NUC TN 1128

4

AD-A954 914

NAVAL UNDERSEA CENTER
San Diego, California

PEARL HARBOR BIOLOGICAL SURVEY-FINAL REPORT

Evan C. Evans III, (Editor)

Contributors:

Norman L. Buske
J. Geoffrey Grovhoug
Eric B. Guinther
Paul L. Jokiel
Dennis T. O. Kam
E. Alison Kay
Gerald S. Key
Thomas J. Peeling
Stephen V. Smith

Hawaii Laboratory
30 AUGUST 1974

85 9 27 040

Best
Available
Copy

EXECUTIVE SUMMARY

As part of the Navy's Environmental Protection Program, a detailed biological survey of Pearl Harbor was conducted by the Naval Undersea Center. At the time the survey commenced (fall 1971), little was known about the living marine resources of that harbor. During the next year and a half, an inventory of marine forms was produced which included a checklist of 393 positively identified species together with maps of the distribution of potential bio-indicator species within the harbor. The effort brought biological knowledge of Pearl Harbor to a par with that of Kaneohe Bay which has been studied by the University of Hawaii for many years. The Navy is now not only able to respond with authority to questions concerning the biological condition of Pearl Harbor often raised by federal and state agencies, but also to take advantage of the environmental research being conducted by the University.

In addition to the basic field work, an efficient analytical procedure was developed for the processing, interpretation and display of the large amounts of data, both biological and physicochemical, obtained on environmental surveys. This analytical system was used in many ways. Internal consistency in the biological data was checked. Marine species having real potential as practical and cost-effective bio-indicators for Navy use were separated from almost 400 possible candidate species; a reduction of almost 80% was achieved. Three promising bio-indicator systems were tested, one using fish populations, one using micromollusca and one using fouling animals. All three systems were mutually consistent in mapping environmental stress within the harbor. The field procedure, needed instrumentation and data analysis techniques for each of these systems are fully described in this report. A fourth system, using bottom animals, originally thought to have great potential, was shown to be consistent with the other systems, but too expensive and time-consuming for routine Navy use.

Data from a survey of water quality and of harbor sediments performed by the Navy Civil Engineering Laboratory was also analyzed. Most of the water quality data showed no useful relation to environmental condition as determined by biological assessment; however, metallic content of the bottom sediments did show reasonable agreement. Survey of the metallic content of sediments is neatly complimentary to a bio-indicator system using micromollusca. Both have potential for determining past environmental condition, an important factor in any impact assessment. Factor analysis of the NCEL sediment data designated clearly a terrigenous and a shipyard "signature" in the metallic burdens. Many metals were shown to be highly correlated with one another; thus, cost savings in the chemical analysis are possible. Furthermore, since the metallic content of sediments from San Diego Bay, Pearl Harbor and Apra Harbor, Guam are shown to be very similar, a combined chemical and biological survey system would appear to be applicable to many harbors used by the Navy.

The power of the analytical system developed is shown by its application to biological data collected from a bay on Hawaii never visited by the NUC survey team. Analysis of this data reproduced exactly the distribution of three different biological communities described by the original survey team. In addition, the analysis classified three sites which had been re-

ported as anomalies in the original survey and identified three additional environmental parameters not considered by the original survey team as the probable reasons for the classification. This demonstration is particularly important to the development of a Navy-wide system of environmental monitoring and interpretation in which data variously collected and reported will have to be analyzed. The basic concepts and procedures for such a system have been developed and are fully described in this report. The Navy can, therefore, develop a coordinated and consistent way of responding to various different federal and state environmental regulations. The combined survey and analytical procedure can also be used to demonstrate quantitatively environmental improvements resulting from Navy pollution abatement programs.

Additional work done in support of the biological survey has shown the importance of ship activity as an oceanographic parameter in Pearl Harbor and probably other shallow harbors. This demonstration is both new and of great environmental interest since ships are shown to increase vertical mixing and thus have some beneficial environmental effects. A possible interaction between ship-induced turbulence, bottom sediments and surface oil was also suggested in the analysis. While complete understanding of this interaction was beyond the scope of the survey, proof of such a phenomenon would be an important factor in the environmental management of heavily utilized harbors. The knowledge that Navy operations can have beneficial as well as detrimental effects on harbor environments is certainly useful in its own right. Formalization of the Pearl Harbor circulation studies also resulted in a mathematical model capable of predicting surface and bottom currents in response to given wind, rainfall and tidal conditions. No such model of the harbor existed prior to the NUC survey.

In summary, neither the general survey of bottom animals nor the broadcast monitoring of numerous water quality parameters are recommended since both are expensive and much of the water quality data obtained is environmentally useless. Bio-indicator systems and sedimentary analysis show great promise as efficient and inexpensive methods of monitoring marine environmental condition. A definite plan for continued development of these techniques as cost-effective survey methods has evolved out of NUC's Pearl Harbor experience. Execution of this plan will put the Navy in a position not only to respond precisely to the intent of the Federal Water Pollution Control Act of 1972, but also to do so at considerable savings in its current monitoring program. There are signs that the Environmental Protection Agency is moving away from the general collection of unanalyzed physicochemical data as proof of compliance with regulations toward the true intent of the Federal Water Pollution Control Act, which states as its objective "...to restore and maintain the ... biological integrity of the Nation's waters." The findings of the Pearl Harbor Biological Survey have provided the experience and the basic concepts needed to respond in an effective and timely manner to these coming changes in federal policy.

PEARL HARBOR BIOLOGICAL SURVEY
FINAL REPORT

Due to the fact that certain sections of the final report required much longer processing times than others, the report was issued serially. The first sections of the report were issued on 23 November 1973 and 20 April 1974. These sections represent the third and final serial issue of the Pearl Harbor Biological Survey report. A brief outline of the entire report showing the dates when each section was issued follows:

1.0 INTRODUCTION - 23 Nov 73

2.0 SURVEYS - 30 Aug 74

- 2.1 FISH SURVEY - 23 Nov 73
- 2.2 BENTHIC SURVEY - 20 Apr 74
- 2.3 MICROMOLLUSCS - 20 Apr 74
- 2.4 PILING SURVEY - 30 Aug 74

3.0 PHYSICAL/CHEMICAL MEASUREMENTS - 30 Aug 74

- 3.1 SEDIMENT - 30 Aug 74
- 3.2 WATER QUALITY - 30 Aug 74
- 3.3 TIDES, RUNOFF AND CURRENTS - 20 Apr 74
- 3.4 SHIP ENERGY - 20 Apr 74

4.0 STATISTICAL ANALYSIS - 23 Nov 73

- 4.1 SEDIMENT - 23 Nov 73
- 4.2 WATER QUALITY - 23 Nov 73
- 4.3 FISH - 23 Nov 73
- 4.4 BENTHIC - 20 Apr 74
- 4.5 MICROMOLLUSCS - 20 Apr 74
- 4.6 PILING - 30 Aug 74
- 4.7 INTERCOMPARISONS - 30 Aug 74

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

INTRODUCTION

J. Geoffrey Grovhoug
Evan C. Evans III

INTRODUCTION

BACKGROUND

Early in 1971 Pearl Harbor was designated as a pilot test study site as part of the Navy Environmental Protection Data Base Program. This pilot study was one of three initial studies throughout the United States designed to test and evaluate methods of collection, analysis, storage, and retrieval for environmental information as related to U.S. naval facilities. Air, noise, water, sediment and biological base-line studies were conducted as integral parts of the pilot study project. The Pearl Harbor Biological Survey (PHBS) was conducted under inter-Navlab contract by the Naval Undersea Center, Hawaii Laboratory (NUC/HL).

OBJECTIVES

The specific objectives of PHBS were:

- to establish a species checklist of resident marine organisms
- to determine the population sizes and geographical distributions of selected resident marine organisms
- to establish a pollution rating index for selected resident organisms
- to provide a statistical basis for evaluating the effects of water quality changes on marine organisms.
- to prepare an instructive document on biological survey techniques.

The first four objectives have been completed and are presented in this report. The instructive document entitled "Biological Survey Techniques for Naval Facilities" was prepared separately.

SAMPLING CRITERIA

Surveys were undertaken at 10 biological sampling stations (bio-stations) in Pearl Harbor, Oahu (Figure 1.0-1) to gather adequate base-line data for fish, benthic and piling/intertidal communities. The number of bio-stations was reduced from 17 to 10 in February, 1972, due to increased field activities arising from a request by NCEL for additional replicate sampling at each station within the constraints of available time, manpower and funds.

Each bio-station was selected (1) for its location near a suspected pollutant source within the harbor and (2) to approximate a uniform geographic distribution of stations throughout the harbor complex. The frequency of each sampling activity was a function of the time available, sampling priorities and special problems which arose during the study. Fish surveys were conducted on a semi-regular basis throughout the study period. Benthic sampling was conducted on an intensive basis during March and April, 1972, but further sampling planned for the fall was precluded by funding cuts. Piling samples were collected during May and November, 1972.

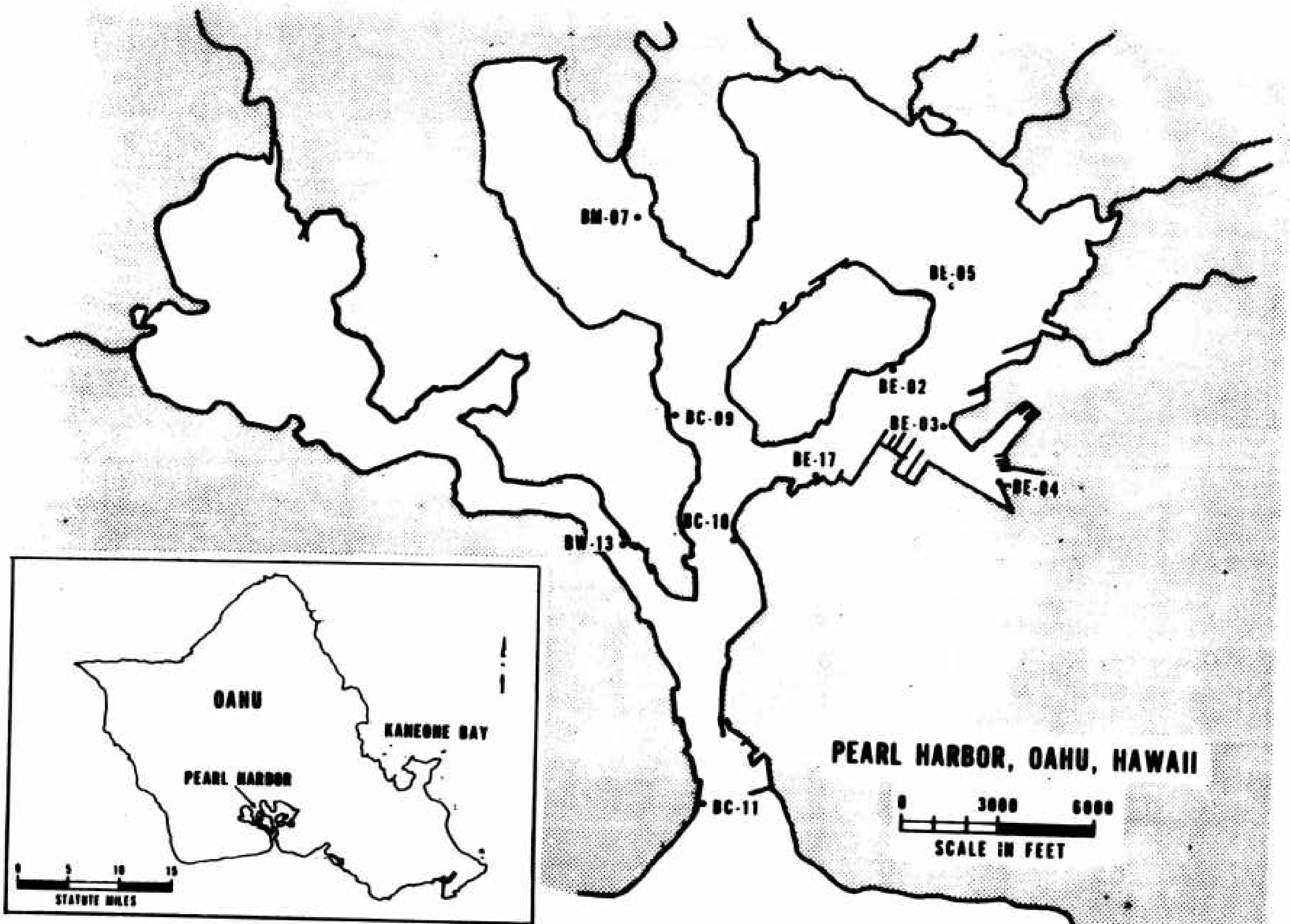


Figure 1.0-1. BIOLOGICAL SAMPLING STATIONS IN PEARL HARBOR, OAHU.

PHBS STATION DESCRIPTIONS

Since various sampling activities were conducted at many locations in Pearl Harbor, it is convenient to designate standardized nomenclature for each type of sampling station. Biological sampling stations are readily recognized by the initial letter "B", which distinguishes these stations from other Data Base collection sites. The second letter following the "B" describes the region within the harbor where the bio-station is located: "E" = East Loch, "M" = Middle Loch, "W" = West Loch, and "C" = Channel areas. Hence, BE-02 is biological sampling station number two located in East Loch. The numerical designators indicate only the order in which the original 17 bio-stations were established during an initial survey of Pearl Harbor (Reference 1.0-1) done prior to Navy Environmental Protection Data Base activity in the harbor. When the total number of bio-stations was reduced to 10, the original numerical designators were retained to maintain continuity with previously reported data. These 10 active bio-stations are: BE-02, BE-03, BE-04, BE-05, BM-07, BC-09, BC-10, BC-11, BW-13 and BE-17.

To describe the bio-stations more completely, cross-sectional diagrams, plan views and above water photographs for each station are incorporated into this section. The plan views show approximate bottom contours at each bio-station as well as the locations of each type of sampling activity. Bottom contours are shown for 3, 5, 10, 15...40 foot depths where appropriate. Drawings are not to exact scale, but are provided to illustrate the general aspect of each bio-station. The general orientation of the cross-sectional diagrams is shown for all bio-stations in Figure 1.0-2 and again in each set of bio-station illustrations.

Each bio-station is described separately in this section. Latitudes and longitudes were taken from NAVOCEANO Chart N. O. 19084, scale 1:12,500, dated January 1971 (FOUO). All underwater visibilities are described for a depth of eight to ten feet at each bio-station because surface waters (first three feet) throughout the harbor are often quite turbid (visibilities of less than six inches are common). Visibility is usually greater below this surface layer, but on some occasions, visibility throughout the water column is considerably reduced by such factors as ship traffic, elevated wind conditions, or freshwater runoff (rain). Values for exposure to ship traffic have been established using the following criteria:

Light (L) = occasional small boat traffic (1 or 2 boats/day) and/or seldom influenced by larger naval ships (up to 1 ship/week);

Moderate (M) = frequent small boat traffic (3-7 boats/day) and/or occasionally influenced by larger naval ships (2-5 ships/week);

Heavy (H) = nearly continuous small boat traffic (more than 8 boats/day) and/or frequently affected by larger naval ship traffic (more than 6 ships/week).

The category "small boats" includes vessels up to 90-100 feet in length such as commercial tour boats, naval torpedo retrievers, and the Ford Island ferry. "Larger naval ships" refers to ships of destroyer

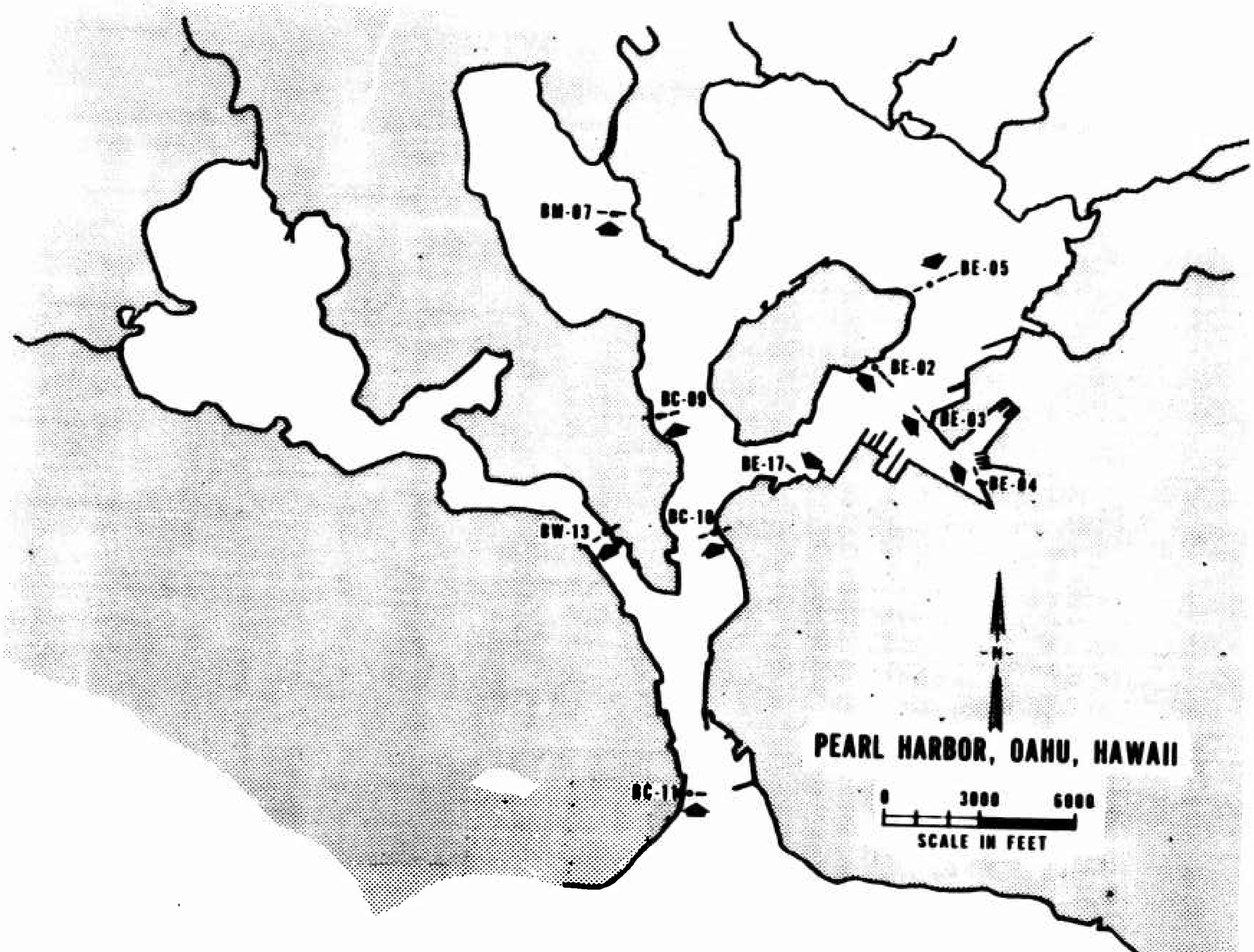


Figure 1.0-2. ARROWS INDICATE OBSERVER POSITION SHOWING CROSS SECTIONAL DIAGRAMS.

escort size (200-350 feet in length) and larger. The range at which ship traffic physically affects a bio-station was selected on the basis of field observations as 300 yards or less; there is significant ship influence at all 10 bio-stations.

For each bio-station, exposure to various specific environmental insults (domestic sewage, industrial effluent, thermal exposure, oil, and siltation) has been estimated on an arbitrary 0 to 5 scale, see Table 1.0-1. These estimates were first based primarily on the proximity of a specific source of insult but were then refined by means of careful field observation over one full year. They are compared later in this report (see Table 4.1-3 and Figure 4.1-6) with certain other statistically derived parameters ranking degree of environmental insult.

Table 1.0-1. ESTIMATED ENVIRONMENTAL CONDITION OF PEARL HARBOR BIO-STATIONS.

Station	Intuitive Ranking	Ship Traffic	Domestic Sewage	Industrial Effluent	Thermal Exposure	Oil	Siltation
BE-02	4th	M	1	1	0	1	2
BE-03	6th	H	0	2	0	3	3
BE-04	10th	H	2	2	0	4	3
BE-05	2nd	M	2	0	0	2	2
BM-07	7th	L	3	0	0	2	2
BC-09	3rd	M	0	0	0	1	2
BC-10	8th	H	0	2	5	3	2
BC-11	1st	H	5	0	0	1	1
BW-13	5th	L	0	1	0	1	3
BE-17	9th	M	3	5	0	3	4

Key: 0 = no observable insult, 1 = very low degree of insult, 2 = low degree of insult, 3 = moderate degree of insult, 4 = high degree of insult, and 5 = very high degree of insult.

Lastly, Table 1.0-1 summarizes an overall intuitive ranking of the general biological status of each bio-station. In this ranking scheme bio-stations are ranked from one to ten, with one being the environmentally least stressed or most "healthy", biologically, and ten being the environmentally most stressed station or most "unhealthy", biologically. Various other rankings, both qualitative and quantitative, are presented in later sections.

STATION BE-02. (Latitude 21°21'56"N, Longitude 157° 57'26"W). Refer to Figure 1.0-3, opposite page. Shoreward of southeast end of pier F-5 (on Ford Island), in the general vicinity of the USS Arizona Memorial. Extends from shoreline to northwest corner of pier F-5. Water depth ranges from 1 to 35 feet. Substrate types include: (1) vertical - concrete pilings, rocks, mud/rock ledge (just below the rock rubble in Figure 1.0-3B) and metal debris; (2) bottom - sand, mud, rocks and silt. Underwater visibility ranges from 2 to 12 feet, usually 8 feet. Ship traffic is moderate: the Ford Island Ferry and numerous water transportation craft pass within 100 yards of the station at regular intervals; larger naval vessels occasionally pass within 300 yards. Estimated degrees of environmental insult include: very low amounts of domestic sewage, industrial effluent and oil; a low amount of siltation is present. Considering the overall biological status observed within the harbor, bio-station BE-02 is ranked fourth in environmental quality. There exists an abundant algal growth of the chlorophyte (*Caulerpa verticillata*) along the sandy shallows (3-8 feet) of the shoreline.

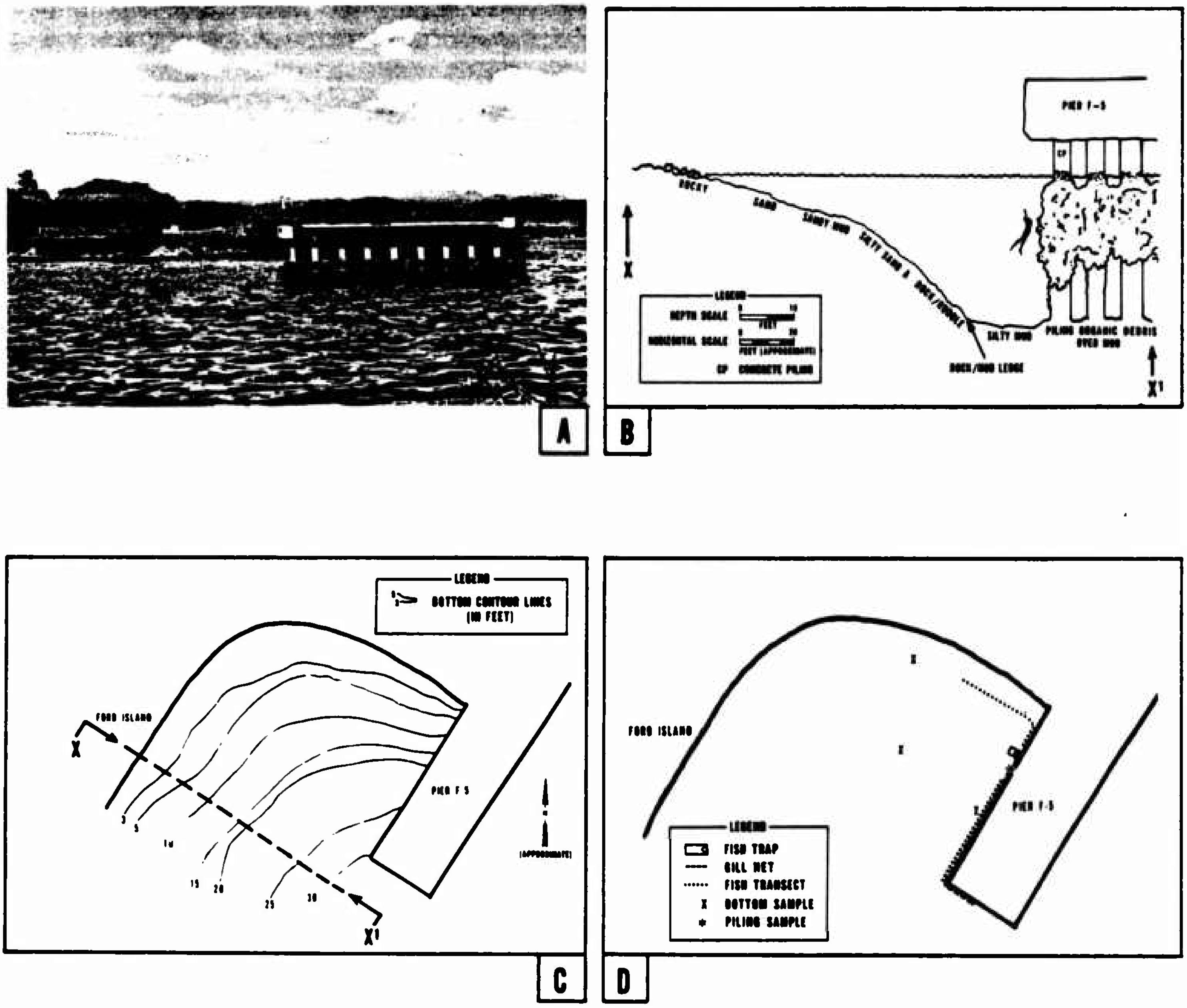


Figure 1.0-3. STATION BE-02

STATION BE-03. (Latitude 21°21'39"N, Longitude 157°57'06"W). Refer to Figure 1.0-4, opposite page. Northwest end of pier Y-3 (eastern shore of the entrance to Southeast Loch). Extends from 100 feet under pier out to channel bottom (about 20 feet out from pier Y-3). Water depth ranges from 3 to 45 feet. Substrate types include: (1) vertical - concrete pilings, rocks and rock ledge (just inside pilings as shown in Figure 1.0-4B); (2) bottom - sandy mud, rock rubble and silt. Underwater visibility ranges from 2 to 8 feet, usually 6 feet. Ship traffic is heavy: numerous naval ships of all classes move within the immediate vicinity of station BE-03. Estimated degrees of environmental insult include: low amounts of industrial effluent; moderate influence of oil and siltation. Considering the overall biological status observed within the harbor, bio-station BE-03 is ranked sixth in environmental quality. There is considerable water motion from boat and ship traffic (especially under the pier); only sparse algal growth is present.

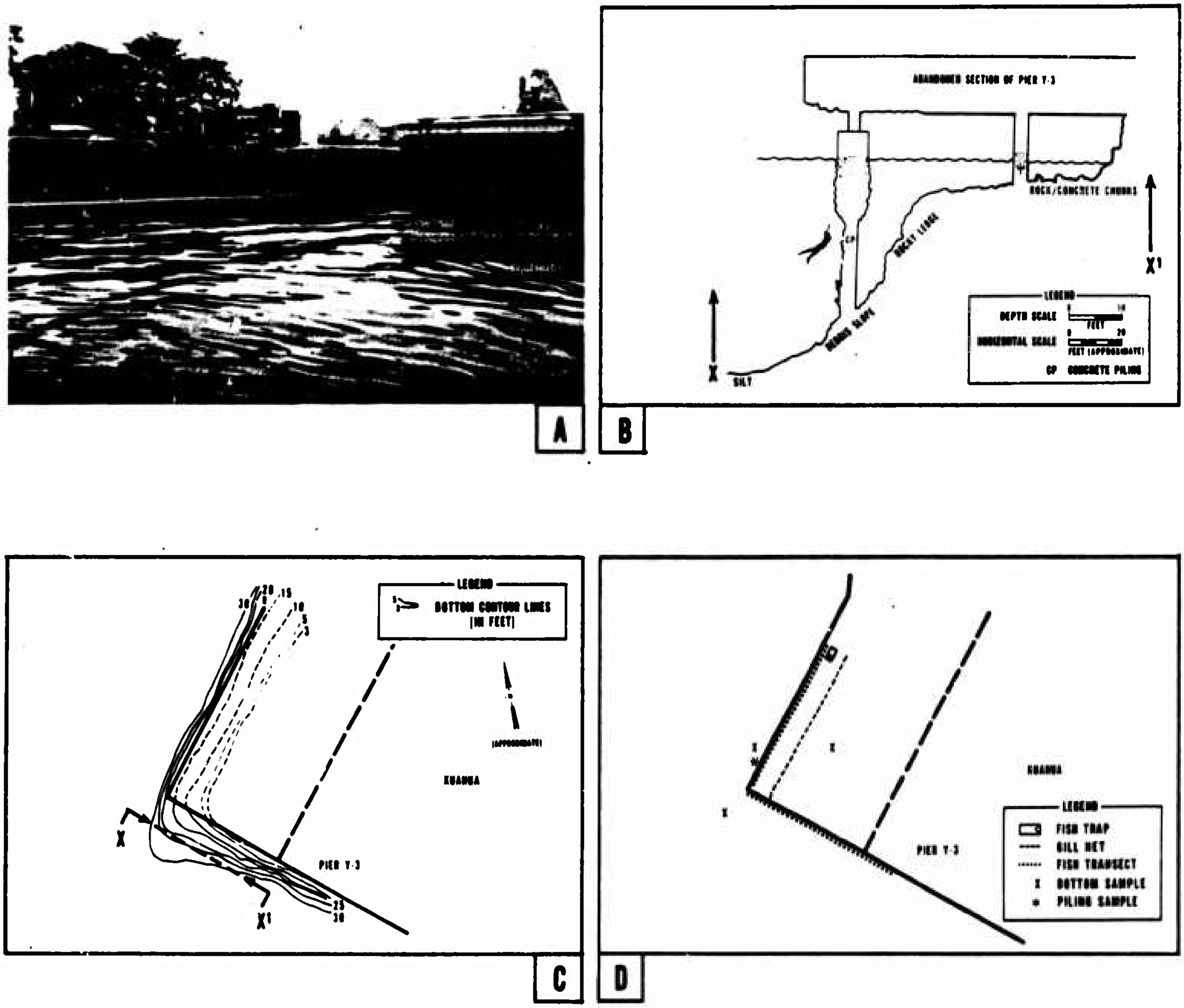


Figure 1.0-4. STATION BE-03

STATION BE-04. (Latitude 21°21'20"N, Longitude 157°56'48"W). Refer to Figure 1.0-5, opposite page. Along the northern diagonal pier face between piers M-2 and M-3 at Merry Point, located in Southeast Loch. Extends from area under pier out to channel bottom. Water depth ranges from 11 to 44 feet. Substrate types include: (1) vertical - concrete pilings and a few wooden pilings; (2) bottom - mud, rocks, metal debris, biogenic debris (mostly vermetid and calcareous worm tubes) and silt. Underwater visibility ranges from 1 to 10 feet, usually 6 feet. Ship traffic is heavy: numerous naval supply, MSTS, destroyer-type and foreign ships of all classes move in the immediate vicinity, but at reduced speeds due to the restricted maneuverability in Southeast Loch. Estimated degrees of environmental insult include: low amounts of domestic sewage and industrial effluent (however, moderate amounts of shipboard wastes are present); moderate siltation; chronically high levels of surface oil. Considering the overall biological status observed within the harbor, bio-station BE-04 is ranked tenth, or lowest, in environmental quality. Benthic algal growth is very sparse; vermetid and sedentary polychaete worm (*Hydroides norvegica*) growth on the concrete pilings is botryoidal, as seen in Figure 1.0-5B.

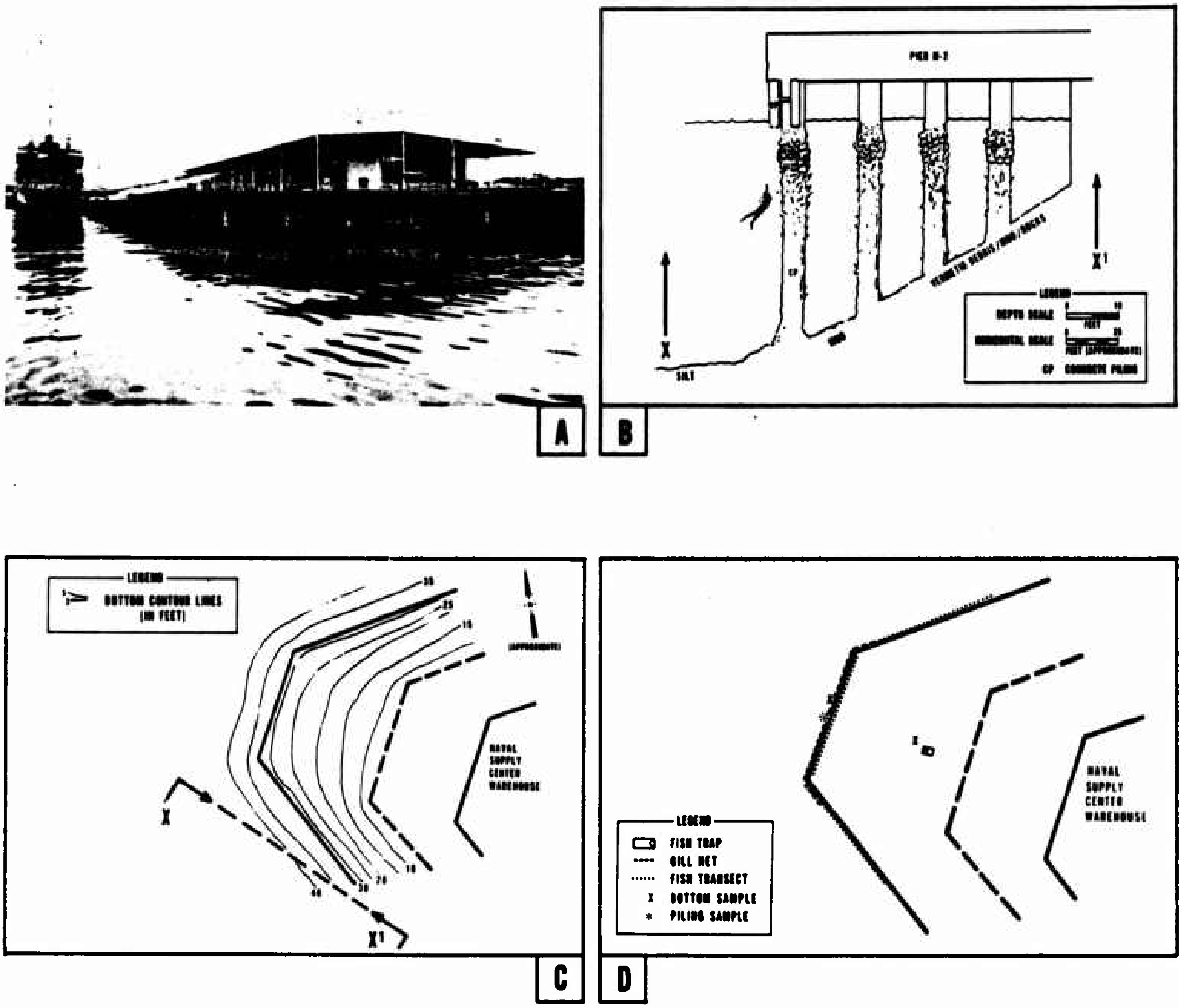


Figure 1.0-5. STATION BE-04

STATION BE-05. (Latitude 21°22'18"N, Longitude 157°57'03"W).

Refer to Figure 1.0-6, opposite page. Northeast side of Mokunui Island (near easternmost shore of Ford Island), East Loch. Extends from island toward buoy "25" and south along rock/mud ledge (adjacent to concrete block, Figure 1.0-6B) near buoy "23" (Figure 1.0-6C). Water depth ranges from 4 to 42 feet. Substrate types include: (1) vertical - concrete block, rock/mud ledge and metal anchor chain; (2) bottom - sandy mud, rock, mud, shell debris and silt. Underwater visibility ranges from 1 to 10 feet, usually 6 feet. Ship traffic is moderate: ships traveling around Ford Island pass within 250 yards of the station; some harbor craft and tour boats traverse the immediate vicinity of BE-05. Estimated degrees of environmental insult include: low amounts of domestic sewage, oil and siltation. Considering the overall biological status observed within the harbor, bio-station BE-05 is ranked second in environmental quality. There is an abundance of algal/sponge growth in shallow (less than 10 feet deep) shell-debris and sandy-mud areas of station BE-05 (Figure 1.0-6C).

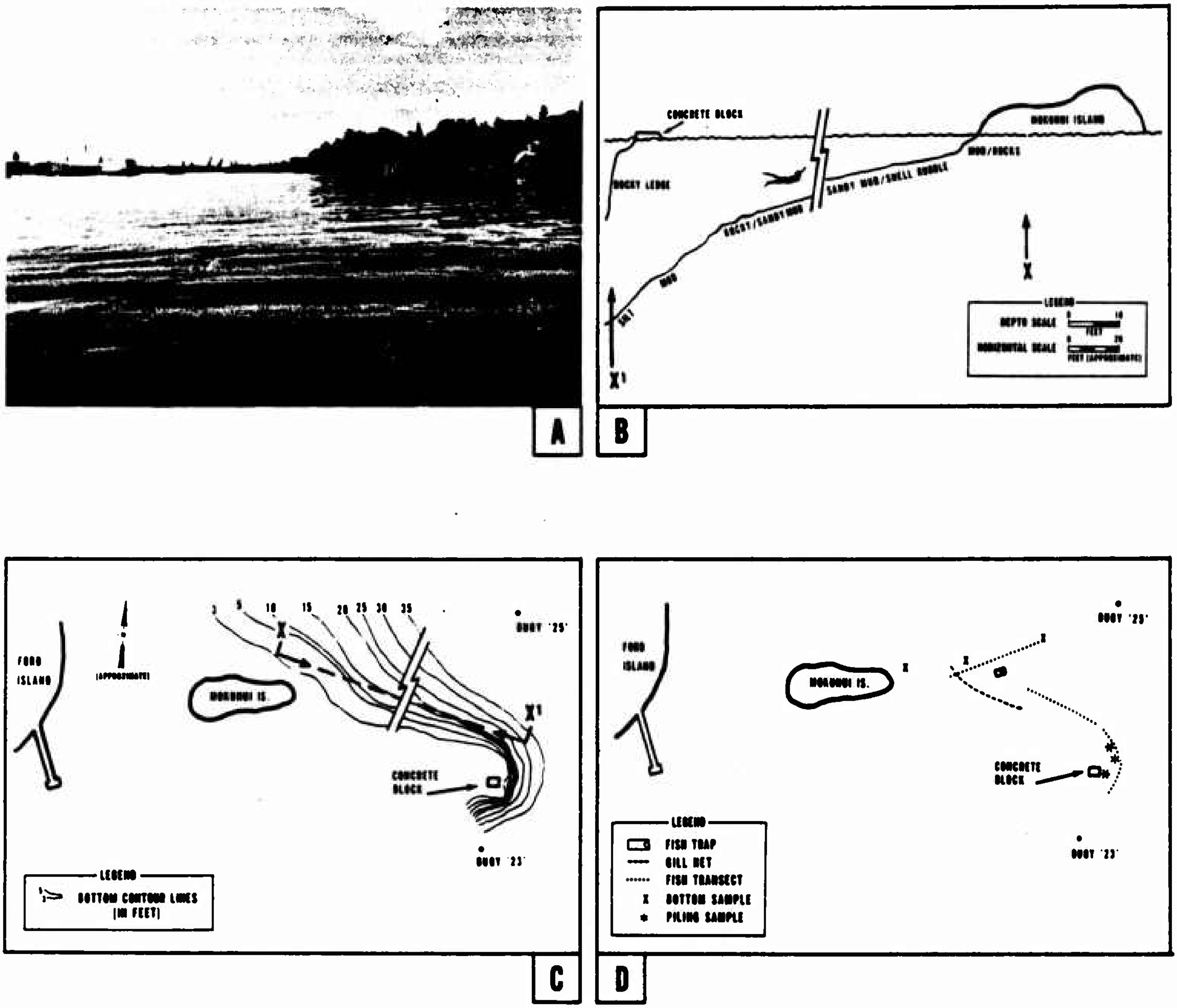


Figure 1.0-6. STATION BE-05

STATION BM-07. (Latitude 21°22'40"N, Longitude 157°58'50"W).

Refer to Figure 1.0-7, opposite page. Includes the area within a 10-yard radius of the wooden dolphin piling just north of the Noise Measurement Facility, Middle Loch. Water depth ranges from 30 to 44 feet. Substrate types include: (1) vertical - wooden pilings; (2) bottom - mud, organic debris (under piling structure as shown in Figure 1.0-7B) and silt. Underwater visibility ranges from 2 to 12 feet, usually 8 feet (below the surface turbid layer). Ship traffic is light: occasionally commercial "Aku" boats (Hawaiian tuna fishermen seine "nehu" in Pearl Harbor and Kaneohe Bay for bait and then fish offshore waters) and harbor craft move in the vicinity of BM-07 (often between dolphin piling and public fishing pier, Figure 1.0-7D). Estimated degrees of environmental insult include: low amounts of oil and siltation; moderate amounts of domestic sewage (primary treatment) from diffuser pipes emptying into Middle Loch near the Inactive Ship Maintenance Facility (seen in Figure 1.0-7C). Considering the overall biological status observed within the harbor, bio-station BM-07 is ranked seventh in environmental quality. No benthic algae have been observed at this station.

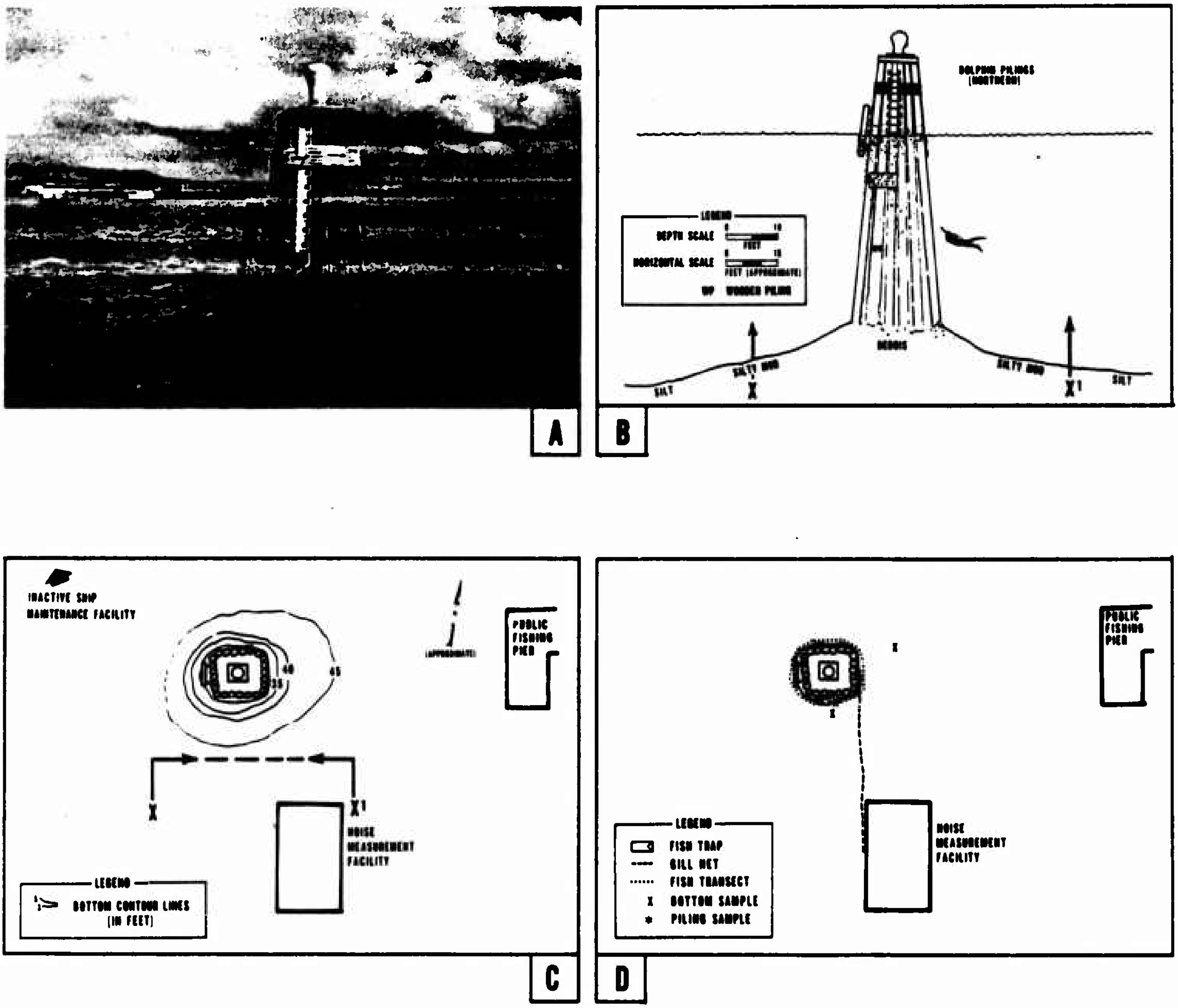


Figure 1.0-7. STATION BE-07

STATION BC-09. (Latitude 21°21'40"N, Longitude 157°58'34"W). Refer to Figure 1.0-8, opposite page. Across channel from the west end of Ford Island along the alignment of channel buoy "40" with the Ford Island flight control tower. Extends from eastern shore of Waipio Peninsula toward buoy "40" until typical soft channel bottom is reached. Water depth ranges from 1 to 38 feet. Substrate types include: (1) vertical - none; (2) bottom - sand, sandy mud, rock and silt. Underwater visibility ranges from 1 to 8 feet, usually 4 feet. Ship traffic is moderate: ships of all classes occasionally pass this station, however, usually at a distance of over 300 yards; some small craft have been observed moving in the vicinity of this station. Estimated degrees of environmental insult include: very low amounts of oil; low amounts of siltation. Considering the overall biological status observed within the harbor, bio-station BC-09 is ranked third in environmental quality. Algal and sponge growth is very abundant on the shallow sandy/rock shelf area near shore (located just ahead of the diver, Figure 1.0-8B, or just shoreward of the vertical pipe, Figure 1.0-8C); people have often been observed gathering "limu" (Hawaiian term for edible algae) along the Waipio shoreline at bio-station BC-09.

