&G.

FAMILY ATHERINIDAE - Silversides

Topsmelt. . . . . *Atherinops affinis* (Ayres)
Gulf of California to 4 mi. west of Sooke Harbor, Vancouver Island, B.C. Bays, sloughs, kelp beds. Los Angeles-Long Beach Harbor: BS, DV1, GN1, GN3, HLA, HLE, S1, S2 (dipnetted at Marina, Watchhorn Basin, SanPedro), Common.

Jacksmelt . . . . *Atherinopsis californiensis* Girard
Santa Maria Bay, Baja California to Yaquina, Oregon. Inshore, bays, Los Angeles-Long Beach Harbor: BS, HLE, S1, S2 (dipnetted at marina, Watchhorn Basin, San Pedro)..

California grunion . . . . *Leuresthes tenuis* (Ayres)
Magdalena Bay to San Francisco. Surface to 60 feet. Los Angeles-Long Beach Harbor: BS, S1, S2, (taken by dipnet at Marina, Watchhorn Basin, San Pedro), S3, Common.

Order Gasterosteiformes

FAMILY SYNGNATHIDAE - Pipefishes

Kelp Pipefish. . . . . *Syngnathus californiensis* Storer
Santa Maria Bay, Baja California to ca. San Francisco. Kelp beds. Los Angeles-Long Beach Harbor: T8, U&G.

Pipefish. . . . . *Syngnathus* sp.
BS, S3, T6, T7, T8, T13, T16.

Order Perciformes (Percomorphi: Acanthopterygii)

FAMILY SERRANIDAE - Sea Basses

Kelp bass . . . . *Paralabrax clathratus* (Girard)
Magdalena Bay, Baja California to Columbia River. Surface to 150 feet. Los Angeles-Long Beach Harbor: BS, DV1, GN1, HLA, HLC, S1.

Spotted sand bass . *Paralabrax maculatofasciatus* (Steindachner)
Mazatlan, Mexico, to Monterey, California, including Gulf of California. To 200 feet. Los Angeles-Long Beach Harbor: BS, DV1, GN1, HLA, HLB, HLC, HLD, S1, S2 (Fish Harbor, Terminal Island), T14 (only one fish taken), Common.

Barred sand bass. . . . . *Paralabrax nebulifer* (Girard)
Magdalena Bay, Baja California, to Santa Cruz, California. Shallow to 600 feet. Los Angeles-Long Beach Harbor: BS, DV1, GN1, HLC, S1, S3, S4, T12, T17.

Giant sea bass. . . . . *Stereolepis gigas* Ayres
Gulf of California to Humboldt Bay. 18 to 100 feet. Los Angeles-Long Beach Harbor: S4.

FAMILY BRANCHIOSTEGIDAE - Tile fishes

Ocean whitefish. . . . . . *Caulolatilus princeps* (Jenyns)
Peru to British Columbia. Surface to 300 feet. Los Angeles-Long Beach Harbor: S3, S4.

FAMILY CARANGIDAE - Jacks and Pompanos

Jack Mackerel. . . . . *Trachurus symmetricus* (Ayres)
Magdalena Bay, Baja California to South East Alaska. Surface to 150 feet. Los Angeles-Long Beach Harbor: S1, S3.

FAMILY POMADASYIDAE - Grunts

Sargo. . . . . *Anisotremus davidsoni* (Steindachner)
Magdalena Bay, Baja California to Santa Cruz, California. Surface to 130 feet. Los Angeles-Long Beach Harbor: BS, HLA, HLE, S3, S4, Common, U.&G.

Salema. . . . . . *Xenistius californiensis* (Steindachner)
Peru to Monterey Bay, Depth 4 to 35 feet. Los Angeles-Long Beach Harbor: BS.

FAMILY SCIANIDAE - Croakers* or Drums

Black croaker. . . . . *Cheilotrema saturnum* (Girard)

Magdalena Bay, Baja California to Point Conception. Surface to 150 feet. Los Angeles-Long Beach Harbor: BS, DV1, S1, S3, T11, (only one fish taken in 46 trawls).

White seabass. . . . . *Cynoscion nobilis* (Ayres)
Magdalena Bay, Baja California to Juneau, Alaska. Surface to 400 feet. Los Angeles-Long Beach Harbor: BS, S3, S4.

White croaker. . . . . *Genyonemus lineatus* (Ayres)
Magdalena Bay, Baja California to Vancouver Island, B.C. Surface to 330 feet. Los Angeles-Long Beach Harbor: BS, GN3, HLA, HLC, HLD, HLE, S1, S2 (Fish Harbor, Terminal Island), S3, S4, T1-T17, U&G, Common.

California corbina . . . . *Menticirrhus undulatus* (Girard)
Gulf of California to Point Conception. Surface to 45 feet. Los Angeles-Long Beach Harbor: BS, HLA, S3, S4.

Spotfin croaker. . . . . *Roncador stearnsi* (Steindachner)
Mazatlan, Mexico, to Point Conception. Surface to 50 feet. Los Angeles-Long Beach Harbor: BS, DV1, S3, S4.

Queenfish. . . . . *Seriphus politus* Ayres
West of Uncle Sam Bank, Baja California to Yaquina Bay, Oregon. Surface to 800 feet. Los Angeles-Long Beach Harbor: BS, GN3, HLA, HLD, S1, S3, S4, T3-T17, U&G. Common.

Yellowfin croaker . . . . *Umbrina roncador* Jordan & Gilbert
Gulf of California to Point Conception. Surface to 150 feet. Los Angeles-Long Beach Harbor: BS, S1.

FAMILY KYPHOSIDAE - Sea Chubs

Opaleye . . . . *Girella nigricans* (Ayres)
Cape San Lucas, Baja California to San Francisco. Intertidal to 95 feet. Los Angeles-Long Beach Harbor: DV1, GN1, S1, S3, U&G.

Halfmoon . . . . . *Medialuna californiensis* (Steindachner)
Gulf of California to Klamath River. Surface to 130 feet. Los Angeles-Long Beach Harbor: DV1, GN1, S1.

FAMILY EMBIOTOCIDAE -Surfperches

Barred surfperch . . . . *Amphistichus argenteus* Agassiz
Playa Maria Bay, Baja California to Bodega Bay. Surface to 130 feet. Los Angeles-Long Beach Harbor: BS, S3, S4.

Calico surfperch, ... *Amphistichus koelzi* (Hubbs)
Arroyo San Isidro, Baja California to Shi Shi Beach, Washington. Surface to 30 feet. Los Angeles-Long Beach Harbor: HLA.

Shiner surfperch . . . . *Cymatogaster aggregata* Gibbons
San Quintin Bay, Baja California to Port Wrangell, Alaska. Surface to 480 feet. Los Angeles-Long Beach Harbor: BS, DV1, GN1, GN3, HLA, HLB, HLC, HLD, HLE, S2 (sight record, Marina, Watchhorn Basin, San Pedro), Common.

Pile surfperch . . . . *Damalichthys vacca* (Girard)
Guadalupe Island to Port Wrangell, Alaska. Surface to 150 feet. Los Angeles-Long Beach Harbor: BS, DV1, GN1, HLA, HLE, S3, S4, T3, T4, T13-T14, Common.

Black surfperch . . . . *Embiotoca jacksoni* Agassiz
Point Abreojos, Baja California to Fort Bragg. Surface to 130 feet. Los Angeles-Long Beach Harbor: BS, DV1, GN1, HLA, HLB, HLC, HLD, HLE, S1, S3, S4, T3, T6, T7, T9-T14, T17, Common.

Walleye surfperch . . . . . *Hyperprosopon argenteum* Gibbons
Point San Rosarito, Baja California to Vancouver Island. Surface to 60 feet. Los Angeles-Long Beach Harbor: BS, HLA, HLD, HLE, S1, S3, S4, T1, T12, T13, T14, Common.

Dwarf surfperch . . . . . . *Micrometrus minimus* (Gibbons)
Cedros Island, Baja Californoa to Bodega Bay. Tidepools to 30 feet. Los Angeles-Long Beach Harbor: BS.

White surfperch . . . . *Phanerodon furcatus* Girard
Point Cabras, Baja California to Vancouver, B.C. Surface to 140 feet. Los Angeles-Long Beach Harbor: BS, DV1, GN1, GN3, HLA, HLD, HLE, S4, T1-T17, U&G, Common.

Rubberlip surfperch . . . . *Rhacochilus toxotes* Agassiz
Thurloe Head, Baja California to Russian Gulch State Beach, Mendocino County, California. Surface to 150 feet. Los Angeles-Long Beach Harbor: BS, DV1, GN1, S3, S4, T2, T3, T6, T8-T13, Common.

Pink surfperch. . . *Zalembius rosaceus* (Jordan & Gilbert)
Gulf of California and San Cristobal Bay, Baja California to Drakes Bay. 30 to 300 feet. Los Angeles-Long Beach Harbor: S4.

Rainbow surfperch . . . . *Hypsurus caryi* (Agassiz)
Rio Santo Tomas, Baja California to Cape Mendocino. Surface to 130 feet. Los Angeles-Long Beach Harbor: DV1, GN1.

FAMILY POMACENTRIDAE - Damselfishes

Blacksmith. . . . . *Chromis punctipinnis* (Cooper)
Point San Pablo, Baja California to Monterey Bay. Surface to 150 feet. Los Angeles-Long Beach Harbor: DV1, GN1, S1, S3.

Garibaldi . . . . *Hypsypops rubicundus* (Girard)
Magdalena Bay, Baja California to Monterey Bay. Surface to 95 feet. Los Angeles-Long Beach Harbor: DV1, GN1, S1, S3.

FAMILY LABRIDAE - Wrasses

Rockwrasse . . . . *Halichoeres semicinctus* (Ayres)
Gulf of California to Point Conception. Surface to 78 feet. Los Angeles-Long Beach Harbor: S1.

TABLE 34 (CONTINUED)

Senorita . . . . *Oxyjulis californica* (Gunther)
Cedros Island, Baja California to Sausalito (Recent only to Santa Cruz). Surface to 180 feet. Los Angeles-Long Beach: DV1, S1.

California sheephead. . . . *Pimelometopon pulchrum* (Ayres)
Cape San Lucas, Baja California to Monterey. Surface to 180 feet. Los Angeles-Long Beach Harbor: DV1, GN1, S3.

FAMILY LUGILIDAE - Mullets

Striped mullet . . . . *Mugil cephalus* Linnaeus
Eastern Pacific, Galapagos Islands to Monterey. Surface to 400 feet. Los Angeles-Long Beach Harbor: BS, S3.

FAMILY SPHYRAENIDAE - Barracudas

California barracuda . . . . . . *Sphyraena argentea* Girard
Cape San Lucas, Baja California to Kodiak Island, Alaska. Surface to 60 feet. Los Angeles-Long Beach Harbor: BS, HLA, S1, S3.

FAMILY POLYNEMIDAE - Threadfins

Yellow bobo . . . . *Polydactylus opercularis* (Gill)
Callao, Peru, to Monterey. Shallow inshore areas. Los Angeles-Long Beach Harbor: Not taken in this study (see Miller & Lea, 1972, pg. 168).

FAMILIY CLINIDAE - Clinids

Spotted kelpfish . . . . *Gibbonsia elegans* (Cooper)
Magdalena Bay, Baja California to Point Piedras Blancas. Surface to 185 feet. Los Angeles-Long Beach Harbor: DV1.

Giant kelpfish . . . . *Heterostichus rostratus* Girard
Cape San Lucas, Baja California to British Columbia. Surface to 132 feet. Los Angeles-Long Beach Harbor: BS, HLC, DV1.

Sarcastic fringehead. . . . . . . *Neoclinus blanchardi* Girard
Cedros Island, Baja California to San Francisco. 10 to 200 feet. Los Angeles-Long Beach Harbor: S4.

Yellowfin fringehead . . . . *Neoclinus stephensae* Hubbs
Point San Hipolito to Monterey 10 to 90 feet. Los Angeles-Long Beach Harbor: DV1 (sight record only).

Onespot fringehead . . . . *Neoclinus uninotatus* Hubbs
San Diego Bay to Bodego Bay. 10 to 90 feet. Los Angeles-Long Beach Harbor: BS, T10.

FAMILY BLENNIIDAE - Combtooth blennies

Rockpool blenny . . . . *Hypsoblennius gilberti* (Jordan)
Magdalena Bay, Baja California to Monterey. Intertidal to 80 feet. Los Angeles-Long Beach Harbor: HLA

Mussell blenny . . . *Hypsoblennius jenkinsi* Jordan & Evermann
Puerta Marquis, Mexico, to Coal Oil Point. Depth Intertidal to 70 feet. Los Angeles-Long Beach Harbor: BS.

FAMILY GOBIIDAE - Gobies

Longjaw mudsucker . . . . *Gillichthys mirabilis* Cooper
Gulf of California to Tomales Bay. Shallows of bays, mudflats. Los Angeles-Long Beach Harbor: S3.

Bay goby . . . . *Lepidogobius lepidus* (Girard)
Cedros Island, Baja California to Vancouver Island, B.C. Shallow bays and to 200 feet. Los Angeles-Long Beach Harbor: DV1, GN1, S4, T3-T11, T13, T14, T16, T17, Common.

Blackeye goby . . . . *Coryphopterus nicholsii* (Bean)
South of Point Rompiente, Baja California to Skidegate Channel, Queen Charlotte Is., B.C. 5 to 80 feet. Los Angeles-Long Beach Harbor: DV1, T4-T8, T11, T14, Common.

Arrow goby . . . . *Clevelandia ios* (Jordan & Gilbert)
Gulf of California to Vancouver Island, B.C. Shallow areas of bays. Los Angeles-Long Beach Harbor: Dipnetted in Fish Harbor: S2.

Chameleon goby . . . . . *Tridentiger trigonocephalus* (Gill)
Los Angeles Harbor and in San Francisco Bay. Shallow bay areas. Los Angeles-Long Beach Harbor: Not taken in this study (see Miller and Lea, 1972, pg. 186).

FAMILY SCOMBRIDAE - Mackerels & Tunas

Slender tuna . . . . *Allothunnis fallai* Serventy
Warm seas, mostly in southern hemisphere; north to Los Angeles Harbor. Depth: Inshore pelagic. Los Angeles-Long Beach Harbor: Not taken in this study (see Miller and Lea, 1972, pg. 194).

Wavyback skipjack* . . . . *Euthynnus affinis* (Cantor)
Indo-Pacific, north to Los Angeles Harbor on our coast. Epipelagic. Los Angeles-Long Beach Harbor: Not taken in this study (see Miller & Lea, 1972, pg. 192).

Pacific bonito . . . . *Sarda chiliensis* (Cuvier)
Chile to Gulf of Alaska. Epipelagic. Los Angeles-Long Beach Harbor: HLA, HLC, S1, S3, Common.

Pacific (Chub) mackerel . . . . . *Scomber japonicus* Houttuyn
Transpacific, in eastern Pacific, Chile to Gulf of Alaska. Surface to 150 feet. Los Angeles-Long Beach Harbor: S1.

Monterey spanish mackerel . . . . . *Scomberomorus concolor* (Lockington)
Gulf of California to Soquel. Nearshore pelagic fish. Los Angeles-Long Beach Harbor: BS.

FAMILY STROMATEIDAE - Butterfish

Pacific butterfish . . . . *Peprilus simillimus* (Ayres)
Magdalena Bay, Baja California to Fraser River, B.C. 30 to 300 feet. Los Angeles-Long Beach Harbor: BS, HLA, HLD, S1, S5, T12, T14, Common.

FAMILY SCORPAENIDAE - Rockfishes

Spotted scorpionfish . . . . *Scorpaena guttata* Girard
Uncle Sam Bank, Baja California to Santa Cruz. Shallow to 600 feet. Los Angeles-Long Beach Harbor: S1, S3, S4, T3, T9, Common.

Brown rockfish . . . . *Sebastes auriculatus* Girard
Hipolito Bay, Baja California to South East Alaska. Shallow to 180 feet. Los Angeles-Long Beach Harbor: T13 (only one fish taken in 46 trawls).

Calico rockfish . . . *Sebastes dallii* (Eigenmann & Beeson)
Sebastian Viscaino Bay, Baja California to San Francisco. 60 to 830 feet. Los Angeles-Long Beach Harbor: S4.

Chilipepper . . . . *Sebastes goodei* (Eigenmann & Eigenmann)
Magdalena Bay, Baja California to Vancouver Island. Surface to 660 feet. Los Angeles-Long Beach Harbor: T3, T8.

Vermilion rockfish . . *Sebastes miniatus* (Jordan & Gilbert)
San Benito Islands, Baja California to Vancouver Island, British Columbia. Shallow to 660 feet. Los Angeles-Long Beach Harbor: T3-T9, T16.

Blue rockfish . . . . *Sebastes mystinus* (Jordan & Gilbert)
Point Santo Tomas, Baja California to Bering Sea. Surface to 300 feet. Los Angeles-Long Beach Harbor: DV1 (sighted only, not taken in 46 trawls), S1.

Boccacio . . . . *Sebastes paucispinis* (Ayres)
Point Blanca, Baja California to Kodiak Island, Alaska. Surface to 1050 feet. Los Angeles-Long Beach Harbor: T3, T5-T8, T11, T12, Common.

Grass rockfish . . *Sebastes rastrelliger* (Jordan & Gilbert)
Playa Maria Bay, Baja California to Yaquina Bay, Oregon. Intertidal to 150 feet. Los Angeles-Long Beach Harbor: DV1, HLC, S1.

Flag rockfish . . . *Sebastes rubrivinctus* (Jordan & Gilbert)
Cape colnett, Baja California to Aleutian Islands. 100 to 600 feet. Los Angeles-Long Beach Harbor: T8 (only one fish taken in 46 trawls).

Striptail rockfish . . . . *Sebastes saxicola* (Gilbert)
Sebastian Viscaino Bay, Baja California to South East Alaska. 192 to 1320 feet. Los Angeles-Long Beach Harbor: T3, T5, T6, T7, T9, T12, Common.

Olive rockfish .*Sebastes serranoides* (Eigenmann & Eigenmann)
San Benito Island, Baja California to Redding Rock, Del Norte County. Surface to 480 feet. Los Angeles-Long Beach Harbor: DV1, GN1, T3-T9, T11, T13, T16, Common.

FAMILY HEXAGRAMMIDAE - Greenlings

Kelp greenling . . . . . . *Hexagrammos decagrammus* (Pallas)
La Jolla to Aleutian Islands, Alaska. Intertidal to 150 feet. Los Angeles-Long Beach Harbor: DV1, GN1.

Lingcod . . . . *Ophiodon elongatus* Girard
Point San Carlos, Baja California to Kodiak Island, Alaska. Surface to 1400 feet. Los Angeles-Long Beach Harbor: HLA.

FAMILY ZANIOLEPIDIDAE - Combfishes

Longspine combfish . . . . . . *Zaniolepis latipinnis* Girard
San Cristobal Bay, Baja California to Vancouver Island, B.C. 120 to 372 feet. Los Angeles-Long Beach Harbor: S4.

FAMILY COTTIDAE - Sculpins

Bonyhead sculpin . . . . *Artedius notospilotus* Girard
Point San Telmo, Baja California to Puget Sound. Intertidal to 150 feet! Los Angeles-Long Beach Harbor: BS, S4, T8.

Roughback sculpin. *Chitonotus pugetensis* (Steindachner)
Santa Maria Bay, Baja California. Intertidal to 465 feet. Los Angeles-Long Beach Harbor: S4, D&G.

