# BASELINE STUDIES AND EVALUATION OF THE PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF NEARSHORE DREDGE SPOIL DISPOSAL, PEARL HARBOR, HAWAII

## PART C

## LONG-TERM EFFECTS OF DUMPING

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# SUMMARY OF FINDINGS

This study has been concerned with the evaluation of geological, water chemistry, and biological samples taken at the Pearl Harbor disposal site, Oahu, Hawaii, immediately after and for a 6-month period following the disposal of dredge spoil. The general conclusions based on the results of the sampling program are that minimal adverse environmental effects have resulted from spoil disposal at the recommended site (21°15.9'N, 157°56.7'W).

## 1. Geology and Physical Oceanography

A total of 36 grab samples have been taken within the general disposal area and when possible close to the previous Part A stations, 30 of which were examined for geological purposes. Four samples were taken along a southwesterly transect extending from the specific dump site approximately 4 miles, to assess possible spoil transport out of the site by bottom currents. Field observations indicate that deposits of coarse-sized sediments, coral rubble, shell fragments and sand are present in the immediate vicinity of the specific dump site. Fine-grained sediments are not predominant in the grab samples, are much more widely dispersed, and now extend over most of the general disposal area.

## 2. Water Chemistry

Surface water samples were collected from seven stations within the disposal area. Results of previous studies indicated that water quality at the dump site returned to pre-disposal conditions within approximately 24 hours after disposal operations had ceased, with the exception of slightly higher heavy metal concentrations in the surface waters. Results of the water chemistry investigations have revealed that concentrations of heavy metals at the disposal site are as low or lower than those found at nearby stations.

The distribution of sediment traced by the metals content indicates a dispersion of spoil approximately two miles westward from the disposal site. A significant increase in total metals concentration was noted in the bottom sediments as compared to the Part B studies.

Many of the individual metal concentrations were higher than those found in the direct analysis of the spoil, leading to the conclusion that other sources, most likely the Sand Island sewage treatment plant outfall, are responsible for the higher metals concentrations.

Examination of body burdens in shrimp (Heterocarpus ensifer) and zooplankton samples revealed no evidence of bioconcentration of heavy metals.

3. Zooplankton

A series of zooplankton tows was taken after the completion of the dredging operations to determine the immediate and long-term response and recovery rates of the zooplankton community to the disposal of dredge spoil. Tows were taken in June, July, September, and December. Comparison of the organisms from the Part C tows with those obtained in Parts A and B has documented an increase in zooplankton populations during dumping, followed by a decrease to levels well in excess of baseline values. The long-term increase was attributed to the relocation of the Sand Island sewage outfall nearer the disposal area and not to dredge spoil disposal.

4. Benthic Biology

A total of 34 grab samples for benthic faunal analyses was obtained during the Part C studies within and adjacent to the general disposal area.

In general, the number of pellets and small tracer species in the Part C samples showed a factor of 10 decrease in abundance as compared to the Part B results. The overall area containing pellets and tracer species has been reduced by approximately half.

Except for the immediate area of the dump site, the benthic foraminifera showed a trend toward recovery to predisposal populations, based on a comparison of pre- and postdisposal species lists.

5. Fisheries

Shrimp traps were set in the general area of the specific dump site and a control area just south of the southwestern boundary of the general disposal area. Total numbers of shrimp captured in the dump site area increased from the predisposal collections in September 1976, and numbers in the control site decreased. Possible explanations for the observed population changes include seasonal fluctuations and variations in specific trap locations.

Two important fisheries, opelu and akule, are known to exist in the Ewa ledge (Barbers Point ledge) area approximately 5-7 miles west of the specific dump site.

Based on the State Fish and Game catch records, the commercial opelu fishery has steadily decreased in value from September 1970 to September 1977. The akule fishery has remained fairly constant. There is no evidence that dredge spoil disposal is influencing these fisheries.

## Recommendation

The evaluation of the data obtained during the Part C studies and that previously analyzed in Parts A and B, has supported our previous recommendation for continued dredge spoil disposal at the specifically designated disposal site, 21°15.9'N, 157°56.7'W. We have found no evidence of significant, long-term, adverse effects on the geological conditions, water quality, or biological communities that may be attributed to the disposal of dredge spoil in this area.

# I. INTRODUCTION

The environmentally acceptable location for the disposal of dredge spoil is a matter of continuing concern, particularly by those faced with the responsibility for maintenance of harbors, marinas, canals, and protected coastal embayments. The Corps of Engineers' nationwide Dredged Material Research Program (DMRP) is an example of the effort that has been, and continues to be provided at the national level to address the problems of dredge spoil disposal. Hawaii's unique geographical position and geological structure do not lend themselves readily to extrapolation of environmental considerations addressed and observed in many of these mainland dredge spoil disposal site studies. For the most part, disposal of sediments along the continental margins of the mainland involves disposal in shallow waters on the continental shelf, or at most the somewhat deeper continental borderland found off the Pacific coast. In either case, transportation time and the attendant costs necessitate disposal within a few miles off shore, at depths generally less than 75 meters and frequently depths less than 30 meters.

In contrast the State of Hawaii, which rises abruptly from the deep sea floor, is characterized by exceedingly deep water within a few miles of most of the shoreline. Environmental considerations for the selection and evaluation of suitable offshore dredge spoil disposal sites must therefore be considered in terms of deep water (>200 fathoms) and oceanic conditions.

The present study represents a major effort to evaluate the unique environmental considerations required for the safe disposal of dredge spoil in deep, near shore, coastal waters. Part A of this study involved the collection of certain baseline data and the selection of an environmentally acceptable disposal site approximately 2½ nautical miles due south of Pearl Harbor, Hawaii (Chave and Miller, 1977. Part A). The second phase (Part B), of the study addressed the actual dumping operation and included monitoring of the distribution of the spoil in the water column, on the bottom, and its immediate effects on the biota. The present report, Part C, deals with the longer term effects of dredge spoil disposal, its transport along the bottom or in the water column, and its effects on the pelagic and benthic faunal communities.

## II. DESCRIPTION OF AREA

The dredge spoil disposal site under study lies off the southern coast of Oahu, Hawaii, in a crescent-shaped area beginning at latitude 21°16.8'N, longitude 157°56.7'W, thence on a line to latitude 21°15.9'N, longitude 157°56.1'W, thence on an arc to the right with a radius of 2½ nautical miles to latitude 21°15.9'N, longitude 157°59.0'W, thence on a line to latitude 21°16.8'N, longitude 157°58.5'W, thence on an arc to the left with a radius of 1½ nautical miles to the point of beginning (Figure II-1). The origin of the radii of the two arcs is the approximate location of the Pearl Harbor Entrance Channel Buoy No. 1. The area of this site is 3.54 $mi^2$ (898 ha). The bottom slopes gently to the southeast, from about 160 fm at the northwest corner to about 240 fm at the southeast corner.

The results of the data obtained during the Part A studies of this project led to the recommendation that all dumping during the Part B studies take place in the southeast sector of the disposal area at the specific dump site coordinates of 21°15.9'N, 157°56.7'W.

Sampling has been conducted throughout the entire area of the disposal site, and along a transect extending outward in a southwesterly direction (245°T) approximately 2 miles from the specific dump site.

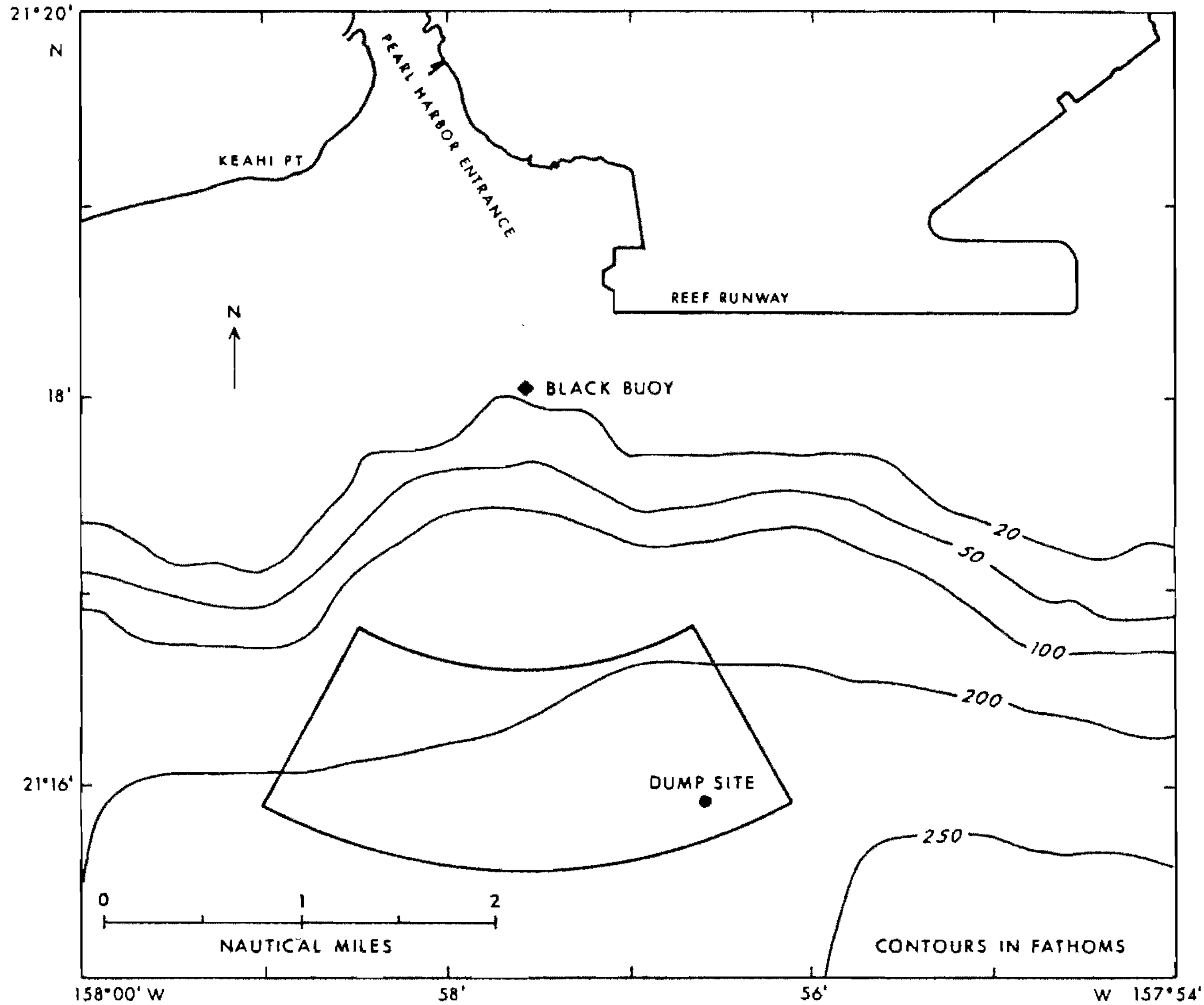


Figure II-1. Location of study area.

# III. GEOLOGY

By

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A. Objectives

The first phase of this project (Chave and Miller, 1977. Part A), was to determine baseline characteristics of the dump site itself, including bathymetry, seismic structure of the substrate, and mineralogy and grain size of the surface sediments.

The second phase (Chave and Miller, 1977. Part B) of the study was designed to observe the behavior of the dredge spoil as it was dumped, the resulting sedimentation, and the short-term geological effects upon the dump site. In addition, a comparison was made between the field observations and the results of a predictive computer simulation of open-ocean dredge spoil disposal (Koh and Chang, 1973; Johnson, 1977).

The objective of this third phase (Part C) of the study is to determine the long-term physical fate of the dredge spoil dumped off Pearl Harbor in May, 1977. To address this aim, grab sampling and bottom photography have been employed. Core sampling to determine the vertical dimension of deposited spoil was originally proposed but discarded, due to the difficulties previously encountered (Part B), that is, because the coarseness of the bottom sediments prevented penetration by the core barrel.

B. Methods

1. Grab Samples

Grab samples were collected on September 28 and 29, October 5 and 6, and December 6 and 9, 1977. The sampling in September and October was done aboard the R/V Machias, using a Petersen grab sampler. The December samples were collected aboard the R/V El Greco, using the Petersen grab sampler and a rotary clam grab sampler. Navigation consisted of radar ranges and visual bearings to objects ashore, with an accuracy of ±200 meters.

During previous work on the project, it was found that most of the fine-grained dredge spoil was either widely dispersed or removed entirely from the area rather than being retained where deposited in large quantities at the designated dump site. Strong and variable currents were measured at the site during Part B studies. These currents, particularly those near the bottom, were thought to be the means by which the suspended sediment was removed from the disposal area. Consequently, starting from the designated dump site, a series of grab samples was taken along a line in the direction of estimated sediment transport from the initial dump site, that is, in the direction of net bottom current flow.

To determine the net bottom current, the mean bottom current values from the Part B report (7.9 cm/sec to the west and 4.3 cm/sec to the south) were added vectorially, resulting in a velocity of 9.3 cm/sec at 245°T. We therefore sampled along a line in a southwesterly direction from the designated dump site (at about the location of Station 20 in Figure III-1) for about four miles. Otherwise, grab sample stations were selected such that a comparison could be made with Part A samples.

Laboratory analysis of the sediments consisted of grain size analysis and X-ray diffraction work to determine mineralogy. The grain size analysis, following the methods of Folk (1974), was carried out by dry sieving, using a Ro-Tap machine for fifteen minutes per sample, for phi sizes -1.5 to 4.5. For the fraction finer than 4.5 phi diameters, an optical extinction centrifuge system was employed. Statistical treatment by Griffith's methods (1967), of the data was done numerically on an IBM 370/158 computer at the University of Hawaii Computing Center.

X-ray diffraction analysis was done using a Phillips-Norelco diffractometer-goniometer system; the diffraction patterns were recorded on paper charts. Diffraction peak identification was accomplished by comparison with standard diffractograms of pure minerals and with search manuals (e.g. Chen, 1977). Peak heights were converted to semi-quantitative data using a Deep Sea Drilling Project computer code (Rex, 1969; Fan & Rex, 1972).

2. Core Samples

Due to the coarseness of the bottom sediments, as shown in the Part C grab samples, it was decided that it would be futile to attempt again to core the cottom.

3. Bottom Photography

On December 28, 1977, the R/V Kana Keoki was in the vicinity of the study area to test bottom camera gear. At our request, the ship obtained a line of bottom photos across the study area along nearly the same track line photographed in Part A (see Figure III-2). A standard E. G. and G. underwater camera was mounted on a sled which was towed across the area from west to east at a speed over the ground of about three knots, taking black and white photos at roughly

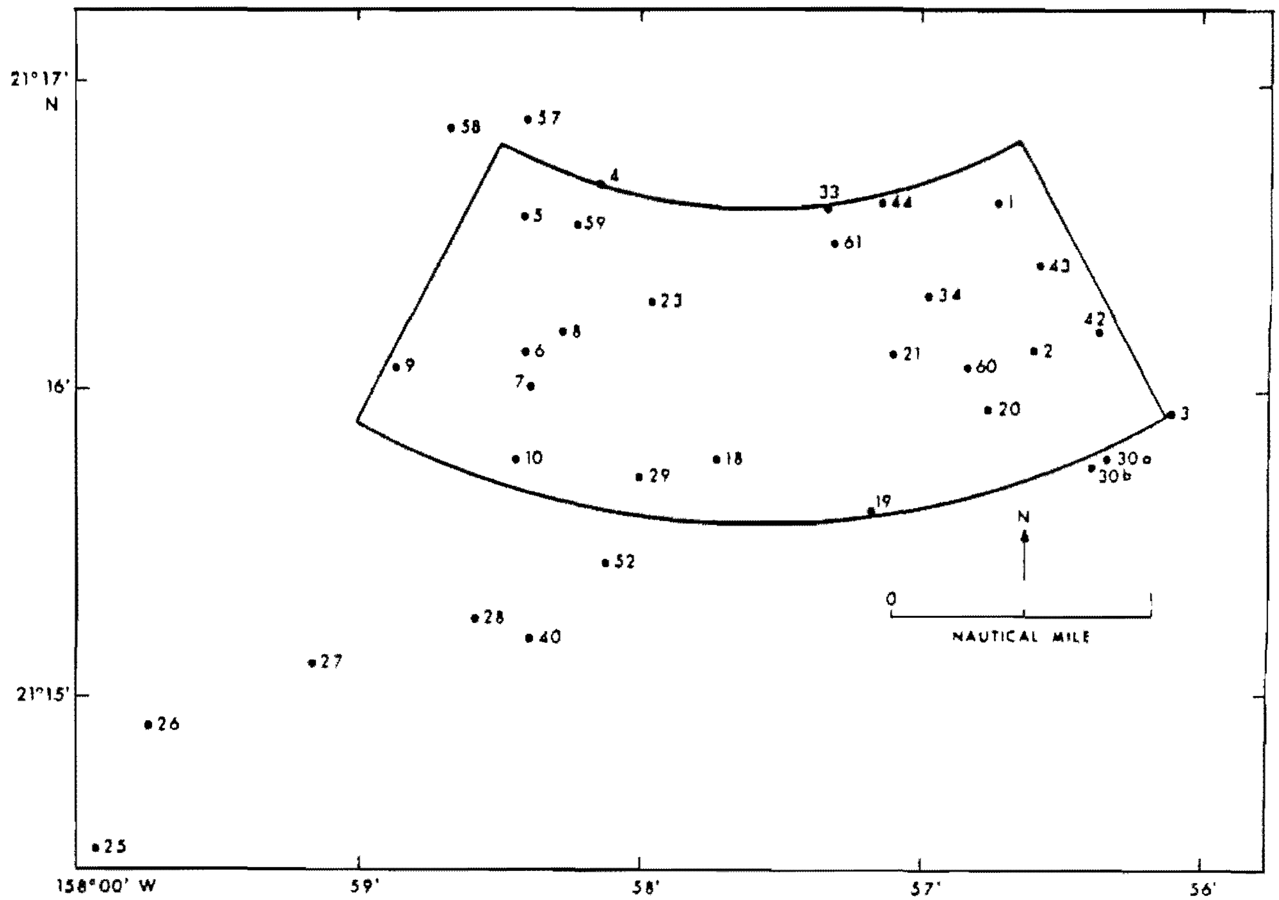
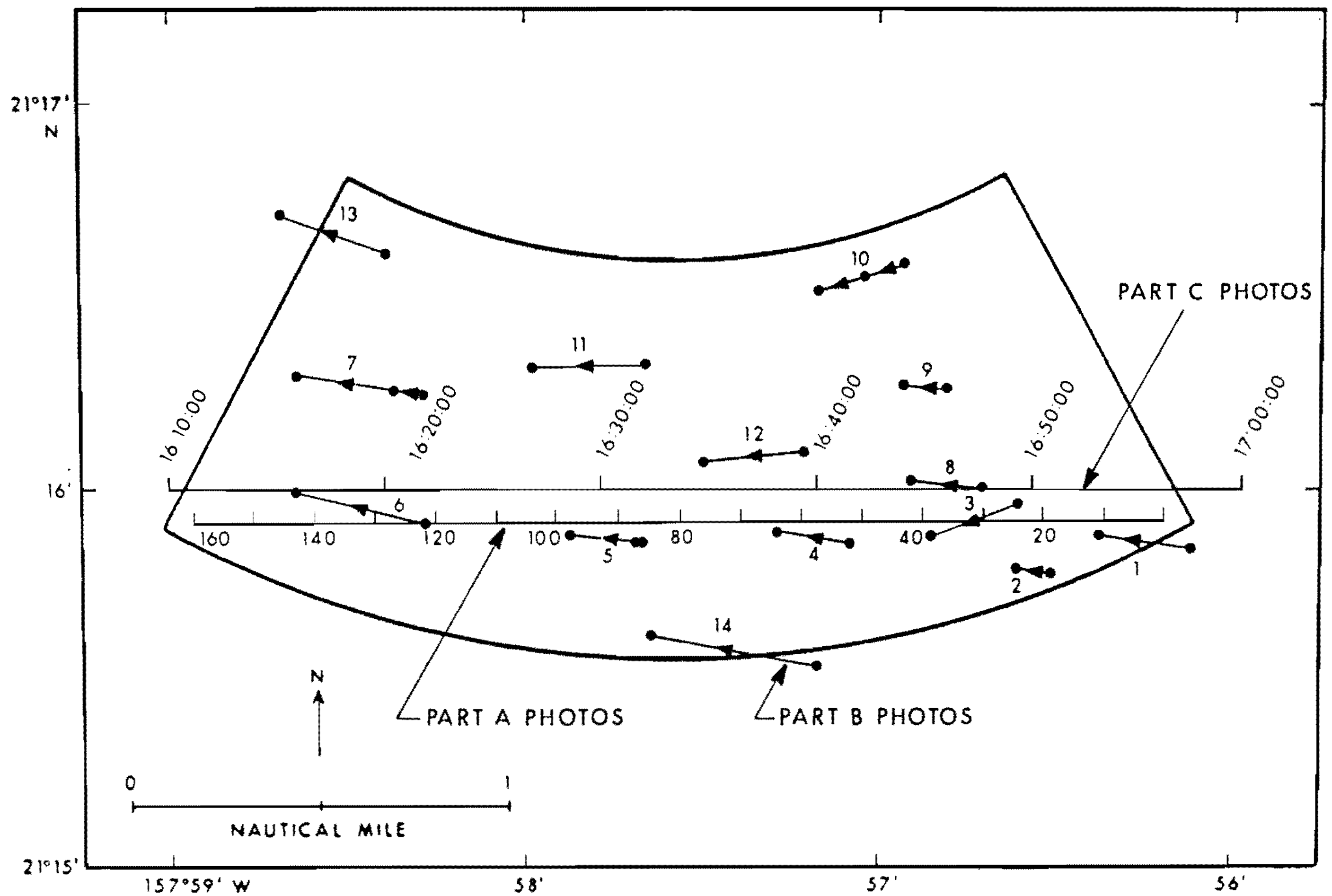



Figure III-1. Locations of grab samples taken six months after cessation of disposal operations. Numerals represent sample numbers referred to in following text, tables, and figures.

Figure III-2. Location of bottom photography done in Part A, Part B, and Part C of this project. Numbers along Part A track line indicate sequential order of photographs. Numbers with the short Part B track lines represent the identification numbers of the particular trawl. Numbers along the Part C track line are the local times (in hours: minutes:seconds) when the photographs were taken.



ten-second intervals. Radar fixes were taken at each end of the photo trawl, as well as at quarter-hour intervals along the line.

C. Results

1. Grab Samples

A total of 36 grab samples was obtained, of which 30 were examined for geological purposes. Table III-1 is a general summary of samples collected. Table III-2 presents grain size analysis. X-ray mineralogy and spoil identification are shown in Tables III-3 and III-4, respectively.

As in Part B of this study, dredge spoil identification was based on comparison with the pre-disposal surface-sediment mineralogy. The Part A samples were almost entirely carbonate (calcite and aragonite) minerals; some had small amounts (<10%) of plagioclase (Part A). By contrast, the sediments of Pearl Harbor, and therefore the dredge spoil, contained one-third to two-thirds carbonate materials, plus appreciable amounts of basaltic suites of materials including plagioclase, augite, magnetite, and olivine, or secondary minerals produced by the weathering of basalt, including hematite, gibbsite, kaolinite, and montmorillonite (Turner, 1975). The detection of magnetite, much plagioclase, goethite (a weathering product of pyrite, magnetite, or iron-silicate minerals) or halloysite (a weathering product of plagioclase) indicated dredge spoil presence in a sample. One sample found to contain chlorite (a clay mineral not found in Part A samples) was taken at the farthest offshore station. This sample was not thought to contain dredge spoil, but instead to represent a deeper water sediment regime. The identification of spoil in the samples based on these criteria appears in Table III-4.

Graphic representation of the X-ray mineralogy of the samples taken before (Part A), during (Part B), and after the dredge spoil disposal (Part C), are shown in Figure III-3 for comparison. The shift in mineralogy toward "other" minerals (halloysite, magnetite, etc.) is readily detected between the "before" and "during" samples. The apparent further spread of "other" minerals between the Part B and Part C samples may be an artifact of the selection of grab sample locations. It should be remembered that there is not a one-to-one correspondence between Part B and Part C sample locations.

Table III-1. Grab sample summary, based on field examination of the samples. See Figure III-1 for sample locations. Depths are uncorrected for tide.

| SAMPLE | DEPTH (fms) | Description |
|---|---|---|
| 1 | 205 | sand, shell, coral fragments (gravel) |
| 2 | 223 | sand, clam shells |
| 3 | 235 | sand |
| 4 | 165 | sand |
| 5 | 160 | sand, coral gravel |
| 6 | 193 | sand |
| 7 | 191 | sand (mineralogy analysis only) |
| 8 | 195 | sand (mineralogy analysis only) |
| 9 | 194 | sand |
| 10 | 217 | sand |
| 18 | 208 | sand, grey paint chips, basalt pebble Fe-oxide coatings on some pebbles |
| 19 | 223 | small sample (mineralogy analysis only) |
| 20 | 222 | oyster shells and sediment, paint chips, worm tubes |
| 21 | 203 | sand, Fe-oxide coatings on pebbles |
| 23 | 190 | sand |
| 25 | 224 | small sand sample (mineralogy analysis only) |
| 26 | 218 | sand |
| 27 | --- | hard bottom--no sample |
| 28 | --- | hard bottom--no sample |
| 29 | 214 | sand, paint chips, oxide coatings on pebbles |
| 30A | 237 | chunk of concrete |
| 30B | 240 | sand and coral rubble, oyster shell fragments, basalt pebbles |
| 33 | 180 | silt, sand, rubble, shells, charcoal, worm tubes, basalt pebbles |
| 34 | 202 | silt, sand, rubble, oyster shells |
| 40 | 217 | sand, small sample (mineralogy analysis only) |
| 42 | 220 | sand (mineralogy analysis only) |
| 43 | 205 | sand (mineralogy analysis only) |
| 44 | 178 | sand (mineralogy analysis only) |
| 52 | 230 | sand (mineralogy analysis only) |
| 57 | 112 | sand (mineralogy analysis only) |
| 58 | 46 | sand (mineralogy analysis only) |
| 60 | 210 | sand (mineralogy analysis only) |
| 61 | 190 | sand (mineralogy analysis only) |

Table III-2. Grain size analysis of Part C samples (weight percentages). Sample locations are shown in Figure III-1.

| Sediment type | Phi | mm | Sample Number | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 9 | 10 | 18 | 20 | 21 | 23 | 26 | 29 | 30B | 33 | 34 |
| gravel | -1.5 | 2.83 | 12.72 | 25.31 | .9 | 12.21 | 9.58 | 3.81 | 14.93 | .56 | 7.85 | 27.48 | 21.47 | 15.52 | .22 | 8.78 | 38.83 | 14.56 | 19.82 |
| | -1.0 | 2.0 | 4.68 | 5.86 | 5.78 | 5.32 | 1.91 | 2.36 | 19.43 | 1.48 | 1.74 | 18.79 | 6.38 | 5.05 | 1.11 | 9.24 | 2.77 | 6.68 | 6.85 |
| | -0.5 | 1.41 | 5.55 | 4.49 | 4.44 | 5.6 | 1.98 | 2.57 | 3.09 | 1.91 | 2.28 | 11.04 | 3.27 | 4.50 | 1.92 | 5.39 | 2.22 | 9.89 | 7.30 |
| | 0.0 | 1.0 | 8.71 | 5.26 | 6.21 | 7.85 | 2.48 | 2.65 | 3.65 | 2.21 | 2.56 | 12.16 | 2.48 | 5.69 | 2.79 | 6.95 | 2.76 | 11.84 | 9.33 |
| | 0.5 | .71 | 12.86 | 7.58 | 6.26 | 10.03 | 3.09 | 2.8 | 5.67 | 2.35 | 3.34 | 8.57 | 2.24 | 5.54 | 6.94 | 7.59 | 3.47 | 9.17 | 9.63 |
| | 1.0 | .5 | 16.41 | 7.26 | 8.02 | 10.15 | 3.85 | 4.22 | 7.33 | 2.86 | 4.39 | 5.24 | 2.92 | 5.65 | 12.90 | 11.56 | 4.15 | 5.51 | 8.43 |
| sand | 1.5 | .35 | 21.46 | 9.22 | 11.22 | 11.86 | 7.47 | 10.78 | 12.09 | 6.68 | 9.49 | 2.85 | 7.48 | 8.20 | 16.83 | 10.36 | 9.39 | 5.84 | 9.19 |
| | 2.0 | .25 | 8.02 | 10.87 | 11.66 | 11.16 | 14.06 | 20.29 | 14.03 | 14.48 | 15.80 | 2.57 | 15.53 | 10.09 | 12.73 | 13.40 | 13.31 | 7.44 | 7.53 |
| | 2.5 | .177 | 2.48 | 8.02 | 6.5 | 8.9 | 18.11 | 21.02 | 8.61 | 15.91 | 19.46 | 1.69 | 18.51 | 9.95 | 16.79 | 13.35 | 8.64 | 9.60 | 5.02 |
| | 3.0 | .125 | 1.52 | 5.89 | 3.43 | 5.26 | 21.96 | 19.12 | 4.56 | 20.03 | 18.68 | 5.71 | 14.66 | 11.93 | 20.79 | 6.70 | 6.75 | 7.08 | 7.81 |
| | 3.5 | .088 | 1.95 | 3.49 | 21.21 | 2.76 | 5.37 | 3.88 | 4.07 | 14.14 | 6.55 | .82 | 2.44 | 3.42 | 4.10 | 4.97 | 4.99 | 7.94 | 3.50 |
| | 4.0 | .0625 | .97 | 2.17 | 5.13 | 1.72 | 3.66 | 2.14 | .85 | 7.02 | 3.49 | .70 | 1.20 | 3.39 | 1.97 | .78 | 1.46 | 1.92 | 1.57 |
| | 4.5 | .044 | .9 | 1.86 | 3.69 | 1.63 | 2.71 | 1.84 | .64 | 4.90 | 2.11 | .74 | .61 | 3.84 | .62 | .40 | 1.26 | 1.15 | 1.43 |
| | 5.0 | .031 | .01 | .01 | .04 | 1.02 | .11 | .51 | .01 | .05 | .02 | .01 | .01 | .13 | .20 | .08 | --- | .01 | .19 |
| | 5.5 | .022 | .01 | .35 | .05 | 1.02 | .07 | 1.23 | .27 | .03 | .02 | .01 | .28 | .34 | .07 | .32 | --- | --- | .06 |
| silt | 6.0 | .0156 | .27 | .9 | .71 | 1.02 | .88 | .7 | .32 | .15 | .04 | .05 | .24 | 1.41 | .01 | .11 | --- | .31 | .04 |
| | 6.5 | .011 | .93 | 1.07 | 2.39 | .97 | 1.63 | .08 | .42 | 1.80 | .75 | .46 | .22 | 2.78 | --- | .01 | --- | .79 | .82 |
| | 7.0 | .0078 | .41 | .37 | 1.71 | .69 | .97 | --- | .02 | 1.57 | .79 | .52 | .06 | 1.88 | --- | --- | --- | .25 | .73 |
| | 7.5 | .0055 | .14 | .02 | .66 | .36 | .13 | --- | --- | 1.43 | .61 | .54 | --- | .67 | --- | --- | --- | .02 | .71 |
| | 8.0 | .0039 | --- | --- | --- | .07 | --- | --- | --- | .44 | .03 | .04 | --- | .01 | --- | --- | --- | --- | .02 |
| clay | 8.5 | .0028 | --- | --- | --- | .07 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | 9.0 | .002 | --- | --- | --- | .33 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TOTAL: | | | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

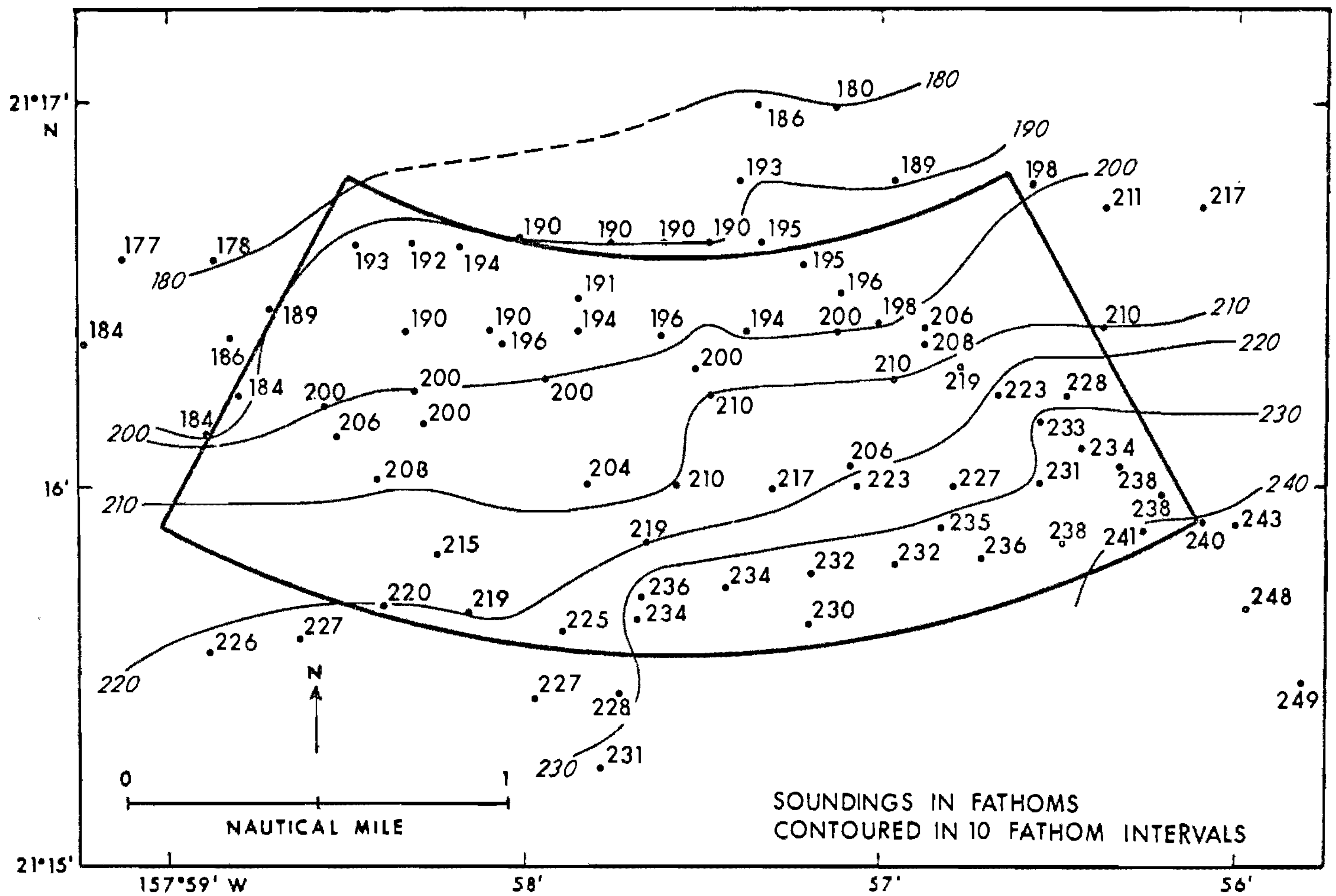



Figure III-4. Bathymetry of disposal site
prior to the 1977 disposal operations.