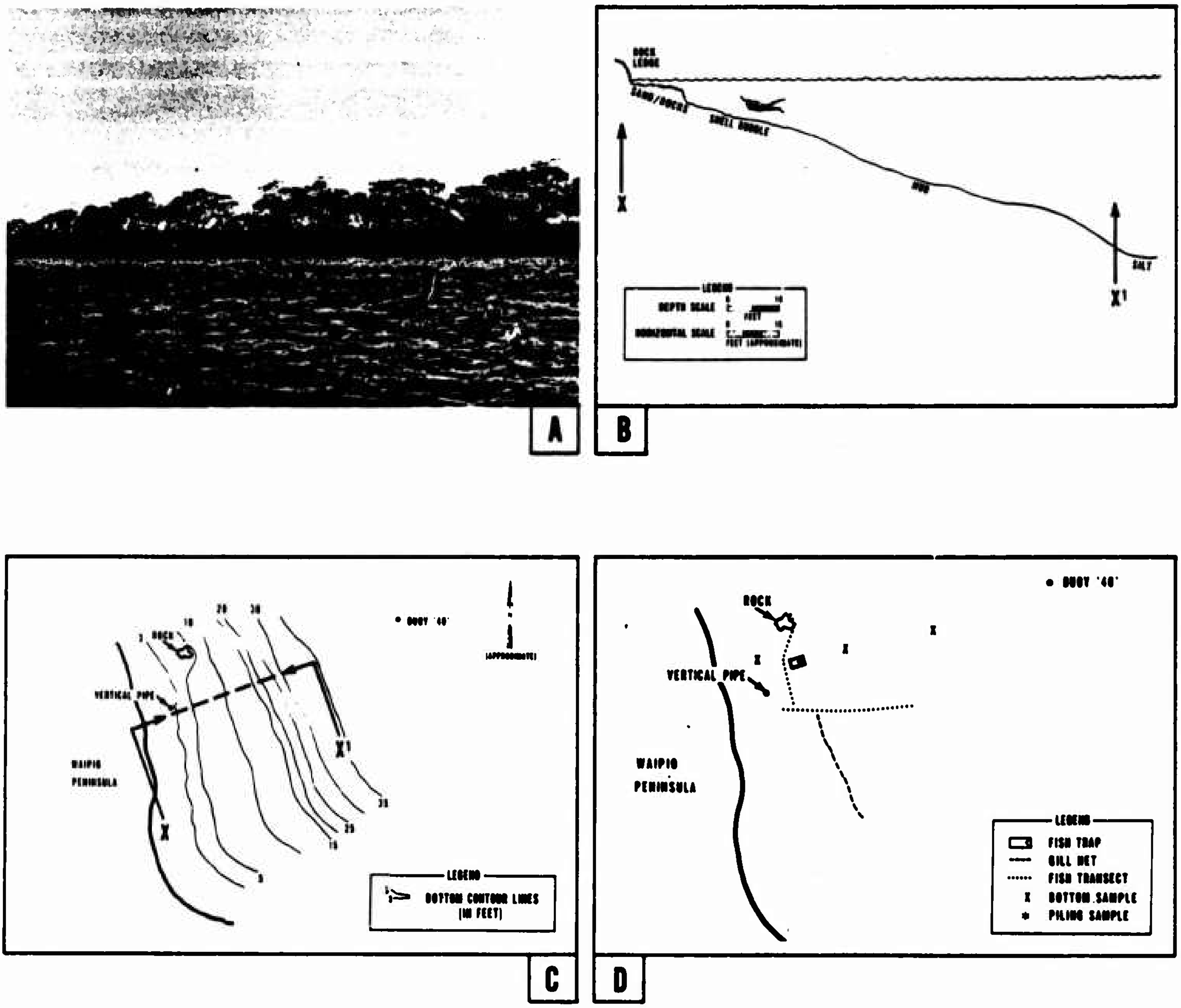


Figure 1.0-8. STATION BC-09

STATION BC-10. (Latitude 21°20'57"N, Longitude 157°58'11"W).

Refer to Figure 1.0-9, opposite page. Adjacent to the thermal outfall from Naval Station Power Plant #3 located on Bishop Point northwest of Dry Dock #4. Extends from the thermal outfall structure for a radius of 50 yards out into the main channel and along the rock ledges on either side of the outfall structure. Water depth ranges from 12 to 45 feet. Substrate types include: (1) vertical - concrete block, rock ledge, some metal debris, (2) bottom - mud, rock, rock-rubble and silt. Underwater visibility ranges from 2 to 10 feet, usually 6 feet. Ship traffic is heavy: all ships entering/exiting Pearl Harbor pass within 250 yards of this station; considerable water motion (especially from commercial tour boats) has been observed. Estimated degrees of environmental insult include: low amounts of industrial effluent and siltation; moderate amounts of oil; a very high degree of thermal insult, especially affecting the surface waters. Considering the overall biological status observed within the harbor, bio-station BC-10 is ranked eighth in environmental quality. There exists abundant sponge/algal growth along the rock ledge area directly ahead of diver in Figure 1.0-9B ; only sparse amounts of benthic algae have been observed along the sloping bottom areas (mostly along the 20-40 foot contours, Figure 1.0-9C).

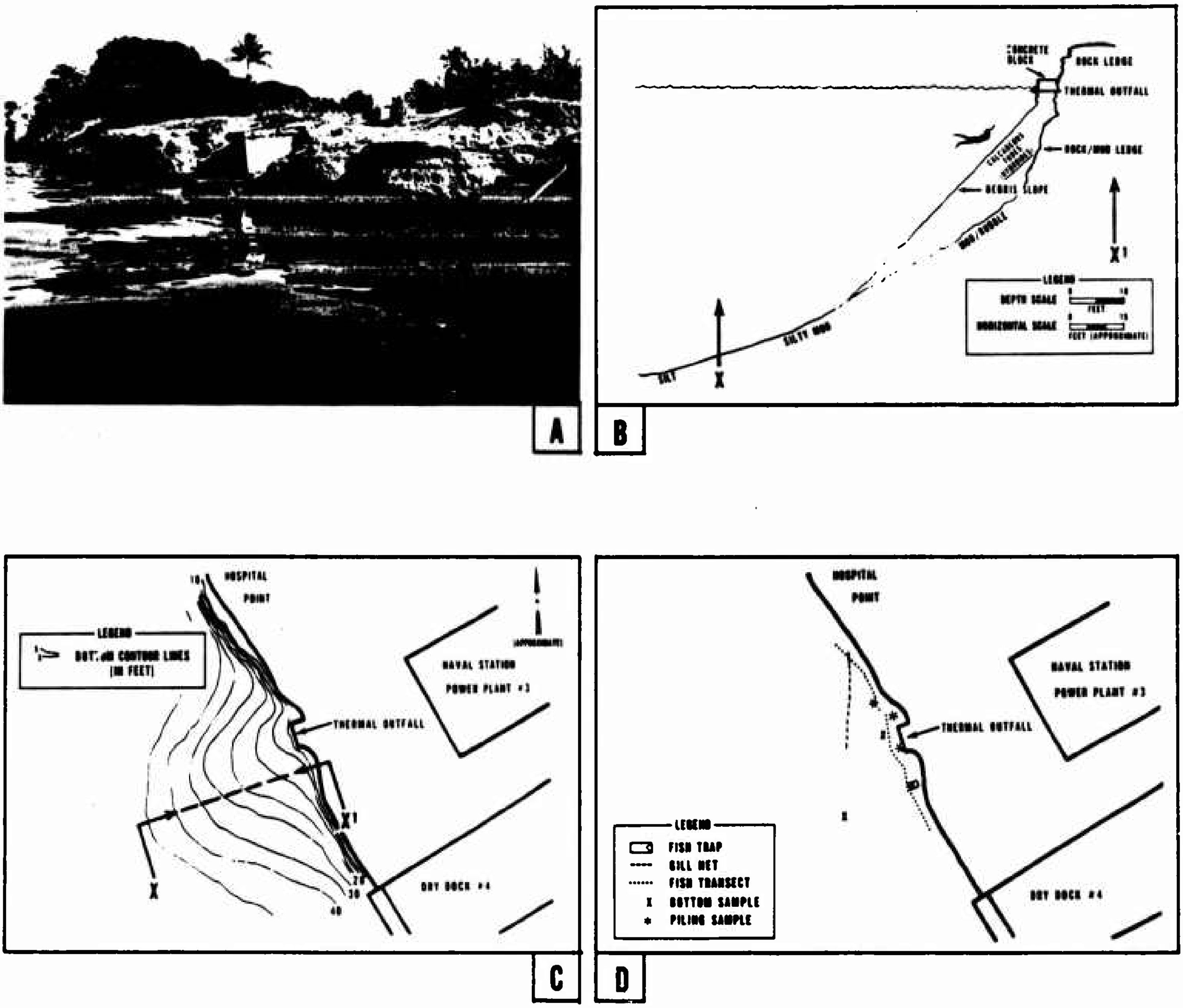


Figure 1.0-9. STATION BC-10

STATION BC-11. (Latitude 21°19'41"N, Longitude 157°58'22"W).

Refer to Figure 1.0-10, opposite page. Southwest of Iroquois Point Sewage Treatment Plant. Extends from shore along the sewage discharge pipe about 40 yards into the entrance channel where the diffuser head is located. Water depth ranges from 1 to 47 feet. Substrate types include: (1) vertical - concrete block, rock ledge, metal pipe; (2) bottom - sand, rock, rock/shell rubble and silt. Underwater visibility ranges from 2 to 15 feet, usually 8-10 feet. Ship traffic is heavy: every vessel entering or exiting Pearl Harbor must pass within 100 to 200 yards of this station at speeds of 5-10 knots. Estimated degrees of environmental insult include: very low amounts of oil and siltation; very high levels of domestic sewage (primary treatment) at diffuser, shown in Figure 1.0-10B. Considering the overall biological status observed within the harbor, bio-station BC-11 is ranked first, highest in overall environmental quality; however, it must be noted that the sewer outfall must cause a significant, but as yet unquantified, departure from an open-ocean marine environment. Algal/sponge/tunicate/sedentary polychaete worm growth is very abundant along the rock ledge at this station (located beneath diver in Figure 1.0-10B); similar abundance exists on the metal diffuser pipe. Numerous organisms associated with coral reef environments have been sighted at or collected from bio-station BC-11. From a biological standpoint, this station is considered most unlike the other bio-stations in the harbor.

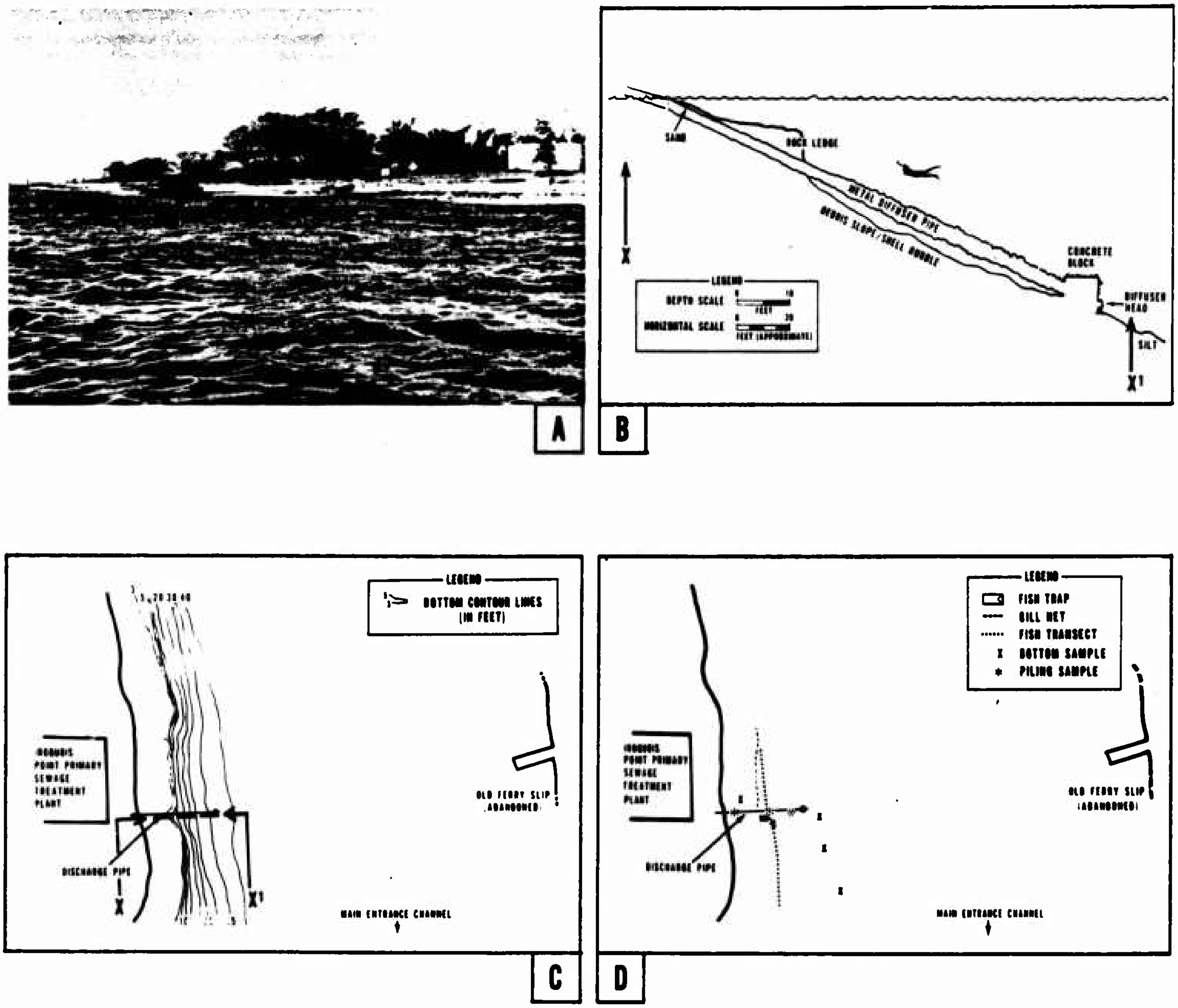


Figure 1.0-10. STATION BC-11

STATION BW-13. (Latitude 21°21'01"N, Longitude 157°58'49"W).
Refer to Figure 1.0-11, opposite page. Station is located in West Loch Channel and approximately 500 yards south of Kekaa Point on the western shore of Waipio Peninsula, adjacent to the southernmost old wooden piers (as shown in Figure 1.0-11C). Extends from shore about 40 yards into the channel parallel to and approximately 25 yards south from the wooden pier. Water depth ranges from 1 to 37 feet. Substrate types include: (1) vertical - wooden pilings, rock ledge and metal sheet piling; (2) bottom - sand, shell/rock rubble, mud and silt. Underwater visibility ranges from 1 to 15 feet, usually 7 feet. Ship traffic is light; occasionally ammunition barges, submarines and harbor craft pass within 300 yards of station BW-13. Estimated degrees of environmental insult include: very low amounts of industrial effluent and oil; moderate amounts of siltation are present. Considering the overall biological status observed within the harbor, bio-station BW-13 is ranked fifth in environmental quality. There is abundant sponge/tunicate and oyster growth on the wooden pilings and metal sheet piling at depths of 10 feet or less.

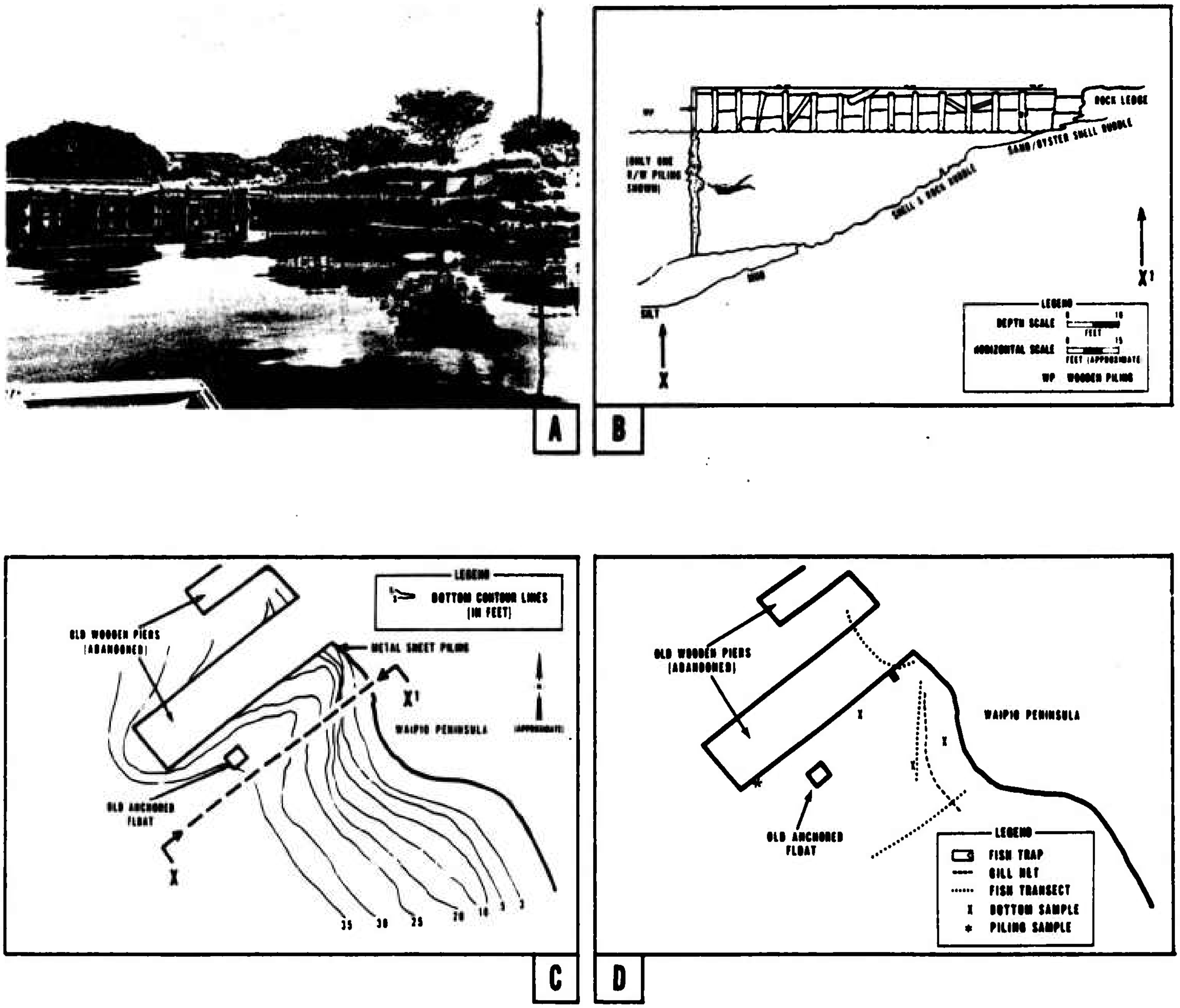


Figure 1.0-11. STATION BW-13

STATION BE-17. (Latitude 21°21'19"N, Longitude 157°57'47"W). Refer to Figure 1.0-12, opposite page. Located along the northeastern end of Dry Dock #3 on the southern shore of South Channel, East Loch (adjacent to the Pearl Harbor Naval Shipyard Facility). Radius of station extends 25 yards from the pilings on north side of Dry Dock #2 to the caisson for Dry Dock #3. Water depth ranges from 18 to 33 feet. Substrate types include: (1) vertical - concrete wall, wooden pilings, metal debris (numerous shipboard items on bottom as seen in Figure 1.0-12B); (2) bottom - organic debris, mud and silt. Underwater visibility ranges from 2 to 10 feet, usually 5 feet. Ship traffic is moderate: mostly yard craft and an occasional small ship or submarine entering Dry Dock #3 at very slow speeds. Estimated degrees of environmental insult include: moderate amounts of domestic sewage and oil; high amounts of siltation; very high amounts of industrial effluent from the shipyard facility. Considering the overall biological status observed within the harbor, bio-station BE-17 is ranked ninth in environmental quality. Very sparse algal growth has been observed at this station. Shipworms (*Teredo* sp.) have been collected from wooden pilings at this station (seen at base of piling shown in Figure 1.0-12B, beneath diver figure).

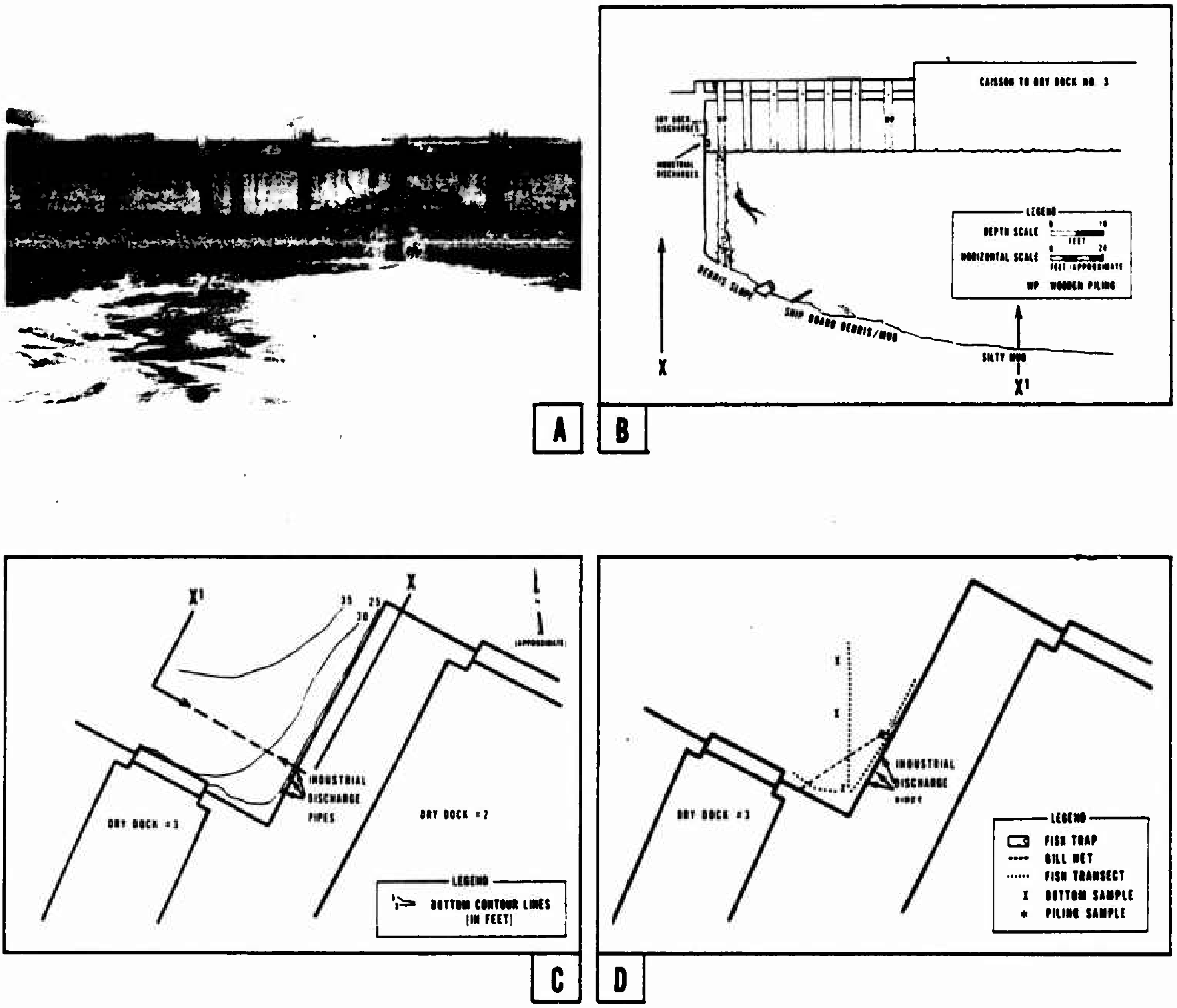


Figure 1.0-12. STATION BE-17

REFERENCES

1.0-1. Evan C. Evans III, A. Earl Murchison, Thomas J. Peeling, and Q. Dick Stephen-Hassard (1972), "A Proximate Biological Survey of Pearl Harbor, Oahu", NUC TP-290.

SURVEYS

The biological survey of Pearl Harbor was a continuously scheduled activity from 1 November 1971 until 31 December 1972. Fish transecting, netting, trapping and tagging constituted an intermittent activity over this entire period. From mid-January to early April 1972, a series of bottom samples were collected for an analysis of benthic organisms. During May and June of 1972 and again in November of 1972, a series of piling samples were collected for analysis.

These surveys are reported as separate sections: first, the fish survey, then the bottom survey divided into a benthic survey and a micromolluscan survey, and lastly, the piling survey. In each section the collection techniques are described in full, both a phyletic and an alphabetic checklist of positively identified organisms are given, and the distribution of organisms within Pearl Harbor is described. Pertinent biological observations are made, such as lengths, weights, or biomass of organisms. General community structure as seen by the field biologist is summarized. No statistical treatment of the data is included, however, in these survey sections. Statistical treatment of the biological survey data may be found in later sections: fish data in Section 4.3, benthos in Section 4.4, micromolluscs in Section 4.5 and piling communities in Section 4.5. The statistical analysis was performed by a different team of scientists using data supplied to them by the field biologists. The separation permitted one set of data to be analyzed while another set was being collected in the field.

FISH SURVEY

J. Geoffrey Grovhoug
Evan C. Evans III

GENERAL INFORMATION

INTRODUCTION

The variety and distribution of fish species inhabiting Pearl Harbor have been known locally for decades; however, quantitative documentation of this resource has been lacking until recently. Data were gathered on fish populations at ten bio-stations within Pearl Harbor during the period 1 November 1971 to 31 December 1972 as part of the Pearl Harbor Biological Survey. Utilizing a variety of sampling methods*, 90 species from 46 families of fishes were collected or sighted during this study (Table 2.1-1). The taxonomic arrangement of the checklist follows Greenwood, et al (Reference 2.1-1); computer address codes (Hawaii Coastal Zone Data Bank, the University of Hawaii) and generalized feeding type are included for each species. Synonomies for species previously reported by the study (Table 2.1-2) have been compared with the Hawaii Coastal Zone Data Bank (HCZDB) listings for August 1973, and further verified (Reference 2.1-2) by Dr. John E. Randall of the Bernice P. Bishop Museum, Honolulu, A reference presentation of ink drawings with scientific, common, Hawaiian names and HCZDB numerical codes for 87 Pearl Harbor fish species is provided as Appendix A. Additionally, an alphabetical listing for all Pearl Harbor fish species is included (Table 2.1-3) for further cross-referencing convenience. Individual species may thus be located phyletically (Table 2.1-1) or alphabetically (Table 2.1-3); ink drawings of all but three species are presented in phyletic order in Appendix A. The HCZDB numbers listed in both Tables 2.1-1 and 2.1-3 may be used to find a phyletic listing by those unfamiliar with the sequence. The HCZDB number (less the prefix 85 which simply designates fish) may be determined from the alphabetic listing (Table 2.1-3), then by running down the HCZDB column in Table 2.1-1, where these numbers appear in numerical sequence, the phyletic location may be found.

METHODS

GILL NETS

Two sizes of gill nets were used throughout the study period: 1) at bio-stations (BE-02, BE-05, BC-09, BC-11, and BW-13) having shallow water depths, 125 x 7 foot nets with 3-inch mesh (stretch) were utilized; 2) at bio-stations (BE-03, BE-04, BM-07, BC-10, and BE-17) with water depths greater than 12 feet, 100 x 20 foot nets with 3-inch mesh (stretch) were set along the 20-foot bottom contour to afford a more complete coverage of

(Text continued on page 2.1-8)

---

* Gill netting, trapping, underwater visual transecting and, to a lesser extent, trawling, spearing, dip netting, hand collecting and handline fishing.

Table 2.1-1. PEARL HARBOR CUMULATIVE FISH SPECIES CHECKLIST

Classification	HCZDB #	Feeding Type*
Chondrichthyes		
Lamnida		
Carcharhinidae		
Carcharhinus limbatus (Valenciennes)	8516120503	C
Sphyrnidae		
Sphyrna lewini (Griffith & Smith)	8516130101	C
Hypotremata		
Myliobatidae		
Aetobatus narinari (Euphrasen)	8517100101	C
Osteichthyes		
Elopiformes		
Elopidae		
Elops hawaiiensis Regan	8521010101	C
Albulidae		
Albula vulpes (Linnaeus)	8521060101	C
Anguilliformes		
Muraenidae		
Gymnothorax flavimarginatus (Rüppell)	8522050605	C
Gymnothorax petelli (Bleeker)	8522050611	C
Gymnothorax undulatus (Lacépède)	8522050613	C
Congridae		
Conger cinreus marginatus Valenciennes	8522120501	C
Clupeiformes		
Engraulidae		
Stolephorus purpureus Fowler	8525070101	C
Salmoniformes		
Synodontidae		
Saurida gracilis (Quoy & Gaimard)	8531470201	C
Synodus variegatus (Lacépède)	8531470304	C
Gonorynchiformes		
Chanidae		
Chanos chanos (Forsskål)	8533060101	H
Lophiiformes		
Antennariidae		
Antennarius chironectes Lacépède	8541070302	C
Gadiformes		
Carapidae		
Carapus margaritiferae (Rendahl)	8542120301	C
Atheriniformes		
Hemiramphidae		
Hemiramphus depauperatus Lay & Bennett	8544015301	C
Belonidae		
Tylosurus crocodilus (Peron & LeSueur)	8544020301	C
Poeciliidae		
Mollienesia latipinna LeSueur	8544130101	H
Beryciformes		
Holocentridae		
Myripristis murdjan (Forsskål)	8546180403	C
Flammeo sammara (Forsskål)	8546180501	C

* Feeding types: C = carnivore, H = herbivore, O = omnivore; specific data References 2.1-2, 2.1-3, and 2.1-4.

Table 2.1-1. (Continued)

Classification	HCZDB #	Feeding Type*
Gasterosteiformes		
Aulostomidae		
Aulostomus chinensis (Linnaeus)	8549060101	C
Syngnathidae		
Micrognathus ?edmondsoni (Pietschmann)	8549120502	C
Scorpaeniformes		
Scorpaenidae		
Brachirus barberi (Eschmeyer & Randall)	8552010301	C
Scorpaenopsis diabolus (Eschmeyer & Anderson)	8552010701	C
Scorpaena coniorta (Jenkins)	8552011101	C
Perciformes		
Kuhliidae		
Kuhlia sandvicensis (Steindachner)	8554140101	O
Priacanthidae		
Priacanthus cruentatus (Lacépède)	8554170101	C
Apogonidae		
Apogon snyderi Jordan & Evermann	8554180404	C
Foa brachygrammus (Jenkins)	8554180701	C
Carangidae		
Scomberoides sancti-petri (Cuvier)	8554290101	C
Gnathanodon speciosus (Forsskål)	8554290801	C
Carangoides gymnostethoides Bleeker	8554291001	C
Caranx ignobilis (Forsskål)	8554291202	C
Caranx melampygus Cuvier & Valenciennes	8554291204	C
Caranx sexfasciatus Quoy & Gaimard	8554291206	C
Caranx mate Cuvier & Valenciennes	8554291207	C
Lutjanidae		
Lutjanus fulvus (Bloch & Schneider)	8554380704	C
Mullidae		
Upeneus arge Jordan & Evermann	8554470101	C
Mulloidichthys samoensis (Günther)	8554470201	C
Mulloidichthys auriflamma (Forsskål)	8554470202	C
Parupeneus pleurostigma (Bennett)	8554470301	C
Parupeneus porphyreus (Jenkins)	8554470303	C
Parupeneus multifasciatus (Quoy & Gaimard)	8554470305	C
Kyphosidae		
Kyphosus cinerascens (Forsskål)	8554530101	H
Scorpididae		
Microcanthus strigatus (Cuvier&Valenciennes)	8554530301	O
Chaetodontidae		
Heniochus acuminatus (Linnaeus)	8554570502	C
Chaetodon auriga Forsskål	8554570706	C
Chaetodon lunula (Lacépède)	8554570708	C
Chaetodon miliaris Quoy & Gaimard	8554570715	C
Cichlidae		
Tilapia mossambica (Peters)	8554630101	H
Pomacentridae		
Dascyllus albisella Gill	8554640101	O
Abudefduf sordidus (Forsskål)	8554640201	O
Abudefduf abdominalis (Quoy & Gaimard)	8554640202	O
Mugilidae		
Mugil cephalus Linnaeus	8555010201	H

Table 2.1-1. (Continued)

Classification	HCZDB #	Feeding Type*
Perciformes (Cont'd)		
Sphyraenidae		
Sphyraena barracuda (Walbaum)	8555030101	C
Polynemidae		
Polydactylus sexfilis (Cuvier & Valenciennes)	8555050101	C
Labridae		
Cheilio inermis (Forsskål)	8555070101	C
Labroides phthirophagus Randall	8555070401	C
Stethojulis balteatus (Quoy & Gaimard)	8555071801	O
Scaridae		
Calotomus spinidens (Quoy & Gaimard)	8555090102	H
Scarus sordidus Forsskål	8555090304	O
Scarus sp. (juvenile)	8555090320	O
Blenniidae		
Exallias brevis (Kner)	8555340101	H
Entomacrodus marmoratus (Bennett)	8555340301	O
Omobranchus elongatus (Peters)	8555340701	C
Gobiidae		
Oxyurichthys lonchotus (Jenkins)	8555600201	O
Ctenogobius tongarevae (Fowler)	8555600701	O
Bathygobius fuscus (Rüppell)	8555600802	C
Opua nephodes Jordan	8555601201	O
Gnatholepis anjerensis (Bleeker)	8555601301	O
Eleotridae		
Asterropteryx semipunctatus Rüppell	8555605301	C
Acanthuridae		
Acanthurus triostegus (Linnaeus)	8555690101	H
Acanthurus olivaceus (Bloch & Schneider)	8555690109	H
Acanthurus dussumieri (Cuvier&Valenciennes)	8555690110	H
Acanthurus xanthopterus (Cuvier&Valenciennes)	8555690111	H
Acanthurus mata (Cuvier)	8555690112	H
Ctenochaetus strigosus (Bennett)	8555690201	H
Zebrasoma flavescens (Bennett)	8555690301	H
Zebrasoma veliferum (Bloch)	8555690302	O
Naso brevirostris (Cuvier & Valenciennes)	8555690403	O
Naso unicornis (Forsskål)	8555690404	H
Zanclidae		
Zanclus canescens (Linnaeus)	8555695101	O
Pleuronectiformes		
Bothidae		
Bothus pantherinus (Rüppell)	8557080402	C
Tetraodontiformes		
Monocanthidae		
Pervagor spilosoma (Lay & Bennett)	8558025201	O
Ostraciontidae		
Ostracion meleagris camurum (Jenkins)	8558030201	O
Tetraodontidae		
Arothron hispidus (Linnaeus)	8558060302	O
Canthigasteridae		
Canthigaster coronatus (Randall P.C.)	8558065101	O
Canthigaster jactator (Jenkins)	8558065102	O
Diodontidae		
Diodon hystrix (Linnaeus)	8558080201	C
Diodon holocanthus (Linnaeus)	8558080202	C

Table 2.1-2. TAXONOMIC SYNONYMS FOR PEARL HARBOR FISH SPECIES

Preferred Generic/Specific Taxon		Synonym
Acanthurus triostegus (Linnaeus)	=	*Acanthurus sandvicensis* (Gosline)
Brachirus barberi (Eschmeyer & Randall)	=	*Dendrochirus brachypterus* (Cuvier)
Calotomus spinidens (Quoy & Gaimard)	=	*Calotomus sandvicensis* (Cuvier & Valenciennes)
Canthigaster coronatus (Randall)	=	*Canthigaster cinctus* (Solander)
Flammeo sammara (Forsskål)	=	*Holocentrus sammara* (Forsskål)
Foa brachygrammus (Jenkins)	=	*Apogon brachygrammus* (Jordan & Evermann)
Lutjanus fulvus (Bloch & Schneider)	=	*Lutjanus vaigiensis* (Quoy & Gaimard)
Myripristis murdjan (Forsskål)	=	*Myripristis berndti* (Jordan & Evermann)
Ostracion meleagris camurum (Jenkins)	=	*Ostracion lentiginosus* (Bloch & Schneider)
Scorpaenopsis diabolus (Eschmeyer & Anderson)	=	*Scorpaenopsis gibbosa* (Bloch & Schneider)
Stethojulis balteatus (Quoy & Gaimard)	=	*Stethojulis axillaris* (Quoy & Ga[illegible]d) and *Stethojulis albovittata* Günther
Tylosurus crocodilus (Peron & LeSueur)	=	*Strongylura gigantea* (Temminck & Schlegel)

Table 2.1-3. AN ALPHABETICAL LISTING OF PEARL HARBOR FISH SPECIES

Species	HCZDB#	Page in Appendix A
Abudefduf abdominalis	54640202	A-10d
Abudefduf sordidus	54640201	A-10b
Acanthurus dussumieri	55690110	A-13c
Acanthurus mata	55690112	A-13b
Acanthurus olivaceus	55690109	A-13a
Acanthurus triostegus	55690101	A-12h
Acanthurus xanthopterus	55690111	A-13g
Aetobatus narinari	17100101	A-3g
Albula vulpes	21060101	A-4a
Antennarius chironectes	41070302	A-5g
Apogon snyderi	54180404	A-7c
Arothron hispidus	58060302	A-15g
Asterropteryx semipunctatus	55605301	A-12f
Aulostomus chinensis	49060101	A-6e
Bathygobius fuscus	55600802	A-12g
Bothus pantherinus	57080402	A-14h
Brachirus barberi	52010301	A-6b
Calotomus spinidens	55090102	A-11d
Canthigaster coronatus	58065101	A-15b
Canthigaster jactator	58065102	A-15d
Carangoides gymnostethoides	54291001	A-7f
Caranx ignobilis	54291202	A-7h
Caranx mate	54291207	A-8e
Caranx melampygus	54291204	A-8a
Caranx sexfasciatus	54291206	A-8c
Carapus margaritiferae	42120301	A-5b
Carcharhinus limbatus	16120503	A-3ab
Chaetodon auriga	54570706	A-9d
Chaetodon lunula	54570708	A-9h
Chaetodon miliaris	54570715	A-10a
Chanos chanos	33060101	A-5e
Cheilio inermis	55070101	A-11e
Conger cinreus marginatus	22120501	A-4d
Ctenochaetus strigosus	55690201	A-13d
Ctenogobius tongarevae	55600701	N.S.
Dascyllus albisella	54640101	A-10g
Diodon holocanthus	58080202	A-15h
Diodon hystrix	58080201	A-15f
Elops hawaiiensis	21010101	A-3h
Entomacrodus marmoratus	55340301	A-12c
Exallias brevis	55340101	A-12a
Flammeo sammara	46180501	A-6c
Foa brachygrammus	54180701	A-7g
Gnathanodon speciosus	54290801	A-7d
Gnatholepis anjerensis	55601301	A-12d
Gymnothorax flavimarginatus	22050605	A-4e
Gymnothorax petelli	22050611	A-4g
Gymnothorax undulatus	22050613	A-4b
Hemiramphus depauperatus	44015301	A-5d
Heniochus acuminatus	54570502	A-9b
Kuhlia sandvicensis	54140101	A-6h
Kyphosus cinerascens	54530101	A-9e

Table 2.1-3. (Continued)

Species	HCZDB#	Page in Appendix A
Labroides phthirophagus	55070401	A-11g
Lutjanus fulvus	54380704	A-8g
Microcanthus strigatus	54530301	A-9g
Micrognathus ?edmondsoni	49120502	A-6g
Mollienesia latipinna	44130101	A-5h
Mugil cephalus	55010201	A-10h
Mulloidichthys auriflamma	54470202	A-8f
Mulloidichthys samoensis	54470201	A-8d
Myripristis murdjan	46180403	A-6a
Naso brevirostris	55690403	A-14e
Naso unicornis	55690404	A-14b
Omobranchus elongatus	55340701	A-12e
Opua nephodes	55601201	A-12b
Ostracion meleagris camurum	58030201	A-15c
Oxyurichthys lonchotus	55600201	N.S.
Parupeneus multifasciatus	54470305	A-9c
Parupeneus pleurostigma	54470301	A-8h
Parupeneus porphyreus	54470303	A-9a
Pervagor spilosoma	58025201	A-15a
Polydactylus sexfilis	55050101	A-11c
Priacanthus cruentatus	54170101	A-7a
Saurida gracilis	31470201	A-5a
Scarus sordidus	55090304	A-11h
Scarus sp. (juvenile)	55090320	N.S.
Scomberoides sancti-petri	54290101	A-7b
Scorpaena coniorta	52011101	A-6f
Scorpaenopsis diabolus	52010701	A-6d
Sphyraena barracuda	55030101	A-11a
Sphyrna lewini	16130101	A-3cd
Stethojulis balteatus	55071801	A-11b
Stolephorus purpureus	25070101	A-4h
Synodus variegatus	31470304	A-5c
Tilapia mossambica	54630101	A-10c
Tylosurus crocodilus	44020301	A-5f
Upeneus arge	54470101	A-8b
Zanclus canescens	55695101	A-14d
Zebrasoma flavescens	55690301	A-13h
Zebrasoma veliferum	55690302	A-14a

N.S. = Not Shown

the water column. A small mesh (1 3/4 inch) net was tested at the beginning of the study but was discontinued because of relatively low numbers of fish captures. Fishes caught in the 3-inch mesh ranged from "nehu" (*Stolephorus purpureus*), measuring 1 3/4 inches (fork length) to an "awa" (*Chanos chanos*), 31 inches (fork length) and weighing over 10 pounds. Considering the size ranges of fishes caught, the 3-inch net is believed to be an adequate sampling device for this and further studies in estuarine environments.

The physical deployment of gill nets in relation to the adjacent shoreline was dependent upon the bottom configuration at each station, but nets were generally set in a position parallel to the shore (Figure 2.1-1). Several plastic 1-gallon containers were tied to the float line, giving the net additional buoyancy to aid in maintaining a full "curtain" of net. Chain links or bound rocks were tied off at each end of the lead line to anchor the net in position.

Initially, all gill nets were set for a period of 24 hours, but fish caught in the nets for this period were often eaten by crabs, eels, sharks, etc., and the stomach contents of those fishes that were not eaten had often deteriorated by the time the nets were recovered. Therefore, in all later samples (including those for fish stomach content analyses), nets were set overnight for a period of 15 to 18 hours. Nets were set in a variety of orientations relative to the shoreline at each bio-station to sample more effectively the "nettable" fish in the area.

FISH TRAPS

Funnel-entrance fish traps were also employed at all bio-stations. Each trap measured 4 x 3 x 1 1/2 feet and was constructed of 3/4-inch medium gauge galvanized poultry wire covering a 3/16-inch metal rod frame (Figure 2.1-2). The top of each trap was covered with palm fronds prior to being set as this additional cover yielded higher catches for tagging purposes and helped conceal the trap from surface detection* at shallow depths. Fish traps were set without bait for a period of three days (or approximately 72 hours) prior to being retrieved. Fish were removed from each trap by hand dip nets; access into the trap was available through a hinged (1-foot square) door located in the end opposite the funnel entrance.

Beginning in May 1972, all fish collected in traps (except those which were dead or obviously unhealthy) were tagged and released. Fish tagging procedures were adapted from techniques utilized by Hawaii Division of Fish and Game. Specific construction of the tags and methods of handling and tagging fish have been described previously (Reference 2.1-5); however, due to the limited distribution of this interim report, the methods are again briefly described. In the tagging operation fish were transferred from the

(Text continued on page 2.1-11)

* Several instances of tampering with fish traps were suspected during the study; two gill nets were stolen, one at bio-station BE-02 and one at bio-station BM-07.

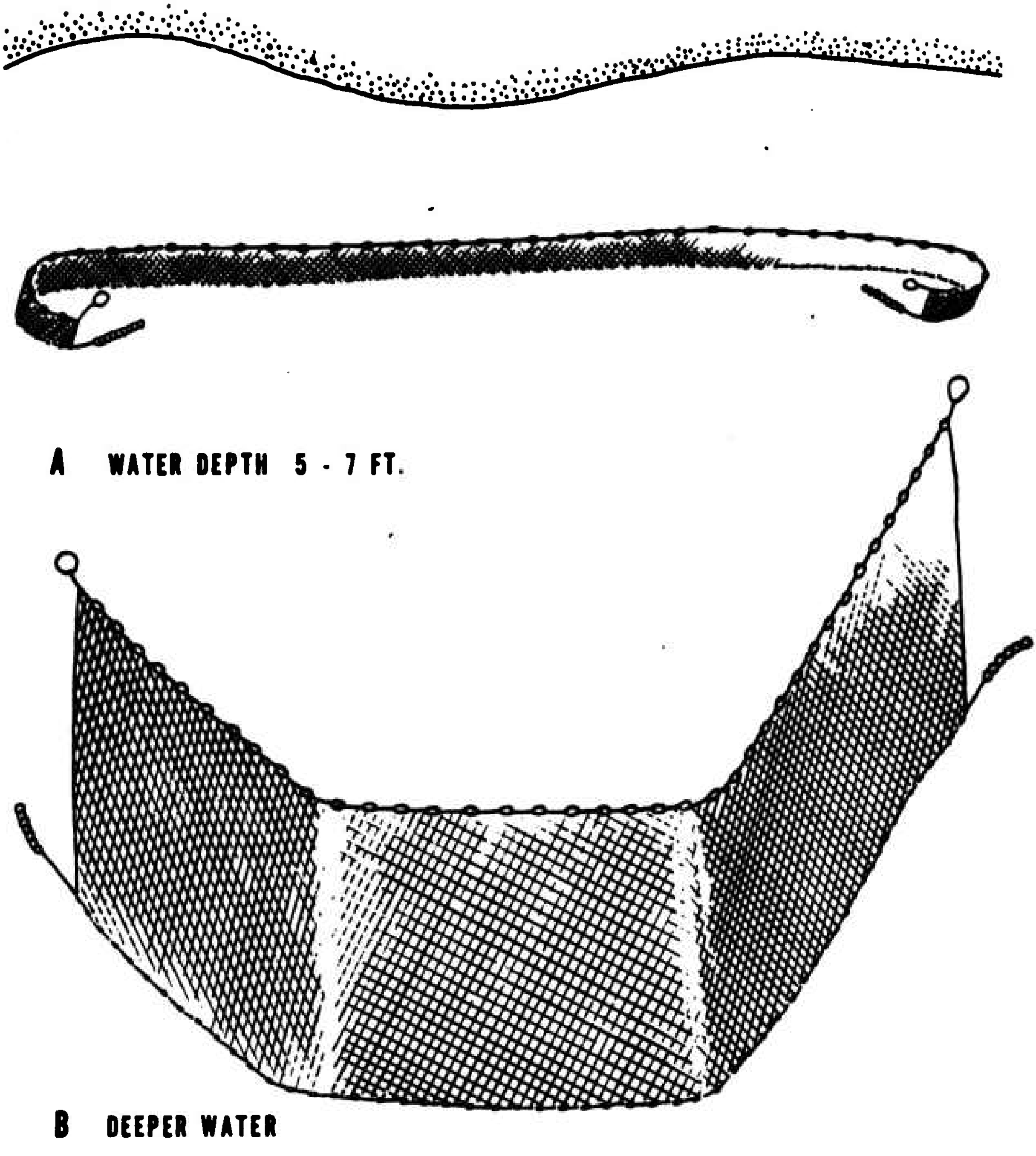


Figure 2.1-1. TYPICAL GILL NET FOR (A) SHALLOW WATER AND (B) DEEPER WATER BIO-STATIONS

Figure 2.1-2. TYPICAL FISH TRAP USED BY PHBS SURVEY TEAM (NOTE PALM FRONDS ON TOP OF TRAP)

trap to an aerated holding tank by means of a hand dip net. Fish were again transferred in groups of one to three, depending upon size and species, to an anesthetizing tub containing 1/2 teaspoon of MS-222 (ethyl-*m*-aminobenzoate methanosulfonate) per gallon of sea water. After two or three minutes, most species collected (moray and conger eels excepted) were sufficiently anesthetized to be handled without harm. An anesthetized fish was placed on a foam rubber mat, measured (fork lengths in most cases) and inspected for general condition. For most species, a 1/4-inch incision was made through the ventral musculature into the coelomic cavity at a point just posterior to and below the pectoral girdle. A prepared tag was then inserted through the incision in such a manner that loss or removal of the tag was prevented by the stomach wall and muscle layer, which offered resistance to the internal disc tag (Figure 2.1-3). The prepared fish tag consisted of an internal oval anchor disc (Howitt Plastic Company) connected to a vinyl tag tube (Floy Tag Company) by means of a beaded plastic line (Secur-A-Tach). After tagging, the fish were placed in a recovery tank containing aerated sea water. Five minutes was usually sufficient time for complete recovery from the effects of anesthesia and handling.