TABLE 34(CONTINUED)

Wooly sculpin. . . . . *Clinocottus analis* (Girard) Asuncion Point, Baja California to Cape Mendocino. Intertidal to 60 feet. Los Angeles-Long Beach Harbor: DV1, GN1, S1, U&G.

Pacific staghorn sculpin. . . . *Leptocottus armatus* Girard San Quintin Bay, Baja California to Chignik, Alaska. Intertidal to 300 feet. Los Angeles-Long Beach Harbor: BS, HLA, S1, S3, T11, T12, T13, T14, Common.

Cabezon . . . . *Scorpaenichthys marmoratus* (Ayres) Point Abreojos, Baja California to Sitka, Alaska. Intertidal to 256 feet. Los Angeles-Long Beach Harbor: DV1, GN1, S1, S3.

FAMILY AGONIDAE - Poachers

Pygmy poacher . . . . *Odontopyxis trispinosa* Lockington Cedros Island, Baja California to South East Alaska. 30 to 1208 feet. Los Angeles-Long Beach Harbor: T3, T6-T9, T14, U&G.

Order Pleuronectiformes (Heterosomata)

FAMILY BOTHIDAE - Left-eye flounders

Pacific sanddab . . . . . . *Citharichthys sordidus* (Girard) Cape San Lucas, Baja California to Bering Sea. 30 to 1800 feet. Los angeles-Long Beach Harbor: T13 (only one fish taken in 46 bottom trawls), Rare, U&G.

Speckled sanddab . . *Citharichthys stigmaeus* Jordan & Gilbert Magdalena Bay, Baja California to Montague Island, Alaska. 10 to 1200 feet (?). Los Angeles-Long Beach Harbor: BS, S3, T2-T14, T16, Common, U&G.

Longfin sanddab . . . . . *Citharichthys xanthostigma* Gilbert Costa Rica to Monterey Bay. Depth 8 to 44 feet. Los Angeles-Long Beach Harbor: BS, U&G.

Rex sole . . . . *Glyptocephalus zachirus* Lockington San Diego trough to Bering Sea. Depth 60 to 2100 feet. Los Angeles-Long Beach Harbor: BS.

Bigmouth sole . . *Hippoglossina stomata* (Eigenmann & Eigenmann) Gulf of California to Monterey Bay. 100 to 450 feet. Los Angeles-Long Beach Harbor: S4, T6, T9, T10.

California halibut . . . . *Paralichthys californicus* (Ayres) Magdalena Bay, Baja California to Quillayute River, B.C. Surface to 300 feet. Los Angeles-Long Beach Harbor: BS, HLA, HLE, S1, S3, T3, T4, T6, T7, T8, T10-T14, G16 U&G, Common.

Fantail sole . . . . . *Xystreurys liolepis* Jordan & Gilbert Gulf of California to Monterey Bay. 15 to 260 feet. Los Angeles-Long Beach Harbor: BS, S4, T9, T10, T11, T13, T14, U&G.

FAMILY PLEURONECTIDAE - Right-eye flounders

Petrale sole . . . . *Eopsetta jordani* (Lockington) Los Coronodos Islands, Baja California to Gulf of Alaska. 60 to 1500 feet. Los Angeles-Long Beach Harbor. S4.

Diamond turbot . . . . *Hypsopsetta guttulata* (Girard) Magdalena Bay, Baja California to Cape Mendocino. 5 to 150 feet. Los Angeles-Long Beach Harbor: BS, S3, S4, T9, T10, T14, U&G.

English sole . . . . *Parophrys vetulus* Girard San Cristobal Bay, Baja California to North West Alaska. 60 to 1000 feet. Los Angeles-Long Beach Harbor: BS, S3, S4, T3, T4, T6, T9-T11, T14, U&G.

C-O turbot. . . . . *Pleuronichthys coenosus* Girard Cape Colnett, Baja California to South East Alaska. Shallow to 210 feet. Los Angeles-Long Beach Harbor: BS, Rare.

Curlfin turbot . . . *Pleuronichthys decurrens* Jordan & Gilbert San Quintin Bay, Baja California to North West Alaska. 60 to 1140 feet. Los Angeles-Long Beach Harbor: BS, S3, S4, T6-T11, T13, T14, Common.

Spotted turbot. . . . *Pleuronichthys ritteri* Starks & Morris Magdalena Bay, Baja California to Point Conception. 4 to 150 feet. Los Angeles-Long Beach Harbor: BS, S4, G9 (only one fish taken in 46 bottom trawls), U&G.

Hornyhead turbot. . *Pleuronichthys verticalis* Jordan & Gilbert Madgalena Bay, Baja California to Point Reys. 30 to 612 feet. Los Angeles-Long Beach Harbor: BS, S1, S3, S4, T2-T14, U&G.

FAMILY CYNOGLOSSIDAE - Tonguefishes

California tonguefish. . *Symphurus atricauda* (Jordan & Gilbert) Cape San Lucas, Baja California to Big Lagoon, Humboldt County. 5 to 276 feet. Los Angeles-Long Beach Harbor: BS, S3, S4, T2-T14, T16, T17, Common, U&G.

G. IMPACT OF THE SANSINENA OIL SPILL ON THE CABRILLO BEACH AREA

INNER CABRILLO BEACH

INTRODUCTION

Inner Cabrillo Beach lies southwest of the site of the explosion of the *Sansinena*, across the shipping channel. The beach is the only remaining area of intertidal sand inside Los Angeles Harbor in San Pedro. The site is a popular recreation area used for swimming, boating, water skiing, fishing, clam digging, and picnicking.

Except for pilings, docks, and the rocks of the main breakwater and jetties, inner Cabrillo Beach was the only intertidal area to receive a large part of the spilled oil from the explosion of the *Sansinena* on December 17, 1976. The observations recorded in this paper present the changes in the flora and fauna at the beach during the year following the spill and suggest ways the biota may have been affected by the oil and tar.

METHODS OF STUDY

Observations of the area began on January 9, 1977 and continued until December 8, 1977 during tides of +2 to -2 feet. Occurrences of oil and tar, plants and animals smeared by tar, dead animals cast ashore, and locations of drift algae were recorded. Lists of readily observable plants and animals in the intertidal zone were maintained for six areas (Figure 103); the cobble(A), from the boulders of the main breakwater to the stretch of sand and cobble at the low water mark; the bend (B), the sand and rocks across from the Cabrillo Marine Museum; the beach (C), along the main parking lot; both sides of the south jetty by the floating dock (D); the rocks and sand by the floating dock (E); and Sea Scout Beach (F), in front of the Cabrillo Beach Sea Scout Base. Notes were made on any obvious increases or declines in the plants and animals, runoff of fresh water, and movements of sand. Voucher specimens of polychaetes, sponges, algae, and bryozoans were collected for identification. Color slides of the marine life and the beach were taken for reference at irregular intervals.

DESCRIPTION OF THE BEACH

Five substrates are present at inner Cabrillo Beach. The inner side of the main breakwater consists of large, hard boulders exposed to the wind chop of the harbor. The jetties contain smaller stacked rocks protected from much action of waves. Cobble (smaller scattered rocks) occurs along the breakwater toward the Cabrillo Marine Museum. The main beach and the intertidal zone below the rocks consist of fine sand, shell chips and a few pebbles with a light covering of silt. At the -2.0 foot tide level, a bottom of sand and clay is exposed near the bend.

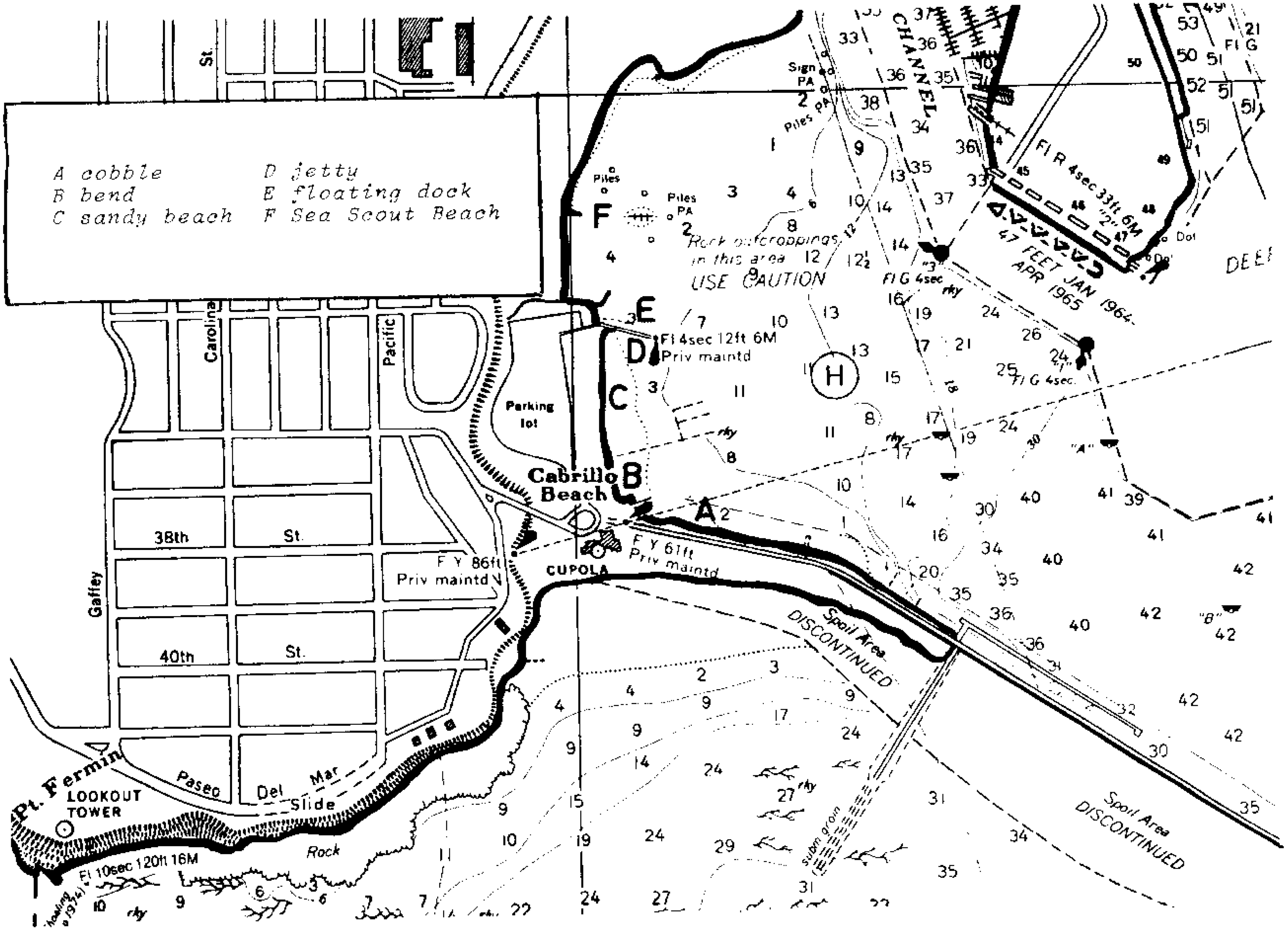


Figure 103. Site of Sansinena Incident (upper right) and Cabrillo Beach.

Although inner Cabrillo Beach is sheltered from the usual ocean waves by the breakwater, the beach is subject to frequent erosion and deposition of sand. During windy days, waves about 1 m high can break on the beach, eroding the sand and exposing shells and buried rocks. Gusty winds dry the sand and blow it into the harbor. During quiet weather, the sand accumulates in drifts. Winter storms can change the profile of the beach extensively (Straughan, 1975).

RESULTS

Oil, Tar, and Other Petroleum Residues

Prior to the explosion of the *Sansinena*, inner Cabrillo Beach occasionally received oil and tar from other parts of the harbor (Straughan, 1975). Oil slicks often were noticed near the boat launching dock, where recreational craft were used. Other possible sources of oil products were recreational marinas in the west harbor area, a small boat repair yard, a Navy oiler terminal and a landing for commercial sport fishing boats. Oil also may have been carried from the main channel on changing tides.

Following the explosion, shiny, iridescent oil slicks were seen at the beach on every day on which observations were made. Tar (black, sticky material) was observed as a thick, black smear across rocks of the upper intertidal zone after the initial spill and as small blobs on the sand during later months. On the beach behind piles of drift algae or in tide pools with slow circulation, a bubbly brown residue ("chocolate mousse") floated on water.

The distribution of the different petroleum residues varied from day to day (Table 35). The tar of the initial spill dried and hardened on the upper rocks, turning rusty in color at the highest tide level by August. Tar on the lower surfaces of rocks, however, collected floating debris and stayed sticky and black until November of 1977. Although the scraping of wind and waves removed much tar on exposed rocks, protected cracks and lower surfaces remained smeared throughout the period of study (Figure 2).

From January 1977 until early December the petroleum products at Cabrillo Beach seemed to dry out or be buried by sand. After windy days or rain storms, oil slicks and tar blobs were more noticeable than after periods of calm weather, although some oil always could be found at the bend. The tar on the upper rocks, except in sheltered spots, dried and was scraped away. In December, however, the entire beach was contaminated by extensive oil slicks, tar blobs, and "chocolate mousse," although there were no storms and few windy days during that part of the month. This new contamination coincided with operations using a pile driver to build a new dock at the site of the explosion, but there may have been other, unidentified sources contributing to the contamination.

Dredging during March, 1977 scooped sand from near the floating dock and dumped it on the upper beach. The dredging cleared the launching ramp until about September, by which time the dredge tailings had dried out, been blown by the wind and eroded by small waves, and had been swept over the jetty back into the boat launching area. Drifts of sand over 2 m high were noticed along the south jetty in November.

During 1977, rain was scant. Run-off of fresh water at the beach was confined to a channel along the south end of Sea Scout Beach, where water from the boat cleaning area ran into the harbor. During a short storm in August, fresh water also ran down the beach near both of the lifeguard towers.

During the period of study, the temperature of the water ranged from 56-70°F (12-20°C), with a temperature of 15°C being most common. The water usually contained floating particles and silt which reduced visibility to about one meter at best.

Plants and Animals

Different associations of plants and animals occur at inner Cabrillo Beach according to the tidal height and the substrate. The biota of the main breakwater is typical of a protected outer coast (Ricketts, Calvin, and Hedgpeth, 1969). The barnacles *Balanus glandula, Chthamalus fissus,* and *Tetraclita squamosa rubsecens* are common, as are acmaeid limpets (*Collisella digitalis* and others), striped shore crabs (*Pachygrapsus crassipes*), and aggregated sea anemones (*Anthopleura elegantissima*). On the cobble, plants and animals of quieter waters occur, such as branched bryozoans (*Bugula neritina*), brown slipper shells (*Crepidula onyx*), and rock crabs (*Cancer anthonyi*). The hermit crab *Pagurus hirsutiusculus*, which tolerates silty water well, can be found by the hundreds here.

The sand has been found to contain between 26 and 31 species of segmented worms of the class Polychaeta (Straughan and Patterson, 1975; Straughan, 1975). Although only seven species were identified from the beach in 1977, dimples and marks of feeding on the sand indicated that others, too small or too deeply buried to be collected, also were present.

In the lower intertidal zone of the sandy areas, gaper clams (*Tresus nuttalli*) and hermit crabs (*Isocheles pilosus*) can be found. The snails *Olivella biplicata* and *Nassarius fossatus* plow through the sand. Small crustaceans (cumaceans and gammarid amphipods) can be common in pools.

The jetties, protected from much wave action, often have silt on the rocks. The flora and fauna of these rocks tend to be less diverse than those of the cobble except at the lowest tidal zones, where a thriving association of red algae (*Neoagardhiella baileyi* and *Gigartina* spp.), tube mollusks (*Serpulorbis squamigerus*) and bryozoans (*Bugula neritina, Watersipora arcuata,* and *Cryptosula pallasiana*) can be found.

On the floating dock, a fauna typical of protected piles (Ricketts et al., 1969) can be found. Great masses of bay mussels (*Mytilus edulis*), tunicates (*Ciona intestinalis*), bryozoans (*Bugula neritina*), and fine red algae (*Polysiphonia* sp.) live on the lower surfaces of the docks.

Birds rest and feed along inner Cabrillo Beach. On the harbor waters, Forster's terns, brown pelicans, and eared grebes hunt for fish. Sanderlings, willets, black-bellied plovers, and marbled godwits forage along the sand. Hundreds of gulls often rest on Sea Scout Beach. Pigeons, crows, and barn swallows feed along the beach. Feral cats sometimes chase the birds or scavenge along the beach, as do the rats that live among the rocks of the breakwater.

Changes in the Plants and Animals

Observers on a boat and along the shore on December 20, the third day after the accident, reported seeing gulls with tar on their feet. Many birds near the Sea Scout base were feeding with no apparent difficulty, however. One or two grebes were reported to have died from oiling following the explosion and fire.

In January 1977 most of the barnacles, limpets and mussels of the main breakwater were coated by tar. The shells of the dead animals remained in place, still anchored by their own attachment or stuck in the tar. Moribund crabs (*Pachygrapsus crassipes* and *Cancer anthonyi*) lay in the lower intertidal zone. On the sand, dead and dying hermit crabs (*Isocheles pilosus*) were found either glued inside their shells by tar or fouled on their respiratory appendages by the sticky material. The isopod *Ligia occidentalis*, which could be found in swarms of hundreds on rocks prior to the spill, was nowhere to be seen on the inner beach.

By March, many of the dead shells had been scraped off the rocks by wind and surf. A vigorous settlement of tiny barnacles, small snails (*Littorina* spp.) and acmaeid limpets (*Collisella digitalis* and others) was observed in tar-free places. By June, most of the scraped areas were repopulated either by the animals or by the algae *Ulva* sp. and *Enteromorpha* sp. which rapidly colonize disturbed areas (Reish, 1964 and 1977).

The biota observed at the beach by July was similar to that observed prior to the spill except for the absence of *Ligia occidentalis* in its former habitats. By this time, the green alga *Ulva* sp. had created a thick green covering over the rocks. Large sea hares (*Aplysia californica*) and striped shore crabs fed on this and other algae.

Toward the end of August, *L. occidentalis* was seen in all the rocky areas of the beach, although only at the bend and near the cobble was it conspicuous. During the same time, the species occurred in swarms on outer Cabrillo Beach, on the seaward side of the main breakwater, which was not affected by the spill. The green alga *Ulva*, common throughout the rocky zones, began to turn yellow and die off.

By late October, the *Ulva* had been reduced to small tufts. Much of the dense growth of red algae had died back in the lower intertidal zone. The rocks of the upper intertidal zone bore a thick covering of large, healthy-looking barnacles and limpets except in cracks or in crevices, where thick tar remained. *Bugula neritina* and *Watersipora arcuata* became very widespread on protected rocks.

Throughout this time, rocks periodically covered by sand bore organisms that appeared adapted for short lives on rocks exposed from sand. The hydroid *Tubularia crocea* and the brown alga *Taonia lennebackeriae* were found on exposed rocks in sandy regions of the low tidal zone. Their appearance coincided with erosion that exposed rocks in the sandy areas.

In December, *Bugula neritina* became less common. Silt covered rocks in the lower intertidal zone. Dead and dying hermit crabs (*Isocheles pilosus*) were found in the oil-smeared sand at the bend. The fauna of the intertidal zone appeared much the same as before the spill, except for the continuing lack of life in the tar-mired cracks and overhangs, the relatively low numbers of *L. occidentalis*, and the hard tar clinging to the shells of barnacles and limpets that survived the initial spill. Complete lists of the organisms observed at the beach and the dates of their occurrences can be found in Tables 36 and 37.