Table III-3. X-ray mineralogy of Part C samples in weight percentages. Copper K-alpha radiation. Sample locations are shown in Figure III-1.

| SAMPLE | calcite | aragonite | plagioclase | halloysite | goethite | magnetite | chlorite |
|---|---|---|---|---|---|---|---|
| 1 | 38.4 | 61.6 | --- | --- | --- | --- | --- |
| 2 | 48.3 | 57.7 | --- | --- | --- | --- | --- |
| 3 | 26.4 | 51.3 | --- | 10.5 | 10.5 | 1.5 | --- |
| 4 | 15.7 | 66.6 | 5.7 | 9.1 | --- | 2.9 | --- |
| 5 | 36.2 | 63.8 | --- | --- | --- | --- | --- |
| 6 | 22.0 | 71.5 | 2.4 | 1.5 | --- | --- | --- |
| 7 | 22.8 | 67.7 | --- | 2.6 | --- | 6.9 | --- |
| 8 | 20.8 | 76.1 | --- | --- | --- | 3.1 | --- |
| 9 | 35.4 | 64.6 | --- | --- | --- | --- | --- |
| 10 | 26.3 | 64.9 | 3.3 | 5.5 | --- | --- | --- |
| 18 | 32.8 | 67.2 | --- | --- | --- | --- | --- |
| 19 | 28.6 | 58.1 | 8.7 | 4.2 | --- | 0.4 | --- |
| 20 | 29.6 | 57.7 | --- | 9.8 | --- | 2.9 | --- |
| 21 | 29.8 | 64.8 | 4.5 | --- | --- | 0.9 | --- |
| 23 | 22.5 | 66.8 | 3.7 | 7.0 | --- | --- | --- |
| 25 | 32.1 | 52.3 | --- | --- | --- | --- | 15.6 |
| 26 | 37.4 | 62.6 | --- | --- | --- | --- | --- |
| 29 | 29.8 | 51.4 | --- | --- | 14.5 | 4.3 | --- |
| 30B | 29.4 | 67.4 | --- | 3.2 | --- | --- | --- |
| 33 | 15.5 | 27.3 | 49.3 | --- | 7.9 | --- | --- |
| 34 | 37.2 | 55.3 | --- | 4.7 | --- | 2.8 | --- |
| 40* | 37.6 | 62.4 | --- | --- | --- | --- | --- |
| 42 | 36.3 | 63.7 | --- | --- | --- | --- | --- |
| 43 | 25.6 | 74.4 | --- | --- | --- | --- | --- |
| 44 | 23.7 | 73.8 | 2.5 | --- | --- | --- | --- |
| 52 | 32.9 | 60.7 | 2.8 | 3.6 | --- | --- | --- |
| 57 | 17.8 | 82.2 | --- | --- | --- | --- | --- |
| 58 | 37.5 | 62.5 | --- | --- | --- | --- | --- |
| 60 | 26.8 | 64.2 | --- | 9.0 | --- | --- | --- |
| 61 | 34.0 | 66.0 | --- | --- | --- | --- | --- |

* a small, but undetermined, amount of boehmite found

Table III-4. Spoil identification in Part C grab samples, based on X-ray mineralogy. Sample locations are shown in Figure III-1.

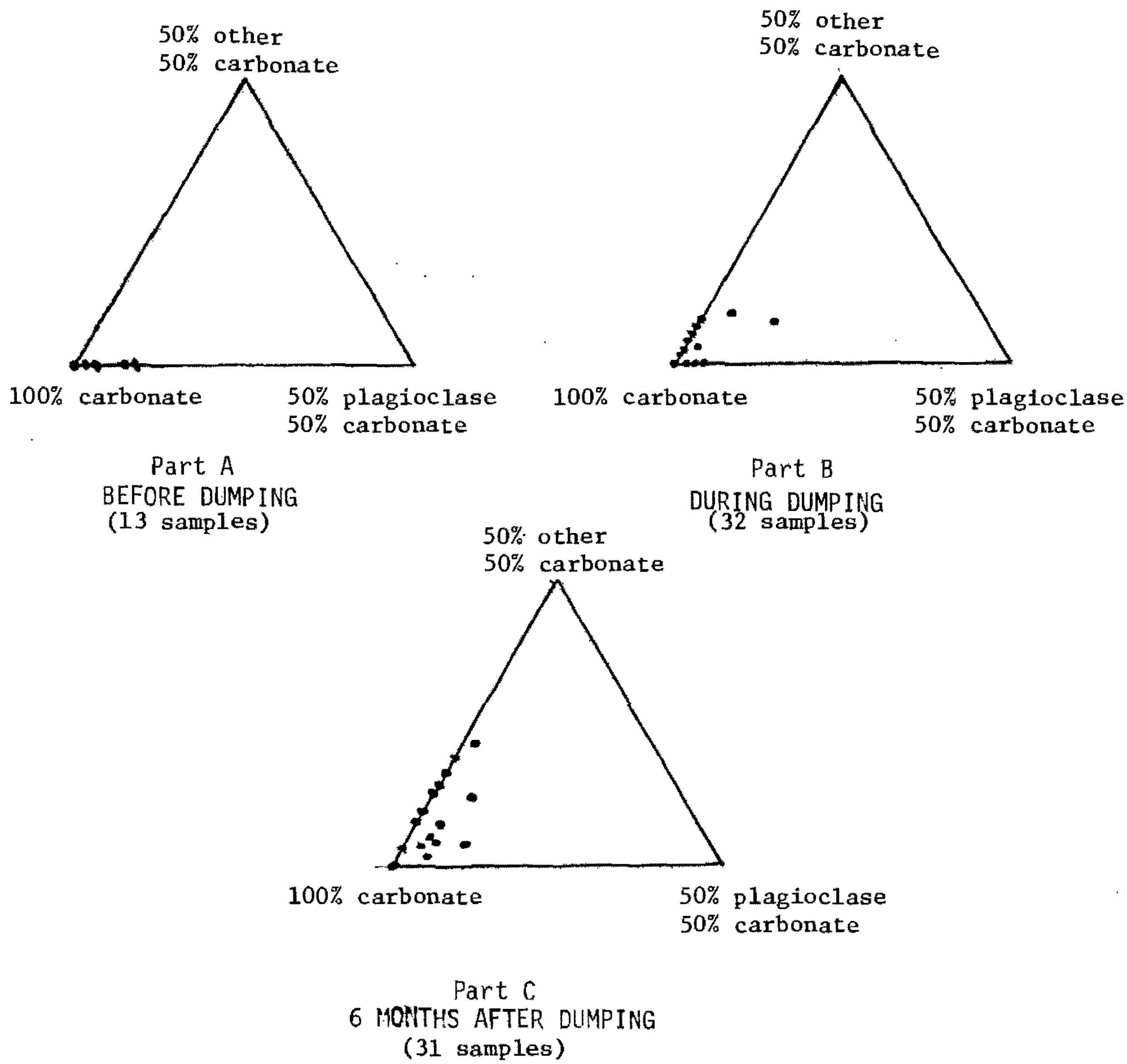
| SAMPLE | SPOIL | NO SPOIL |
|---|---|---|
| 1 | | ✓ |
| 2 | ✓ (1) | |
| 3 | ✓ | |
| 4 | ✓ | |
| 5 | | ✓ |
| 6 | ✓ | |
| 7 | ✓ | |
| 8 | | ✓ |
| 9 | | ✓ |
| 10 | ✓ | |
| 18 | ✓ (1) | |
| 19 | ✓ | |
| 20 | ✓ | |
| 21 | ✓ | |
| 23 | ✓ | |
| 25 | | ✓ |
| 26 | | ✓ |
| 27 | | ✓ (2) |
| 28 | | ✓ (2) |
| 29 | ✓ | |
| 30A | ✓ (3) | |
| 30B | ✓ | |
| 33 | ✓ | |
| 34 | ✓ | |
| 40 | | ✓ |
| 42 | | ✓ |
| 43 | | ✓ |
| 44 | ✓ | |
| 52 | ✓ | |
| 57 | | ✓ |
| 58 | | ✓ |
| 60 | ✓ | |
| 61 | | ✓ |

(1) Although sample is entirely carbonate minerals, presence of shallow water clam shells indicates spoil content.

(2) No sample, i.e. hard bottom.

(3) Chunk of concrete, and therefore considered to be spoil.

Figure III-3. Comparison of bulk mineralogy of surface sediments in the study area before, during and six months after dredge spoil disposal. Carbonate means aragonite and calcite. 'Other' means magnetite, halloysite, etc. (see text).



Grain size analysis of the Part C sediment samples (Table III-2) revealed little difference from Part A or Part B samples, which consisted mostly of sand with some gravel, and very little silt or clay.

The sediments of Pearl Harbor are on the average 24 per cent sand and gravel and 76 per cent silt and clay (Youngberg, 1973). The sediments sampled at the dump site prior to dumping were mostly sand and gravel, with small amounts of silt and clay (Part A). It was thought that deposition of dredge spoil at the dump site would create a shift in the grain size distribution of the bottom sediments towards the silt and clay fraction. Part B work showed that this, however, did not happen. Instead, it became apparent that selective deposition of coarse material was occurring immediately beneath the dump site, the fines being "winnowed out" by current action. These fines were being either dispersed over a much wider area or removed completely. Whichever case may have occurred, it was not possible to detect by means of grain size analysis any wider pattern of deposition. Further, the coarse material deposited in the disposal area was so similar to the pre-dumping sediments (in terms of grain size) that it was impossible to attempt spoil identification on the basis of grain size analysis. Hence, the mineralogy of the sediments was used.

Similar reasoning applies to the Part C samples. No further dumping had occurred, so that the deposited spoil cannot have increased in amount. Ocean processes may have altered the deposited spoil since deposition, however, but do not seem to have changed the distribution of grain sizes significantly. The evolution of the surface sediments throughout the disposal area is shown in Figure III-4. The average grain size distribution of all of the samples taken in each part of the project has been computed and condensed into gravel, sand, and silt/clay categories for comparison with the averages from Pearl Harbor.

2. Core Samples

As stated before, coring was considered unproductive and was therefore not attempted in Part C.

3. Bottom Photography

A summary of the bottom photography appears in Table III-5. Approximately three hundred photos were taken, of which ninety-seven were selected for printing. Representative photographs appear in Figures III-5 through 9. In general, along the western half of the track line, the photos show mostly flat-lying sand and some

Figure III-4. Comparison of average grain size analysis of surface sediments in the study area before, during, and six months after disposal operations. (||||||) = silt & clay (═══) = sand and gravel.

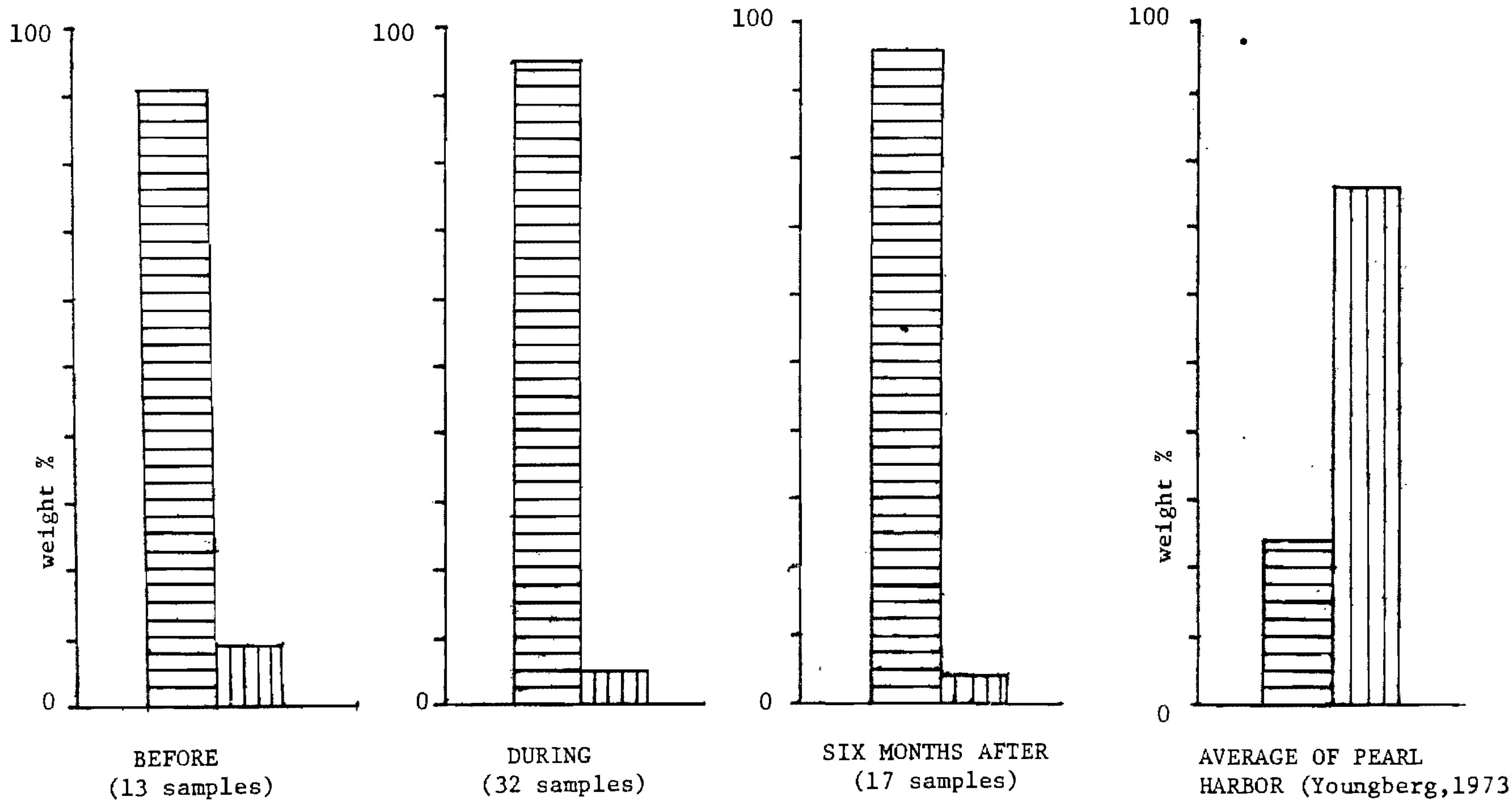


Table III-5. Summary of bottom photography. See Figure III-2 for the location of the photo trawl.

| TIME (hr:min:sec) | REMARKS |
|---|---|
| 16:00:00 | camera put in water |
| 16:10:00 | camera on bottom |
| 16:00:00-16:33:12 | mostly rippled sand, with occasional rubble, occasional patches of old reef |
| 16:33:21-16:40:04 | gravel and rubble in increasing amounts; more man-made debris |
| 16:40:14-17:01:00 | sand and gravel, encrusted boulders, encrusted man-made debris, few current ripples. |

Figure III-5. Sand with current ripples. Photo taken at 16:15:40 hours; see Figure III-2 for location. Depth is 207 fm.

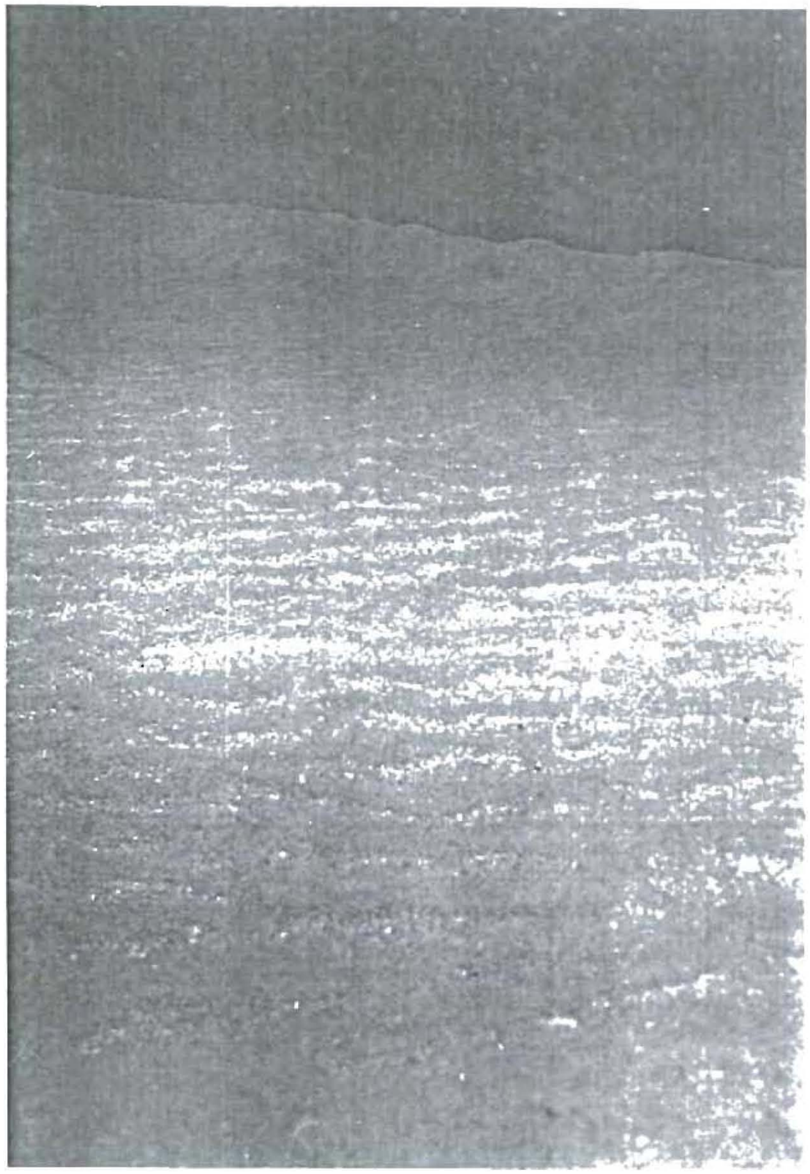


Figure III-6. Patch of old reef with surrounding sand. Photo taken at 16:24:31 hours; see Figure III-2 for location. Depth is 208 fm.

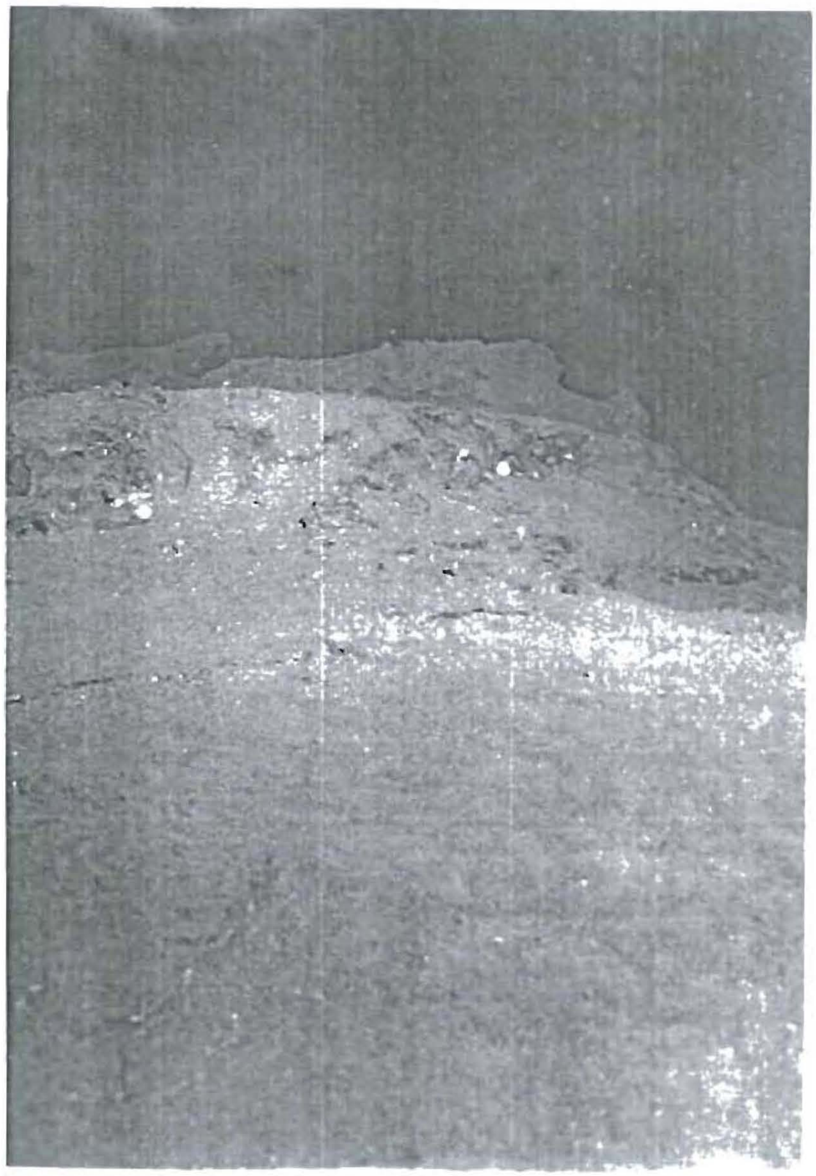


Figure III-7. Flat-lying sand and gravel. Photo taken at 16:40:34 hours; see Figure III-2 for location. Depth is 218 fm.

Figure III-8. Sand, gravel, and man-made debris. Photo taken at 16:45:18 hours; see Figure III-2 for location. Depth is 225 fm.

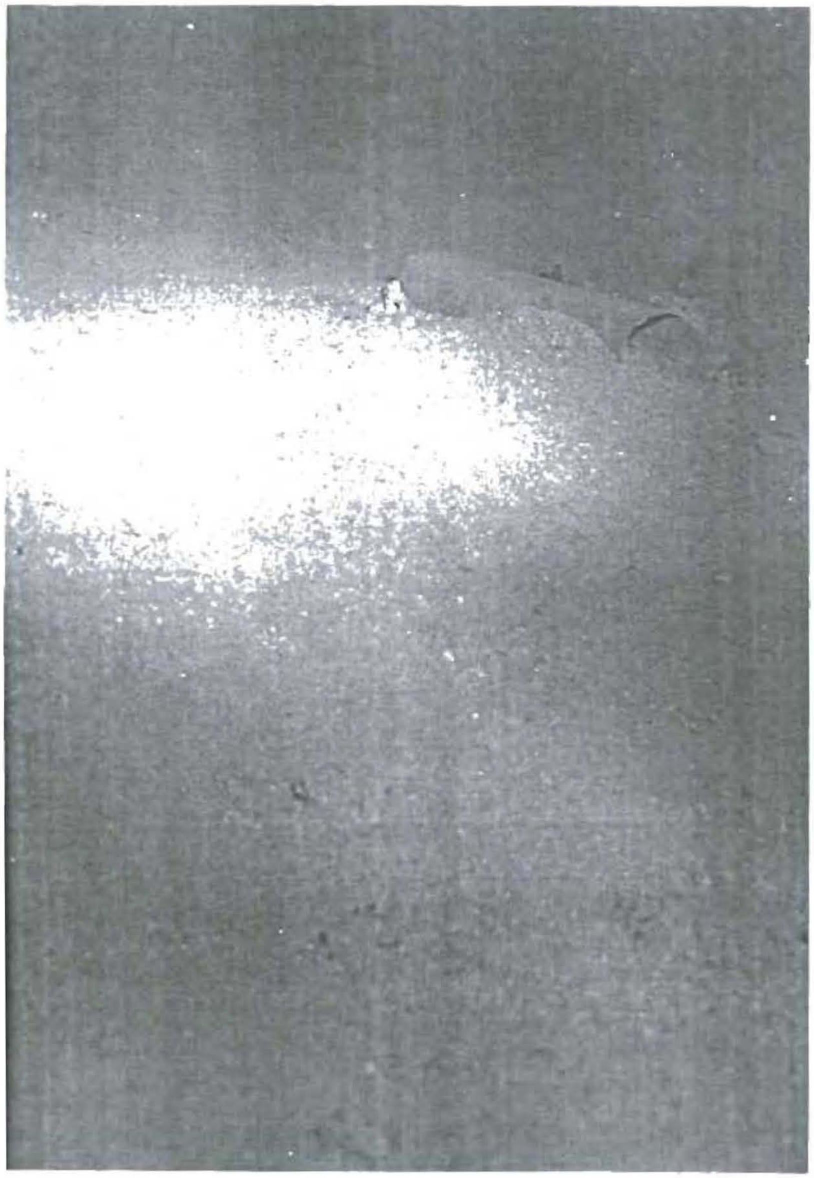
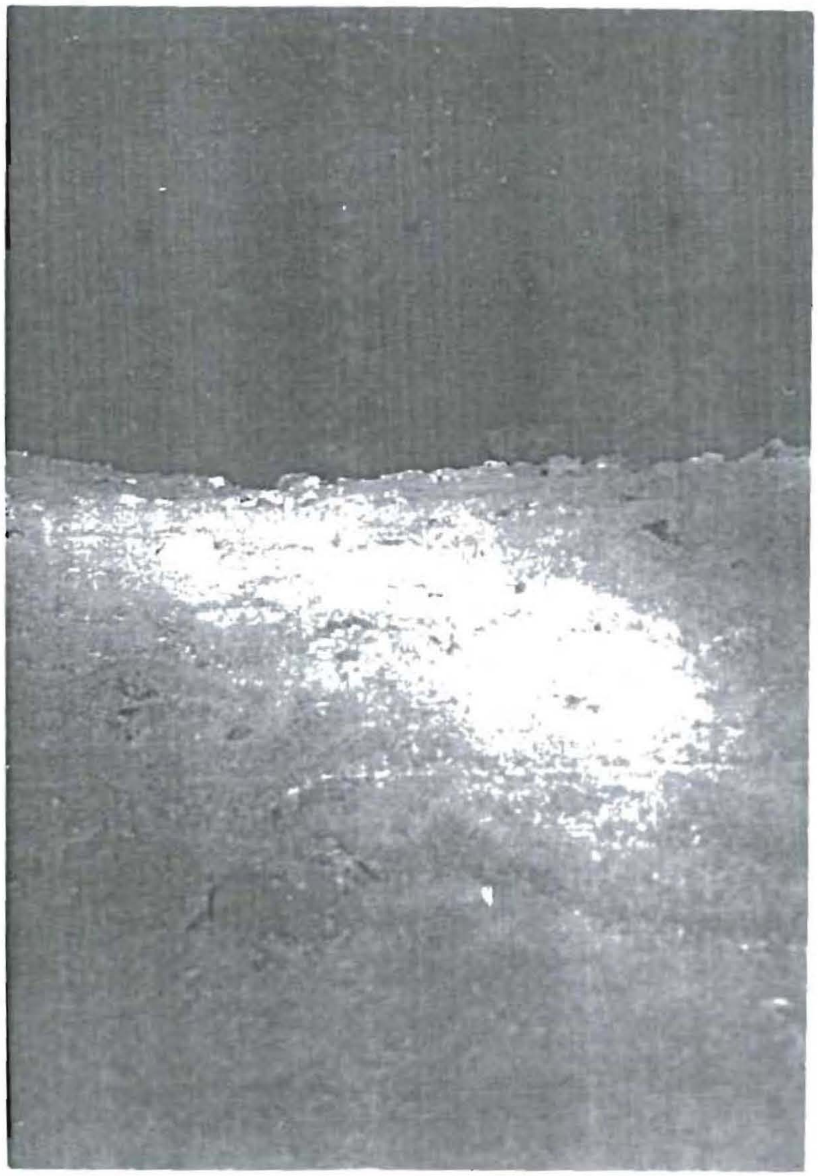


Figure III-9. Sand and rubble. Note the slight changes in topography. Photo taken at 17:00:00 hours; see Figure III-2 for location. Depth is 235 fm.



gravel, with occasional patches of rippled sand and sections of old reef. Moving eastward, the terrain remains relatively smooth, as was seen prior to dumping, but there is more coarse rubble. Figures III-5 and III-6 are representative of the western part of the area, showing sand with current ripples and sand with a patch of old reef, respectively. Coarse rubble, sand and man-made debris, shown in Figures III-7, III-8, and III-9, are more in evidence in the vicinity of the designated dumping site in the eastern part of the disposal area.

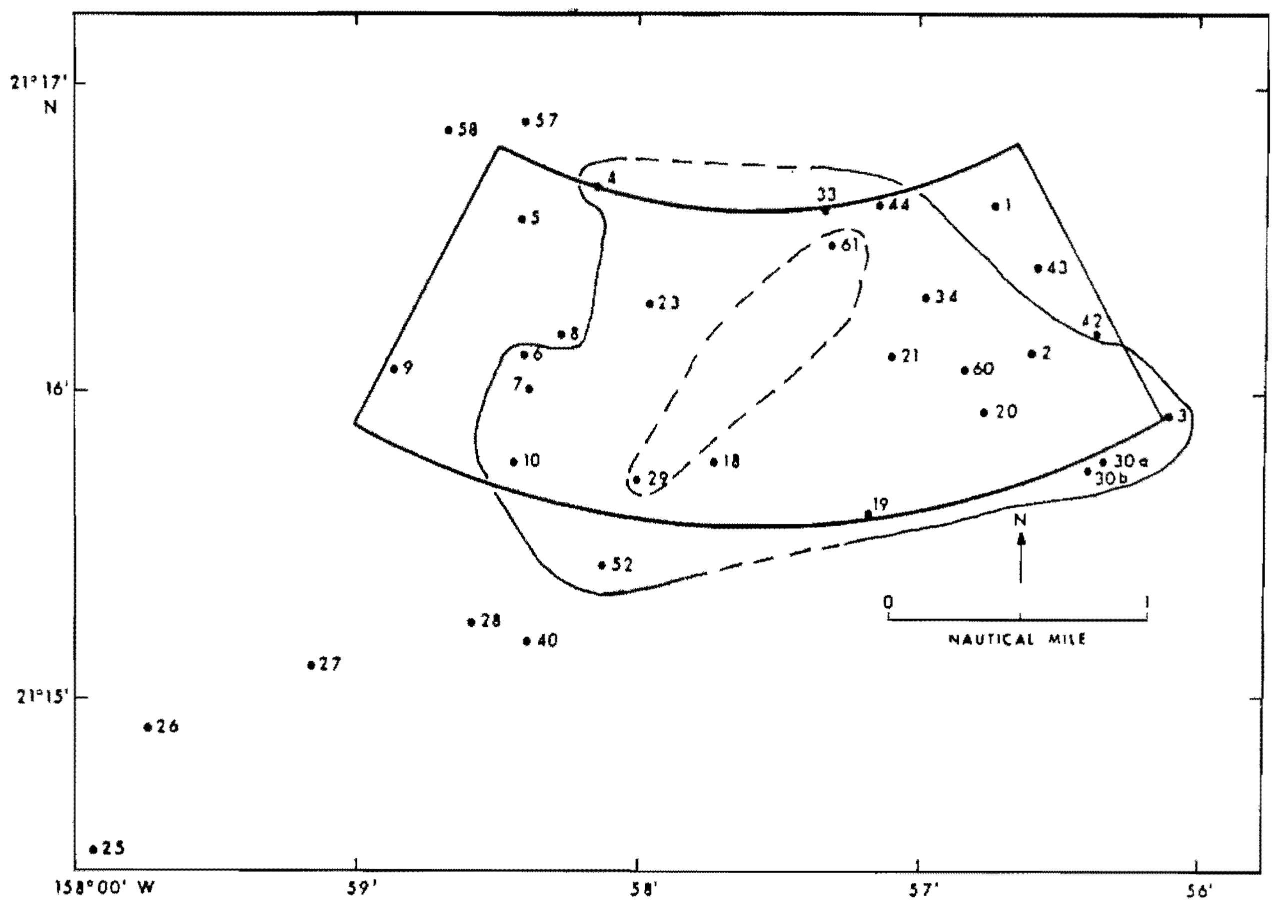
During the photographic track, a 3.5 kHz echo sounder was operating. The fathogram record indicated that there was no soft (acoustically penetrable) sediment along the photo track line detectable at the frequency of the instrument, i.e. no mud thicker than about 30 cm.

## D. Discussion and Conclusions

The areas containing spoil are indicated on Figure III-10. For comparison, the extent of spoil deposition found during Part B work, based also on X-ray mineralogy, is shown in Figure III-11. As in the Part B sampling, the Part C samples taken near the designated dump site (approximately Station 20), and at the temporary dump site (slightly north of Station 44) contained dredge spoil. Spoil presence was also detected in samples to the west of the two points, as in Part B, but the spoil appears to have spread out over a larger area on the bottom. The bottom currents measured at the site (Part B) are quite sufficient to transport fine sand, silt, and clay (Blatt *et al*., 1972) and are also oscillatory, which might help to redistribute the deposited spoil over a wider area. Based upon the bottom photography, the overall nature of the surface sediments of the site is unchanged, remaining predominantly carbonate sand and rubble. The terrain has undergone no significant change, remaining relatively smooth, flat and featureless. From a geological point of view, the spoil disposal has had no adverse effect.

Because considerable amounts of dredge spoil from Pearl Harbor have in the past been dumped in the vicinity of the study area, it seems reasonable to conclude that some or even most of the surface bottom sediments there may be this older dredge spoil. That the mineralogy of these sediments is almost entirely composed of carbonate minerals may mean that (1) the non-carbonate minerals have been physically removed by currents from the disposal site, or (2) the non-carbonate minerals have been chemically or biologically altered at the dump site.

Figure III-10. Spoil identification based on mineralogy in surface sediments of the study area, six months after cessation of disposal operations. Dashed lines indicate possible extent of spoil; solid lines indicate observed spoil. This difference results from the lack of samples in the central portion of the area. Numerals are sample numbers.



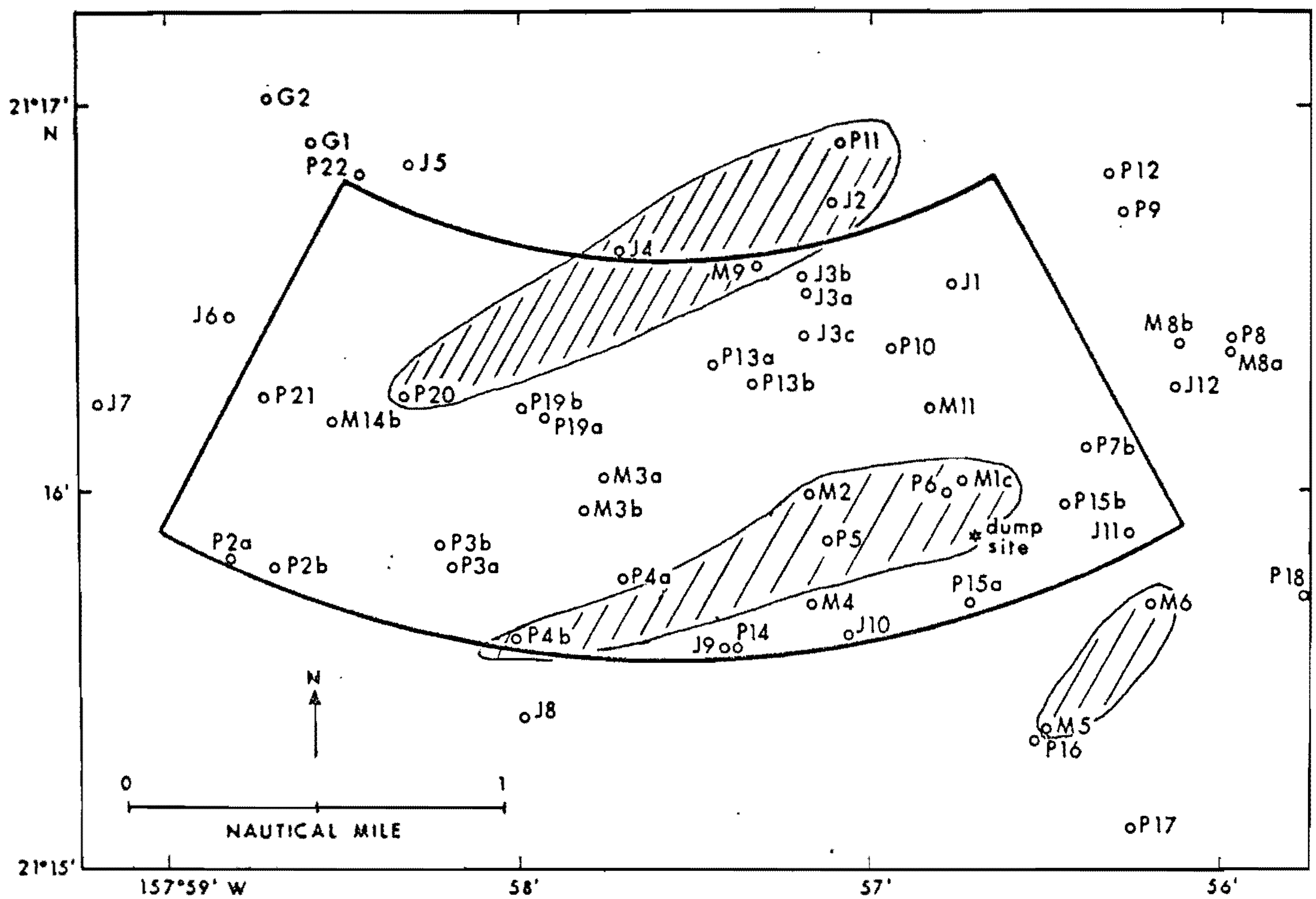



Figure III-11. Spoil identification in the study area, during disposal operations, for comparison with Figure III-10. Numerals are sample numbers. Location of grab samples taken on April 22, 1977 (M), May 18, 1977 (J) and May 31-June 1, 1977 (P).