VISUAL TRANSECTS

Underwater visual transects were conducted at all bio-stations throughout the study period in order to quantitate existing fish populations. Accurate fish transects were contingent upon optimal water clarity at a given station; when such conditions prevailed, transects were conducted for a distance of 20 meters (66 feet). This distance was chosen in order to remain within the limits of each bio-station. Two diving biologists, swimming either side by side or one above the other, recorded all underwater observations on plastic slates (number of individuals per species and estimated lengths). Distances between the divers (generally from 6 to 12 feet) were dependent upon the range of visibility for each transect. Individual counts were made by each diver; however, total counts for a transect (summing both divers' observations) are presented in the data/results section. By establishing predetermined angular restrictions on counting areas for each diver, duplicate counting of the same fish was minimized. "Identifiable visibility" was recorded for all fish transects conducted and is defined to mean: "The maximum distance through the water column where a stationary or slow moving fish (larger than 4 inches in length) can be readily identified to species by a competent diving biologist, i.e. one familiar with the fish fauna in the study area." The visibilities (a radius, in feet, for the arc of identifiable visibility from the observer) for fish transects reported in the data/results section are either 10 feet (5 feet on either side of the transect line) or 5 feet (2½ feet on either side of the transect line), respectively, Cryptic species* of fishes (i.e. gobies, blennies, eleotrids and juveniles of various species) were excluded from transect counts because,

(Text continued on page 2.1-13)

---

*Cryptic species are those fish species not easily observed due to behavior, habitat or coloration; often secretive, small (several inches or less) benthic forms.

TAGGING A SOFT PUFFER
(AROTHRON HISPIDUS)

A TAGGED MORAY EEL
(GYMNOTHORAX FLAVIMARGINATUS)

Figure 2.1-3. TYPICAL FISH TAGGING OPERATIONS as has been found by other researchers (Reference 2.1-6 and 2.1-7), enumeration of cryptic species is usually inaccurate.

Additionally, numerous incidental observations were made while conducting activities such as collecting bottom samples, setting and recovering fish traps and gill nets, collecting piling samples, taking underwater photographs, etc. These observations have been recorded and incorporated into the species checklist and other tables in this report. These observations have provided an ample basis for qualitative estimates of fish population composition at all bio-stations.

TRAWLING

As previously described (Reference 2.1-5), trawling was evaluated using a 16-foot otter trawl at several locations in Pearl Harbor. This method of sampling was discontinued after the initial tests because it was ineffective and costly, and because it provided little additional useable data for the survey.

SPEARING

Several fish species were collected with either a Hawaiian tri-prong spear or a single rubber arbolete-type gun. However, collecting fish specimens by spearing was only rarely done.

DIP NETS

Several species were collected by hand dip nets along the shoreline while skin or SCUBA diving, or from the survey boat. Several times during the survey, fish were found floating (dead) at or near a bio-station and were collected using a dip net.

HAND COLLECTING

Through SCUBA diving, field personnel collected certain fish species by hand or coaxed specimens into a nylon collecting bag. Usually, only juvenile, small or cryptic species were collected using this simple, yet tedious, method.

HAND-LINE FISHING

Only one species, the mongoosefish (*Cheilio inermis*), was collected using the hand-line method.

OTHER METHODS AND OBSERVATIONS

Several times during the survey catches from Aku boats or the National Marine Fisheries Service vessel, Research Vessel Cromwell, were inspected by the survey team. Also, boat- and/or shore-bound recreational fishermen were interviewed to observe what species were being caught. While these observations provided no significant additions to the species checklist, they did provide data on general areal distributions for certain fish species.

METHODS NOT EMPLOYED

Neither beach seines nor poison stations were utilized during the fish surveys. A paucity of available seining areas (i.e. gently sloping shorelines relatively free from subsurface obstructions) precluded the use of beach seines at most PHBS bio-stations. Poisoning was considered unnecessary for the establishment of a valid fish species checklist, and its negative aspects (non-selective marine organism mortality at poison sites and probable unfavorable public reaction) rendered it unsuitable for this survey. Additionally, the lack of isolated or restricted locations within the harbor which could be poisoned without seriously affecting adjacent areas further precluded the use of this sampling method.

MEASUREMENTS

Fish lengths (to the nearest 1/8 inch) and weights (to the nearest 1/10 pound) were recorded throughout this survey. Lengths were measured for all fishes collected and were estimated for those sighted on visual transects. For sharks, rays, and members of the families Muraenidae, Congridae, and Carapidae, TOTAL lengths were recorded. FORK lengths were measured for all other fish species.

To expedite their return in a viable condition, only length measurements were obtained for fishes collected in traps and subsequently tagged and returned. However, estimated weights were computed for trapped and sighted individuals from calculated weight-length conversion coefficients. These species-specific conversion coefficients were computed from available data* using the following equation:

$$k = \frac{W/(L)^3}{n} \qquad (1)$$

where W = measured weight (pounds), L = measured length (inches), and n = number of individuals. These coefficients were then used in conjunction with

* Where adequate additional weight-length data for fishes were collected by PHBS, the older Hawaii Division of Fish and Game coefficients were updated.

observed lengths to estimate fish weights from the following form of Equation (1):

$$W = k(L)^3 \qquad (2)$$

An updated listing of weight-length conversion coefficients for 63 species of Pearl Harbor fishes is provided in Table 2.1-4. Where two conversion coefficients are presented for a single species, the coefficient based on the larger number of individuals (n) was used. Species for which no conversion coefficients exist were necessarily omitted from weight computations. These species were, by definition, rare and their omission from the weight/transect computations is not considered significant.

Some of the differences between the weight-length coefficients from equivalent numbers of individuals by both Hawaii Division of Fish and Game and PHBS may reflect actual differences between separate populations of a single species of fish. The Fish and Game data were computed from reef areas, mostly along leeward Oahu, while all PHBS data were from fishes collected within Pearl Harbor. It seems entirely possible that a species of fish may have quite different growth rates in Pearl Harbor versus the open coast reef flat areas.

DATA/RESULTS

CATCH DATA

Ninety species of fishes from 46 families were recorded by this study in Pearl Harbor during the period 1 November 1971 through 21 December 1972. An alphabetical listing of these species and their method of collection or observation is presented in Table 2.1-5. Additionally, a listing of species presence and numerical abundance at each bio-station is presented in Table 2.1-6. The notation "S" signifies those species which were sighted, but not actually collected, at a particular bio-station.

Sixty-nine of these 90 species were actually collected by one or more of the methods discussed under Sampling Methods and Equipment. For the two primary methods of collection (i.e. gill nets and fish traps), the total (all species) biomass recorded at each bio-station is presented in Table 2.1-7. These data were used to compute a catch-per-unit-effort (CPUE) in lbs/hour for both collection methods. CPUE values are plotted in Figure 2.1-4. The plot suggests that two behaviorally different populations were sampled, net-prone species and trap-prone species. This suggestion is further supported by the fact that little overlap exists in the species composition of fish collected by the two methods. While the two CPUEs are not correlated ($r = 0.18$), a Student's t-test (Reference 2.1-8) indicates a higher mean CPUE for gill netting at all bio-stations. The conclusion that CPUE is higher for gill netting would be conservative since the average set time was less than 24 hours. Figure 2.1-5 maps the CPUEs for gill netting and shows a significantly reduced catch-rate in Southeast Loch, an area experiencing the greatest naval activity. Catch-rate data for trapping shows no such pattern, and therefore is not mapped (see Table 2.1-7).

(Text continued on page 2.1-27)

Table 2.1-4. WEIGHT-LENGTH CONVERSION FACTORS FOR PEARL HARBOR FISH SPECIES

Abudefduf abdominalis (.00080)-171

Abudefduf sordidus (.00063)-#

Acanthurus dussumieri (.00072)-21 *(.00110)-3

Acanthurus mata (.00123)-4 *(.00107)-30

Acanthurus olivaceus (.00068)-11

Acanthurus triostegus (.00132)-113 *(.00157)-12

Acanthurus xanthopterus (.00102)-4 *(.00100)-23

Aetobatus narinari *(.00004)-3

Albula vulpes *(.00051)-15

Apogon snyderi (.00058)-142

Arothron hispidus (.00145)-10 *(.00136)-9

Aulostomus chinensis (.00006)-71

Brachirus barberi (.00075)-17

Calotomus spinidens (.00096)-1

Canthigaster coronatus (.00104)-3

Caranx mate *(.00059)-6

Caranx melampygus (.00064)-# *(.00078)-25

Caranx sexfasciatus *(.00072)-18

Carcharhinus limbatus *(.00015)-3

Chaetodon auriga (.00100)-26 *(.00152)-3

Chaetodon lunula (.00124)-25

Chaetodon miliaris (.00119)-222

Chanos chanos (.00060)-# *(.00050)-26

Cheilio inermis (.00021)-1

Conger cinreus marginatus (.00020)-40 *(.00021)-3

Ctenochaetus strigosus (.00094)-54

Dascyllus albisella (.00132)-65

Diodon hystrix (.00093)-#

Elops hawaiiensis *(.00028)-96

Flammeo sammara (.00057)-19

Foa brachygrammus (.00073)-92 *(.00067)-10

Gymnothorax flavimarginatus (.00004)-7

Gymnothorax undulatus (.00028)-60

Heniochus acuminatus (.00103)-4

Kuhlia sandvicensis (.00053)-3 *(.00085)-9

Kyphosus cinerascens (.00074)-5

Labroides phthirophagus (.00041)-3

Lutjanus fulvus *(.00067)-31 (computed fm F&G wts./lengths)

Mugil cephalus *(.00049)-74

Mulloidichthys auriflamma (.00044)-10

Mulloidichthys samoensis (.00039)-39 *(.00078)-13

Myripristis murdjan (.00082)-16

Naso brevirostris (.00070)-10 *(.00075)-2

Naso unicornis (.00064)-2 *(.00085)-3

Ostracion meleagris camurum (.00157)-20

Parupeneus pleurostigma (.00045)-10

Parupeneus porphyreus (.00084)-15 *(.00088)-33

Parupeneus multifasciatus (.00081)-13

Pervagor spilosoma (.00082)-26

Polydactylus sexfilis *(.00063)-13

Priacanthus cruentatus (.00059)-33

Scarus sordidus (.00118)-114

Table 2.1-4. (Continued)

Scomberoides sancti-petri *(.00033)-12

Scorpaena coniorta (.00102)-6

Scorpaenopsis diabolus (.00109)-7

Sphyrna lewini *(.00014)-30

Stethojulis balteatus (.00054)-6

Synodus variegatus (.00032)-7

Tylosurus crocodilus (.00004)-1

Upeneus arge (.00048)-# *(.00069)-4

Zanclus canescens (.00102)-28

Zebrasoma flavescens (.00128)-28

Zebra veliferum (.00084)-1

Legend: () = Hawaii Division of Fish and Game computation

*() = Pearl Harbor Biological Survey computation

Note: The number following weight/length conversion factor is the number of individuals (of a given species) used for computation. The number symbol (#) indicates that the weight/length conversion factor was obtained from an older F&G list of constants where the number of individuals (n) was not recorded.

Table 2.1-5. PEARL HARBOR FISH SURVEYS: METHODS OF COLLECTION/OBSERVATION

Species	Gill Net	Trap	Various*	Sightings**
Abudefduf abdominalis	-	X	-	C
Abudefduf sordidus	-	X	-	C
Acanthurus dussumieri	X	-	-	P
Acanthurus mata	X	X	-	D
Acanthurus olivaceus	-	X	-	R
Acanthurus triostegus	X	X	-	C
Acanthurus xanthopterus	X	X	-	D
Aetobatus narinari	X	-	-	R
Albula vulpes	X	-	-	-
Antennarius chironectes	-	-	BG	-
Apogon snyderi	-	-	HN	R
Arothron hispidus	-	X	HN	D
Asterropteryx semipunctatus	-	-	HN,BS	TNTC
Aulostomus chinensis	-	-	-	R
Bathygobius fuscus	-	-	HN,BS	TNTC
Bothus pantherinus	X	-	-	R
Brachirus barberi	-	X	HN	P
Calotomus spinidens	X	-	-	-
Canthigaster coronatus	-	-	-	R
Canthigaster jactator	-	-	-	R
Carangoides gymnostethoides	X	-	-	-
Caranx ignobilis	X	-	-	-
Caranx mate	X	-	HN	P
Caranx melampygus	X	X	-	D
Caranx sexfasciatus	X	-	-	P
Carapus margaritiferae	-	-	BG	-
Carcharhinus limbatus	X	-	-	R
Chaetodon auriga	X	X	-	C
Chaetodon lunula	-	X	-	P
Chaetodon miliaris	X	X	-	C
Chanos chanos	X	-	-	-
Cheilio inermis	-	-	HL	-
Conger cinreus marginatus	-	X	-	P
Ctenochaetus strigosus	-	-	-	P
Ctenogobius tongarevae	-	-	HN	-
Dascyllus albisella	-	-	-	P
Diodon holocanthus	-	-	-	P
Diodon hystrix	-	-	HN	P
Elops hawaiiensis	X	-	-	-
Entomacrodus marmoratus	-	-	HN	R
Exallias brevis	-	-	BG	-
Flammeo sammara	-	X	-	P
Foa brachygrammus	-	X	HN	TNTC
Gnathanodon speciosus	-	-	-	P
Gnatholepis anjerensis	-	-	SA	-
Gymnothorax flavimarginatus	-	X	-	-
Gymnothorax petelli	-	-	-	R
Gymnothorax undulatus	-	X	-	P
Hemiramphus depauperatus	-	-	-	P
Heniochus acuminatus	-	-	-	P
Kuhlia sandvicensis	X	X	-	C
Kyphosus cinerascens	X	-	-	-

Species	Gill Net	Trap	Various*	Sightings**
Labroides phthirophagus	-	-	-	R
Lutjanus fulvus	-	X	-	-
Microcanthus strigatus	-	X	-	P
Micrognathus ?edmondsoni	-	-	-	R
Mollienesia latipinna	-	-	HN	P
Mugil cephalus	X	-	-	P
Mulloidichthys auriflamma	X	-	-	-
Mulloidichthys samoensis	X	X	-	C
Myripristis murdjan	-	-	-	R
Naso brevirostris	X	X	-	C
Naso unicornis	X	-	-	-
Omobranchus elongatus	-	-	HN	P
Opua nephodes	-	-	SA	-
Ostracion meleagris camurum	-	-	-	R
Oxyurichthys lonchotus	-	-	HN,BS	-
Parupeneus multifasciatus	-	-	-	R
Parupeneus pleurostigma	X	-	-	C
Parupeneus porphyreus	X	X	-	D
Pervagor spilosoma	-	-	-	R
Polydactylus sexfilis	X	-	-	-
Priacanthus cruentatus	-	-	BG	R
Saurida gracilis	-	-	SP	P
Scarus sordidus	X	-	-	-
Scarus sp. (juvenile)	-	-	-	C
Scomberoides sancti-petri	X	-	-	P
Scorpaena coniorta	-	-	HN	-
Scorpaenopsis diabolus	-	-	HN	R
Sphyraena barracuda	X	X	-	C
Sphyrna lewini	X	-	-	R
Stethojulis balteatus	-	-	HN	P
Stolephorus purpureus	X	-	-	-
Synodus variegatus	-	-	-	R
Tilapia mossambica	-	-	HN	P
Tylosurus crocodilus	-	-	-	P
Upeneus arge	X	X	-	P
Zanclus canescens	-	-	-	P
Zebrasoma flavescens	-	-	-	C
Zebrasoma veliferum	-	X	-	P

* Various secondary methods of collection:
BG = collected by hand and placed in divers bag
HN = collected with hand dip net
BS = collected in bottom sampler (incidental to benthic sampling)
HL = collected by hand-line fishing
SA = observed and identified during stomach analysis of gill netted fish
SP = collected by spearing (using Hawaiian tri-prong spear)

** Code of relative abundance (from sightings only):
R = Rare (1-2 individuals &/or at 1 bio-station)
P = Present (3-6 individuals &/or at 2-3 bio-stations)
C = Common (7-15 individuals &/or at 4-6 bio-stations)
D = Dominant (15+ individuals &/or at 7-10 bio-stations)
TNTC = Too Numerous to Count (at 5-10 bio-stations)

Table 2.1-6. FISH SURVEYS: DATA FOR INDIVIDUALS COLLECTED (NUMBERS) AND SPECIES SIGHTED (S) AT EACH BIO-STATION IN PEARL HARBOR. "-" INDICATES NOT SIGHTED OR COLLECTED.

SPECIES	Q*	f*	BE-02	BE-03	BE-04	BE-05	BW-07	BC-09	BC-10	BC-11	BW-13	BE-17	Total
Abudefduf abdominalis	25	1.5	1	S	S	4	S	S	S	S	S	S	5
Abudefduf sordidus	25	1.5	S	1	-	S	S	-	-	S	S	S	1
Acanthurus dussumieri	11	2.3	-	-	-	-	-	-	1	3	-	-	4
Acanthurus mata	16	1.8	3	14	-	1	5	1	3	8	4	1	40
Acanthurus olivaceus	4	2.8	-	-	-	-	-	-	-	3	-	-	3
Acanthurus triostegus	21	1.0	S	1	-	S	-	S	-	12	S	-	13
Acanthurus xanthopterus	25	1.2	3	4	S	16	25	2	7	5	10	7	79
Aetobatus narinari	25	0.9	S	S	-	S	-	1	1	2	1	S	5
Albula vulpes	17	1.9	-	-	-	-	-	12	-	1	7	-	20
Antennarius chironectes	-	-	-	-	-	-	-	-	-	1	-	-	1
Apogon snyderi	11	2.3	-	-	-	-	-	-	S	2	S	-	2
Arothron hispidus	25	0.6	38	48	18	9	28	7	26	2	5	81	262
Asterropteryx semipunctatus (TNTC**)	25	1.5	S	S	S	S	S	S	S	S	S	S	-
Aulostomus chinensis	5	2.7	-	-	-	-	-	-	-	S	-	-	-
Bathygobius fuscus (TNTC)	18	1.8	S	S	-	S	-	S	-	-	S	-	-
Bothus pantherinus	25	1.5	-	-	-	-	-	-	-	-	1	S	1
Brachirus barberi	22	1.2	-	S	-	-	-	1	-	1	2	-	4
Calotomus spinidens	5	2.7	-	-	-	-	-	-	-	1	-	-	1
Canthigaster coronatus	4	2.8	-	-	-	-	-	-	-	S	-	-	-
Canthigaster jactator	-	-	-	-	-	-	-	-	-	S	-	-	-
Carangoides gymnostethoides	-	-	-	-	-	-	-	-	-	-	1	-	1
Caranx ignobilis	25	1.5	-	1	-	-	-	-	-	-	-	-	1
Caranx mate	26	1.4	S	-	-	S	5	-	1	-	***7	-	13
Caranx melampygus	18	1.8	1	4	-	2	S	2	13	4	4	1	31
Caranx sexfasciatus	18	1.8	1	2	4	2	1	1	7	S	S	1	19
Carapus margaritiferae	-	-	-	-	-	-	-	-	-	1	-	-	1
Carcharhinus limbatus	25	0.9	-	-	-	-	-	3	S	-	-	-	3
Chaetodon auriga	24	1.4	S	S	-	2	S	-	22	26	S	2	52
Chaetodon lunula	17	1.9	-	-	-	-	-	-	13	9	-	S	22
Chaetodon miliaris	20	1.6	-	1	-	-	-	-	33	43	-	-	77
Chanos chanos	21	1.0	-	-	-	5	-	23	1	-	3	-	32
Cheilio inermis	7	2:7	-	-	-	-	-	-	-	1	-	-	1

Table 2.1-6. Continued

SPECIES	Q	f	BE-02	BE-03	BE-04	BE-05	BW-07	BC-09	BC-10	BC-11	BW-13	BE-17	Total
Conger cinreus marginatus	15	1.8	-	-	-	-	-	-	4	8	-	1	13
Ctenochaetus strigosus	18	1.8	-	-	-	-	S	-	-	S	S	-	-
Ctenogobius tongarevae	-	-	-	-	-	-	-	-	3	-	-	-	3
Dascyllus albisella	16	1.8	S	S	-	-	-	-	S	S	S	-	-
Diodon holocanthus	13	2.1	-	-	-	-	-	-	S	S	-	-	-
Diodon hystrix	13	2.1	-	-	-	-	-	-	S	1	-	-	1
Elops hawaiiensis	25	1.5	5	3	13	35	11	22	8	2	5	4	108
Entomacrodus marmoratus	10	2.4	-	-	-	-	-	-	-	1	-	-	1
Exallias brevis	-	-	-	-	-	-	-	-	-	1	-	-	1
Flammeo sammara	11	2.3	-	-	-	-	-	-	1	S	S	-	1
Foa brachygrammus (TNTC)	25	1.5	S	S	S	S	S	S	S	S	S	S	-
Gnathanodon speciosus	20	1.6	S	-	-	-	-	-	S	S	S	-	-
Gnatholepis anjerensis	-	-	-	-	-	-	-	-	1	-	1	-	2
Gymnothorax flavimarginatus	15	2.1	-	-	-	-	-	-	-	3	-	-	3
Gymnothorax petelli	10	2.4	-	-	-	-	-	-	-	S	-	-	-
Gymnothorax undulatus	20	1.2	S	S	-	1	-	1	1	3	1	-	7
Hemiramphus depauperatus	25	1.5	-	-	-	S	S	-	S	-	-	-	-
Heniochus acuminatus	4	2.8	-	-	-	-	-	-	-	S	-	-	-
Kuhlia sandvicensis	25	1.5	S	S	-	-	3	-	4	S	5	-	12
Kyphosus cinerascens	5	2.7	-	-	-	-	-	-	-	2	-	-	2
Labroides phthirophagus	5	2.7	-	-	-	-	-	-	-	S	-	-	-
Lutjanus fulvus	17	1.9	1	-	-	1	-	-	-	1	-	1	4
Microcanthus strigatus	5	2.7	-	-	-	-	-	-	-	1	S	-	1
Micrognathus ?edmondsoni	-	-	-	-	-	-	-	-	-	S	-	-	-
Mollienisia latipinna	43	2.6	-	-	-	-	-	-	-	-	S	-	-
Mulloidichthys auriflamma	-	-	-	-	-	-	-	-	-	1	-	-	1
Mulloidichthys samoensis	16	1.8	S	1	-	-	-	-	S	13	S	-	14
Mugil cephalus	25	1.2	-	1	-	-	32	32	-	8	1	-	74
Myripristis murdjan	11	2.3	-	-	-	-	-	-	S	S	-	-	-
Naso brevirostris	16	1.8	S	-	-	8	-	-	6	-	S	-	14
Naso unicornis	5	2.7	-	-	-	-	-	-	-	3	-	-	3
Omobranchus elongatus	11	2.3	-	-	-	-	-	-	-	-	3	-	3
Opua nephodes	-	-	-	-	1	-	-	-	1	-	-	-	2
Ostracion meleagris camurum	5	2.7	-	-	-	-	-	-	S	S	-	-	-

Table 2.1-6. Continued

SPECIES	Q	f	BE-02	BE-03	BE-04	BE-05	BW-07	BC-09	BC-10	BC-11	BW-13	BE-17	Total
Oxyurichthys lonchotus	-	-	2	-	-	-	-	-	-	-	-	-	2
Parupeneus multifasciatus	11	2.3	-	-	-	-	-	-	-	S	-	-	-
Parupeneus pleurostigma	11	2.3	-	-	-	-	-	-	S	S	S	-	-
Parupeneus porphyreus	23	1.3	16	54	-	88	-	4	7	48	2	34	253
Pervagor spilosoma	5	2.7	-	-	-	-	-	-	-	S	-	-	-
Polydactylus sexfilis	16	1.8	-	-	-	-	-	3	11	-	-	-	14
Priacanthus cruentatus	4	2.8	-	-	-	-	-	-	-	1	-	-	1
Saurida gracilis	11	2.3	-	S	-	-	-	-	S	1	-	S	1
Scarus sp. (juvenile)	-	-	S	-	-	-	-	-	-	S	S	-	-
Scarus sordidus	5	2.7	-	-	-	-	-	-	-	1	-	-	1
Scomberoides sancti-petri	25	1.5	-	-	2	9	S	2	-	-	-	-	13
Scorpaena coniorta	-	-	-	-	-	-	-	-	-	1	-	-	1
Scorpaenopsis diabolus	-	-	-	-	-	-	-	-	-	1	-	-	1
Sphyraena barracuda	25	1.5	1	1	-	S	S	S	-	S	S	-	2
Sphyrna lewini	25	0.9	4	2	3	36	23	10	10	S	2	-	90
Stethojulis balteatus	14	2.0	S	S	-	-	-	-	-	1	S	-	1
Stolephorus purpureus	25	1.5	3	-	-	S	S	-	-	-	-	-	3
Synodus variegatus	7	2.6	-	-	-	-	-	-	-	S	-	-	-
Tilapia mossambica	39	2.3	-	-	-	-	S	-	-	-	S	-	-
Tylosurus crocodilus	20	2.0	-	-	-	-	S	-	S	-	-	-	-
Upeneus arge	25	1.5	3	-	-	1	-	13	1	S	-	1	19
Zanclus canescens	11	2.3	-	S	-	-	-	-	S	S	-	-	-
Zebrasoma flavescens	16	1.8	S	-	-	S	-	-	-	S	S	-	-
Zebrasoma veliferum	16	1.8	-	-	-	1	-	-	-	S	S	-	1
Total individuals per station (mean=136.7; st.dev.=±62.5)			82	138	41	221	133	140	186	227	65	134	1367
Total species per station (mean=31.7;st.dev.=±16.7)			31	29	10	28	22	24	42	70	43	19	

* Q = environmental preference rating; f = preference strength; see text and Table 2.1-15. Species without ratings have not been sufficiently observed for environmental preferences to be estimated.
** TNTC - too numerous to count
*** indicates juveniles collected with jellyfish, *Mastigias papua*

Table 2.1-7. FISH SURVEY, CATCH-PER-UNIT-EFFORT

Station	Total hrs.	Total lbs.	Catch/unit effort (lbs/hr)
BE-02	Trap = 576 Net = 120	50.20 24.60	0.09 0.21
BE-03	Trap = 638 Net = 120	76.03 48.40	0.12 0.40
BE-04	Trap = 576 Net = 120	7.20 39.10	0.01 0.33
BE-05	Trap = 720 Net = 144	112.90 187.60	0.16 1.30
BM-07	Trap = 576 Net = 120	25.30 102.70	0.04 0.86
BC-09	Trap = 576 Net = 144	16.68 285.70	0.03 1.98
BC-10	Trap = 504 Net = 120	55.99 75.00	0.11 0.15
BC-11	Trap = 504 Net = 120	105.71 76.60	0.21 0.64
BW-13	Trap = 576 Net = 120	7.25 65.70	0.01 0.55
BE-17	Trap = 576 Net = 120	89.25 10.40	0.16 0.09

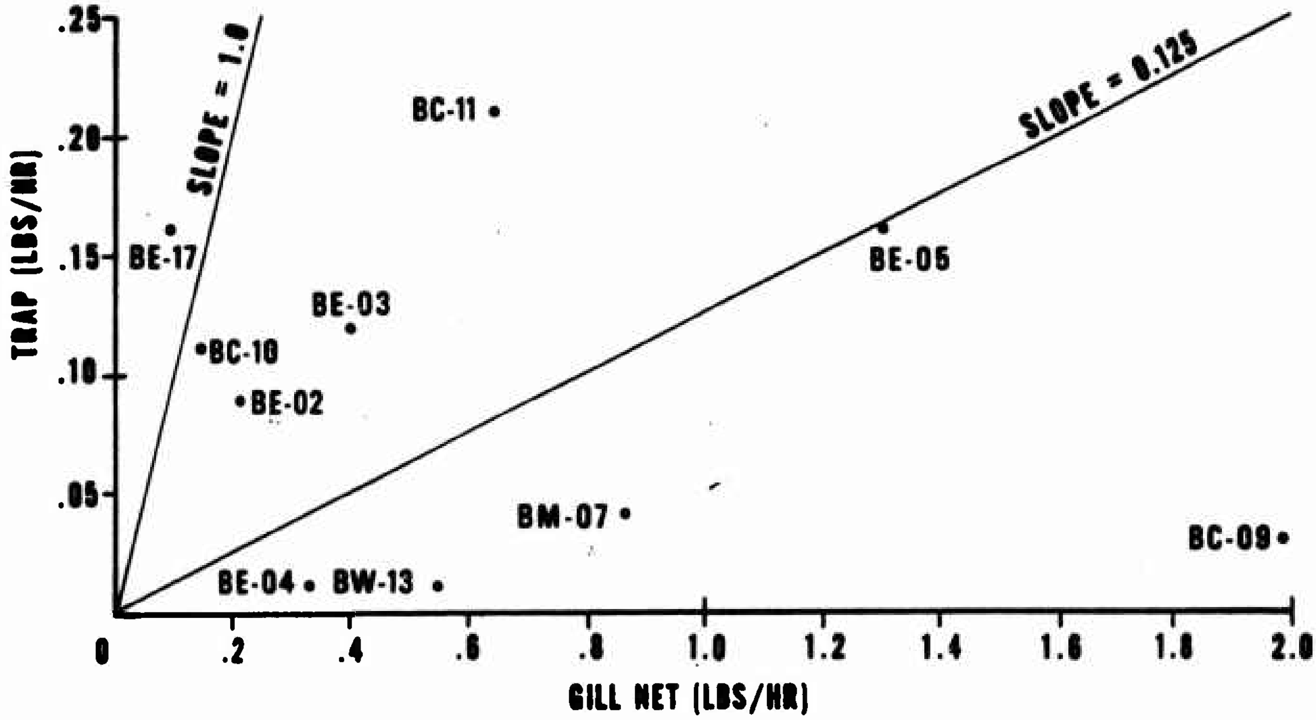


Figure 2.1-4. COMPARISON OF CATCH-PER-UNIT-EFFORT BY FISH TRAPS AND GILL NETS AT 10 BIO-STATIONS IN PEARL HARBOR

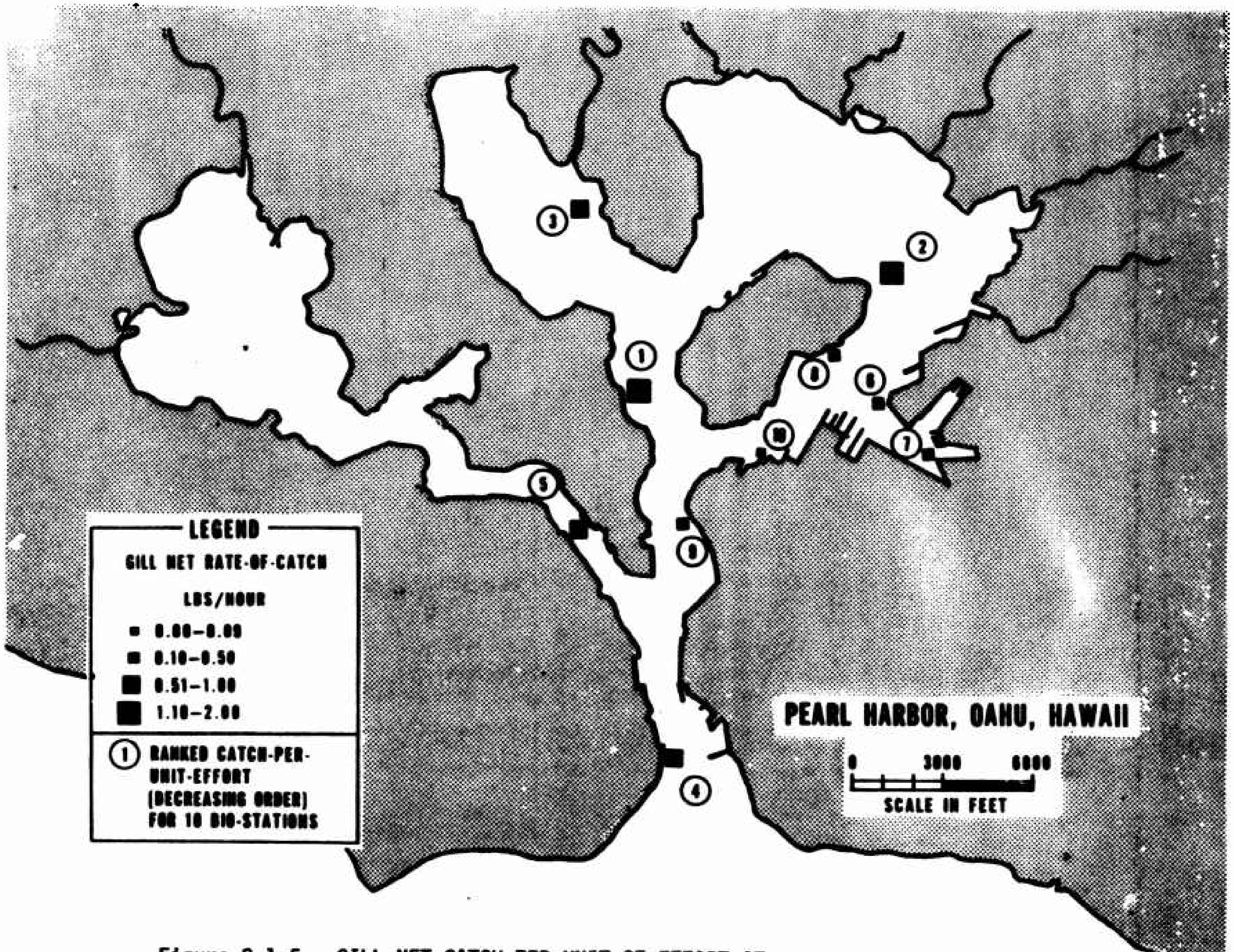


Figure 2.1-5. GILL NET CATCH PER UNIT OF EFFORT AT TEN BIO-STATIONS IN PEARL HARBOR.

Catch data for individual species collected more than three times are listed in Table 2.1-8. Weight-length conversion factors have been calculated for these 32 species, except nehu (*Stolephorus purpureus*) for which insufficient weight data were obtained. Ranges and means for length and weight data are presented for each species listed. Catch data for species rarely collected (i.e. one or two individuals) are presented in Table 2.1-9. Location, date and collection method, as well as length and weight data, are given for each species.

TAGGING

PHBS began tagging fishes caught in fish traps on 4 May 1972 and received its last recaptured fish on 1 May 1973. Except for July and August 1972, a monthly trapping and tagging schedule was carried out from May to December 1972. During this period a total of 525 fish were trapped, tagged and released in Pearl Harbor (Table 2.1-10). Only 41 of these tagged fish were recaptured either by PHBS traps and gill nets or by sport or commercial fishermen. Furthermore, over half the returns were from a single species, *Parupeneus porphyreus*, a red goatfish highly prized as a food fish. In fact, several tags from this species were returned from the Honolulu fish markets.

Long distance movements of tagged fish from the site of initial tagging and release were sometimes observed. A notable example was a solitary soft puffer, *Arothron hispidus*, which was tagged at bio-station BC-10 on 15 June 1972 and recovered from a fisherman at Heeia Pier in Kaneohe Bay on 10 September 1972 (Figure 2.1-6). This distance record might be explained as follows: an "aku boat" may have inadvertently netted the tagged puffer while seining for baitfish (nehu) adjacent to BC-10. Then, after leaving Pearl Harbor and subsequently standing into Kaneohe Bay for fuel, the bait tanks were "cleaned" (i.e. pumped over the side into the bay) and the puffer was thus released near Heeia Pier, where it was finally caught.

During October and November 1972, *P. porphyreus* tagged at various sites within Pearl Harbor showed definite movements to points as distant as Sand Island (Figure 2.1-6). Recaptures were made in January 1972 in the Fort Kamehameha and Sand Island areas and in May 1972 in the Ewa Beach area. Although our data are insufficient, it seems likely that Pearl Harbor, like Kaneohe Bay (Reference 2.1-9 and 2.1-10), is a breeding/nursery/feeding ground for a number of species, including perhaps *P. porphyreus*, *Sphyrna lewini* and *Stolephorus purpureus*. Also, it is important to note that although a total of 74 individuals from three species of butterflyfishes (Chaetodontidae) were tagged during this study, none were recaptured. As a group, chaetodontids are generally small and somewhat "delicate" fishes and the tagged individuals released in Pearl Harbor may have experienced heavy tag-related mortality.

FISH TRANSECTS

Fish transects were conducted during August, September and October 1972. An attempt was made to perform these transects during periods of

(Text continued on page 2.1-34)

Table 2.1-8. PEARL HARBOR: CATCH DATA FOR SPECIES WHERE THREE OR MORE INDIVIDUALS WERE COLLECTED

Species	(Wt/Length Conv. Factor)(#)	Cnt.	Length (in.) Range	Length (in.) Mean	Weight (lbs.) Range	Weight (lbs.) Mean
Acanthurus dussumieri	(.00072)(21)	4	12.00-6.00	9.03	1.7-0.3	0.9
Acanthurus mata	**(.00107)(30)	40	11.00-4.50	6.97	1.6-0.1	0.4
Acanthurus olivaceus	(.00068)(11)	3	8.25-6.50	7.42	0.4-0.2	0.3
Acanthurus triostegus	(.00132)(113)	13	7.25-3.25	5.60	0.5-0.1	0.3
Acanthurus xanthopterus	*(.00100)(23)	60	13.75-3.50	7.64	2.5-0.04	0.5
Aetobatus narinari	*(.00004)(3)	3	49.00-40.50	43.63	3.9-2.9	3.4
Albula vulpes	*(.00051)(15)	15	17.50-11.50	15.15	3.0-0.8	1.8
Arothron hispidus	*(.00136)(9)	183	11.75-4.75	7.08	2.3-0.2	0.6
Brachirus barberi	(.00075)(17)	4	4.76-4.21	4.46	0.08-0.06	0.1
Caranx mate	*(.00059)(6)	6	9.75-6.88	8.86	0.5-0.2	0.4
Caranx melampygus	**(.00078)(25)	26	13.50-5.13	8.85	1.5-0.1	0.6
Caranx sexfasciatus	*(.00072)(18)	18	16.00-7.25	11.53	3.0-0.3	1.2
Carcharinus limbatus	*(.00015)(3)	3	34.00-24.00	30.17	4.5-2.7	3.9
Chaetodon auriga	(.00100)(26)	40	7.00-2.75	5.04	0.3-0.02	0.2
Chaetodon lunula	(.00124)(25)	18	5.75-2.75	4.54	0.2-0.03	0.1
Chaetodon miliaris	(.00119)(222)	51	5.13-3.13	3.77	0.2-0.04	0.1
Chanos chanos	*(.00050)(26)	26	27.50-13.75	23.27	10.6-1.3	6.6
Conger cinreus marginatus	(.00020)(40)	12	39.50-24.75	32.11	12.3-3.0	7.0
Elops hawaiiensis	*(.00028)(96)	96	31.00-13.50	19.16	7.4-0.7	2.0
Gymnothorax flavimarginatus	(.00004)(7)	3	36.50-35.50	35.83	2.0-1.8	1.9
Gymnothorax undulatus	*(.00009)(4)	7	35.50-23.25	29.84	4.0-1.1	2.5
Kuhlia sandvicensis	*(.00085)(9)	12	10.00-4.25	8.02	0.9-0.1	0.5
Lutjanus fulvus	(.00067)(31)	4	9.00-7.63	8.53	0.5-0.3	0.4
Mugil cephalus	*(.00049)(74)	74	14.75-11.75	13.32	1.7-0.8	1.2
Mulloidichthys samoensis	(.00039)(39)	14	12.50-8.30	10.46	1.5-0.3	0.8

Table 2.1-6. (Continued)

Species	(Wt/Length Conv. Factor)(#)	Cnt	Length (in.) Range	Mean	Weight (lbs.) Range	Mean
Naso brevirostris	(.00070)(10)	6	8.25-4.88	6.67	0.4-0.1	0.3
Naso unicornis	**(.00085)(3)	3	16.25-6.50	11.42	2.9-0.3	1.5
Parupeneus porphyreus	*(.00088)(33)	197	13.25-5.25	9.56	2.1-0.1	0.9
Polydactylus sexfilis	*(.00063)(14)	14	14.75.8.50	11.05	2.0-0.4	0.9
Scomberoides sancti-petri	*(.00033)(12)	12	16.75-11.25	13.13	1.1-0.6	0.7
Sphyrna lewini	*(.00014)(30)	86	36.50-19.50	24.37	7.3-1.0	2.2
Stolephorus purpureus	CNA	3	2.38-1.75	1.96	CNA	
Upeneus arge	*(.00069)(4)	16	11.50-8.00	9.97	1.1-0.4	0.7

LEGEND: () = Hawaii Division of Fish and Game computation (5 digits

*() = Pearl Harbor Biological Survey computation (which either agrees with F&G constant or is an addition to the list of known Wt/Length Conversion Factors).

**() = Pearl Harbor Biological Survey computation (which significantly disagrees with F&G computations).

CNA = Wt/Length Conversion Factor Not Available.

(#) = Number of individuals used for computation of Wt/Length Conversion Factors.

Cnt = Count, number of individuals collected.

Table 2.1-9. FISH SURVEY, PEARL HARBOR: COLLECTING METHODS AND MEASUREMENTS FOR FISH SPECIES RARELY COLLECTED

Species	Station	Date	Collection Method	Length	Weight
Abudefduf abdominalis	BE-02	24 Nov 71	T	4.84	0.3
Abudefduf sordidus	BE-03	5 May 72	T	4.50	0.3
Antennarius chironectes	∿ BC-11	29 Dec 72	BG	5.50	0.6
Apogon snyderi	BC-11	25 Oct 72	HN	4.50	0.1
Bothus pantherinus	BW-13	27 Apr 72	GN	6.00	0.1
Calotomus spinidens	BC-11	16 Nov 72	GN	9.00	0.6
Carangoides gymnostethoides	BW-13	5 Dec 72	GN	6.75	0.3
Caranx ignobilis	BE-03	25 Apr 72	GN	19.50	6.0
Carapus margaritiferae	∿ BC-11	31 Jan 72	BG	3.13	CNA
Cheilio inermis	∿ BC-11	4 May 72	FL	12.75	0.6
Ctenogobius tongarevae	BC-10	31 Mar 72	HN	1.25	CNA
Diodon hystrix	BC-11	5 Dec 72	HN	21.25	7.7
Entomacrodus marmoratus	∿ BC-11	2 Oct 72	HN	3.75	CNA
Exallias brevis	∿ BC-11	11 Feb 72	BG	1.25	CNA
Flammeo sammara	BC-10	6 Oct 72	T	5.50	0.1
Kyphosus cinerascens	BC-11	18 Oct 72	GN	7.50	0.7
" "	BC-11	16 Nov 72	GN	7.00	0.4
Microcanthus strigatus	BC-11	15 Sep 72	T	3.88	CNA
Mulloidichths auriflamma	BC-11	1 Sep 72	GN	7.75	0.4
Omobranchus elongatus	BW-13	17 Nov 72	HN	2.25	CNA
Oxyurichthys lonchotus	BE-02	20 Jan 72	HN	1.75	CNA
Priacanthus cruentatus	∿ BC-11	25 Oct 72	BG	10.50	0.7
Saurida gracilis	BC-11	4 Nov 72	SP	13.50	1.2
Scarus sordidus	BC-11	1 Sep 72	GN	9.75	0.6
Scorpaena coniorta	∿ BC-11	11 Feb 72	HN	1.75	0.01

Table 2.1-9. (Continued)

Species	Station	Date	Collection Method	Length	Weight
Scorpaenopsis diabolus	BC-11	3 Apr 72	HN	4.75	0.1
Sphyraena barracuda	BE-02	10 Nov 72	T	21.00	2.5
" "	BE-03	8 Dec 72	GN	18.00	1.7
Stethojulis balteatus	BC-11	3 Apr 72	HN	0.75	NA
Tilapia mossambica	Middle Loch-shoreline	5 May 72	HN	11.75	2.1
Zebrasome veliferum	∿BE-05	21 Nov 72	T	6.50	0.2

LEGEND: 1) Methods of Collection

SP = Hawaiian three-prong spear
BG = Diver's bag (organism usually collected underwater by hand)
T = PHBS fish trap
HN = Hand or dip net
GN = PHBS gill net
FL = Fishing line, rod and reel fishing

2) ∿Indicates adjacent to, or in the vicinity of, a bio-station

3) Measurement:
Lengths are in inches; fork lengths are measured
Weights are in pounds to the nearest tenth of a pound

4) Weight/length conversion factor not available indicated by CNA

Table 2.1-10. LIST OF FISH TAGGED IN PEARL HARBOR

Species	# Tagged	@#Bio-stations	# Recaptured
Acanthurus mata	10	5	0
Acanthurus triostegus	2	2	0
Acanthurus xanthopterus	37	7	4
Arothron hispidus	182	10	10
Caranx melampygus	1	1	0
Caranx sp. (juvenile)	2	2	0
Chaetodon auriga	34	3	0
Chaetodon lunula	12	2	0
Chaetodon miliaris	38	3	0
Conger ~~cinreus~~ marginatus	11	3	1
Flammeo sammara	1	1	0
Gymnothorax flavimarginatus	3	1	0
Gymnothorax undulatus	7	5	1
Kuhlia sandvicensis	3	1	0
Lutjanus fulvus	4	4	0
Microcanthus strigatus	1	1	0
Naso brevirostris	3	2	2
Parupeneus porphyreus	162	8	23
Upeneus arge	12	3	0
	525		41

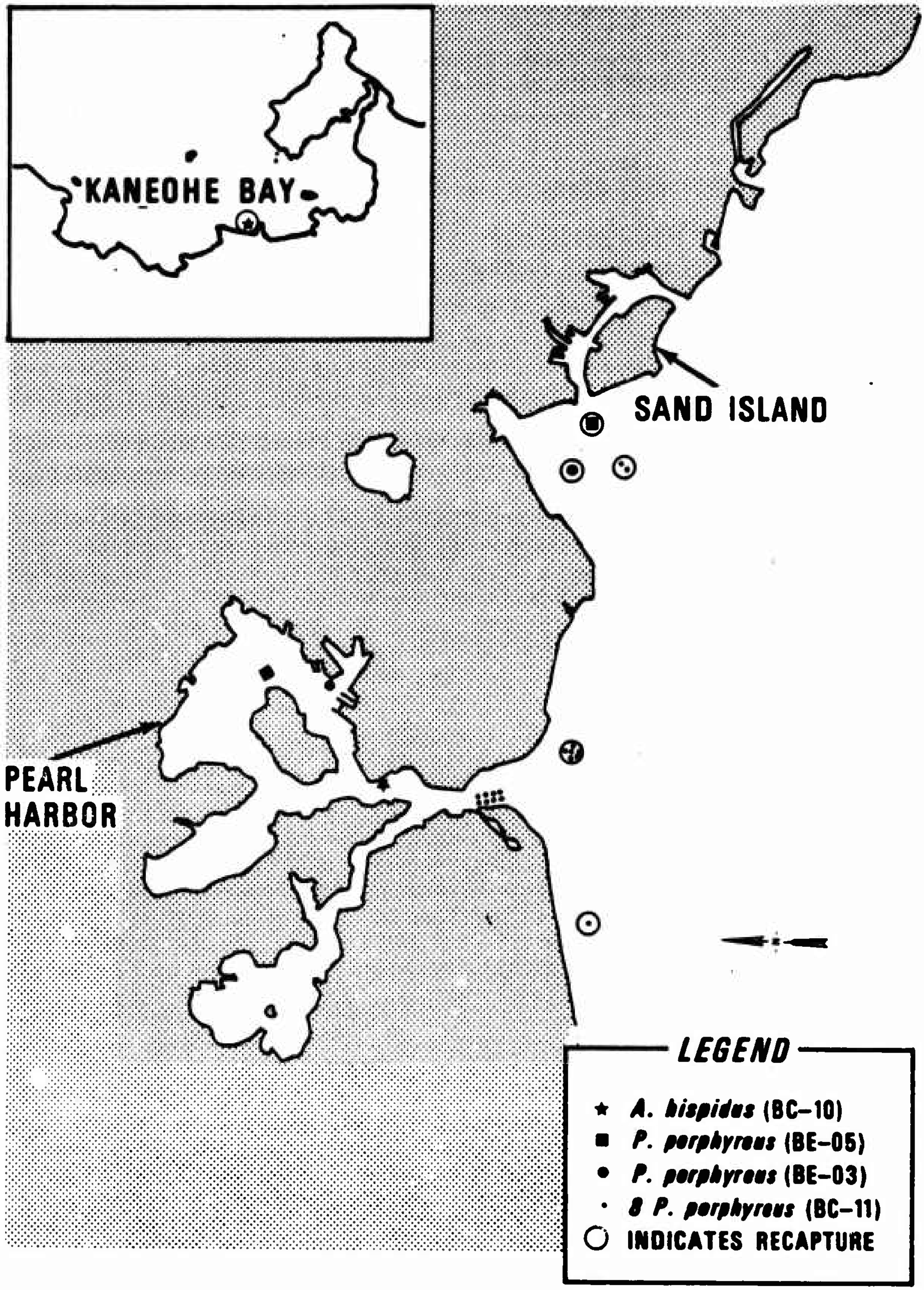


Figure 2.1-6. FISH RECAPTURES FOR PEARL HARBOR RELEASES

maximum water clarity. While the optimal time of day was generally found to be early or mid-morning, before visibility reducing factors became significant, fish transects were conducted on an unscheduled basis due to variable underwater visibility. The maximum "identifiable" visibility* recorded at any single bio-station was about 15 feet; minimum observed visibility was less than 1 foot. Reduced visibility is believed to be due to a variety of factors, including ship traffic, wind and weather conditions and, to a lesser extent, tidal flow. Often, fish transects were obtained during occasions of increased water visibility while the field team was at a bio-station for another sampling activity. In general, the late summer to early fall months provided the optimal periods of water clarity at the 10 bio-stations.