DISCUSSION AND CONCLUSIONS

The most obvious effect of the spill on the beach, the miring by tar of invertebrate organisms, was most serious immediately after the spill. The scouring action of natural processes appears to have removed much of the tar and weathering has dried it. Barnacles and other sessile organisms were able to resettle previously mired areas after the tar was scraped off.

The oil on the beach may have killed animals inhabiting the sand. Unfortunately, sampling of deep burrowing animals could not be done to compare the fauna with that reported previously by Straughan (1975) and Straughan and Patterson (1975). Removal of several feet of sand by bulldozers in cleanup operations, continuing dislocations of the sand due to winds and waves, and deposition of drifts of rotting *Ulva* sp. up to a meter high might have affected the fauna as much as or more than the deposition of oil. Harpacticoid copepods and polychaetes were abundant even under the "chocolate mousse" on the beach.

The death of the hermit crabs (*I. pilosus*) and the other crabs found on the beach after the spill and in December, 1977 may have been due to fouling of the respiratory apparatus. These crustaceans maintain a flow of water across their gills by rapid flicking of appendages in the mouth region. If these appendages cannot move, the crab suffocates. At least four of the hermit crabs found in January had the entire mouth region smeared with tar.

Barnacles, limpets, and mussels of the upper intertidal zones were probably killed by several means after miring by tar. The tar may have sealed off respiratory passages in the animals, preventing flow of oxygen to their bodies. A tight seal of tar prevented some barnacles and mussels from opening their shells. Barnacles are known to suffer from increased stress of heat (the black body effect) when their shells are coated by black tar (Straughan, 1976). The combination of the physical effects and the toxic effects of various fractions in the oil and tar killed hundreds of these sessile animals and probably was responsible for the die-off of *Ligia* *occidentalis* on the inner beach while they survived on the outer beach.

The die-off of *Ligia occidentalis* might have contributed to the accumulation of rotting algae in drifts on the beach in spring and early summer of 1977. *Ulva* and *Enteromorpha* can grow rapidly in harbors, break off, die and decompose. In the absence of herbivores, the decomposing algae can cause odors and sometimes depletion of the dissolved oxygen in areas of reduced circulation of water (Reish, 1977). Although flies, sea hares, and striped shore crabs probably fed on the algae, *Ligia* is one of the most active herbivores of the upper intertidal zone. A single average *Ligia* may consume .0384 grams of brown algae (*Sargassum* sp.) per day. Since about 315 of these isopods can occur in one square meter of a favorable beach, the amount of algae consumed by these animals can be considerable (R. Brusca, pers. comm.).

The resumption of disturbances in the explosion site by the pile driving appears to have dislodged remains of tar that escaped the cleanup operations and settled on the bottom near the site of the wreck. This new dispersion of oil and tar could create further problems for the marine life by miring it, exposing it to harmful chemicals, or creating stressful situations that could prevent the organisms from spawning. New disturbances by dredging, churning by ships' propellers, storms and hot weather could cause blobs to surface and form slicks on the rocks and sand. Allowing the tar residue to dry and be scraped off the breakwater, rocks, and pilings by natural processes and letting the normal siltation of the harbor cover the tar and oil on the bottom seem to be the best means to allow the area to return to "normal" conditions.

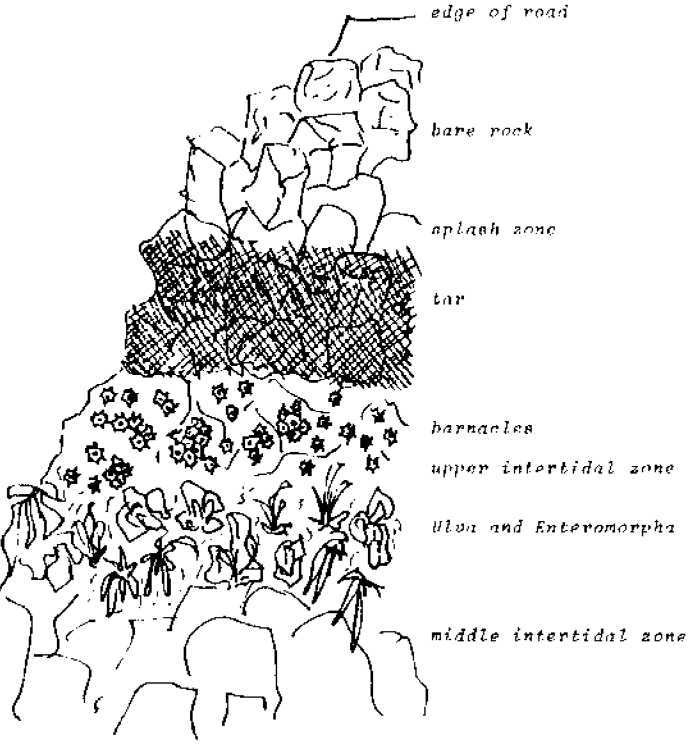
No serious effects of the usual slicks on the biota have been detected. The flora and fauna appear to be normally diverse and numerous following recovery from the accident.

NOTES ON EFFECTS OF THE OIL SPILL ON CRABS AT CABRILLO BEACH

A qualitative survey was made on January 15, 1977 during a low tide, along the inside beach at Cabrillo Beach, near the Cabrillo Museum in San Pedro. Abnormal behavior and casualties caused by the oil spill were noted in four species of anomuran and brachyuran crustaceans. Most obvious was damage to the sand-dwelling hermit crab, *Isocheles pilosus*. These animals, studied at this location during 1976, normally live in soft sand from the 0.0 foot tide level to about 25 feet deep. During low tides when they are dislodged from the sand by light surf, they are carried up the beach, but are able to return to their habitat by running or by using the chelipeds and walking legs to bury themselves and their shells in the sand within 20 seconds (Wicksten, unpubl. manuscript). Of 10 hermit crabs found on this date, two were dead, and completely "glued" in their shells by a thick coating of sticky black tar which filled the apertures of the shells. Five others had patches of tar on the eyes, antennae, chelipeds, walking legs and maxillipeds. These five wiggled when picked off the sand, but were unable to bury themselves when set on the sand. Three of these five died within 24 hours after collection. One other crab had a light smear of tar on the chelipeds, but could bury itself normally and survived up to present. Another two had no tar, buried themselves normally, and also survived.

The crabs coated with tar were observed trying to scrape it off with the walking legs, chelipeds, and maxillipeds. They were not successful - one was seen with the endopodites of the third maxillipeds stuck together.

As is normal during winter, dead post-reproductive adults of *Pugettia producta, Cancer anthonyi,* and *C. antennarius* were found cast ashore. However, at least five dead *Pachygrapsus crassipes* were seen, as well as live subadult *Cancer antennarius* and *C. anthonyi* in the mid-intertidal zone. One rarely finds subadults of the genus higher than the low intertidal zone, and then half-buried in sand. These crabs were sitting, poorly covered, under rocks. Large adult *Pachygrapsus crassipes* were found under cobble in the low intertidal zone, where they usually are not encountered. Considering that the nearest rocks in the higher intertidal zones, where one usually finds *Pachygrapsus*, were thickly coated with tar, the crabs may have moved to escape the tar.



Text Figure 2. Sketch of Breakwater near Cobble, April 17, 1977.

OBSERVATIONS ON THE BIOTA OF THE CABRILLO FISHING PIER: 1977

INTRODUCTION

The Cabrillo Fishing Pier is located 0.5 mile from the Marine Museum at Cabrillo Beach, San Pedro, California. It lies almost directly south of the site of the explosion of the Sansinena. The pier is available to the public for hook and line fishing and using traps to catch crabs.

METHODS OF STUDY

Observations of the organisms present and their depths of occurrence were made while SCUBA diving on February 18, February 20, and August 26, and by snorkeling on June 29. Notes were made of any oil or tar present and possible effects of them on marine organisms. Color slides of conspicuous organisms were taken for reference with a Nikonos II camera, close-up lens, and Nikonos flash attachment.

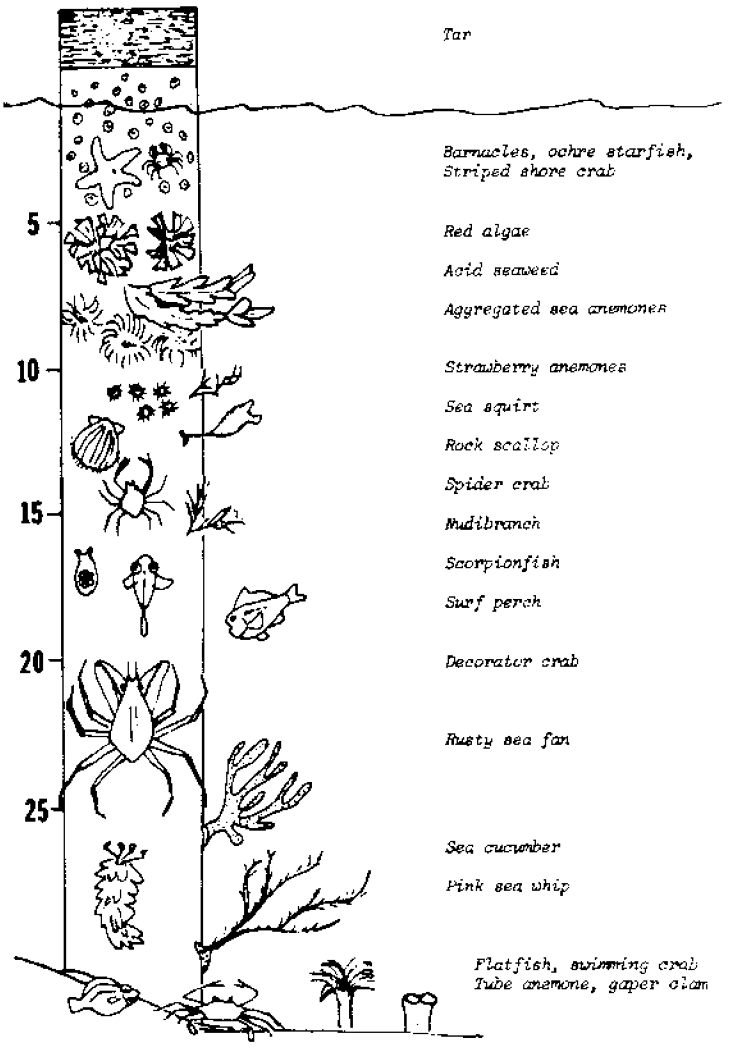
RESULTS

The pilings of the pier rise from a sloping sandy bottom at depths of eight to 28 feet, the end toward the Marine Museum (the west end) being the shallower one. The only petroleum residues seen on the pilings was a thick coating of sticky black tar at the high tide level. Under the tar were empty shells of barnacles (*Balanus glandula*) and bay mussels (*Mytilus edulis*), although most of the tarred zone was free of either live animals or dead shells. No evidence of resettlement of the tarred zone by plants or animals was seen during the period of study.

Below the water level, the piles normally support a biota typical of protected piles (Ricketts, Calvin, and Hedgpeth, 1969). In the first five feet under the water, barnacles (*Balanus glandula*), striped shore crabs (*Pachygrapsus crassipes*), and ochre starfish (*Pisaster ochraceus*) are common. At about five feet, red algae, a brown alga (*Desmarestia* sp.), and aggregated sea anemones (*Anthopleura elegantissima*) occur. At 10 to 20 feet, a diverse association can be found of strawberry anemones (*Corynactis californica*), hydroids (*Obelia* sp. and others), rock scallops (*Hinnites multirugosus*), spider crabs (*Pugettia richii* and *Scyra acutifrons*), nudibranchs (*Polycera atra* and others), tunicates (*Styela montereyensis* and others), and small fish (*Gibbonsia* sp., small *Scorpaena guttata* and others). At depths of 20 feet or more, gorgonians (*Muricea californica* and *Lophogorgia chilensis*), decorator crabs (*Loxorhynchus crispatus*), and sea cucumbers (*Parastichopus parvimensis*) live. The sandy bottom below the pilings is inhabited by tube anemones (*Pachycerianthus* sp.), swimming crabs (*Portunus xantusii*), terebellid worms, gaper clams (*Tresus nuttalli*), green paper bubble shells (*Haminoea virescens*), and flatfishes (family Pleuronectidae). A complete list of plants and animals observed during the dives in 1977 is given in Table 3.

Observations of the fauna of the pilings during previous years suggest that much of the motile fauna moves from piling to piling, from pilings to other hard substrates, or across the sand. Opisthobranchs (nudibranchs, green paper bubble shells, and the California Navanax) may be seen by the hundreds during one dive and then be absent on the next, possibly in response to the supply of their particular prey. Their absence during one particular day of diving, therefore, probably is due to normal movements rather than to oil pollution.

Except for the barnacles and mussels of the upper intertidal zone, the attached fauna of the piling showed no effect of the oil or tar. However, many of these animals feed on particulate material suspended in the water. Contamination of the water by petroleum products could result in these organisms becoming saturated with hydrocarbons. This could create stressful conditions that would interfere with the normal life processes of the animals. Detailed studies of these animals would be necessary before one could say whether they and the organisms that prey on them are harmed by petroleum residues.



Text Figure 3. Vertical Distribution of Biota on Piling.

Table 35. Petroleum Residues at Inner Cabrillo Beach

1977	Cobble	Bend	Beach	Jetty	Launch Area	SeaScout Beach
Jan 15	Xt		Xt	Xt	Xt	
Mar 6						
13						
Apr 14	Xt,o	Xc,o			Xt	
17	Xt,o	Xc,o				
May 1	Xt	Xo		Xt	Xt	Xt
6						
13	Xt	Xo				
15	Xt	Xo			Xt,o	
22	Xt	Xt,o			Xo	Xt,o
26					Xo	
29	Xt	Xt,o			Xt	
Jun 4	Xt,o	Xc,o	Xo			
5		Xo	Xo			Xo
19	Xt	Xt,o	Xo		Xt	
25	Xt,o	Xt,o	Xt,o		Xo	
Jul 17	Xt	Xc,o	Xo		Xt	
23	Xt	Xc,o	Xo	Xt	Xo	
29	Xt	Xc,t,o				
Aug 2	Xt	Xo			Xt,o	Xt
18		Xc,o	Xt,o		Xo	Xt,o
28	Xt	Xo				
Sep 10	Xt	Xo				
25	Xt,o	Xc,o		Xt		Xt
Oct 9	Xt	Xo	Xt,o		Xt	Xt,o
13		Xc,o				
15		Xo				
25		Xo	Xo		Xt,o	
Nov 11	Xt	Xt,o	Xo			Xo
20	Xt	Xt,o	Xc,o		Xt	Xt,o
Dec 8	Xc,t,o	Xc,t,o	Xc,t,o	Xt,o	Xt,o	Xo

c = chocolate mousse
t = tar
x = residue present
o = oil

Table 36

Species of Plants and Animals at Inner Cabrillo Beach

	Tidal range	Substrate
PLANTS		
Chlorophycophyta: green algae		
Bryopsis sp.	L	R
Chaetomorpha sp.	M	R
Enteromorpha sp.	H	R
Ulva sp.	L-H	R
Phaeophycophyta: brown algae		
Desmarestia sp.	L	R
Egregia menziesii	L	R
Sargassum sp.	L	R
Taonia lennebackeriae	L	R
Rhodophycophyta: red algae		
Gigartina leptorhynchos	L-M	R
Gigartina spinosa	L-M	R
Iridaea sp.	L	R
Neoargardhiella baileyi	L	R
Porphyra sp.	M-H	R
Rhodoglossum affine	M	R
Microalgae (unidentified)	L-M	R
ANIMALS		
Porifera: sponges		
Haliclona ecbasis	L	R
Hymeniacidon sinapium	L	R
Coelenterata		
Class Hydrozoa: hydroids		
Hydroidea, unidentified	L	R
Obelia sp.	L	R
Tubularia crocea	L	R

Key:

L: low tide M: mid-tide H: high tide R: rocks or other hard substrates S: sand

Table 36 (Continued)

Class Anthozoa: sea anemones		
Anthopleura elegantissima	M	R
Pachycerianthus sp.	L	S
Platyhelminthes: flatworms		
Unidentified species	L	R
Annelida: segmented worms		
Cirratulidae	L	S
Capitellidae	L	S
Diopatra ornata	L	S
Eupomatus gracilis	L	R
Halosydna tuberculifer	L	R
Lumbrineris sp.	L	S
Nepthys ferruginea	L	S
Nereis latescens	L	S
Pectinaria californiensis	L	S
Phragmatopoma californica	M	R
Platynereis bicanaliculata	L	S
Spiochaetopterus costarum	L	S
Mollusca: shelled animals		
Class Gastropoda		
Acanthina spirata: unicorn snail	L-M	R
Amphissa sp.: dove shell	L	R
Aplysia californica: sea hare	L	R
Collisella digitalis: finger limpet	H	R
Collisella limatula: file limpet	M	R
Collisella scabra: rough limpet	H	R
Crepidula onyx: brown slipper shell	L	R
Crepidula perforans?: flat slipper shell	L	R
Crepipatella lingulata: half slipper shell	L	R
Dialula sandiegensis: nudibranch	L	R
Haminoea virescens: green paper bubble shell	L	R,S
Hermissenda crassicornis: opalescent nudibranch	L	R
Littorina planaxis: flat periwinkle	H	R
Littorina scutulata: checkered periwinkle	H	R
Mitrella carinata: keeled dove shell	L	R
Nassarius fossatus: basket whelk	L	S
Ocenebra poulsoni: dwarf triton	L	R
Olivella biplicata: olive shell	L	S
Polycera atra: nudibranch	L	R
Serpulorbis squamigerus: tube snail	L	R
Tegula funebralis: black turban snail	H	R
Tegula gallina: checkered turban snail	H	R
Triopha grandis: nudibranch	L	R

Table 36 (Continued)

Class Amphineura: chitons		
Cyanoplax hartwegii	M	R
Mopalia muscosa	L-M	R
Class Pelecypoda		
Amiantis callosa: white clam	L	S
Chama pellucida: jewel box shell	L	R
Clinocardium nuttalli: Nuttall's cockle	L	S
Hiatella arctica: nestling clam	L	R
Hinnites multirugosus: rock scallop	L	R
Macoma secta: white sand macoma	L	S
Mytilus edulis: bay mussel	L-M	R
Protothaca staminea: rock cockle	L	R,S
Tellina idae: Ida's tellin	L	S
Tivela stultorum: Pismo clam	L	S
Tresus nuttalli: gaper clam	L	S
Zirfaca pilsbryi: rough piddock	L	clay
Arthropoda: joint-legged animals		
Class Crustacea		
Balanus glandula: acorn barnacle	H	R
Balanus pacificus: barnacle	L	R
Balanus tintinnabulum: striped barnacle	L	R
Betaeus longidactylus: visored shrimp	L	R
Cancer antennarius: rock crab	L	R
Cancer anthonyi: yellow rock crab	L	R
Cancer gracilis: graceful rock crab	L	S
Caprella californica: skeleton shrimp	L	R
Caprella laeviuscula: skeleton shrimp	L	R
Caprella mendax: skeleton shrimp	L	R
Chthamalus fissus: buckshot barnacle	H	R
Cumacea	L	S
Exosphaeroma inornata: isopod	L	R
Cirolana harfordi: isopod	M	R
Gammaridea: beach hoppers	L-M	R,S
Harpacticoida	L-M	S
Hemigrapsus oregonensis: bay shore crab	L-M	R
Heptacarpus pictus: broken back shrimp	L	R
Isocheles pilosus: hermit crab	L	S
Ligia occidentalis: isopod	H	R
Loxorhynchus grandis: sheep crab	L	R
Pachycheles rudis: porcelain crab	L	R
Pachygrapsus crassipes: striped shore crab	M-H	R
Pagurus granosimanus: hermit crab	L	R
Pagurus hirsutiusculus: hermit crab	L	R
Pagurus samuelis: hermit crab	L-M	R
Petrolisthes cabrilloi: porcelain crab	L-M	R

Table 36 (Continued)

Class Crustacea		
Portunus xantusii: swimming crab	L	S
Pugettia producta: kelp crab	L	R
Tetraclita squamosa: red barnacle	M	R
Class Insecta		
Diptera: flies	H	R,S
Hymenoptera: ants	H	R
Class Pycnogonida: sea spiders		
Ammothea hilgendorfi	L-M	R
Phylum Entoprocta: nodding moss animals		
Barentsia sp.	L	R
Phylum Bryozoa: moss animals		
Bowerbankia gracilis	L	R
Bugula californica	L	R
Bugula neritina	L	R
Celleporaria brunnea	L	R
Cryptosula pallasiana	L	R
Watersipora arcuata	L-M	R
Echinodermata: spiny-skinned animals		
Class Asteroidea: starfish		
Pisaster ochraceus: ochre starfish	L	R
Class Echinoidea: sea urchins		
Strongylocentrotus franciscanus: long-spined red sea urchin	L	R
Strongylocentrotus purpuratus: purple sea urchin	L	R
Class Holothuroidea: sea cucumbers		
Parastichopus parvimensis	L	S
Chordata		
Class Ascidacea: tunicates		
Botrylloides sp.	L	R
Ciona intestinalis	L	R
Styela plicata	L	R

Table 36 (Continued)

Class Pisces: fishes	
Atherinidae: top smelt	L
Clinocottus analis: wooly sculpin	L
Cottidae: sculpins	L
Embiotocidae: surfperches	L
Leuresthes tenuis: grunion	H
Class Aves: birds	
Actitis macularia: spotted sandpiper	
Aechmophorus occidentalis: western grebe	
Arenaria inerpres: ruddy turnstone	
Catoptrophorus semipalmatus: willet	
Corvus brachyrhynchos: common crow	
Crocethia alba: sanderling	
Gavia immer: common loon	
Hirundo rustica: barn swallow	
Hydroprogne caspia: Caspian tern	
Larus delawarensis: ring-billed gull	
Larus heermanni: Heermann's gull	
Larus philadelphia:Bonaparte's gull	
Limosa fedoa: marbled godwit	
Megaceryle alcyon: belted kingfisher	
Numenius americanus: long-billed curlew	
Pelecanus occidentalis: brown pelican	
Podiceps caspicus: eared grebe	
Squatarola squatarola: black-bellied plover	
Stercorarius parasiticus: parasitic jaeger	
Sterna albifrons: least tern	
Sterna forsteri: Forster's tern	
Class Mammalia: mammals	
Felis domestica: cat	
Rattus sp.: rat	

Table 37. Intertidal Organisms at Inner Cabrillo Beach, 1977.