The net effect is that after a certain length of time, presumably longer than the six-month time period observed in this study, the surface sediments will revert to their predumping, mostly carbonate, composition. This is quite possibly what happens to Pearl Harbor sediments that are carried out to sea by normal tidal flushing of the estuarine system, in the absence of dredging activity. If so, the dredging and offshore disposal operations may simply be an acceleration of seaward transport of the Pearl Harbor sediments.

## E. Summary

Six months after cessation of dredge spoil disposal in the study area off Pearl Harbor, spoil can still be detected in the mineralogy of the surface sediments. The spoil appears to be spreading out over a somewhat larger area than that which was determined by sampling during and immediately after disposal operations, and now is detected across most of the study area. Strong and variable bottom currents are probably the cause of this redistribution. With more time, the surface sediments may attain the composition and texture that was at the site before this latest episode of dumping.

## F. Acknowledgements

We wish to express our appreciation for the efforts of the skippers and crews of the R/V Machias and R/V El Greco, and to Dr. James E. Andrews, Hawaii Institute of Geophysics, for the bottom photography done aboard the R/V Kana Keoki.

## G. Literature Cited

Blatt, H., G. Middleton and R. Murray, 1972. Origin of Sedimentary Rocks. Prentice-Hall, New Jersey.

Chave, K.E., and J. N. Miller, 1977. Baseline studies and evaluation of physical, chemical and biological characteristics of nearshore dredge spoil disposal, Pearl Harbor, Hawaii. Parts A and B. Environmental Center Final Report, University of Hawaii.

Chen, Pei-Yuen, 1977. Table of key lines in X-ray powder diffraction patterns of minerals in clays and associated rocks. Department of Natural Resources, Indiana Geological Survey Occasional Paper 21.

Fan, P.R. and R.W. Rex, 1972. X-ray mineralogy studies. Initial reports of the Deep Sea Drilling Project, Vol. 14, pp. 677-726.

Folk, R.L., 1974. Petrology of Sedimentary Rocks. Hemphill Publishing Co., Austin, Texas.

Griffiths, J. C., 1967. Scientific Method in Analysis of Sediments. McGraw-Hill, New York.

Johnson, B. H., 1977. Numerical model results of dredge material disposal at ten proposed ocean disposal sites in the Hawaiian Islands, Misc. Paper H-77-6, U. S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.

Koh, C. Y. and Chang, Y. C., 1973. Mathematical model for barged ocean disposal of wastes. EPA Report EPA-660/2-73-029.

Rex, R. W., 1969. X-ray mineralogy studies. Initial reports of the Deep Sea Drilling Project, Vol. 1, pp. 354-367.

Turner, B. W., 1975. Mineral distribution within the sediments of Pearl Harbor, University of Hawaii M. S. thesis (unpublished).

Youngberg, A. D., 1973. A study of the sediments and soil samples from the Pearl Harbor area, Naval Civil Engineering Laboratory, Port Hueneme, California.

# IV. WATER CHEMISTRY

by
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A. Objectives

The effects of the disposal of dredge spoil on the water quality in the deep water disposal area off of Pearl Harbor, Hawaii, have been monitored throughout this project. Water quality studies during Part A provided certain pre-dump baseline data and the Part B studies included monitoring of changes in these parameters during actual dumping operations (Chave and Miller, 1977. Parts A and B). The current study, Part C, examines the longer-term impacts on the water quality and the potential effects of heavy metal concentrations in the sediment and on certain biota.

The specific objectives of the Part C water chemistry investigations were:

1. The assessment of the long-term impact of Pearl Harbor dredge spoil disposal on water and sediment quality at the disposal site;
2. Monitoring the long-term sediment transport out of the study area using the sediment metals burden as a label;
3. A comparison of the heavy metal body burdens in shrimp and zooplankton samples collected from the study site to samples collected from a nearby control area.

B. Methods

1. Sampling Stations, Depths, and Dates

a. Receiving Water Stations

Receiving water stations 1 through 7 were established as shown in Figure IV-1. Station 2 was located at the designated Pearl Harbor dredge spoil disposal site (21°15.9' N, 157°56.7' W). Sample collections were limited to surface samples only since the results from the Part B Section IV monitoring studies indicate that water quality at the disposal site returned to pre-disposal conditions approximately 24 hours after disposal operations had ceased. The only exceptions appeared to be the heavy metals concentrations in a surface sample collected at the disposal site (Station 2). The relatively higher metal concentrations observed in this sample on this date (June 1, 1977) seemed to indicate the presence of particulate spoil material, although none was visible in surface waters (Part B). Sample collection during the present study was performed on September 28 and 29, 1977.

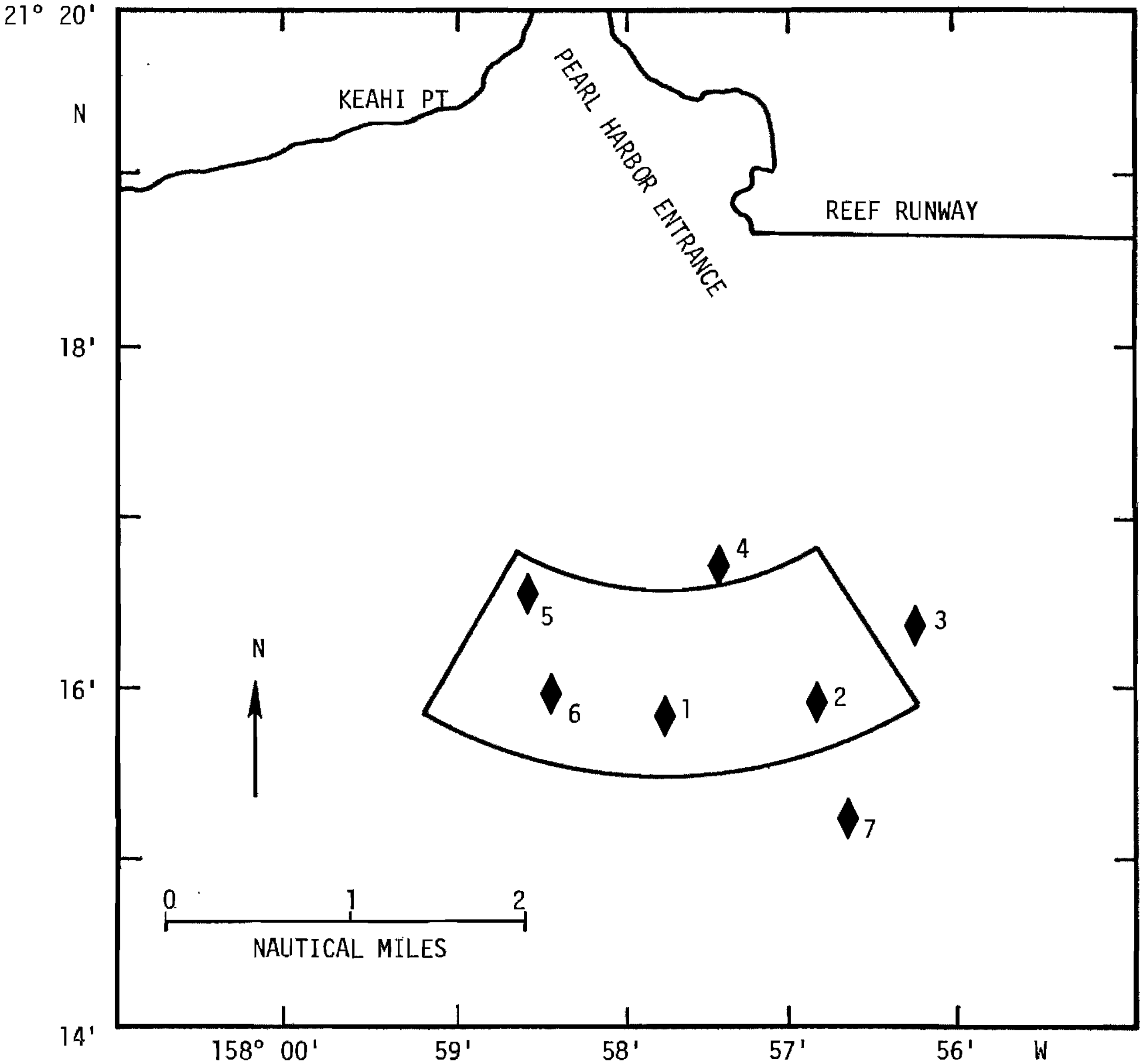



Figure IV-1. Pearl Harbor dredge spoil disposal site study, water chemistry stations, Part C.

♦ = water chemistry stations, Part C.

b. Sediment Stations at the Disposal Site

Results from the Part B monitoring studies indicate that spoil material was initially deposited within a short distance (0.5 mile radius) of the designated dump site. Twenty-three sediment stations (Figure IV-2) were sampled and analyzed for heavy metals during the present study to trace the long-term dispersal of spoil from the disposal site. Sampling began in late September and was completed on December 9, 1977.

c. Shrimp trapping and Zooplankton Stations

Shrimp (Figure IV-3) and zooplankton samples for heavy metals analysis were collected on December 8 and 9, 1977. Zooplankton only was collected on September 13, 1977. All zooplankton collections for heavy metals were made in the vicinity of the designated dump site.

2. Field Methods: Collection and Preservation of Samples

a. Receiving Water Samples

Receiving water surface samples were collected and preserved as described in the Part A baseline study.

b. Sediment Samples from the Disposal Site

Sediment samples were collected with a small, Petersen-type grab sampler, and a clam grab sampler, stored in plastic bags, and refrigerated at 4° C.

c. Shrimp and Zooplankton Samples

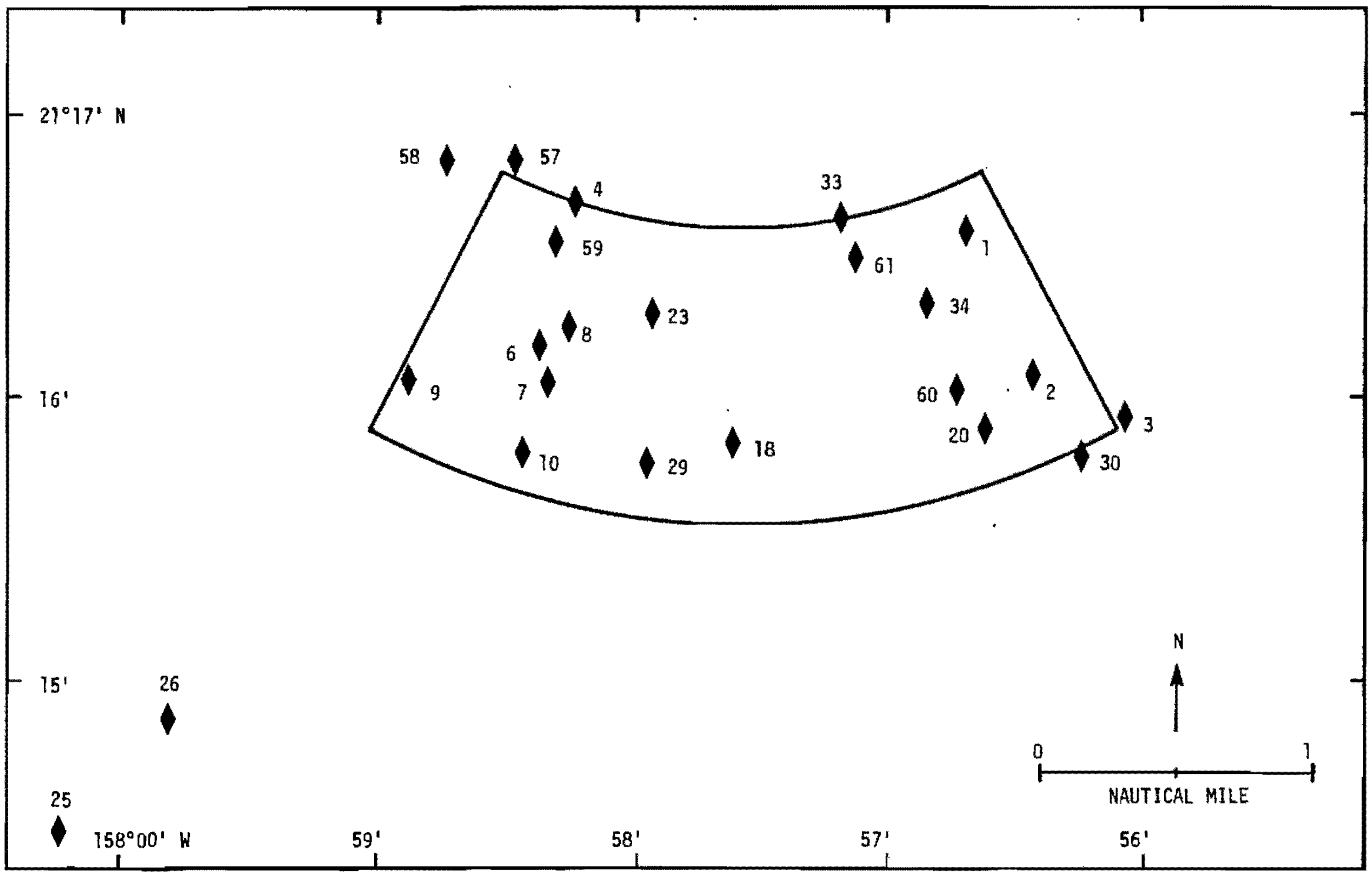
Shrimp were collected in traps as described in Part A, Section VII, and zooplankton tows were performed as described in Part A, Section V. Shrimp were frozen and zooplankton preserved with formaldehyde before heavy metals analysis.

3. Methods of Analysis

a. Receiving Water Samples

Following a preliminary chelation-extraction procedure developed by the United States Geological Survey (Brown et al., 1970), analysis for receiving water heavy metals was completed on a Perkin-Elmer model 305A atomic absorption spectrophotometer.

Figure IV-2. Location and sample number of sediment samples analyzed for heavy metals concentrations, Part C. ♦ = location of sample



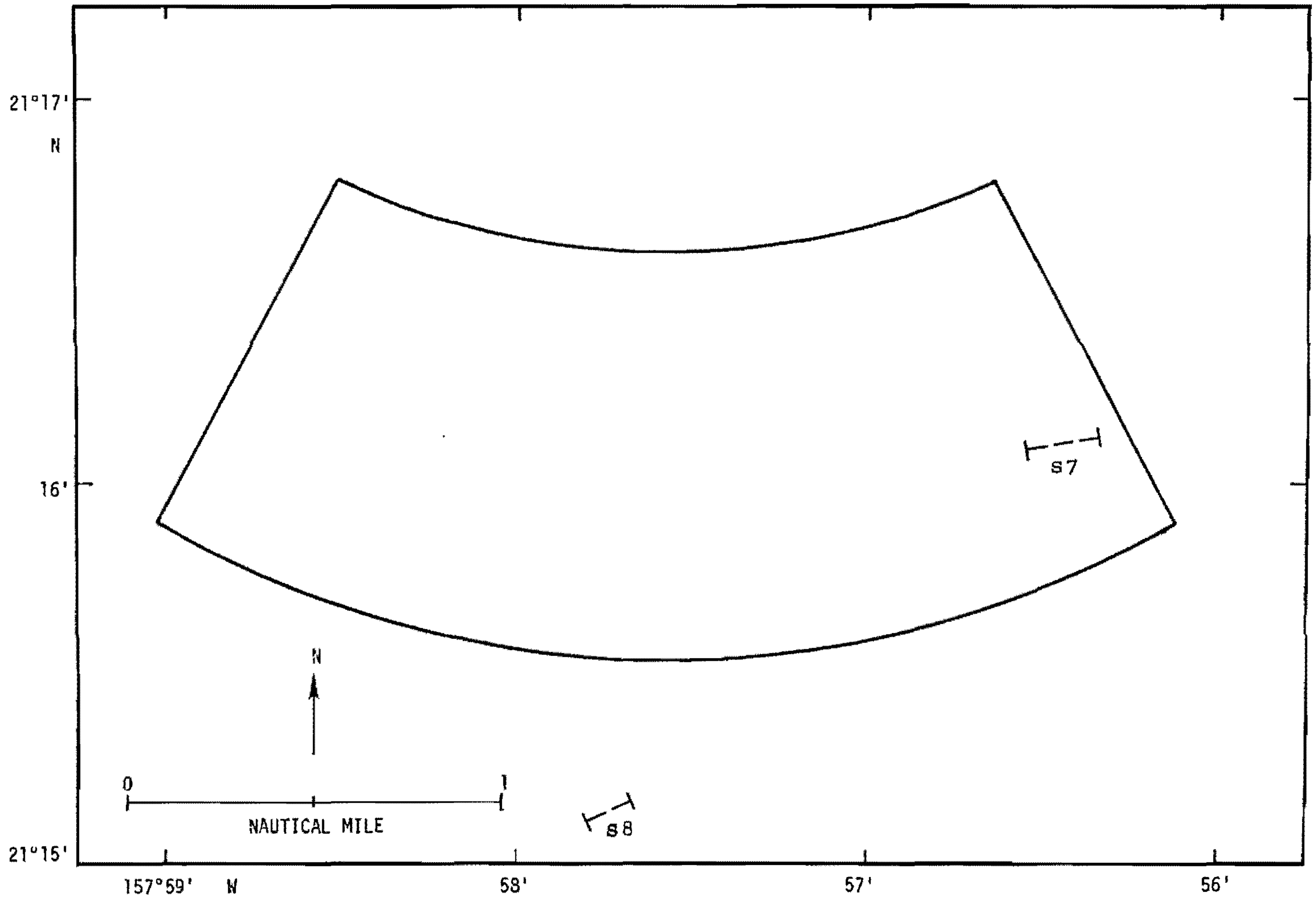



Figure IV-3. Location of shrimp trap sets, S7 and S8, December 1977.
|---| = shrimp trap set locations.

b. Sediment Samples from the Disposal Site

Metals in sediment collected from the disposal site were extracted by nitric acid-hydrogen peroxide digestion (Krishnamurty et al., 1976). Analysis was completed on the same Perkin-Elmer atomic absorption spectrophotometer as used for receiving water samples.

c. Shrimp and Zooplankton Samples

Shrimp and zooplankton were analyzed for heavy metals following ashing of the samples and extraction with dilute nitric acid. The results are expressed on a wet weight basis as mg of metal per kg of muscle tissue for shrimp and as mg of metal per kg of whole organisms for zooplankton.

## C. Results

Results of the analysis for concentrations of heavy metals in the receiving water surface samples are presented in Table IV-1. Sediment metal concentrations (Table IV-2) were summed together to yield "total sediment metals" as shown in Figure IV-4. Heavy metal body burdens for shrimp and zooplankton are given in Tables IV-3 and IV-4, respectively.

## D. Discussion

1. Receiving Water Survey

Receiving water metals (Table IV-1), primarily zinc, are generally of the same order of magnitude as the Part A and B surface water samples (excluding the disposal site). However, Stations 4 and 5 of the present investigations exhibit zinc concentrations equal in magnitude to those observed at the designated dump site (Station 2) during Part B studies. The reason for these relatively higher concentrations is not clear and may have been due to sampling or analytical error. These higher values do not appear to be the result of suspended sediment from spoil disposal operations ending four months earlier. Also, the dissolution of metals from deposited spoil as a probable cause of higher concentrations at Stations 4 and 5 is not likely since dissolved metals would be "trapped" below the thermocline, and even if they were able to reach surface waters they would be more widely distributed as a result of the widespread distribution of deposited dredge spoil on the bottom (refer to Section III. "Geology and Physical Oceanography" and discussion of spoil distribution below). Rather, the higher values observed at Stations 4 and 5 appear to have been a localized phenomenon unrelated to dredge spoil disposal. As such, further monitoring of post disposal surface water quality is unwarranted at this time.

Table IV-1. Receiving water surface samples, heavy metals ($\mu g/l$)

| Station | Ag | Cd | Cr | Cu | Hg | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | 1. | 1.2 | ND | 2. | 6. |
| 2 | ND | ND | ND | ND | ND | ND | 3. | 13. |
| 3 | <1. | ND | ND | 1. | 0.2 | ND | 2. | 18. |
| 4 | <1. | ND | ND | ND | 0.2 | ND | 2. | 84. |
| 5 | <1. | ND | ND | ND | ND | ND | 2. | 116. |
| 6 | <1. | ND | ND | ND | ND | ND | <1. | 12. |
| 7 | <1. | ND | ND | ND | 2.6 | ND | 2. | 12. |
| lower reportable limits | 1. | 1. | 5. | 1. | 0.2 | 3. | 1. | 1. |

ND = not detectable

Table IV-2. Sediment metal concentrations (mg/kg dry weight)

| Station | Ag | Cd | Cr | Cu | Ni | Pb | Zn | Total Metals |
|---|---|---|---|---|---|---|---|---|
| 1 | 3. | 4. | 30. | 14. | 85. | 50. | 35. | 221. |
| 2 | 4. | 4. | 34. | 21. | 97. | 43. | 49. | 252. |
| 3 | 4. | 3. | 119. | 92. | 144. | 89. | 182. | 633. |
| 4 | 5. | 4. | 101. | 38. | 158. | 41. | 66. | 413. |
| 6 | 3. | 3. | 84. | 21. | 121. | 44. | 53. | 329. |
| 7 | 3. | 4. | 68. | 24. | 130. | 45. | 54. | 328. |
| 8 | 4. | 3. | 56. | 82. | 181. | 44. | 150. | 520. |
| 9 | 4. | 4. | 78. | 20. | 126. | 50. | 69. | 351. |
| 10 | 4. | 3. | 80. | 24. | 132. | 41. | 56. | 340. |
| 18 | 5. | 4. | 112. | 100. | 214. | 69. | 160. | 664. |
| 20 | 3. | 3. | 109. | 66. | 148. | 37. | 93. | 459. |
| 23 | 2. | 2. | 184. | 69. | 177. | 23. | 88. | 545. |
| 25 | 3. | 4. | 41. | 15. | 99. | 48. | 1137. | 1347. |
| 26 | 4. | 5. | 38. | 9. | 105. | 44. | 1006. | 1211. |
| 29 | 3. | 4. | 83. | 18. | 174. | 39. | 667. | 988. |
| 30 | 3. | 4. | 62. | 24. | 115. | 43. | 638. | 889. |
| 33 | 3. | 4. | 54. | 47. | 141. | 118. | 212. | 579. |
| 34 | 4. | 4. | 90. | 38. | 134. | 58. | 88. | 416. |
| 57 | 6. | 6. | 47. | 32. | 152. | 109. | 581. | 933. |
| 58 | 6. | 7. | 21. | 8. | 127. | 63. | 270. | 502. |
| 59 | 6. | 6. | 36. | 27. | 143. | 57. | 200. | 475. |
| 60 | 4. | 3. | 161. | 89. | 190. | 80. | 186. | 713. |
| 61 | 6. | 5. | 78. | 168. | 177. | 105. | 212. | 751. |

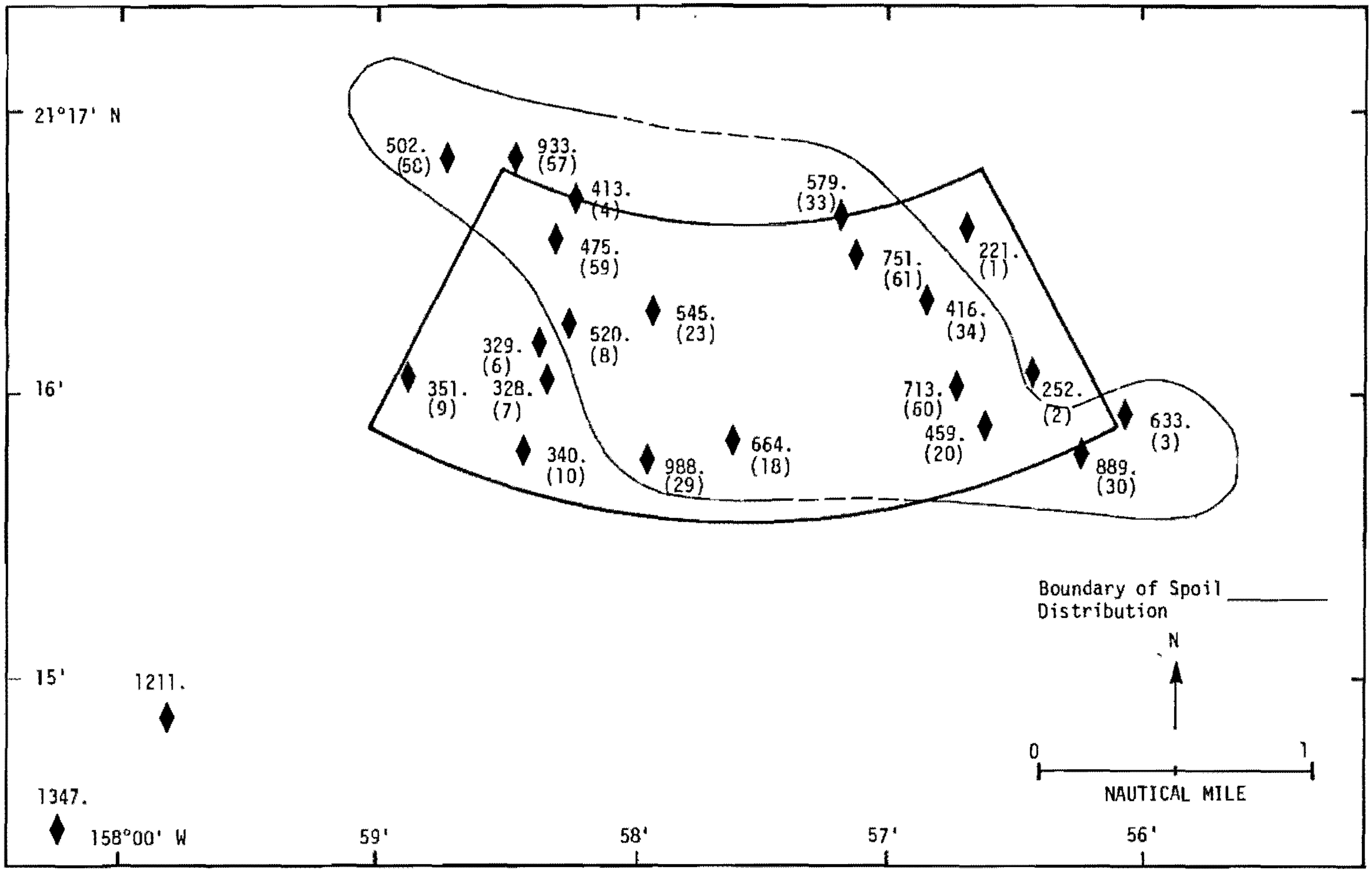



Figure IV-4. Total metal concentrations in bottom sediments. Dashed lines indicate possible extent of spoil; solid lines indicate boundary of observed spoil. This difference results from lack of samples in the central portion of the area.

♦ ( ) = station location with sample number in parentheses

000. = total metal concentration (mg/kg dry weight)

Table IV-3. Heavy metal concentrations in shrimp (*Heterocarpus ensifer*) collected in December 1977 (mg/kg wet weight)

| Station | Ag | Cd | Cr | Cu | Ni | Pb | Zn | Total |
|---|---|---|---|---|---|---|---|---|
| S7 (dump site) | ND | ND | ND | 8. | ND | ND | 7. | 15. |
| S8 (control site) | ND | ND | ND | 8. | ND | ND | 8. | 16. |

ND = not detectable

Table IV-4. Heavy metal concentrations in zooplankton collected during Parts A, B, and C (mg/kg wet weight)

| Part | Date | Location | Whole/Split | Ag | Cd | Cr | Cu | Ni | Pb | Zn | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 7/21/76 | dump site, tow 1 | (15/16 aliquot) | ND | ND | ND | 19. | ND | 13. | 39. | 71. |
| B | 6/15/77 | dump site, tow 12 | chaetognaths | ND | ND | ND | 2. | ND | ND | 13. | 15. |
| | 6/15/77 | dump site, tow 13 | (15/16 aliquot) | ND | ND | ND | 1. | ND | 3. | 20. | 24. |
| C | 9/13/77 | dump site, tow 5 | whole | ND | ND | 34. | 6. | ND | 157. | 118. | 315. |
| | 12/08/77 | dump site, tow 10 | whole | ND | ND | 3. | 89. | ND | 35. | 70. | 197. |

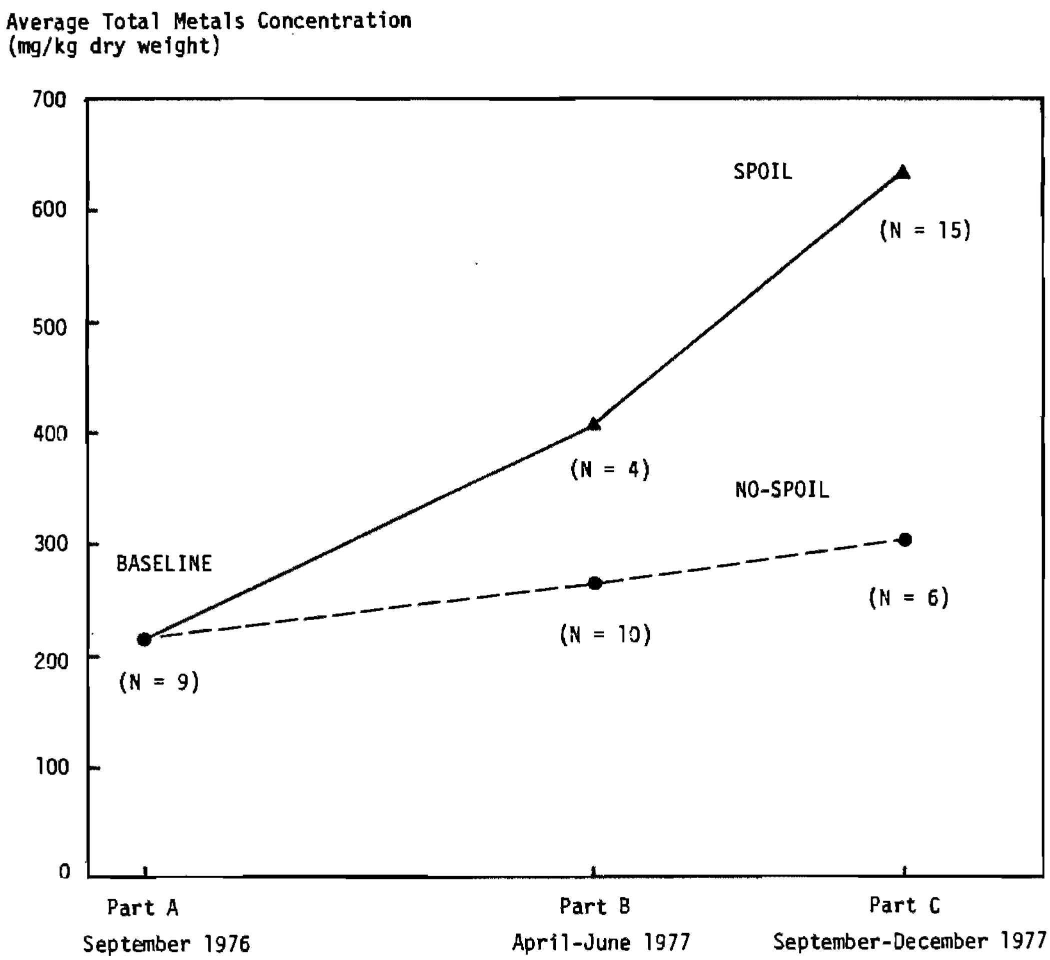
ND = not detectable

2. Disposal Site Sediments

Total metals concentrations for bottom grab samples are shown in Figure IV-4. From these data it is apparent that the distribution of spoil derived sediment is much more widespread than that observed during Part B disposal monitoring studies. While dumping operations were confined to the southeastern corner of the study area, higher metal concentrations reflecting the presence of dredge spoil were found in sediment grab samples throughout the eastern and almost the entire western portions of the study site (Figure IV-4). Tidally induced, oscillatory bottom currents with a net transport in a westerly direction are probably responsible for redistributing the deposited spoil over a wider geographic area. Samples 25 and 26 are apparently different mineralogically from study site sediments (Michael Allen, personal communication) and have been excluded from all further discussion.

The trend of average total metals concentrations in sediments through Parts A, B, and C of this study is shown in Figure IV-5. For ease of discussion, the subscripts "S" and "NS" will be used to denote areas characterized by spoil and no-spoil deposition, respectively. Thus A, $B_{NS}$, and $C_{NS}$ represent areas where heavy metals data indicate no spoil accumulating, and $B_S$ (within a 0.5 mile radius of the designated dump site) and $C_S$ represent areas of dredge spoil deposition. Differences in the arithmetic means of total metals concentrations were tested using the t test for two independent samples which assumes the true population standard deviations to be equal (i.e. $\sigma_1 = \sigma_2$) permitting a "pooled" estimate of the sample variance to be calculated from the two sets of data. Using this method, the differences in mean total metals concentrations between $B_S$ and $B_{NS}$, and between $C_S$ and $C_{NS}$ were significant ($p<.05$). This result is expected and only lends credence to the delineation of spoil and no-spoil areas for Parts B and C of this study. Comparison of the mean total metals concentrations between A and $B_{NS}$, and between $B_{NS}$ and $C_{NS}$ reveals no significant differences ($p>0.05$). This indicates that the baseline (Part A) and no-spoil sediment concentrations have not changed significantly over the course of this study. However, comparing the mean total metals concentrations of $B_S$ and $C_S$ reveals an increase (from 407 to 632 mg / kg; Figure IV-5) which is significant (although just barely, $p \approx 0.03$). There are several possible explanations for this apparent increase. First, the small sample size (N=4) may have underestimated the true average total metals concentration for $B_S$.

Figure IV-5. Average total metal concentrations through Parts A, B, and C (N = number of stations, i.e, samples, examined)



Furthermore, while there is much concern for dredged materials releasing metals and other pollutants to the water column (Keeley and Engler, 1974), the possibility of dissolved metals being removed by sediment and adding to the total metals concentration of the sediment should not be overlooked (Bradford, 1976). Thus a second alternative explanation for the higher values of total metals in $C_S$ is that there is another source of metals in the sediments other than dredge spoil. The basis for this alternative is that many of the individual metal concentrations found in sediment from the study site (Table IV-2) are higher than those in the dredge spoil itself (Part B; Table IV-9). This leads to speculation as to other possible sources of heavy metals. Sewage from the City and County of Honolulu's Sand Island Sewage Treatment Plant has been mentioned in the Part B report as a possible factor in adding suspended matter and nutrients below the level of the thermocline. Sewage could also possibly add significant amounts of heavy metals to the water which could increase sediment metals either directly, through deposition of solids, or indirectly, by making dissolved metals available for absorption to already deposited sediment. While it has been shown that treated sewage effluent contains only small concentrations of heavy metals (Nomura and Young, 1974), with most of the metals being removed with sludges in primary treatment and further removal occurring through biological uptake in secondary treatment, the raw sewage being discharged by the Sand Island Sewage Treatment Plant contains both liquid and solid components, and therefore, the bulk of its original metal content.