The total numbers of fishes sighted on transects at each station have been tabulated in pounds per transect (Table 2.1-11) using weight-length conversion coefficients (Table 2.1-4) applied to estimated lengths. Only the data for 2 of the transects available from each bio-station were chosen for presentation in Table 2.1-11. These transects were selected on the basis of the diver's evaluation of transects which 1) were most representative of a given station's general physiography and 2) included the greatest number of species. The second criterion is based on the assumption that more species were present at a given bio-station than were ever observed at any one time. The transects with the maximum number of species were considered the "best estimate" of the true fauna for that environment. Both transects at each station are segregated into columns of equal identifiable visibility, since this parameter has a profound effect on the transect results reported.

The fish population for bio-station BC-09 is considerably underestimated by transect data. This is chiefly attributable to the generally poor visibility at this channel station and the fact that most fishes captured at BC-09 were large, fast-swimming, pelagic or benthic species which are unlikely to be seen on a fish transect (especially where visibility is limited to less than five feet). Otherwise, data presented in Table 2.1-11 compare favorably with data obtained by other sampling methods and with qualitative estimates based on observations made on non-transect dives. Figure 2.1-7 maps mean weight per transect into the harbor. Station weights for BE-05, BM-07 and BW-13 are loaded heavily with large numbers of surgeonfish (family Acanthuridae). Species composition is much more varied at BC-11.

DISTRIBUTION

The total number of species of fishes collected and sighted at each bio-station is presented in Figure 2.1-8. Station BC-11 stands alone as the most diverse bio-station in relation to fish data. Bio-stations BC-10 and BW-13 are geographically nearest BC-11, but provide only slightly more

(Text continued on page 2.1-38)

---

* Defined as the maximum distance at which fish can be positively identified during fish transecting; see earlier discussion under visual transects in methods section.

Table 2.1-11. TOTAL COMPUTED WEIGHTS OF FISHES SIGHTED ON TRANSECTS IN PEARL HARBOR, OAHU. (IDENTIFIABLE VISIBILITIES ARE IN PARENTHESES).

Station	1A (10')	1B (5')	2A (10')	2B (5')	Mean Wt/Transect
BE-02	11.9	-----	2.7	-----	7.3
BE-03	19.6	-----	37.3	-----	28.5
BE-04	0.5	-----	0.1	-----	0.3
BE-05	9.5	-----	188.2	-----	98.9
*BM-07	150.0	-----	-----	-----	150.0
BC-09	-----	1.8	-----	-----	1.8
BC-10	-----	32.6	-----	7.7	20.2
BC-11	62.5	-----	65.9	-----	62.2
BW-13	135.2	-----	5.3	-----	70.3
BE-17	-----	13.7	-----	12.4	13.1

Key:

1 = first transect

2 = second transect

A = "good" visibility (10 feet)

B = "poor" visibility (5 feet)

* represents count for total fish population at bio-station

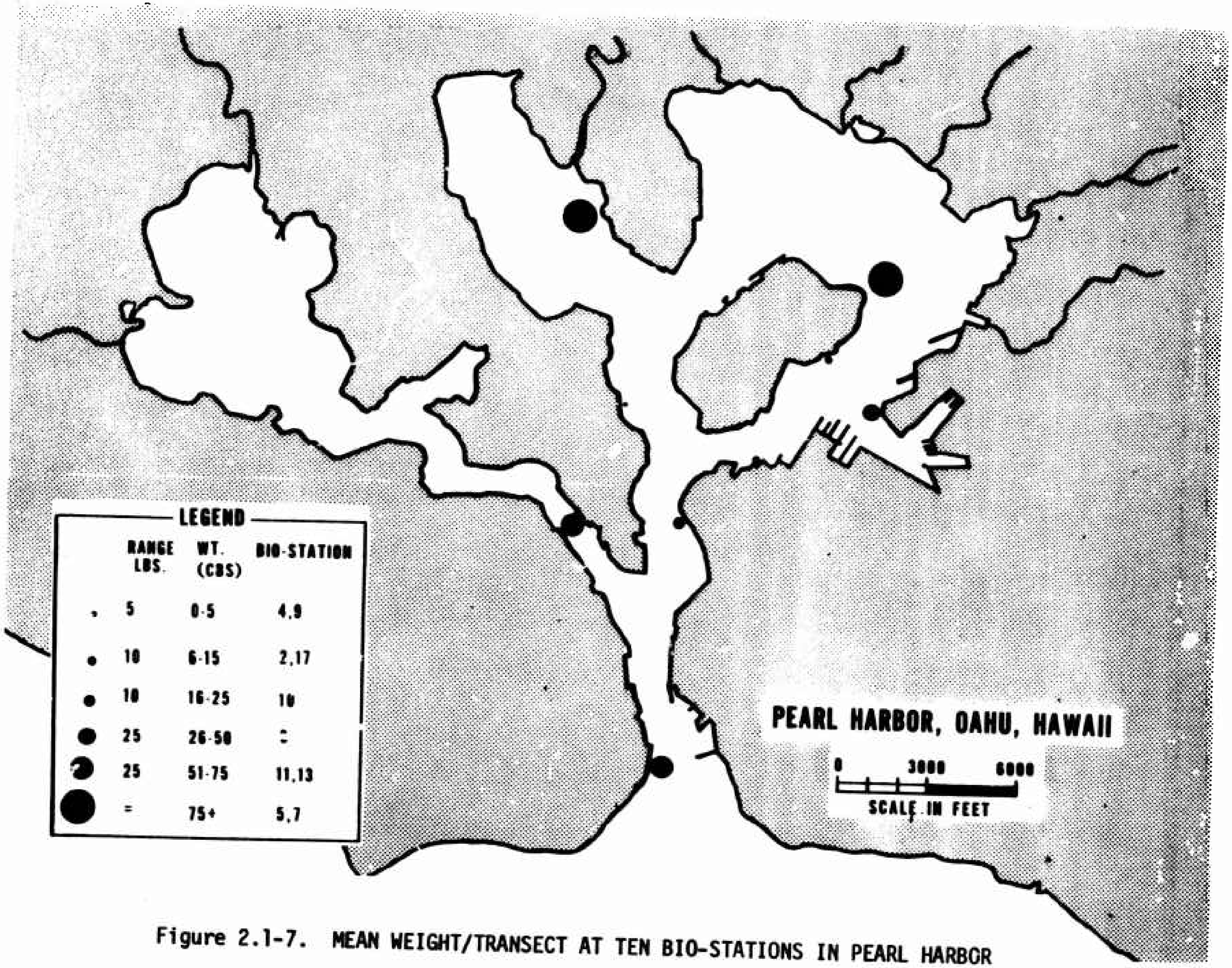


Figure 2.1-7. MEAN WEIGHT/TRANSECT AT TEN BIO-STATIONS IN PEARL HARBOR

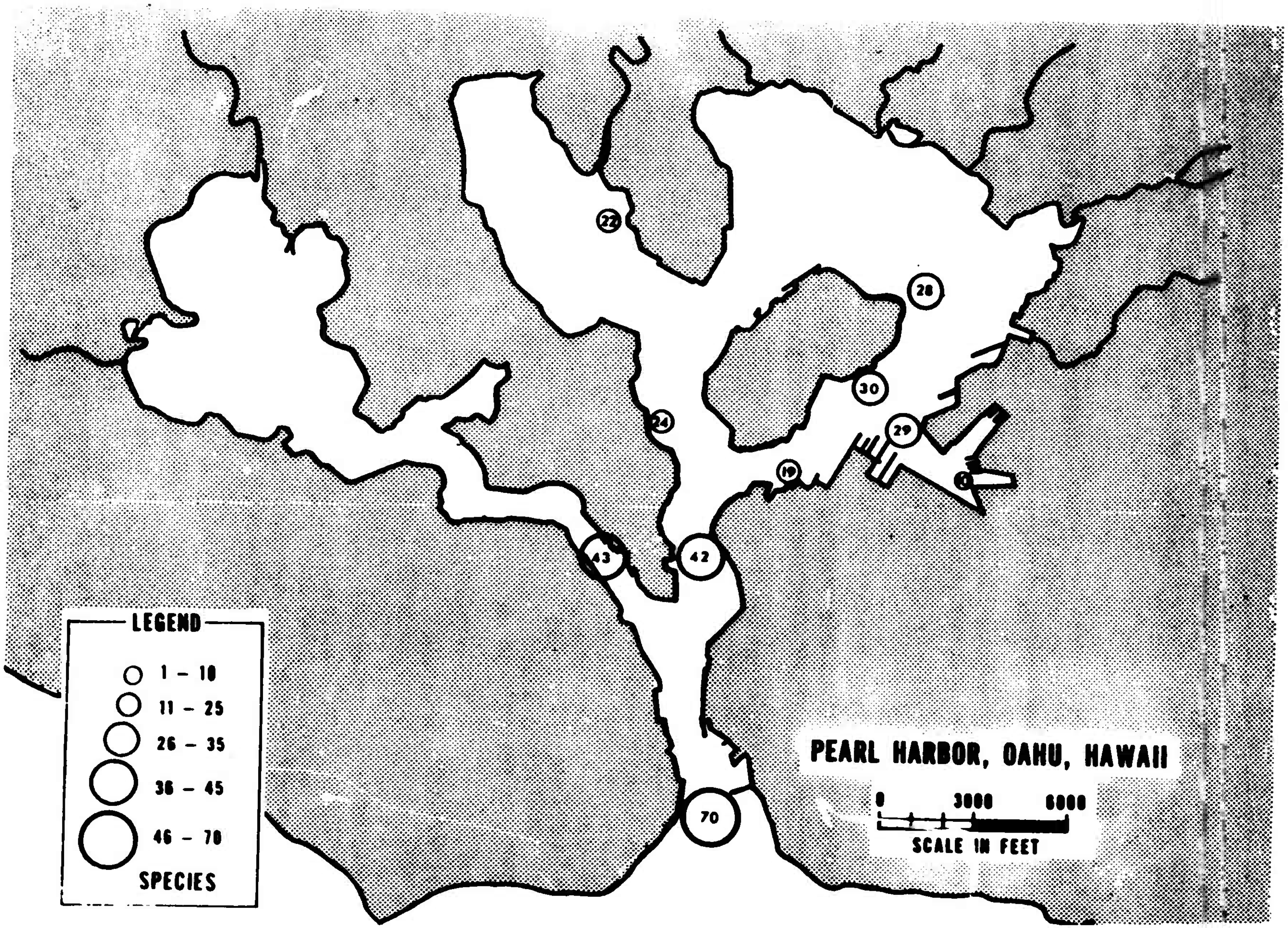


Figure 2.1-8. NUMBER OF SPECIES OF FISHES COLLECTED AND SIGHTED AT EACH BIO STATION IN PEARL HARBOR.

than half the number of fish species. The remaining bio-stations fail to show distinctive patterns; however, the lowest numbers of fish species are present at BE-04 and BE-17, two bio-stations which are probably most stressed by shipyard activities.

Ten selected species of fishes, chosen by feeding habits, are listed in Table 2.1-12 and are geographically mapped on Figures 2.1-9 through 2.1-18. These fishes are representative of the range of feeding types inhabiting Pearl Harbor. The results of a stomach analysis content study conducted by Dr. Thomas A. Clarke of the Hawaiian Institute of Marine Biology, Coconut Island, are additionally provided as Appendix B. The fishes used in Clarke's study were collected by gill nets set at the 10 PHBS bio-stations from September 1972 to May 1973.

Ranked listings of the 5 most abundant fish species at each bio-station based on collections and sightings are presented in Table 2.1-13. Although the common species as determined by either method are similar (part B of Table 2.1-13), the population composition shown in the ranking is different. This difference is better illustrated by Table 2.1-14. Only half the 24 common species are represented in this table; however, it can be seen that the acanthurids tend to dominate the ranking by sighting while ranking by collection tends to be dominated by *Arothron hispidus* and other species which do not appear in the former ranking. This difference and the low scores along the matrix diagonal both indicate that species collected, primarily by gill net and trap, tend not to be sighted, and those sighted (primarily by fish transecting, although incidental observations have been included) tend not to be collected. These real differences in observed fish populations support the validity of inventorying fish by as many methods as feasible to obtain complete coverage of resident species composition.

ENVIRONMENTAL PREFERENCE RATING

A formal system of recording fish's environmental preference has been developed in an attempt to improve the utilization of fish populations for determining general environmental status. This system has been previously reported (Reference 2.1-5 and 2.1-11) at earlier stages in its development. At its present stage, the system provides a concise way of recording environmental preferences observed in the field and a mathematically rigorous method of converting those preferences into numerical values. This system is not yet complete in the sense that many more field observations are needed to improve the observed species environmental preference ratings; it is presented here mainly as an exemplar of the rating method.

The environmental preference ratings (EPR) for 76 species resident in Pearl Harbor are presented in Table 2.1-15. An arbitrary scale of 0 to 5 is used to indicate environmental preference, 0 signifying clear, coral-reef waters and 5 signifying turbid brackish waters which also may have a high probability of being polluted. The estimated pollution tolerance range is indicated by the bottom row of "x"s immediately following the species name. Environmental preference within this tolerance range is indicated by stacking the "x"s vertically in the appropriate environmental columns. Since the true environmental status of the waters is not yet fully known, the ratings

(Text continued on page 2.1-61)

Table 2.1-12. FISHES PRESENTED ON DISTRIBUTIONAL MAPS

General Feeding Types

Carvinores:

Sphyrna lewini - both benthic and open water piscivore
Elops hawaiiensis - mid-water/ benthic fish & invertebrates
Caranx melampygus - mid-water piscivore
Parupeneus porphyreus - benthic invertebrates

Herbivores: *Acanthurus xanthopterus* - grazer/browser
Naso brevirostris - macrophytic algal feeder
Chanos chanos - unicellular algae (over soft bottom)

Mugil cephalus - a detrital feeder

Omnivores: *Arothron hispidus* - benthic invertebrates, faculative
Chaetodon auriga - benthic invertebrates, corals

Legend for numbers of individuals collected:

•	1-2
●	3-5
●	6-10
●	11-20
●	21-50
●	51+
S	sighted only
O	not collected or sighted

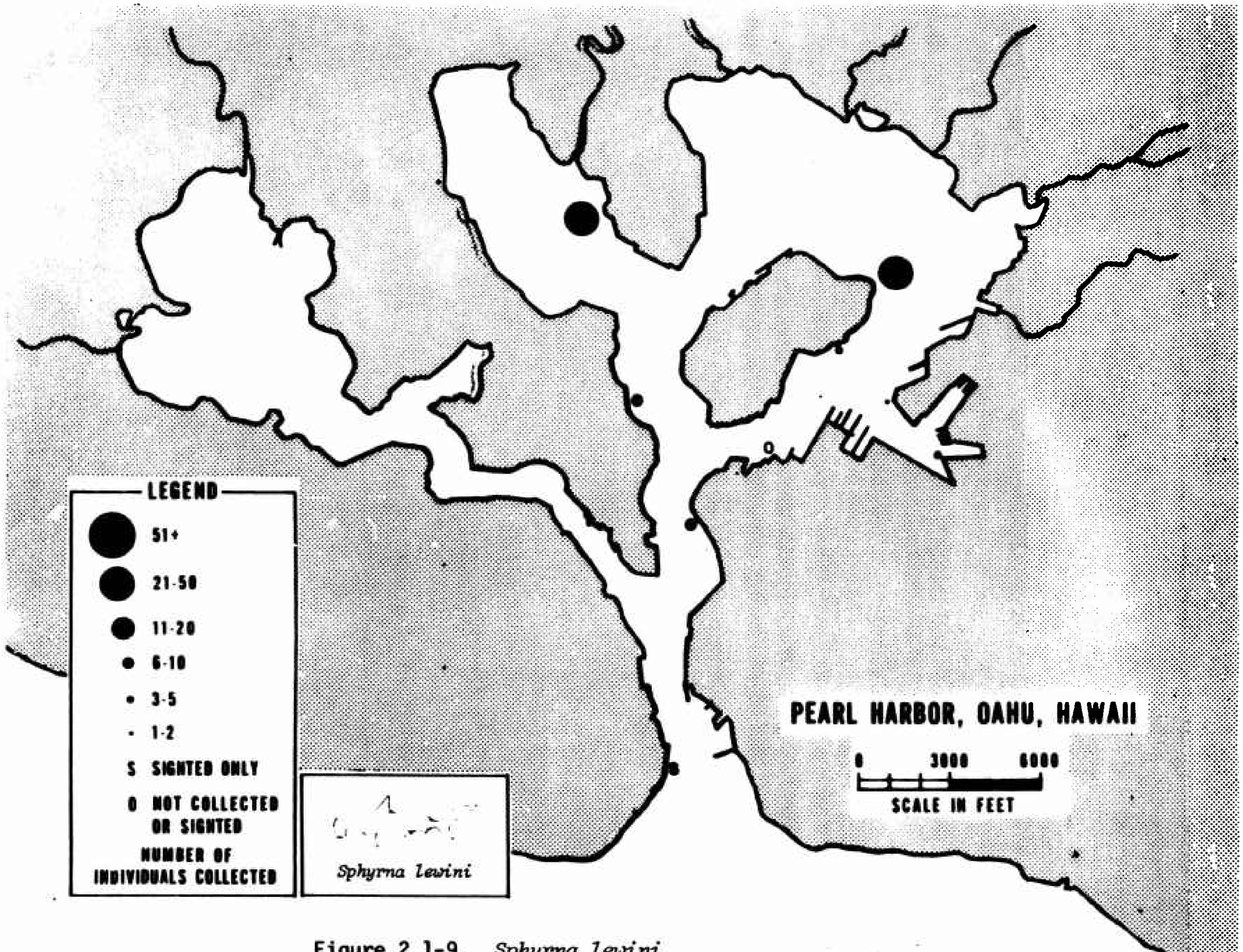


Figure 2.1-9. *Sphyrna lewini*

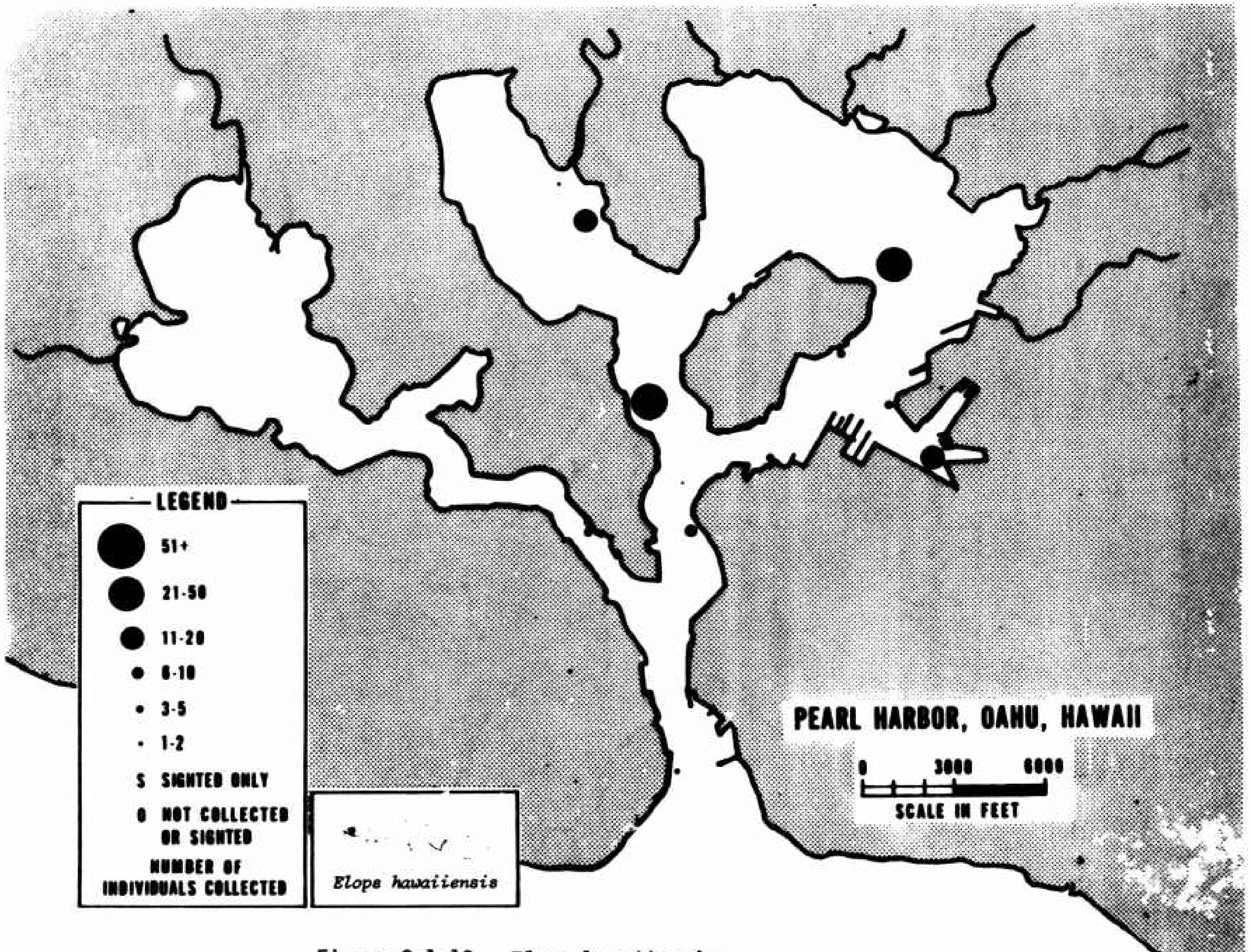


Figure 2.1-10. *Elops hawaiiensis*

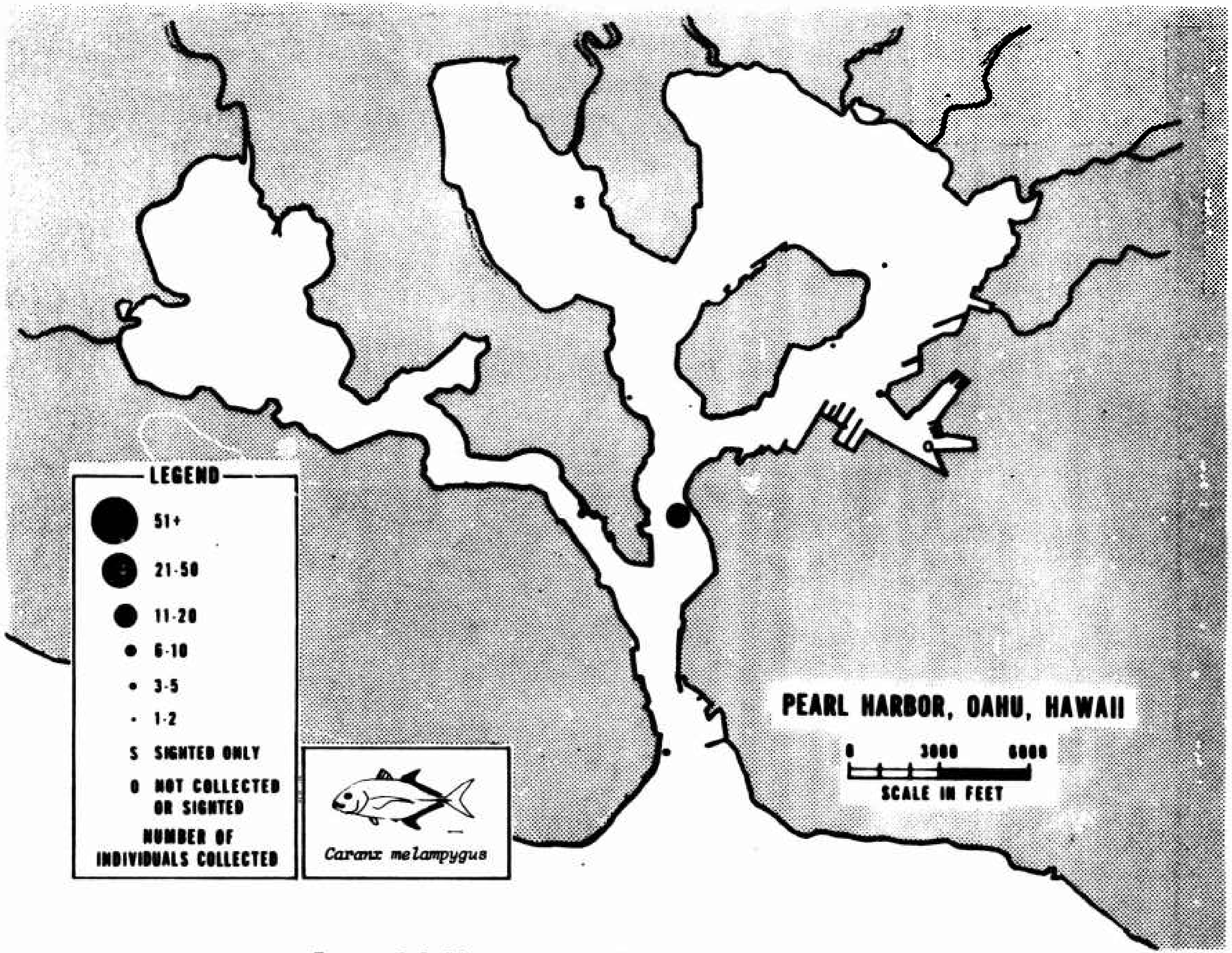


Figure 2.1-11. *Caranx melampygus*

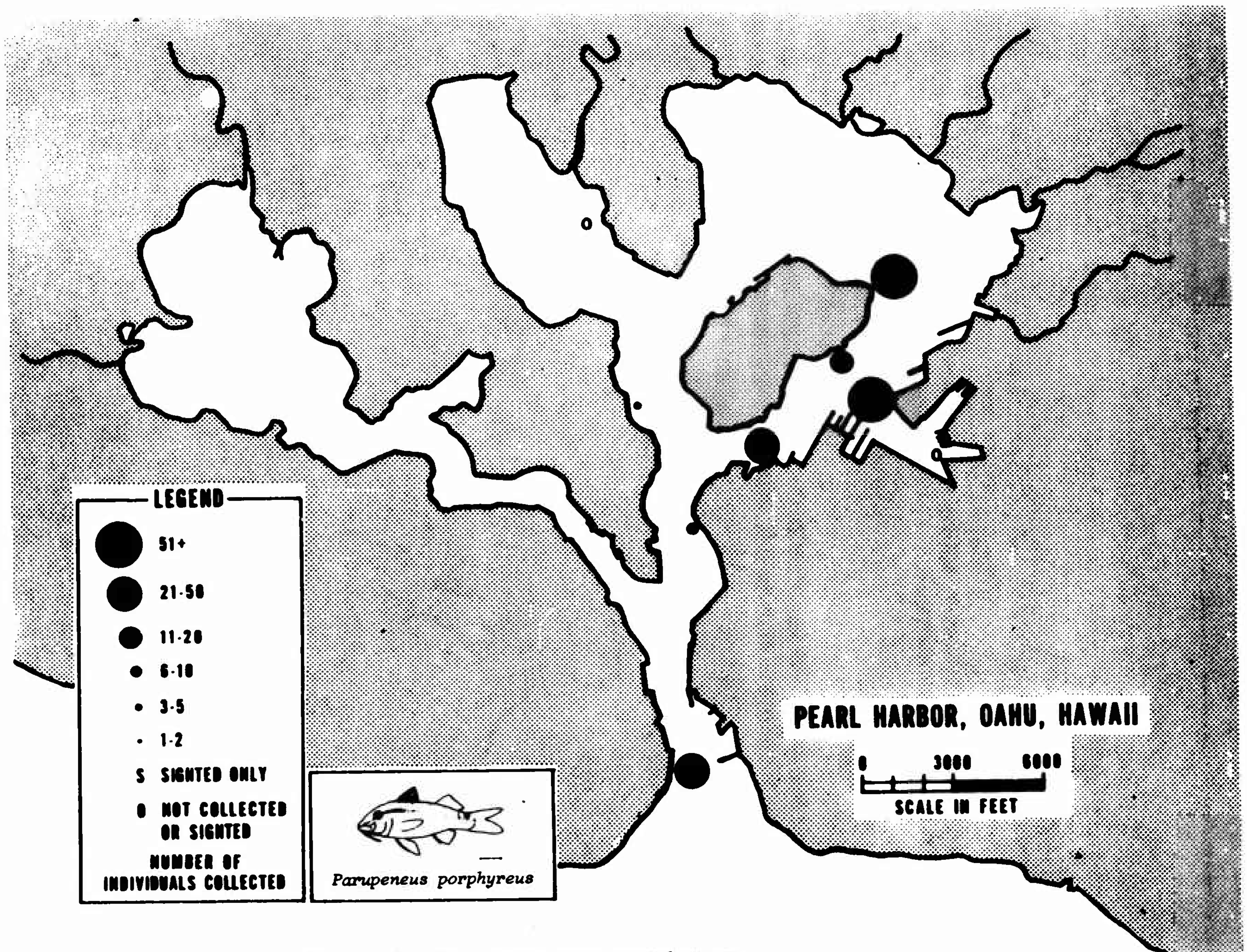


Figure 2.1-12. *Parupeneus porphyreus*

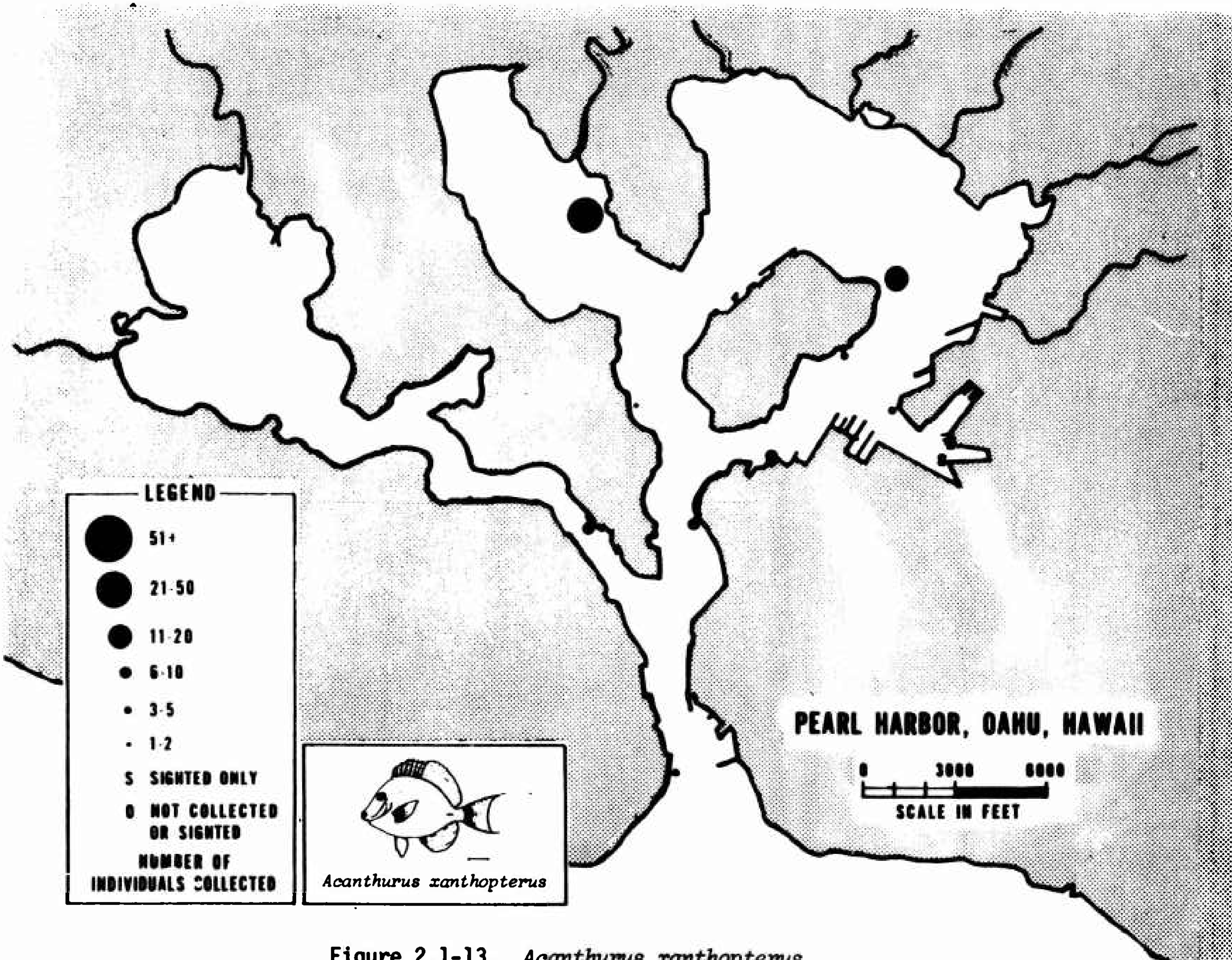


Figure 2.1-13. *Acanthurus xanthopterus*

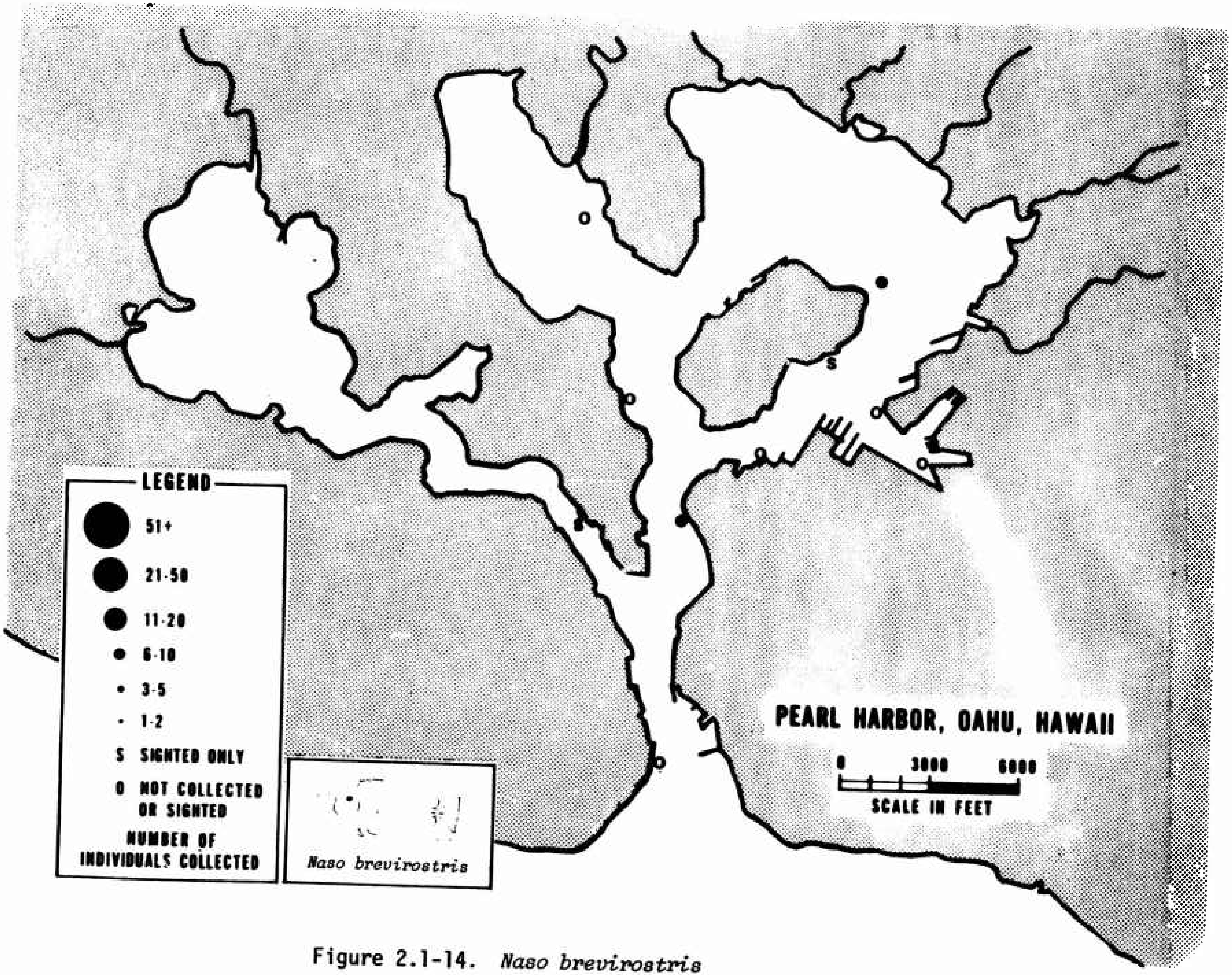


Figure 2.1-14. *Naso brevirostris*

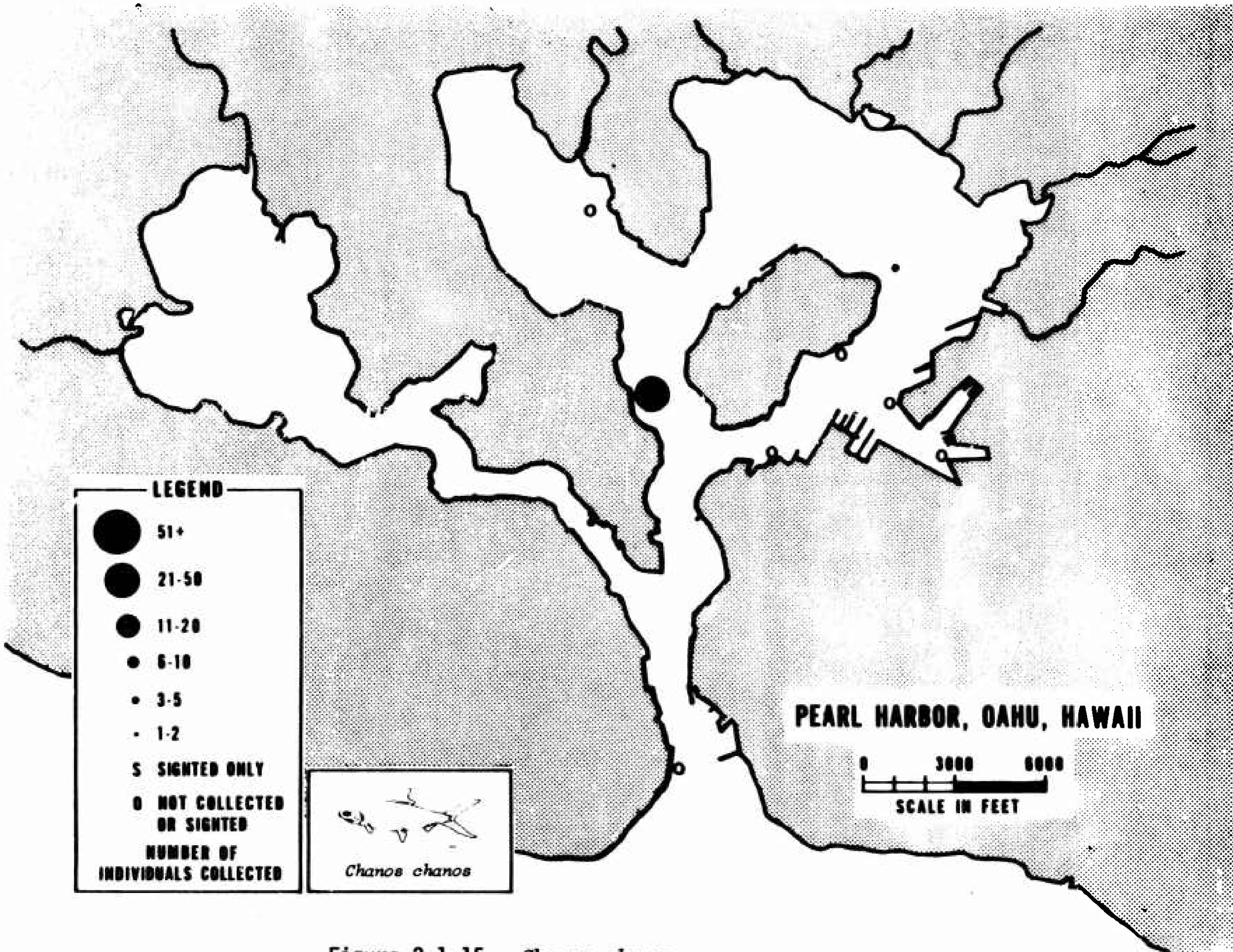


Figure 2.1-15. *Chanos chanos*

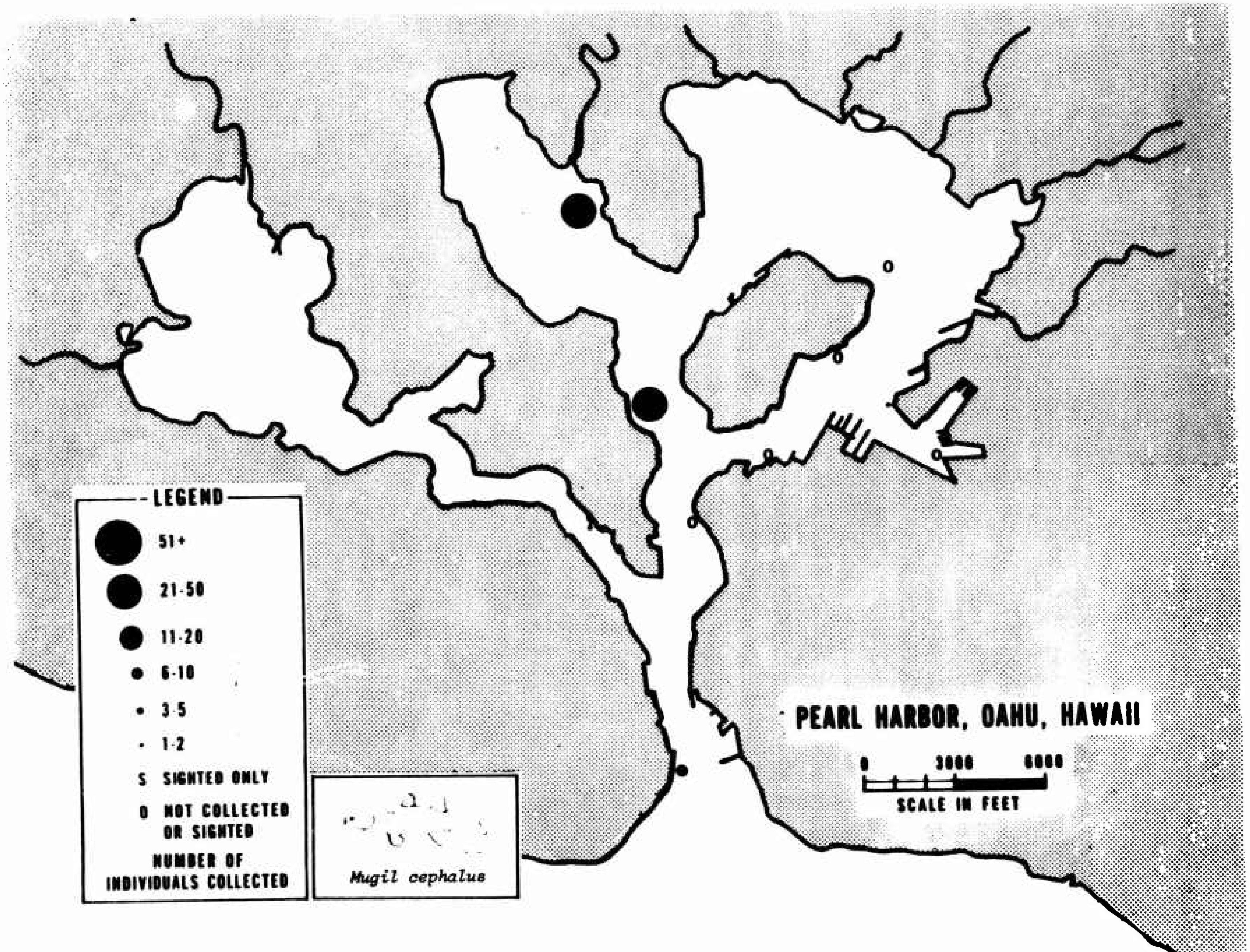


Figure 2.1-16 *Mugil cephalus*

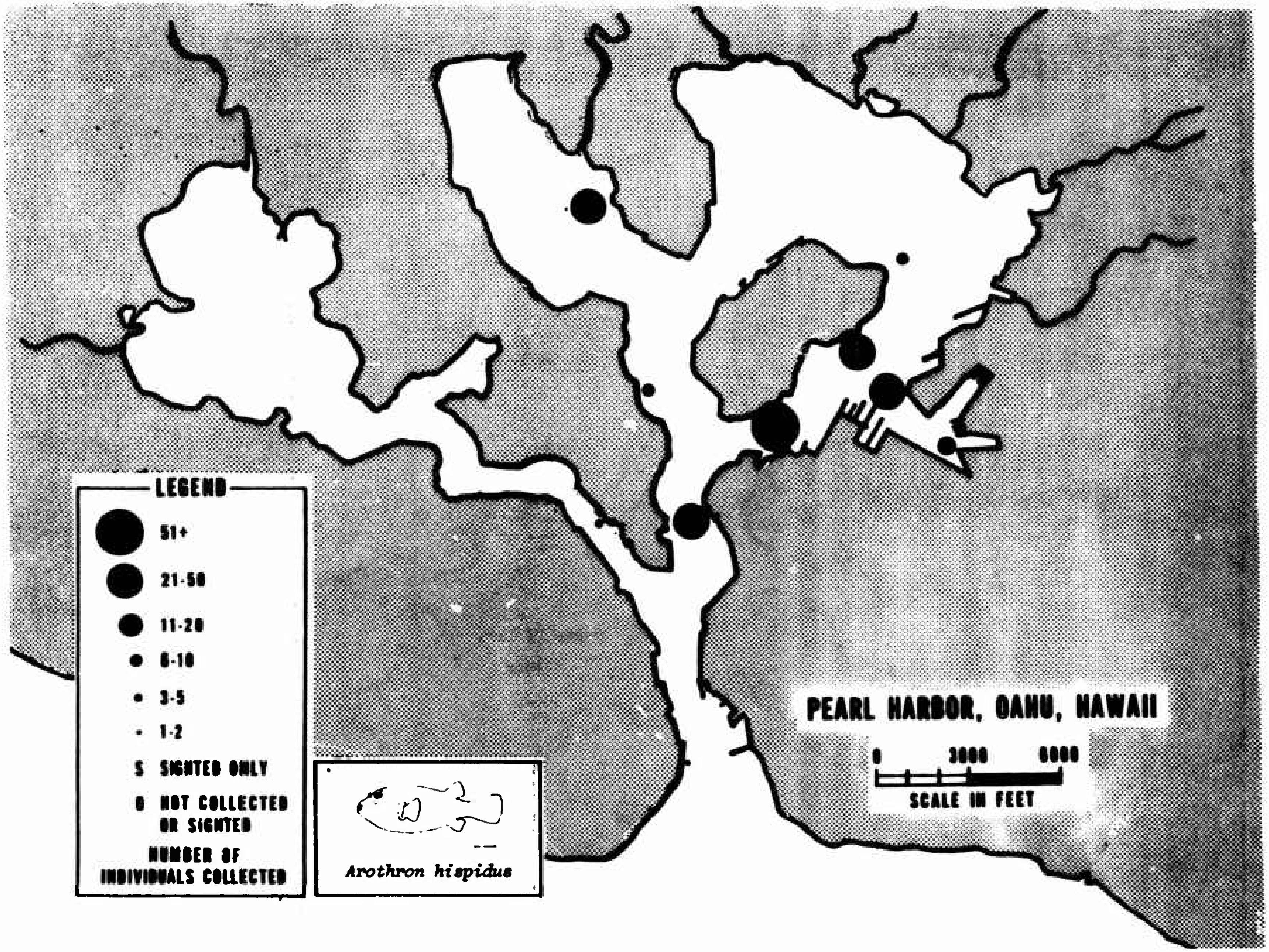


Figure 2.1-17. *Arothron hispidus*

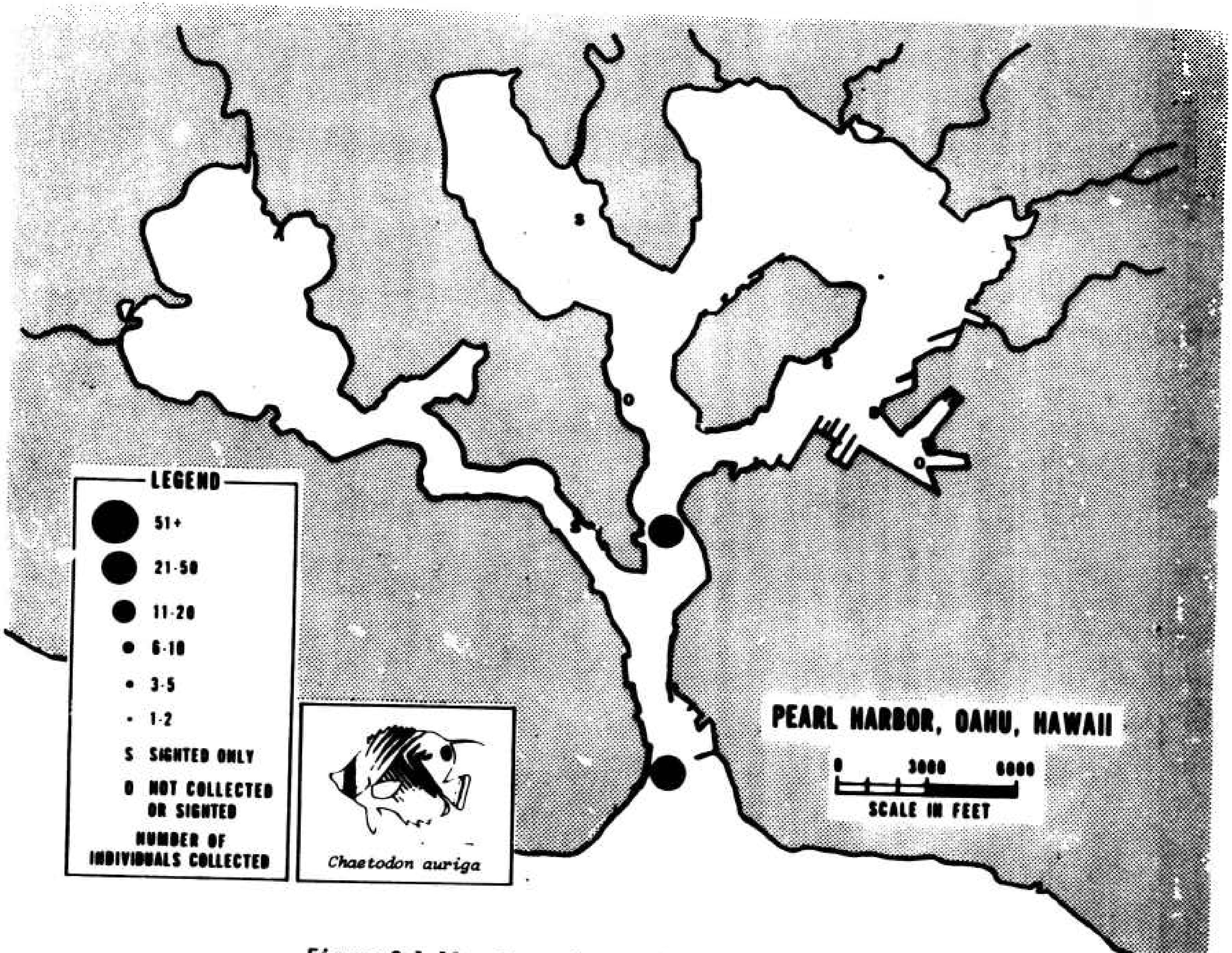


Figure 2.1-18. *Chaetodon auriga*

Table 2.1-13. Part A. RANKED LISTING OF MOST COMMON FISHES BASED UPON COLLECTIONS AND SIGHTINGS AT EACH PHBS BIO-STATION*