ORGANISM	Jan.	March		April		May							June				July			August			Sept.		October				Nov.		Dec
	15	6	13	14	17	1	6	13	15	22	26	29	4	5	19	25	17	23	29	2	18	28	10	25	9	13	15	25	11	20	8
PLANTS																															
CHLOROPHYCOPHYTA																															
Bryopsis sp.											+																				
Chaetomorpha sp.																		+	+			+	+	+	+	+		+		+	+
Enteromorpha sp.					+	+		+	+	+		+	+		+	+	+	+	+	+	+	+	+	+							
Ulva sp.		+		+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
PHAEOPHYCOPHYTA																															
Desmarestia sp.				+		+																									
Egregia menziesii											+		+	+		+															
Sargassum sp.														+																	
Taonia lennebackeriae		+																									+		+		
RHODOPHYCOPHYTA																															
Gigartina spp.		+				+			+			+	+	+	+		+	+	+	+	+		+	+	+	+	+	+	+	+	+
Iridaea sp.												+			+																
Neoagardhiella baileyi		+			+	+						+	+	+	+				+		+	+		+	+	+	+	+			+
Porphyra sp.				+		+			+			+				+	+	+	+				+								
Rhodoglossum affine													+						+		+		+	+	+	+		+			
Microalgae (unident.)															+	+	+	+	+					+						+	
ANIMALS																															
PORIFERA																															
Haliclona ecbasis																										+	+	+			+
Hymeniacidon sinapium																												+			
COELENTERATA																															
Hydroidea (unident.)															+												+		+	+	
Obelia sp.																												+			
Tubularia crocea			+												+	+	+			+		+		+				+			
Anthopleura elegantissima				+	+	+				+	+	+	+	+	+	+	+	+	+	+		+	+	+	+		+	+	+	+	+
Pachycerianthus sp.														+																	
PLATYHELMINTHES																										+					

Table 37 (continued)

ORGANISM	Jan	March		April		May							June				July			August			Sept.		October				Nov.		Dec
	15	6	13	14	17	1	6	13	15	22	26	29	4	5	19	25	17	23	29	2	18	28	10	25	9	13	15	25	11	20	8
ANNELIDA																															
Polychaeta																															
Cirratulidae													+														+		+		+
Capitellidae																											+				
Diopatra ornata						+							+		+											+			+		+
Eupomatus gracilis									+				+	+	+	+	+			+	+	+	+	+	+	+	+	+	+	+	+
Halosydna tuberculifer											+			+	+	+											+	+	+	+	
Lumbrineris sp.																													+		
Nephtys ferruginea																											+		+		+
Nereis latescens																											+				
Pectinaria californiensis																													+		
Phragmatopoma californica									+			+					+					+		+	+	+			+		
Platynereis bicanaliculata																													+		
Spiochaetopterus costarum																													+		
MOLLUSCA																															
Gastropoda																															
Acanthina spirata				+								+	+	+	+	+		+		+	+	+		+	+	+	+	+	+	+	+
Amphissa sp.																											+				
Aplysia californica		+	+	+		+		+	+	+			+		+																
Collisella digitalis				+	+			+	+	+		+				+	+	+	+	+	+	+	+	+	+			+	+	+	+
Collisella limatula				+								+		+			+	+	+			+	+	+	+			+		+	+
Collisella scabra																						+	+					+		+	
Crepidula onyx			+										+	+	+											+	+	+	+		+
Crepidula perforans																													+		
Crepipatella lingulata														+													+		+		
Dialula sandiegensis																															+
Haminoea virescens															+																
Hermissenda crassicornis			+																												
Littorina planaxis										+							+						+		+				+		+
Littorina scutulata				+	+			+		+						+	+	+	+				+	+				+			+
Mitrella carinata													+		+											+	+		+		+

Table 37 (continued)

ORGANISM	Jan	March		April		May							June				July			August			Sept.		October				Nov.		Dec
	15	6	13	14	17	1	6	13	15	22	26	29	4	5	19	25	17	23	29	2	18	28	10	25	9	13	15	25	11	20	8
MOLLUSCA (Continued)																															
Gastropoda																															
Nassarius fossatus																													+		
Ocenebra poulsoni														+	+																
Olivella biplicata					+	+							+		+		+		+					+		+	+		+		+
Polycera atra													+													+		+			
Serpulorbis squamigerus													+													+		+	+	+	+
Tegula funebralis				+					+	+		+				+	+	+	+	+	+	+	+	+	+			+	+	+	+
Tegula gallina				+																											
Triopha grandis													+																		
Amphineura																															
Cyanoplax hartwegii														+																	
Mopalia muscosa					+				+				+	+	+		+				+	+		+		+	+	+	+		+
Pelecypoda																															
Amiantis callosa			+										+														+				+
Chama pellucida													+																		
Clinocardium nuttalli													+																		
Hiatella arctica											+																	+			
Hinnites multirugosus														+																	
Macoma secta													+														+				
Mytilus edulis				+					+	+	+	+			+	+		+	+	+	+	+	+	+	+		+	+	+	+	+
Tellina idae													+																		
Tivela stultorum													+																+		
Tresus nuttalli			+			+						+	+	+	+					+		+	+	+		+	+		+	+	+
Zirfaea pilsbryi													+																		
Protothaca staminea													+	+								+		+			+				+
ARTHROPODA																															
Crustacea																															
Balanus glandula				+	+	+		+	+	+		+	+		+	+	+	+	+	+	+	+	+	+	+			+	+	+	+
Balanus pacificus													+													+			+		+
Balanus tintinnabulum											+																				

Table 37 (continued)

ORGANISM	Jan.	March		April		May							June				July			August			Sept.		October				Nov.		Dec.
	15	6	13	14	17	1	6	13	15	22	26	29	4	5	19	25	17	23	29	2	18	28	10	25	9	13	15	25	11	20	8
ARTHROPODA (Continued)																															
Crustacea																															
Betaeus longidactylus																										+					
Cancer antennarius	+																						+			+	+		+		
Cancer anthonyi	+	+			+								+	+	+		+						+	+	+	+	+		+	+	+
Cancer gracilis													+																		
Caprella californica														+																	
Caprella laeviuscula																													+		
Caprella mendax																											+				
Chthamalus fissus				+		+		+	+	+		+			+	+	+	+	+	+	+	+	+	+	+			+	+	+	+
Cirolana harfordi																								+							
Cumacea																													+		
Exosphaeroma inornata																											+				
Gammaridea											+		+			+	+			+				+		+		+			+
Harpacticoida								+			+																+				
Hemigrapsus oregonensis				+	+	+			+			+		+	+	+	+			+	+	+	+	+	+			+	+	+	+
Heptacarpus pictus													+	+	+											+	+			+	
Isocheles pilosus	+	+											+													+		+	+		+
Ligia occidentalis										+						+	+	+	+	+	+	+	+	+	+			+	+	+	+
Loxorhynchus grandis													+																		
Pachycheles rudis																											+				
Pachygrapsus crassipes	+			+	+	+		+	+	+		+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Pagurus granosimanus																														+	
Pagurus hirsutiusculus		+											+	+	+		+						+				+	+	+	+	+
Pagurus samuelis										+		+		+	+	+	+	+		+		+		+	+		+	+	+		
Petrolisthes cabrilloi														+	+							+		+	+	+	+	+	+	+	+
Portunus xantusii													+																		
Pugettia producta	+												+																		
Tetraclita squamosa												+			+																

Table 37 (continued)

ORGANISM	Jan	March		April		May							June				July			August			Sept.		October				Nov.		Dec
	15	6	13	14	17	1	6	13	15	22	26	29	4	5	19	25	17	23	29	2	18	28	10	25	9	13	15	25	11	20	8
ARTHROPODA (Continued)																															
Insecta																															
Diptera				+	+	+	+		+	+	+	+	+		+	+	+	+	+												
Hymenoptera						+				+					+		+		+												
Pycnogonida																															
Ammothea hilgendorfi															+																
ENTOPROCTA																															
Barentsia **sp.**																															+
BRYOZOA																															
Bowerbankia gracilis																										+	+				
Bryozoa, unidentified			+		+						+	+	+	+	+	+	+						+	+			+	+			
Bugula californica																	+														
Bugula neritina											+		+	+	+	+	+						+	+	+	+	+	+			
Celleporaria brunnea																										+	+				
Cryptosula pallasiana																										+	+	+	+		+
Watersipora arcuata																											+		+	+	+
ECHINODERMATA																															
Pisaster ochraceus													+	+	+			+			+			+		+	+	+	+		+
Strongylocentrotus franciscanus														+																	
Strongylocentrotus purpuratus														+													+		+		+
Parastichopus parvimensis													+																+		
CHORDATA																															
Ascidiacea																															
Botrylloides **sp.**														+																	
Ciona intestinalis																											+	+	+	+	+
Styela plicata														+		+												+			
Osteichthys																															
Atherinidae (unident.)																+															
Leuresthes tenuis										+																					
Cottidae (unident.)														+	+																

Table 37(continued)

ORGANISM	Jan.	March		April		May							June				July			August			Sept.		October				Nov.		Dec.
	15	6	13	14	17	1	6	13	15	22	26	29	4	5	19	25	17	23	29	2	18	28	10	25	9	11	15	25	11	20	8
CHORDATA (Continued)																															
Clinocottus sp.														+																	
Embiotocidae (unident.)																+														+	
Aves																															
(Common names)																															
Spotted sandpiper						+																									
Western grebe							+				+				+																
Ruddy turnstone							+																								
Willet																					+						+	+		+	+
Crow							+										+														+
Sanderling				+	+		+																						+	+	+
Common loon				+							+				+																
Barn swallow											+				+																
Caspian tern																					+										
Ring-billed gull				+	+	+	+	+	+		+		+	+	+		+	+		+			+	+	+			+	+	+	+
Heermann's gull													+				+							+		+	+	+		+	+
Bonaparte's gull							+	+																							+
Marbled godwit				+																					+					+	+
Belted kingfisher																													+		
Long-billed curlew							+																								
Brown pelican										+	+		+		+		+						+	+		+	+	+			
Eared grebe													+											+		+	+	+		+	
Black-bellied plover							+														+						+		+	+	+
Parasitic jaeger																											+				
Least tern																		+													
Forster's tern								+	+		+							+	+	+	+	+	+	+	+	+	+	+	+	+	+
Mammalia																															
Domestic cat																															+
Rat															+		+														

MARINE STUDIES OF SAN PEDRO BAY, CALIFORNIA. PART 15. DECEMBER 1978

H. DIVER SURVEYS OF THE SANSINENA OIL SPILL IMPACTS ON BENTHIC INVERTEBRATES

INTRODUCTION

Following the explosion of the Sansinena on December 17, 1976, the presence of Bunker C oil on the surface of the bottom substrate was first observed and photographed on January 4, 1977 by the Harbors Environmental Projects (USC) team of divers. Three original transects were sampled (Fig. 1) and oil was found in small globules, patches (10-25 cm in diameter) and in a large pool near the ship's stern.

To determine the persistence of the oil and its impact upon the large benthic invertebrates which make up the faunal component of this bottom community, a monthly study was established along three 800 ft = 244 m transects (Fig. 2). Beginning in late January and continuing through September of 1977, the transects were analyzed for both invertebrates and the presence of oil. Photographs and species counts were taken at 32 m intervals along the transect to document any changes in the oil, substrate or benthic fauna with time.

METHODS

Transect lines consisting of 244 m (800 ft.) 6 mm (¼") polypropylene line were weighted at 30.5 m (100 ft) intervals with 250 g lead weights. A 500 g cylindrical anchor was attached at an end and the line was laid out along the harbor bottom along the designated transect locations. When laid, one end was buoyed with a small float and a diver team descended to the harbor bottom and sampling proceeded along the line.

The number of organisms visible within a 3.5 x 3.5 m radius of each weight along the line was recorded. A photograph was taken at each 30.5 m interval by holding the camera 1.8 m above the bottom.

All photographs were made with a Nikonos III camera equipped with twin Vivitar strokes (Model 292) housed in Ikelite cases.

Once the nine stations were sampled along each transect, the line was retrieved and moved to the next transect location.

RESULTS

Preliminary Survey

In the emergency reconnaissance survey of January 4, 1977, oil was found in small quantities spread over a large area southwest of the ship and two sizeable oil pools were present near the ship's bow and stern. Much of the oil appeared to be broken up into small clumps or globules and covered with silt; as such it was not apparent on the bottom unless touched. Figure 1 shows the January transects.

Patches of oil werefound on benthic organisms and large areas covered with oil pools appeared to be devoid of invertebrates. Three species were found to be quite numerous in the area outside the pools: *Pachycerianthus johnsoni*, a burrowing anemone; *Stylatula elongata*, the sea pen; *Cancer anthonyi*, a large crab; and *Panope generosa*, the geoduck clam.

A few dead burrowing anemones were found and oil was observed on and around sea pens and anemones, but no marked mortality was apparent.

Monthly Surveys

The three transects sampled for the monthly surveys are indicated on Fig. 2. The depths for each station on the transects are given in Table 1.

Transect I proceeded toward the southwest from the mid-ship position. The depth remained at 8-10 m (26-33 ft) for the first 7 stations and then sloped abruptly down to 15-18 m (50-60 ft) at stations 8 and 9, because of the ship channel irregularities near the dock. Transect II approached the ship from the stern and was entirely within the ship channel, ranging in depth from 15-18 m. Transect III crossed a relatively shallow and somewhat rocky portion of the harbor near the ship's bow and ranged from 8-18 m, (26-60 ft) in depth.

Benthic Oil

The oil which appeared to be scattered in the relatively shallow areas southwest of the ship was observed at stations 5-7 of transect I in the February-March study but soon disappeared (Table 2). Oil remained in the deeper ship channel in considerable amounts through the entire study period.

Transect II passed directly through a large pool near the stern of the ship. This pool persisted throughout the study and was in fact still present on December 2, 1977 (see Part I, this volume).

Transect III, in the bow area only passed through small traces of oil and these also disappeared from view with time.

Marine Life

The species and numbers of benthic invertebrates observed along each transect are summarized in Table 3. Burrowing anemones (*Pachycerianthus johnsoni*), sea pens (*Stylatula* and *Virgularia*) and the geoduck (*Panope generosa*) are all sessile, long-lived suspension feeders and their total population density seemed not be affected by the oil spill. Both *Hermissenda crassicornis* (nudibranch) and *Cancer anthonyi* are mobile and probably move about seasonally. They were not common enough to indicate any trend but also appeared unaffected by the presence of oil.

DISCUSSION

The impact of oil on benthic invertebrates was probably considerable. The oil that formed pools near the ship's stern for many months probably killed all the marine life which had occurred there. However, transects which covered large portions of the surrounding area indicated little or no quantitative impact upon the benthic invertebrates (Table 3).

Exact quantitative comparisons on a month to month basis were not possible for our data because the transect could not be laid in exactly the same location each month. Permanent lines could not be installed because of the salvage efforts that continued on the ship's hulk. However, the same general areas were sampled each time and invertebrate densities were similar for each species throughout the study period. Tables 4-11 give monthly transect survey data.

There was a period in April and May of 1977 when poor visibility made underwater observations almost impossible and very low numbers of animals were hence observed. The numbers in the table thus reflect the poor visibility rather than depleted fauna.

Sampling for June through September, when visibility improved, indicated that population densities were approximately the same as at the start of the study. Since these organisms are mainly long-lived suspension feeders, it is reasonable to assume that they were present but not counted in the spring surveys of April and May.

The general benthic community in the shallower water (Transects I and III) is probably richer due to the lack of dredging and large ship traffic in those areas. Only small amounts of oil settled in the shallow areas, probably spread by the explosion itself. This diverse and highly productive area seems relatively unaffected by the spill.

The deeper ship channel of transect II and stations 8 and 9 of transect I were more seriously affected by the oil spill. However this area had been continually disturbed by ship traffic before the explosion and the impact in terms of total density appears not to have been great. Stations 8 and 9 of transect II were beneath a sizeable oil pool for over 12 months and marine life in that local area probably was killed. No studies of biological recovery have been made since the end of the cleanup operations and resumption of docking.

Table 38. Union Transect* Depths, 26 January 1977

TRANSECT I - Midship from SW to Tanker.

Station	Depth (feet)
1	25-30
2	25-30
3	25-30
4	25-30
5	25-30
6	25-30
7	25-30
8	50-60
9	50-60

TRANSECT II - S.E. to Stern.

Station	Depth (feet)
1	50-60 ALL STATIONS
2	
3	
4	
5	
6	
7	
8	
9	

TRANSECT III - S.W. to Bow.

Station	Depth (feet)
1	25-30
2	25-30
3	25-30
4	50-60
5	50-60

---

* Transects began 800 ft from the Sansinena and terminated at the ship site, with stations at 100 ft intervals, except for the S.W. bow transect.