3. Heavy Metal Body Burdens in Shrimp and Zooplankton

The heavy metal body burdens of shrimp (Heterocarpus ensifer) collected from the study area are presented in Table IV-3. As in the Part B monitoring studies, copper and zinc were the only metals detected with the analytical methods employed. Again, there seemed little difference between shrimp collected from the dump site (Set 7) and from the "control" station (Set 8). There was also no evidence to suggest that bioconcentration of metals was occurring at the dump site. Unfortunately, as noted above, the "control" station was not without the influence of dredge spoil material.

Results of heavy metals analysis of preserved zooplankton samples are shown in Table IV-4. Comparative data from samples collected during Parts A and B are also included. Samples were either whole or split (aliquoted), with the exception of one sample (June 15, 1977) which was handpicked and consisted entirely of chaetognaths. Preliminary examination of the data revealed an apparent bioconcentration of metals, with higher concentrations appearing in samples collected during the present study. However, closer examination revealed the actual reason for this observation. Split or handpicked samples (Parts A and B) are an order of magnitude lower in total metals concentrations than whole samples (Part C). Furthermore, Part C whole samples would be expected to contain appreciably more suspended metals due to the abundance of non-living suspended matter presumably introduced by the diversion of the Sand Island sewage treatment plant effluent to a new deep ocean outfall, ca. December 1976. Therefore, whole samples contained a large fraction of non-living suspended matter which could not be physically separated from living material (i.e. zooplankton) except by handpicking or to a lesser extent by splitting of samples. It is interesting to note that the one handpicked sample containing only chaetognaths, a higher order carnivore, contained the lowest concentration of total metals of all the samples examined. Thus, bioconcentration of heavy metals by zooplankton, either temporally or through trophic levels, could not be documented in this study without expedient methods to physically separate non-living and living components.

E. Summary

1. Receiving water samples were collected and analyzed for heavy metals. Only surface samples were collected and processed since results from the earlier Part B monitoring study indicate that the effects of dredge spoil disposal on the quality of the water column are relatively short lived. The only possible exception appeared to be heavy metals in surface samples. However, examination of data collected in the present study reveals that concentrations of heavy metals at the disposal site (Station 2) are as low or lower than those found at nearby stations.

2. The distribution of sediment metals indicates a more widespread distribution of spoil material on the bottom since the conclusion of Part B monitoring studies. Spoil derived material was found as far as two miles to the west of the designated disposal site. Tidally induced, oscillatory bottom currents are primarily responsible for redistributing spoil material on the bottom. It is expected that further dispersion and dilution of deposited spoil material will occur in the future. Bottom sediment from areas characterized by spoil deposition showed a marked increase in mean total metals concentrations (632 mg/kg) over Part B studies (407 mg/kg) dry weight. Sewage from the Sand Island sewage

treatment plant could be another significant source of metals to bottom sediments at the study site.

3. Examination of body burdens in shrimp (Heterocarpus ensifer) and zooplankton samples reveals no evidence of bioconcentration of heavy metals occurring at this time. Examination of zooplankton samples collected in the present study was complicated by the presence of a large fraction of suspended matter which is believed to be sewage from the Sand Island outfall, Honolulu.

## F. Acknowlegements

Lab space was furnished by Dr. Reginald H. F. Young, Assistant Director of the Water Resources Research Center, University of Hawaii. Mike Allen, Edith Chave, and John Walters assisted in collecting samples in the field. Special thanks to Jacquelin N. Miller for her guidance throughout all parts of this study. We gratefully acknowledge the efforts, generosity, and patience of these and others who have made this study possible.

## G. Literature Cited

Bradford, W.L., 1976. Distribution and movement of zinc and other heavy metals in South San Francisco Bay, California. Water-Resources Investigations 37-75. USGS, Water Resources Division, Menlo Park, California.

Brown, E., M.W. Skougstad, and M.J. Fishman, 1970. Methods for the Collection and Analysis of Water Samples for Dissolved Minerals and Gases. USGS, Washington, D.C.

Chave, K.E. and J.N. Miller, 1977. Baseline studies and evaluation of physical, chemical and biological characteristics of nearshore dredge spoil disposal, Pearl Harbor, Hawaii. Parts A and B. Environmental Center Final Report, University of Hawaii.

Keeley, J.W. and R.M. Engler, 1974. Discussion of regulatory criteria for ocean disposal of dredged materials: Elutriate test rationale and implementation guidelines. U.S. Army Engineer Waterways Experiment Station, Office Dredged Material Research, Vicksburg, Mississippi.

Krishnamurty, K.V., E. Shpirt, and M.M. Reddy, 1976. Trace metal extraction of soils and sediments by nitric acid-hydrogen peroxide. Atomic Absorption Newsletter 15(3):68-70.

Nomura, M.M. and R.H.F. Young, 1974. Fate of heavy metals in the sewage treatment process. Technical Report No. 82. Water Resources Research Center, University of Hawaii.

# V. ZOOPLANKTON

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A. Objectives

The zooplankton community is an integral link in the marine food chain, supporting populations of many commercial and sport fishes. In addition, larger marine animals often have zooplanktonic larval forms. Dredge spoil disposal was anticipated to affect the zooplankton in the disposal area through possible effects of suspended particles on feeding and respiration and elutriated heavy metals from deposited spoil. Part A of this study obtained baseline population sizes of zooplankton in the disposal area before dumping and recommended a specific dump site in the southeast corner of the disposal area. Part B monitored the dredge spoil disposal and looked for immediate effects of suspended sediment on the zooplankton (Chave and Miller, 1977). The objectives of the present Part C study were twofold: Determination of the short-term response of the zooplankton community to decreasing loads of suspended sediment in the water column, and investigation of long-term effects of heavy-metal elutriates from deposited spoil.

B. Methods

The Part C zooplankton sampling required a different sampling schedule than the other phases of the Part C study. Since the zooplankton community was anticipated to respond to rapidly-diminishing quantities of suspended dredge spoil over a period of days to weeks, it was essential to begin the Part C zooplankton sampling immediately after cessation of dumping. Thus, much of the Part C zooplankton sampling was done during the latter stages of the Part B study. The effects of elutriates from deposited dredge spoil were anticipated to appear over a period of months; samples for heavy metals analysis were collected during the regular Part C cruises.

To investigate the short-term response of the zooplankton to cessation of dumping, a series of eight tows was taken the night of June 15-16, 1977, two weeks after dumping stopped (Table V-1, Figure V-1), and a series of nine tows was taken the night of July 15-16, 1977, six weeks after dumping stopped (Table V-2, Figure V-2). These tows were oblique tows with a 1-meter conical plankton net of 333μ mesh, as in the previous two parts of the study. Maximum depths as determined by a Benthos time-depth recorder were approximately 60-80 fathoms

Table V-1. Plankton tows, June 15-16, 1977

| Tow Number | Time | Duration (min) | Depth (fm) | Volume Filtered ($m^3$) |
|---|---|---|---|---|
| 11 | 2112-2130 | 18 | 60 | 838 |
| 12 | 2205-2216 | 11 | 65 | 552 |
| 13 | 2235-2248 | 13 | 70 | 615 |
| 14 | 2305-2317 | 12 | 65 | 580 |
| 15 | 2338-2351 | 13 | 80 | 581 |
| 16 | 0006-0018 | 12 | 80 | 682 |
| 17 | 0035-0047 | 12 | 75 | 424 |
| 18 | 0107-0140 | 33 | 155 | 1461 |

Table V-2. Plankton tows, July 15-16, 1977

| Tow Number | Time | Duration (min) | Depth (fm) | Volume Filtered ($m^3$) |
|---|---|---|---|---|
| 19 | 2202-2208 | 4 | 15 | 132 |
| 20 | 2231-2243 | 12 | 70 | 287 |
| 21 | 2305-2315 | 10 | 75 | 232 |
| 22 | 2332-2342 | 10 | 70 | 254 |
| 23 | 0002-0025 | 23 | 180 | 531 |
| 24 | 0110-0119 | 9 | 75 | 278 |
| 25 | 0145-0154 | 9 | 75 | 303 |
| 26 | 0210-0221 | 11 | 70 | 278 |
| 27 | 0242-0309 | 27 | 190 | 633 |

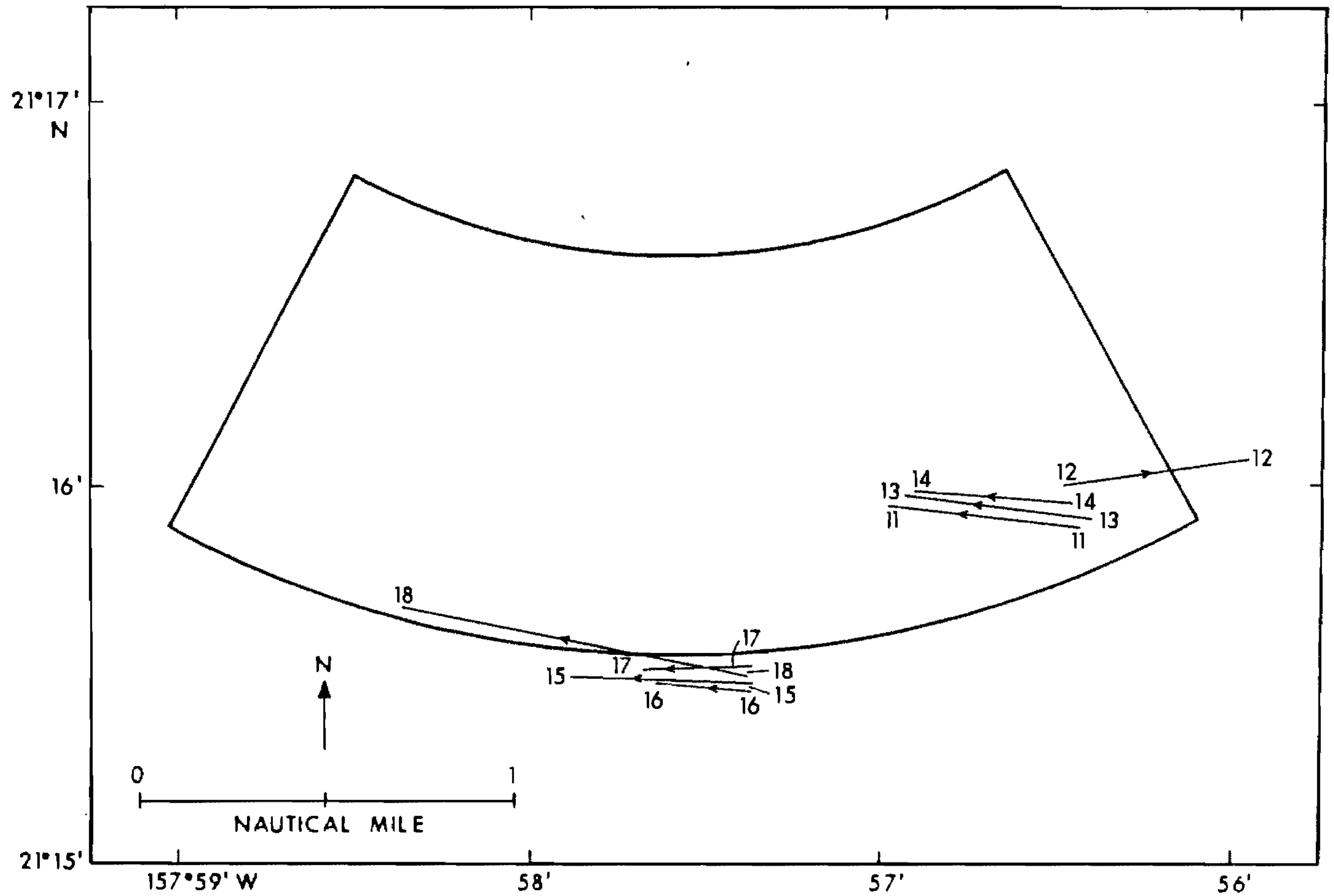
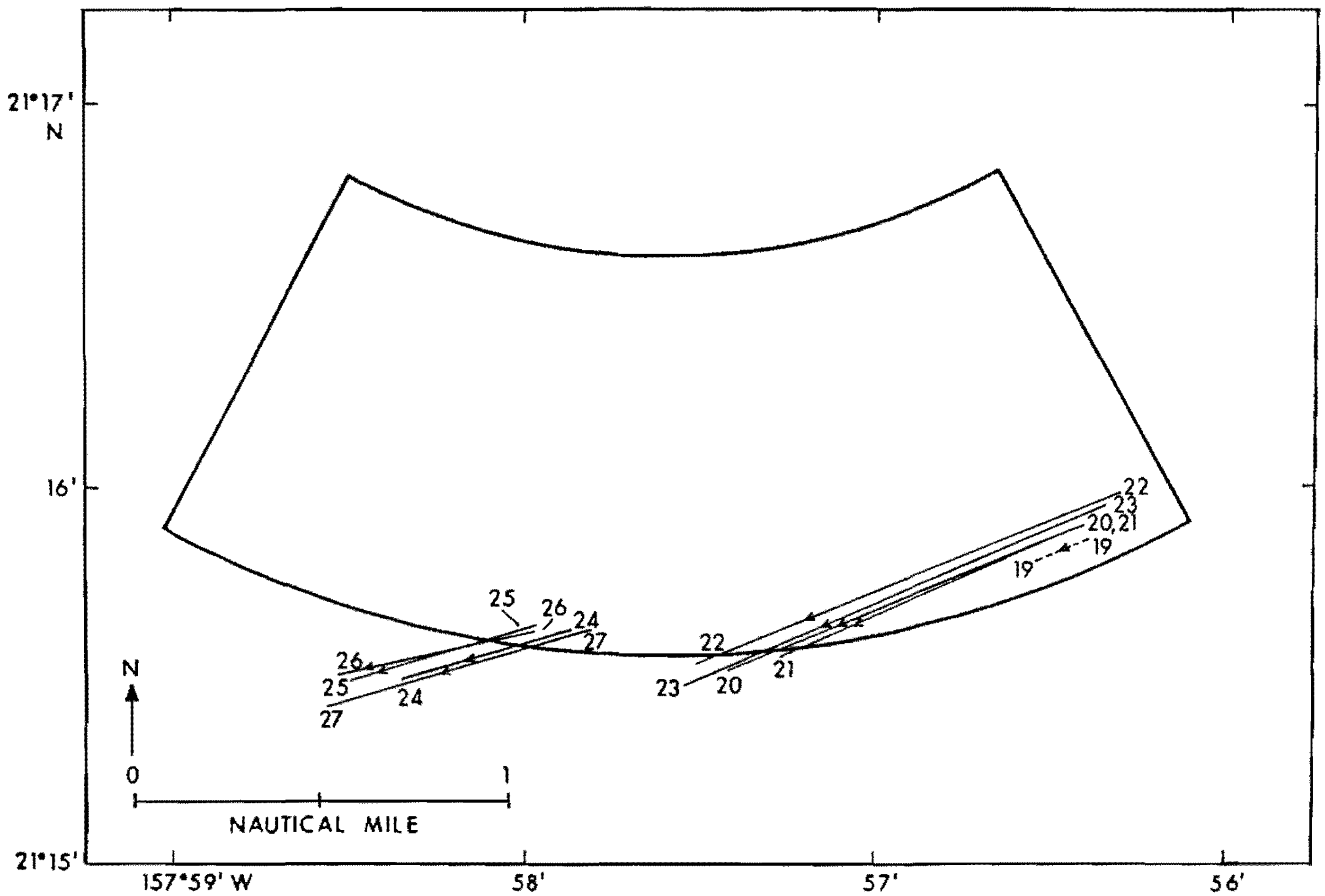



Figure V-1. Plankton tows, June 15-16, 1977.
⟵ = path and direction of tow.

Figure V-2. Plankton tows, July 15-16, 1977.
--<--- aborted tow
——<—— path and direction of tow



(110-150 m), except for the abortive tow no. 19, which sampled to only 15 fm (30 m), and tows no. 18, 23, and 27, which sampled down to 155-190 fm (285-350 m) to check on the abundance of the deeper zooplankton.

Two sets of zooplankton samples for heavy metals analysis were planned at three and six months after cessation of dumping. Sampling gear and methods were as described above. The three-month samples were collected on September 13, 1977 (Table V-3, Figure V-3). Maximum depths were estimated from the amount of wire paid out and its angle with the sea surface and ranged from 120 to 140 fm (215-260 m). The six-month samples were collected on December 8, 1977 (Table V-4, Figure V-3); maximum depths were again estimated from wire angle and ranged from 155 to 165 fm (280-305 m).

Zooplankton samples from all the tows were preserved in 5 per cent formalin, and aliquots from each June and July sample were sorted into major taxa and counted. In order to estimate seasonal effects on zooplankton numbers, three samples each from the September and December tows (nos. 1-3 and 7-9) were also counted. The raw counts were converted into numbers per square meter of sea surface as in the Part A and Part B reports (Maynard et al., 1975).

A series of preserved zooplankton samples from the Part A and Part B studies and the September and December collections of this study were selected for heavy metals analysis. To check for possible bioconcentration of metals in the higher trophic levels of the food chain, all the chaetognaths (an important zooplanktonic carnivore) were sorted out of a sample from the Part B study. Analysis of the heavy metals in the zooplankton was performed by Alvin Char, and the results are presented in Part IV of this report.

## C. Results

The composition of the zooplankton community sampled by the plankton tows is presented as numbers per square meter of sea surface and as percentages of the whole sample in Tables V-5 through V-10. As before, copepods were the dominant group, comprising about 50 to 70 per cent of the total sample. Ostracods were also moderately abundant, as were the euphausiids in June and September. Tow no. 27, a deep tow in July, took large numbers of ostracods, more than 20 per cent of the sample. The other crustacea category, made up mostly of crab and decapod shrimp larvae, comprised up to 12 per cent of some of the July samples. A larval bivalve was extremely abundant in the December

Table V-3. Plankton tows, September 13, 1977

| Tow Number | Time | Duration (min) | Depth (fm) | Volume Filtered ($m^3$) |
|---|---|---|---|---|
| 1 | 1930-1951 | 21 | 120 | 616 |
| 2 | 2005-2025 | 20 | 140 | 627 |
| 3 | 2042-2102 | 20 | 140 | 594 |
| 4 | 2120-2138 | 18 | 125 | 538 |
| 5 | 2202-2221 | 19 | 140 | 564 |
| 6 | 2234-2252 | 18 | 140 | 570 |

Table V-4. Plankton tows, December 8, 1977

| Tow Number | Time | Duration (min) | Depth (fm) | Volume Filtered ($m^3$) |
|---|---|---|---|---|
| 7 | 1907-1925 | 18 | 155 | 722 |
| 8 | 1937-1955 | 18 | 155 | 667 |
| 9 | 2022-2037 | 15 | 155 | 623 |
| 10 | 2045-2102 | 17 | 165 | 692 |
| 11 | 2108-2126 | 18 | 155 | 742 |
| 12 | 2133-2150 | 17 | 165 | 652 |

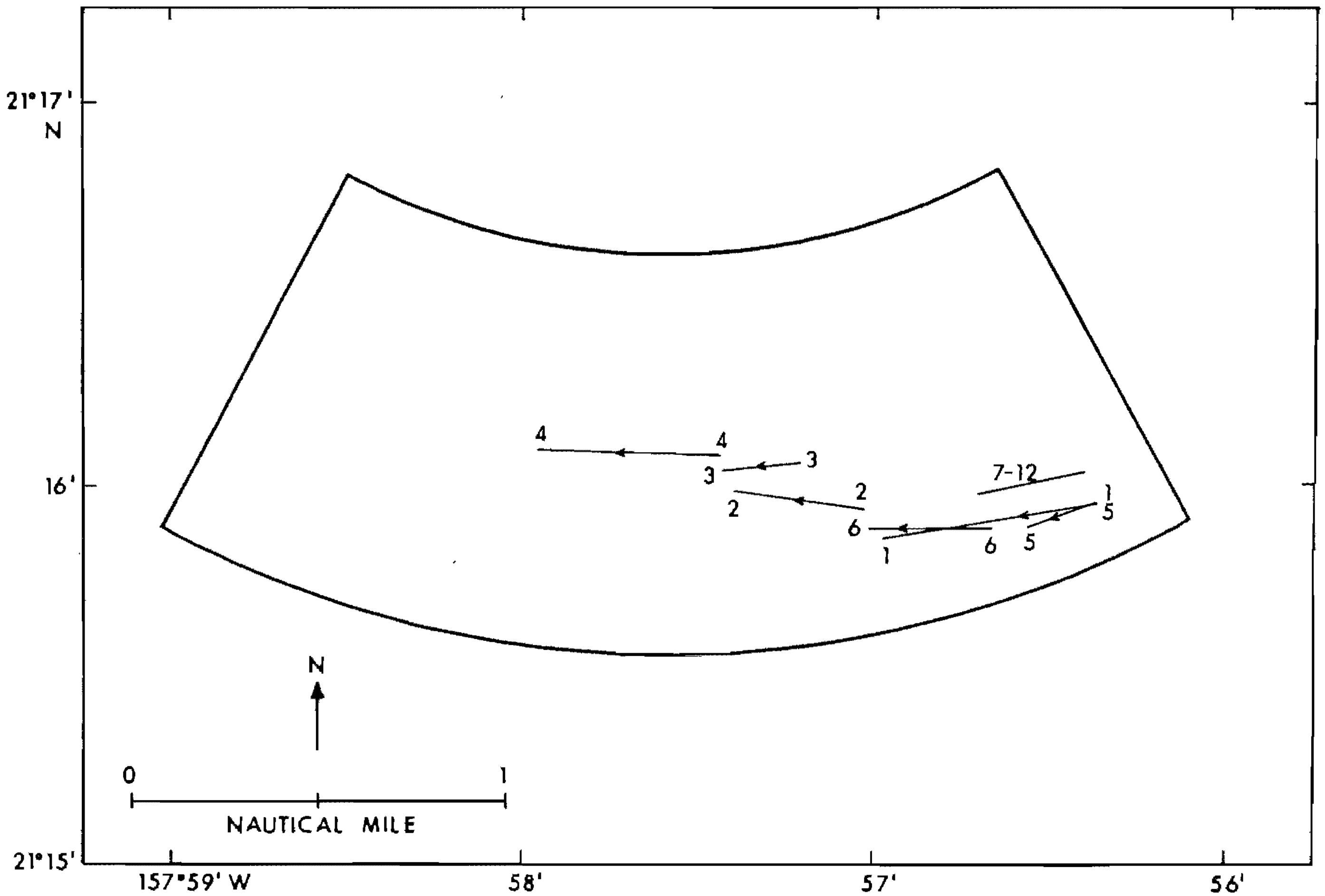



Figure V-3. Plankton tows, September 13, 1977 (1-6) and approximate track of tows of December 8, 1977 (7-12). ⟵ = path and direction of tow

Table V-5. Zooplankton composition, June 15-16, 1977. Numbers per $m^2$ of sea surface.

| | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|
| Copepods | 11,600 | 16,600 | 14,100 | 14,800 | 16,500 | 14,800 | 20,100 | 11,700 |
| Ostracods | 880 | 1,760 | 1,300 | 1,460 | 1,610 | 1,060 | 2,530 | 1,060 |
| Amphipods | 189 | 33 | 32 | 166 | 0 | 106 | 211 | 156 |
| Euphausiids | 2,770 | 2,800 | 2,340 | 3,250 | 578 | 1,900 | 3,750 | 1,250 |
| Other Crustacea | 503 | 666 | 715 | 828 | 248 | 563 | 1,430 | 811 |
| Molluscs | 985 | 4,330 | 292 | 2,680 | 660 | 598 | 634 | 499 |
| Siphonophore Fragments | 252 | 732 | 1,010 | 894 | 743 | 598 | 1,110 | 343 |
| Chaetognaths | 482 | 1,300 | 1,200 | 1,460 | 1,160 | 1,090 | 1,530 | 1,090 |
| Larvaceans | 210 | 1,700 | 974 | 1,460 | 1,360 | 1,370 | 1,640 | 1,810 |
| Other Jelly | 126 | 599 | 325 | 199 | 619 | 669 | 581 | 312 |
| Larval Fishes | 21 | 0 | 130 | 166 | 206 | 246 | 370 | 156 |

Table V-6. Zooplankton composition, June 15-16, 1977. Per cent of total sample.

| | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|
| Copepods | 64.4 | 54.5 | 62.8 | 54.1 | 69.6 | 64.3 | 59.3 | 61.0 |
| Ostracods | 4.9 | 5.8 | 5.8 | 5.3 | 6.8 | 4.6 | 7.5 | 5.5 |
| Amphipods | 1.0 | 0.1 | 0.1 | 0.6 | 0.0 | 0.5 | 0.6 | 0.8 |
| Euphausiids | 15.4 | 9.2 | 10.4 | 11.9 | 2.4 | 8.3 | 11.1 | 6.5 |
| Other Crustacea | 2.8 | 2.2 | 3.2 | 3.0 | 1.0 | 2.5 | 4.2 | 4.2 |
| Molluscs | 5.5 | 14.2 | 1.3 | 9.8 | 2.8 | 2.6 | 1.9 | 2.6 |
| Siphonophore Fragments | 1.4 | 2.4 | 4.5 | 3.3 | 3.1 | 2.6 | 3.3 | 1.8 |
| Chaetognaths | 2.7 | 4.2 | 5.4 | 5.3 | 4.9 | 4.7 | 4.5 | 5.7 |
| Larvaceans | 1.2 | 5.6 | 4.4 | 5.3 | 5.8 | 6.0 | 4.8 | 9.4 |
| Other Jelly | 0.7 | 2.0 | 1.5 | 0.7 | 2.6 | 2.9 | 1.7 | 1.6 |
| Larval Fishes | 0.1 | 0.0 | 0.6 | 0.6 | 0.9 | 1.1 | 1.1 | 0.8 |

Table V-7. Zooplankton composition, July 15-16, 1977. Numbers per $m^2$ of sea surface.

| | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|
| Copepods | 3,040 | 12,300 | 11,600 | 13,400 | 11,900 | 9,180 | 9,610 | 9,660 | 12,800 |
| Ostracods | 91 | 349 | 512 | 696 | 1,190 | 661 | 1,400 | 1,800 | 4,950 |
| Amphipods | 36 | 279 | 326 | 287 | 397 | 428 | 480 | 225 | 442 |
| Euphausiids | 163 | 593 | 652 | 410 | 397 | 272 | 517 | 749 | 885 |
| Other Crustacea | 508 | 1,400 | 2,370 | 1,470 | 1,290 | 311 | 813 | 674 | 1,420 |
| Molluscs | 127 | 523 | 1,910 | 983 | 497 | 505 | 370 | 599 | 265 |
| Siphonophore Fragments | 127 | 523 | 605 | 369 | 596 | 233 | 444 | 374 | 708 |
| Chaetognaths | 100 | 872 | 512 | 532 | 894 | 544 | 333 | 75 | 442 |
| Larvaceans | 118 | 1,010 | 885 | 1,430 | 397 | 272 | 148 | 899 | 44 |
| Other Jelly | 163 | 453 | 466 | 328 | 199 | 233 | 407 | 674 | 1,020 |
| Larval Fishes | 0 | 35 | 47 | 205 | 0 | 0 | 0 | 225 | 44 |

Table V-8. Zooplankton composition, July 15-16, 1977. Per cent of total sample.

| | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|
| Copepods | 68.0 | 67.1 | 58.3 | 66.6 | 67.0 | 72.6 | 66.2 | 60.6 | 55.7 |
| Ostracods | 6.9 | 1.9 | 2.6 | 3.5 | 6.7 | 5.2 | 9.7 | 11.3 | 21.5 |
| Amphipods | 1.0 | 1.5 | 1.6 | 1.4 | 2.2 | 3.4 | 3.3 | 1.4 | 1.9 |
| Euphausiids | 3.7 | 3.2 | 3.3 | 2.0 | 2.2 | 2.2 | 3.6 | 4.7 | 3.8 |
| Other Crustacea | 11.4 | 7.6 | 11.9 | 7.3 | 7.3 | 2.5 | 5.6 | 4.2 | 6.1 |
| Molluscs | 2.8 | 2.9 | 9.6 | 4.9 | 2.8 | 4.0 | 2.5 | 3.8 | 1.2 |
| Siphonophore Fragments | 2.8 | 2.9 | 3.0 | 1.8 | 3.4 | 1.8 | 3.1 | 2.3 | 3.1 |
| Chaetognaths | 2.2 | 4.8 | 2.6 | 2.6 | 5.0 | 4.3 | 2.3 | 0.5 | 1.9 |
| Larvaceans | 2.6 | 5.5 | 4.4 | 7.1 | 2.2 | 2.2 | 1.0 | 5.6 | 0.2 |
| Other Jelly | 3.7 | 2.5 | 2.3 | 1.6 | 1.1 | 1.8 | 2.8 | 4.2 | 4.4 |
| Larval Fishes | 0.0 | 0.2 | 0.2 | 1.0 | 0.0 | 0.0 | 0.0 | 1.4 | 0.2 |

Table V-9. Zooplankton composition, September 13, 1977 (1-3) and December 8, 1977 (7-9). Numbers per $m^2$ of sea surface.

| | 1 | 2 | 3 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|
| Copepods | 32,600 | 17,200 | 19,000 | 12,000 | 7,590 | 7,900 |
| Ostracods | 2,350 | 1,200 | 2,300 | 2,820 | 806 | 862 |
| Amphipods | 1,010 | 358 | 343 | 714 | 269 | 790 |
| Euphausiids | 3,350 | 1,240 | 1,170 | 1,090 | 538 | 575 |
| Other Crustacea | 838 | 684 | 515 | 838 | 538 | 503 |
| Molluscs | 1,840 | 358 | 755 | 5,620 | 2,080 | 2,510 |
| Siphonophore Fragments | 223 | 423 | 240 | 93 | 202 | 144 |
| Chaetognaths | 726 | 521 | 378 | 279 | 269 | 287 |
| Larvaceans | 614 | 781 | 686 | 807 | 605 | 431 |
| Other Jelly | 838 | 619 | 961 | 217 | 336 | 216 |
| Larval Fishes | 0 | 0 | 0 | 0 | 0 | 0 |

Table V-10. Zooplankton composition, September 13, 1977 (1-3) and December 8, 1977 (7-9). Per cent of total sample.

| | 1 | 2 | 3 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|
| Copepods | 73.5 | 73.5 | 72.2 | 49.0 | 57.4 | 55.6 |
| Ostracods | 5.3 | 5.2 | 8.7 | 11.5 | 6.1 | 6.1 |
| Amphipods | 2.3 | 1.5 | 1.3 | 2.9 | 2.0 | 5.6 |
| Euphausiids | 7.5 | 5.3 | 4.4 | 4.4 | 4.1 | 4.0 |
| Other Crustacea | 1.9 | 2.9 | 2.0 | 3.4 | 4.1 | 3.5 |
| Molluscs | 4.2 | 1.5 | 2.9 | 22.9 | 15.7 | 17.7 |
| Siphonophore Fragments | 0.5 | 1.8 | 0.9 | 0.4 | 1.5 | 1.0 |
| Chaetognaths | 1.6 | 2.2 | 1.4 | 1.1 | 2.0 | 2.0 |
| Larvaceans | 1.4 | 3.3 | 2.6 | 3.3 | 4.6 | 3.0 |
| Other Jelly | 1.9 | 2.6 | 3.6 | 0.9 | 2.5 | 1.5 |
| Larval Fishes | 0 | 0 | 0 | 0 | 0 | 0 |

samples, when the molluscs made up 15 to 20 per cent of the community. Larvaceans, which had been extremely abundant in the Part B samples, were much less numerous in the Part C samples, although their numbers remained greater than in the Part A samples.

Tows over the dump site in June and July were compared with tows made in a control area in the southwest corner of the disposal area, and the relatively shallow normal tows (60-80 fm maximum depth) were compared with the deeper tows (155-190 fm maximum depth) made at the same time (Table V-11). Many of these comparisons showed statistically significant differences (t test, $p<0.05$), but not in a consistent direction. For example, most of the zooplankton groups averaged greater numbers in the control tows than in the dump site tows in June, but the reverse was true in July. The deep tow at the control site in July took larger numbers of most groups than the corresponding shallow tows, but the opposite was true at the dump site. Larger numbers of animals in deep oblique tows often mean substantial populations living below the maximum depth of shallow oblique tows. In this case, however, it appears more likely that there were no significant differences between the shallow and deep tows or between the dump site and control tows, and that the observed differences were merely due to zooplankton patchiness.

## D. Discussion

Because of the heavy contamination of the Part B samples with sewage, the maximum depths of most June and July tows were limited to about 80 fm (150 m), as the sewage appeared to have been present only in the thermocline. No sewage was found in these samples, and none was found in the accompanying deep tows, which were intended to insure sampling the entire zooplankton community with a minimum of equipment fouling by sewage. As a result, the September and December tows resumed sampling the lower thermocline down to about 190 fm (350 m), again without encountering sewage. The December tows were made during a period of kona weather similar to the conditions prevailing during the Part B sampling. Evidently kona conditions alone were insufficient to permit an influx of sewage into the disposal area.

The results of studies of water chemistry and sediment behavior presented in other sections of this report indicate that some dredge spoil material has been dispersed westward from the dump site. An unfortunate result of this westward movement is that the area chosen as a control in this zooplankton study

Table V-11. Comparison of zooplankton taken in tows at the dump site with zooplankton taken in tows at the control area, June 15-16 and July 15-16, 1977. Zooplankton are given in numbers per $m^2$ of sea surface.