Station	From individuals collected	From individuals sighted
BE-02	*Arothron hispidus*	*Kuhlia sandvicensis*
	Parupeneus porphyreus	*Acanthurus xanthopterus*
	Elops hawaiiensis	*Acanthurus triostegus*
	Sphyrna lewini	Labrid (juvenile)
	Acanthurus xanthoperus	*Caranx sp.*
BE-03	*Parupeneus porphyreus*	*Acanthurus xanthopterus*
	Arothron hispidus	*Kuhlia sandvicensis*
	Acanthurus mata	Labrid (juvenile)
	Caranx melampygus	*Abudefduf abdominalis*
	Acanthurus xanthopterus	*Arothron hispidus*
BE-04	*Arothron hispidus*	*Abudefduf* sp. (juvenile)
	Elops hawaiiensis	*Acanthurus xanthopterus*
	Caranx sexfasciatus	*Arothron hispidus*
	Sphyrna lewini	*Scomberoides sancti-petri*
	Scomberoides sancti-petri	*Caranx* sp.
BE-05	*Parupeneus porphyreus*	*Acanthurus xanthopterus*
	Sphyrna lewini	*Acanthurus mata*
	Elops hawaiiensis	*Parupeneus porphyreus*
	Acanthurus xanthopterus	*Abudefduf abdominalis*
	Scomberoides sancti-petri	*Acanthurus triostegus*
BM-07	*Mugil cephalus*	*Acanthurus xanthopterus*
	Arothron hispidus	*Acanthurus mata*
	Acanthurus xanthopterus	*Mugil cephalus*
	Sphyrna lewini	*Arothron hispidus*
	Elops hawaiiensis	*Caranx melampygus*
BC-09	*Mugil cephalus*	*Acanthurus xanthopterus*
	Chanos chanos	*Acanthurus mata*
	Elops hawaiiensis	*Upeneus arge*
	Upeneus arge	
	Albula vulpes	
BC-10	*Chaetodon miliaris*	*Chaetodon auriga*
	Arothron hispidus	*Caranx* sp.
	Chaetodon auriga	*Hemiramphus depauperatus*
	Caranx melampygus	*Acanthurus* sp. (juvenile)
	Chaetodon lunula	*Chaetodon lunula*
BC-11	*Parupeneus porphyreus*	*Acanthurus triostegus*
	Chaetodon miliaris	*Ctenochaetus strigosus*
	Chaetodon auriga	*Chaetodon miliaris*
	Mulloidichthys samoensis	*Abudefduf abdominalis*
	Acanthurus triostegus	*Mulloidichthys samoensis*

Station	From individuals collected	From individuals sighted
BW-13	*Acanthurus xanthopterus*	*Acanthurus xanthopterus*
	Caranx mate	*Caranx melampygus*
	Albula vulpes	*Abudefduf abdominalis*
	Elops hawaiiensis	*Mulloidichthys samoensis*
	Kuhlia sandvicensis	*Acanthurus mata*
BE-17	*Arothron hispidus*	*Acanthurus xanthopterus*
	Parupeneus porphyreus	*Arothron hispidus*
	Acanthurus xanthopterus	Labrid sp. (juvenile)
	Elops hawaiiensis	*Chaetodon lunula*
	Chaetodon auriga	*Parupeneus porphyreus*

* Ranked listing excludes gobies, eleotrids, blennies and juveniles of several species which are considered too numerous to accurately count on visual transects; these cryptic species have also been excluded from quantitative considerations of other recent researchers (see text).

Table 2.1-13. Part B. ALPHABETIC LISTING OF FISHES APPEARING IN THE ABOVE RANKING OF COMMON SPECIES

COLLECTED (times)	SIGHTED (times)	TOTAL
	Abudefduf abdominalis (4)	4
	Abudefduf sp. (juv.) (1)	1
Acanthurus mata (1)	*Acanthurus mata* (4)	5
Acanthurus triostegus (1)	*Acanthurus triostegus* (2)	3*
Acanthurus xanthopterus (6)	*Acanthurus xanthopterus* (8)	14*
	Acanthurus sp. (juv.) (1)	1
Albula vulpes (2)		2
Arothron hispidus (6)	*Arothron hispidus* (4)	10*
Caranx mate (1)		1
Caranx melampygus (2)	*Caranx melampygus* (2)	4
Caranx sexfasciatus (1)		1
	Caranx sp. (3)	3*
Chaetodon auriga (3)	*Chaetodon auriga* (1)	4*
Chaetodon lunula (1)	*Chaetodon lunula* (2)	3*
Chaetodon miliaris (2)	*Chaetodon miliaris* (1)	3*
Chanos chanos (1)		1
	Ctenochaetus strigosus (1)	1
Elops hawaiiensis (7)		7
	Hemirhamphus depauperatus (1)	1
Kuhlia sandvicensis (1)	*Kuhlia sandvicensis* (2)	3
	Labrid (juv.) (3)	3
Mugil cephalus (2)	*Mugil cephalus* (1)	3*
Mulloidichthys samoensis (1)	*Mulloidichthys samoensis* (2)	3*
Parupeneus porphyreus (5)	*Parupeneus porphyreus* (2)	7*
Scomberoides sancti-petri (2)	*Scomberoides sancti-petri* (1)	3*
Sphyrna lewini (4)		
Upeneus arge (1)	*Upeneus arge* (1)	2*
20 species	19 species	

* appearing in intercomparison matrix, Table 2.1-14

Table 2.1-14 INTERCOMPARISON OF RANKINGS OF COMMON FISH BY COLLECTION AND BY SIGHTING

RANK BASED ON SPECIES COLLECTION

RANK BASED ON SPECIES SIGHTED	1st	2nd	3rd	4th	5th
1st	Ax 13	0	Ax 07 Ax 17 Cha 10	Ax 05	Ax 03 At 11
2nd	Ah 17	0	0	0	Ax 02
3rd	Ah 04 Pp 05 Mc 07	Chm 11	0	Ua 09	0
4th*	0	Ah 07	0	0	Ss 05
5th*	0	Ah 03	Csp 04	Ms 11	Chl 10

key:

Ah	= *Arothron hispidus*	02	= BE-02
At	= *Acanthurus triostegus*	03	= BE-03
Ax	= *Acanthurus xanthopterus*	04	= BE-04
Cha	= *Chaetodon auriga*	05	= BE-05
Chl	= *Chaetodon lunula*	07	= BM-07
Chm	= *Chaetodon miliaris*	09	= BC-09
Csp	= *Caranx* sp.	10	= BC-10
Mc	= *Mugil cephalus*	11	= BC-11
Ms	= *Molloidichthys samoensis*	13	= BW-13
Pp	= *Parupeneus porphyreus*	17	= BE-17
Ss	= *Scomberoides sancti-petri*		
Ua	= *Upeneus arge*		

* because only 3 sightings are listed for bio-station BC-09, intercomparison in these two rows is incomplete

Table 2.1-15. ESTIMATED ENVIRONMENTAL PREFERENCES FOR FISHES COMMON TO PEARL HARBOR.

Species	Environ. Pref. Rating						Q	f
	0	1	2	3	4	5		
			x	x				
		x	x	x	x			
Abudefduf abdominalis	x	x	x	x	x	x	25	1.5
			x	x				
		x	x	x	x			
Abudefduf sordidus	x	x	x	x	x	x	25	1.5
	x	x						
	x	x	x					
Acanthurus dussumieri	x	x	x	x			11	2.3
	x	x	x					
	x	x	x	x				
Acanthurus mata	x	x	x	x	x		16	1.8
	x							
	x	x						
Acanthurus olivaceus	x	x					4	2.8
	x	x	x	x				
	x	x	x	x	x			
Acanthurus triostegus	x	x	x	x	x	x	21	1.0
		x	x	x	x			
		x	x	x	x			
Acanthurus xanthopterus	x	x	x	x	x	x	25	1.2
			x	x				
	x	x	x	x	x	x		
Aetobatus narinari	x	x	x	x	x	x	25	0.9
		x	x					
	x	x	x	x				
Albula vulpes	x	x	x	x	x		17	1.9
	x	x						
	x	x	x					
Apogon snyderi	x	x	x	x			11	2.3
		x	x	x	x			
	x	x	x	x	x	x		
Arothron hispidus	x	x	x	x	x	x	25	0.6

Table 2.1-15. (Continued)

Species	Environ. Pref. Rating 0	1	2	3	4	5	Q	f
Asterropteryx semipunctatus	X	X X	X X X	X X X	X X	X	25	1.5
Aulostomus chinensis	X X X	X X X					5	2.7
Bathygobius fuscus	X X	X X X	X X X	X X X	X		18	1.8
Bothus pantherinus	X	X X	X X X	X X X	X X	X	25	1.5
Brachirus barberi	X X	X X X	X X X	X X X	X X	X	22	1.2
Calotomus spinidens	X X X	X X X					5	2.7
Canthigaster coronatus	X X X	X X					4	2.8
Caranx ignobilis	X	X X	X X X	X X X	X X	X	25	1.5
Caranx mate	X	X X	X X X	X X X	X X X	X	26	1.4
Caranx melampygus	X X	X X X	X X X	X X X	X		18	1.8
Caranx sexfasciatus	X X	X X X	X X X	X X X	X		18	1.8

Table 2.1-15. (Continued)

Species	Environ. Pref. Rating 0	1	2	3	4	5	Q	f
Carcharhinus limbatus	X X	X X	X X X	X X X	X X	X X	25	0.9
Chaetodon auriga	X	X X X	X X X	X X X	X X	X	24	1.4
Chaetodon lunula	X X	X X X	X X X	X X	X		17	1.9
Chaetodon miliaris	X X	X X X	X X X	X X X	X X		20	1.6
Cheilio inermis	X X X	X X	X				7	2.7
Chanos chanos	X X X	X X X	X X X	X X X	X X	X	21	1.0
Conger marginatus	X X X	X X X	X X X	X X X			15	1.8
Ctenochaetus strigosus	X X	X X X	X X X	X X X	X		18	1.8
Dascyllus albisella	X X X	X X X	X X X	X X	X		16	1.8
Diodon holocanthus	X X X	X X X	X X	X X			13	2.1
Diodon hystrix	X X X	X X X	X X	X X			13	2.1

Table 2.1-15. (Continued)

Species	Environ. Pref. Rating 0	1	2	3	4	5	Q	f
			x	x				
		x	x	x	x			
Elops hawaiiensis	x	x	x	x	x	x	25	1.5
	x	x	x					
	x	x	x					
Entomacrodus marmoratus	x	x	x				10	2.4
	x	x						
	x	x	x					
Flammeo sammara	x	x	x	x			11	2.3
			x	x				
		x	x	x	x			
Foa brachygrammus	x	x	x	x	x	x	25	1.5
		x	x	x				
	x	x	x	x	x			
Gnathanodon speciosus	x	x	x	x	x		20	1.6
		x	x					
	x	x	x	x				
Gymnothorax flavimarginatus	x	x	x	x			15	2.1
	x	x	x					
	x	x	x					
Gymnothorax petelli	x	x	x				10	2.4
	x	x	x	x	x			
	x	x	x	x	x			
Gymnothorax undulatus	x	x	x	x	x		20	1.2
			x	x				
		x	x	x	x			
Hemiramphus depauperatus	x	x	x	x	x	x	25	1.5
	x							
	x	x						
Heniochus acuminatus	x	x					4	2.8
			x	x				
		x	x	x	x			
Kuhlia sandvicensis	x	x	x	x	x	x	25	1.5

Table 2.1-15. (Continued)

Species	Environ. Pref. Rating						Q	f
	0	1	2	3	4	5		
	x	x						
	x	x						
Kyphosus cinerascens	x	x					5	2.7
	x	x						
	x	x						
Labroides phthirophagus	x	x					5	2.7
		x	x					
	x	x	x	x				
Lutjanus fulvus	x	x	x	x	x		17	1.9
	x	x						
	x	x						
Microcanthus strigatus	x	x					5	2.7
					x	x		
					x	x		
Mollienisia latipinna				x	x	x	43	2.6
		x	x	x	x			
		x	x	x	x			
Mugil cephalus	x	x	x	x	x	x	25	1.2
	x	x	x					
	x	x	x	x				
Mulloidichthys samoensis	x	x	x	x	x		16	1.8
	x	x						
	x	x	x					
Myripristis murdjan	x	x	x	x			11	2.3
	x	x	x					
	x	x	x	x				
Naso brevirostris	x	x	x	x	x		16	1.8
	x	x						
	x	x						
Naso unicornis	x	x					5	2.7
	x	x						
	x	x	x					
Omobranchus elongatus	x	x	x	x			11	2.3

Table 2.1-15. (Continued)

Species	Environ. Pref. Rating 0	1	2	3	4	5	Q	f
	x	x						
	x	x						
Ostracion meleagris camurum	x	x					5	2.7
	x	x						
	x	x	x					
Parupeneus pleurostigma	x	x	x	x			11	2.3
	x	x						
	x	x	x					
Parupeneus multifasciatus	x	x	x	x			11	2.3
			x	x				
	x	x	x	x	x			
Parupeneus porphyreus	x	x	x	x	x	x	23	1.3
	x	x						
	x	x						
Pervagor spilosoma	x	x					5	2.7
	x	x	x					
	x	x	x	x				
Polydactylus sexfilis	x	x	x	x	x		16	1.8
	x							
	x	x						
Priacanthus cruentatus	x	x					4	2.8
	x	x						
	x	x	x					
Saurida gracilis	x	x	x	x			11	2.3
	x	x						
	x	x						
Scarus sordidus	x	x					5	2.7
			x	x				
		x	x	x	x			
Scomberoides sancti-petri	x	x	x	x	x	x	25	1.5
			x	x				
		x	x	x	x			
Sphyraena barracuda	x	x	x	x	x	x	25	1.5

Table 2.1-15. (Continued)

Species	Environ. Pref. Rating						Q	f
	0	1	2	3	4	5		
			x	x				
	x	x	x	x	x	x		
Sphyrna lewini	x	x	x	x	x	x	25	0.9
	x	x	x					
	x	x	x	x				
Stethojulis balteatus	x	x	x	x			14	2.0
			x	x				
		x	x	x	x			
Stolephorus purpureus	x	x	x	x	x	x	25	1.5
	x	x						
	x	x						
Synodus variegatus	x	x	x				7	2.6
					x	x		
				x	x	x		
Tilapia mossambica			x	x	x	x	39	2.3
		x	x	x				
		x	x	x				
Tylosurus crocodilus	x	x	x	x	x		20	2.0
			x	x				
		x	x	x	x			
Upeneus arge	x	x	x	x	x	x	25	1.5
	x	x						
	x	x	x					
Zanclus canescens	x	x	x	x			11	2.3
	x	x	x					
	x	x	x	x				
Zebrasoma flavescens	x	x	x	x	x		16	1.8
	x	x	x					
	x	x	x	x				
Zebrasoma veliferum	x	x	x	x	x		16	1.8

shown in Table 2.1-15 are somewhat subjective; this limitation can, however, be corrected with further field observation. The system is flexible and unambiguous. Once the field of "x"s under environmental preference is completed, the environmental preference rating, Q, and the preference strength, f, are rigorously determined. The Q-value is simply ten times the average of all "x"s in the field, giving each "x" the value of the EPR column under which it appears. The f-value, which is an expression of the strength of preference, is determined as follows: Starting near the center of the field of "x"s, choose one of the highest columns of "x"s. Give all "x"s in that column a value of +10 and sum the column. Next, subtract from that sum all "x"s in the two nearest columns, giving these "x"s a value of -1. Next, subtract from the remaining sum all "x"s in the next two nearest columns, giving these "x"s a value of -2. Next, subtract from the remaining sum all remaining "x"s, giving each a value of -4. Divide the result by 10 to obtain the f-value. This procedure will give an f-value of 3.0 for a single column of 3 "x"s and a value of 0 for a field in which all six EPR columns are filled with "x"s. The calculated Q-values and f-values are given in Table 2.1-15.

These Q and f values are used with the fish catch data (Table 2.1-6) to estimate environmental status either on the basis of presence/absence (P/A) data or abundance data. Many environmental indices may be used. An index used in previous reports (Reference 2.1-5) is:

$$\text{Index B}' = \frac{\Sigma f_i Q_i}{n \Sigma f_i}$$

where n = number of species, and f and Q are as defined above.

A plot of the Pearl Harbor bio-stations so ranked is shown in Figure 2.1-19. In this plot, the lower B' values represent unpolluted conditions while high values represent the reverse. Most of the Pearl Harbor bio-stations are rated at nearly the same state of pollution. BC-11 is singular as a bio-station exhibiting low pollution, while BE-04 exhibits a high state of pollution. This situation is the result of two factors. As later shown in Section 4.2, water quality is nearly uniform throughout most of the inner harbor; this situation also appears to be indicated by Index B' as well as by other statistical analyses based on fish populations (Section 4.3). A second factor which tends to cause uniformity is the natural conservatism of the biologists making the environmental preference ratings. Of the 76 species listed in Table 2.1-15, 29 or almost 40% are listed with Q-values between 20 and 30. Although this could be the actual situation in a harbor like Pearl, it is more likely to be due to conservative rating procedures. The situation is more forcefully illustrated in Figure 2.1-20, where the sum of the f-values in each Q class is plotted for the 10 bio-station fish catches. The very high central values are readily apparent; however, the uniqueness of bio-station BC-11 is still apparent despite the masking of this central tendency. The additional fact that f-values tend to be low for centrally rated fish only further emphasizes the differences shown in the plot.

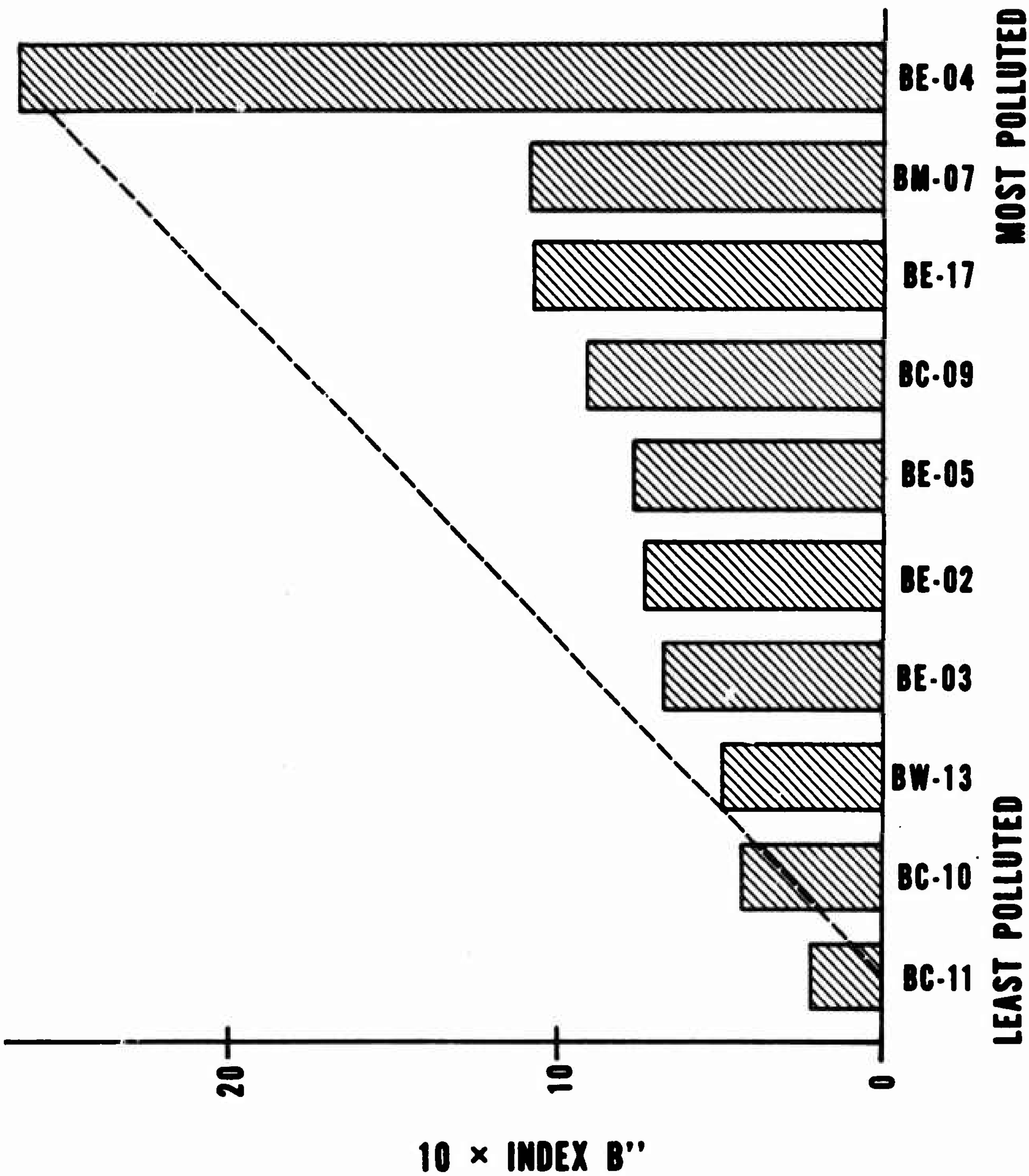
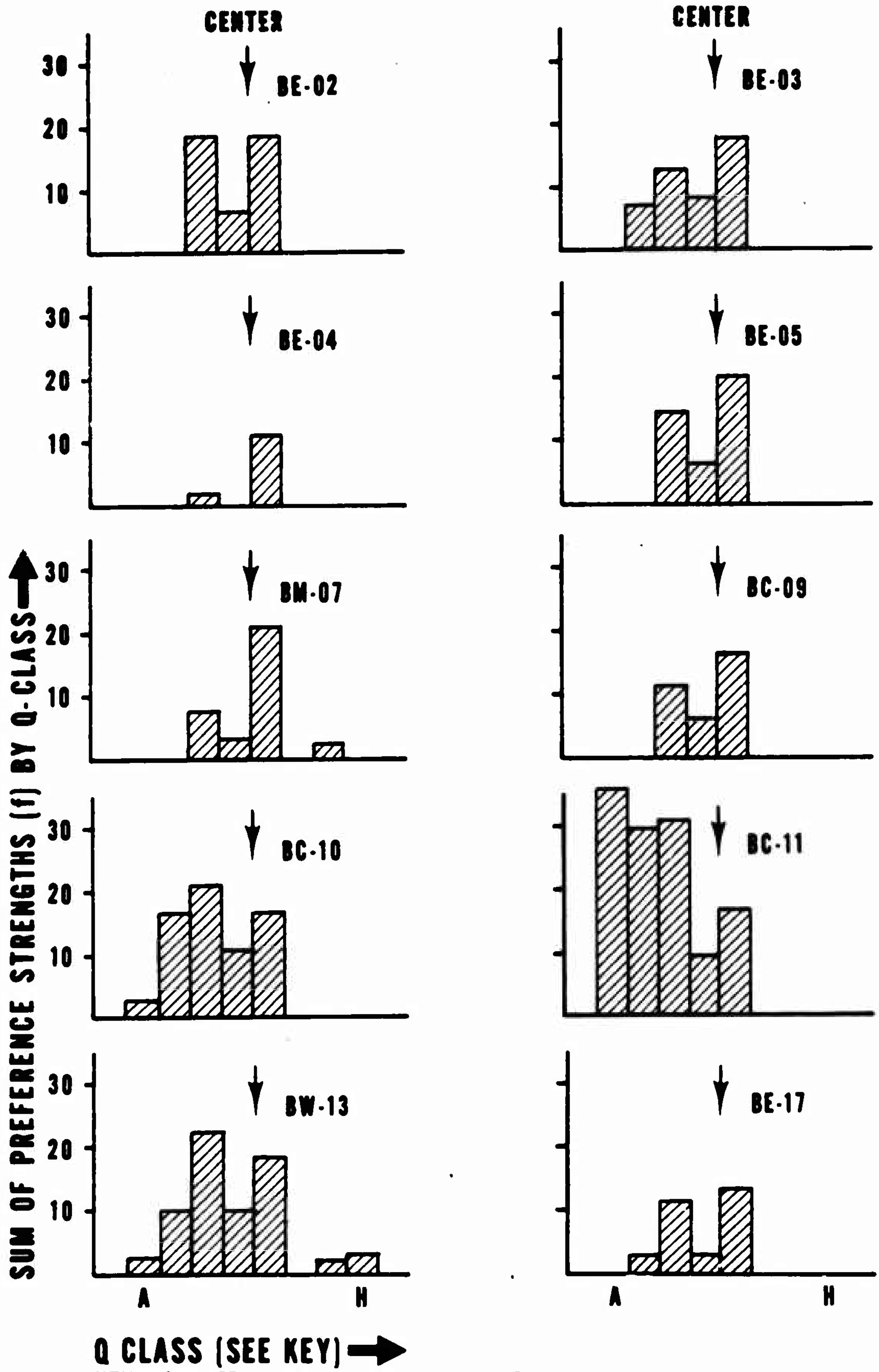


Figure 2.1-19. HISTOGRAM OF PHBS BIO-STATIONS RANKED BY INDEX "B" (SEE TEXT)



KEY A = EPR from 0 to 6, B = 7-12, C = 13-18, D = 19-24,
E = 25-30, F = 31-36, G = 37-42, H = 43-48

Figure 2.1-20. HISTOGRAM OF SUMMED ENVIRONMENTAL PREFERENCE STRENGTH, f, FOR EACH BIO-STATION

REFERENCES

2.1-1 P. Humphrey Greenwood, et al (1966), "Phyletic Studies of Teleostean Fishes, with a Provisional Classification of Living Forms", Bulletin of the American Museum of Natural History, New York.

2.1-2 Personal communication with Dr. John E. Randall (January 1973), Bernice Pauhi Bishop Museum, Honolulu.

2.1-3 William A. Gosline and Vernon E. Brock (1960), Handbook of Hawaiian Fishes, University of Hawaii Press, Honolulu.

2.1-4 Robert W. Hiatt and Donald W. Strasburg (1960), Ecological Relationships of the Fish Fauna on Coral Reefs of the Marshall Islands, Ecological Monographs, Vol. 30, No. 1. (Also published as HIMB Contribution No. 128).

2.1-5 T. J. Peeling, J. G. Grovhoug, and Evan C. Evans III, "PHBS: Report on First Survey Cycle" (August 1972), NUC TN-801, Hawaii Laboratory.

2.1-6 Dr. Stephen V. Smith, et al (February 1973), Atlas of Kaneohe Bay: A Reef Ecosystem Under Stress, UNIHI Seagrant TR 72-01, Honolulu.

2.1-7 John C. McCain and James Peck (1972), "Kahe Fish Survey", Environmental Report prepared by Hawaiian Electric Company's Environmental Office.

2.1-8 Robert R. Sokal and F. James Rohlf (1969), Biometry: The Principles and Practice of Statistics in Biological Research, W. H. Freeman Company, San Francisco.

2.1-9 A. L. Tester (1951), "The Distribution of Eggs and Larvae of the Anchovey, *Stolephorus purpureus* Fowler in Kaneohe Bay, Oahu, with a Consideration of the Sampling Problem", Pacific Science, 5(4):321-346.

2.1-10 Dr. Thomas A. Clarke (April 1971), "The Ecology of the Scalloped Hammerhead Shark, *Sphyrna lewini*, in Hawaii", Pacific Science, 25(2):133-144.

2.1-11 "Surveillance, Sewage and Surprises", Navy Action '72, pages 59-76, Environmental Conference on Monitoring and Surveillance of Pollution, April 20-21, Honolulu.

BENTHIC SURVEY

J. Geoffrey Grovhoug
Eric B. Guinther

GENERAL INFORMATION

Benthic marine organisms, i.e. those which live either on and/or in bottom sediments, were collected from ten stations located in Pearl Harbor, Oahu (Figure 1.0-1) during the period from 18 January 1972 to 7 April 1972. The rationale for sampling benthic organisms during this baseline study includes: 1) benthic organisms constitute a major percentage of the biota in nearshore marine ecosystems (in terms of both number of species and number of individuals; 2) the benthos are highly important food organisms for larger invertebrates, fishes (see Appendix B and Holme, Reference 2.2-1), and for man in most coastal areas; 3) benthic organisms are directly exposed to contaminants which are present in both the bottom substrata and the water column; 4) the benthos are indirectly exposed to various other stresses (such as surface oil, red tides, effluent discharges, ship-propagated turbulence, etc.) which may characterize naval harbor operations; and 5) the benthic organisms are usually present in sufficient numbers within a relatively small area to provide an easily collected, reliable and reproducible statistical basis for general evaluation of naval harbor complexes.

Thorson (Reference 2.2-2) provides a convenient description of three essential component groups of organisms inhabiting benthic marine environments: 1) the epifauna (Figure 2.2-1), "comprising all animals living upon or associated with rocks, stones, shells, vegetation..." and typified in Pearl Harbor by organisms such as bryozoans, shrimp, tunicates, anemones, etc.; 2) the infauna (Figure 2.2-2) "comprising all animals inhabiting the sandy or muddy surface layers (of the bottom)... i.e. living buried or digging in a substratum..." typified in Pearl Harbor by organisms such as alpheid shrimp, bivalve mollusca, certain errant and sedentary polychaetes, sipunculid worms, etc.; and 3) "bottom dwelling fishes and motile invertebrates..." typified in Pearl Harbor by organisms such as gobies, shrimp and crabs which are intimately related to the other organisms of the benthos. The first two groups (epifauna and infauna) have been intensively sampled during the benthic survey; the third group has been examined in the fish survey and additionally, through general diving observations at each bio-station.

An inadequate standardization of sampling methods for benthic organisms has often precluded any meaningful comparison of data. With this perspective, the Pearl Harbor benthic survey methods are being presented in detail for evaluation as a standard for future surveys.

METHODS

A standard of methodology for sampling the benthic environment has been lacking in many geographical areas, even in locations as intensively studied as San Francisco Bay (Nicols, Reference 2.2-3). A 0.3 ft^3 bottom sampler for potential navy use was designed and used for the collection of adequate and comparable (Jerome, et. al., Reference 2.2-4) amounts of bottom sediments. The sampler can be efficiently operated by two SCUBA divers (thus eliminating the "blind" sampling effect of surface-operated grabs). The sampler functions efficiently to sample a wide range of benthic organisms (even highly motile shrimp, crabs and bottom fishes) within a reproducible sample size.

Figure 2.2-1. CLOSEUP OF TYPICAL EPIFAUNAL COMMUNITY. (Modified from Thorson, Reference 2.2-2)

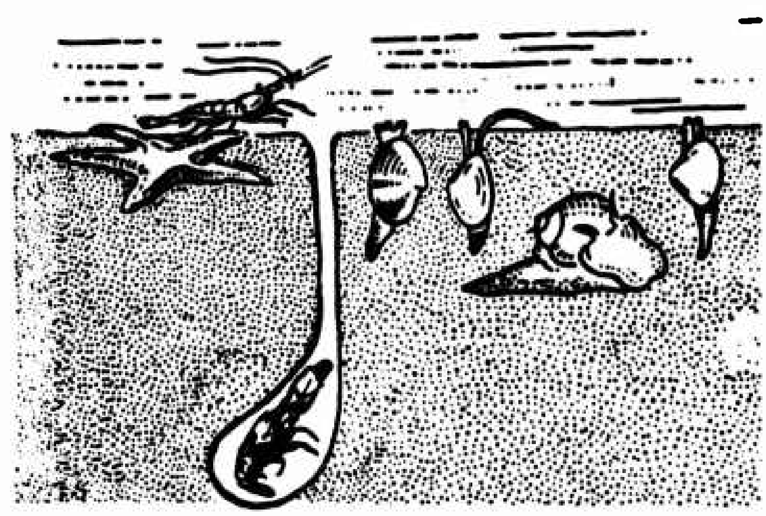


Figure 2.2-2. CROSS SECTIONAL VIEW OF TYPICAL INFAUNAL COMMUNITY. (Modified from Thorson, Reference 2.2-2)

During the benthic survey, all available bottom substrate types were sampled at each bio-station, with an average of three samples per station. The number of substrate types present was determined subjectively through diving observations of the entire bio-station several weeks prior to collection of the samples. A minimum of two samples per station were collected during each series. Replicate sampling (5 samples/substrate/station) was conducted at all ten bio-stations. One complete series consisting of 29 samples (sampling each major substrate per station at all ten stations) required five full field days of effort. Three of these series (87 samples) have been completely analyzed and are presented in this report. An analysis of all benthic algae contained in 145 benthic samples has been completed, however, and is provided herein. Only 83 benthic samples (which contained organisms) were subjected to multivariate statistical analysis. The four samples which contained no organisms were: #11506, BE-05, 38'; #12202, BE-04, 44'; #12307, BC-11, 38' and #12506, BE-05, 40' (# indicates sample number).

All PHBS benthic faunal samples were collected with a diver-operated bottom sampler designed by T. J. Peeling and J. G. Grovhoug, NUC Hawaii Laboratory (see Figure 2.2-3). The sampler consists of a 12" x 12" x 4" aluminum box-scoop with forward and after sliding doors. The sampling device is fitted with large handles so that two SCUBA divers (one on either side) can push the scoop through soft sediment to collect the sample. After the sliding doors are removed, the scoop is pushed into the sediment to a depth of four inches. The sampler is then moved horizontally until the metal box is entirely filled with sediment and associated organisms. The end doors are replaced, thus securely enclosing a 0.3 ft^3 sample. The sample is then brought to the surface and is screened in the diving boat using surface water. The fraction of material retained between ½ inch and 420 micron standard screen size (including all organisms larger than ½ inch) is then placed in one or two one-gallon plastic containers and frozen at the end of the working day. Usually six such samples were collected during a sampling day. The bottom sampler proved effective for collecting some motile organisms such as gobioid fishes and shrimp as well as the benthic epifaunal and infaunal organisms.

Geographic locations of specific benthic sampling sites at each bio-station may be located in the plan views (block D's in Figures 1.0-3 through 1.0-12, in Section 1.0). Depths of these samples may be observed from contour lines (block C's, Section 1.0) and are also summarized with other pertinent field data in Table 2.2-1.

Bottom sample processing was performed through two series of contracts: 1) initial sorting into phyla by Pan Pacific Institute of Ocean Science (four biological technicians), and 2) final identification, enumeration and weighing by Environmental Consultants, Inc. All taxonomic identifications were made by Eric B. Guinther, a graduate student at the University of Hawaii's marine laboratory (HIMB, Coconut Island) or by specialists on certain taxa to whom Mr. Guinther sent specimens. In the laboratory a small number of samples (3-5) were removed from the freezer and allowed to thaw.

Primary sorting was conducted as soon as possible after thawing, usually within half a working day. All separated material was fixed in a 10% formalin solution. Although a consistent 12" x 12" x 4" (approximately 8 quarts) sample was collected in the field, volumes after field screening varied from one pint

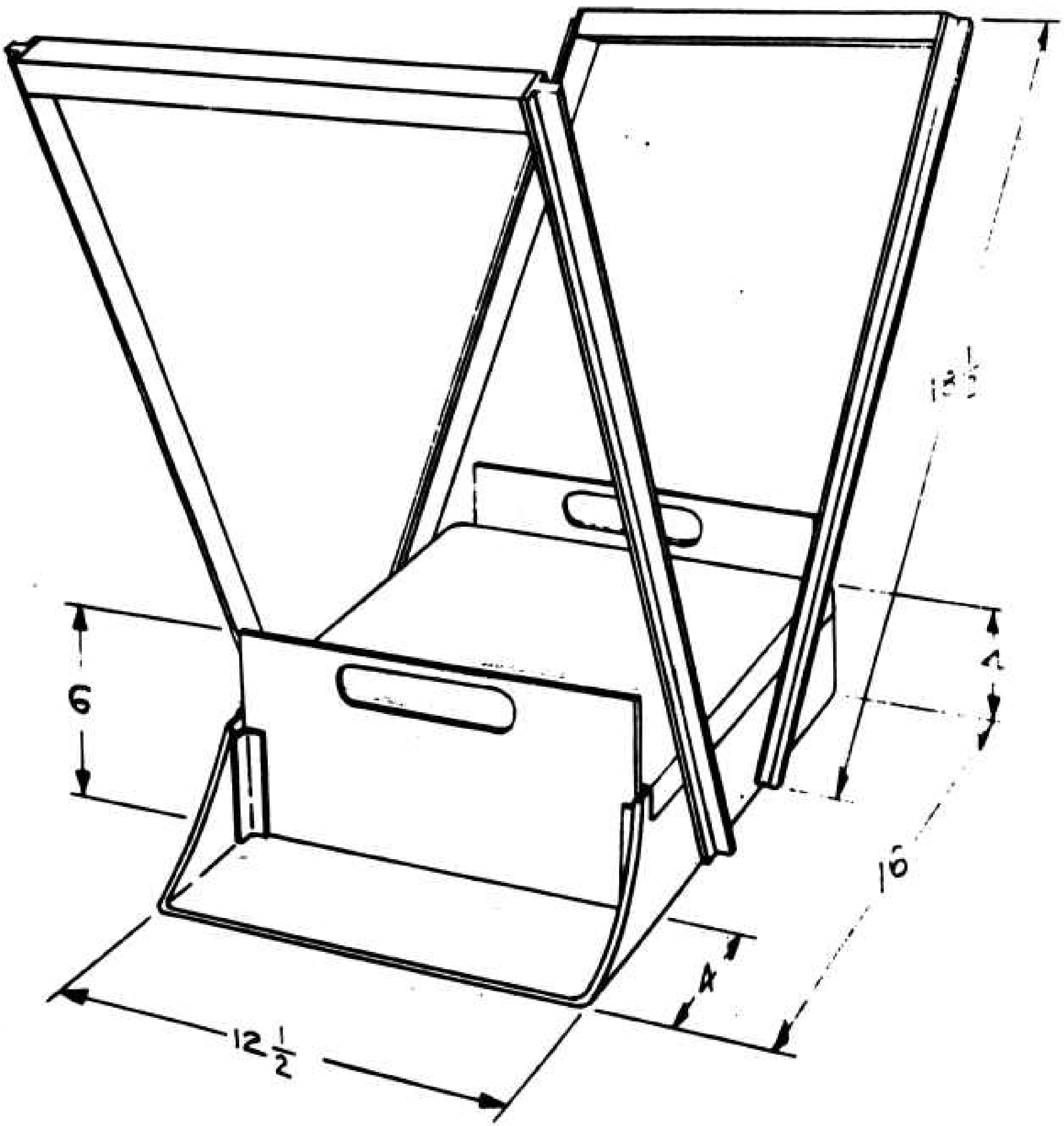


Figure 2.2-3. BOTTOM SAMPLING APPARATUS

TABLE 2.2-1. BENTHIC FAUNAL SURVEY FIELD & PROCESSING NOTES

Bio-station	Sample #	Collection (Time/Date)*	Depth (ft.)	Composition (%)**
BE-02	03401	0750/20 I	3	55SF/40cS/5DP
"	11101	0820/13 III	3	75cS&FF/20SF/5DP
"	12101	0824/20 III	1.5	50cS/45SF/5DP
"	13201	0743/28 III	3	65cS&FF/25SF/10DP&pT
"	14201	0844/ 4 IV	4	60cS&FF/20SF/20pT&DP
"	03402	0852/20 I	12	55cS/40SF/5DP
"	11102	0928/13 III	14	95cS&FF/5cT
"	12102	0906/20 III	14	95cS&FF/5SF
"	13202	0823/28 III	6	70cS&FF/25SF/5DP
"	14202	0915/ 4 IV	19	75cS&FF/20SF/5pT
"	03403	1025/20 I	25	40R,LF&LT/30sF/20SF/10DPW
"	11103	1030/13 III	24	75cS&FF/15SF/10DP
"	12103	0952/20 III	22	50cS&FF/40SF/10DP
"	13203	0901/28 III	28	50SF/40cS&FF/10pT
"	14203	1001/ 4 IV	31	50cS&FF/45SF/5pT
BE-03	04404	1112/27 I	2	70cS,cT&CM/25SF/5SP
"	11104	1150/13 III	3	80cS/15SF/5SP
"	12104	1038/20 III	2	65cS&sF/20SF/15SP
"	13504	0953/31 III	2	60CM.R&cT/30SP&pT/10SF
"	14504	1043/ 7 IV	2	70CM&R/25SP&pT/5SF
"	04406	1320/27 I	25	85cS&FF/15SF
"	11105	1225/13 III	24	80cS&FF/15SF/5SP&DP
"	12105	1112/20 III	24	65cS&FF/30SF/5SP&DP
"	13505	1016/31 III	23	80cS&FF/15SF/5SP&DP
"	14505	1105/ 7 IV	31	85cS&FF/15SF/5SP&DP
"	04405	1152/27 I	38	75cS&FF/25SF
"	11106	1328/13 III	36	80cS&FF/20SF
"	12106	1155/20 III	34	85cS&FF/15SF
"	13506	1048/31 III	43	80cT&FF/15SF/5DPW
"	14506	1205/ 7 IV	45	40cT/40SF/20DPW&SP
BE-04	05101	0758/31 I	10	80cT/15SF/5DPW
"	11201	0800/14 III	14	95cT/5SF
"	12201	0935/21 III	14	70cS&cT/30SF
"	13301	0713/29 III	11	80cT/20SF
"	14301	0959/ 5 IV	11	80cT/20SF
"	05102	0842/31 I	28	100cT
"	11202	0852/14 III	30	85cT/15SF
"	12202	1020/21 III	44	60cT/40SF
"	13302	0748/29 III	43	90cT/10SF
"	14304	1042/ 5 IV	37	90cT/10SF

TABLE 2.2-1 (continued)