Table 39. Distribution of Oil on the Benthos.

Transect I

		28 Feb-4 Mar.	26 April	25 May	29 June	25 July	26 August	29 Sept.
Station	1	0	*	*	0	0	0	0
	2	0	-	-	0	0	0	0
	3	0	-	-	0	0	0	0
	4	0	-	-	0	0	0	0
	5	L	-	-	0	0	0	0
	6	L	-	-	0	L	0	0
	7	L	-	-	0	L	L	L
	8	L	-	-	0	M	L	L
	9	L	-	-	M	M	L	M

*No records made

Transect II

		28 Feb-4 Mar.	26 April	25 May	29 June	25 July	26 August	29 Sept.
Station	1	0	0	-	0	0	0	0
	2	0	0	-	0	0	0	0
	3	0	0	-	0	0	0	0
	4	0	0	-	0	0	0	0
	5	0	0	-	0	0	0	0
	6	0	0	-	0	0	0	0
	7	M	0	-	0	L	0	M
	8	H	H	-	H	M	H	H
	9	H	H	-	H	H	H	H

Transect III

		28 Feb-4 Mar.	26 April	25 May	29 June	25 July	26 August	29 Sept.
Station	1	0	-	0	0	L	0	0
	2	0	-	0	0	L	0	0
	3	0	-	0	0	0	0	0
	4	0	-	0	0	0	0	0
	5	L	-	0	0	0	0	0
	6	L	-	0	0	0	0	0
	7	L	-	L	L	0	0	0
	8	0	-	0	0	0	0	0
	9	0	-	0	0	0	0	L

L = light (small globules)
M = medium (large globules)
H = heavy (pool)

Table 40. Benthic Invertebrates Observed in Diver Transects, 1977.

Transect I

SPECIES	DATE, 1977							
	26 January	28 Feb. 4 March	26 April	25 May	29 June	25 July	26 Aug.	29 Sept.
Coelenterata								
Pachycerianthus johnsoni (burrowing anemone)	31	57	4	6	16	65	22	31
Stylatula elongata (sea pen)	40	16	0	0	13	4	7	12
Virgularia sp. (sea pen)	18	21	1	0	0	0	1	4
Mollusca								
Panope generosa (geoduck clam)	51	66	0	0	80	40	62	45
Hermissenda crassicornis (nudibranch)	2	11	0	0	0	1	0	8
Arthropoda								
Cancer anthonyi	4	0	0	0	2	0	0	1
TOTALS	146	171	5	6	111	110	102	101

TABLE 40 (Continued)

Transect II

SPECIES	DATE, 1977 26 January	28 Feb. 4 March	26 April	25 May	29 June	25 July	26 Aug.	29 Sept.
Coelenterata								
Pachycerianthus johnsoni	24	*	1	*	5	65	22	31
Stylatula elongata				-	2	4	7	12
Mollusca								
Panope generosa	20	-	0	-	22	45	62	50
Hermissenda crassicornis	5	-	0	-	0	1	0	8
Arthropoda								
Cancer anthonyi	4	-	0	-	0	0	2	1
TOTALS	103	-	1	-	29	115	93	102

*no data due to poor visibility and low light.

TABLE 40 (Continued)

Transect III

SPECIES	DATE, 1977 26 January	28 Feb. 4 March	26 April	25 May	29 June	25 July	26 Aug.	29 Sept.
Coelenterata								
Pachyceriamthus johnsoni	26	32	2	18	43	29	64	91
Stylatula elongata	1	28	1	2	14	5	4	0
Virgularia sp.	7	8	0	0	0	5	1	2
Mollusca								
Panope generosa	53	64	2	35	118	31	0	11
Hermissenda crassicornis	0	22	0	2	2	1	0	72
Arthropoda								
Cancer anthonyi	0	12	0	0	0	0	0	0
TOTALS	87	166	5	57	177	91	69	176

Table 41. Animals and Oil Found Along the Sansinena Transects Diver Survey, 26 January 1977.

SPECIES / Stations	Transect I								
	1	2	3	4	5	6	7	8	9
Coelenterata									
Cerianthid (large)	6		3	3	5	4	1		2
Cerianthid (small)	4	1	1				1		
Stylatula sp. (sea pen)		20	5	2	13				
Virgularia sp. (sea pen)	3		15						
Mollusca									
Hermissenda sp. (nudibranch)	1			1					
Panope sp. (clam)	7	8	24	7	5				
Arthropoda Crustacea									
Cancer sp.		1*	1			3			

SPECIES / Stations	Transect II								
	1	2	3	4	5	6	7	8	9
Coelenterata						Large oil pool - no animals at all!		LARGE OIL POOL!	
Cerianthid (large)	1	3	1	1	1		15		
Cerianthid (small)				1			1		
Mollusca									
Hermissenda sp. (nudibranch)			3		2				
Panope sp. (clam)		15	5						
Arthropoda Crustacea									
Cancer sp.	2				1				1

SPECIES / Stations	Transect III				
	1	2	3	4	5
Coelenterata					
Cerianthid (large)	6	8	2	7	2
Cerianthid (small)		1			
Stylatula sp. (sea pen)	1				
Virgularia sp. (sea pen)	3	1		3	
Mollusca					
Hermissenda sp. (nudibranch)			3		
Panope sp. (clam)	13		10	28	
Miscellaneous (orange Cerianthid)		1			

*Organism was found dead.

Table 42. Animals and Oil found along the Sansinena Transects I - III.

February-March, 1977

ANIMALS	Transect I (3/4/77)								
Depth (in ft)	20	22	22	24	25	25	45	50	50
Station	1	2	3	4	5	6	7	8	9
Coelenterata									
Cerianthid (large)	2	2		2	6	9	8	1	
Cerianthid (small)	2	2		2	4	8	8	1	
Stylatula sp. (sea pen)	1	12				2			1
Virgularia sp. (sea pen)	2	10		6			3		
Mollusca									
Hermissenda sp. (nudibranch)			3		2	6			
Panope sp. (clam)	10	10	12	12	11	5	6		
Oil Presence					SOME				

ANIMALS	Transect II (2/28/77)								
Depth (in ft.)	55	55	52	53	55	55	55	55	55
Station	1	2	3	4	5	6	7	8	9
Miscellaneous									
Kelp Fish				1					
(OVERCAST AND RAIN MADE CONDITIONS VERY DARK, AND OBSERVATIONS IMPOSSIBLE; NO OTHER ANIMAL SIGHTINGS MADE.)									
Oil Presence					Some		Large Pools		S.

S = Some

ANIMALS	Transect III (3/4/77)								
Depth (in ft.)	15	15	15	15	20	30	30	35	35
Station	1	2	3	4	5	6	7	8	9
Coelenterata									
Cerianthid (large)		3	10					10	5
Cerianthid (small)								2	2
Stylatula sp. (sea pen)					7	5	10	1	5
Virgularia sp. (sea pen)	3			1	1				3
Gorgonians				+	+				
Mollusca									
Hermissenda sp. (nudibranch)		5	5			3	6		3
Hinnites sp. (rock scallop)				+	+				
Panope sp. (clam)	25	3		6		12		3	15
Arthropoda									
Cancer sp. (crab)					12				
Oil Presence					Some				

+ = presence

Table 43. Animals and Oil found along the Sansinena Transects I-III. 26 April, 1977

Station	Transect I								
ANIMALS	1	2	3	4	5	6	7	8	9
Coelenterata Cerianthid (large)								3	1
Virgularia sp. (sea pen)					1				
Depth (in feet)	25	25	25	30	33	35	50	52	52
Visibility (in feet)	3	3	3	6	8	8	8	8	8

Station	Transect II								
ANIMALS	1	2	3	4	5	6	7	8	9
Coelenterata Cerianthid (large							1		
Depth (in feet)	52 feet								
Visibility (in feet)	3								
Oil									Pool

Station	Transect III								
ANIMALS	1	2	3	4	5	6	7	8	9
Coelenterate Cerianthid (large)				1					1
Stylatula sp.				1					
Mollusca *Panope* sp. (clam)							2		
Depth (in feet)	12	13	13	20	26	30	35	38	38
Visibility (in feet)	1	1	1	3	6	8	8	8	8

Table 44. Animals and Oil found along the Sansinena Transects I-III. 25 May, 1977.

Station ANIMALS	Transect I							
	1	2	3	4	5	6	7	8
Coelenterata								
Cerianthid (large)		1	1	2	2			
Cerianthid (small)					2			
Depth (in feet)	22	23	25	25	25	25	32	32
Visibility (in inches)	3	6	6	6	6	36	60	60

Transect II
A stern transect was not possible due to the presence of an oil recovery operation in the transect area. The June survey will indicate the success of recovery.

Station ANIMALS	Transect III								
	1	2	3	4	5	6	7	8	9
Coelenterata									
Cerianthid (large)			1		3		1	3	10
Stylatula sp. (sea pen)						2			
Mollusca									
Hermissenda sp.								2	
Panope sp. (clam)				10			20	5	
Depth (in feet)	12	12	15	15	18	20	30	35	35
Visibility (in feet)	1	1	1	1	3	3	8	8	8
Oil							*		

* Indicates presence of oil.

Table 45. Animals and Oil found along the Sansinena Transects I-III. June 29, 1977.

ANIMALS	Transect I								
	1	2	3	4	5	6	7	8	9
Coelenterata Cerianthid (large)	3	2	2	5	3	1			
Stylatula sp. (sea pen)	2	2	2		3	1	1	2	
Mollusca *Panope* sp. (clam)	15	12	10	13	15	15			
Arthropoda *Cancer* sp.	1							1	
Depth (in feet)	25	25	25	25	25	35	48	50	50
Oil									pres.

ANIMALS	Transect II								
	1	2	3	4	5	6	7	8	9
Coelenterata Cerianthid (large)			1	1	1	1		1	
Stylatula sp. (sea pen)		1				1			
Mollusca *Panope* sp. (clam)				5		4	2	11	
Depth	50	50	50	50	50	50	50	50	50
Oil								present*	
Miscellaneous (dead fish)							X		

ANIMALS	Transect III								
	1	2	3	4	5	6	7	8	9
Coelenterata Cerianthid (large)	4	10		5	5	4	2	2	10
Stylatula sp. (sea pen)	3	4		3		4			
Mollusca *Hermissenda* sp. (nudibranch		1	1						
Panope sp. (clam)	20	15	18	10	20	10	10	10	5
Depth	15	15	15	15	15	30	35	35	40
Oil							pres.		
Other (reef present)			X						

* Transect line did not go into area under barge where oil pool had previously been located.

Table 46. Animals found along the Sansinena Transect lines. July 25, 1977.

SPECIES	Transect I								
	1	2	3	4	5	6	7	8	9
Coelenterata									
Cerianthid (large)	1	3	5	7	5	2	3	1	0
Cerianthid (small)	0	2	1	0	35	0	0	0	0
Stylatula sp. (sea pen)	0	2	1	1	0	0	0	0	0
Mollusca									
Panope sp. (clam)	5	5	10	15	10	0	0	0	0
Hermissenda sp. (nudibranch)	0	0	1	0	0	0	0	0	0
Echinodermata									
Pisaster brevispinus	0	1	0	0	0	0	0	0	0
Oil	0	0	0	0	0	L	L	M	M
Depth	25	25	25	25	25	45	45	45	50

SPECIES	Transect II								
	1	2	3	4	5	6	7	8	9
Coelenterata									
Cerianthid (large)	0	1	0	0	1	1	0	0	0
Mollusca									
Panope sp. (clam)	0	0	9	0	4	2	2	0	0
Oil	0	0	0	0	0	0	L	M	H
Depth	50	50	50	50	50	50	50	50	50

L = light amount of oil
M = medium amount of oil
H = heavy amount of oil

Table 46 (Continued)

SPECIES	Transect III								
	1	2	3	4	5	6	7	8	9
Coelenterata									
Cerianthid (large)	1	5	3	0	0	2	1	4	6
Cerianthid (small)	0	2	1	1	0	0	1	2	0
Stylatula sp. (sea pen)	1	0	0	0	0	0	1	1	2
Virgularia sp. (sea pen)	1	0	3	0	0	1	0	0	0
Mollusca									
Panope sp. (clam)	3	3	5	0	5	0	10	5	0
Hermissenda sp. (nudibranch)	0	0	0	0	1	0	0	0	0
Oil	L	L	0	0	0	0	0	0	0
Depth	25	25	20	20	35	35	35	35	35

L = light amount of oil M = medium amount of oil
H = heavy amount of oil

Table 47. Animals found along the Sansinena transect lines. August 26, 1977.

SPECIES	Transect I								
	1	2	3	4	5	6	7	8	9
COELENTERATA									
Cerianthid, large	2	1	2	3	2	4	1		
Cerianthid, small			1		1	3	1	1	
Stylatula sp. (sea pen)	1	2	1	1	1		1		
Virgularia sp. (sea pen)					1				
MOLLUSCA									
Panope sp. (clam)	45	5		7	5				
Nudibranch, white									1
ARTHROPODA									
Cancer sp.					2				
Oil							L	VL	L
Depth (in feet)	25	25	25	27	29	45	45	50	50

SPECIES	Transect II								
	1	2	3	4	5	6	7	8	9
COELENTERATA									
Cerianthid, large			4			2	1		
Cerianthid, small						1	4		
MOLLUSCA									
Panope sp. (clam)		2	5	3		1			
ARTHROPODA									
Cancer sp.				1					
Oil								H	H
Depth (in feet)	53	50	50	50	50	50	50	50	50

SPECIES	Transect III								
	1	2	3	4	5	6	7	8	9
COELENTERATA									
Cerianthid, large	1	3	2	3	3	7	8	5	2
Cerianthid, small	2	7	3	2			2		14
Stylatula sp. (sea pen)	1		1				1		1
Virgularia sp. (sea pen)							1		
MOLLUSCA									
Panope sp. (clam)									
Depth (in feet)	20	20	20	20	20	25	35	30	30

L = light; VL = very light; H = heavy.

Table 48. Animals found along the Sansinena transect lines. September 29, 1977.

Station / SPECIES	Transect I								
	1	2	3	4	5	6	7	8	9
COELENTERATA									
Cerianthid, large	2	3		3		15		3	
Cerianthid, small			2			2		1	
Stylatula sp. (sea pen)	3		3		1	5			
Virgularia sp. (sea pen)		1				3			
MOLLUSCA									
Hermissenda crassicornis		2					3	2	1
Panope generosa	20	5		5	10	5			
ARTHROPODA									
Cancer sp.								1	
OIL							L	L	M
Depth (in feet)	25	25	25	28	30	35	50	50	50

Station / SPECIES	Transect II								
	1	2	3	4	5	6	7	8	9
COELENTERATA									
Cerianthid, large	3	3	2			2	2	2	
Cerianthid, small			1	1	1				
MOLLUSCA									
Hermissenda crassicornis			2	3				5	
Panope generosa	3	10	10		20	30	10	10	
OIL							M	H	H
Depth (in feet)	52	52	52	52	52	52	52	52	52

Station / SPECIES	Transect III								
	1	2	3	4	5	6	7	8	9
COELENTERATA									
Cerianthid, large	6	4	4	5	10	6	8	10	3
Cerianthid, small		1	2	10	5	5		5	
Virgularia sp. (sea pen)					1		1		
MOLLUSCA									
Hermissenda crassicornis	7	10	15	10		20		10	
Panope generosa	2	3	3				3		
OIL									L
Depth	20	20	20	20	20	27	40	46	40