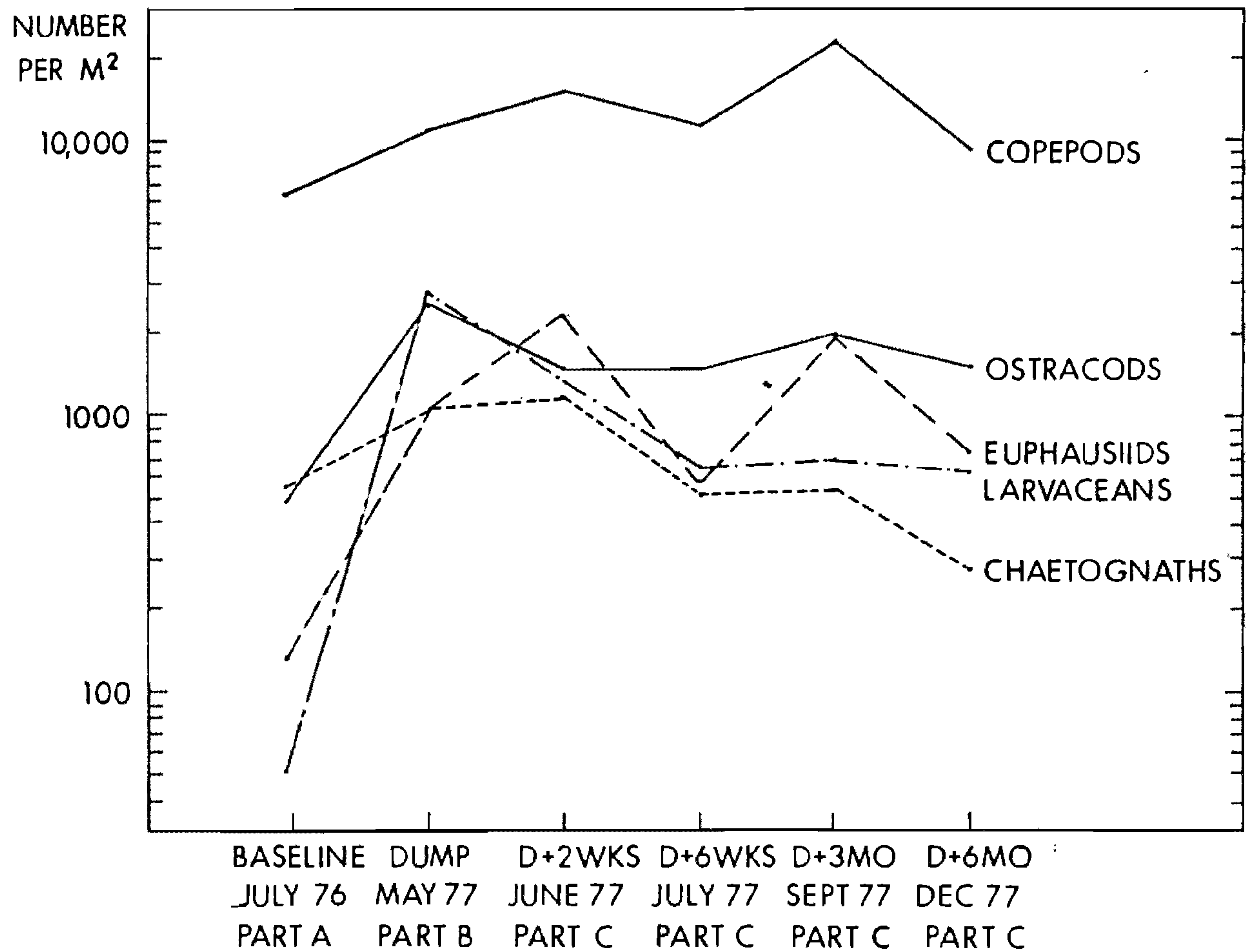
| Tow Numbers: | Shallow Dump #11-14 | Shallow Control #15-17 | Deep Control #18 | Shallow Dump #20-22 | Deep Dump #23 | Shallow Control #24-26 | Deep Control #27 |
|---|---|---|---|---|---|---|---|
| Copepods | 14,300 | 17,100 | 11,700 | 12,400 | 11,900 | 9,480 | 12,800 |
| Ostracods | 1,350 | 1,730 | 1,060 | 519 | 1,190 | 1,290 | 4,950 |
| Amphipods | 105 | 106 | 156 | 297 | 397 | 378 | 442 |
| Euphausiids | 2,790 | 2,080 | 1,250 | 552 | 397 | 513 | 885 |
| Other Crustacea | 678 | 747 | 811 | 1,750 | 1,290 | 599 | 1,420 |
| Molluscs | 2,070 | 631 | 499 | 1,140 | 497 | 491 | 265 |
| Siphonophore Fragments | 722 | 658 | 343 | 499 | 596 | 350 | 708 |
| Chaetognaths | 1,110 | 1,260 | 1,090 | 639 | 894 | 317 | 442 |
| Larvaceans | 1,090 | 1,460 | 1,810 | 1,110 | 397 | 440 | 44 |
| Other Jelly | 312 | 623 | 312 | 416 | 199 | 438 | 1,020 |
| Larval Fishes | 79 | 274 | 156 | 96 | 0 | 75 | 44 |

may have also been affected by dredge spoil disposal, thus accounting for the lack of consistent differences between study and control populations reported in Table V-11. The control area was chosen to have approximately the same water depth and distance from shore as the dump site. It was considered undesirable to locate the control area east of the dump site because of the proximity of the Sand Island sewage outfall. West of the disposal area, the bottom becomes shallower, so that the control area would have to have been considerably farther from shore than the dump site, raising the possibility of a more open-ocean zooplankton community. The area chosen was as far as practicable from the dump site, but it appears that it may not have been totally free from dredge spoil effects.

The Part B study compared a series of samples taken during dumping at a temporary site with samples taken at the usual site. At the time, I thought the samples at the usual site represented conditions two days after cessation of dumping, and my Part B report and Pre-Final Part C report reflected this view. However, dumping had actually been halted for only twelve hours at the usual site, probably not long enough for the zooplankton to respond. Thus the differences between zooplankton populations at the two sites probably reflected the different locations rather than an initial response to cessation of dumping, as I had first believed.

The most striking result of the Part B sampling was the large increase in zooplankton numbers over those found in the Part A baseline study. The Part B study considered the effects of seasonality, dredge spoil disposal, and kona weather on the zooplankton community and concluded that the most important of these effects was that of the kona weather. Figure V-4 compares the results of the first two studies with those of the present study for five important zooplankton groups: copepods, ostracods, euphausiids, chaetognaths, and larvaceans. Note that neither axis of the graph is linear. Only the ostracods displayed population changes of a sort that might represent a reaction to dredge spoil, in this case an increase in numbers during dumping followed by a decline to an approximately constant population size within about two weeks after cessation of dumping. Except for the copepods, which reached a maximum population size in the September samples, these groups showed a population increase during dumping followed by a moderate decline through the Part C sampling, with numbers in December, 1977 still considerably higher than in the July, 1976 baseline samples.

Figure V-4. Variation in number of five zooplankton groups with time.



The population trends observed in Figure V-4 undoubtedly reflect some seasonal variations in population sizes. Some groups not plotted in this figure, such as the molluscs and other crustacea, include variations due to introduction of meroplanktonic larval stages. Because the Part A samples were collected in May and the Part B samples were collected in July, an attempt was made in the Part B report to use the results of previous zooplankton studies in Hawaiian waters to estimate the importance of seasonality on the observed population increase. The present study includes July samples taken six weeks after dumping stopped. The large difference between the zooplankton numbers observed in July, 1976 and July, 1977 reaffirm the conclusion of the Part B report that seasonality alone cannot explain the difference.

The results of the December sampling, six months after cessation of dumping, raise doubts about the conclusion of the Part B report as to the importance of kona weather during the May sampling period in increasing zooplankton numbers. Kona weather prevailed during sampling in December as in May, yet the numbers of most zooplankton groups were much lower in December than in May. A more detailed examination of the weather conditions in the days prior to sampling suggests that rainfall associated with the kona weather was the critical factor in increasing the zooplankton populations. In the first week of December, winds were consistently southerly, but there was heavy rainfall only on December 3 before the sampling on December 8. In May, kona winds began on May 10, and there was heavy rainfall during May 10-14 before the sampling on May 18. Stream runoff adds nutrients from the land and stimulates phytoplankton productivity, leading to an increase in zooplankton (the "island mass" effect: Doty and Oguri, 1956). Gilmartin and Revelante (1974) showed that the effects of stream runoff normally extend only about 1 km offshore under trade wind conditions. Current measurements off the southern coast of Oahu suggest that water remains almost stationary during kona weather (DPW-Honolulu, 1972: Figure 12); land-derived nutrients might not disperse rapidly under these conditions and increased primary productivity might extend farther offshore. Increased stream runoff and the other effects of kona weather postulated in the Part B report should have been much less marked in December, presumably explaining why the December zooplankton population size did not increase.

The most surprising result of the Part C study was the failure of the zooplankton populations to return to the vicinity of their baseline values.

While a number of effects of dredge spoil disposal could be hypothesized that would lead to a prolonged depression of zooplankton population sizes, it is difficult to imagine an effect producing a prolonged increase in the zooplankton. Any nutrients released from the deposited dredge spoil would be prevented by the thermocline from increasing the productivity of the euphotic zone in the disposal area. The most likely cause of increased productivity in the disposal area is the Sand Island sewage outfall, which was relocated between the Part A and Part B studies. The new outfall is considerably farther offshore and nearer the disposal area than the old outfall, and though it is deeper than the old outfall (40 fm vs. 5 fm), the sewage is still discharged into the mixed layer above the thermocline under usual conditions (DPW-Honolulu, 1972). While movement of the sewage is normally offshore, enough of it may remain in the vicinity of the disposal area to account for the increase in zooplankton productivity. The many diatom frustules found by E.H. Chave in the Part C sediment samples (Section VI) indicate that primary productivity has increased in the disposal area. Whether or not this explanation is correct, it seems clear that dredge spoil disposal cannot be responsible for the changed conditions.

## E. Summary

1. Most zooplankton groups decreased in abundance from the high values observed in the Part B studies during the first six months after cessation of dumping, with most of the decrease occurring in the first two weeks. Population sizes remained substantially higher than during the Part A baseline sampling.

2. The failure of zooplankton numbers to return to their baseline values seems to be due to increased nutrient input to the disposal area from the relocated Sand Island sewage outfall and not to any effect of the deposited dredge spoil.

## F. Acknowledgements

I would like to thank Jed Hirota and Richard Young for the loan of sampling gear and Saul Price for consultation about weather conditions. Thanks also to the captains and crews of Machias, Easy Rider, and El Greco for their assistance in the sampling.

## G. Literature Cited

Chave, K.E., and J.N. Miller, 1977. Baseline studies and evaluation of physical, chemical, and biological characteristics of nearshore dredge spoil disposal, Pearl Harbor, Hawaii. Parts A and B. Environmental Center Final Report, University of Hawaii.

Department of Public Works, City and County of Honolulu, 1972. Environmental Impact Statement for Sand Island sewage treatment plant and outfall sewer. 190 pp

Doty, M.S., and M. Oguri, 1956. The island mass effect. J. Cons. 22:33-37.

Gilmartin, M. and N. Revelante, 1974. The "island mass" effect on the phytoplankton and primary production of the Hawaiian Islands. J. Exp. Mar. Biol. Ecol. 16:181-204.

Maynard, S.D., F.V. Riggs, and J.F. Walters, 1975. Mesopelagic micronekton in Hawaiian waters: Faunal composition, standing stock, and diel vertical migration. Fishery Bulletin, U.S. 73:726-736.

# VI. BENTHIC BIOLOGY

by

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## A. Objectives

The evaluation of the effects of dredge spoil disposal on the deep, nearshore benthic biological community has been a primary objective of this project. The first phase (Part A) of the study dealt with the collection and establishment of baseline data with special emphasis on the foraminiferan and micromolluscan assemblages (Chave and Miller, 1977: Parts A and B). The second phase (Part B) of the study examined the immediate and short-term effects of dumping on the benthic fauna. The basic objective of the Benthic Biology study during Part C was to determine the long range effects of dredge spoil on benthic fauna at the Pearl Harbor disposal area and its surroundings.

The specific objectives accomplished in this part of the survey were:

1. Quantitative analyses of fecal pellets and other dredge spoil tracer species obtained in grab samples.
2. Quantitative and qualitative comparisons of the benthic micromollusks and foraminifera in grab samples obtained from the original baseline stations (Part A) in 1976 with samples taken at these same stations during this part of the study.
3. Examination of living, non-commercial macrofauna in and around the disposal area.

## B. Methods

Samples were taken in September, October, and December 1977 by the research vessels Machias and El Greco.

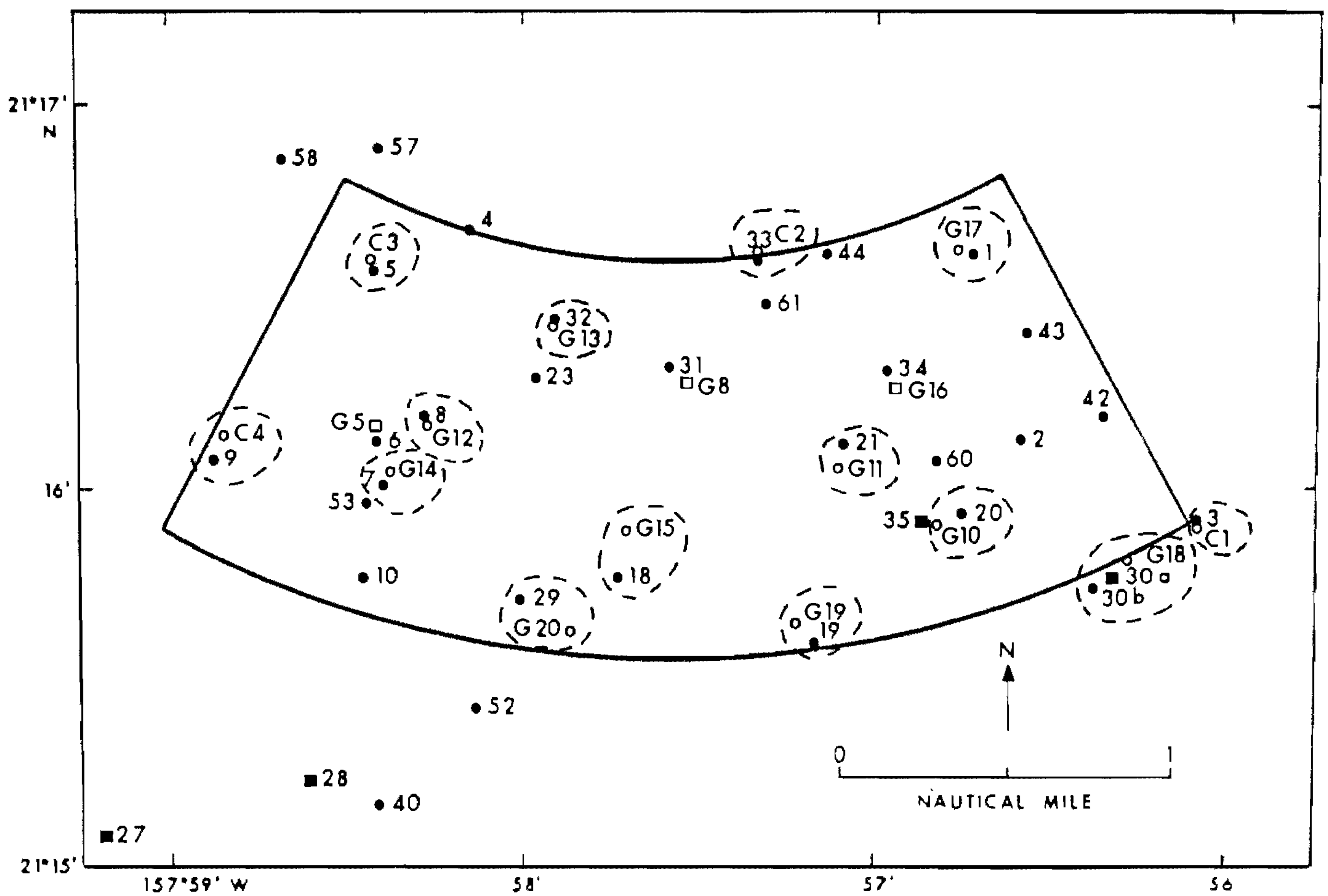
### 1. Field Methods

Samples for micromollusks and foraminifera were obtained using a Petersen grab sampler and a rotary clam grab sampler. Cobbles were removed from the samples, examined and placed in alcohol to preserve living material. All grab samples were infused with rose bengal to stain living tissue.

All 18 of the September 1976 stations were resampled in September 1977. The Part C stations (1977) are paired with corresponding Part A stations (1976) in Figure VI-1. Differences in station location between years was due to the ship's drift from the 1976 station locations during sampling. Of the 18 paired stations, 17 yielded soft sediment samples during both years. Of these, 12 station pairs were examined. The 1976 stations C1, C4, G5, G6, G8 were very small samples used

Figure VI-1. September 1976 and 1977 stations in the Pearl Harbor dredge spoil disposal area. The 1976 stations begin with the letters C and G; those which begin with a number are 1977 stations. Dashed circles indicate those 1976-1977 samples paired for faunal comparison. Refer to Appendix 2 for data list.

| 1976 | 1977 | |
|---|---|---|
| □ | ■ | Rocks or hard substrate |
| ○ | ● | Soft substrate |



in micromollusk analysis only (Appendix 1). Station G16 contained rocks in 1976. Bottom type and macrofauna were observed in pictures obtained from a photo line taken in December 1977. For comparison purposes, this December line and the previous photo lines are shown in Figures VI-2 and -3. The method of obtaining the Part C photos is described by Allen (Part C, Section III). Macrofauna was collected in September and December 1977 by trapping as described by Chave (Part B, Section VII).

2. Laboratory Methods

a. Foraminifera and Sediments

The sediment samples were washed and sieved to remove the mud fraction (<0.062 mm). They were then dried, and 25 ml of each sample was split into 1 ml aliquots and examined. Some of the samples were smaller than 25 ml, but all contained sufficient material for comparative studies. The samples were divided into a coarse fraction (>2 mm) and a fine fraction (between 0.062 and 2 mm).

All soft sediment samples were examined for fecal pellets and tracer species (see Part B, Section VI for definitions of pellets and tracer species). The abundance of two species of foraminifera was checked. The origin of sediment grains and degree of wearing of the grains was also examined (see Part A, Section VI for a description of methods).

Intact foraminifera from the 12 paired stations were counted and expressed in number/ml sediment. Benthic forams were identified to species whenever possible.

The following references were used for foraminifera identification and origin: Barker (1960), Bell (1976), Coulbourn and Resig (1975), Cushman (1932-1942), Ellis and Messina (1940+), Loeblich and Tappan (1961), and Resig (1969).

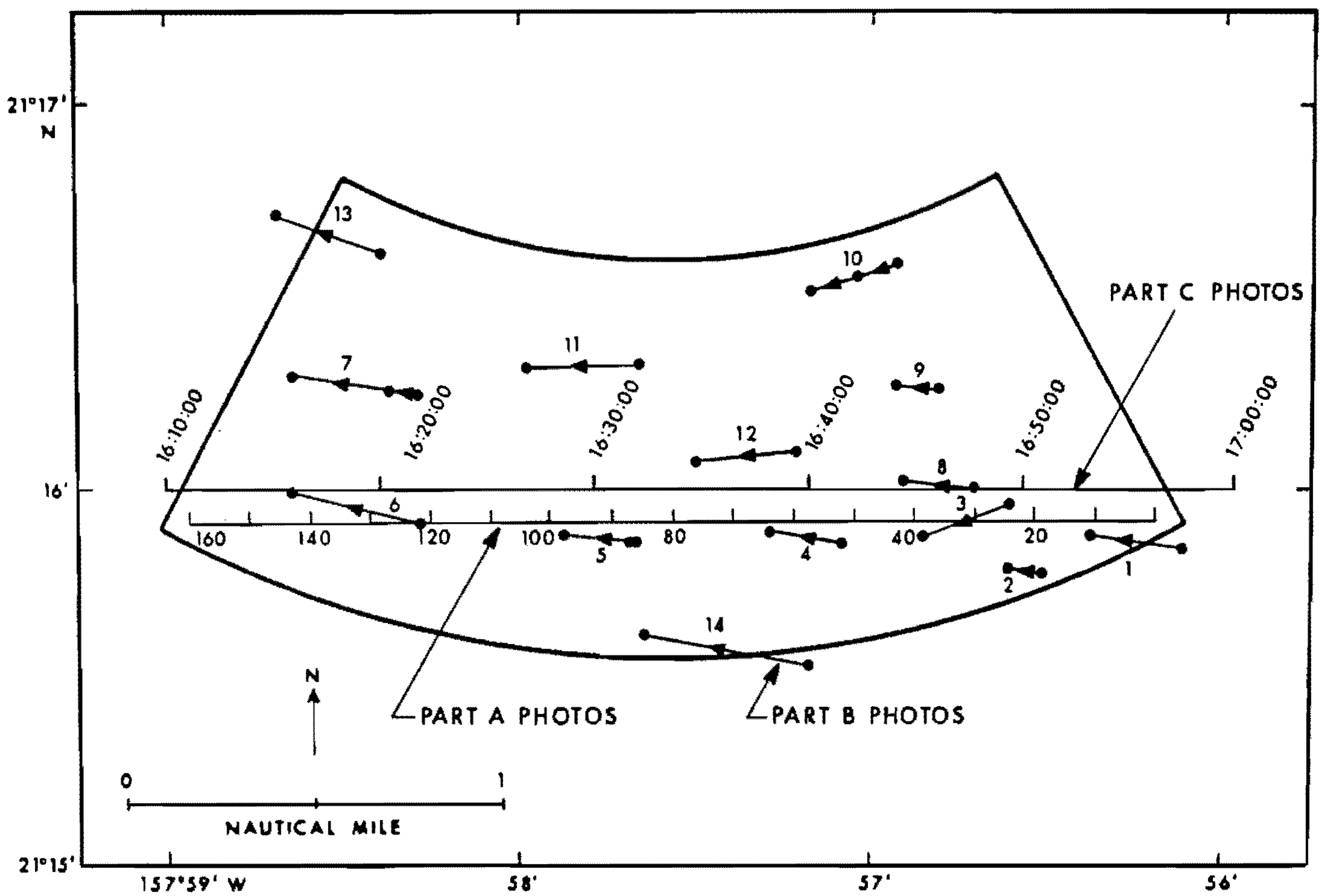
b. Living Microfauna (other than micromollusks)

All stained organisms in the grab samples were sorted, counted, identified, and expressed in numbers per ml of sediment. Animals attached to cobbles or gravel were measured and expressed in percent cover of rock surfaces.

c. Micromollusks

Micromollusks in the grab samples were analyzed by E.A. Kay and are discussed in Appendix 1.

Figure VI-2. Location of the photo lines. Part A photos include numbers 1-160 on the single E-W track. Part B photos include the short tracks numbers 1-14. The numbers along the December 1977 (Part C) line correspond to the time the photos were taken.



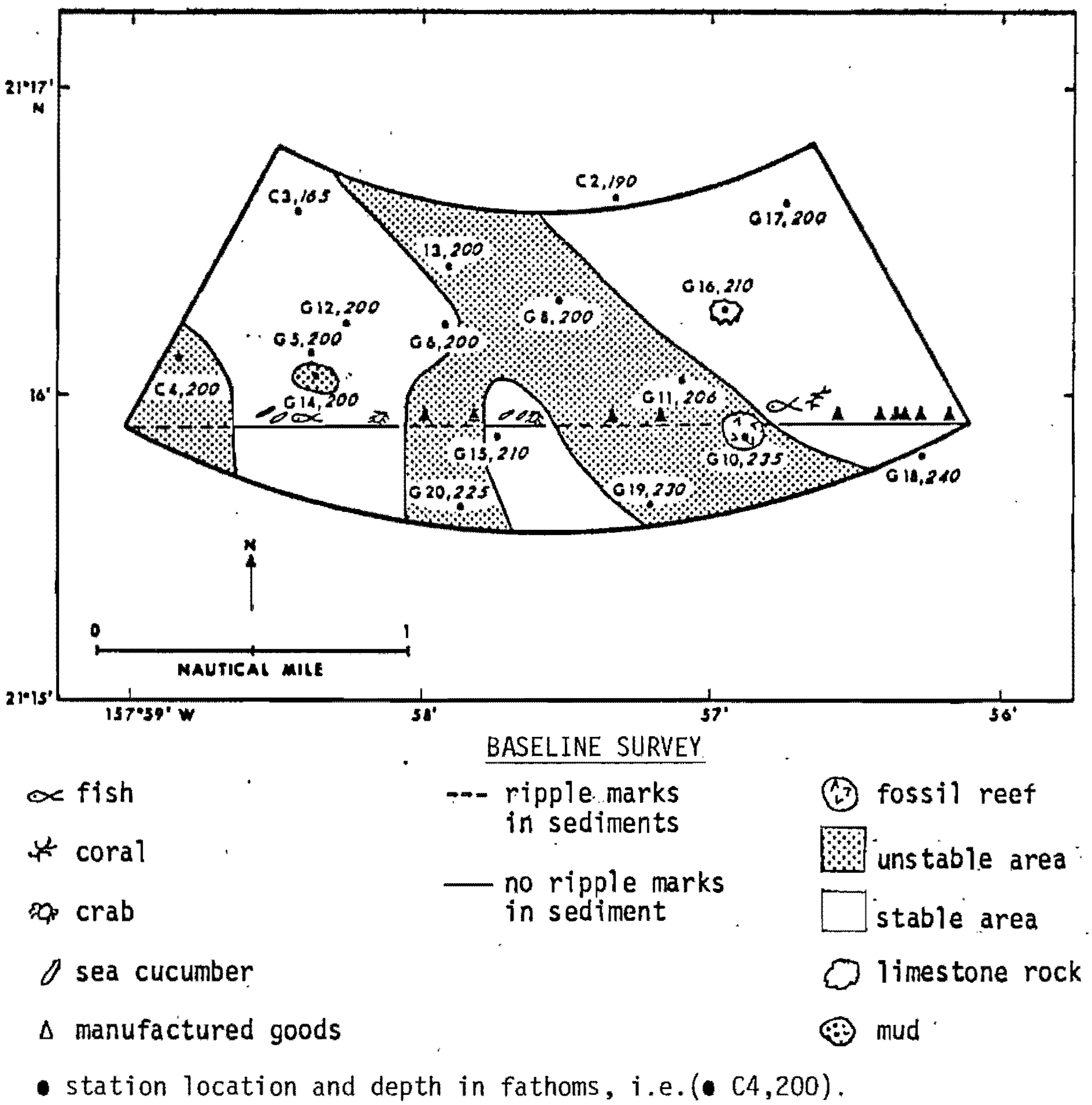



Figure VI-3. Location of stable and unstable areas at the proposed Pearl Harbor dredge spoil disposal site. The photo transect is shown as the dashed and solid line across the site. From Part A.

d. Macrofauna

Large benthic organisms caught in traps or seen on the photo line were identified and expressed in numbers per trap or number per photo.

## C. Results

### 1. Fecal Pellets and Dredge Spoil Tracer Species

Figure VI-4 shows the location and abundance of pellets and tracer species. The main concentration of this material has remained at the dump site (Station 20) with a lesser amount located in two areas, Stations 21 and 34, and Stations 4 and 32. Small numbers of pellets occurred in the two areas surrounding the stations of heaviest concentration. Station 35 near the dump site contained a coral cobble with attached large tracer species. Station 25, 1 mile southwest, and Station 26, ½ mile southwest of Station 27, shown on Figure III-1, did not contain pellets or tracer species.

### 2. Foraminifera in Paired (1976-1977) Stations

Appendix 2 lists the benthic foraminifera found in the Pearl Harbor dredge spoil disposal area for the 12 paired 1976-1977 September stations studied. Part of Table VI-1 was constructed from this appendix. Appendix 3 lists a series of rare foraminifera species found only in trace quantities.

In the Pearl Harbor dredge spoil disposal area during 1976 and 1977, there were 22 common to abundant foraminifera with living representatives in at least one sample (Table VI-1). Six species (*Ammobaculites sp.*, *Amphisorus hemptrichii*, *Biloculinella globula*, *Cylindroclavulina bradyi*, *Nubeculina divaricata* and *Robulus calcar*) were taken in large numbers in predisposal samples, although a few specimens were also observed in postdisposal samples. Eight species (*Anomalina colligera*, *Bueningia creeki*, *Gaudryina quadrangularis*, *Lenticulina suborbicularis*, *Miliolinella circularis*, *Quinqueloculina bicarinata*, *Q. poeyana*, and *Triloculina oblonga*) were observed in large numbers in postdisposal samples. The most abundant species was *Cibicides lobatulus*, which was common in half of the stations examined.

A total of 196 species were found, 34 in predisposal samples only, 25 in postdisposal samples, and 137 in both sets of samples. The lowest numbers of foram species occurring in both sets of samples per station pair were at the dump site, station pair 20-G10 (9 per cent) and at station pair 21-G11 (12 per cent).

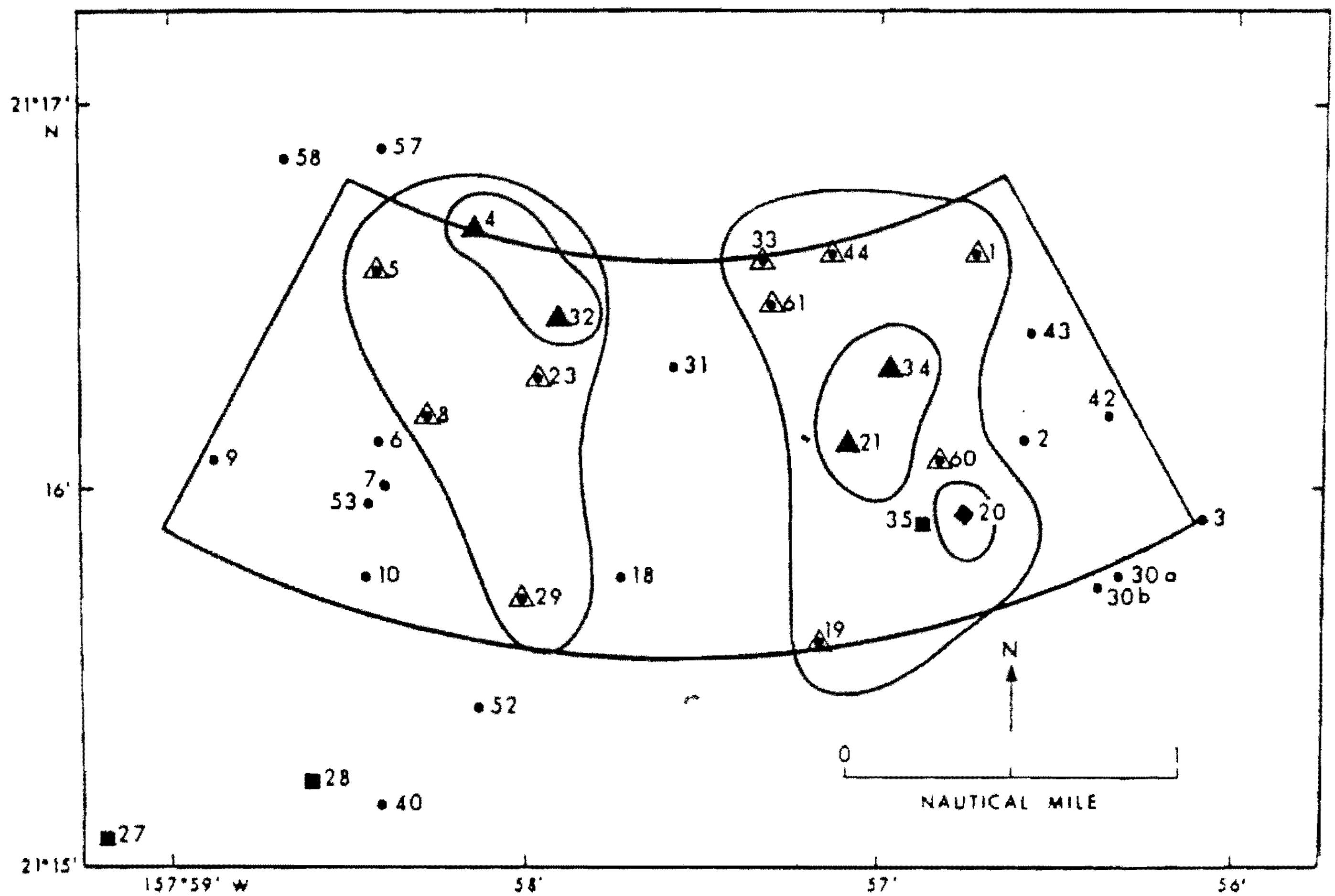



Figure VI-4. Number of pellets and presence of tracer species at each station in and around the disposal site in September and December 1977. ◆ >1000 pellets/ml, tracer species present; ▲ >100 pellets/ml, tracer species present; △ <100 pellets/ml; ● no pellets or tracer species, ■ cobbles or hard substrate.

Table VI-1. Properties of sediments obtained from the Pearl Harbor disposal study area in September of 1976 and 1977. The 1976 stations are paired with 1977 stations with similar coordinates. Living individuals of forams observed in the samples are marked with a +. *Marginopora vertebralis* and *Amphistegina lessoni*, shallow water reef species, are excluded.

| Date | 1977 | 1976 | 1977 | 1976 | 1977 | 1976 | 1977 | 1976 | 1977 | 1976 | 1977 | 1976 | 1977 | 1976 | 1977 | 1976 | 1977 | 1976 | 1977 | 1976 | 1977 | 1976 | 1977 | 1976 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | 20 | G10 | 21 | G11 | 32 | G13 | 19 | G19 | 1 | G17 | 29 | G20 | 5 | C3 | 8 | G12 | 33 | C2 | 30B | G18 | 7 | G14 | 18 | G15 |
| Depth fms | 222 | 235 | 203 | 206 | 185 | 200 | 223 | 230 | 205 | 200 | 214 | 225 | 167 | 165 | 195 | 200 | 180 | 190 | 240 | 240 | 195 | 200 | 208 | 210 |
| Substrate (mud, sand, gravel, cobbles) | MSGC | SC | S | SG | SC | SG | SG | SG | S | S | S | S | S | S | S | SG | SG | SG | SG | S | S | M | S | SG |
| Pellets - many, few, none | many | none | many | none | many | none | few | none | few | none | few | none | few | none | few | none | few | none | none | none | none | none | none | none |
| Forams > 40% benthic | | | | + | + | + | | + | + | | | + | + | | + | | + | | | + | + | | + | |
| No. foram spp. both stations* | 2 | | 3 | | 3 | | 9 | | 15 | | 7 | | 32 | | 20 | | 20 | | 17 | | 11 | | 28 | |
| No. foram spp. one station** | 2 | 19 | 12 | 7 | 1 | 6 | 19 | 4 | 9 | 9 | 5 | 3 | 6 | 2 | 12 | 2 | 3 | 17 | 0 | 3 | 7 | 3 | 8 | 8 |
| ≥100 indiv. of following foram spp. present | | | | | | | | | | | | | | | | | | | | | | | | |
| Ammobaculites sp.+ | | | | | | | | | | | | | | + | | + | | + | | | | | | |
| Amphisorus hemptrichii + | | + | | | | | | | | | | | | | | | | | | | | | | |
| Amphistegina bicirculata + | | | | | | | | | | | + | + | | + | + | | | | | | | | | |
| Anomalina colligera + | | | + | | | | + | | | | | | | | | | | | | | | | | |
| Biloculinella globula + | | + | | | | | | | | | | + | | | | | | | | | | | | |
| Bueningia creeki | | | | | | | | | | | | + | | | | | | | | + | | | | |
| Cibicides lobatulus + | | + | + | | | | + | + | | | | | | + | + | | + | | + | + | + | + | | |
| C. refulgens + | | | | | | | | + | + | + | | | | | | | + | + | | | | | + | + |
| Cibicidoides pseudoungerianus+ | | | | | | | | + | | | | | | | + | | | | | + | + | + | | + |
| Cylindroclavulina bradyi + | | | | + | | | | | + | | | | | + | | + | | + | | | | | | |
| Cymbaloporetta bradyi + | | | | | | | | | | | | | | | | | | | | | + | + | | |
| Gaudryina quadrangularis | | | | | | | | | | | | | | | | | | | | | | | + | |
| Hoeglundina elegans + | | | | | | | | | | + | | | | | | | | | | | | | | |
| Lenticulina suborbicularis | | | | | | | | | | | | | + | | | | | | | | | | | |
| Miliolinella circularis + | | | | | | | | | | | | | | | + | | | | | | | | | |
| Nubeculina divaricata | | | | | | | | | | | | | | | | | | | | | | | | + |
| Quinqueloculina bicarinata + | | | | | | | + | | | + | | | | | | | | | | | | | | |
| Q. granulocostata + | | | | | | | | | | | | | | | | | | | | | + | + | | |
| Q. lamarckiana + | | | | + | | | | | + | | | | | + | | | | | | | | | | |
| Q. poeyana | | | | | | | | | | | | | + | | | | | | | | | | | |
| Robulus calcar + | | | | | | | | | | + | | | | | | | | | | | | | | |
| Triloculina oblonga | | | | | | | | | | | | | + | | | | | | | | | | | |

* Number of species shared by the station pair
** Number of species in either the 1976 or 1977 station of the pair
\+ Living individuals in samples

Station pairs 5-C3, 19-G19, and 32-G13 shared 20, 28, and 30 per cent of the species, respectively. The rest of the station pairs shared from 46 to 85 per cent of the foram species.