Bio-station	Sample #	Collection(Time/Date)*	Depth (ft.)	Composition (%)**
BE-05	03201	0848/18 I	4	60SF/35cS/5sF
"	11504	1105/17 III	4	50cT&pT/25SF/25SP
"	12504	1045/24 III	4	50pT,cS&FF/50SF
"	13204	1030/28 III	4	60SF/35FF&R/5DP
"	14204	1040/ 4 IV	5	75cT&FF/25SF
"	03202	1032/18 I	15	60cS&FF/35SF/5DPW
"	11505	1208/17 III	15	60cS&FF/40SF
"	12505	1130/24 III	18	70cS&FF/30SF
"	13206	1232/28 III	18	55cS&FF/40SF/5DPW
"	14205	1115/ 4 IV	15	80cS&FF/20SF
"	03203	1122/18 I	32	85sF/10cS/5SF
"	11506	1258/17 III	38	80LF&cS/15SF/5DP
"	12506	1236/24 III	40	70SF/30DPW
"	13205	1116/28 III	38	60SF/40cs&FF
"	14206	1203/ 4 IV	40	80cS&FF/20SF
BM-07	04302	0829/26 I	38	70cS,cT&FF/20pT/10SF
"	11204	1115/14 III	40	50cT/40pT/10SF
"	12203	1110/21 III	38	50cS&cT/25SF/25SP
"	13303	0838/29 III	36	40pT/40SF/20cS&FF
"	14301	0812/ 5 IV	38	60cT&FF/30pT/10SF
"	04301	0738/26 I	42	55pT&DP/30SF/15cS,cT&FF
"	11203	1005/14 III	43	40cT/40pT/20SF
"	12204	1143/21 III	43	60cT/40SF
"	13304	0914/29 III	42	80SF/20cT&FF
"	14302	0849/ 5 IV	47	60cT&FF/35SF/5pT
BC-09	04210	1040/25 I	2	90cS&FF/10SF
"	11501	0835/17 III	2	98SP&pT/2SF
"	12404	1110/23 III	2	95SP&pT/5SF
"	13404	1040/30 III	1	95SP&pT/5SF&FF
"	14404	1056/ 6 IV	2	95SP&pT/5SF
"	04211	1148/25 I	14	55cS&FF/40SF/5pT
"	11502	0908/17 III	12	60SP/30cS&FF/10SF
"	12405	1125/23 III	14	75cS&FF/25SF
"	13406	1159/30 III	16	80cS&FF/10SF/10SP
"	14405	1123/ 6 IV	12	80cS&FF/15SF/5SP
"	04212	1245/25 I	28	60G&FF/30cS/10SF
"	11503	0945/17 III	32	98FF&cS/2SF
"	12406	1242/23 III	35	65cS&FF/35SF
"	13405	1102/30 III	35	50cS&FF/45SF/5SP&pT
"	14406	1215/ 6 IV	32	85cS&FF/15SF
BC-10	03303	1015/19 I	14	90cT/10SF
"	11301	0758/15 III	14	80cT/20SF
"	12301	0812/22 III	18	75cT&cS/25SF
"	13101	0818/27 III	18	60cT/40SF
"	14101	0814/ 3 IV	18	75cT/20SF/5pT&DP

Bio-station	Sample #	Collection(Time/Date)*	Depth (ft.)	Composition (%)**
BC-10	03304	1114/19 I	36	70cS/25SF/5DPW
"	11302	0908/15 III	30	80cS&FF/20SF
"	12302	0846/22 III	48	75cS/25SF
"	13102	0905/27 III	41	70cS&FF/25SF/5DPW
"	14102	0846/ 3 IV	45	80cS&FF/20SF
BC-11	04101	0905/24 I	3	90pT/10SF
"	11303	1030/15 III	2	95pT/5SF
"	12303	0945/22 III	2	90pT/10SF
"	13103	1002/27 III	2	95pT/5SF&FF
"	14103	0940/ 3 IV	2	90pT/5LF&R/5SF
"	04102	0933/24 I	12	60pT/35cS/5SF
"	11304	1105/15 III	23	90cS&FF/5pT/5SF
"	12304	1025/22 III	24	65pT/35SF
"	13104	1025/27 III	25	80cS&FF/15SF/5pT
"	14104	1016/ 3 IV	24	80SF/20cS&G
"	04103	1038/24 I	42	50cS/40SF/10DP
"	11305	1228/15 III	42	70cS/30SF
"	12305	1115/22 III	40	65cS&FF/35SF
"	13105	1120/27 III	34	60cS&FF/35SF/5DP
"	14105	1108/ 3 IV	37	85cS&FF/15SF
"	04104	1142/24 I	38	85cS&FF/10SF/5DP
"	11306	1310/15 III	44	75cS/25SF
"	12306	1255/22 III	39	95cS&FF/5SF
"	13106	1202/27 III	39	70cS/30SF
"	14106	1144/ 3 IV	40	80cS&FF/20SF
"	04105	1245/24 I	36	50cS&FF/30SF/20DP
"	11307	1410/15 III	47	60cS/40SF
"	12307	1335/22 III	38	55cS&FF/45SF
"	13107	1305/27 III	41	55SF/40cS&FF/5DP
"	14107	1245/ 3 IV	38	80cS&FF/20SF
BW-13	03501	0805/21 I	1	95cS&FF/5SP
"	11401	0825/16 III	3	45SF/40cS/15SP
"	12401	0805/23 III	3	50cS&FF/45SF/5SP
"	13401	0816/30 III	2	55cS&FF/40SF/5SP&pT
"	14401	0808/ 6 IV	2	40cS&FF/30SF/30SP&pT
"	03502	0905/21 I	12	40sF/30R,LF&pT/25SF/5DP
"	11402	0918/16 III	16	85cS,FF&G/15SF
"	12402	0852/23 III	14	65cS&FF/35SF
"	13402	0853/30 III	16	70cS&FF/25SF/5SP&DP
"	14402	0848/ 6 IV	17	80cS&FF/20SF
"	03503	1025/21 I	25	50SF/40cS&FF/10DPW
"	11403	1023/16 III	24	60cS&FF/30SF/10pT
"	12403	0950/23 III	25	65cS&FF/35SF
"	13403	0939/30 III	31	70cS&FF/25SF/5pT
"	14403	0943/ 6 IV	37	60cS&FF/35SF/5pT

TABLE 2.2-1 (continued)

Bio-station	Sample #	Collection(Time/Date)*	Depth (ft.)	Composition (%)**
BE-17	04401	0805/27 I	25	75cS&FF/20DP/5SF
"	11404	1208/16 III	24	60cS&FF/35SF/5DPW
"	12501	0750/24 III	25	50cS&FF/40SF/10DP
"	13501	0812/31 III	25	70cS&FF/25SF/5DP
"	14501	0822/ 7 IV	23	85cS&FF/10SF/5DPW
"	04402	0920/27 I	33	60cS,cT&FF/30SF/10DP
"	11405	1308/16 III	31	40cT&cS/40DP/20SF
"	12502	0855/24 III	30	55cS&FF/35SF/10DP
"	13502	0842/31 III	31	55SF/30cT&FF/15DPW
"	14502	0914/ 7 IV	30	60cS/25DP/15SF
"	04403	1012/27 I	32	60cS.cT&FF/30SF/10DP
"	11406	1350/16 III	33	55SF/45cS&FF/5DP
"	12503	0940/24 III	30	70cS&FF/25SF/5DP
"	13503	0916/31 III	32	45 DPW/30cS&cT/25SF
"	14503	0953/ 7 IV	32	60cS&FF/40SF

* All samples were collected during the calendar year 1972

** Composition given is the percentage of original laboratory volume (minus fine sediments screened in the field) which was estimated during the laboratory separation. Key: SF=silt and fine sand; cS=coarse sand; CM=clay material; cT=calcareous worm tubes (*Hydroides*); pT=parchment worm tubes; FF=shell fragments; sF=small shell fragments; LF=large shell fragments; G=gravel; R=rubble; DP=detritus and terrestrial plant parts; DPW=detritus, plant parts and wood chips; SP=sponge to nearly 8 quarts, usually 3 to 4 quarts. Primary sorting was accomplished in two stages. Separations were made using a CCl_4-flotation technique modified after Birkett (Reference 2.2-5) and shown in Figure 2.2-4. Use of this technique should be restricted to well-ventilated areas, e.g. under a chemical hood, due to the hazardous nature of carbon tetrachloride. During the first stage, silt and fine sand were removed by washing small portions of the sample in a 1 mm mesh brass sieve. Material retained by the sieve was transferred to a shallow wash dish. After several such portions had accumulated, the material in the pan received 10 to 20 additional seawater washings with agitation. The wash water containing the less dense material (and remaining silt) was decanted through the 1 mm sieve. Most of the smaller organisms and "detrital" material were separated from the sand and gravel by this process. Larger organisms (such as clams, crabs and larger polychaetes) were removed by hand from the sand fraction. Both the "water floatable" and sand/gravel fractions were preserved separately in 10% formalin. An estimate (percent of original field-processed volume) of the sample components lost through the sieve, retained on the sieve and remaining in the wash pan was made (see composition column, Table 2.2-1).

The CCl_4-flotation technique was useful in separating small organisms from mineral sediments. However, the method is inadequate where organic material or small calcareous tubes represent the bulk of the sample, since both readily float on CCl_4 (the latter because of air bubbles trapped in the tubes). The technique was, however, used successfully to separate small organisms remaining in the washed sand/gravel fraction. A half quart aliquot of this fraction was placed in a one-quart plastic container to which several drops of concentrated soap solution were added. Enough CCl_4 was added to cover the aliquot to a depth of several inches. A quarter-inch layer of seawater was floated on top of the CCl_4 to reduce the vapor hazard. The aliquot was stirred gently and material floating to the CCl_4/water interface was collected by sweeping a fine mesh net through this surface region. The fraction obtained by this means was washed in seawater and preserved in 10% formalin; the remaining material was discarded.

Secondary sorting of each sample was again accomplished in two stages: 1) small portions placed in wash dishes and covered with tap water were initially scanned under an illuminated magnifying lens, and 2) rescanned under a binocular dissection microscope (10x-70x variable power). Organisms removed were sorted by broad taxonomic groupings (usually phyla) and preserved in 5% formalin (polychaetes and fishes) or 70% ETOH (ethanol)/isopropyl alcohol.

Tertiary sorting involved differentiation of species and the enumeration/weighing of each organism in the sample. Counts were based on some recognizable feature occurring singly in each individual (head, mouth parts, oral disc, etc.) since many organisms were damaged in the collection/sorting process. Wet weights were based on all the parts ascribable to a species recovered from the samples. All organisms were transferred to 70% ethanol prior to weighing; wet weighing was performed on a Mettler (P 160) balance after first towel drying the organisms to be weighed. The original raw data (from Environmental Consultants, Inc.) have been incorporated into the University of Hawaii's Coastal Zone Data Bank.

Times and estimated costs of the bottom sample processing have been revised from those last reported (Table 7 of Reference 2.2-6) and are summarized in the following breakdown:

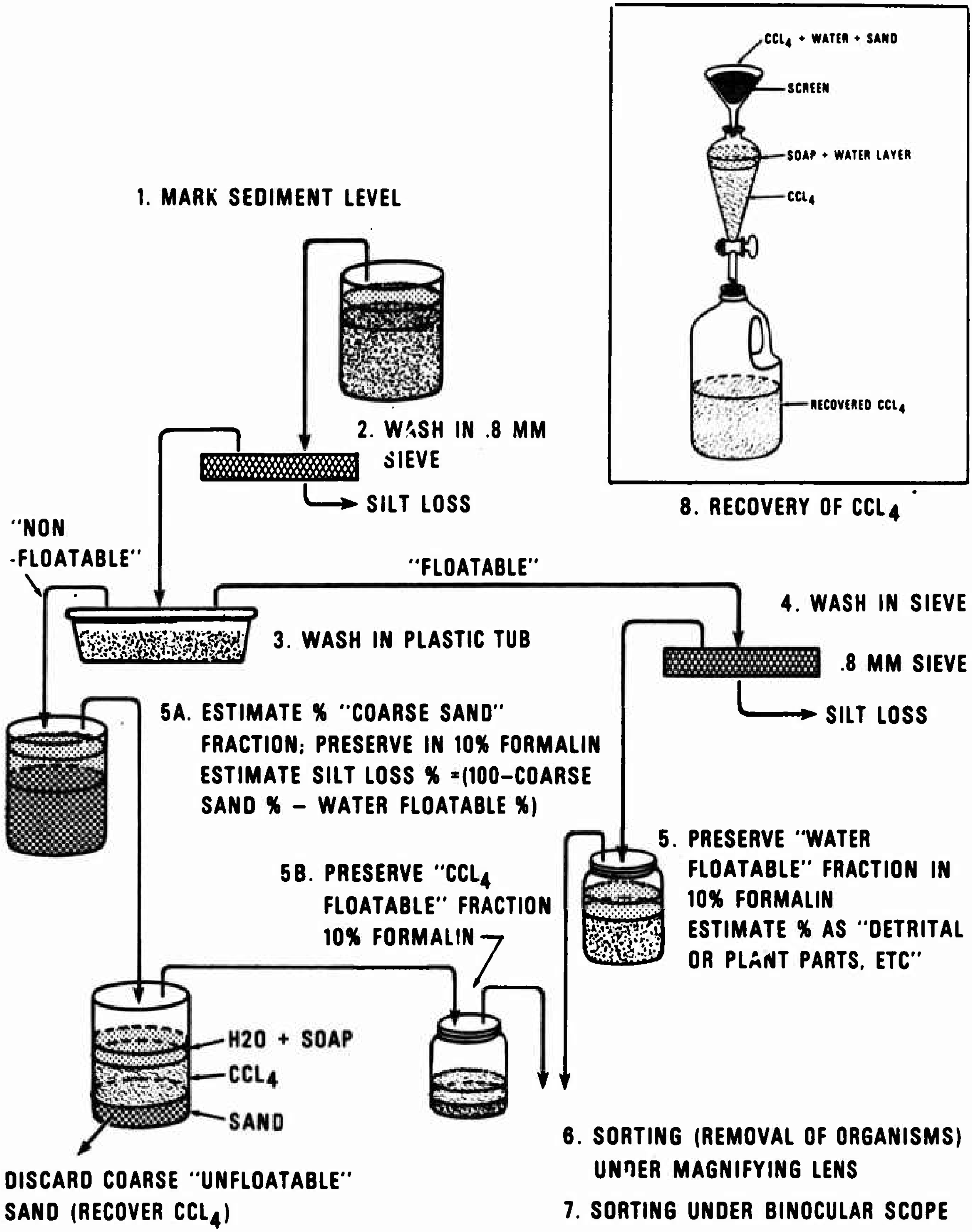


Figure 2.2-4. CARBON TETRACHLORIDE FLOTATION TECHNIQUE USED DURING BOTTOM SAMPLE ANALYSIS

Operation	Time (hr)	Cost ($/hr)
Primary sorting, including CCl_4-flotation	2	3.50
Secondary separation and sorting	4-6	3.50
Sorting into major groups (usually phyla)	3	3.50
Weighing and counting	2	3.50
Routine identifications	1	3.50
Special identifications	2-5	8.00
Preservation	1	3.50
TOTAL	15-19 per sample	$61.50 to $92.50 per sample

As may be seen, processing takes 15 to 19 hours per sample at an estimated cost of $61.50 to $92.50 per sample. This is somewhat higher than the $45-$60 range estimated previously (Reference 2.2-6); however, these revised figures represent a more realistic breakdown established through actual analyses performed on more than 200 samples (benthic and piling samples). The average cost of these samples was about $80.00/sample for the present contractual arrangements.

A brief analysis of the merit of replicate sampling has been conducted (Figure 2.2-5) for the first three series of benthic samples. The number of species/taxa added with each series is seen to significantly diminish after the third replicate series (e.g. an average of only 3 new species/sample/station compared with an average of 8 additional species gained during the second replicate series). The information provided by the first three series is considered to be cost-effective; however, the fourth and fifth series appear to be only marginally informative from a cost-effectiveness standpoint.

The procedure utilized for benthic sample analysis undoubtedly loses the smaller organisms (such as nematodes, copepods, etc.) less than 1 mm in greatest dimension. Sponges, bryozoans, and hydroids (several species of each) were present but could not be individually enumerated because of their colonial nature. Ostracods were generally rare, except at station BC-11. The annelids and crustacea are the most diverse groups present. Among the annelids, several new records for Hawaiian distributions were made. Among the crustaceans, specifically, the Alpheid or snapping shrimp, 4 species represent first reports for Hawaii (*Alpheus rapacida, Alpheus rapax, Synalpheus pachymeris* and *Synalpheus thai*); also a new species, *Leptalpheus pacificus* was collected. These discoveries will be formally reported in Pacific Science in the near future by Professors D. M. and A. H. Banner, at the University of Hawaii's Marine Laboratory, Coconut Island (HIMB).

DATA/RESULTS

A phyletic checklist of all organisms collected during the benthic survey is presented as Table 2.2-2. Hawaii Coastal Zone Data Bank numbers and general feeding/habitat type for each organism have been incorporated into this list. To facilitate rapid cross-referencing of organisms, an alphabetical listing by species (with HCZDB numbers and adjective identifiers) is also provided (Table 2.2-3). A total of 114 genera and/or species have been positively identified from 87 samples. These data (including presence/absence, number of individuals

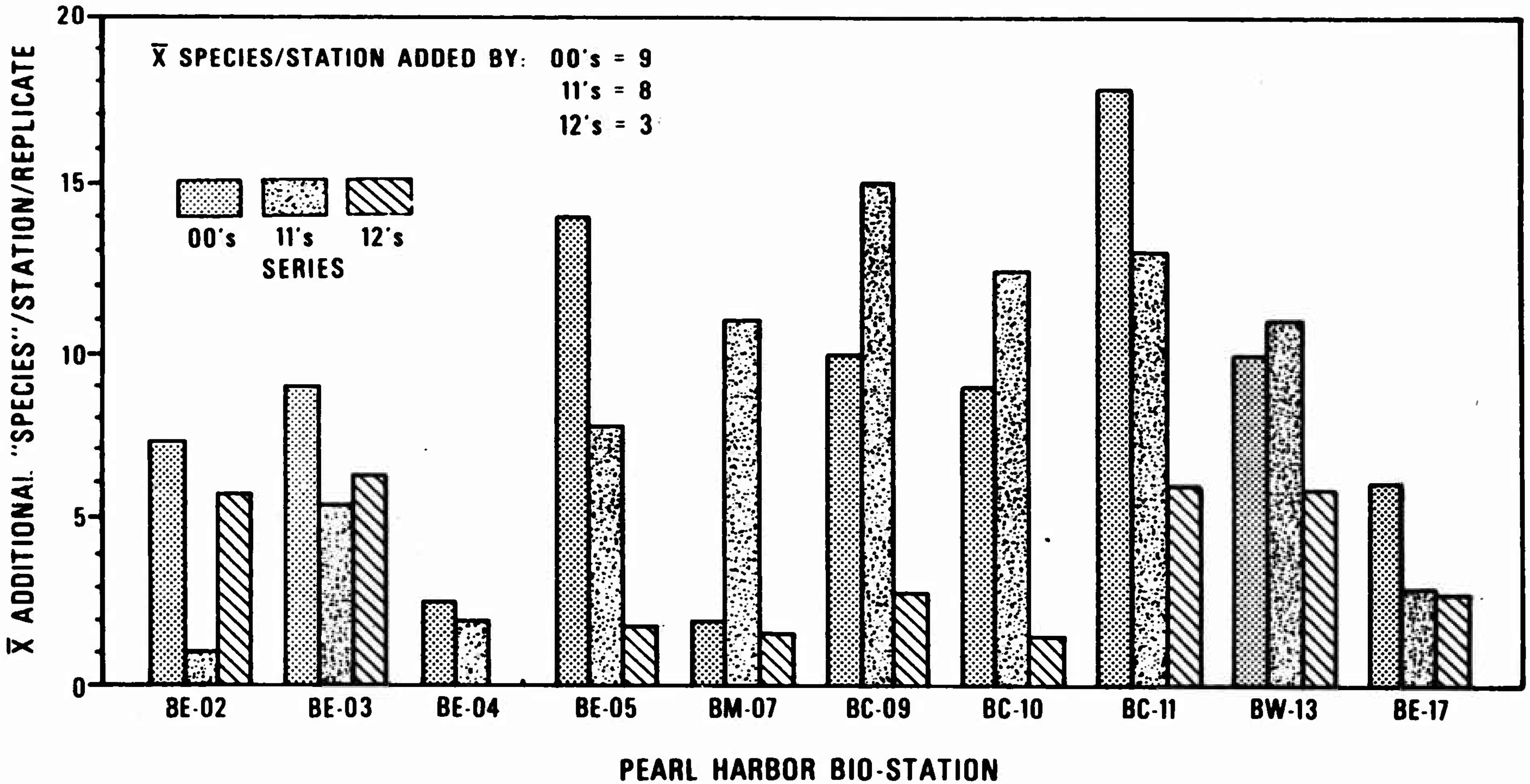


Figure 2.2-5. SPECIES ADDED BY EACH REPLICATE BENTHIC SAMPLE.

Table 2.2-2. A PHYLETIC CHECKLIST OF BENTHIC ORGANISMS COLLECTED FROM PEARL HARBOR

Species/Group	HCZDB #	Feeding/Habitat Type*
Porifera		
Demospongiae	352XXXXXXX	S-s
Cnidaria		
Hydrozoa		
Hydroida	3711XXXXXX	S-s
Anthozoa		
Actinaria		
Stoichactinidae		
Radianthus cookei	3742200101	C-s
Isophellidae		
Epiphellia humilis	3742290201	C-s
Nematoda	51XXXXXXXX	O-p/f
Annelida		
Polychaeta		
Errantia		
Aphroditidae		
Paralepidonotus ampulliferus	5511012201	C-f
Iphione muricata	5511012401	C-f
Amphinomidae		
Eurythoe complanata	5511040201	O-m
Syllidae		
Syllis sp.	5511140100	H-f
Syllis (Haplosyllis) spongicola	5511140108	O-f
Syllis (Langerhansia) cornuta	5511140109	H-m
Trypanosyllis zebra	5511140301	O-f
Opisthosyllis sp.	5511140400	O-f
Nereidae		
Ceratonereis sp.	5511160100	H-f
Nereis sp.	5511160400	C-f
Micronereis sp.	5511160500	H-f
Platynereis sp.	5511160600	C-f
Perinereis sp.	5511160800	C-f
Perinereis cultrifera	5511160803	O-f
Laeonereis sp.	5511160900	H-f
Eunicidae		
Eunice antennata	5511200102	C-f
Eunice australis	5511200103	O-f
Eunice filamentosa	5511200105	O-f
Eunice vittata	5511200108	C-f
Eunice (Palolo) siciliensis	5511200109	O-f
Eunice (Nicidion) sp.	5511200111	H-f
Marphysa sanguinea	5511200303	C-f
Nematonereis unicornis	5511200401	O-f

Paramarphysa sp.	5511200500	O-f
Diopatra sp.	5511202200	S-t
Oenone fulgida	5511204201	O-f
Lumbrinerid sp.	5511206201	D-f
Arabella sp.	5511208100	O-f
Annelida		
Polychaeta		
Sedentaria		
Cirratulidae		
Cirratulus sp.	5521040100	D-b/f/m
Chaetopteridae	552107XXXX	S-t
Orbiniidae	552108XXXX	D-f/t
Capitellidae	552113XXXX	D-b
Dasybranchus lumbricoides	5521130101	D-b/f
Terebellidae	552122XXXX	S-t
Sabellidae	552123XXXX	S-t
Serpulidae		
Hydroides norvegica	5521244201	S-s/c/t
Hydroides lunulifera	5521244204	S-s/c/t
Sipunculida		
Phascolosoma dentigerum	5611010103	D-b/f
Arthropoda		
Pycnogonida	639XXXXXXX	C-f
Crustacea		
Ostracoda	643XXXXXXX	S-f
Cirripedia		
Balanidae		
Balanus amphitrite hawaiiensis	6451070102	S-s
Malacostraca		
Tanaidacea		
Apseudes sp. 1	6468010102	H-f
Apseudes sp. 2	6468010103	H-f
Leptochelia dubia	6468130101	O-f
Anatanais insularis	6468140201	C-f
Isopoda		
Mesanthura hieroglyphica	6471060201	H-f
Hansenolana sphaeromiformis	6471160201	O-f
Limnoria sp.	6471210100	O-b
Paracerceis sculpta	6471220201	H-f
Colidotea edmondsoni	6471270101	O-f
Amphipoda		
Lembos macromanus	6473080405	S-t
Corophium acherusicum	6473180103	D-t
Ericthonius brasiliensis	6473180201	S-t
Elasmopus rapax	6473250209	D-f
Leucothoe hyhelia	6473380101	D-f
Caprellidae	6473XXXXXX	C-f

Decapoda/Natantia		
Alpheus sp.	6483411000	D-t/b
Alpheus lobidens polynesica	6483411001	D-t/b
Alpheus mackayi	6483411002	D-t/b
Alpheus rapax	6483411003	D-t/b
Alpheus rapacida	6483411004	D-t/b
Alpheus platyunguiculatus	6483411005	D-t/b
Alpheus paracrinitus	6483411024	D-t/b
Alpheus lanceloti	6483411027	D-t/b
Alpheus heeia	6483411036	D-t/b
Leptalpheus pacificus	6483411101	D-t/b
Synalpheus pachymeris	6483411201	D-t/b
Synalpheus thai	6483411202	D-t/b
Synalpheus streptodactylus	6483411204	D-t/b
Synalpheus bituberculatus	6483411212	D-t/b
Decapoda/Reptantia		
Calcinus latens	6487130302	D-t(shell)
Parthenope whitei	6488260104	D-f
Libystes nitidus	6488311201	D-f
Portunus longispinosus	6488312106	D-f
Thalamita integra	6488313301	D-f
Thalamita admete	6488313303	D-f
Grapsid sp.	648832XXXX	D-f
Platypodia eydouxi	6488330504	D-f
Lophozozymus dodone	6488330602	D-f
Madaeus simplex	6488330801	D-f
Leptodius sanguineus	6488331001	D-f
Xanthias sp.	6488331100	D-f
Carpilodes bellus	6488331404	D-f
Etisus electra	6488331901	D-f
Etisus laevimanus	6488331905	D-f
Panopeus pacificus	6488332201	D-f
Phymodius nitidus	6488332303	D-f
Cholorodiella laevissima	6488332402	D-f
Pilumnus oahuensis	6488335806	D-f
Macrophthalmus telescopicus	6488371301	D-f
Stomatopoda		
Pseudosquilla ciliata	6489010101	C-f
Gonodactylus falcatus	6489010201	C-f
Mollusca		
Gastropoda		
Mesogastropoda		
Vermetidae		
Dendropoma platypus	7022430101	S-t/c
Cerithiidae		
Bittium unilineatum	7022540202	H-f
Hipponicidae		
Hipponix sp.	7022720100	H-f
Hipponix pilosus	7022720101	H-f

Table 2.2-2. (Continued)

Calyptraeidae		
Crucibulum spinosum	7022750101	H-f
Crepidula aculeata	7022750201	H-f
Naticidae		
Natica gualteriana	7022910101	C-f
Cymatiidae		
Cymatium sp.	7022940100	C-f
Mollusca		
Bivalvia		
Mytiloida		
Mytilidae		
Brachidontes (=Hormomya) crebristriatus	7054010301	S-s
Pterioida		
Ostreidae		
Crassostrea sp.	7055060100	S-s/c
Ostrea thaanumi	7055060202	S-s/c
Spondylidae		
Spondylus sp.	7055130100	S-s/c
Anomiidae		
Anomia nobilis	7055200101	S-s/c
Veneroida		
Lucinidae		
Ctena bella	7056290101	S-f
Tellinidae		
Angulus nucella (=Pinguitellina robusta)	7056620302	S-f
Myoida		
Hiatellidae		
Hiatella hawaiensis	7057100101	S-b/m/t
Ectoprocta		
Gymnolaemata		
Ctenostomata		
Vesiculariidae		
Amathia distans	7511010101	S-s
Cheilostomata		
Bicellariellidae		
Bugula neritina	7513060101	S-s
Bugula californica	7513060102	S-s
Echinodermata		
Asteroidea		
Gnathophiurida		
Ophiactidae		
Ophiactis savignyi	7841010102	D-f/b
Amphiuridae		
Amphiopholis squamata	7841030301	D-f/b

Table 2.2-2. (Continued)

Holothuroidea		
Aspidochirota		
Holothuridae		
Holothuria pervicax	7871030306	S-f/b
Chordata		
Urochordata		
Ascidiacea		
Phallusidae		
Ascidia sp.	8311040100	S-s
Polyclinidae		
Polyclinum sp.	8311130200	S-s
Styelidae		
Styela sp.	8312020100	S-s
Chordata		
Osteichthyes		
Perciformes		
Gobiidae		
Oxyurichthys lonchotus	8555600201	O-f/b
Bathygobius fuscus	8555600802	C-f
Eleotridae		
Asterropteryx semipunctatus	8555605301	C-f/b

*LEGEND

first letter (indicates general feeding type)

C = carnivore
H = herbivore
O = omnivore
S = suspension feeder
D = detritivore, scavenger

second (or third, fourth...) letter (habitat/attachment-related information)

f = free-living
p = parasitic
s = sessile, attached to substrate
t = tube-dwelling
c = cement-forming
m = mat forming
b = burrowing, boring, or nestling

Table 2.2-3. AN ALPHABETICAL LIST OF PEARL HARBOR BENTHIC ORGANISMS COLLECTED JAN-MAR 1972.

Species	Common Name*	HCZDB #
Alpheus heeia	SS	6483411036
Alpheus lanceloti	SS	6483411027
Alpheus lobidens polynesica	SS	6483411001
Alpheus mackayi	SS	6483411002
Alpheus paracrinitus	SS	6483411024
Alpheus platyunguiculatus	SS	6483411005
Alpheus rapacida	SS	6483411004
Alpheus rapax	SS	6483411003
Alpheus sp.	SS	6483411000
Amathia distans	BR	7511010101
Amphipholis squamata	BS	7841030301
Anatanais insularis	TA	6468140201
Angulus nucella	BI	7056620302
Anomia nobilis	BI	7055200101
Apseudes sp. 1	TA	6468010102
Apseudes sp. 2	TA	6468010103
Arabella sp.	EP	5511208100
Ascidia sp.	AS	8311040100
Asterropteryx semipunctatus	FISH	8555605301
Balanus amphitrite hawaiiensis	BA	6451070102
Bathygobius fuscus	FISH	8555600802
Bittium unilineatum	GA	7022540202
Brachidontes (=Hormomya) crebristriatus	BI	7054010301
Bugula californica	BR	7513060102
Bugula neritina	BR	7513060101
Calcinus latens	HC	7487130302
Carpilodes bellus	TC	6488331404
Ceratonereis sp.	EP	5511160100
Chlorodiella laevissima	TC	6488332402
Cirratulus sp.	SP	5521040100
Colidotea edmondsoni	IS	6471270101
Corophium acherusicum	AM	6473180103
Crassostrea sp.	BI	7055060100
Crepidula aculeata	GA	7022750201
Crucibulum spinosum	GA	7022750101
Ctena bella	BI	7056290101
Cymatium sp.	GA	7022910101
Dasybranchus lumbricoides	SP	5521130101
Dendropoma platypus	GA	7022430101
Diopatra sp.	EP	5511202200
Elasmopus rapax	AM	6473250209
Epiphellia humilis	SA	3742290201
Ericthonius brasiliensis	AM	6473180201
Etisus electra	TC	6488331901
Etisus laevimanus	TC	6488331905
Eunice antennata	EP	5511200102
Eunice australis	EP	5511200103

Table 2.2-3. (Continued)

Eunice filamentosa	EP	5511200105
Eunice (Palolo) siciliensis	EP	5511200109
Eunice vittata	EP	5511200108
Eunice (Nicidion) sp.	EP	5511200111
Eurythoe complanata	EP	5511040201
Gonodactylus falcatus	MS	6489010201
Hansenolana sphaeromiformis	IS	6471160201
Hiatella hawaiiensis	BI	7057100101
Hipponix pilosus	GA	7022720101
Hipponix sp.	GA	7022720100
Holothuria pervicax	SC	7871030306
Hydroides lunulifera	SP	5521244204
Hydroides norvegica	SP	5521244201
Iphione muricata	EP	5511012401
Laeonereis sp.	EP	5511160900
Lembos macromanus	AM	6473080405
Leptalpheus pacificus	SS	6483411101
Leptochelia dubia	TA	6468130101
Leptodius sanguineus	TC	6488331001
Leucothoe hyhelia	AM	6473380101
Libystes nitidus	TC	6488311201
Limnoria sp.	IS	6471210100
Lophozozymus dodone	TC	6488330602
Lumbrinerid sp.	EP	5511206201
Macrophthalmus telescopicus	TC	6488371301
Madaeus simplex	TC	6488330801
Marphysa sanguinea	EP	5511200303
Mesanthura hieroglyphica	IS	6471060201
Micronereis sp.	EP	5511160500
Natica gualteriana	GA	7022910101
Nematonereis unicornis	EP	5511200401
Nereis sp.	EP	5511160400
Oenone fulgida	EP	5511204201
Ophiactis savignyi	BS	7841010102
Opisthosyllis sp.	EP	5511140400
Ostrea thaanumi	BI	7055060202
Oxyurichthys lonchotus	FISH	8555600201
Panopeus pacificus	TC	6488332201
Paracerceis sculpta	IS	6471220201
Paralepidonotus ampulliferus	EP	5511012201
Paramarphysa sp.	EP	5511200500
Parthenope whitei	TC	6488260104
Perinereis cultrifera	EP	5511160803
Perinereis sp.	EP	5511160800
Phascolosoma dentigerum	PW	5611010103
Phymodius nitidus	TC	6488332201
Pilumnus oahuensis	TC	6488335806
Platynereis sp.	EP	5511160600
Platypodia eydouxi	TC	6488330504
Polyclinum sp.	AS	8311130200

Table 2.2-3. (Continued)

Portunus longispinosus	TC	6488312106
Pseudosquilla ciliata	MS	6489010101
Radianthus cookei	SA	3742200101
Spondylus sp.	BI	7055130100
Styella sp.	AS	8312020100
Syllis cornuta	EP	5511140109
Syllis spongicola	EP	5511140108
Syllis sp.	EP	5511140100
Synalpheus bituberculatus	SS	6483411212
Synalpheus pachymeris	SS	6483411201
Synalpheus streptodactylus	SS	6483411204
Synalpheus thai	SS	6483411202
Thalamita admete	TC	6488313303
Thalamita integra	TC	6488313301
Trypanosyllis zebra	EP	5511140301
Vermetid sp.	GA	7022430000
Xanthias sp.	TC	6488331100

*Common Name/adjective identifier
Key:
AM = amphipod crustacean
AS = ascidian, tunicate
BA = barnacle
BI = bivalve mollusk, clam-like
BR = bryozoan
BS = brittle star
EP = errant polychaete worm
GA = gastropod mollusk, snail-like
HC = hermit crab
IS = isopod crustacean
MS = mantis shrimp
PW = peanut worm
SA = sea anemone
SC = sea cucumber
SP = sedentary polychaete worm
SS = snapping shrimp
TA = tanaid crustacean
TC = true crab

and alcohol weights) for each organism are listed in Table 2.2-4. Where an organism is present at a given bio-station, three entries are made in vertical sequence: top = number of individuals, middle = total wet weight of all individuals, and bottom = mean individual wet weight (a dash in the middle position indicates that the particular organism was not found at the given bio-station). It is significant to note initially that 28 of these taxa (or 24.5% of the 114 genera/species) occurred only at bio-station BC-11. This bio-station has continued to represent the greatest variability and diversity of Pearl Harbor organisms. While originally chosen for its proximity to a domestic sewage outfall, bio-station BC-11's geographic position at the entrance to Pearl Harbor strongly influences its biotic constituents. Of the 28 organisms collected only at BC-11, 21 species were crustaceans (including 4 alpheid species), 4 molluscan species, 2 polychaete species and one species of holothurian (sea cucumber).

Summary data for benthic organisms (by station) are listed in Table 2.2-5 and displayed geographically in Figures 2.2-6 (# species), 2.2-7 (mean number of individuals) and 2.2-8 (mean wet (alcohol) weights). Bio-stations BC-11, BW-13, BC-09 and BE-05 exhibit the most diverse benthic faunas, i.e. the greatest number of species and individuals. Wet weight values are significantly elevated for these 4 bio-stations due to abundant sponge growth (Table 2.2-6); many other organisms (especially polychaetes, certain crustaceans such as alpheid shrimp and amphipods, and the mollusc, *Hiatella hawaiensis*, have a strong affinity for sponge communities. The absence of major phyla or other large groups (see Table 2.2-6) from certain bio-stations (BE-04, BE-02, BE-03, and BE-17) indicates some degradation in those environments. Specifically, the absence of echinoderms, amphipods, isopods/tanaids and decapods at bio-station BE-04 supports the position that it is the least favorable bio-station for benthic organisms. One phylum, the echinoderms, sharply divides the ten bio-stations in half on the basis of presence or absence. With the exception of BM-07, the most biologically healthy bio-stations would appear to be those where echinoderms were present.

As may be seen from Table 2.2-4, many benthic organisms occur at only a few bio-stations. However, some organisms are common to many of the bio-stations and 14 of these more common benthic species have been selected to represent distributional patterns within the harbor. The selection of these species from a range of major taxonomic groups (i.e. annelids, crustaceans, mollusca, echinoderms, bryozoans and tunicates) enables numerical comparisons (mean number of individuals and mean wet weight values) among bio-stations. Furthermore, the species selected represent the most widely distributed species in the samples and at the ten bio-stations. These species inhabit a greater range of Pearl Harbor benthic environments and, presumably, exhibit a wider range of environmental tolerance than those organisms occurring, for instance, only at BC-11 (see discussion of these 28 species earlier in this section). These 14 selected common benthic organisms are listed in Table 2.2-7 with pertinent summary data. There are no strong depth specificity patterns for any of these species. The polychaete worm, *Nereis* sp., and the bryozoan, *Bugula neritina*, do, however, show a tendency to inhabit deeper waters (22-28 ft.). The crustaceans, *Pilumnus oahuensis* and *Apseudes* sp. 1, tend to be more numerous in shallower waters (11-12 ft.). Most of the selected organisms were collected from a wide range of depths (2-45 ft.).

Table 2.2-4. **BENTHIC ORGANISMS PRESENT IN SAMPLES COLLECTED FROM PEARL HARBOR, OAHU.** ALL DEPTHS COMBINED AT EACH BIO-STATION: TOTAL NUMBER INDIVIDUALS PER SPECIES; TOTAL (ALCOHOL) WT. (GRAMS); INDIVIDUAL WT. (GRAMS); # = NUMBER UNCERTAIN; * = ESTIMATED. See note 1.

Species/Group	Bio-Station									
	BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
Porifera/Demospongiae	# .038 #	# 194.19 #	# .099 #	# 587.377 #	# 3.213 #	# 2106.11 #	# 4.184 #	# 221.713 #	# 229.87 #	# .452 #
Coelenterata/Hydrozoa	-	-	-	-	-	-	# .041 #	# <.001 #	# <.001 #	-
Coelenterata/Anthozoa	-	-	-	-	-	3 .317 .106	-	-	1 .003 .003	1 .002 .002
/Anthozoa *Radianthus cookei*					1 1.480 1.480	-	-	-	-	-
/Anthozoa *Epiphellia humilis*	-	-	-	-	-	31 .508 .016	-	-	149 3.330 .022	-
Aschelminthes/Nematoda	-	1 <.001 <.001	-	-	-	26 .004 .00015	-	11 .004 .00036	-	1 <.001 <.001
Annelida/Polychaeta (misc.)	# .178 #	# 1.347 #	# .006 #	# 5.475 #	# .030 #	# 2.032 #	# 4.358 #	# 7.714 #	# .759 #	# .102 #
Annelida/Aphroditidae *Paralepidonotus ampulliferus*	2 .354 .177	1 .063 .063	-	-	-	-	1 .494 .494	3 .266 .089	2 .196 .098	*2 .488 .244
/Aphroditidae *Iphione muricata*	-	-	-	-	-	-	-	1 .014 .014	-	-
/Amphinomidae *Eurythoe complanata*	3 .043 .014	6 .599 .100	-	# 8.414 *.051	-	# .119 #	1 .009 .009	# 31.648 *.052	# 1.831 *.021	1 .023 .023
/Syllidae *Syllis* sp.	-	# .012 #	-	# .019 #	14 <.001 #	47 .010 #	-	-	-	-

Table 2.2-4. (Continued)

Species/Group	BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
				Bio-Station						
Annelida (continued										
/Syllidae *Syllis (Haplosyllis) spongicola*	-	-	-	# # #	-	-	-	-	-	-
/Syllidae *Syllis (Langerhansia) cornuta*	-	-	-	-	-	-	-	-	1 <.001 #	-
/Syllidae *Trypanosyllis zebra*	1 <.001 #	1 <.001 #	-	-	-	-	8 .002 .0003	13 .026 .002	-	-
/Syllidae *Opisthosyllis* sp.	-	-	-	1 <.001 #	-	-	-	-	-	-
/Nereidae *Ceratonereis* sp.	-	-	-	-	2 .043 .022	-	-	2 .036 .018	3 .005 .002	-
/Nereidae *Nereis* sp.	19 .020 .001	8 .013 .002	15 .014 .001	2 .004 .002	5 .008 .002	7 .076 .011	4 .019 .005	339 1.199 .004	47 .064 .001	41 .205 .005
/Nereidae *Micronereis* sp.	-	-	-	-	-	-	-	-	3 .003 .001	-
/Nereidae *Platynereis* sp.	-	-	-	3 .010 .003	-	5 .040 .008	-	-	-	-
/Nereidae *Perinereis* sp.	1 .145 .145	-	-	-	-	-	-	-	-	-
/Nereidae *Perinereis cultrifera*	-	-	-	-	-	-	1 .033 .033	-	-	-
/Nereidae *Laeonereis* sp.	-	-	-	-	-	-	-	3 .017 .006	-	-
/Eunicidae *Eunice antennata*	1 .135 .135	2 .222 .111	-	6 1.741 .290	-	1 .303 .303	1 .205 .205	4 .214 .054	1 .104 .104	-

Table 2.2-4. (Continued)

Species/Group	Bio-Station BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
Annelida (continued)										
/Eunicidae		2							1	
Eunice australis	-	.013	-	-	-	-	-	-	.220	-
		.007							.220	
/Eunicidae						15			1	
Eunice filamentosa	-	-	-	-	-	1.838	-	-	.016	-
						.123			.016	
/Eunicidae	1			839		2	4	59	109	1
Eunice vittata	.012	-	-	10.513	-	.069	.028	.590	1.536	.005
	.012			.013		.035	.007	.010	.014	.005
/Eunicidae		5		37				3		
Eunice (Palolo) siciliensis	-	.111	-	1.134	-	-	-	.096	-	-
		.022		.031				.032		
/Eunicidae		9		4		7		250	6	
Eunice (Nicidion) sp.	-	.021	-	.022	-	.037	-	2.880	.044	-
		.002		.006		.012		.012	.007	
/Eunicidae				1		45			4	
Marphysa sanguinea	-	-	-	.017	-	9.239	-	-	.458	-
				.017		.205			.115	
/Eunicidae	20	20	2	26		5	4	92	21	2
Nematonereis unicornis	.016	.018	.002	.013	-	.002	.003	.077	.007	<.001
	.001	.001	.001	<.001		.0004	.001	<.001	.0003	#
/Eunicidae									5	
Paramarphysa sp.	-	-	-	-	-	-	-	-	.008	-
									.002	
/Eunicidae						3			21	
Diopatra sp.	-	-	-	-	-	.031	-	-	.049	-
						.010			.002	
/Eunicidae								4		
Oenone fulgida	-	-	-	-	-	-	-	.223	-	-
								.056		
/Eunicidae		3		7		3		92	23	1
Lumbrinerid sp.	-	.011	-	.026	-	.018	-	.233	.100	.001
		.004		.004		.006		.003	.004	.001
/Eunicidae		#						6		
Arabella sp.	-	.200	-	-	-	-	-	.156	-	-
		*.040						.026		

Table 2.2-4. (Continued)

Species/Group	Bio-Station BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
Annelida (continued)										
/Cirratulidae *Cirratulus* sp.	-	1 .426 .426	-	-	-	-	-	-	-	-
/Chaetopteridae	-	-	-	-	-	# 5.477 #	-	-	-	-
/Orbiniidae	-	-	-	8 .105 .002	-	-	1 .022 .022	-	-	-
/Capitellidae (misc.)	-	-	-	-	-	-	-	# 2.694 *.018	-	-
/Capitellidae *Dasybranchus lumbricoides*	-	-	-	-	-	46 .168 .004	-	-	-	-
/Terebellidae	1 .262 .262	-	-	# 17.856 #	1 .96 .296	6 .875 .146	-	# 6.067 #	12 6.356 .530	-
/Sabellidae	-	-	-	6 .374 .062	-	# 22.957 #	-	-	-	-
/Serpulidae *Hydroides norvegica*	-	-	# .003 #	-	# .025 #	# # #	-	-	# # #	1 <.001 <.001
/Serpulidae *Hydroides lunulifera*	-	-	-	2 .032 .016	-	14 .152 .011	-	-	1 .018 .018	-
Sipunculida (misc.)	-	4 .008 .002	-	77 .933 .012	-	1 .038 .038	-	46 13.128 .285	5 .286 .057	-
Sipunculida *Phascolosoma dentigerum*	-	-	-	-	-	-	-	72 9.873 .137	-	-
Arthropoda/Pycnogonida	-	15 .006 .0004	-	-	1 .001 .001	-	-	1 .002 .002	1 <.001 <.001	1 <.001 <.001

Table 2.2-4. (Continued)

Species/Group	BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
	Bio-Station									
Arthropoda (continued)										
/Ostracoda	1					1		29		
	<.001	-	-	-	-	<.001	-	.015	-	-
	<.001					<.001		<.001		
/Tanaidacea		2				6		53	1	
(misc.)	-	<.001	-	-	-	.001	-	.152	.001	-
		<.001				:0002		.003	.001	
/Tanaidacea	14	2		395		1		564	56	
Apseudes sp. 1	.064	.005	-	.916	-	.001	-	1.314	.160	-
	.005	.002		.002		.001		.002	.003	
/Tanaidacea		1		327	1	169		119	36	
Apseudes sp. 2	-	.001	-	.640	.002	.274	-	.176	.083	-
		.001		.002	.002	.002		.001	.002	
/Tanaidacea	1			72		478		1183	104	
Leptochelia dubia	<.001	-	-	.006	-	.032	-	.342	.010	-
	<.001			<.0001		<.0001		.0003	.0001	
/Tanaidacea						2		13		
Anatanais insularis	-	-	-	-	-	<.001	-	.005	-	-
						<.001		.0004		
/Isopoda sp. 1	1	2		41			16	260	16	1
	.003	.004		.188			.027	1.649	.034	.001
	.003	.002		.005			.002	.006	.C02	.001
/Isopoda sp. 2								13		
	-	-	-	-	-	-	-	.083	-	-
								.006		
/Isopoda								2		
Cirolanidae	-	-	-	-	-	-	-	.005	-	-
								.003		
/Isopoda								319		
Mesanthura hieroglyphica	-	-	-	-	-	-	-	.908	-	-
								.003		
/Isopoda								1		
Hansenolana sphaeromiformis	-	-	-	-	-	-	-	.002	-	-
								.002		
/Isopoda		1								
Limnoria sp.	-	.003	-	-	-	-	-	-	-	-
		.003								