L = light amount of oil M = medium amount of oil
H = heavy amount of oil

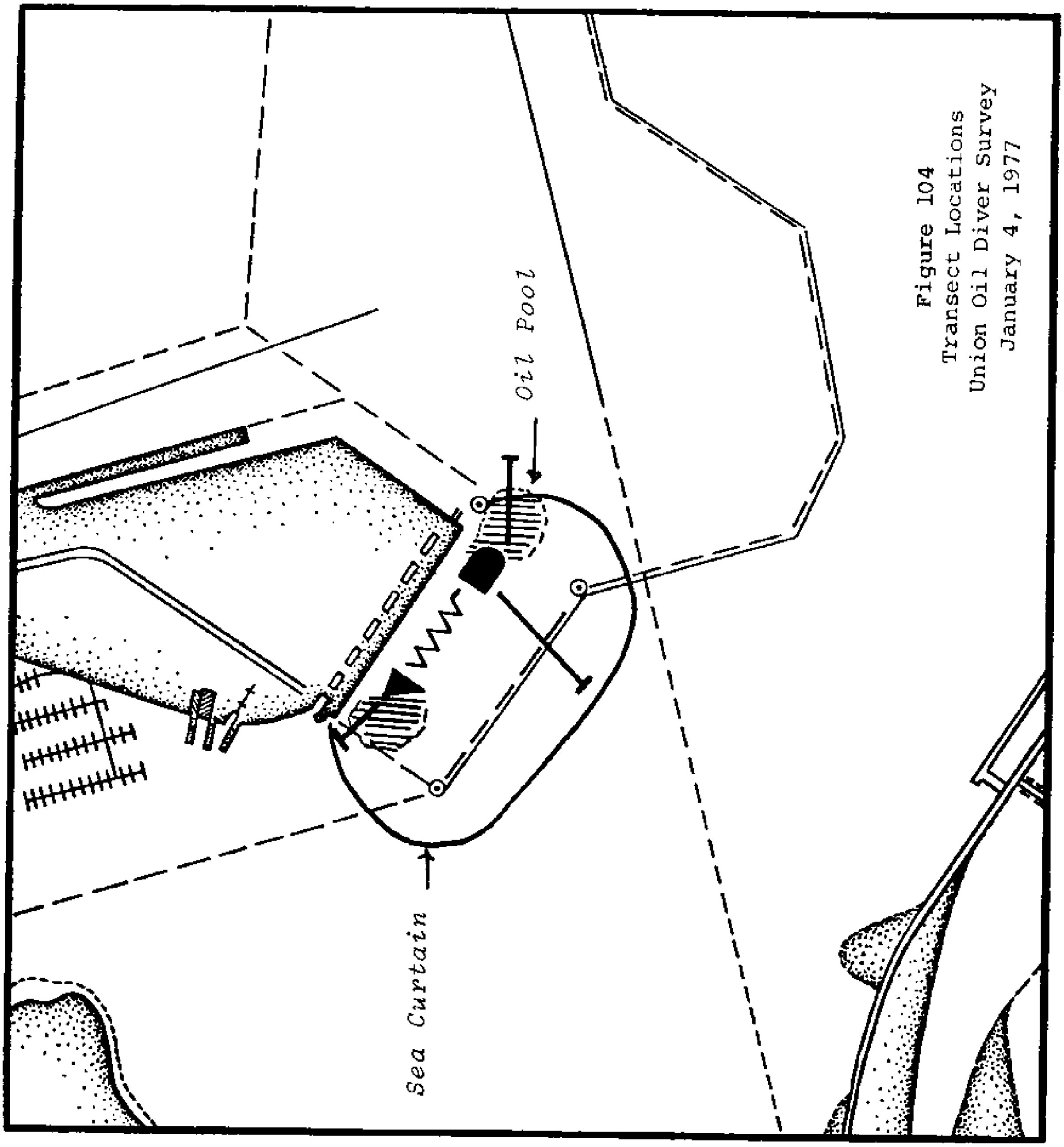


Figure 104
Transect Locations
Union Oil Diver Survey
January 4, 1977

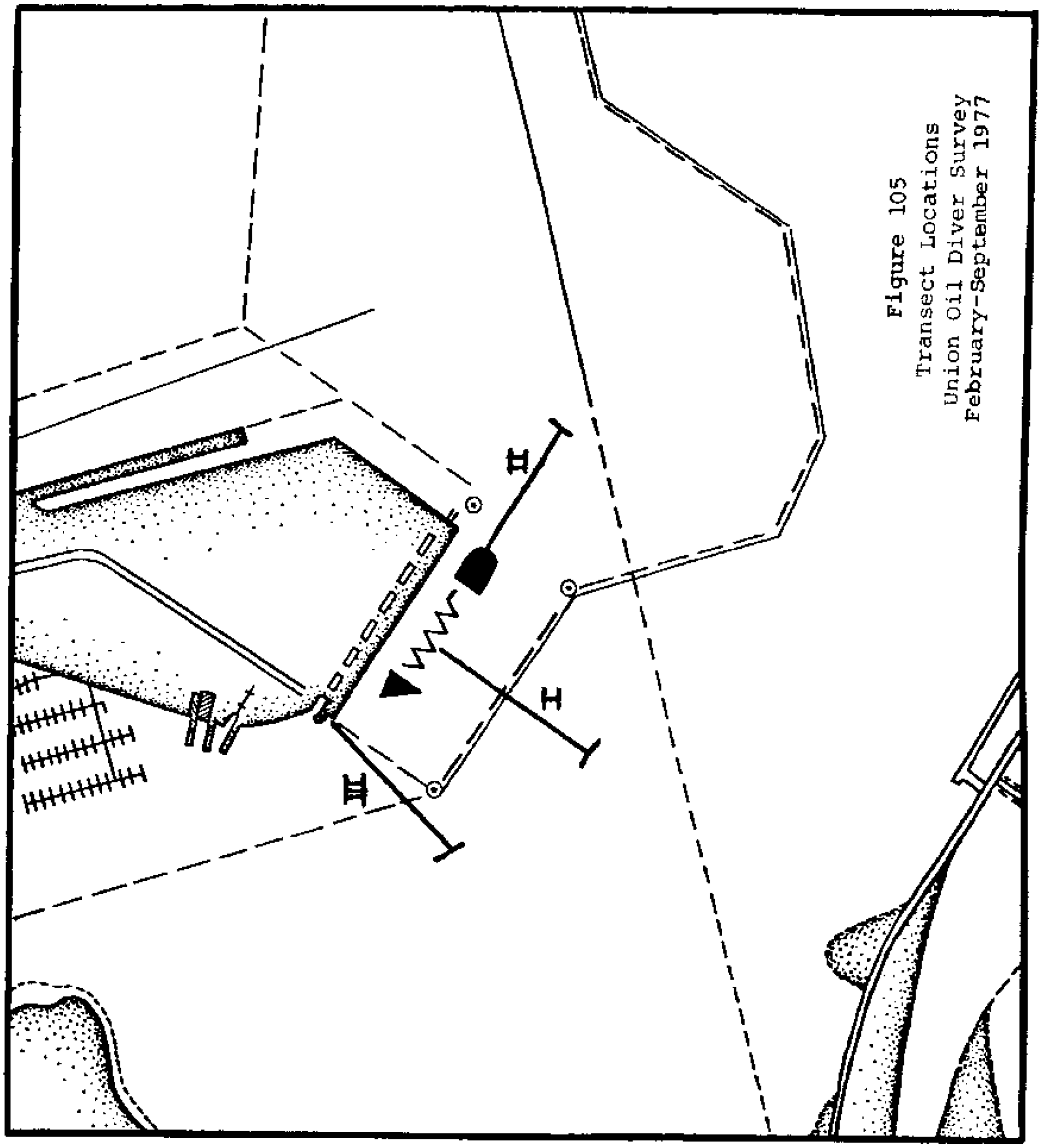


Figure 105
Transect Locations
Union Oil Diver Survey
February-September 1977

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IV. OTHER EFFECTS OF TANKER INCIDENTS

A. PRELIMINARY REPORT ON THE PHYSICAL AND SENSORY EFFECTS OF THE EXPLOSION OF THE OIL TANKER *SANSINENA*

by

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On December 17, 1976 an explosion destroyed the Liberian registered tanker, *Sansinena*, at its berth in Los Angeles Harbor. Property damage was incurred in the residential areas adjacent to the explosion and the blast was heard over a much larger area of southern California. A two-part survey was undertaken to ascertain the size and shape of the area sustaining physical damage and the size and shape of the area over which the blast had been perceived.

A house-to-house survey of physical damage was conducted by 120 students from three geography classes from the University of Southern California. This survey covered a large part of San Pedro as well as transects in Wilmington and Long Beach. Students also observed and recorded on questionnaire forms any visible evidence of damage. They then interviewed the occupants, asking about structural damage, broken glass, interruption of utilities and oil aerosol fallout. They also asked each interviewee his recollection as to what he had thought had happened at the time of the explosion. Over 2,600 buildings were surveyed in this manner.

The second part of the survey took the form of a mail-back questionnaire sent through the campus mail service to all employees of the University of Southern California. Each addressee was asked if he had seen, heard, or felt the explosion and what his perception of the nature of the explosion had been. Approximately 1,200 replies were received.

The information collected was transferred to punch cards for computer analysis. The analyses being carried out include computer generated 2- and 3-dimensional maps showing patterns of damage, perception of the incident, and the influence of distance and land form on these patterns.

The first data item to be tabulated and analyzed was the response given in the house-to-house survey to the question, "Did your home or building sustain any damage in the explosion?". Response to this question are tallied in Table 1. In this table the column headed "no response" includes buildings where no one was at home, persons who refused to answer, and persons who claimed to be unable to speak English.

The accompanying computer-generated maps are a results of this on-going analysis. These maps depict in three different forms, each giving a different perspective, the responses to the question on damage to buildings.

The first map, drawn by a computer plotter, shows the responses grouped within the boundaries of census tract block groups. Inasmuch as census boundaries usually are city streets, this map is useful in identifying where damage occurred (Figure 1).

The second map, produced in typescript by the computer line printer, is a contour or isoplethic map based on the centroids of census tract block groups. The interpolative algorithm used in the production of this map is useful in showing trends or patterns (Figure 2).

The third map, also drawn by the computer's pen plotter, is a three dimensional block diagram or model of the same information.

The factor illustrated on these three maps is the number of buildings damaged. No attempt was made to assess the severity nor the dollar value of the damage. Nonetheless, in spite of giving all reported damage equal weight, the number of buildings damaged can be seen to be a valid measure of the effect of the explosion over an area. The maps, especially the contour and the three dimensional, dramatically demonstrate the effects of the explosion diminishing in a radial pattern with distance from the blast, especially to the west along the Palos Verdes Hills above San Pedro.

Data on the number of buildings damaged at Fort MacArthur, Ports of Call, and the Coast Guard station were not available when these maps were compiled, since they did not respond to mailed surveys. However, examination of a topographic map of the area (Figure 4) shows that the damage was related to elevation contours. Toward the north, where elevations were lower, less damage was noted than was the case toward the west. There, the higher elevations are delineated by damage even though the points were approximately the same distance from the center of the explosion as the less damaged lower areas.

Table 1. Damage Survey of the Sansinena Explosion.

Census Tract/ Block Group	**Number of Buildings Damaged**	**Number of Buildings Not Damaged**	**No Response**
29621	2	0	0
29622	2	3	0
29624	5	13	2
29625	22	6	1
29661	17	28	41
29662	9	3	0
29663	4	21	1
29664	3	7	5
29671	7	41	1
29672	6	32	6
29681	2	8	17
29682	10	53	30
29683	0	4	3
29691	0	3	7
29692	2	10	5
29693	16	21	25
29694	4	46	42
29695	3	10	17
29711	0	3	0
29712	30	27	33
29713	10	9	2
29714	46	36	53
29715	46	25	18
29721	52	54	62
29722	7	16	14
29723	16	28	50
29724	44	85	52
29725	12	40	66
29731	2	4	3
29732	5	25	23
29751	17	26	17
29752	12	46	4
29753	12	34	2
29761	72	19	24
29762	7	5	0
29763	32	3	47
29764	55	14	92
29765	15	17	33

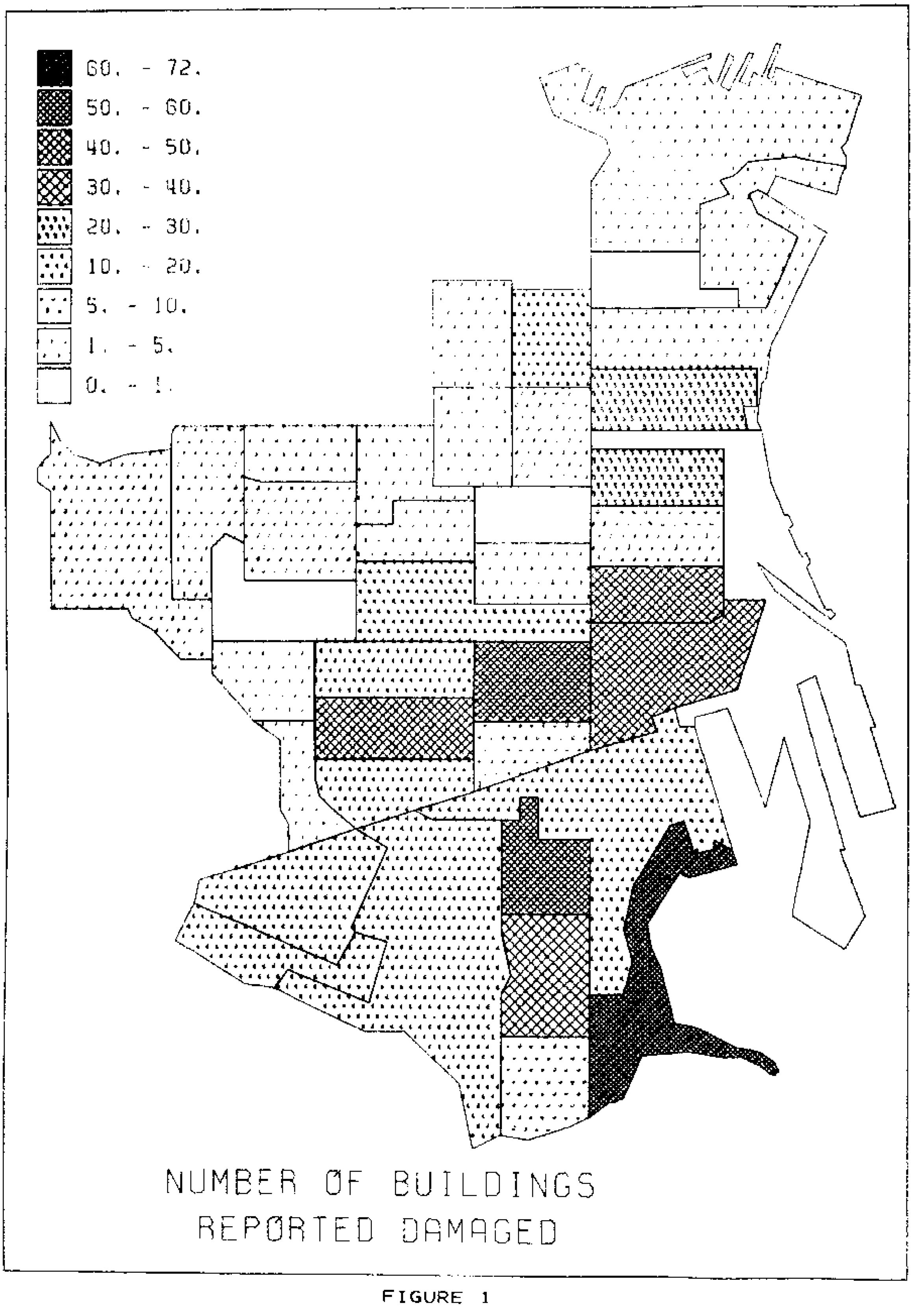
60. - 72.
50. - 60.
40. - 50.
30. - 40.
20. - 30.
10. - 20.
5. - 10.
1. - 5.
0. - 1.
NUMBER OF BUILDINGS
REPORTED DAMAGED

FIGURE 1

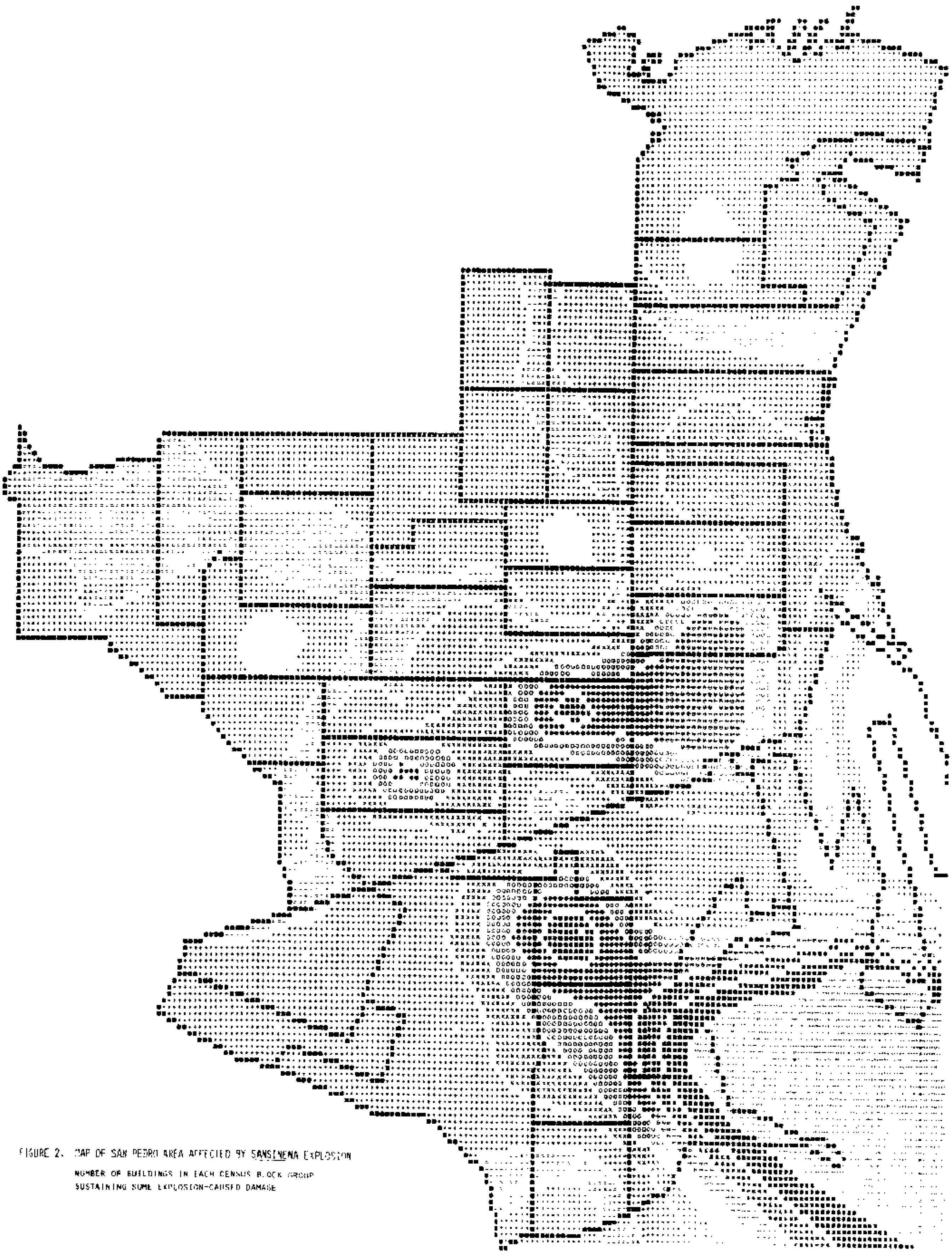

FIGURE 2. MAP OF SAN PEDRO AREA AFFECTED BY SANSINENA EXPLOSION

NUMBER OF BUILDINGS IN EACH CENSUS BLOCK GROUP
SUSTAINING SOME EXPLOSION-CAUSED DAMAGE

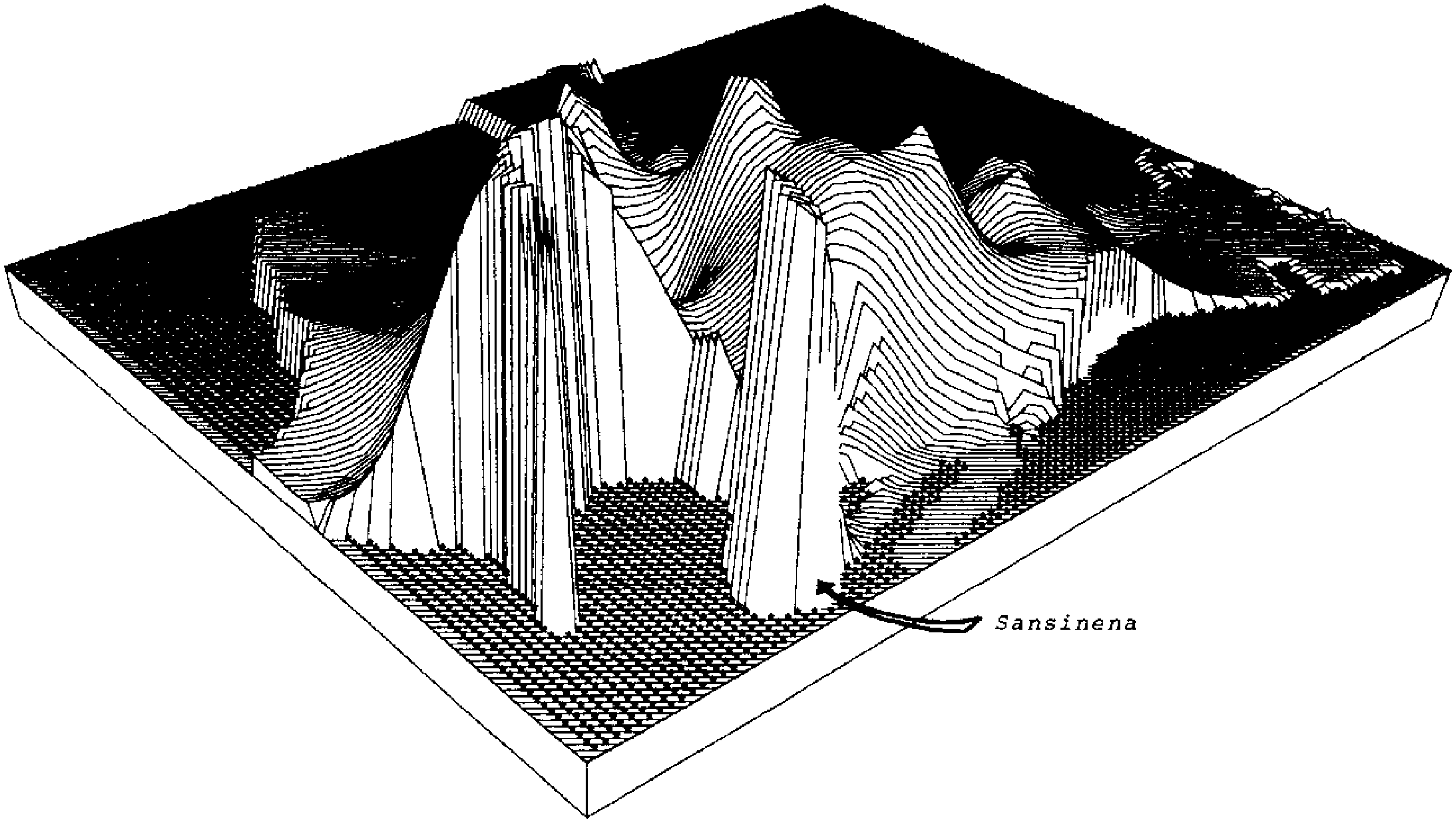

FIGURE 3. SANSINENA EXPLOSION - NUMBER OF BUILDINGS DAMAGED

AZIMUTH = 309 ALTITUDE = 45
*WIDTH = 8.00 *HEIGHT = 3.00

Figure 4. Excerpt, USGS Topographic Map of San Pedro Quadrangle.