3. Foraminifera and Sediments - All Stations

An analysis of Table VI-1, the photo line (Figure VI-2), and the degree to which the sediment grains were worn or broken yielded the results shown in Figures VI-5 and VI-6. A large fraction of worn and polished sediments was present in three areas (Figure VI-5). In between these areas sediments were unworn. This is reflected in the distribution of two foraminifera species, Cibicides lobatulus and C. refulgens. C. refulgens has a test more resistant to breakage than C. lobatulus (Figure VI-6).

Planktonic foraminifera were extremely abundant in deep water sediments. Essentially all forams in shallow water were benthic. The samples below the 200 fm contour in unworn sediments contained less than 40 per cent benthic species and more than 60 per cent planktonic species. Above 200 fathoms, all stations contained more than 40 per cent benthic and less than 60 percent planktonic species. All unstable (worn) station sediments contained more than 40 per cent benthic species. On the basis of the information available, it is uncertain whether these values are significant in the stable areas. In unstable areas, the more delicate planktonic forams were mostly broken, possibly skewing the benthic/planktonic ratio.

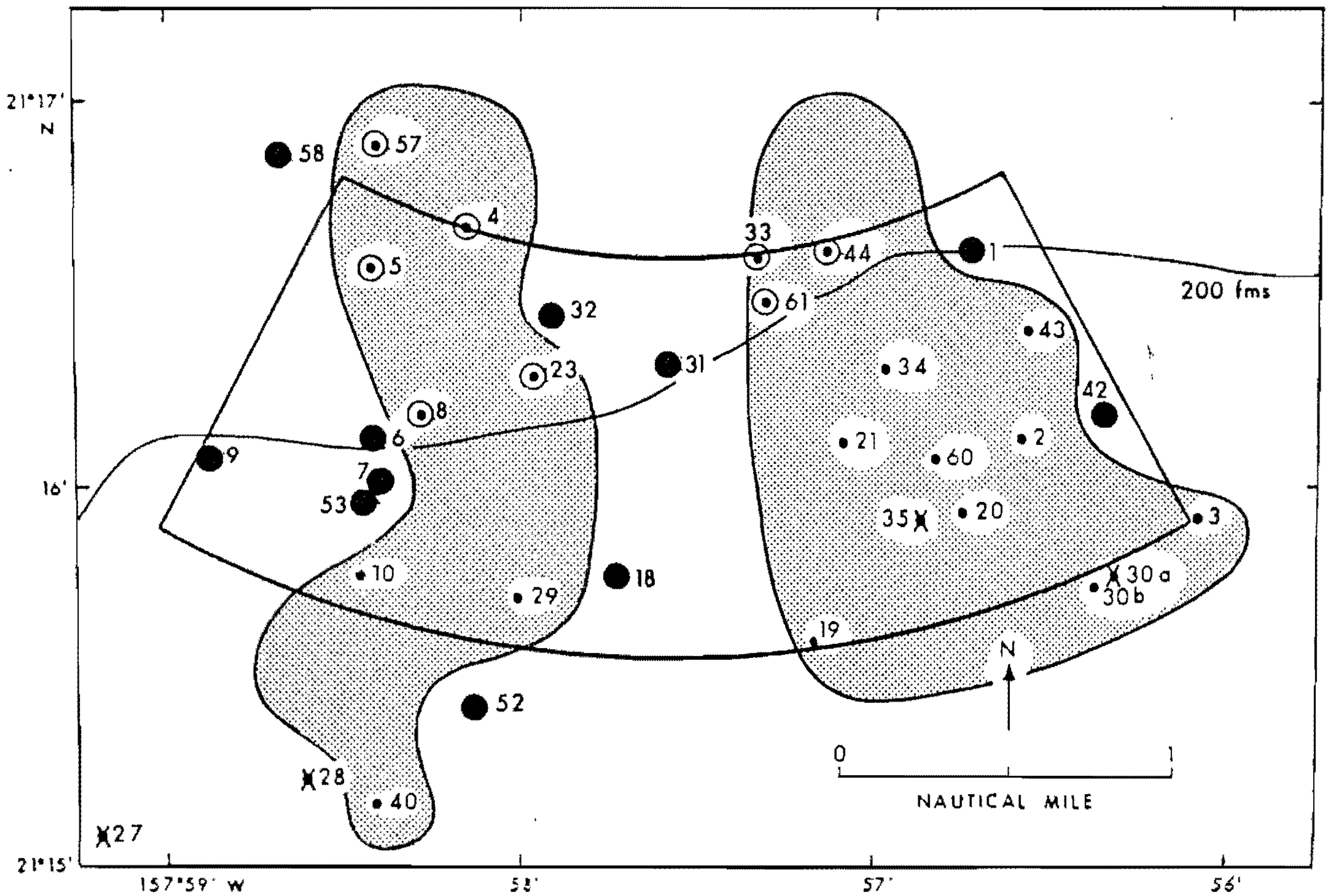
4. Living Microfauna

Living specimens of all foram species listed in Table VI-1 were observed in the samples (0.46/ml sediment). Polychaete worms comprised 0.032/ml of sediment. These two taxa were the most abundant forms in the sediment.

Rocks were covered with about 1 per cent living animals including forams (Carpenteria, Miniacina, Homotrema spp.), bryozoans and sponges, small crabs, and ophiuroids.

At several stations at and northwest of the dump site, a large number of diatom skeletons were found, indicating that there had been a phytoplankton bloom during or after dumping. This bloom may have accounted for the large amount of zooplankton observed by Walters (Figure V-4).

Figure VI-5. Stable and unstable areas in and around the Pearl Harbor dredge spoil disposal study area. Stable areas are stippled, unstable areas are clear.
● worn sediments > 40% benthic forams; • unworn sediments < 40% benthic forams;
⊙ unworn sediments > 40% benthic forams; X hard substrate or rocks.



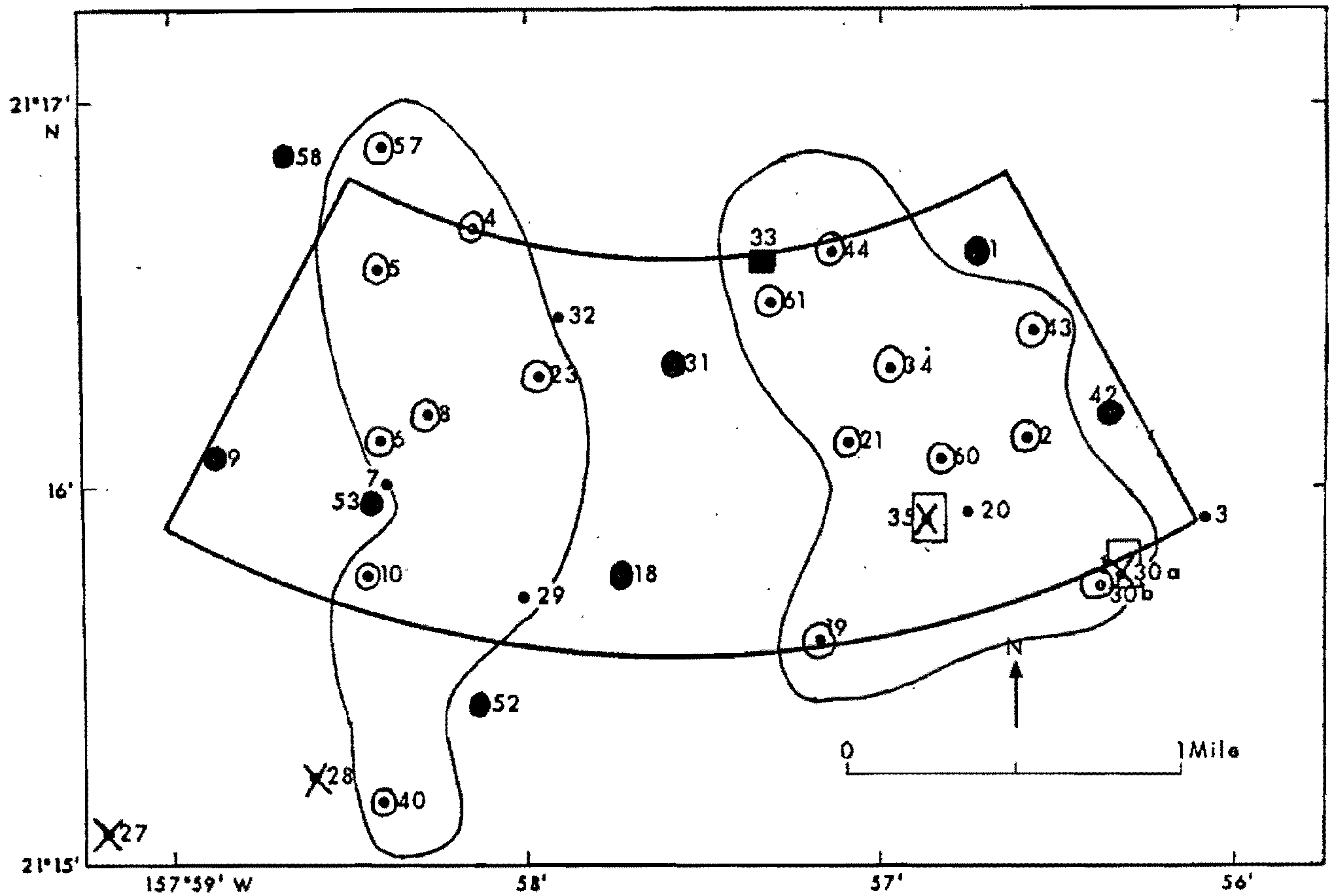



Figure VI-6. Distribution of Cibicides lobatulus and Cibicides refulgens in Pearl Harbor dredge spoil disposal area. ◉>100 C. lobatulus/ml, ●>100 C. refulgens/ml, ■ >200 both species/ml, • <100 both species/ml., X No sample, hard substrate, $\boxed{X}$ Rocks.

The phytoplankton population may have been influenced either by nutrients in the spoil or the influx of the sewer effluent to the water column.

5. Living Noncommercial Macrofauna

Table VI-2 shows the results of macrofaunal studies in 1977 and compares them with the 1976 baseline survey. Comparative results will be discussed in Section VI-D.

Sea pens (pennatulids) were the most common animals along the 1977 photo line (Figure VI-7). Juvenile whip corals and "stick" corals were the next most abundant (Figures VI-8 and VI-9). The two latter organisms were found in highest concentrations in the dredge spoil area around the dump site. Some excellent closeup photos were obtained along this photo line and included fishes, Coelorhynchus and Chaunax (Figures VI-10, 11), a squid and the shrimp, Heterocarpus ensifer one mile east (Figure VI-12). See Figure VI-2 for the location of these photographs. Figures VI-9 and VI-12 were taken from photos along the line east of the disposal area and are not shown in Figure VI-2. They are, however, the best photographic examples of stick coral and Heterocarpus ensifer which did occur in the study area.

## D. Comparison of Results and Discussion

Comparisons among the baseline survey, monitoring survey, and long term effects survey after the dumping of dredge spoil had ceased have yielded some interesting information regarding recovery of the benthic community in the Pearl Harbor dredge spoil disposal area.

1. Fate of the Dredge Spoil

Except for the dump site, and Stations 4, 21, 29, 32, 34, and 60, the number of pellets and small tracer species in almost all samples obtained in September through December 1977 has decreased by a factor of 10 from the number counted in samples taken during spoil disposal in April and May 1977 (compare Figures VI-4 and VI-13). The area containing pellets and tracer species now has been reduced to half. Further reductions in area are apparent when samples of <100 pellets are considered.

The biological results (Figure VI-4) agree with the minerological studies by Allen (Figure III-10) for two-thirds of the stations. The differences

Table VI-2. Living macrofauna at the Pearl Harbor dredge spoil disposal area identified from photos and specimens obtained in traps.

| Taxons | Abundance (indiv./unit) 1977 (97 photos) (38* traps) | 1976 (160 photos) (30 traps) |
|---|---|---|
| Coral | | |
| "stick coral" (*Schizopathes*) | 0.14/photo | 0.10/photo |
| whip coral (*Lepidisis*) | 0.24/photo | .031/photo |
| other gorgonians | .017/photo | .006/photo |
| hydroids | .013/photo | .006/photo |
| sea pens (pennatulids) | 0.32/photo | .206/photo |
| anemones | .004/photo | --- |
| Sponges and Tunicates | .013/photo | .042/photo |
| Echinoderms | | |
| holothuroids | .045/photo | .025/photo |
| Molluscs | | |
| *Umbilacrum* sp. | 0.05/trap | --- |
| squid | .013/photo | --- |
| Crustaceans | | |
| hermit crabs | .009/photo | --- |
| crabs | .013/photo | .013/photo |
| *Crytomya smithi* | 0.18/trap<br>--- | 0.2/trap<br>.03/photo |
| *Homala japonica* | 0.23/trap | 0.4/trap |
| *Randalia distincta* | --- | 0.2/trap |
| *Parthenope stellata* | --- | .15/trap |
| *Cancer* cf. *macropthalmus* | --- | .16/trap |
| *Thelexiope* sp. | --- | .15/trap |
| *Heterocarpus ensifer* | 1.0/photo<br>50.7/trap | ---<br>27.1/trap |
| anemone crab/anemone | 0.7/trap | 0.2/trap |
| *Pandalus martius* | --- | 2.8/trap |
| Fishes | | |
| *Conger wilsoni* | .056/trap | .15/trap |
| *Coelorhynchus* sp. | 0.18/photo | --- |
| *Chaunax*? | .004/photo | --- |
| *Parapercidae* | .009/photo | --- |
| unidentified | .04/photo | .013/photo |
| *Gymnothorax nuttingi* | --- | .04/trap |

*Forty traps were set, two were open on recovery.

Figure VI-7. Photo 16:54:29, 238 fm. See Figure VI-2. Sea pens located near the dump site.

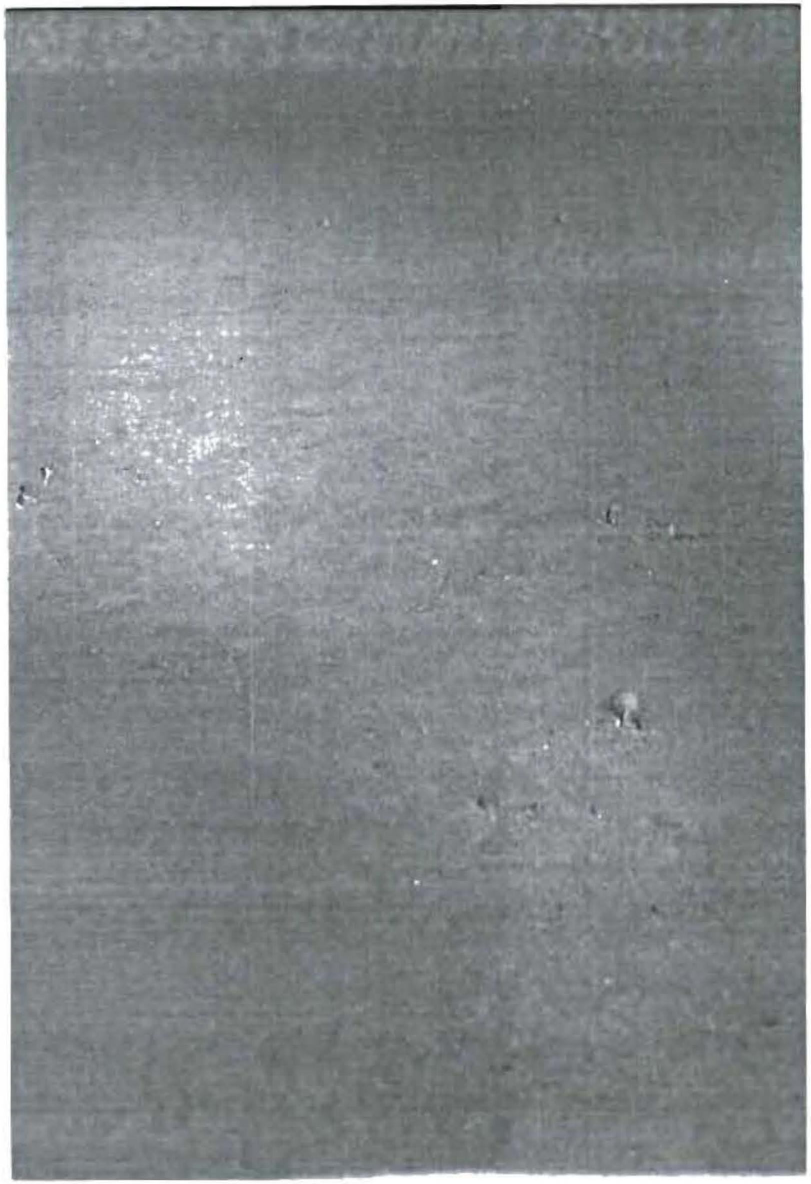


Figure VI-8. Photo 16:44:59, 225 fm. See Figure VI-2. Whip corals and a sea cucumber near the dump site.

Figure VI-9. Photo 17:01:12, immediately east of the study area, 240 fm. See Figure VI-2. A "stick" coral in the foreground.

Figure VI-10. Photo 16:40:24, 220 fm. See Figure VI-2. A clear water angler fish (Chaunax) near the dump site. A rock is obscuring its pelvic fins.

Figure VI-11. Photo 16:35:29, west of the dump site, 212 fm. See Figure VI-2. Coelorhychus sp. in the foreground by the rock.

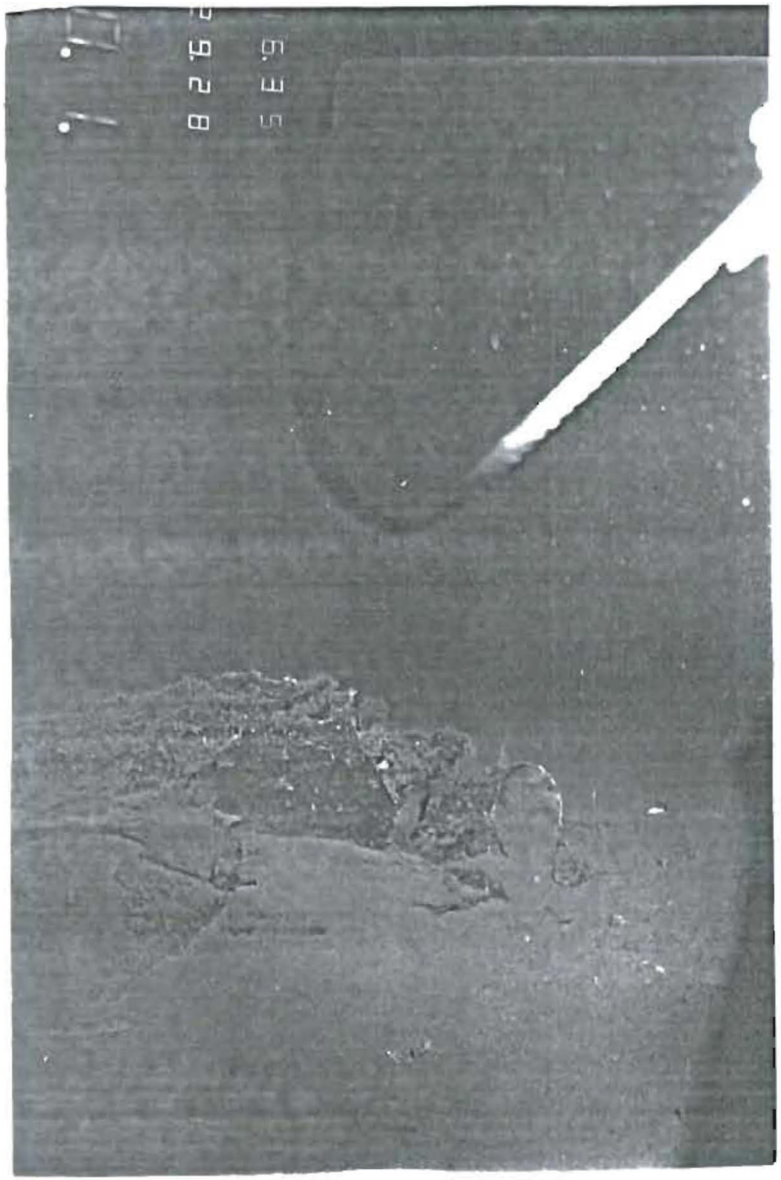


Figure VI-12. Photo 17:15:57, one mile east of the study area, 240 fm. See Figure VI-2. A squid near the substrate and Heterocarpus ensifer in the upper left margin of the photo.

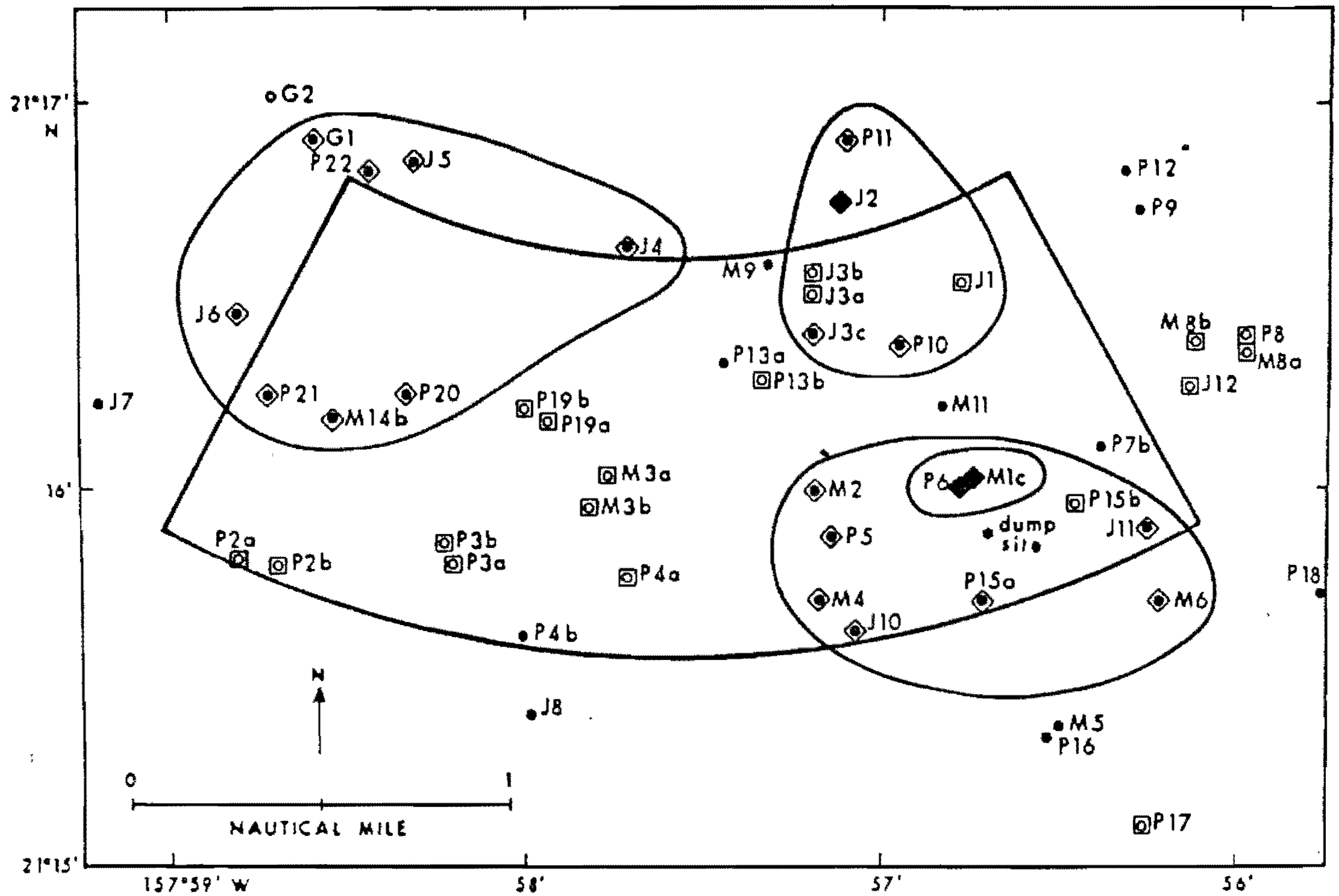



Figure VI-13. Number of pellets/ml sample at each station in and around the Pearl Harbor disposal area in May and June, 1977. Redraft from Figure VI-8, Part B. ◆ >1000 pellets/ml, ◇ = between 100 and 999 pellets/ml, ● <100 pellets/ml, ○ no pellets in sample, ⊡ cobbles or hard substrate.

between our summary figures are attributable either to differences in our methods (six stations) or to which of us analyzed the very small samples (four stations). Stations 31 and 41, which Allen did not study, lacked pellets and tracer species. Station 32, not studied by Allen, contained indications of dredge spoil although pellets and tracer species were absent. Stations 6, 7, 10, and 52 were found by X-ray mineralogy to contain dredge spoil but lacked pellets or tracer species, Stations 29 and 61 the reverse. Allen and I found rusty material and shells at Stations 2 and 18. Both of us felt that this might have been predisposal material; Allen included these in his dredge spoil area, I did not.

My findings suggest that the dredge spoil has probably drifted in a northwesterly direction from the original dump site and in a westerly direction from Station J2. (Compare Figures VI-4 and VI-13.)

2. Comparison of Station Pairs - Population Recovery of Foraminifera

Comparison of 12 paired September 1976-1977 stations indicate both similarities and differences in their foraminifera assemblages. The differences are in part due to sampling, since the compared stations were not exactly in the same spot, and consequently paired stations may have had different substrate compositions and were at slightly different depths (see Table VI-1). Differences were also attributable to shifting of soft sediments and dredge spoil.

Despite sampling differences, of the 196 species of forams recorded during the three phases of this study, 137 were found in both pre- and postdisposal site samples, and 59 species were restricted to either one or the other. This plus the fact that the predisposal samples of station pairs contained only nine more species than postdisposal station pairs seems to indicate that the area is recovering. The area that shows the least recovery is at the dump site (Station 20 had 17 fewer species than its 1976 counterpart, Station G10) and at Station 33 near the alternate dump site J2 (Station 33 had 14 fewer species than its 1976 counterpart, Station C2). The greatest recovery is at Station 19, which has 15 more foram species than its counterpart Station G19. Station pairs 21-G11 and 8-G12 showed this same trend. Stations 21 and G11, however, had only 12 percent of their species in common, indicating that a number of new species were recruited. Of the new species, 9 out of 12 were shallow water lagoon or reef forms (Coulbourn and Resig, 1975, and Resig, 1969). This was not the case for Station pair 8-G12, where several resident species entered the area in 1977. The rest of the stations had approximately identical numbers of species and shared from 46 to 85 percent of the same species. This indicates, for benthic foraminifera at least, that the postdisposal area is recovering except at the dump sites.

3. Stability of Sediments and Dredge Spoil

Comparison of the photo lines and grab samples from 1976 and 1977 indicates that the unstable and stable sediments have shifted somewhat during the year. (Compare Figures VI-3 and VI-5.) There is still a large unstable area between the two stable portions. The stable areas on Figure VI-5 appear to be similar to the dredge spoil distribution map (Figure VI-4). It appears that when the spoil moves into the unstable areas the biological fraction is worn by sand movement, and other materials are carried down or up slope depending on tidal action. This central unstable area seems to account for the areas of dredge spoil charted in Figures III-10, IV-4 and VI-4.

Analyses of the 1977 photo line data shows rippled sand in the unstable areas and smooth sand, boulders, rubble and debris in the stable areas.

4. Living Microfauna

Almost all microfauna lives in the top two millimeters of sediment. Samples obtained in the area by the Petersen grab and rotary clam grab were small, predominantly surface samples and therefore contained a high percentage of living animals. The volume of the samples in the 1976 collections tended to be much greater, and consequently the surface layer with its assemblage of live fauna was more diluted than in the 1977 samples. This probably accounts for the greater number per milliliter of living polychaete worms and foraminifera in the 1977 samples. Despite the sample size differences, live animals were found at all stations including the dump site. However, since the number of live animals per station is correlated with the size of the sample obtained, further analysis was not justified.

The coverage of live encrusting forms on rocks, however, was definitely lower in the 1977 samples, since many of the rocks examined and included in the analysis were in dredge spoil areas. Some of the living animals may have been smothered, and some of the rocks were from Pearl Harbor, on which deep-water encrusting animals had only recently settled.

5. Living Noncommercial Macrofauna

Table VI-2 compares the macrofauna obtained in traps and observed in the 1976 and December 1977 photos.

Trapped noncommercial macrofauna differed considerably between the two years, probably owing to the differences of location of the sets. For example, in 1976 the shrimp Pandalus (Plesionika) martius was taken in water shallower than 200 fm (see Part A, Section VII, Set 1, Figure VII-2). It was never taken in the spoil monitoring or recovery studies probably because all sets were placed at 230 fm, which was deeper than the known depth range for this shrimp. (Clarke, 1972; Strusaker and Aasted, 1974.)

Although three sets of the bottom photographs were taken at different times of year and were not exactly in the same location, they yielded more information about the noncommercial macrofauna than the traps.

There were a number of similarities between the 1976 and December 1977 photo lines. First, there were a great number of "man-made artifacts" along the lines. Many of these may have come from passing ships or from previous dumping in the area prior to 1977. Second, the major part of the fauna occurred in stable areas. Third, sea pens were the most common animals in the photos. Fourth, compared to shallow water areas, the biomass was very low (Parts A and B).

The most interesting difference between photos of the baseline and recovery phases of the work was an increase by 80 per cent in the numbers of the whip coral Lepidisis in 1977. All these corals appeared to be quite young and were located around but not at the dump site. This difference does not appear to be attributable to differences in the 1976 and December 1977 photo line locations, since a few very small whip corals were seen in the July 1977 photo lines, also in the region of the dump site. The other faunal variations between areas appears to be a function of how close the camera was to the bottom and the amount of hard substrate (boulders, artifacts, etc.) encountered.

## E. Summary and Recommendations

Although there are several differences between the baseline and present studies, it appears that dumping of dredge spoil has only severely affected the benthic biota at the dump site itself.

In December of 1977, pellets and Pearl Harbor tracer species were present in two areas, one to the west of the alternate dump site (Station J2, Figure VI-13) and one to the northwest of the dump site (Station 20). Explanations to account for this observed distribution include the suggestion that the region between the two dredge spoil areas is unstable and the spoil material has become too worn for recognition or has been moved out of the area.

The number of pellets decreased by a factor of ten from the Part B samples in most of the stations, and the area containing pellets and tracer species is much smaller than immediately after dumping.

Analysis of paired 1976 and 1977 stations indicates that differences between them may be due to slight variations in station location and to shifting of sediments and dredge spoil. The foraminifera population in the area appears to be recovering except at the dump site. Living foraminifera and polychaetes were present in all 12 paired stations. There was an increase in the number of whip corals from 1976. These corals were located on either side of the dump site and were young animals.

Based on benthic biological studies, it is recommended that dumping be confined to the specific dump site, 21°15.9'N, 157°56.7'W. It is further suggested that dumping not be conducted above the 200 fm contour line since tidal action and westerly currents may spread the material shoreward out of the studied area. Dumping material in the unstable area (e.g., at Station 18) might tend to spread material faster, but it is not clear whether the material would be carried shoreward or away from the site.

## F. Acknowledgements

I wish to thank James Andrews of the Department of Oceanography, University of Hawaii, for making his photographs of the Pearl Harbor dredge spoil disposal area available to us. Greatly appreciated is the scientific advice of Johanna Resig (Geology, University of Hawaii-Foraminifera), Katie Musik (Invertebrate Section-Smithsonian Institution-Corals) and Ann Fielding (Invertebrate Section Bishop Museum-Crustaceans). I also wish to thank Philip Papish for sorting the forams and the personnel of the R/V Machias and R/V El Greco.

## G. Literature Cited


Barker, R.W., 1960. Taxonomic notes of the species figured by H.B. Brady in his report on the foraminifera dredged by the HMS Challenger during the years 1873-1876. Soc. Econ. Paleo. and Mineral. Spec. Pub. 9:1-238.

Bell, J.A., 1976. Benthonic Foraminifera of Kaneohe Bay. M.S. Thesis. University of Hawaii.

Chave, K.E. and J.N. Miller, 1977. Baseline studies and evaluation of physical, chemical, and biological characteristics of nearshore dredge spoil disposal, Pearl Harbor, Hawaii. Parts A and B. Environmental Center Final Report, University of Hawaii.

Clarke, T.A., 1972. Explorations of deep benthic fish and crustacean resources in Hawaii. HIMB Tech. Rep. 29:1-18.

Coulbourn, W.T. and J.M. Resig, 1975. On the use of benthonic foraminifera as sediment tracers in a Hawaiian bay. Pac. Sci. 29 (1):99-115.

Cushman, J.A., 1932-1942. The Foraminifera of the Tropical Pacific Collections of the Albatross 1899-1900. U.S. Nat. Mus. Bul. Parts 1-3:1-139.

Ellis, B. and A. Messina, 1940+. Catalogue of Foraminifera. Am. Mus. Nat. Hist.

Loeblich, A.R. and H. Tappan, 1961. Treatise on Invertebrate Paleontology. Geol. Soc. Amer. Part C, 1 and 2.

Resig, J.M., 1969. Paleontological investigations of deep borings on the Ewa Plain, Oahu, Hawaii. HIG Report 69-2, University of Hawaii.

Struhsaker, P. and D.C. Aasted, 1974. Deepwater shrimp trapping in the Hawaiian Islands. Mar. Fish. Rev., 36(10):24-30.

# APPENDIX 1

## MICROMOLLUSCAN ASSEMBLAGES

E. Alison Kay

The micromolluscan constitutents of 20 sediment samples from the dredge spoil disposal site off Pearl Harbor, Oahu, are described. A definition of micromollusks, the rationale for utilizing micromollusks as indices of marine benthic communities, and the methodology involved in analyzing the assemblages are discussed in the Part A report. In the Part A report on samples obtained in 1976 prior to deposition of the dredge spoil, benthic micromollusks were divided into two components, one representative of depths of 10 to 80 fathoms (shallow water species), the other of mollusks known only from depths greater than 130 fathoms (deep water species). This distinction is followed below. As in the Part A report, micromollusks were sorted from sediment samples of from 5 to 25 $cm^3$.

### Results and Conclusions

Numbers of micromollusks per $cm^3$ of sediment and species composition are shown in Table 1. Benthic mollusks comprised only about 5 per cent of the total molluscan assemblages in the sediments, the greater bulk of the assemblages being made up of planktonic forms. Numbers of benthic mollusks ranged from 0.33 to 17.2 per $cm^3$ of sediment.

Shallow benthic mollusks comprised from 23 to 93 per cent of the benthic assemblages in the samples. These figures are similar to those of the 1976 samples. Shallow benthic species comprised more than 50 per cent of the assemblages in 60 per cent of the samples (12 of the 20 samples). In the 1976 samples, shallow benthic species comprised more than 50 per cent of the assemblages in 87 per cent of the samples. Stations where shallow benthic species were dominant are shown in Figure 1.

As in the 1976 samples, the shallow water assemblage was a mixed assemblage comprised primarily of the micromollusks dominant in Mamala Bay at depths of 15 to 55 fathoms (30-100 m)(Kay, 1975). The dominant components were members of the families Rissoidae and Dialidae, which together comprised an average of 75 per cent of the assemblages in Mamala Bay (Kay, 1978).