Table 2.2-4. (Continued

Species/Group	Bio-Station BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
Anthropoda (continued)	/									
/Isopoda Anthuridae	-	-	-	-	-	-	-	33 .021 .001	-	-
/Isopoda *Paracerceis sculpta*	-	-	-	13 .086 .007	-	10 .063 .006	-	-	-	-
/Isopoda *Colidotea edmondsoni*	-	-	-	-	-	-	-	2 .004 .002	-	-
/Amphipoda (misc.)	13 .011 <.001	21 .014 <.001	-	>163 .275 #	25 .026 .001	>158 .065 #	-	>93 .706 #	>45 .037 #	4 .002 .0005
/Amphipoda *Lembos macromanus*	58 .045 .0008	-	-	20 .013 .001	-	# # #	-	175 .160 .001	4 .002 .0005	-
/Amphipoda *Corophium acherusicum*	5 .002 .0004	3 .001 .0003	-	1607 .454 .0003	-	390 .094 .0002	1 .001 .001	53 .025 .0005	743 .444 .0006	-
/Amphipoda *Ericthonius brasiliensis*	-	-	-	1 .001 .001	49 .073 .0007	# # #	-	69 .055 .001	-	-
/Amphipoda *Elasmopus rapax*	-	13 .004 .0003	-	1091 .867 .001	-	1007 .841 .0008	-	# # #	-	-
/Amphipoda *Leucothoe hyhelia*	-	-	-	-	-	-	-	3 .001 .0003	32 .021 .001	-
/Amphipoda Caprellidae	-	-	-	57 .017 .003	-	5 .001 .0002	-	6 .009 .002	-	-
Decapoda/Nantatia (misc.)	-	-	-	-	-	-	-	# .078 #	-	-
Decapoda/(Misc. Caridea)	-	1 .005 .005	-	6 .047 .008	1 .032 .032	2 .029 .015	3 .045 .015	3 .182 .061	1 .003 .003	-

Table 2.2-4. (Continued)

Species/Group	BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
	Bio Station									
Anthropoda (continued)										
/Decapoda (misc. Alpheid shrimp)	-	-	-	-	-	# .260 #	# .002 #	>3 .248 #	5 # #	# .002 #
/Decapoda *Alpheus* sp.	-	3 .284 .095	-	1 .001 .001	-	-	6 .091 .015	>2 .220 .110	-	-
/Decapoda *Alpheus lobidens polynesica*	7 .358 .051	1 .307 .307	-	-	-	54 5.125 .095	8 .445 .056	52 3.734 .072	4 .200 .050	8 1.350 .169
/Decapoda *Alpheus mackayi*	-	1 .236 .236	-	-	1 .549 .549	3 .499 .166	-	-	4 1.320 .330	4 1.908 .477
/Decapoda *Alpheus rapax*	2 .174 .086	-	-	1 .002 .002	-	1 .017 .017	3 .872 .291	-	1 .018 .018	-
/Decapoda *Alpheus rapacida*	3 .194 .064	-	-	-	-	-	-	-	2 .007 .004	-
/Decapoda *Alpheus platyunguiculatus*	-	-	-	-	-	-	1 .016 .016	-	-	-
/Decapoda *Alpheus paracrinitus*	-	-	-	-	-	2 .004 .002	-	2 .040 .020	-	-
/Decapoda *Alpheus lanceloti*	-	-	-	-	-	-	-	3 .076 .025	-	-
/Decapoda *Alpheus heeia*	-	-	-	-	-	-	-	13 .578 .044	-	-
/Decapoda *Leptalpheus pacificus*	-	-	-	-	-	-	-	1 .045 .045	-	-
/Decapoda *Synalpheus pachymeris*	-	-	-	-	-	-	-	4 .446 .111	-	-
/Decapoda *Synalpheus thai*	-	-	-	-	-	6 .537 .090	-	2 .196 .098	1 .032 .032	-

Table 2.2-4. (Continued)

Species/Group	Bio-Station BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
Anthropoda (continued)										
/Decapoda *Synalpheus streptodactylus*	-	-	-	-	-	-	-	2 .059 .030	-	-
/Decapoda *Synalpheus bituberculatus*	-	1 .064 .064	-	-	-	8 .490 .061	-	28 1.177 .042	21 1.799 .086	1 .019 .019
Decapoda/Reptantia (misc.)	-	-	-	-	-	-	-	# .078 #	-	-
/Paguridae (misc.)	-	-	-	-	-	-	-	1 .002 .002	-	-
/Paguridae *Calcinus latens*	-	-	-	-	-	-	-	4 .056 .014	-	-
/Parthenopidae *Parthenope whitei*	-	-	-	-	-	-	-	1 .524 .524	-	-
/Portunidae (misc.)	-	-	-	-	-	-	-	-	1 .003 .003	-
/Portunidae *Libystes nitidus*	-	-	-	-	-	-	-	-	5 1.077 .215	-
/Portunidae *Portunus longispinosus*	-	-	-	-	-	-	-	2 .133 .067	-	-
/Portunidae *Thalamita integra*	3 .104 .035	2 2.119 1.059	-	12 3.103 .259	2 2.028 1.014	16 2.620 .164	3 .108 .054	10 .385 .039	8 .135 .017	1 .158 .158
/Portunidae *Thalamita admete*	-	-	-	-	-	10 1.553 .155	-	12 .226 .019	-	1 .003 .003
/Grapsidae (misc)	-	-	-	-	-	-	-	1 .017 .017	-	-
/Xanthidae (misc)	-	-	-	-	-	1 .003 .003	-	10 .263 .026	1 .020 .020	-

Table 2.2-4. (Continued)

Species/Group	BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
	Bio-Station									
Anthropoda (continued)										
/Xanthidae *Platypodia eydouxi*	-	-	-	-	-	1 1.134 1.134	-	15 3.067 .204	1 .027 .027	-
/Xanthidae *Lophozozymus dodone*	-	-	-	-	-	-	-	4 2.000 .500	-	-
/Xanthidae *Madaeus simplex*	-	-	-	-	-	-	-	15 8.763 .584	-	-
/Xanthidae *Leptodius sanguineus*	-	-	-	-	-	-	-	1 4.024 4.024	-	-
/Xanthidae *Xanthias* sp.	-	-	-	-	-	-	-	20 5.564 .278	-	-
/Xanthidae *Carpilodes bellus*	-	-	-	-	-	-	-	1 .022 .022	-	-
/Xanthidae *Etisus electra*	-	-	-	-	-	-	1 .010 .010	35 6.928 .198	-	-
/Xanthidae *Etisus laevimanus*	-	-	-	2 .306 .153	-	1 2.187 2.187	1 .014 .014	55 1.188 .022	7 1.930 .276	-
/Xanthidae *Panopeus pacificus*	-	-	-	1 .036 .036	-	77 6.254 .081	-	-	-	-
/Xanthidae *Phymodius nitidus*	-	-	-	-	-	-	-	-	7 .097 .014	-
/Xanthidae *Cholorodiella laevissima*	-	-	-	-	-	1 .044 .044	-	-	-	-
/Xanthidae *Pilumnus oahuensis*	5 .200 .040	8 .672 .084	-	68 7.493 .110	-	50 2.439 .049	1 .065 .065	24 1.884 .079	5 .291 .058	1 .167 .167

Table 2.2-4. (Continued)

Species/Group	Bio-Station BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
Anthropoda (continued)										
/Ocypodidae *Macrophthalmus telescopicus*	7 5.509 .787	-	-	-	-	-	-	7 .032 .005	-	-
/Stomatopoda (misc.)	-	-	-	-	-	-	-	2 # #	-	-
/Stomatopoda *Pseudosquilla ciliata*	-	-	-	-	-	1 .062 .062	-	-	-	-
/Stomatopoda *Gonodactylus falcatus*	-	-	-	-	-	1 1.112 1.112	-	3 1.521 .507	-	-
Mollusca/Gastropoda (misc.)	-	-	-	1 .018 .018	-	1 .004 .004	-	-	-	-
/Vermetidae (misc.) (w/o shell)	1 .291 .291	1 .806 .806	-	-	-	-	-	-	-	-
/Vermetidae *Dendropoma platypus*	-	-	-	-	-	-	-	6 10.360 1.727	-	-
/Cerithiidae *Bittium unilinaatum*	-	-	-	34 .945 .028	-	-	-	-	-	-
/Hipponicidae *Hipponix* sp.	-	-	-	-	-	-	-	20 5.716 .286	-	-
/Hipponicidae *Hipponix pilosus*	-	28 2.600 .129	7 .484 .069	-	-	83 15.933 .192	-	1 .171 .171	-	-
/Calyptraeidae *Crucibulum spinosum*	-	-	-	-	-	-	-	6 2.647 .441	1 1.192 1.192	-
/Calyptraeidae *Crepidula aculeata*	-	15 16.908 1.127	-	-	-	8 5.308 .664	9 4.070 .452	26 11.691 .450	8 1.599 .200	-

Table 2.2-4. (Continued)

Species/Group	BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
	Bio-Station									
Mollusca (continued)										
/Naticidae *Natica gualteriana*	-	-	-	-	-	-	1 .009 .009	1 .006 .006	-	-
/Cymatiidae *Cymatium* sp.	-	-	-	1 10.776 10.776	-	-	-	1 2.397 2.397	-	-
Mollusca/Bivalvia (misc.)	-	-	-	-	-	-	-	1 .005 .005	-	-
/Mytilidae *Brachidontes crebristriatus*	-	-	-	-	-	-	1 .046 .046	48 5.102 .106	-	-
/Ostreidae (misc.) (misc.)	-	-	-	-	-	-	-	1 .101 .101	-	-
/Ostreidae *Crassostrea* sp.	-	-	-	3 15.061 5.020	1 2.731 2.731	18 44.079 2.449	-	-	-	-
/Ostreidae *Ostrea thaanumi*	-	-	-	-	-	-	-	2 2.620 1.310	-	-
/Spondylidae *Spondylus* sp.	1 *.300 *.300	-	-	-	-	-	-	-	-	-
/Anomiidae *Anomia nobilis*	-	-	-	4 7.644 1.911	-	1 3.013 3.013	-	-	-	-
/Lucinidae *Ctena bella*	-	1 2.980 2.980	-	4 4.000 1.000	-	-	1 1.400 1.400	3 5.263 1.754	9 25.200 2.800	-
/Tellinidae *Angulus nucella*	-	-	-	-	-	-	-	1 .176 .176	-	-
/Hiatellidae *Hiatella hawaiiensis*	9 .121 .013	131 .866 .007	-	276 4.686 .017	45 .129 .003	269 9.915 .037	2 .015 .008	298 12.648 .042	190 1.095 .006	6 .074 .012
Ectoprocta/Bryozoa (misc.)	-	# .005 #	-	-	-	-	-	-	-	# .010 #

Table 2.2-4. (Continued)

Species/Group	Bio-Station BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
Ectoprocta (continued)										
Ectoprocta/Vesiculariidae										
Amathia distans	-	# <.001 #	# .008 #	-	# .738 #	# .002 #	# .003 #	-	# .001 #	-
/Bicellariellidae										
Bugula neritina	-	# .147 #	# .040 #	-	# 9.910 #	# .002 #	# .067 #	# .008 #	# .002 #	# .063 #
/Bicellariellidae										
Bugula californica	-	-	-	-	-	-	-	# .001 #	-	-
Echinodermata/Ophiuroidea										
/Ophiactidae										
Ophiactis savignyi	-	-	-	25 .178 .007	4 .020 .005	772 11.286 .015	-	206 2.414 .012	181 1.550 .009	-
/Amphiuridae										
Amphipholis squamata	-	-	-	23 .045 .002	-	2 .006 .003	-	16 .018 .001	-	-
/Holothuridea										
Holothuria pervicax	-	-	-	-	-	-	-	1 .189 .189	-	-
Urochordata/Ascidiacea (misc.)	-	1 10.000 10.000	-	-		2 2.097 1.048	-	-	# .106 #	-
/Ascidiacea										
Ascidia sp.	-	1 .194 .194	-	4 4.474 1.119	2 .115 .058	1 1.126 1.126	2 1.183 .592	1 2.031 2.031	5 .746 .149	-
/Polyclinidae										
Polyclinum sp.	-	-	-	-	-	# 1.043 #	-	# .052 #	-	-
/Styelidae										
Styela sp.	-	-	-	3 .428 .143	-	62 18.531 .299	-	1 .817 .817	1 1.103 1.103	-
Chordata/Osteichthyes (misc.)	-	-	-	1 0.134 .134	-	5 .110 .022	-	-	-	-
/Gobiidae										
Oxyurichthys lonchotus	1 1.179 1.179	-	-	-	-	-	-	-	-	-

Table 2.2-4. (Continued)

Species/Group	Bio-Station									
	BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
Chordata (continued)										
/Gobiidae	1									
Bathygobius fuscus	.467	-	-	-	-	-	-	-	-	-
	.467									
/Eleotridae										
Asterropteryx	3	1		3		1				1
semipunctatus	.060	1.159	-	1.165	-	<.001	-	-	-	.015
	.020	1.159		.388		<.001				.015

Note 1.
Where an organism is present at a given bio-station, three entries are made in vertical sequence: top = number of individuals, middle = total wet weight of all individuals, and bottom = mean individual wet weight. (A dash in the middle position indicates that the particular organism was not found at the given bio-station)

Table 2.2-5. SUMMARY DATA FOR ORGANISMS COLLECTED DURING THE PEARL HARBOR BENTHIC FAUNAL SURVEY.

Bio-station	No. Samples analyzed	No. species (minimum)	total individuals ($\overline{X}$ individuals/sample)		total weight(grams) ($\overline{X}$ weight/sample)	
BE-02	9	30	185	(21)	10.29	(1.14)
BE-03	9	43	308	(34)	217.60	(24.18)
BE-04	6	8	24	(4)	.75	(0.13)
BE-05	9	51	5256	(584)	698.00	(77.56)
BM-07	6	21	155	(26)	21.41	(3.57)
BC-09	9	70	3945	(438)	2288/62	(254.30)
BC-10	6	32	85	([illegible])	17.89	(2.98)
BC-11	15	99	4968	(331)	411.92	(27.46)
BW-13	9	61	1923	(214)	285.61	(31.73)
BE-17	9	25	80	(9)	5.04	(0.56)

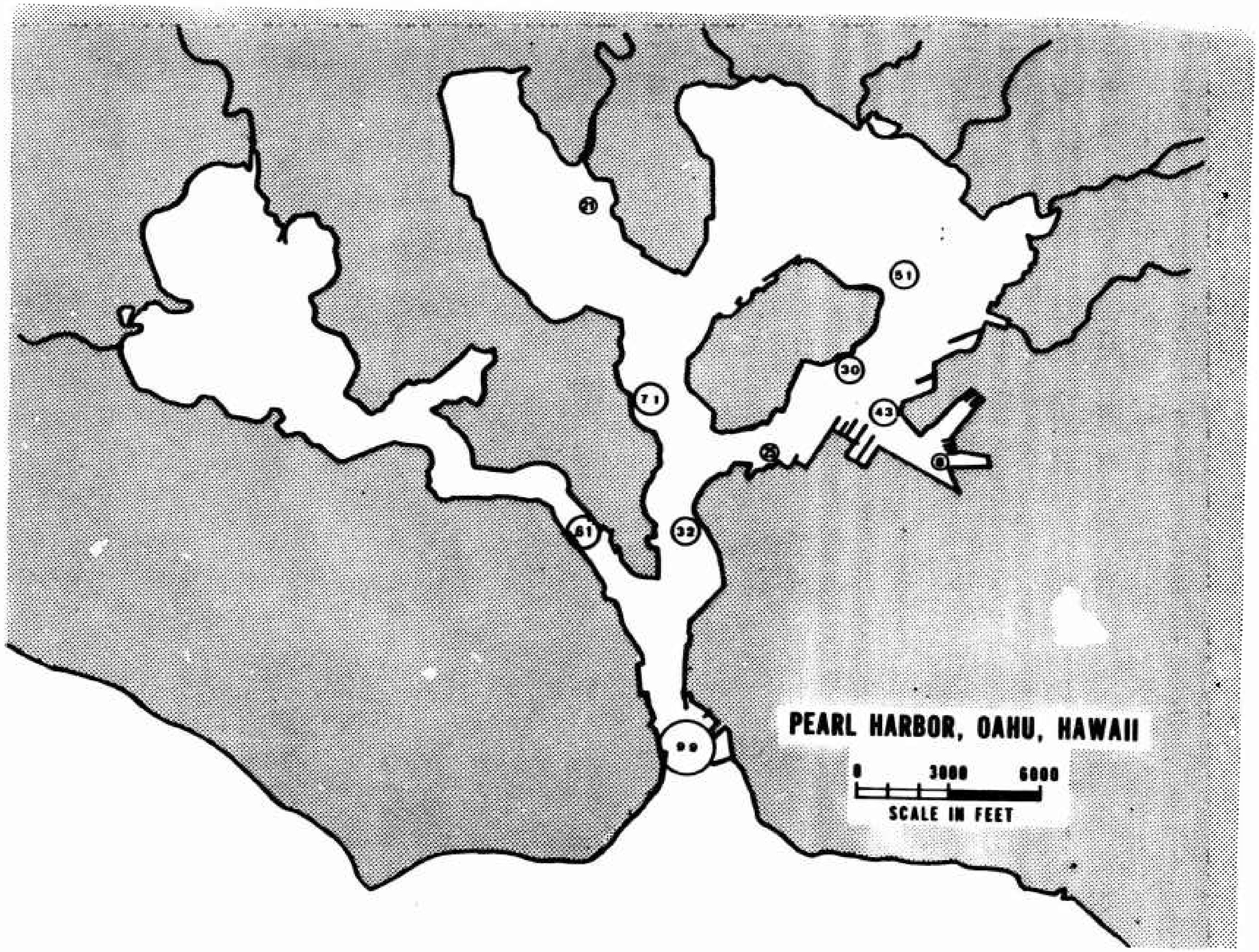


Figure 2.2-6. NUMBER OF BENTHIC FAUNAL SPECIES PER STATION (ALL DEPTHS).

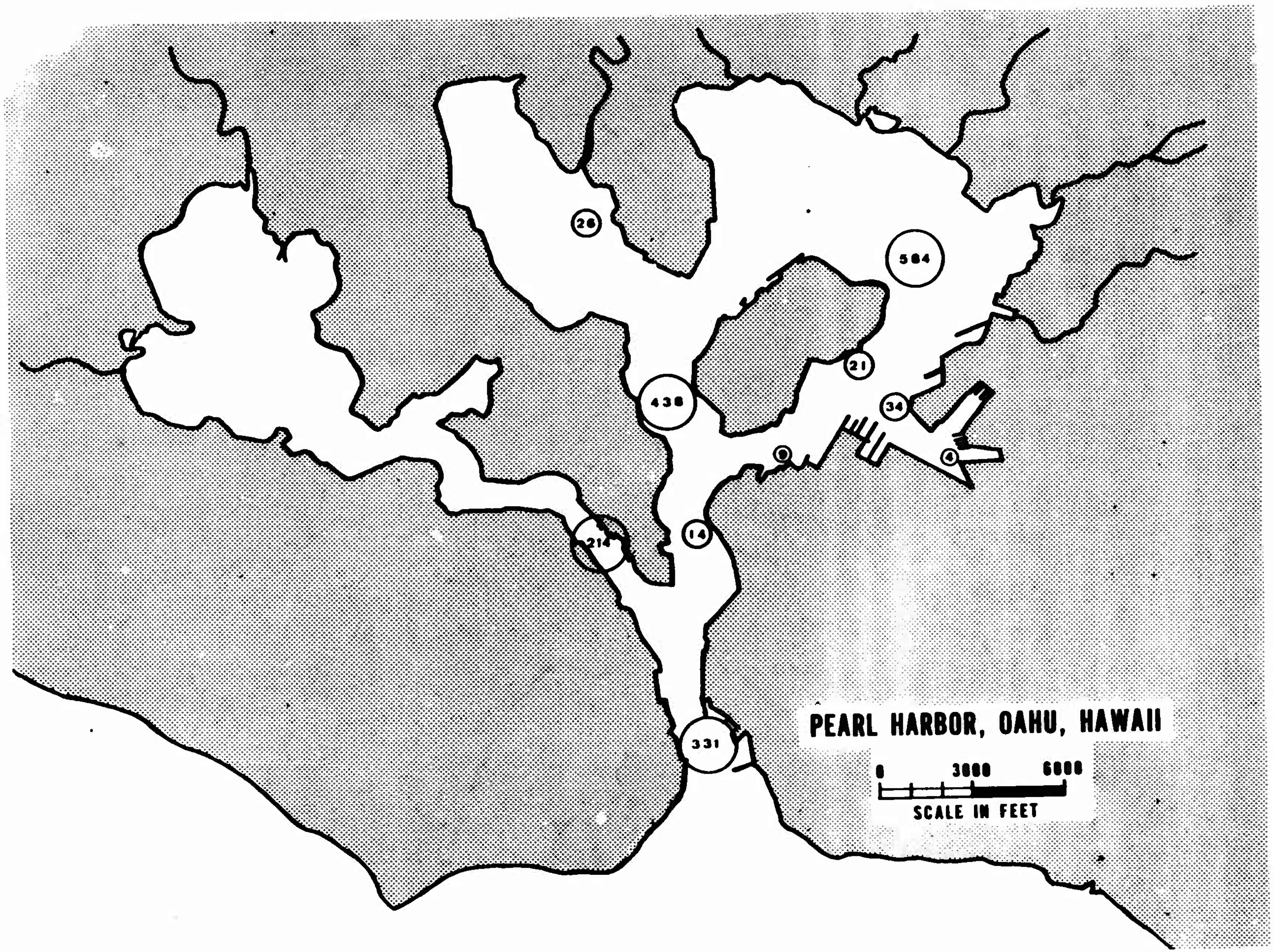


Figure 2.2-7. $\overline{X}$ NUMBER OF INDIVIDUALS OF BENTHIC FAUNAL ORGANISMS PER STATION (ALL DEPTHS).

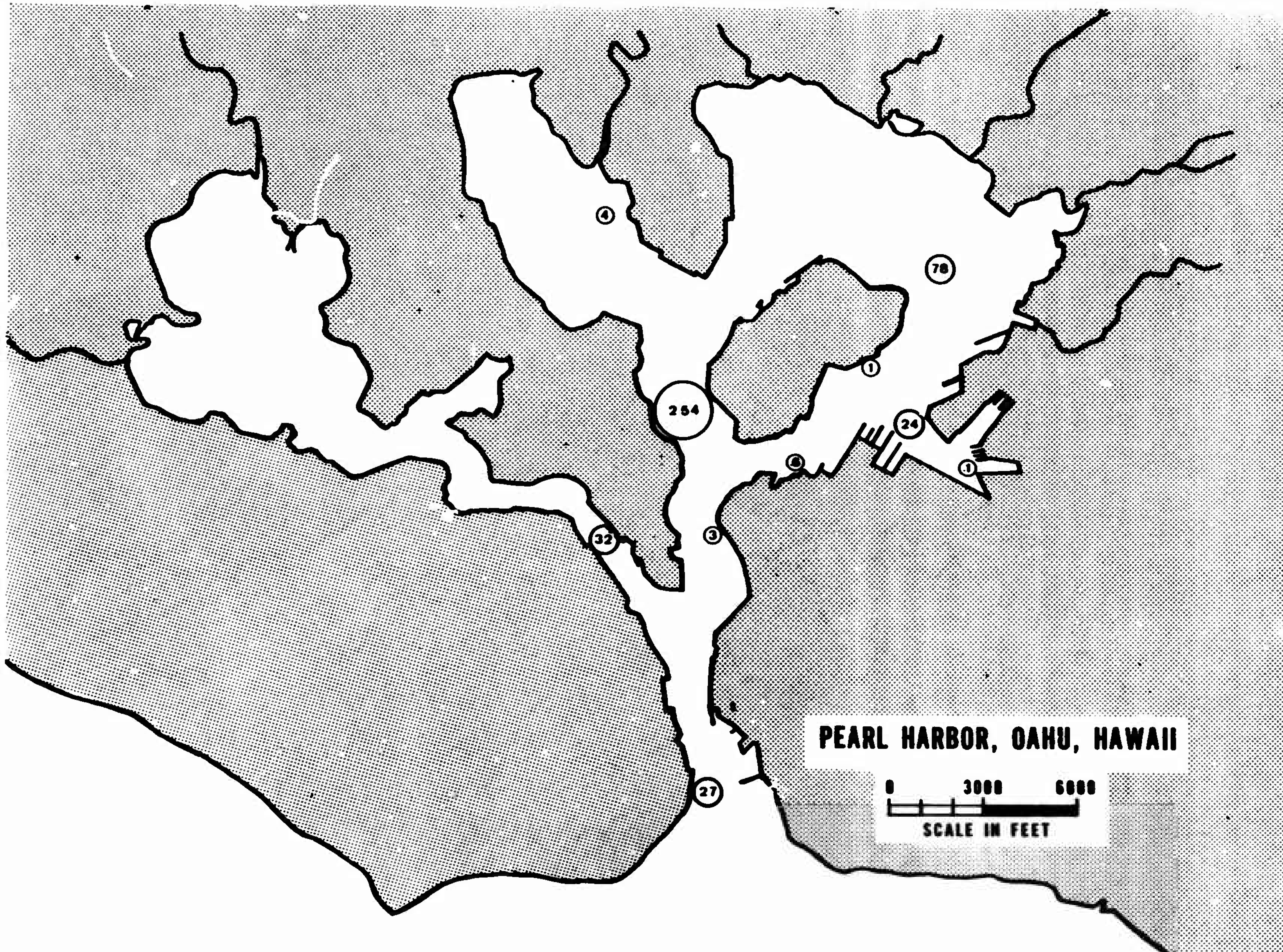


Figure 2.2-8. $\overline{X}$ WET WEIGHT OF BENTHIC FAUNAL ORGANISMS PER STATION (GRAMS) (ALL DEPTHS).

Table 2.2-6. MEAN WET WEIGHT (GRAMS) PER SAMPLE OF MAJOR BENTHIC FAUNAL GROUPS IN PEARL HARBOR AT TEN BIO-STATIONS.

Bio-station	Sponges	Bryo-zoans	Poly-chaetes	Mol-lusc	Echino-derms	Amphipods	Isopods/ Tanaids	Decapods
BE-02	.038	-	.130	.013	-	.007	.008	.724
BE-03	21.576	.017	.340	2.829	-	.002	.003	.410
BE-04	.017	.008	.004	.081	-	-	-	-
BE-05	65.264	-	5.084	4.792	.025	.181	.204	1.220
BM-07	.536	1.183	.067	.477	.003	.010	.001	.471
BC-09	234.012	.001	4.827	8.695	1.253	.111	.041	2.714
BC-10	.697	.431	.850	.937	-	.001	.005	.307
BC-11	14.781	.001	3.601	3.927	.175	.073	.311	2.811
BW-13	25.541	.001	1.308	3.234	.172	.056	.224	.774
BE-17	.050	.007	.092	.008	-	.001	.001	.401

Table 2.2-7. SELECTED COMMON BENTHIC FAUNAL ORGANISMS PRESENT IN SAMPLES FROM PEARL HARBOR.

Species	Common name*	# Samples containing organism	# Bio-stations containing organism	Depth (ft.) range	Depth (ft.) mean
Hiatella hawaiiensis	BI	44	9	1-47	15.9
Nereis sp.	EP	33	10	1.5-48	21.4
Bugula neritina	BR	27	8	2-48	27.8
Corophium acherusicum	AM	26	7	1.5-48	14.6
Apseudes sp. 2	TA	26	6	2-40	13.6
Eurythoe complanata	EP	25	8	1.5-32	13.9
Nematonereis unicornis	EP	23	8	1.5-44	15.3
Pilumnus oahuensis	TC	23	8	2-31	11.8
Thalamita integra	TC	21	9	2-44	17.4
Apseudes sp. 1	TA	21	6	2-42	12.7
Ophiactis savignyi	BS	20	5	2-42	13.3
Etisus laevimanus	TC	12	5	2-48	18.8
Crepidula aculeata	GA	12	5	2-36	13.2
Ascidia sp.	AS	9	7	3-43	19.2

*legend for common names may be found in Table 2.2-3.

Distributional patterns for these selected species are mapped in Figures 2.2-9 through 2.2-22. Except for colonial organisms, the mean number of individuals (per cubic foot*) is given first followed by the mean wet weight (per cubic foot) given in parentheses. The presence of *Bugula neritina*, a colonial bryozoan, is indicated by the letter "P". Zero indicates the absence of a species at a particular bio-station. A dot indicates presence in low numbers (mean number of individuals <0.5).

The three polychaete worms, *Nereis* sp., *Eurythoe complanata*, and *Nematonereis unicornis*, are widely distributed throughout the harbor. The high mean abundance of *Nereis* at bio-station BE-17 (see Figure 2.2-9) is indicative of its high tolerance for a benthic environment high in total heavy metal content (see Section 4.1). *Eurythoe complanata* and *Nematonereis unicornis* are most numerous at bio-stations BE-05 and BC-11, stations with relatively more diverse, and presumably higher, quality benthic environments (see Figures 2.2-10 and 2.2-11).

The tanaid crustaceans, *Apseudes* sp. 1 and *Apseudes* sp. 2, are most abundant at bio-stations BE-05, BW-13, BC-09 and BC-11 illustrating their affinity for the diverse sponge growth at these bio-stations. The amphipod, *Corophium ascherusicum*, shows a similar distributional pattern (see Figure 2.2-14).

The xanthid crabs, *Pilumnus oahuensis* and *Etisus laevimanus*, show somewhat contrasting distributional patterns throughout the harbor, with some exceptions. *Pilumnus* can tolerate most benthic environments, even in the shipyard complex, but is conspicuously absent from BE-04 and the sometimes anoxic bottom at BM-07. *Etisus* is not found at any inner harbor bio-stations except BE-05 and BC-09, two remarkably similar, higher quality benthic environments located at opposite ends (east-west) of Ford Island (see Figure 2.2-17). A third crab, the portunid (*Thalamita integra*), is widely distributed in the harbor; however, it again occurs most numerously at BE-05 and BC-09. All aforementioned crabs are benthic scavengers whose distributions may vary seasonally with available food supplies.

The bivalve mollusk, *Hiatella hawaiiensis*, was collected in more benthic samples (44) than any other single organism (see Table 2.2-7). This small nestling clam inhabits benthic environments at all bio-stations except BE-04, indicating a tolerance for all but the most stressed areas. *Crepidula aculeata*, a gastropod mollusk, is predominantly distributed at the channel stations BC-11, BC-10 and BC-09, but is also present at BW-13 and BE-03 (see Figure 2.2-19). This species has an affinity for vertical rock or piling surfaces.

The brittle star, *Ophiatis savgnyi*, is present only at bio-stations not located in the shipyard/southeast loch complex and is most numerous at bio-station BC-09 (see Figure 2.2-20). Echinoderms in general (with the exception of another brittle star, *Amphipholis squamata* and the holothurian, *Opheodesoma spectabilis*) are remarkably absent from inner Pearl Harbor. Echinoids (sea urchins) have been observed only at bio-station BC-11.

---

* for convenience in presentation, values have been converted from the actual sample volume of 0.3 ft^3 to a standard volume of one cubic foot.

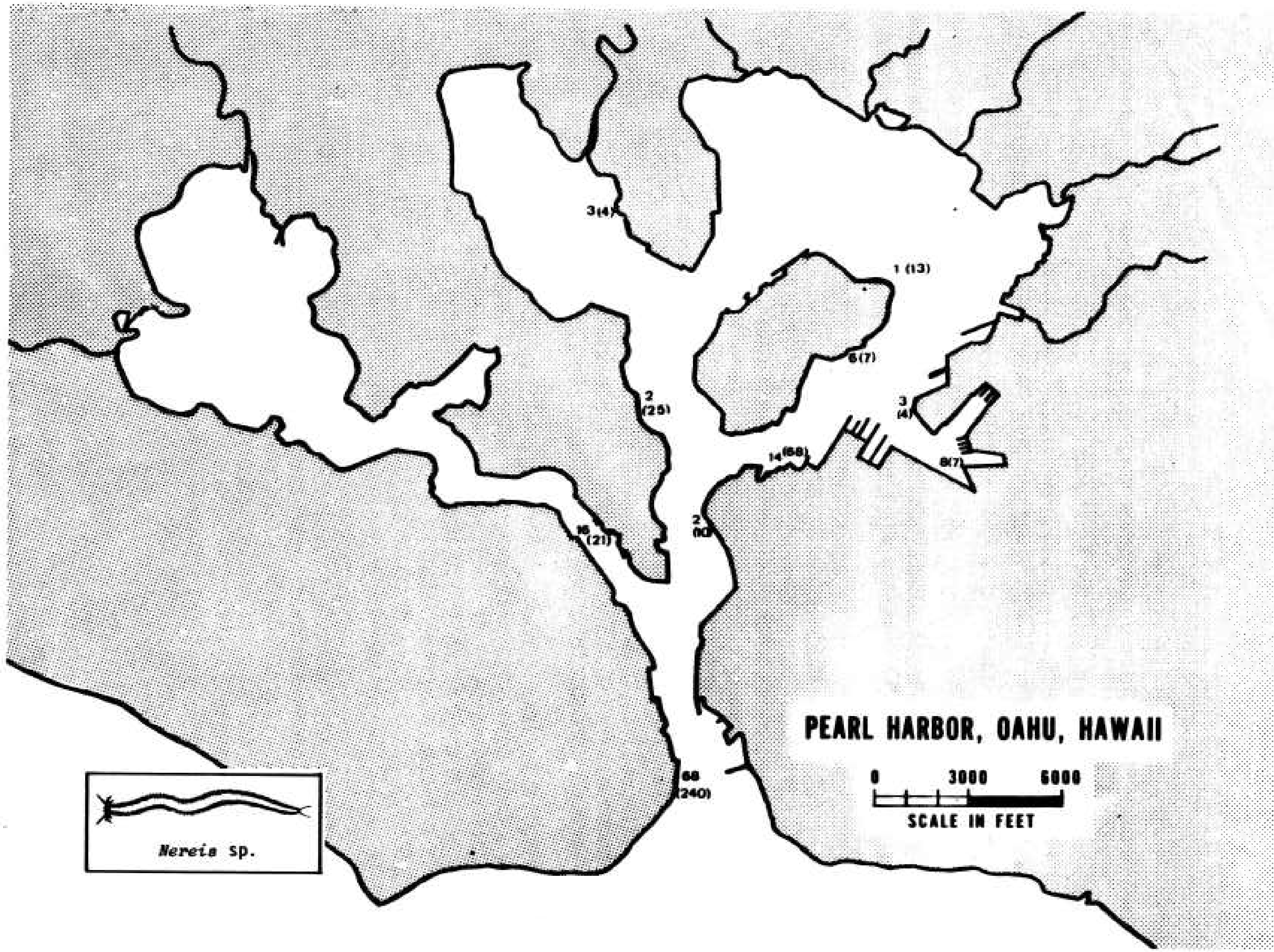


Figure 2.2-9. *Nereis* sp.