IV.B. A REVIEW OF THE EFFECTS OF SPILLED BUNKER C FUEL ON MARINE ENVIRONMENTS

by

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FATE OF THE COMPONENTS OF THE OIL IN SEA WATER

The most abundant components of Bunker C fuel oil are alkyl phenols, indoles, and naphthalenes (Winters and Parker, 1977). Upon exposure to sea water, highly volatile fractions of the oil escape into the atmosphere, while insoluble residues may form floating masses or hard, pavement-like surfaces on sediments (Guard, Hunter and DiSalvo, 1975; Thomas, 1973).

Guard, *et al.*(1975) found that about 100 mg of each liter of oil (10%) is estimated to leach into sea water. The major components of seawater extracts of Bunker C fuel oil are acetophenone, naphthalene, phenol, o- and p-cresol. Methylnaphthalene and xylenols are present in minor amounts. Winters and Parker (1977) reported that over 80% of the naphthalenes are lost during the first 12 hours after exposure. Most of the alkyl benzenes, naphthalenes, biphenyls, and hydrocarbons will evaporate before reaching less well mixed water. The remaining fractions, however, can be carried for many miles by ocean currents and can continue to mix with ocean waters during that time (Guard, *et al.*, 1975).

EFFECTS IN ROCKY HABITATS

There have been two major spills of Bunker C fuel oil in areas with rocky habitats: in February, 1970, at Chedabucto Bay, Nova Scotia (Thomas, 1973) and in January, 1971, in San Francisco Bay, California (Chan, 1977). In both areas the oil washed ashore and coated intertidal rocks. The oil deposited on the rocks killed barnacles (*Balanus* spp.) by suffocation. Major die-offs of the striped shore crab *Pachygrapsus crassipes* were reported in San Francisco Bay. In Chedabucto Bay, the brown alga *Fucus serratus* was broken off the rocks and cast ashore after being coated with oil. *Fucus spiralis* was eliminated entirely in areas where oiling was severe. Populations of the snail *Littorina obtusata*, which inhabits *F. serratus*, declined.

Sublethal effects of extracts of Bunker C fuel oil have been discovered in two rocky intertidal organisms. At concentrations of more than 50%, number six bunker oil is toxic to fertilization of eggs of the sea urchin, *Strongylocentrotus purpuratus*. Cleavage stages of the fertilized eggs are even more sensitive to the oil (Allen, 1971). Periwinkle snails (*Littorina littorea*) increase their rates of crawling and respiration in the presence of Bunker C oil (Hargrave, 1973).

Recovery of oiled rocky intertidal areas appears to be rapid except in sheltered areas. Within three years after the spill in San

Francisco Bay, Chan (1977) found that recruitment had doubled the mean population of invertebrates found in study areas immediately after the spill. No lingering effects of the oil were observed except a continued low population of shore crabs. Exposure to crude oils has been found to inhibit chemoreception, feeding responses, and mating activities in these crabs (Kittredge, Takahashi, and Sarinana, 1975).

In Chedabucto Bay, the oil on the rocks declined rapidly during the winter of 1970-71, probably due to rough weather and scouring by ice. The remaining oil on the rocks, however, formed a coating which would warm up, soften, and cause re-oiling.

Recolonization of oiled rocky areas in Chedabucto Bay proceeded rapidly. The snails *Littorina saxatilis*, *Littorina littorea*, and *Littorina obtusata* became abundant. The brown alga *Ascophyllum nodosum* appeared not to have been affected by the oil, perhaps due to a thick coating of mucilage which repelled the oil. *Fucus spiralis*, however, did not settle again in oiled areas (Thomas, 1973).

EFFECTS IN SAND, MUD, AND SALT MARSHES

Bunker C fuel oil was spilled on beaches, in lagoons, and in salt marshes in Chedabucto Bay in 1970 (Thomas, 1973). Some Bunker C oil was spilled in Chesapeake Bay in February, 1976, although most of that spill consisted of number six fuel oil (Westree, 1977; Hershner and Moore, 1977). Oil from the spill in San Francisco Bay drifted north to contaminate Stinson Beach (Chan, 1977).

Contamination by Bunker C fuel oil had worse effects in areas of soft sediments in Chedabucto Bay than in rocky areas. Thomas (1973) noted that lagoons acted as "oil traps." Salt marsh grass (*Spartina alterniflora*) was eliminated in oiled areas. The edible soft-shell clam *Mya arenaria* was killed by oiling or forced from its burrow and eaten by predators. Even when these clams were moved to clean sediment, they ejected visible oil for at least one month.

Vandermeulen (1975) and Vandermeulen and Keizer (1977) found that the sediments of the beaches of Chedabucto Bay acted as a sink for stranded oil. Persistence of the oil in these sediments was estimated at 150 years. Because of this long residence, burrowing and rooted organisms would be subjected continuously to high levels of petroleum hydrocarbons.

Significant levels of contamination were found in the eel grass *Zostera marina* in Chedabucto Bay. Hydrocarbons remained fairly constant in the gut-hepatopancreas-foot complex and adductor muscles of bivalve mollusks. No Bunker C contamination, however, was detected in the "common mussel" (probably *Mytilus edulis*) (Vandermeulen, 1975; Vandermeulen and Keizer, 1977).

In Chesapeake Bay, fuel oil was buried to a depth of 10 cm in beaches. Tidal action re-exposed this oil from time to time, causing new contamination. Oil smothered benthic organisms, including oysters; coated marsh grass (*Spartina* sp.), and tainted edible oysters, clams and crabs. Ribbed mussels (*Modiolus demissus*) died as temperatures rose in contaminated areas in April and May (Roland, Moore, and Bellanca, 1977; Hershner and Moore, 1977).

The spill in Chesapeake Bay occurred during the winter, when much of the biota of the marshes is inactive. After cutting and removal of oiled grasses, a greater proportion of the new stems from remaining rhizomes flowered and produced seed heads than in areas without oil. The snail *Littorina irrorata* reinvaded the new patches of salt grass (Hershner and Moore, 1977).

At Stinson Beach (California), slight gains occurred in the populations of the sand worm *Nephthys* sp. and the mole crab *Emerita analoga* by 1974. However, neither population regained its numbers prior to the oil spill (Chan, 1977).

EFFECTS ON SUBTIDAL AREAS

Thomas (1973) reported that oil in subtidal sediments in lagoons in Chedabucto Bay was released on disturbance. Four species of shallow-water demersal fish were found dead on the beach in an area where chemicals were used in the clean-up of oil in the bay. Divers in San Francisco Bay saw iridescent films, heavy patches of oil, and soft black globules which floated about one foot below the surface (White, 1971).

EFFECTS ON BIRDS

In both the San Francisco Bay spill and the Chesapeake Bay spill, grebes were among the birds suffering highest mortalities (Anonymous, 1971; Roland, Moore, and Bellanca, 1977). Sea ducks (scoters and oldsquaws), loons, murres, and cormorants died by the hundreds. Off San Francisco, immature murres, which rest on water at night, suffered worse damage from the spread of the oil at night than cormorants, which roost on rocks at night.

Bunker C oil consumed by birds has a short but lethal effect on their eggs. Japanese quail, chickens, and Canada geese fed 200 mg of Bunker C fuel oil laid eggs with grossly abnormal yolk on the following day. After four days, however, the egg-laying habits of the birds returned to normal (Anonymous, 1977).

Bourne (1975) found that damage to oiled birds is related both to the type of oil and the temperature. The worst damage is caused by fresh, fluid oils which clog plumage and break down its insulating capacity. Fuel oils, which are liquid until dispersed, cause more harm than crude oils, which form "mousse" or tar balls. At higher temperatures, refined oils tend to disappear entirely and crude oils lose their volatile and soluble toxic components, becoming biologically inert solids. At lower temperatures, however, these processes are slowed or halted, impairing the ability of an oiled bird to rid itself of its contamination.

CLEAN TECHNIQUES FOR SPILLS OF BUNKER C FUEL OIL

Three methods were used with some success in the Chesapeake Bay spill: scooping up pools of heavy oil or sand and oil with front-end loaders, cutting and removal of oiled marsh grass, and spraying rocks, piers, and groins with a high pressure water hose. Booms failed to contain the spill due to waves, wind, and tidal action. Vacuum trucks were ineffective due to the viscosity of the oil (Roland, Moore, and Bellanca, 1977).

Westree (1977) noted that the mixing of oil with the soil during cutting of salt grass caused additional contamination. The oil presumably becomes a long-term pollutant, contaminating rhizomes and burrowing organisms for years in the future.

After the spill in Chesapeake Bay, return of the recovered oil to dealers was found to be too costly. Some of the oil was used for roads. Most of the rest was put into steel drums and was burned. Although this procedure removed the oil, it produced a cloud of objectionable black smoke (Wise and Brunk, 1977).

Some of the beaches in Chedabucto Bay were cleaned with chemical dispersal agents. However, due to the isolation and cover of ice in many areas, most of the oil was left untouched (Thomas, 1973).

In San Francisco Bay, straw was spread on oil on land and water. After the straw became soaked, it was gathered and put into garbage dumps or pits to decompose. Plastic booms, vacuum hoses, and skimmers were used to collect some of the oil for shipment to refineries. Shredded styrofoam, spread on the oil to collect it, proved difficult to gather (White, 1971).

Oiled birds in San Francisco Bay were collected by volunteers, cleaned with a bath of mineral oil, dried in a mixture of flour and corn meal, and kept in a warm place for observation. The birds were fed a mixture of water, fish, antibiotics, and vitamin B_1. Despite these precautions, the rate of survival of the treated birds was extremely low (White, 1971; Anonymous, 1971).

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MARINE STUDIES OF SAN PEDRO BAY, CALIFORNIA. PART 15. DECEMBER 1978

OIL, FISHERIES, AND THE HEALTH OF THE ECOSYSTEM: A REVIEW

by

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ABSTRACT. An overview of the effects of petroleum hydrocarbons in the marine environment on fisheries and on ecosystems is presented. Assessments of damage from major spills are reviewed.

ACKNOWLEDGMENT. This review was adapted from a background report to the Marine Fisheries Advisory Committee (MAFAC) of the National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Department of Commerce.

IV. C. OIL, FISHERIES, AND THE HEALTH OF THE ECOSYSTEM

INTRODUCTION

Input of Petroleum Hydrocarbons to Marine Waters

Each year 6 million metric tons of petroleum hydrocarbons enter the ocean (Nat. Acad. Sci., 1975). Of this amount 1% is attributable to offshore production, 44% is introduced from municipal and industrial wastes and river and urban runoff, 35% from transport and offloading operations, and 20% from natural seeps and atmospheric fallout (Table 1). Measured against this total, an acute tanker spill represents a relatively small percentage of annual input. The Argo Merchant spill, while spectacular, represented 1% of the total annual input of oil in the marine environment.

Damage Assessment Problems

During the next decade the demand for oil products will result in continued spillage and damage to coastal fisheries and their environments. The full impact of this oil on the marine ecosystem is difficult to assess in the absence of coordinated scientific assessment programs. It is clear, however, based on our studies in National Marine Fisheries Service and from a search of the literature, that most damage to fisheries has been in nearshore waters. For the most part, damage has been localized. Depending on the extent of exposure and the type of oil involved, recovery of marine populations to former abundance levels can range from weeks to years. The effects of oil on resource populations on a global scale are not known. Studies are just now being initiated to evaluate the effects of petroleum hydrocarbons and other hazardous substances on the mortality and physiology (e.g., genetics, histopathology, biochemistry) of resource populations on the continental shelves.

Assessments of petroleum effects on marine organisms have been largely restricted to laboratory toxicity experiments on individual species. It is difficult to translate these findings to actual environmental conditions. A more serious problem is the difficulty in extrapolating from the results of short-term studies of an acute spill to the long-term impact on population levels, without adequate baseline information on natural population fluctuations in the vicinity of the spill.

Oil Effects on Marine Fish and Shellfish

Oil is a complex mixture of hydrocarbons. Its toxicity to marine organisms is roughly proportional to its aromatic content. The olefin compounds present in refined oils combine with other elements (e.g., hydrogen, sulphur, chlorine, oxygen) to produce toxins that can persist in marine organisms for long periods. The extent of damage from oil on marine organisms is dependent on a number of factors including the type of oil, residence time, rate of evaporation, dissolution, and degradation.

The effects of oil on marine organisms based largely on laboratory toxicity studies have recently been summarized by Sindermann (1978):

> 1. Direct Lethal Toxicity. Soluble aromatic hydrocarbons can be lethal to adults in low concentrations (1-100 ppm), and to the more sensitive larval stages at even lower concentrations (0.1 to 1 ppm).
>
> 2. Sublethal Disruption of Physiological or Behavioral Activities. Sublethal effects may occur in adults in the 10-100 ppb range and are varied, depending on the species tested. Larvae can be affected by concentrations as low as 1-10 ppb. Some lethal effects are: inhibition of mating responses, reduced fecundity, chromosomal abnormalities in eggs, abnormal larval development, decreased feeding activities, and interference with neurosecretory responses.
>
> 3. Effects of Direct Coating and Ingestion of Oil. Mortality can result from the occlusion of gills or digestive tract, entanglement of appendages, or smothering and asphyxiation of sedentary forms. Sublethal effects induce irritation of mucous membrances, important in respiration.
>
> 4. Tainting of Edible Fish and Shellfish. Tainting can result from exposure of fish and shellfish to as little as 1 ppb soluble petroleum components; human detection levels in tissues are 5-550 ppm.
>
> 5. Accumulation of Potentially Carcinogenic Polycyclic Aromatic Compounds in Food Chains. Some of the components of crude oil have been determined (in experiments with terrestrial animals) to be carcinogenic. These compounds occur in the marine environment, and can be accumulated and retained in marine animals.
>
> 6. Changes in Habitats and Ecosystems. Transient changes in the upper layers of the ocean in the immediate vicinity of oil spills, and longer lasting changes in the bottom sediments and associated benthic animals have been observed. Short-term and long-term changes in predator-prey relationships have also been reported."

IMPACTS OF MAJOR SPILLS

Nearshore Impacts

Greatest damage from a spill of petroleum hydrocarbons in a shallow nearshore environment results from the mixing of petroleum hydrocarbons in the water column, and subsequent penetration in the sediments. This action increases the residence time of the oil. Case histories of oil spills in embayments and other littoral environments describe a wide range of lethal and sublethal effects on fish, benthos, algae, and the disruption of ecosystem stability (Clark and Finley, 1977). In each of the cases reviewed where significant damage was demonstrated, the petroleum hydrocarbons persisted at high levels for days and even weeks in acute releases from wrecked tankers, ruptured pipelines, and leaking storage tanks. Damage in areas where petroleum hydrocarbons penetrate the substrate can persist for several years. For example, Dow et al. (1975) reported a loss, over 3 years of 50 million clams, representing 85% of a stock in the immediate vicinity of a No. 2 fuel oil spill in Searsport, Maine.

Buzzards Bay Spill

An instance of severe, but localized damage was reported for a spill of No. 2 fuel oil from a grounded barge in Buzzards Bay, Mass., in 1969. Following the spill, large-scale mortalities of fish, molluscs, and other invertebrates in the tidal and intertidal areas of the wild Harbor area of Buzzards Bay were reported. Later sampling of the area in spring, 1970, revealed massive mortalities of benthic invertebrates. The species composition of the surviving benthos shifted from a typical mixed community to a single species dominance of a pollution indicator--the polychaete worm, *Capitella capitata*. Within two years of the spill, the area showed some signs of recovery. However, eight years later, at least one sampling location did not reach its normal species assemblage. And in the other sampling locations sublethal chronic effects have been detected in fish and crab populations. The clam flats have not yet been reopened (Sanders, 1977).

Chedabucto Bay Spill

A spill of 500,000 gallons of Bunker C fuel oil in 1969 caused severe damage in Chedabucto Bay, Nova Scotia. Approximately 100 kilometers of shoreline were adversely affected. Losses of shellfish, intertidal crustaceans, and attached algae were reported just after the spill. Subsequent monitoring of the area has been continued. It was estimated that 4 to 8 years would be required for recovery of the algal populations. The clam (*Mya arenaria*) populations will require an estimated 10 years to reach half of their former population densities (Vandermeulen, 1977).

Amoco Cadiz Spill

Damage information is incomplete at this time on the impact of the Amoco Cadiz spill. However, direct reports from NOAA members of the Spilled Oil Research Team visiting the site report that damage is extensive. The spill is the largest on record. Some 29 million gallons were released and drifted onto the shore of Brittany in late March 1978 when the vessel ruptured. Wave action was responsible for massive infusion of oil into the sediments. Immediate harvesting saved some of the valuable shellfish beds (oysters, mussels). It is unlikely that the area will be free of oil in time for seeding next crop. Massive mortalities of fish, shellfish, algae, subtidal crustaceans, and birds were observed. Oil has moved into several of the large estuaries causing widespread damage to shellfishing areas (J. Robinson, NOAA/ERL, Boulder; Personal Communication).

Offshore Impacts

Most studies on the effects of oil on fish and shellfish have been concerned with the onshore or nearshore impacts on littoral organisms (Sanders, 1977). Sublethal effects of crude oil have been described for saithe, *Pollachius virens* (pollock), in the immediate vicinity of a grounded tanker off the Norwegian coast (Grahl-Nielsen et al., 1976). In experiments where salmon and saithe were exposed to moderate levels of oil (=50 ugms EKOFISK crude oil/liter seawater) both species showed residues of petroleum hydrocarbons within 7 hrs of dosing. Following termination of dosing after 68 days, both species showed naphthaline levels comparable to those existing prior to dosing, indicating that at moderate dosage levels, effects are sublethal and reversible (Brandal et al., 1976).

Most of the more sensitive egg and larval stages of fish and molluscs are planktonic. They are carried by the tides and currents, lack the ability to avoid oil spill areas, and are subject to large-scale mortality from oil, particularly in the surface and near-surface waters. Laboratory studies have shown that crude oil can damage developing fish eggs and cause high mortalities in cod, herring, and capelin embryos (Kühnold, 1969, 1974; Johannessen, 1976). Also, plaice larvae and other species from the Black Sea suffered high mortalities from exposure to crude oil in laboratory experiments at exposures as low as 0.1 ppm (Mironov, 1968, 1969). Aromatic hydrocarbons (e.g. benzene, toluene) are highly toxic to fish larvae. High mortalities and serious sublethal deformities were observed among Pacific herring and northern anchovy dosed with concentrations as low as 5 ppm (Struhsaker et al., 1974). Observations from collections made at sea have shown that zooplankters, particularly copepods, can ingest particles of oil and pass them through the gut without any observable negative effects (Conover, 1971; Parker, 1970). Some species of adult fish have been observed to avoid areas contaminated with oil. Bivalve shellfish (quahogs, scallops, mussels) are sedentary and have only limited capability to purge themselves externally and internally of large amounts of petroleum hydrocarbons. They suffer significant mortalities in areas where sediments become contaminated with oil (Blumer, et al., 1970; Thomas, 1973, Jeffries and Johnson, 1975). While oil damage has been demonstrated on the continental shelf, based on short-term studies, little is known of the longer-term effects of chronic exposures. Proper assessments of the impact of oil on the continental shelf ecosystem will require the combined effort of extensive sea sampling and experimental support studies.