Table 1. Species composition and standing crop of benthic micromolluscan assemblages.

| Station No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 18 | 19 | 20 | 20c | 23 | 25 | 26 | 29 | 30b | 34 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (fm) | 205 | 223 | 235 | 165 | 167 | 193 | 195 | 195 | 198 | 217 | 211 | 225 | 222 | 230 | 203 | 224 | 218 | 214 | 240 | 180 |
| No. in sample | 176 | 67 | 17 | 54 | 59 | 35 | 69 | 74 | 86 | 29 | 9 | 3 | 40 | 44 | 62 | 97 | 64 | 36 | 29 | 77 |
| Deep water | 74 | 48 | 10 | 4 | 11 | 24 | 35 | 31 | 43 | 21 | 5 | 1 | 6 | 4 | 22 | 73 | 15 | 13 | 13 | 55 |
| Shallow water | 102 | 19 | 7 | 50 | 48 | 11 | 36 | 43 | 43 | 8 | 4 | 2 | 34 | 40 | 40 | 24 | 49 | 23 | 16 | 22 |
| No. per $cm^3$ | 8.8 | 3.6 | 3.4 | 4.5 | 5.9 | 7.0 | 6.9 | 7.4 | 17.2 | 2.5 | 1.8 | 0.33 | 1.6 | 1.8 | 6.2 | 12.9 | 12.8 | 7.2 | 5.8 | 7.7 |
| Percent composition | | | | | | | | | | | | | | | | | | | | |
| Shallow water | 58 | 28 | 41 | 93 | 81 | 31 | 52 | 58 | 50 | 27 | 44 | + | 87 | 91 | 64 | 25 | 77 | 64 | 55 | 28 |
| Crepidula | 1 | - | - | - | - | - | 3 | 2 | - | - | - | - | - | 20 | - | - | - | - | - | 9 |
| Pyramidellids | 8 | - | - | 48 | 4 | 8 | 3 | 9 | - | 12 | - | - | 17 | 35 | 7 | 4 | 4 | 4 | 12 | 9 |
| Deep water | 42 | 72 | 59 | 7 | 19 | 69 | 48 | 42 | 50 | 73 | 56 | + | 12 | 9 | 36 | 75 | 23 | 36 | 45 | 71 |
| "Circulus" | 1 | - | - | - | - | 4 | - | - | 5 | - | - | - | 17 | - | 18 | 1 | - | - | 15 | 11 |
| Benthonella | 23 | 46 | 60 | 50 | - | 25 | 21 | 16 | 9 | 52 | 60 | + | 33 | 100 | 18 | 44 | 60 | 85 | 69 | 33 |
| Argyropeza | 34 | 29 | 20 | - | 82 | 33 | 42 | 35 | 35 | 19 | - | - | 17 | - | 9 | 16 | 27 | - | - | 16 |
| Cephelaspids | 7 | 6 | - | 25 | - | 4 | - | - | 9 | - | 20 | - | - | - | 18 | 7 | - | - | - | 7 |
| Nucula | 28 | 8 | - | - | - | 4 | 15 | 22 | 19 | 19 | - | - | 33 | - | - | 14 | 7 | - | - | 18 |

*Additional sample near station 20.

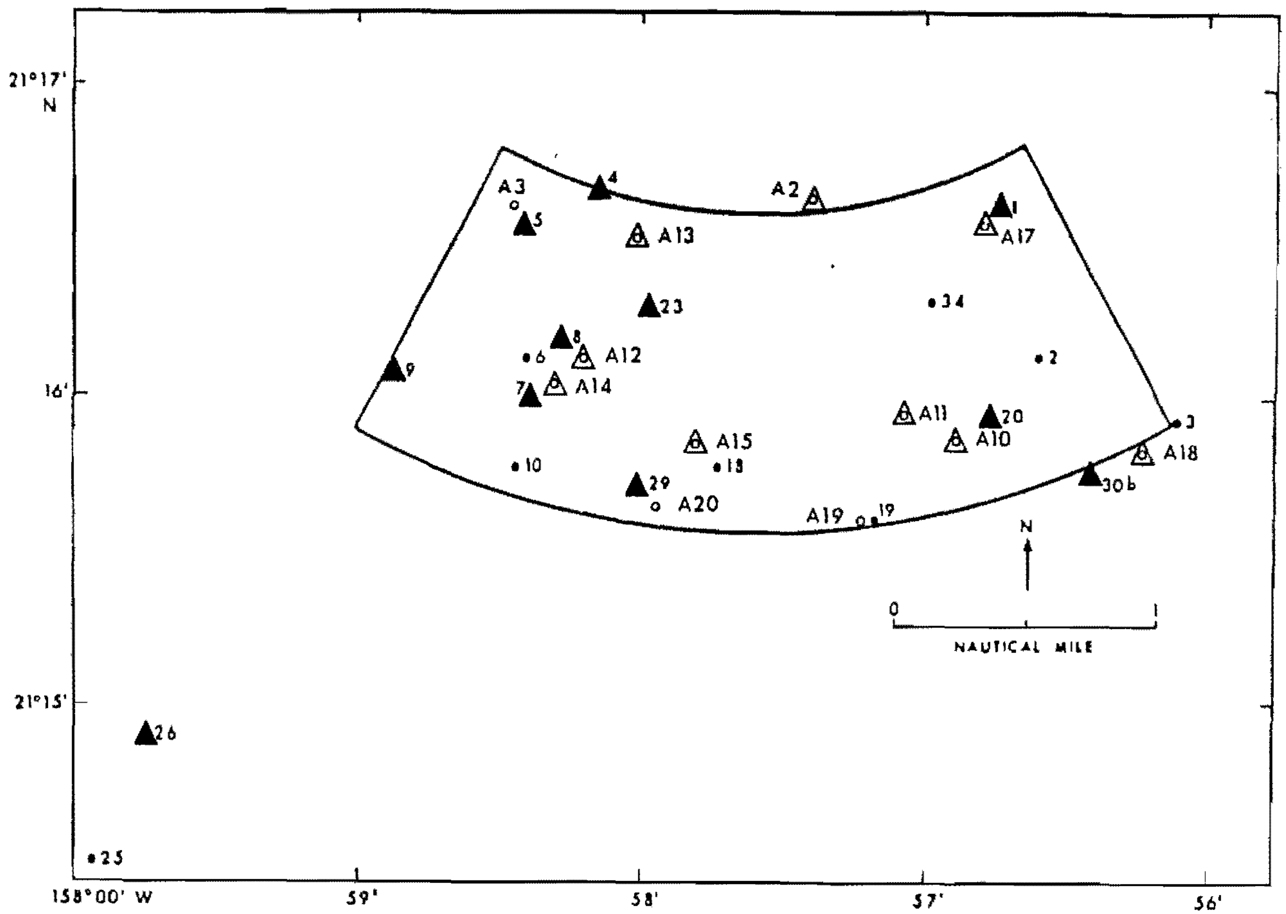



Figure 1. Distribution of stations with 50 per cent or more shallow benthic micromolluscan assemblages (triangles). Open symbols: △ o=1976 (station numbers begin with A). Closed symbols: ▲ ●= 1977.

Among the shallow water benthic mollusks, three species may be considered as possible indicators of dredge spoil materials: the calyptraeid Crepidula aculeata and the pyramidellids Odostomia oodes and O. indica. The three species were recorded in large numbers in Pearl Harbor in 1974 (Kay, 1974). None of the three species are common or abundant in Mamala Bay (Kay, 1978). I have not recorded Crepidula in any of 29 samples off the Keehi sewer outfall (depths of 15 to 55 fathoms). Pyramidellids occurred in 45 per cent of the Keehi samples, but in none of the samples did they form more than 1 per cent of the assemblage. In the samples reported here, Crepidula occurred in 25 per cent of the samples, comprising up to 20 per cent of the benthic mollusks present. The pyramidellids were found in 75 per cent of the samples, forming up to 48 per cent of the shallow benthic assemblages. The greatest concentrations of Crepidula occurred at stations 20c and 9, the greatest concentrations of pyramidellids at stations 4, 20c, 20 and 30b.

Both Crepidula and the pyramidellids were recorded in the 1976 samples. Crepidula was found in 33 per cent of the samples (Figure 2) and formed an average of 7.2 per cent of the mollusks in the assemblages in which it was found. These 1976 Crepidula occurrences most probably represented the remains of an earlier dredge spoil dump. Comparison of the distribution and numbers of Crepidula in the site between 1976 and 1977 suggests that Crepidula was not an especially useful indicator species in this instance, in that there was very little difference between the 1976 and 1977 distributions or numbers.

The distribution and numbers of pyramidellids, on the other hand, differed considerably between the 1976 and the 1977 samples (Figure 3). The pyramidellids appeared to be far more widespread in the 1977 samples than they were in 1976, and they also comprised a higher proportion of the samples in which they occurred than they did in 1977.

Another possible indicator of dredge spoil could be the occurrence of terrestrial pulmonate shells in the sediment samples. These shells should be interpreted with caution, however, in that all of the land shells recorded (with perhaps one exception) appeared to represent extinct species. Land shells occurred in four samples in 1976 and in four of the samples in 1977 (Figure 4). None of the samples coincided, but all came from the western half of the disposal area. From one to three shells were in each of the samples containing land shells, and most of the shells appeared to represent fossil endodontids.

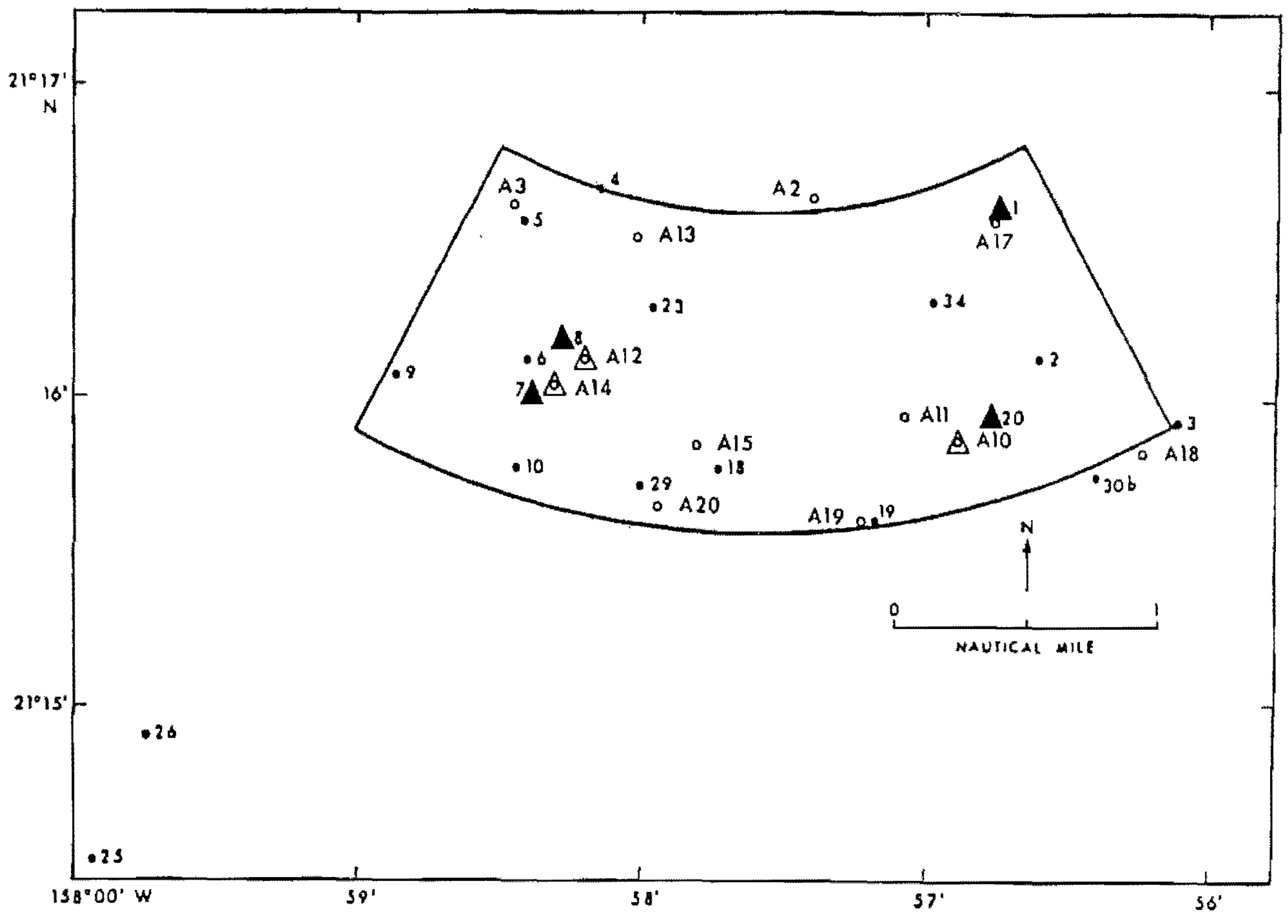
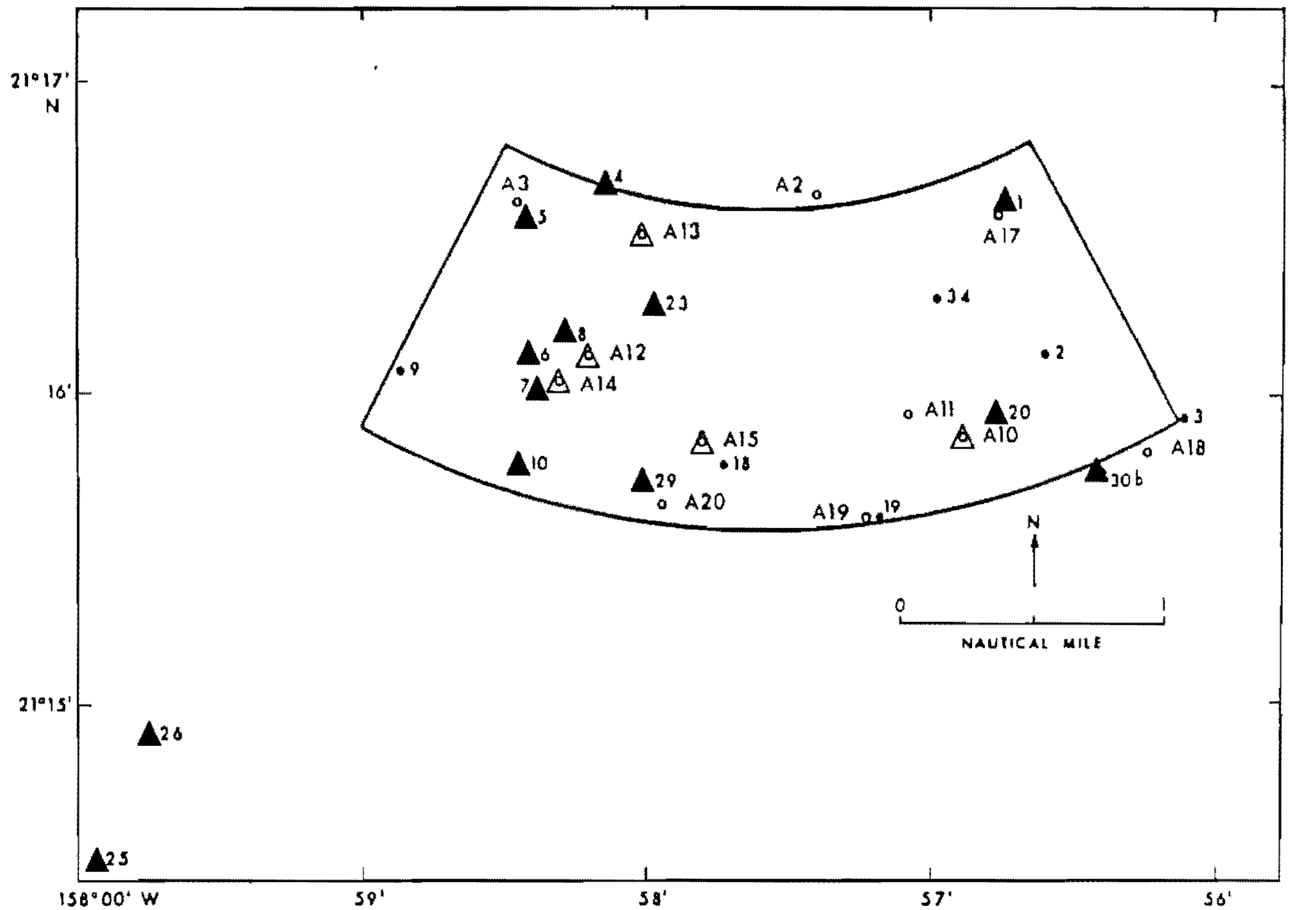



Figure 2. Distribution of Crepidula (triangles).
o ⚠ = 1976. ● ▲ = 1977.

Figure 3. Distribution of the pyramidellids *Odostomia oodes* and *O. indica* (triangles). o △ = 1976. ● ▲ = 1977.



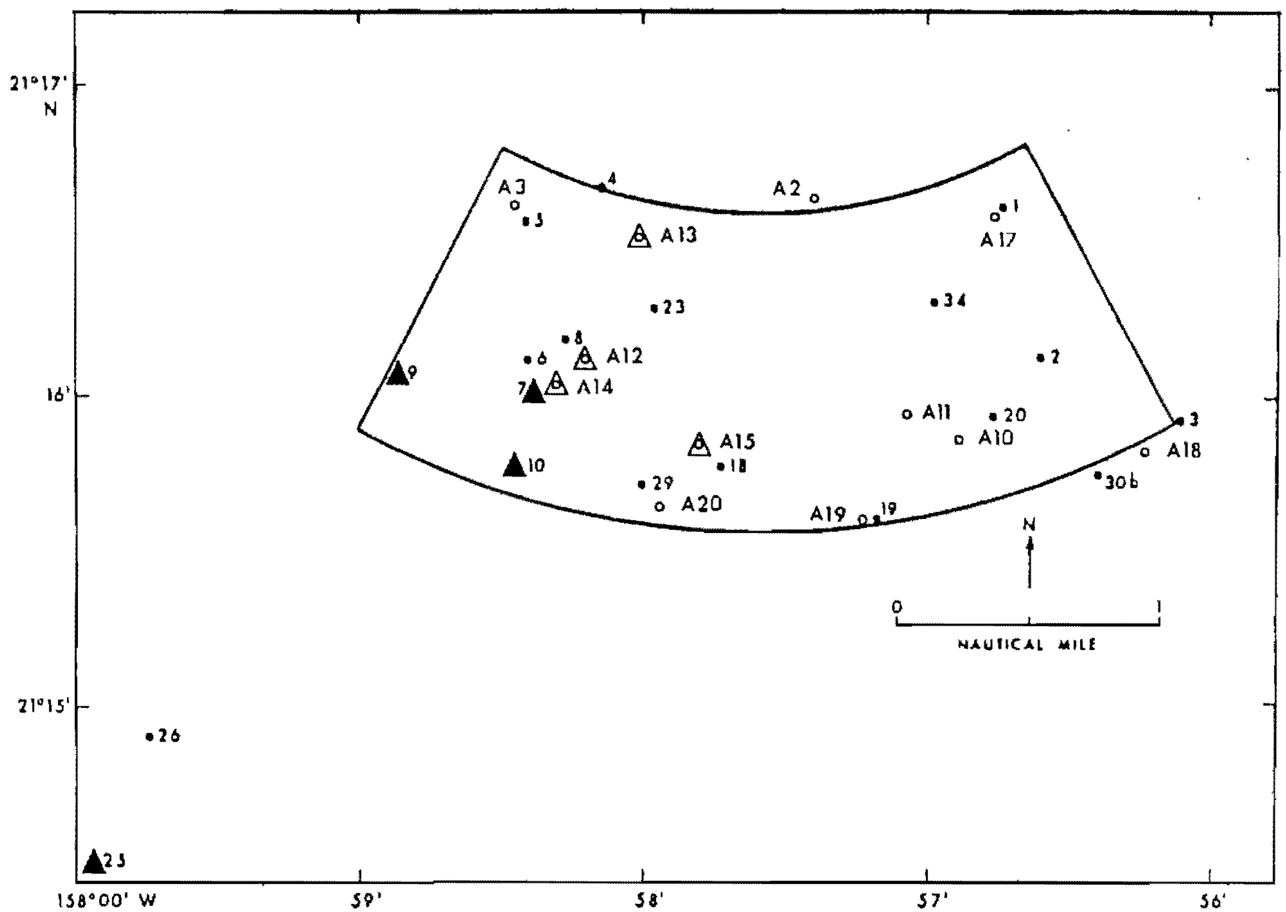



Figure 4. Distribution of terrestrial pulmonate sheels (triangles).
o △ = 1976. ● ▲ = 1977.

As in 1976, the dominant deepwater micromollusks were "Circulus", Benthonella, Argyropeza, cephalaspids, and the bivalve Nucula. The epifaunal browsers Benthonella and Argyropeza dominated the assemblages as they did in 1976, with the infaunal cephalaspids and bivalves comprising lesser proportions of the assemblages (Table 1). There appeared to be little difference in either numbers or species composition between the 1976 and the 1977 samples. The distribution of the infaunal mollusks is shown in Figure 5 and shows a slightly more widespread distribution of infaunal forms. This may be only an artifact of a more comprehensive sampling program.

## Summary

A comparison of the 1976 and 1977 distributions of the dredge spoil indicator species shows little apparent difference with the exception of the two pyramidellid species. Since indicator species were present before the 1977 dredge spoil disposal operation, this may indicate only that it is difficult to distinguish new spoil from old spoil. However, the lack of an increase in the concentration of tracer species after the 1977 dump suggests that new spoil deposits are inconspicuous in the disposal area. Thus it appears that dredge spoil disposal at the designated dump site has had a minimal impact on the composition of the sediments in the dredge spoil disposal area.

## References

Kay, E.A., 1974. Micromolluscan survey. In: E.C. Evans (ed.), Pearl Harbor Biological Survey Final Report. Naval Undersea Center TN 1128.

Kay, E.A., 1975. Micromolluscan assemblages from the Sand Island sewer outfall, Mamala Bay, Oahu. Water Resources Research Center, Interim Progress Report Project F-322-74 for the City and County of Honolulu.

Kay, E.A., 1977. Micromolluscan assemblages from offshore Pearl Harbor. In: K.E. Chave and J.N. Miller, 1977. Baseline studies and evaluation of the physical, chemical, and biological characteristics of nearshore dredge spoil disposal, Pearl Harbor, Hawaii. Part A, Section VI, Appendix 1. Environmental Center Final Report, University of Hawaii.

Kay, E.A., 1978. Summary of micromolluscan data. Typescript report to L.S. Lau and G. Richardson. Water Resources Research Center and Department of Public Works, City and County of Honolulu.

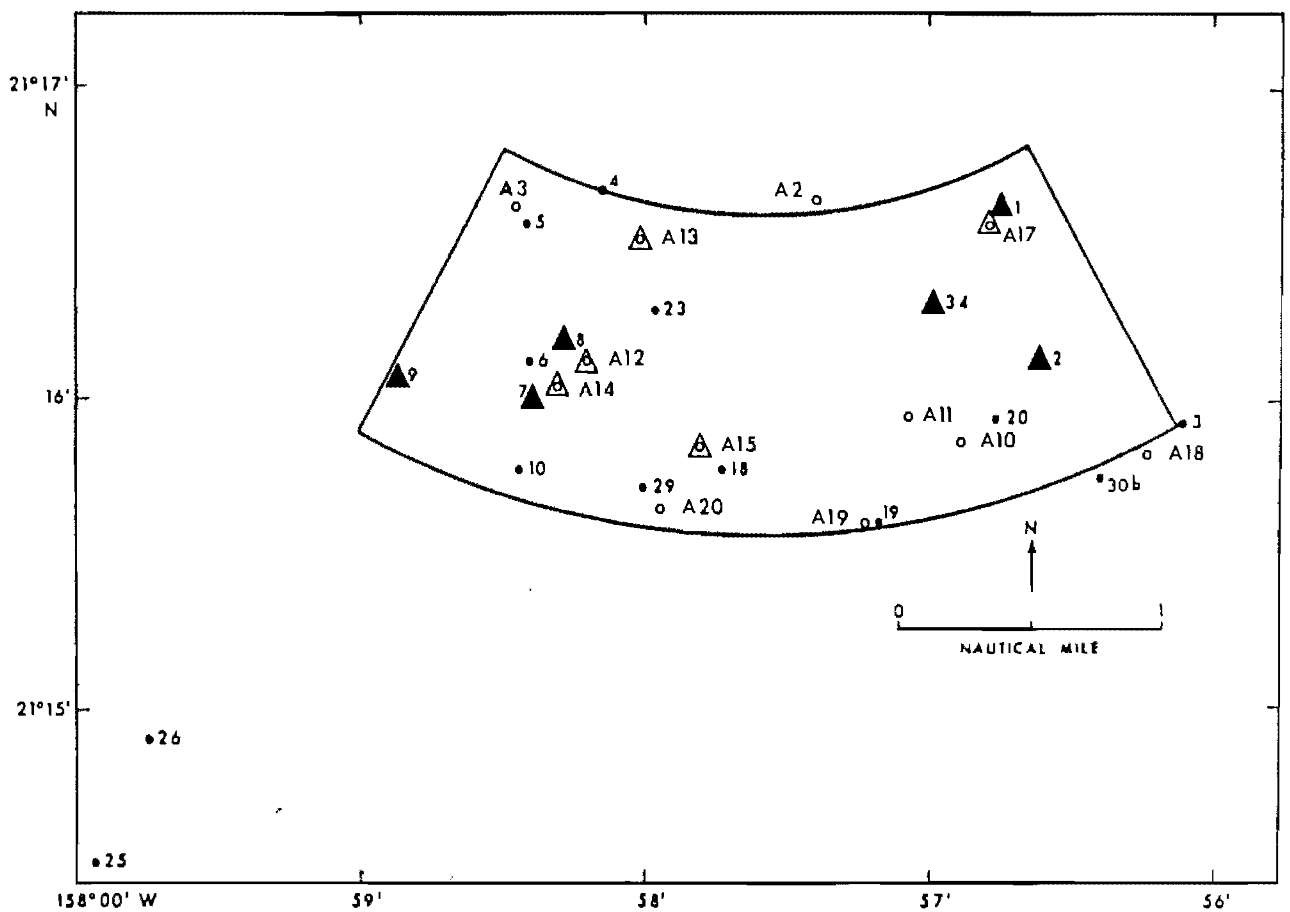



Figure 5. Distribution of deep benthic infaunal mollusks (triangles).
o △ = 1976. ● ▲ = 1977.

# APPENDIX 2

Table 1. Foraminifera species found in the Pearl Harbor dredge disposal area at a depth of 165 to 240 fathoms. The 1976 and 1977 stations with similar navigation coordinates are paired. 1977 stations precede the 1976 stations in each pair. + is greater than 20 individuals/ml sediment; ++is greater than 100 individuals/ml.

| Station Number | 1 1977 | G17 1976 | 5 1977 | C3 1976 | 7 1977 | G14 1976 | 8 1977 | G12 1976 | 18 1977 | G15 1976 | 19 1977 | G19 1976 | 20 1977 | G10 1976 | 21 1977 | G11 1976 | 29 1977 | G20 1976 | 30B 1977 | G18 1976 | 32 1977 | G13 1976 | 33 1977 | C2 1976 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name: | | | | | | | | | | | | | | | | | | | | | | | | |
| Alabamina sp. | | | | | | | + | + | + | + | | | | + | | | | | + | + | | + | | |
| Alliantina sp. | | | | | | | | | | | + | | | | | | | | | + | | | | |
| Ammobaculites sp. | + | | + | ++ | | | + | ++ | + | + | | | | | | | | | | | + | + | + | ++ |
| Ammonia beccari tepida | + | | + | | | | | | | | | | + | | + | | | | | | | | | |
| Amphicoryna sp. | | | | | | + | | | | | | | | | | | | | | | | | | |
| Amphisorus hemptrichii | | | | + | | | | | + | | | + | | ++ | | | | | | + | | | | |
| Amphistegna bicirculata | + | + | + | ++ | + | + | ++ | + | + | + | + | + | | + | | + | ++ | ++ | + | + | | + | + | |
| A. lessoni | + | + | + | ++ | + | + | + | + | + | ++ | + | + | | | + | | + | | | | + | + | + | ++ |
| Angulogerina angulosa | | | + | + | | | | | | | | | | | | | | | | | | | | |
| A. carinata | | | | | | | | | | + | | | | | | | | | | | | | | |
| Anomalina colligera | + | + | + | + | | | | | | | ++ | | | + | ++ | | + | | | | | | | |
| A. glabrata | | | | | | | | | | | | | | | | | + | + | | | | | | + |
| A. globosa | | | | | | | | | | + | | | | | | | | | + | + | | | | |
| Articulina pacifica | | + | | | | | | | | | ++ | | | | | | | | | | | | | |
| Astacolus cf. cepidulus | | | | | | | | | | | + | | | | | | | | | | | | | |
| A. sp. | | | | | | | | | | | | | | | | | | | | | | | + | + |
| Biloculinella globula | | | + | + | | | | | | | | | | ++ | | | | ++ | + | + | + | + | | |
| B. glutinata | | + | | | | | + | | | | | | | | | | | | | | | | + | + |
| B. "nobilis" | | | ++ | + | | | + | + | | | + | | + | + | | | | | | | | | | |
| B. striatula | | | + | | | | + | | | | + | | | | + | | + | | + | | | | | |
| B. subreticulata | | | | | | | + | | | | | | | | | | | | | | | | | |
| B. sp. | | | | | | | | | | | + | | | | | | | | | | | | | |
| Bolivinita sp. | | | | | | | | | | | | + | | | | | | | | | | | | |
| Borelis melo | | | | | | | | | | + | | | | | | | + | | | | | | | |
| Bueningia creeki | | | | | | | + | | ++ | + | | | | | | | | ++ | | + | | | + | + |
| Bulamina affinis | | | | | | | + | + | | | | | | | + | | | | | | | | + | |
| Buliminella milletti | | | | | | | | | | | | | | | + | | | | | | | | | |
| Buliminoides sp. | | | | | | | | | + | + | | | | | | | | | | | | | | |
| Cassidella schreibersiana | | | + | | | | | | | | | | | | | | | | | | | | | |
| Cassidulina minuta | + | + | | | + | | + | + | + | + | + | + | | | + | | | + | | | | | + | + |
| C. moluccensis | | | | | | | + | | | | | | | | | | | | | | | | | |
| Cassidulinoides parkeriana | | | + | + | | | | | + | | + | | | | | | | | | | | | | |

| Station Number | 1 1977 | G17 1976 | 5 1977 | C3 1976 | 7 1977 | G14 1976 | 8 1977 | G12 1976 | 18 1977 | G15 1976 | 19 1977 | G19 1976 | 20 1977 | G10 1976 | 21 1977 | G11 1976 | 29 1977 | G20 1976 | 30D 1977 | G18 1976 | 32 1977 | G13 1976 | 33 1977 | C2 1976 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cibicides lobatulus | + | + | + | ++ | ++ | ++ | ++ | + | + | + | ++ | ++ | | ++ | ++ | | + | + | ++ | ++ | | | ++ | + |
| C. refulgens | ++ | ++ | + | + | + | + | | | ++ | ++ | + | + | | + | | | | + | + | + | | | ++ | ++ |
| Cibicidoides pseudoungerianus | + | + | + | + | ++ | ++ | ++ | + | + | ++ | + | ++ | | | | + | + | + | + | ++ | | | | |
| Cornuspira planorbis | | + | + | | | | | | + | | | | | | | | | | | | | | | |
| Cornuspiroides foliaceus | | | | | | + | | | + | | | | | | | | | | | | | | | |
| Cylindroclavulina bradyi | ++ | + | + | ++ | + | + | + | ++ | | + | | | | + | | ++ | | | | | | | + | ++ |
| Cymbaloporetta bradyi | + | + | + | + | ++ | ++ | ++ | + | + | + | + | | | + | | | | | | | | | + | + |
| C. squamosa | | + | + | + | | | | | | | | + | | + | | | | + | | | | | | |
| Dentalina cf. communis | | | | | | | | | | | | | | | | | | | + | + | | | | + |
| Dentalina cf. vertebralis | | | | | | | | | | | | | | | | | | | | | | | | + |
| Discorbinella sp. | + | | | + | | | | | | | + | | | | | | | | | | | | | + |
| Discorbis sp. | | | + | + | | | | | | | | | | | | | | | | | | | | |
| Elphidium advenum | | | + | | | | | | | | | | | | | | | | | | | | | |
| E. hyalocostatum | | + | | | | | | | | | + | | | | | | | | | | | | | |
| Fijiella simplex | | | | | + | | + | | | | + | | | | | | | | | | | | | |
| Florilus japonicus | | | + | | | | | | | | | | | | | | | | | | | | | |
| Gaudryina paupercula | | | | | | | + | + | + | + | | | | | | | | | | | + | | | |
| G. quadrangularis | + | | + | + | | | | | ++ | + | | | | | | | | | | | | + | + | |
| G. sp. | + | | | | | | | | + | + | | | | | | | | | | | | | | |
| Glabratella patelliformis | + | | | | | | | | | | | | | | | | | | | | | | | |
| Gyrodina lamarckiana | | + | | | | | | | | | | | | + | | | | | | | | | | |
| Heterostegina depressa | | | + | + | | | + | ++ | | + | | | | | | | | | | | | + | | |
| Hoeglundina elegans | ++ | + | + | + | + | | | | + | + | + | + | | | + | | | | | | | + | + | + |
| Hopkinsina pacifica | | | | | | | | | + | | | | | | | | | | | | | | | |
| Karreriella sp. | | | | | | | | | | | | | | + | + | | | | | | | | | |
| Lagena sp. | | | | | | | | | | | + | + | | | | | | | | | | | | + |
| Lenticulina cf. suborbicularis | + | + | ++ | ++ | | | | + | | + | + | + | | + | | | | + | | | | | | + |
| L. sp. | | | + | + | | | | | + | | | | | | | + | | | + | + | | | | + |
| Marginopora vertebralis | + | | + | ++ | | + | | | | + | | + | | + | | ++ | | | | | + | | | |
| Marginulina striatula | | | | | | | | | | | | | | | | | | | | | | | | + |
| Miliolinella circularis | | + | + | + | + | + | ++ | + | | | + | | | | | | | | | | | | | + |
| M. subrotunda | | | + | + | | | + | + | | | + | | | | | + | | | | | | | | + |
| Mississippina concentrica | | | | | | | | | | | + | | | | | | | | | | | | | |
| Nubeculina divaricata | | + | | | | | | + | + | ++ | | | | | | | | | | | | | | + |
| Operculina ammonoides | | | | | | | | | | | | | | | | | | | | | | + | | |
| Oridorsalis umbonatus | | | | | | | | | | | + | | | | | | | | | | | | | |
| Peneroplis pertusus | | + | | | | | + | | | | | + | | | | | + | + | | | + | + | | |
| Pullenia quinqueloba | | | | | | | | | | | + | | | | | | | | | | | | | |
| Pyrgo comata | | | | + | + | + | | | | | | | | | | | | | | | | | | |
| P. denticulata | | | | | | | + | | | | | | | | | | | | | | | | | + |
| P. elongata | | | | | | | | | | | | | | | | | | + | | | | | + | + |
| P. vespertilio | | | | + | | | + | | | | | | | | | + | + | + | + | + | + | + | | + |

| Station Number | 1 1977 | G17 1976 | 5 1977 | C3 1976 | 7 1977 | G14 1976 | 8 1977 | G12 1976 | 18 1977 | G15 1976 | 19 1977 | G19 1976 | 20 1977 | G10 1976 | 21 1977 | G11 1976 | 29 1977 | G20 1976 | 30B 1977 | G18 1976 | 32 1977 | G13 1976 | 33 1977 | C2 1976 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quinqueloculina bicarinata | + | ++ | | | + | + | + | + | | + | ++ | + | | | | | | | | | | | | |
| Q. bosciana | + | | + | | + | | + | | + | | | | + | | | | | | | | | | + | |
| Q. granulocostata | | | + | + | ++ | ++ | + | + | | | + | | | | | | | | | | | | | + |
| Q. lamarckiana | ++ | + | + | ++ | + | + | | | + | + | | | | | ++ | ++ | + | + | | | | + | + | + |
| Q. parkeri | | | | | | | | | | | | | | + | | | + | | | | | | | |
| Q. poeyana | + | | ++ | | | | + | | | | | | + | | | | | | | | | | | |
| Q. spp. | + | + | + | + | + | + | | | + | + | + | | | | + | | | | | | | | | |
| Reophax dentaliniformis | | | | | | | + | + | | | | | | | | | | | | | | + | | |
| Robertinoides bradyi | | | | | | | | | | | | | | | | | | | + | + | | | | |
| Robulus calcar | + | ++ | + | + | + | | + | + | + | + | + | | | + | | | | | + | + | | | | + |
| R. cf. iota | + | | | | | | | | | | | | | | | | | | | | | | | |
| Rosalina cf. concinna | | | | | | | | | + | + | | | | + | | | | | | | | | + | + |
| R. cf. vilardeboana | | | + | + | | | | | + | + | | | | | | | | | | | | | | |
| Saracenaria sp. | | | | | | | | + | | | | | | | | | | | | | | | | |
| Siphogenerina columellaris | | | | | | | | | + | + | | | | | | | | | | | | | | |
| S. irregularis | | | | + | + | + | | | | + | | + | | | | | | | | | | | + | + |
| Siphotextularia concava | | | | | | | | | + | + | | | | | | | | | | | | | | |
| Siphouvigerina asperula | | | | | + | | | | + | | | | | | + | | | | | | | | | |
| S. interrupta | + | + | | | | | + | + | | | | | | | | | | | | | | | | + |
| Sphaeroidina bulloides | | | | | | | | | | | | | | | | | | | + | + | | | | |
| Spiroloculina communis | + | | | | | | | + | | | | | | | | | | | | | | | | |
| S. corregata | | | + | + | + | + | | | + | | | | | | | | | | | | | | | + |
| Sorites marginalis | | | | | | | + | | | | | + | | | | | | | | | | | | + |
| Textularia agglutinans | | | | | | | + | + | + | + | | | | | | + | | | | | | | + | + |
| T. agglufistinans fistula | | | + | + | | | | | | + | | | + | + | + | + | + | + | | | | | | |
| T. candeina | | | | | | | | | + | + | | | | | | | | | | | | | | |
| T. spp. | | | | | | | | | | | | | + | + | | | | | | | | | | |
| Textulariella barretti | | | | | | | | | | | | | | | | | | + | + | + | | | | |
| Trepomphalus bulloides | | | | | | | | | | | | | | | | | | | + | + | | | | |
| T. milletti | | | | | | | | | | | | | | | | | | | | | | | + | + |
| Trifarina reussi | | | | | | | | | | | | | | | | | | | + | + | | | | |
| Triloculina linneiana | | | | | | | | | | + | | | | | | | | | | | | | | |
| T. oblonga | | | ++ | + | | | | | | | | | | | | | | | | | | | | |
| T. tricarinata | | | | | | | + | | + | + | | | | | | | | | | | | | | + |
| T. cf. trigonula | | | + | + | | | | | | | | | | | | | | | | | | | | + |
| Uniliolina oblonga | | | + | + | | | | | | | | | | | | | | | + | + | | | + | + |
| Uvigerina cf. canariensis | | | + | + | | | + | | | | | | | | | | | | | | | | | |
| U. irregularis | + | + | | | | | + | + | + | + | | | | | | | + | | | | | | | |
| Wiesnerella auriculata | | | | | | | | | + | | | | | | | | | | | | | | | |

# APPENDIX 3

Table 1. Foraminifera species present but rare in the Pearl Harbor dredge spoil disposal area samples.

| | |
|---|---|
| Acervulina sp. | Gyrodinoides sp. |
| Amphistegina lobifera | Haplophragmoides cf. canariensis |
| Astacolus cf. insolitus | Hauerina sp. |
| Bolivina bradyi | Homotrema rubra |
| B. hantkeniana | Lingualinopsis carlofortensis |
| B. rhomboidalis | Loxostomium pacificum |
| B. spinescens | L. porrectum |
| Bulimina marginata | Marginulina sp. |
| Carpenteria utricularis | Miniacina sp. |
| C. sp. | Nodosaria catesbyi |
| Cassidulina subglobosa | Quinqueloculina spp. |
| C. sp. A | Parrina bradyi |
| Cassidulinoides rotundata | Rectoglandulina torrida |
| Chilostomella ovoidea | Rhabdamina sp. |
| Clavulina pacifica | Robulus vortex |
| Cribrostomoides cf. subglobosum | Siphogenerina bifrons striatula |
| Erhenbergina pacifica | Sphaerogypsina globulus |
| E. trigona | Spiroloculina serratula |
| Fissurina marginata | Tholosina sp. |
| Gaudryina siphonifera | Vertebralina striata |

# VII. FISHERIES

By
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A. Objectives

The only commercially important organisms found in the disposal area are heterocarpid shrimp, and since an important fishery for akule and opelu is located on the Ewa (Barbers Point) ledge, these two fisheries were reexamined for possible modification in their populations attributable to dredge spoil. The specific objectives were:

1. Quantitative investigations of the benthic shrimp fauna at the dump site and control areas.
2. Investigation of the commercial akule and opelu fishery during September of 1977 and a comparison of the 1977 catch statistics with the month of September of 1970-1976.

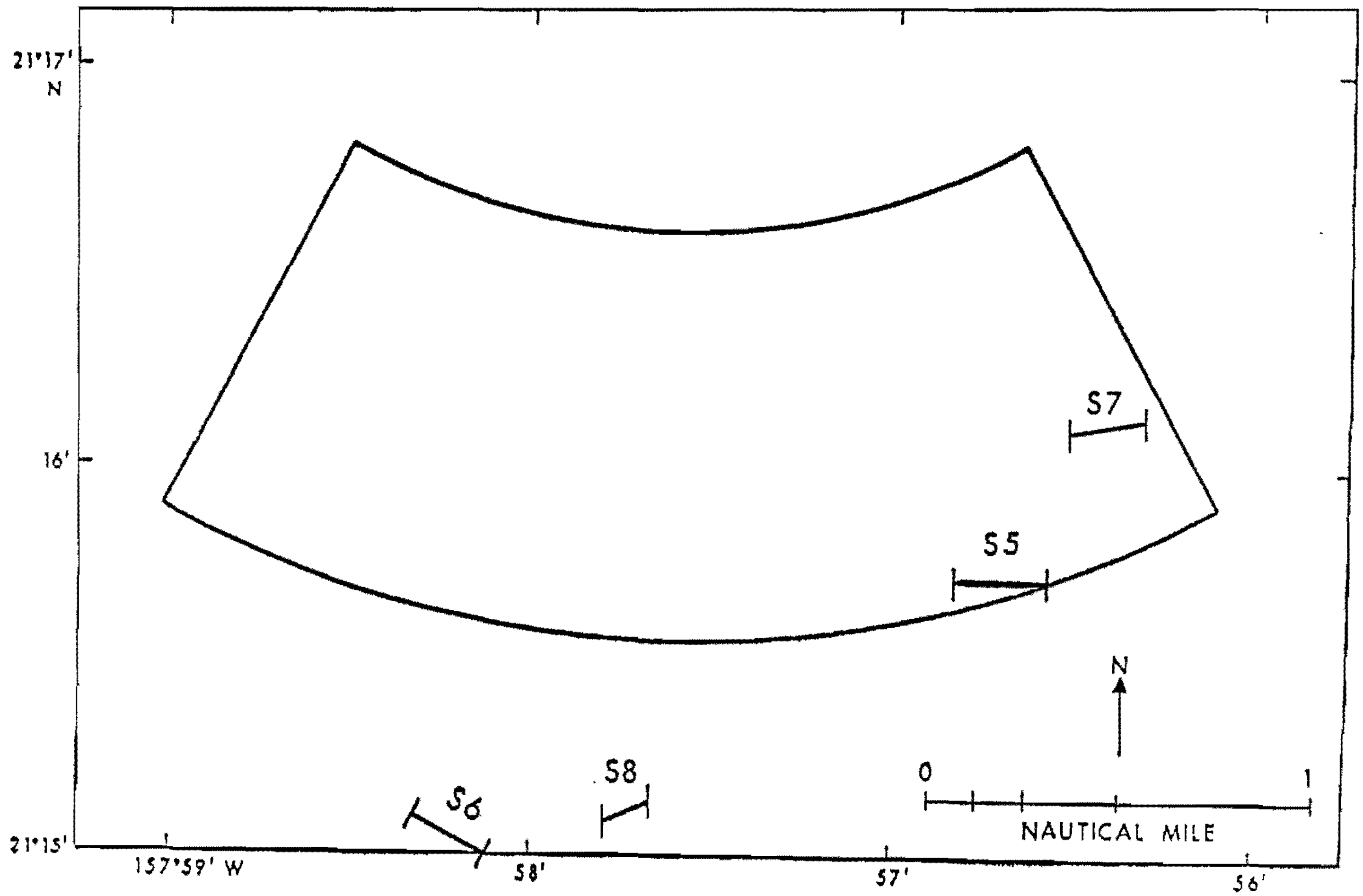
B. Methods

The methods used in this study are similar to those described in Section VII, Parts A and B (Chave and Miller, 1977), with the following exception: In the monitoring phase, Part B, it was suggested that the shrimp populations be examined near but not at the 1977 sites to determine whether their populations reach commercially valuable quantities. The rationale behind this recommendation came from the hypothesis that the decrease in the number of shrimp taken on July 18, 1977, may have been due to depletion of the population by the previous set on May 18, 1977. Confirmation of this hypothesis would require extensive and regular trapping, a level of collection beyond the scope of this study. To reduce the likelihood of introducing errors through depletion of the population by fishing at the same site each time, the traps were not set in exactly the same locations. Instead, an effort was made to set the traps in the same general area and at the same depth for each collection. The locations of the trap lines set on September 29 and December 8, 1977, are shown in Figure VII-1.

The gills and intestines of 20 shrimp were examined for evidence of dredge spoil.

Fish catch data for September 1970-1977 were examined using the computer printout from the Hawaii State Department of Fish and Game. Statistics for October through December were not available. The eastern part of Fish and Game areas 401 and 421 (Pearl Harbor to Barbers Point) is shown in Figure VII-2. Since Area 401 is located from the shoreline two miles oceanward and Area 421

Figure VII-1. Locations of the September and December 1977 shrimp trap lines in the area. S5 and S6 were set in September, S7 and S8 in December. S6 and S8 are control sets, S5 and S7 are near the dump site.



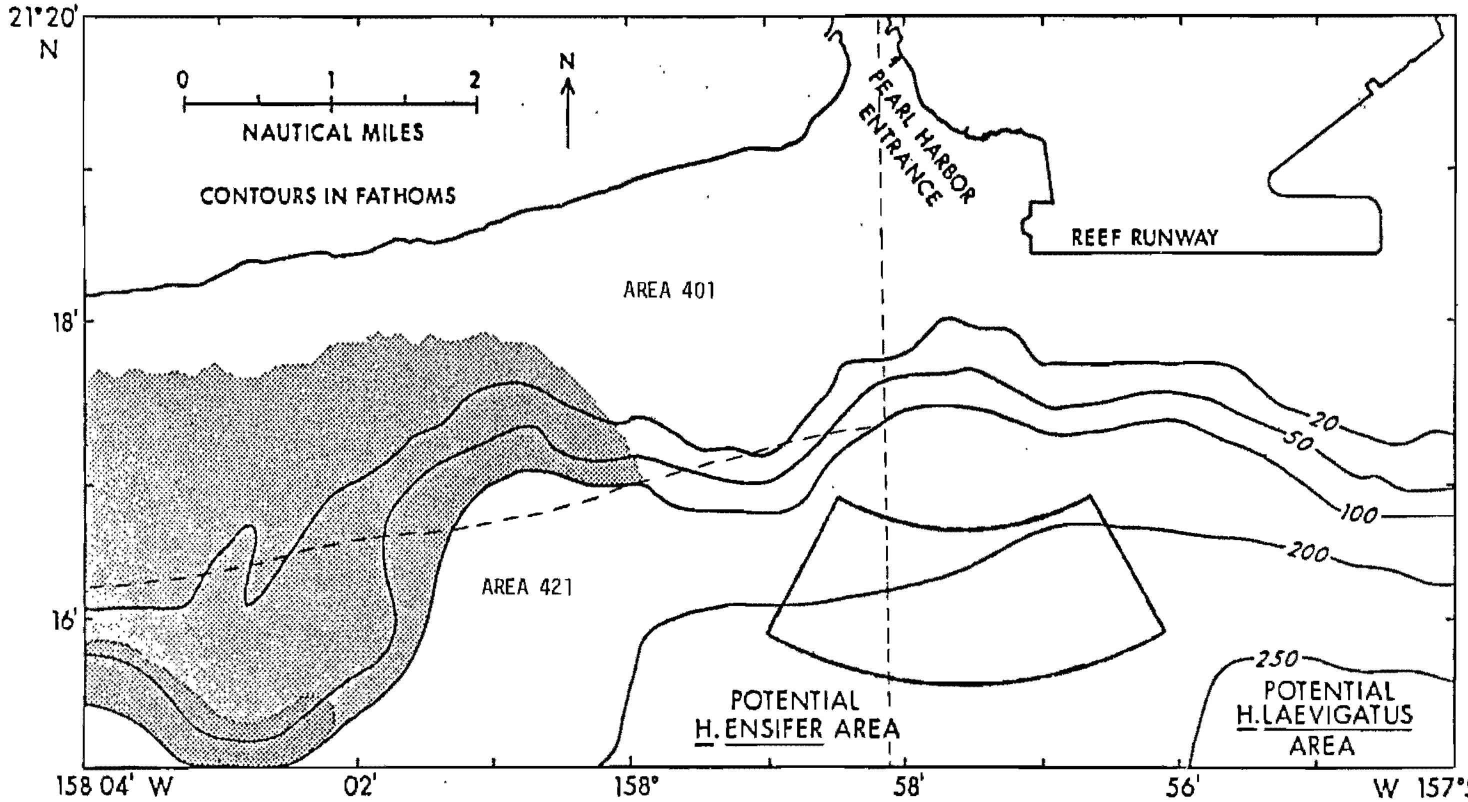



Figure VII-2. Map of the Pearl Harbor to Barbers Point fisheries. Dark area contains the highest concentrations of akule and opelu. (----) = designates approximate southern and eastern boundary of Area 401 and northern and eastern boundary of Area 421.

= Ewa (Barbers Point ledge fishery area

= Highest concentrations of akule and opelu continues seaward from Area 401, part of the Ewa (Barber's Point) ledge is not covered in Area 401. The fishermen that frequent the Ewa ledge compensate for this and usually report all opelu and akule as caught in area 401, since they often use the 100 fathom contour line to delineate the boundary between the two areas. However, fish catch statistics for both areas must be examined for these two fishes because occasionally the two are reported from both areas.

## C. Results

### 1. Shrimp

The only commercially important species taken in the traps was Heterocarpus ensifer. The numbers taken and subsample size distributions are summarized in Figure VII-3.

In September 1977, the dump site collection contained 452 individuals; the control site, 776 individuals. In December 1977, the dump site contained 386 individuals; the control site, 317. These numbers are not commercially significant (Clarke, 1972; Struhsaker and Aasted, 1974).

The animals were in good condition. Their gills and intestines did not contain dredge spoil.

### 2. Fish

A large catch of young and adult akule and a very small opelu catch were taken in Area 401. In the offshore area (421), three fishes made up the greatest percentage of the catch by value: aku $14,121, mahimahi $1,350, and ahi $898.

## D. Discussion and Recommendations

### 1. Shrimp

Figures VII-4, VII-5, and Table VII-1 compare the shrimp catch for the years 1976-1977. All 1977 stations were set at 230 fm to insure similar depth of capture for comparison with the September 1976 traps located near the dump sites. In 1976, Sets 1 and 3 were in shallower water than Set 2 in the dump site area (see Map 1 and p. VII-3, Part A) and consequently are not compared with the 1977 traplines.

The results summarized in Table VII-1 show fluctuations in numbers of shrimp per trap in the dump site and control areas throughout the 12-15 month period studied. The May and September 1977 traps yielded the highest numbers of animals in the control area; the July and December traps had the fewest. There

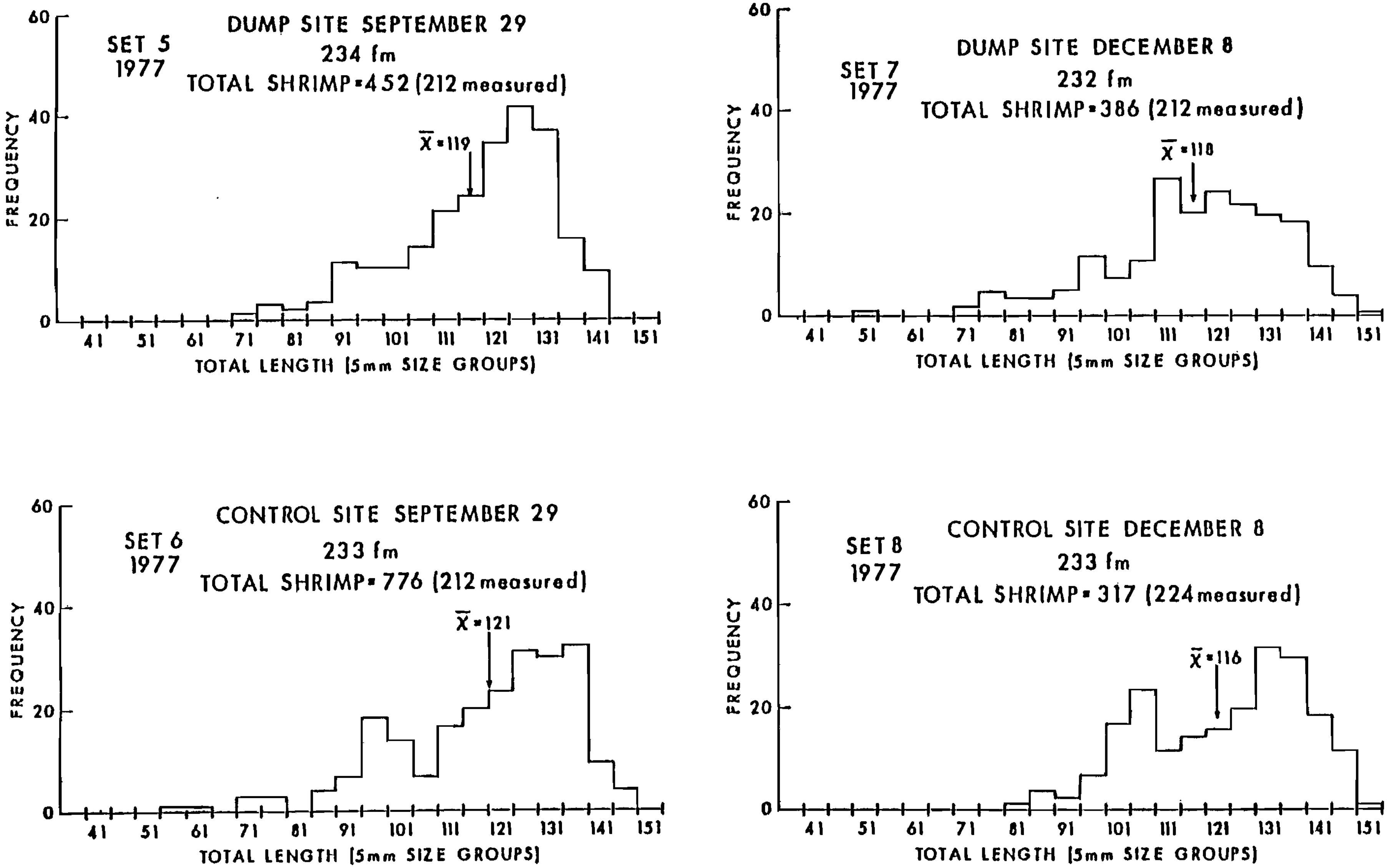
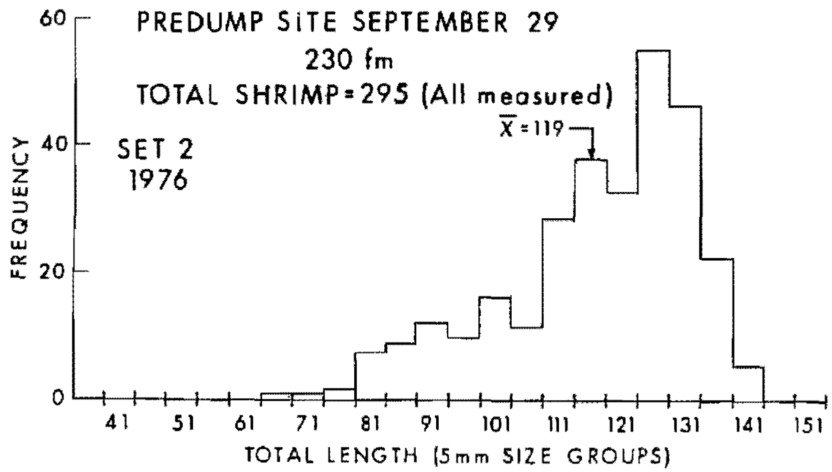
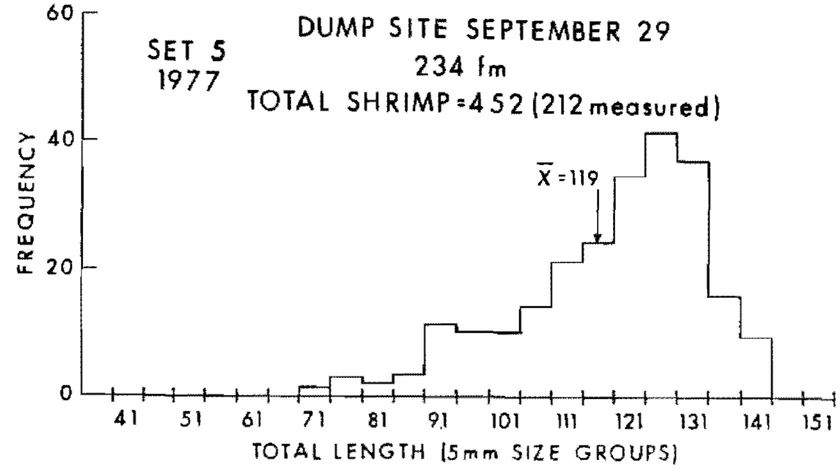
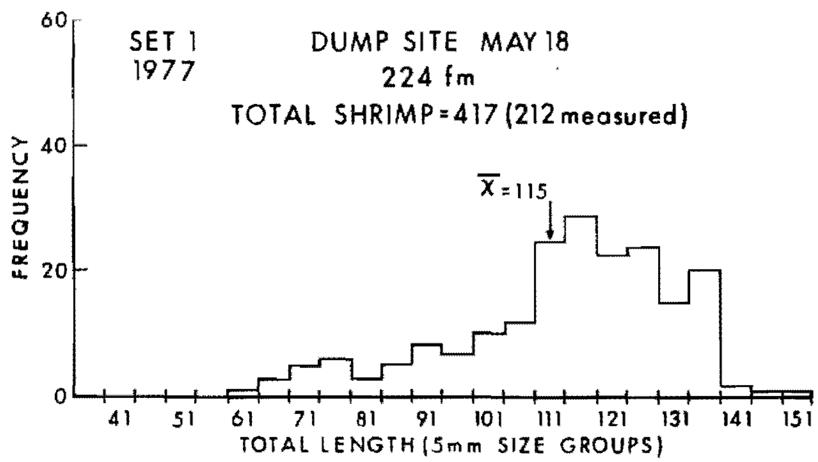
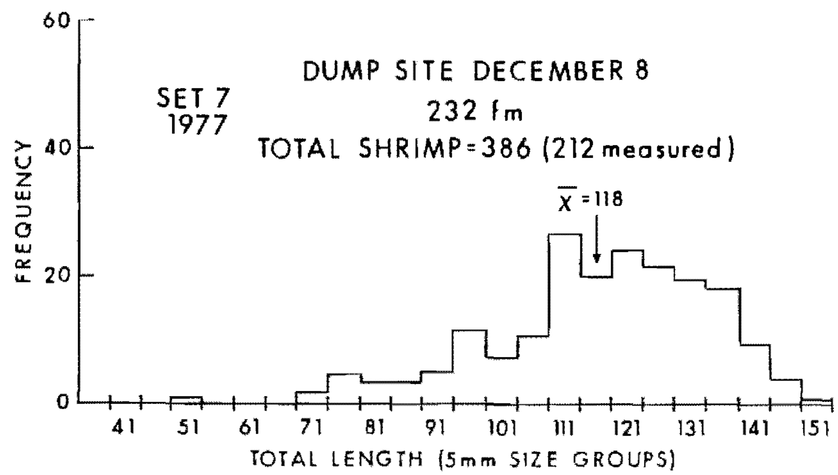



Figure VII-3. Length-frequency histograms of Heterocarpus ensifer subsamples in the Pearl Harbor dredge spoil disposal area on September 29 and December 8, 1977.



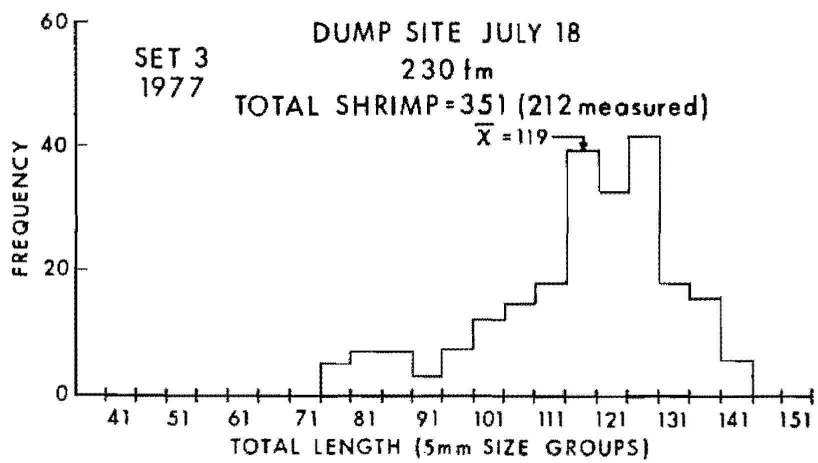




Figure VII-4. Length-frequency histograms of *Heterocarpus ensifer* subsamples at the dump site from September 1976 to December 1977.

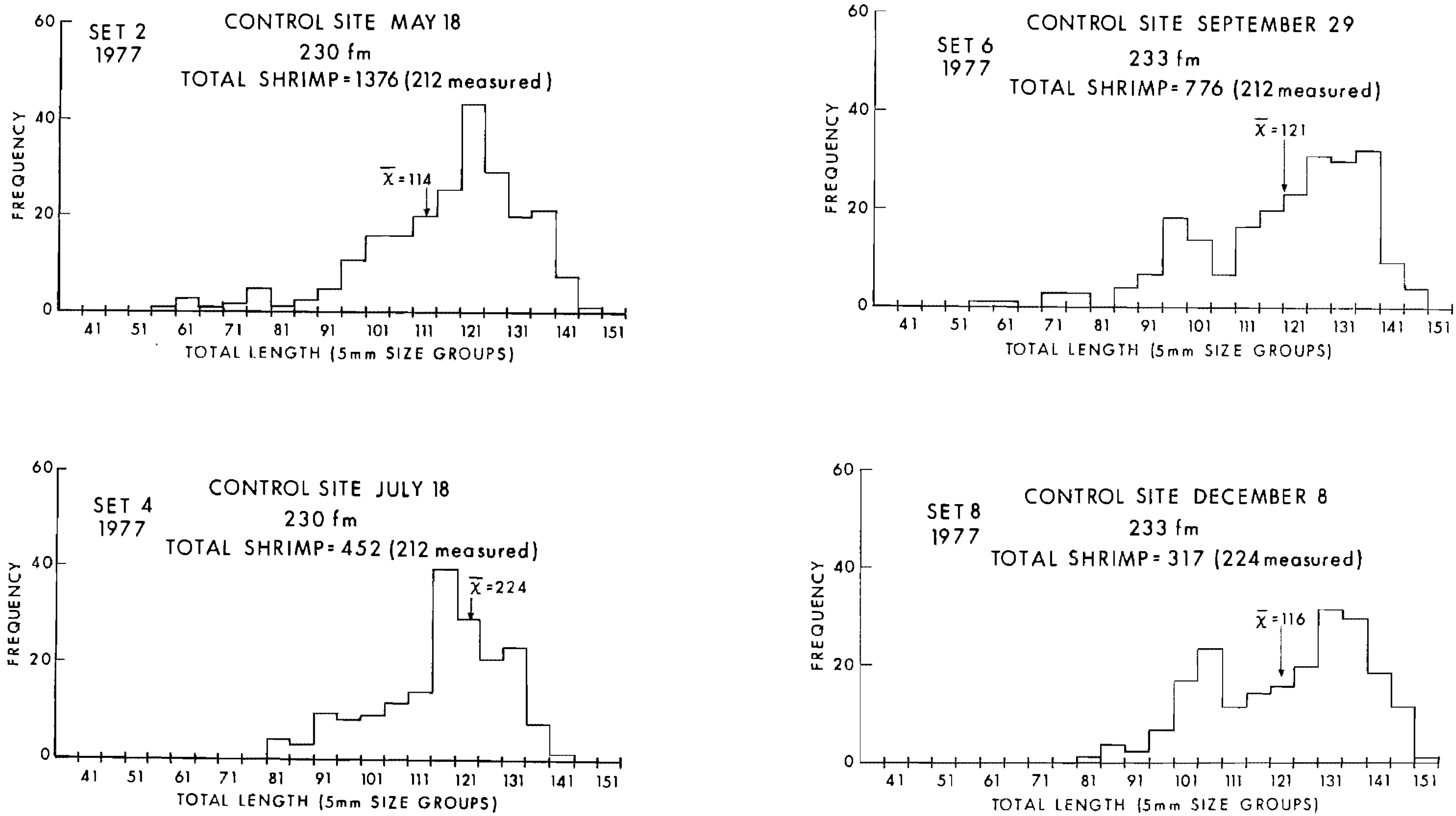



Figure VII-5. Length-frequency histograms of Heterocarpus ensifer subsamples at the control site from May 1977 to December 1977.

Table VII-1. *Heterocarpus ensifer* mean lengths in mm and number per trap during the five trapping periods in the area.

| | Sept 1976 | May 1977 | July 1977 | Sept 1977 | Dec 1977 |
|---|---|---|---|---|---|
| No/Trap Dump | 29.5 | 41.7 | 35.1 | 45.2 | 37.7 |
| No/Trap Control | --- | 137.6 | 45.2 | 77.6 | 48.3 |
| Length Dump | 119.0 | 114.7 | 119.3 | 119.0 | 118.2 |
| Length Control | --- | 114.1 | 123.5 | 121.3 | 115.7 |

was no significant difference in the number of shrimp taken at the dump site in May and December. It was previously postulated (Part B) that the July shrimp population might have decreased from the May value at the control site because the traplines were set in the same area during both months. The September and December traplines were consequently set in slightly different areas. The number of shrimp per trap at the dump site remained relatively stable. In the control area, the catch fluctuated. The May shrimp trap population at the control site was larger than that in July; in December, it decreased from September values. Therefore, overfishing does not seem to be a factor in the observed catch.

It was suggested that the fluctuations in shrimp number were a function of more or less suitable substrates in the May and July 1977 control sets (Part B). Subsequently, samples of sediment taken from traps in both sets 6 and 8 at the control site contained fine, unworn sand. Therefore, sediment type does not seem to account for the differences in shrimp abundance between sets. Furthermore, observations of living _Heterocarpus ensifer_ at the Waikiki Aquarium and seen in the photos in the Pearl Harbor dredge spoil disposal area have shown that the shrimp move about on the sediment, swim above it, or hide under rocks. They do not burrow into the sediment in the Aquarium. Consequently, it is felt that the fluctuations in the control site samples of shrimp population are attributable to changes within the shrimp populations themselves; _e.g._ mortality, recruitment, etc.

The low but consistent number of shrimp at the dump site during 1977 indicates that there is a smaller population in this area. There is an even lower number of shrimp in the 1976 sample. Although the reasons for this are not known, dumping may have increased the population in the dump site area and did not appear to be detrimental to the shrimp population (see also Spencer, in TetraTech, 1977).

Figures VII-4 and VII-5 and Table VII-1 show that the mean length of animals during dumping in May 1977 decreased at both the dump and control sites and might be due to natural population fluctuations. Note also that the control site's December population decreased in size, and the mean length of the individuals was considerably smaller than individuals obtained near the dump site. There was no correlation between size-of-individual and population size.

Since the shrimp trap population data taken in the dump and control areas are of marginal commercial value at most and do not indicate deleterious effects from dredge spoil, it is recommended that dumping proceed in the area. A localized dumping area to minimize shrimp mortality is not necessary.

2. Fish

Table VII-2 shows the monetary results of the akule and opelu fisheries at the Ewa (Barbers Point) ledge. The opelu fishery has steadily dropped from September 1970 to September 1977. The akule fishery has increased in value and appears to fluctuate. Prices for these fishes have changed somewhat from 1970 to 1977. Consequently, the large September 1977 catch of akule is about equal in number of fish caught to those taken in 1971. There were no apparent dredge spoil effects on the akule population. The reasons for the steady yearly decrease in the opelu population are not known, but dredge spoil does not appear to be a factor.

It is recommended that dumping be limited to the southeastern sector of the dredge spoil disposal study area to minimize potential contamination of the Ewa ledge area.

## E. Summary

The fisheries in and around the Pearl Harbor dredge spoil disposal area showed no discernable effects of dredge spoil contamination. Shrimp biomass was consistently lower and more stable at the dump site than at the control site prior to and after dumping, indicating a smaller population there. The reasons for this are unknown. The number of shrimp caught did not represent a commercially important resource.

## F. Acknowledgements

I wish to thank Richard B. Spencer for his help in obtaining the specimens. I appreciate the help of the captain and crews of the research vessels Machias and El Greco for their support in the project. Again, I would like to thank Mr. Clyde Miyazawa of the State Department of Fish and Game for his assistance with fish catch statistics.

Table VII-2. Values of Hawaiian akule and opelu fisheries around the disposal area (Fish and Game area 401-402) during September 1970-1977.

| September | Value $ of akule | Value $ of opelu |
|---|---|---|
| 1970 | 2,291 | 3,156 |
| 1971 | 3,038 | 1,834 |
| 1972 | 2,286 | 1,543 |
| 1973 | 432 | 742 |
| 1974 | 2,325 | 270 |
| 1975 | 2,171 | 947 |
| 1976 | 2,286 | 627 |
| 1977 | 4,724 | 72 |

## G. Literature Cited


Chave, K.E. and J.N. Miller, 1977. Baseline studies and evaluation of physical, chemical, and biological characteristics of nearshore dredge spoil disposal, Pearl Harbor, Hawaii. Parts A and B. Environmental Center Final Report, University of Hawaii.

Clarke, T.A., 1972. Explorations of deep benthic fish and crustacean resources in Hawaii. HIMB Tech. Rep. 29:1-18.

Spencer, R., 1977. In: TetraTech. Ocean disposal of harbor dredged materials in Hawaii. Final Report. T.T. 852:1-153.

Struhsaker, P. and D.C. Aasted, 1974. Deep water shrimp trapping in the Hawaiian Islands. Mar. Fish. Rev. 36(10):24-30.