The Argo Merchant Spill

Prior to the Argo Merchant spill in December 1976, no large-scale effort to assess oil-related biological damage had been undertaken in the open waters of the continental shelf off the northeast coast. The investigators participating in the damage assessment studies emphasized the difficulties in attributing changes in the abundance and condition of marine populations to oil as compared to changes from other causes. They recognized that attempts made to isolate oil-induced mortalities or sublethal effects need to be viewed against the background of natural fluctuations and the complexities of multispecies interactions at different trophic levels and over a range of spatial and temporal scales. Moreover, studies to deal with these problems need to be in place and operational long before any acute spill event (Sherman and Busch, 1978). The damage assessment of the Argo spill was based on multidisciplinary studies of both changes in population levels and the physiological conditions of the principal species.

The results were sufficient to indicate that the impact of Argo oil on the populations of Nantucket Shoals was minimal based on the short-term assessment studies carried out during the 12 months following the spill. Supporting evidence for this conclusion was found in both the population stuides and the physiological effects studies done at the tissue and organism levels for molluscs, fish, birds, zooplankton, and benthic crustaceans. In the histopathological, biochemical and physiological studies the recovery from initial observations of sublethal impact to "normal" conditions was reported for each of the groups of organisms examined, except for marine birds. The bird mortalities caused by oil, however, were few and the impact on bird stocks was not considered significant.

Studies conducted after the spill showed significant impact of Argo oil on the viability of cod and pollock eggs. High mortalities, and malformed embryos attributed to oil-caused cytogenetic damage were collected from the spill zone. Mortalities ranged from 20% to 80% of the embryos collected from the spill zone (Longwell, 1978). The genetic damage observed in developing cod and pollock embryos was localized, and it is unlikely to have had a significant effect on subsequent year-class recruitment of these stocks. Laboratory exposures of cod eggs to water-soluble fractions similar to the Argo No. 6 oil caused sublethal damage (reduced heart-beat rates) at doses of 100 ppb and high mortalities at exposures of 250 ppb (Kühnhold, 1978). Although levels exceeding 250 ppb of oil were detected following the spill, the area of concentration was limited to the immediate vicinity of the Argo wreck and is likely to have affected a relatively small fraction of the Nantucket Shoals cod stocks.

Trophic pathways of Argo oil were observed among the zooplankton and benthos leading directly to important fish stocks. Further comprehensive stomach analyses of fish revealed a minor incidence of "oiled" prey in the digestive tracts of fish. Less than 5% of the fish examined showed any traces of Argo oil in tissue samples collected within 30 days of the spill. On subsequent surveys of bottom fish no Argo oil traces were found in fish, shellfish, or zooplankton samples. Commercial catches and bottom trawl surveys of the spill zone and adjacent areas showed no evidence of reduction in the population densities of the more important fish and shellfish stocks.

The limited short-term impact was attributed to the mitigating ecological circumstances during the spill: (1) biological productivity was at an annual low, (2) no large-scale deposition of oil was observed in the sediments, and (3) the high velocity wind and currents of the season carried the oil, which was largely limited to the surface in vertical distribution, rapidly offshore while it was in the process of evaporation, emulsification, and dissipation in the turbulent upper layers of the water column.

The EKOFISK-Bravo Blowout

The impact of the Bravo blowout during April, 1977, in the EKOFISK Field off Norway in the North Sea was also minimal. During the 7.5 days that Bravo remained uncapped, 3.8 million gallons of EKOFISK crude oil spread over an area of about 4,000 km^2 in the central North Sea. The Institute of Marine Research at Bergen initiated the first survey of the ecosystem and maintained liaison with vessels of other countries that later joined in the effort (Denmark, Fed. Rep. of Germany, England, Scotland). An attempt was made to sample the area containing oil and also sample adjacent "clean" waters as a control. Sampling was designed to obtain information on changes in abundance and distribution of living resources, record mortalities, monitor water chemistry, study microbial degradation, and monitor hydrographic conditions.

Chemical sampling included collections through the water column at 1 and 5 m and samples of fish and zooplankton that were frozen for petroleum hydrocarbon analysis. In addition, collections were also made to obtain samples of hydrocarbon degrading bacteria. Phytoplankton standing stock and productivity measurements were made to estimate the possible effects of oil on primary productivity. Ichthyoplankton were collected at each of the sampling locations. Fish distributions were tracked with echosounders, and sampled with pelagic and bottom trawls.

From the preliminary results it was apparent that the spring bloom triggering the onset of the growing season for larval fish had not yet developed at the time of the blowout. The water column was thermally mixed and temperatures were lower than normal. Primary production was at a low level. Spawning activity was also minimal. Only a "few" eggs were collected representing five species--whiting, haddock, cod, dab, and plaice. Sand eel larvae and "cat fish" larvae were present in low numbers. The fish biomass was also low as recorded in echograms and verified from pelagic and bottom trawl catches.

After considering the observed low levels of hydrocarbons in the water and the scarcity of commercial-size fish, scientists at the Institute of Marine Research concluded that it was," . . . unlikely that serious effects on the production of fish resources have occurred." Other trophic levels may have been more seriously affected. Evidence was found of an area of reduced primary productivity extending 10 nautical miles eastward of the Bravo platform where "some" dead fish eggs and copepods were found. Additional surveys were later conducted in cooperation with other North Sea countries to investigate the sublethal, chronic effects of the spill on the marine ecosystem. The result of these studies is not yet available.

Mitigating Biological and Environmental Conditions

To date no comprehensive study has been completed on the effects of oil on the productivity of marine populations of a continental shelf area. The recent *Argo Merchant* spill along with the Bravo blowout represent case studies for which the long-term effects studies are continuing. Preliminary findings are similar with respect to the minimal impact observed on the mature stages of fish. No evidence of massive mortalities was reported associated with the two spills. However, in both cases sublethal chronic effects were detected. More immediate impact on the ecosystem was observed in the Nantucket Shoals area where *Argo Merchant* oil was suspected as the cause of cod and pollock embryo mortality. Also, oil was ingested by filter feeding copepods and entered the food web. It is important to note that in both cases the spill event was during a period of low biological productivity. The impacts would have been far more severe had they occurred during the spring and summer, when many of the important fish species spawn. Fish eggs and larvae are sensitive to petroleum hydrocarbons. Mortalities have been reported at levels of 100 ppb and concentrations of up to 250 ppb were found in the vicinity of the *Argo* wreck.

During the warmer months of the year eddy systems are well developed on the continental shelves. The large volume of oil carried by the supertankers, if released into an eddy system in spring or summer, could cause significant damage to fish eggs and larvae. These sensitive early developmental stages are most abundant during the warmer months in temperate waters. They undergo high natural mortality. Additional losses of the small percentage of survivors caused by toxic petroleum hydrocarbons could seriously impact recruitment, should a spill coincide with the peak hatching and early larval growth period. Contamination of the microzooplankton utilized as food by first-feeding larvae could also prove disastrous to an incoming year-class of fish.

Ecosystem Impacts

In stressed ecosystems it has been observed that the primary production level remains relatively constant. Significant shifts occur among the species composition of primary and secondary producers. Smaller species gain a competitive advantage for available space and food over the larger species. The species shift results in the accelerated growth of fast-growing, smaller, and generally less desirable species (Steele and Frost, 1977).

Experimental Results

Results from recent experiments tend to support the size-selection hypothesis. Several large plastic enclosures placed in deep water off the British Columbia coast were "seeded" with local phytoplankton, microzooplankton, and macrozooplankton populations and dosed with No. 2 fuel oil. Other enclosures were "seeded" with similar populations and used as experimental controls. The plankton populations within the oil-contaminated enclosures shifted after dosing from essentially a large-celled diatom and large copepod fauna to a dominance of microflagellates, and small microzooplankton, including small copepods (Lee & Takahashi, 1976).

Recent studies in large-scale microcosms at the University of Rhode Island have also revealed adverse effects of oil on experimental populations. After the dosing of No. 2 fuel oil at levels of 100-150 ppb, the population numbers of copepods were reduced and inhibited in their physiological responses (S. Vargo, URI, Personal Communication).

The experiments demonstrate the significant adverse impact of oil-induced stress on controlled ecosystems. It is difficult to extrapolate these findings to actual *in situ* conditions. The results, however, corroborate other observations made recently in the North Sea and off the northeast coast of the U.S.

The North Sea Ecosystem

It has been suggested that the stress of overfishing and/or environmental changes in the North Sea has resulted in a species shift in abundance from large pelagic species--mackerel and herring--to smaller, fast-growing, and less desirable (from an economic point of view) species, e.g., sand lance, sprat, and Norway pout (Hempel, 1978; Ursin, 1977).

Other significant changes in the North Sea have been reported for the plankton populations (Robinson, 1970; Colebrook, 1972). During the past two decades a shift has been observed in species composition of the phytoplankton and zooplankton. The spring phytoplankton bloom has been delayed with the initiation later in spring now than in the 1950's. Also, rather than the large diatom cells dominating the spring bloom, smaller dinoflagellate cells predominate now. This shift from larger to smaller cells may have affected the species composition of the zooplankton favoring the development of the smaller copepod species. The causes for the long-term shifts in species composition are not known. Whether the changes are attributable to fishing pressure, cyclical or natural environmental fluctuations, reduction in the stock size of principal zooplankton-feeding fish (mackerel, herring), or the impact of pollutants remains an open question.

The Georges Bank-Gulf of Maine-Middle Atlantic Bight Ecosystems

Off the northeast coast mackerel and herring populations have been reduced during the past decade. In fact, the entire biomass of economically valuable food fish has decreased over 50% in the Georges Bank-Gulf of Maine-Middle Atlantic Bight areas since 1958 (Clark and Brown, 1977). Much of the decrease is the result of heavy fishing pressure and to a lesser degree environmental changes. The effects of large-scale dumping of oil and other industrial and urban wastes may also have contributed to the decline. Unfortunately, the systematic physiological baseline data required to separate the various components of mortality--fishing, natural, and pollution induced--are not yet available.

Some evidence, however, is now available suggesting a marked increase in the abundance of larvae of the sand lance (*Ammodytes americanus*) off the northeast coast. Whether this marks a shift in the species composition of the pelagic fish fauna from the dominance of mackerel and herring to a fast growing, smaller and less desirable species like the sand lance is not clear. Additional studies are underway to verify earlier findings, showing an increase of sand lance. In 1966 they constituted less than 20% of the spring larval ichthyoplankton community. Their densities increased to 85% in spring, 1977.

Environmental conditions off the Mid-Atlantic Bight have been the subject of an intensive study by the NMFS and NOAA/MESA program for several years. In 1976 a dramatic reduction of oxygen off the New Jersey coast resulted in mass mortalities of bivalve molluscs. The causes for the anoxic condition appear to be in part the result of unique hydrographic conditions (Armstrong, 1977). However, if a tanker had grounded in the busy shipping lanes in the vicinity of the mortality and released large amounts of oil, the ecological damage assessment would have become even more complex. It is likely that petroleum hydrocarbons would have been implicated as a source of the mortality. The scenario may not be too far from reality. As the multiple use of continental shelf resources grows, the complexities of the ecological interactions become more difficult to separate. Fortunately, sufficient "baseline" data were available to sort out the alternative possibilities for the mortalities, and offer a reasonable hydrographic explanation.

In summary, off the northeast coast the fish stocks are in a stressed condition. Much of the reduction in biomass is related to heavy fishing mortality. But, the impact of the increasing pollution of the area cannot be discounted as a contributing agent without further study.

DISCUSSION

Prognosis for the 1980's

The scientific literature on the effects of petroleum hydrocarbons is based largely on laboratory toxicological and bioassay studies. Exposures to petroleum fractions at levels 100 ppb can be lethal to a wide array of marine species ranging from protozoans to chordates (Craddock, 1977). The critical questions, as yet unanswered, are concerned with how to estimate damage to populations under *in situ* conditions. Analysis of sea water and tissues for petroleum hydrocarbon levels is difficult to separate from naturally occurring hydrocarbons in marine organisms, particularly at low levels. Analytical methods are expensive, requiring sophisticated equipment and highly trained personnel. While some progress has been made, it has not been of sufficient scope to provide definitive answers to key questions:

(1) How best can the effects of petroleum hydrocarbons on fish stocks and their environments (ecosystems) be assessed quantitatively?

(2) Are the alterations observed in the nearshore areas from the contamination of petroleum hydrocarbons reversible?

(3) Can we continue to input massive amounts of petroleum hydrocarbons into the ecosystem with little risk of ecological disaster?

These questions are not readily answered. The problems are important and they should be addressed not only in the context of oil pollution but they should be expanded to include the effects of other hazardous substances in marine waters.

We have not been treating the problem of petroleum hydrocarbon pollution adequately. Our scientific studies have been generally short-term and not designed to answer the three questions. They have not been formulated, as yet in an urgent sense, stated as objectives, and programmed for solution. For questions 1 and 2, partial answers can be formulated. Some effort has been directed to the initiation of a balanced programmed program to quantitatively monitor population changes and physiological condition or "health" of the key marine populations on the continental shelf. With respect to question 2, perusal of the literature provides some insight to the solution. If the oil does not penetrate the sediment of a spill area, recovery can be measured in weeks or months. When the petroleum enters the sediments the recovery process can take years, or in the worst cases, no full recovery can be expected. Sediments in Raritan Bay and the New York Bight contain thousands of parts per million of long-chain petroleum hydrocarbons. In areas of chronic discharge, bivalve mollusc populations show high hydrocarbon levels initially. These are then reduced as the organisms develop resistance. Although the community may return to pre-spill species composition and densities it is likely that the tainted condition of the benthos, particularly bivalve molluscs,will preclude their use as a marketable product.

The answer to the third question is an enigma. The approach to the problem has been piecemeal. Responsibility for assessing ecosystem damage has been divided among several agencies (*e.g.*, EPA, BLM, NOAA, DOT), then given minimal support. Legislative authority for getting on with the job may rest with NOAA in the Marine Protection Research and Sanctuaries Act of 1972 and the Fisheries Conservation and Management Act of 1976. More recent legislation now pending (Ocean Pollution Research and Monitoring Act S-1617) clarifies the problem, the responsibility, and provides the basis for the necessary budgetary support to mount a comprehensive program.

During the next decade the demand for oil will impact more directly on fisheries. Damage can be expected from both chronic and acute input of petroleum hydrocarbon and other toxic substances. The probability for greater input is heightened with the expanding development of continental shelf gas and oil reserves (e.g., pipeline ruptures, transport accidents, storage tank leakage, offloading seepage). A summary of oil spill events in the waters adjacent to the U. S. is given in Table 2. The present background levels of petroleum hydrocarbons may be sufficiently persistent to damage the more sensitive species of phytoplankton and fish eggs and larvae inhabiting the surface waters of the continental shelf.

The surface plankton community known collectively as "neuston" is most susceptible to petroleum contaminants. Significant amounts of tar balls persist in surface waters off the east coast of the United States. Larval bluefish, flounder, tuna, marlin and other important resource species have been collected in neuston nets contaminated with tar (Sherman *et. al.*, 1974). The level of oil and tar contamination in neuston samples taken between Virginia and Cape Cod is low but persistent (0.05 mg/m^2 to 1.04 mg/m^2 in 1972-73). At least 30% of the samples collected from the area were contaminated. The percentage of samples and weight of the tar mass collected increased in the Gulf Stream and off the Bahamas (Table 3). More recently, qualitative estimates were made of particulate oil and tar in 332 samples collected from the Georges Bank Nantucket Shoals area. Of this number, 36% were contaminated with oil (Sherman and Busch, 1978). Tar clumps have been found in surface water throughout the Atlantic. Morris and Butler (1973) estimate the standing stock at 86,000 metric tons, with concentrations in the Sargasso Sea 3.6 times greater than the average weight of daytime zooplankton (9.5 gm/m^2 *versus* 2.6 gm/m^2). Tar clumps constituted about 20% of the weight of neuston samples collected by them south of the Grand Banks. The effect of oil residues on neuston populations is not clear, and needs to be addressed.

Long-Term Assessments

The grounding and breaking of the *Argo Merchant* and subsequent groundings of other oil tankers on the continental shelf are dramatically illustrative of specific events that are not predictable. For example, the Northeast Fisheries Center is frequently requested by responsible officials -- local, state and federal -- to assess the impact of major environmental incidents on the fishery resources of the northeast continental shelf. To deal with these incidents special studies are initiated to assess the impact on the environment and living resources. These efforts, however, are of limited duration and conducted with little information on the initial physiological condition of the living resources. Information on the baseline conditions or health of the stocks is inadequate. We are dealing with a complex system that requires a combination of short-term tactical observations that can be evaluated against a background of long-term baseline information on the condition and health of fish and shellfish stocks.

Ocean Pulse

In order to effectively assess pollution damage an approach is needed that: (1) encompasses the coordination of the short-term assessment studies of various groups and agencies conducted in response to a pollution "event," (2) provides for regionally oriented long-term monitoring of ocean environments and populations, and (3) provides suitable information for interim or near-term policy guidance and decision making. Because the pollution "event" can occur at any site over the continental shelf, an integrated approach is being developed that couples in-depth physiological baseline studies (*e.g.*, genetics, histopathology, biochemistry) at specific sites with long-term monitoring of changes in the abundance of the populations of fish and other key species in the ecosystem.

Table 1. Petroleum Hydrocarbons in the Ocean. Adapted from NAS, 1975.

Input	Million Metric Tons per Annum	Percent of Total
Transportation Tankers, dry docking, terminal operation, bilges, accidents	2.133	35
Coastal refineries, municipal and industrial waste	0.8	13
Offshore oil productions	0.08	01
River and urban runoff	1.9	31
Atmospheric fallout	0.6	10
Natural seeps	0.6	10
TOTAL	6.113	100

Table 2. Incidence of Oil spills in U.S. Navigable Waters Including Spills beyond the Contiguous Zone which Threatened the Contiguous Zone. From Project Development Plan, Office of Assistant Administrator for Research and Development, NOAA, March 1978.

	Under 10,000 gal.		10-100,000 gal.		100,000 - 1,000,000 gal.		>1,000,000 gal.		Total	
	Number	Volume (gal.)	Number	Volume (gal.)	Number	Volume (gal.)	Number	Volume (gal.)	Number	Volume (gal.)
1974	13,765	2.9 million	169	1.7 million	30	7.1 million	2	2.3 million	13,966	16.9 million
1975	10,067	2.2 million	94	2.5 million	16	4.8 million	4	5.0 million	10,141	14.4 million
1976	10,553	2.4 million	90	2.4 million	13	3.1 million	4	16.2 million	10,600	23.1 million

Table 3. Percent Occurrence, and Average Concentrations (mg/m^2) of Tar by Areas in Summer 1972 (July-August 1972) and Winter 1973 (January-March 1973) during MARMAP Survey Operations. From NBS Spec. Publ. 409, December 1974.

Survey	Region	No. of Neuston Tows	Percent w/Tar	Concentration mg/m^2
S	Va-Cape Cod (coastal)	29	31	0.18
W	VA-Cape Cod (coastal)	29	38	1.04
S	Va-Cape Cod (offshore)	52	83	0.77
W	Va-Cape Cod (offshore)	51	59	0.05
S	N.C.-Florida (Gulf Stream)	32	78	0.23
W	N.C.-Florida (Gulf Stream)	48	90	1.22
S	N. Antilles & Bahamas	39	87	3.9
W	N. Antilles & Bahamas	47	96	4.8

(S-Summer & W-Winter)

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