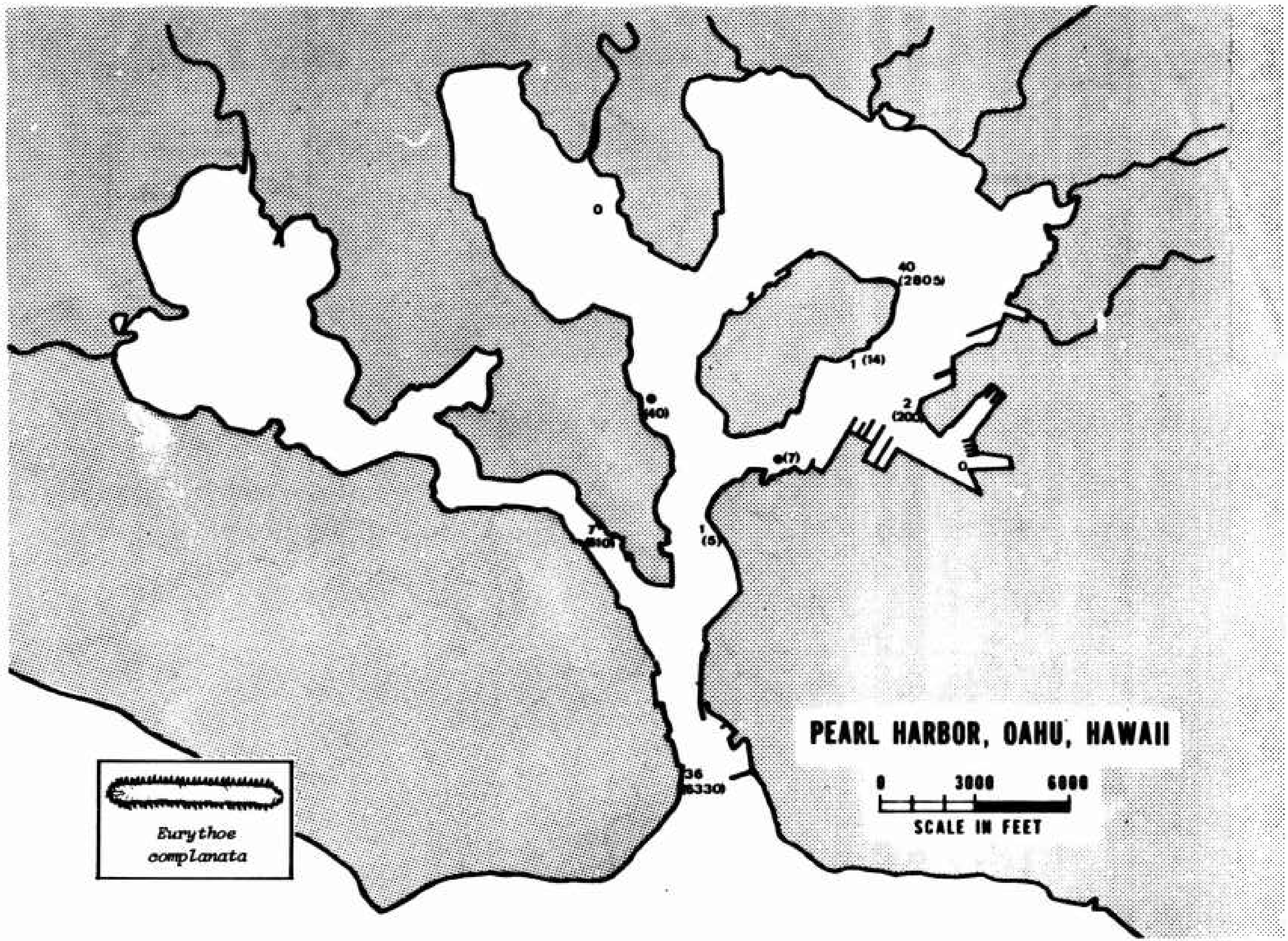


Figure 2.2-10. *Eurythoe complanata*

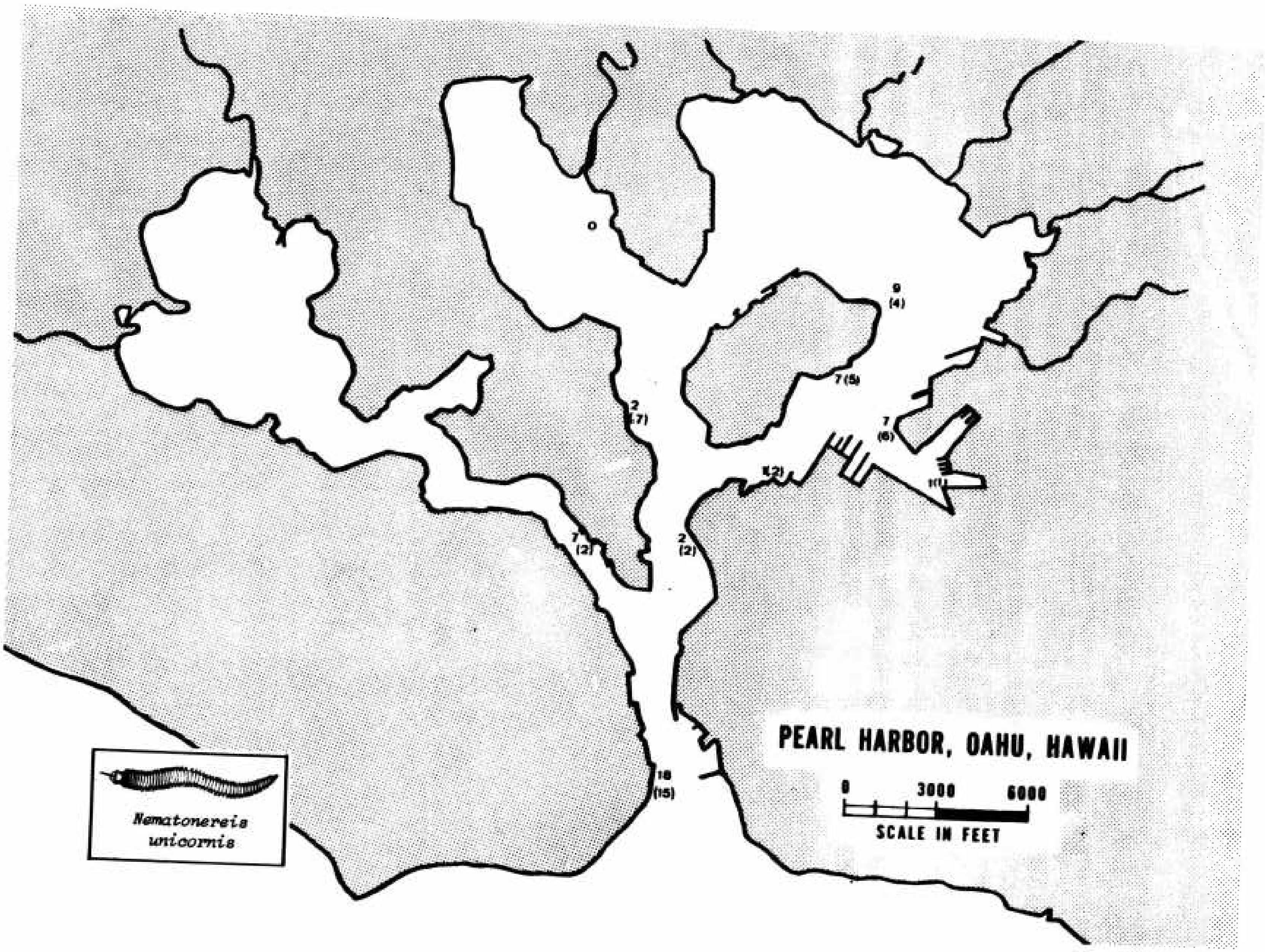


Figure 2.2-11. *Nematonereis unicornis*

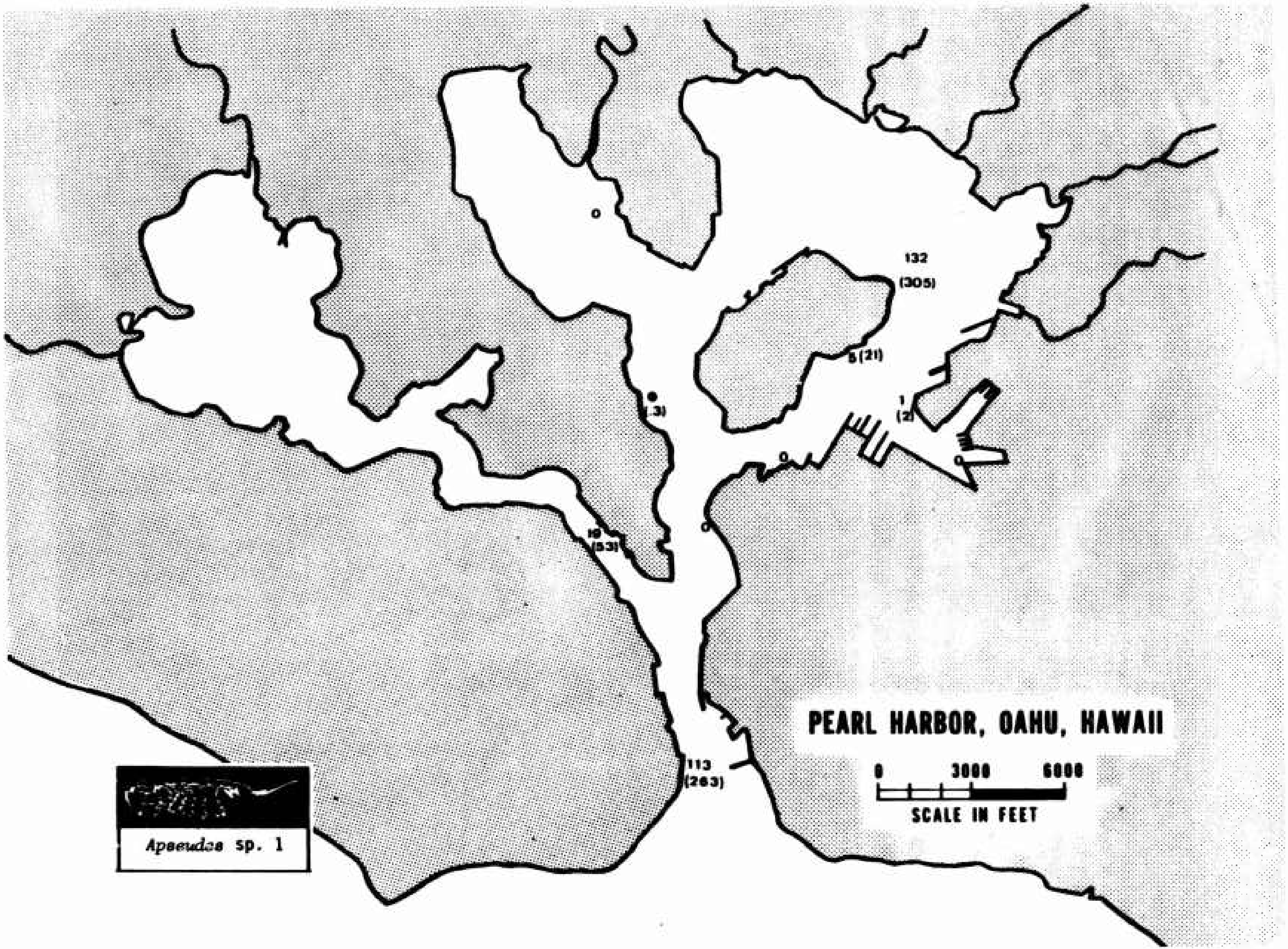


Figure 2.2-12. *Apseudes* sp. 1

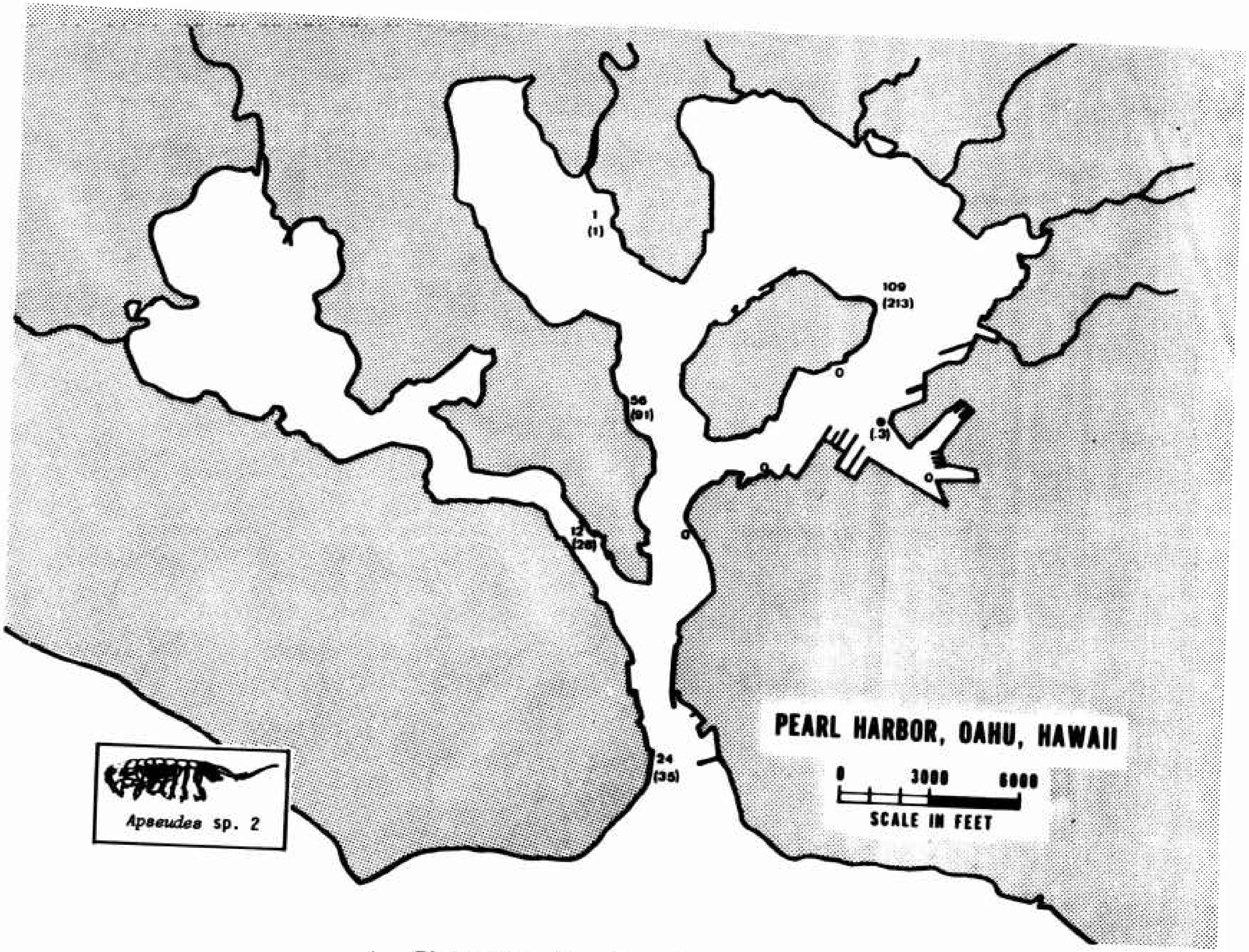


Figure 2.2-13. *Apseudes* sp. 2

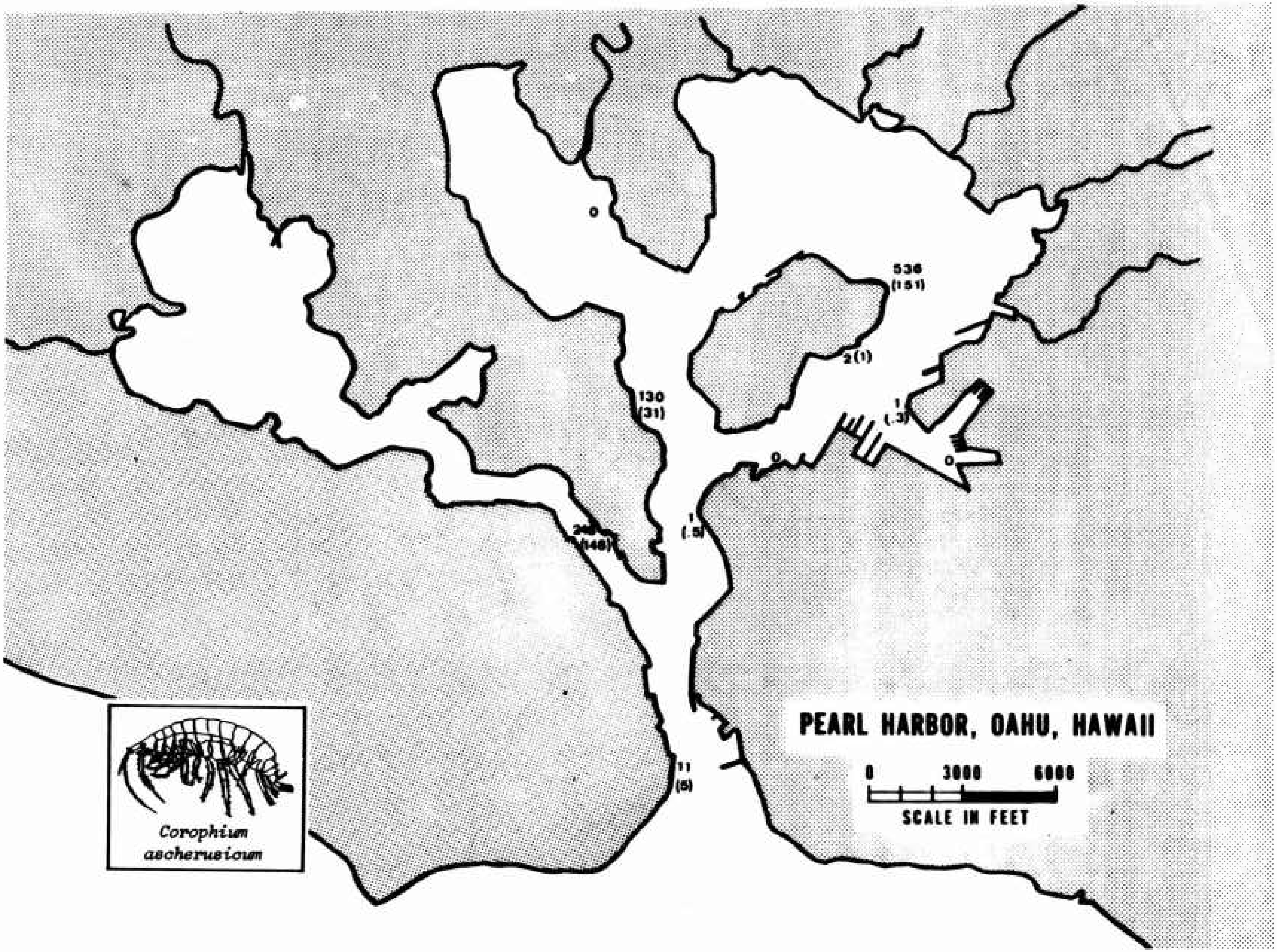


Figure 2.2-14. *Corophium ascherusicum*

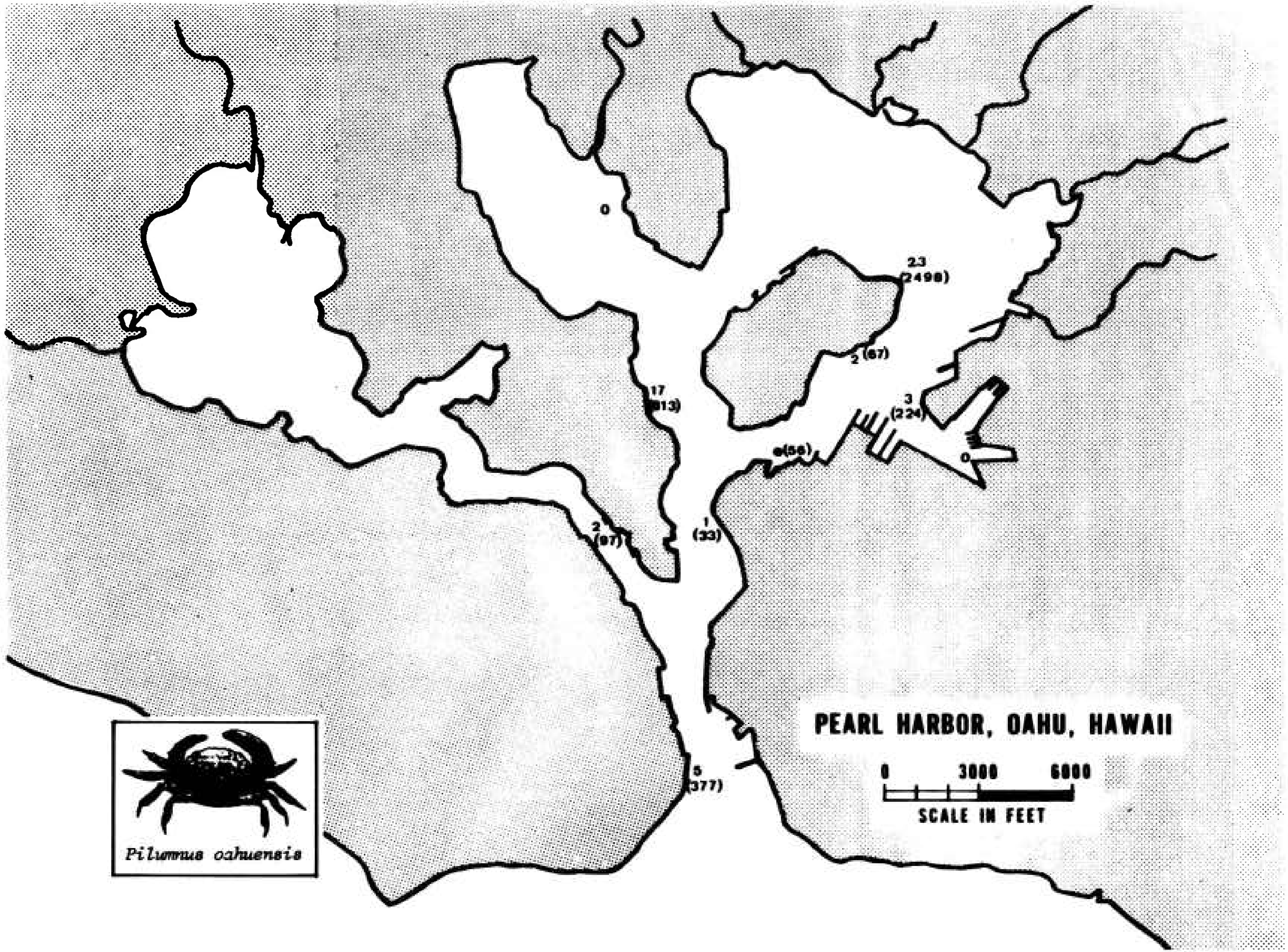


Figure 2.2-15. *Pilumnus oahuensis*

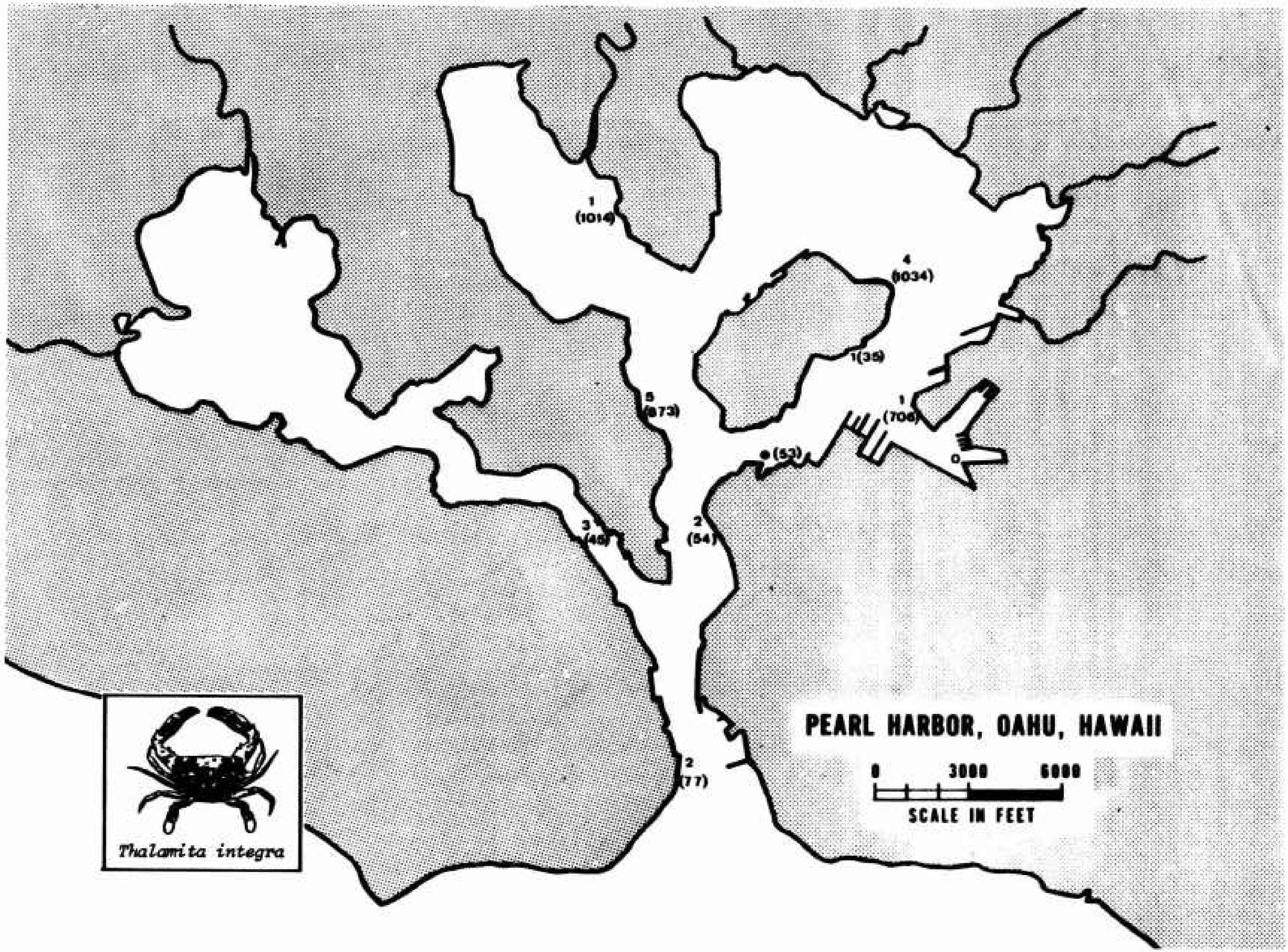


Figure 2.2-16. *Thalamita integra*

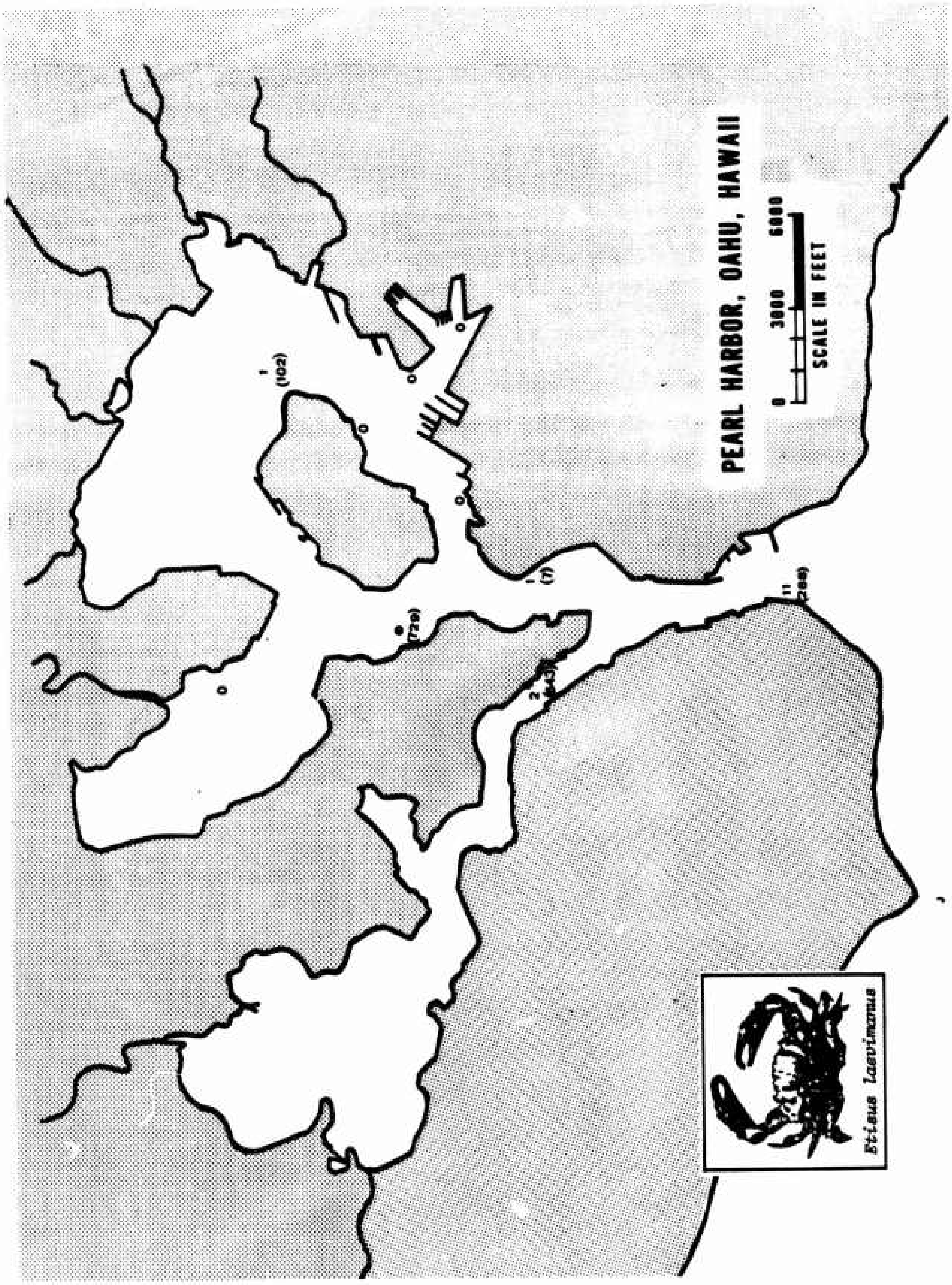


Figure 2.2-17. *Etisus laevimanus*

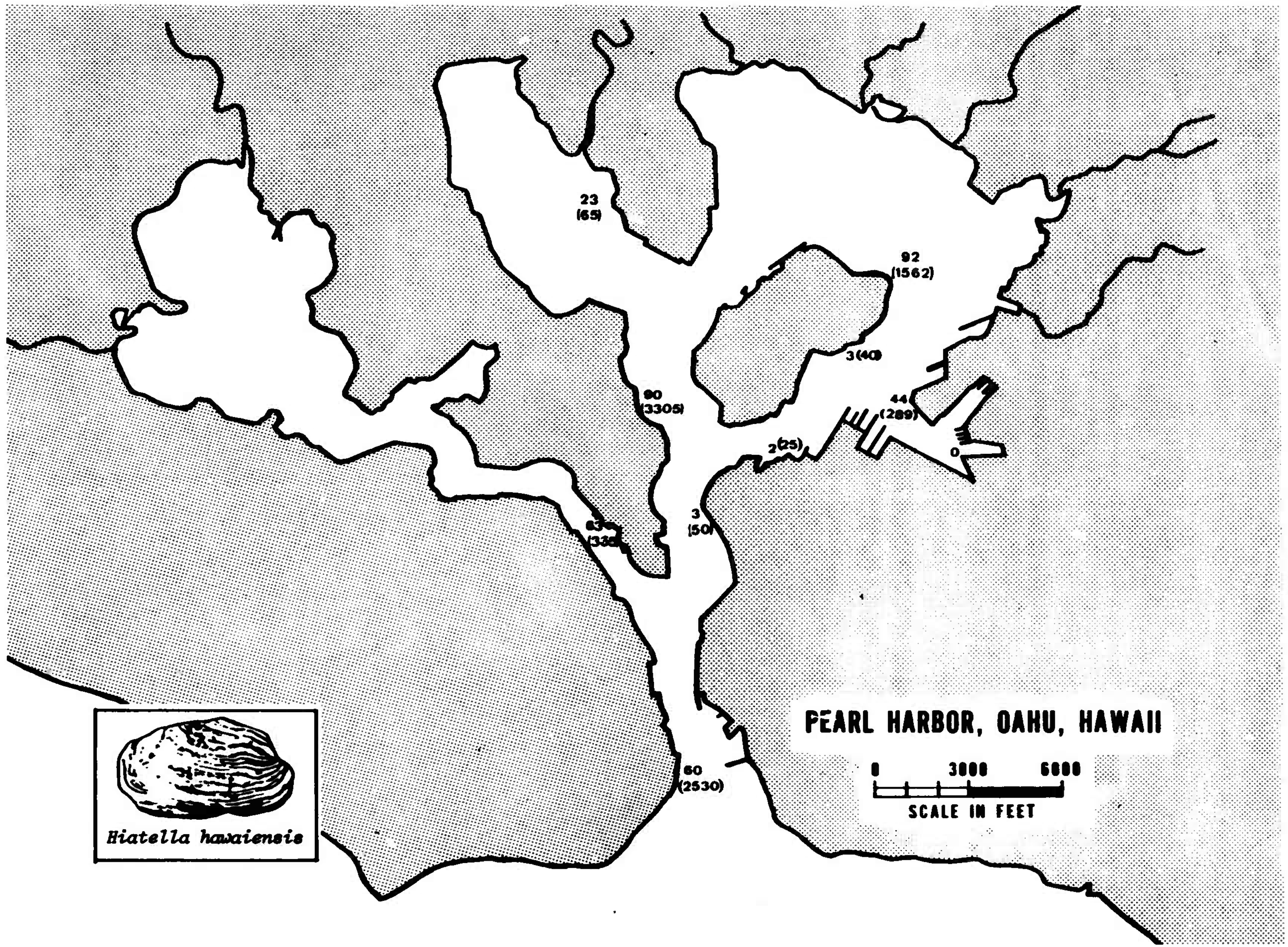


Figure 2.2-18. *Hiatella hawaiensis*

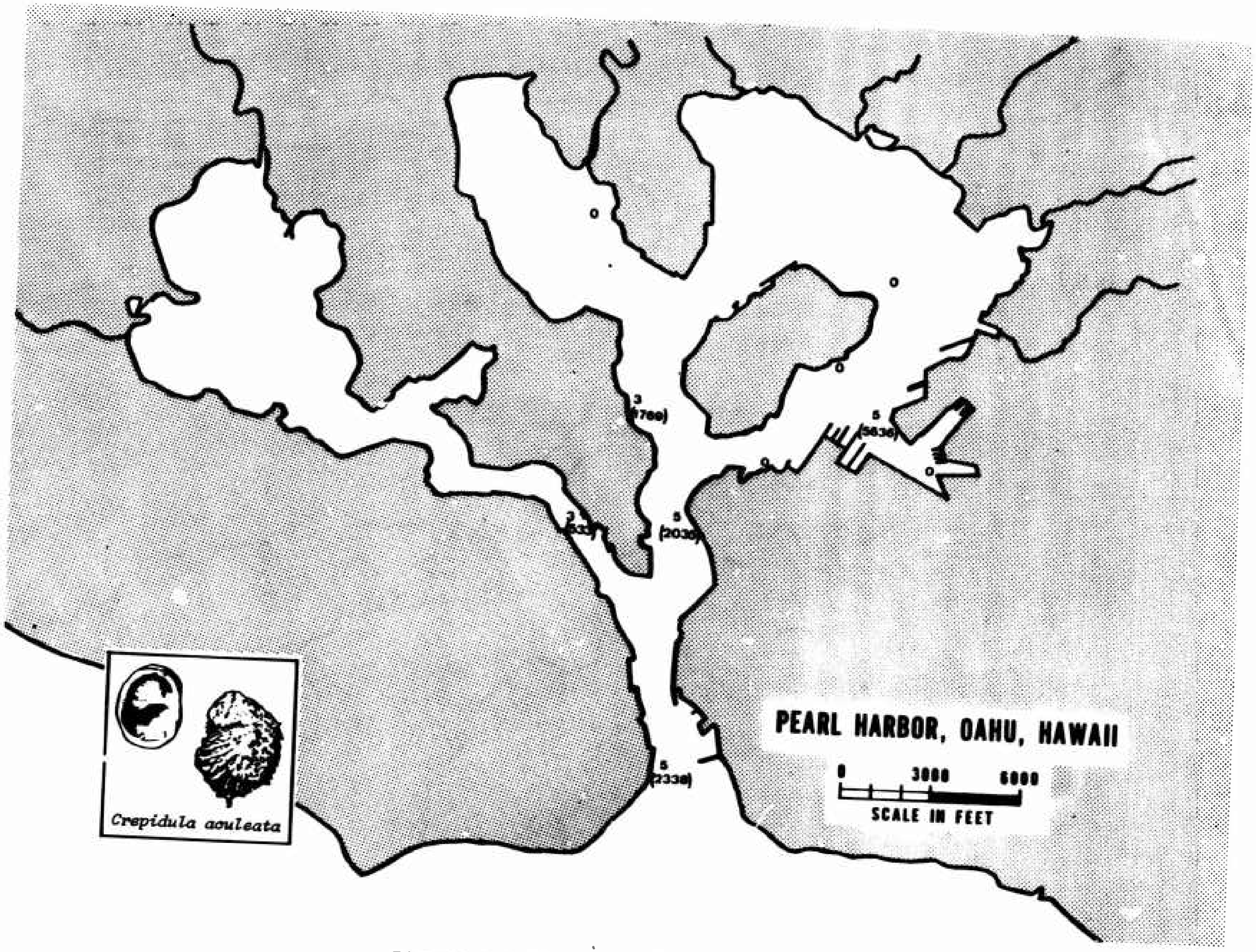


Figure 2.2-19. *Crepidula aculeata*

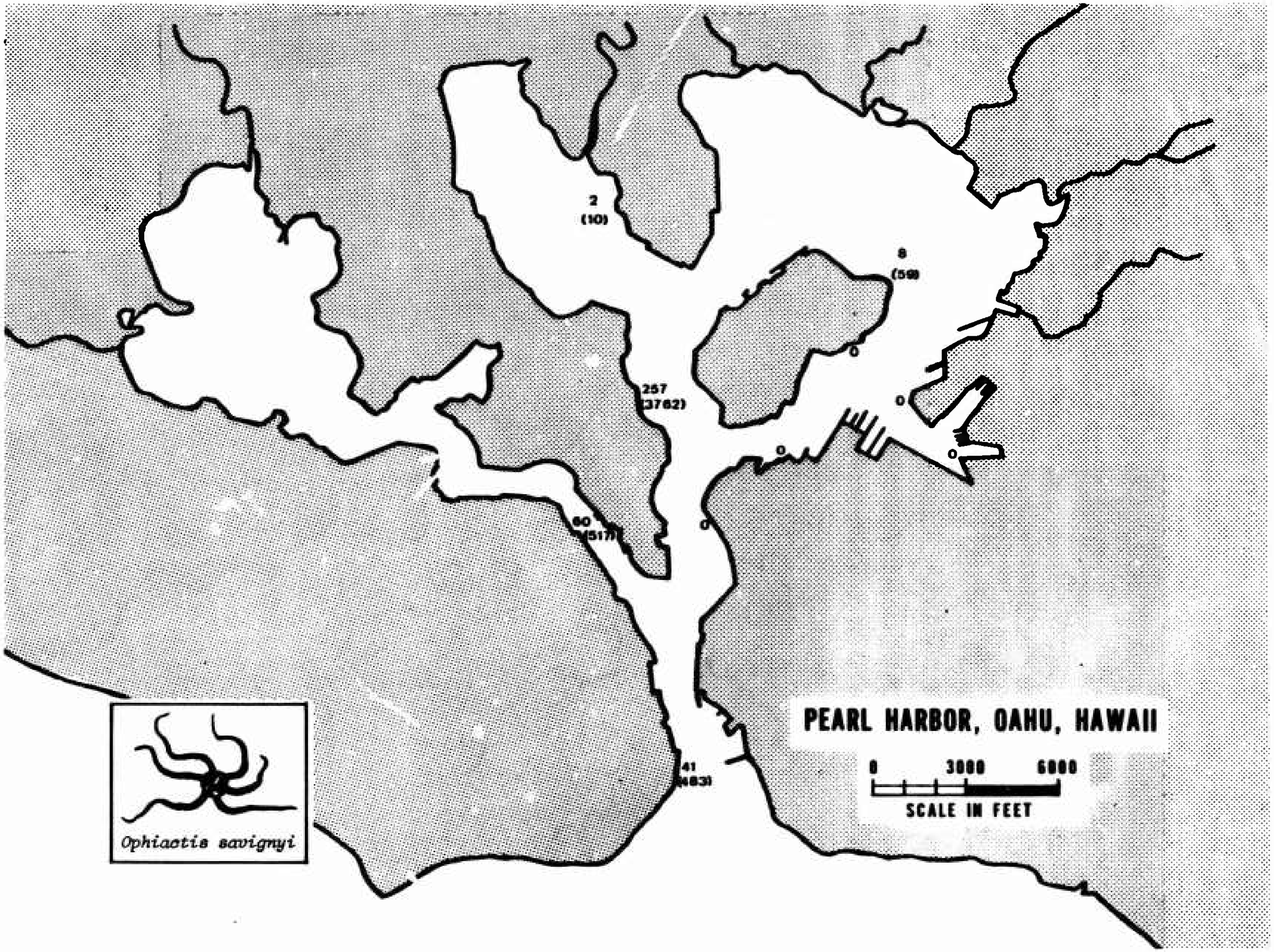


Figure 2.2-20. *Ophiactis savignyi*

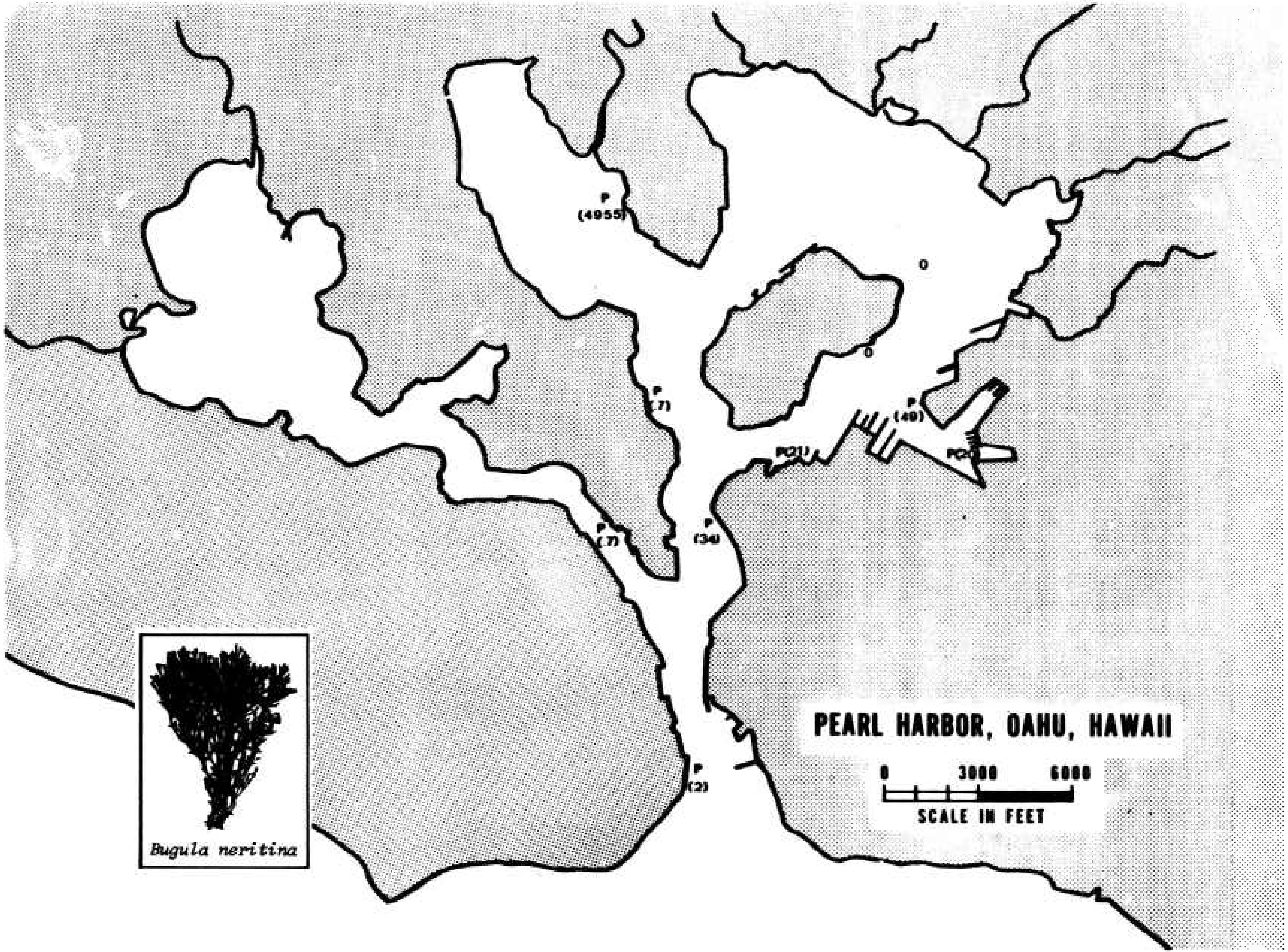


Figure 2.2-21. *Bugula neritina*

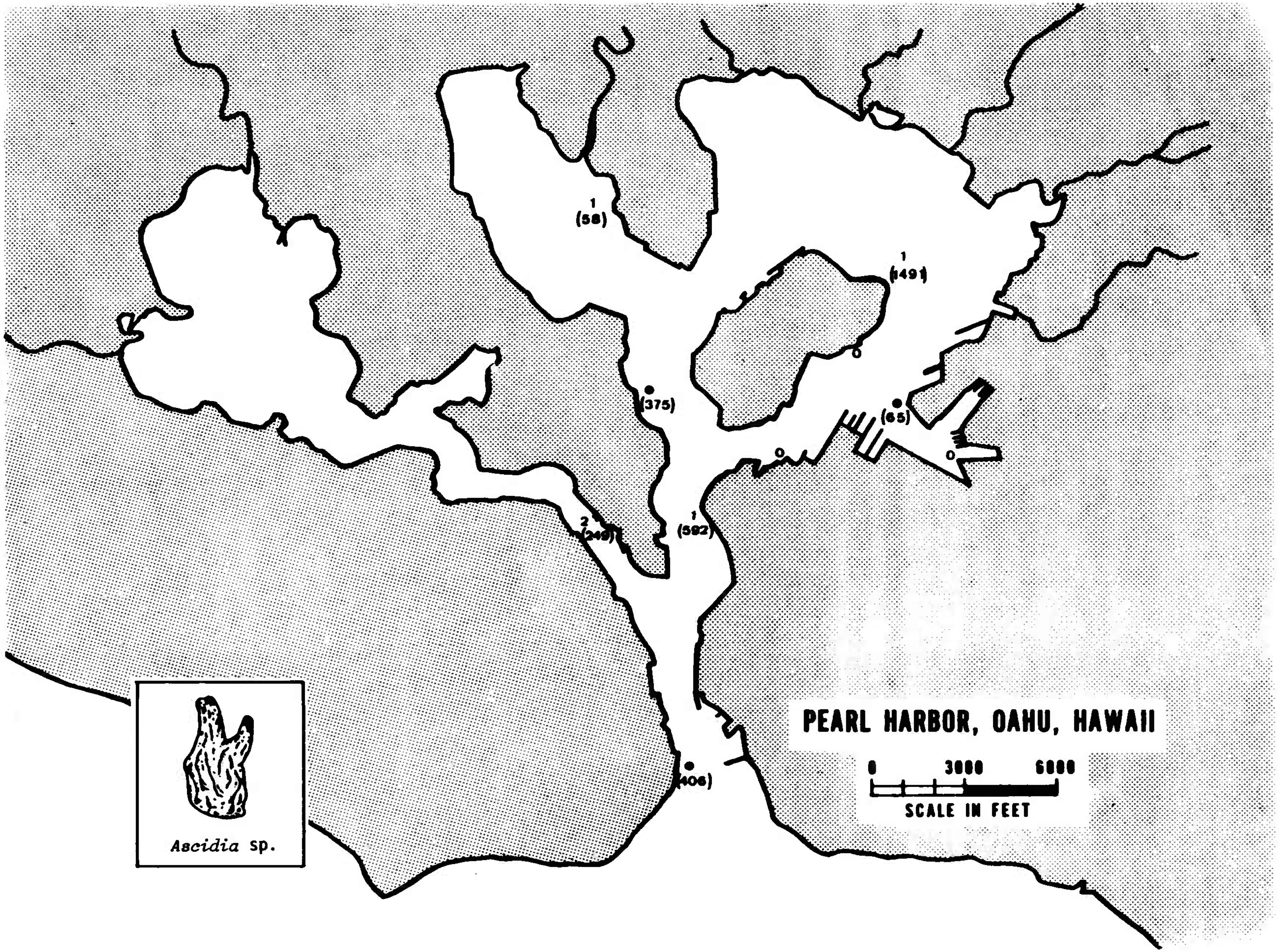


Figure 2.2-22. *Ascidia* sp.

The bryozoan, *Bugula neritina*, is seen to be most abundant well inside the harbor at bio-stations BM-07, BE-03, BC-10, BE-17 and BE-04 which are subjected to the greatest shipyard and domestic sewage influences. *Bugula neritina* has been well documented as a major fouling organism (Reference 2.2-7) and this hardy species indeed thrives inside Pearl Harbor. The solitary tunicate, *Ascidia* sp., is evenly distributed at 7 bio-stations, but is absent from bio-stations BE-02, BE-04 and BE-17, again indicating an intolerance for only the most stressed benthic environments.

Ten species of benthic algae have been identified from 145 benthic samples. These data are summarized in Table 2.2-8. Algae were completely absent from samples at bio-stations BM-09 and BE-03. The number of algal species present at the 8 remaining bio-stations is presented in Figure 2.2-23. Volumetric measurements (millimeters of water displaced) are presented for the combined benthic algal species collected at each bio-station in Figure 2.2-24 (reported values represent the mean per sample). The benthic algal species and abundance data again illustrate that the bio-station cluster BC-11, BC-09, BW-13 and BE-05 represents the more productive and diverse benthic environments within Pearl Harbor.

The ulvoids, *Ulva reticulata* and *Ulva* sp., are the most widely distributed (7 bio-stations) and abundant algal species within the harbor. *Acanthophora spicifera* and *Hypnea cervicornis* occur only at shallow depths (1-4 ft.), while other algal species exhibited no strong depth specificities.

DISCUSSION

The species and numbers of organisms collected during the benthic survey provide certain patterns in distribution throughout Pearl Harbor. These patterns are related to a combination of factors in the benthic environment. Substrate type undoubtedly is a major factor in producing these variations in distribution. Water circulation, siltation and the presence of certain toxic contaminants both in the water column and in the sediments are also important limiting factors to the benthic biota.

The most obvious patterns observed are the uniqueness of the benthic organisms inhabiting bio-station BC-11, the marked similarity of benthic faunas at bio-stations BC-09 and BE-05, and the similarity of benthic flora and fauna in the shipyard/southeast loch stations (BE-04, BE-03, BE-02, and BE-17). Recognition of these major areas is discernible through their benthic faunas.

The selection of certain organisms commonly occurring in the benthic samples has provided an opportunity to reevaluate their tolerances for living in stressed benthic environments. Specifically, organisms such as *Bugula neritina* appear to indicate an affinity for degraded environmental quality as exists at bio-station BE-04. A variety of organisms must be examined if any useful patterns in environmental conditions are to be evaluated. For further analyses of these data, see Section 4.4.

Table 2.2-8. BENTHIC ALGAE PRESENT IN BOTTOM SAMPLES COLLECTED FROM PEARL HARBOR (mls displaced in all samples).

Species*	BE-02	BE-04	BE-05	BC-09	BC-10	BC-11	BW-13	BE-17
Acanthophora spicifera	-	-	1.0	276.5	-	18.5	0.5	-
Caulerpa verticillata	114.0	-	1.0	-	-	-	6.0	-
Centroceras clavulatum	-	-	1.0	1.5	-	-	0.5	-
Cladophora sp.	-	-	-	12.5	0.5	3.5	-	-
Gracilaria lichenoides	-	-	-	4.C	-	1.0	-	-
Griffithsia sp.	-	-	44.0	-	-	-	-	-
Hypnea cervicornis	-	-	-	232.5	-	88.5	-	-
Spyridia filamentosa	-	-	1.0	-	-	-	-	-
Ulva reticulata	-	0.5	-	-	-	85.5	0.5	1.0
Ulva sp.	0.5	-	-	155.0	0.5	58.5	0.5	0.5

* A phyletic listing for these species is presented in the Cumulative Checklist of the Report.

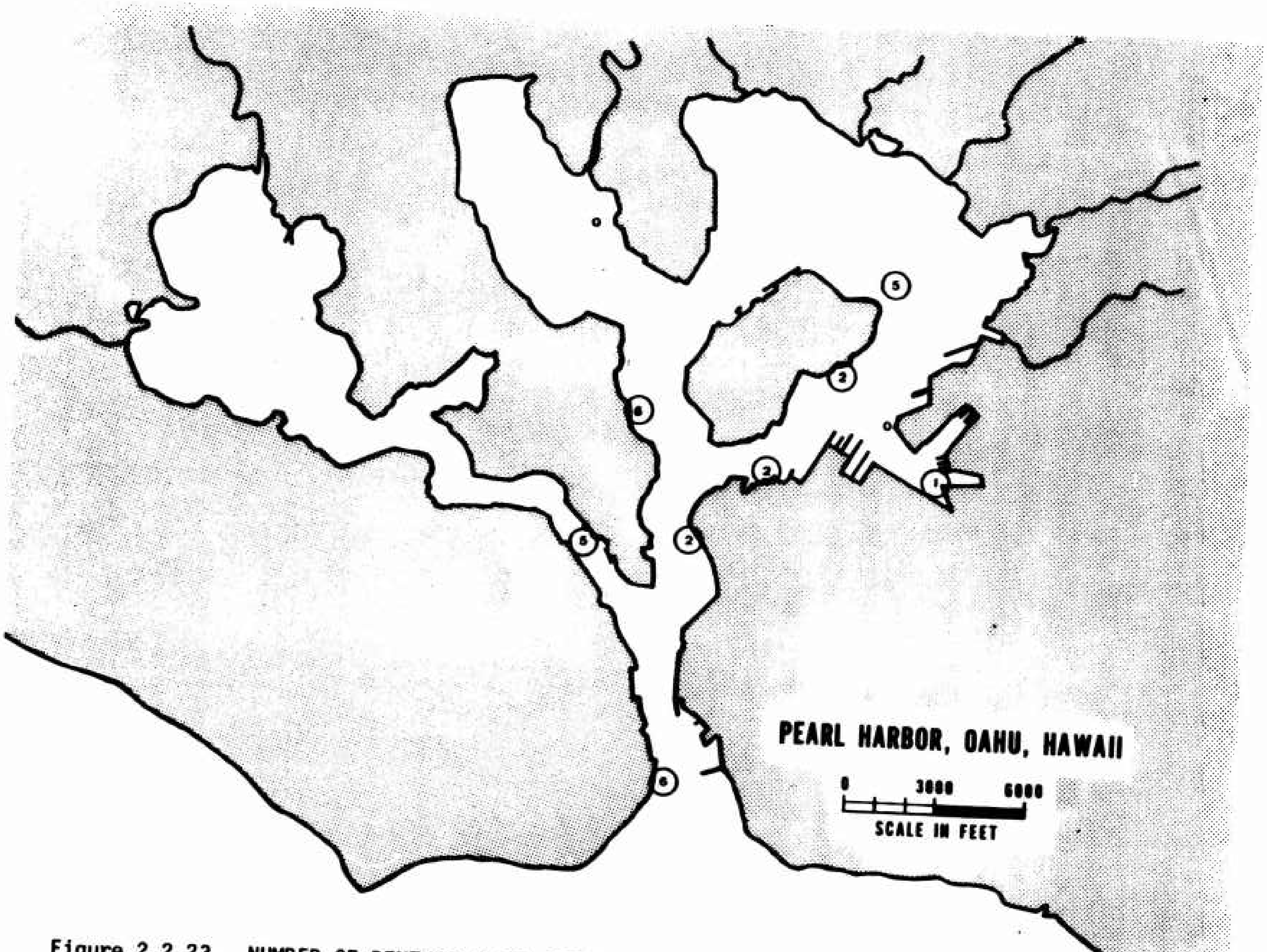


Figure 2.2-23. NUMBER OF BENTHIC ALGAL SPECIES COLLECTED FROM BIO-STATIONS IN PEARL HARBOR.

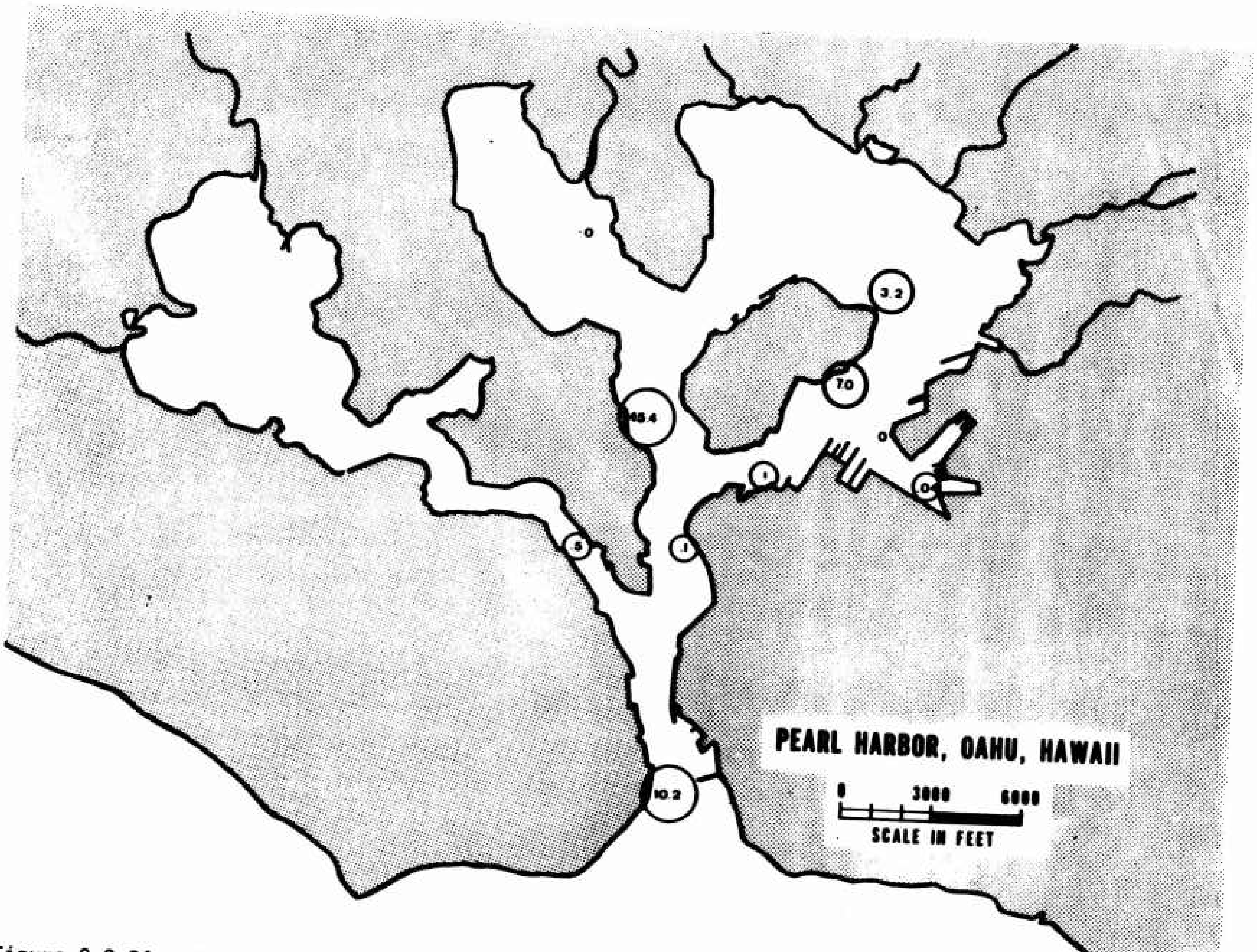


Figure 2.2-24. MEAN DISPLACEMENT VALUES FOR BENTHIC ALGAE COLLECTED FROM BIO-STATIONS IN PEARL HARBOR.

REFERENCES

2.2-1. N. A. Holme (1964), "Methods of Sampling the Benthos", Advances in Marine Biology Series, New York, Vol. 2, pp 171-260.

2.2-2. Gunnar Thorson (1957), "Bottom Communities" (Chapter 17) in Treatise on Marine Ecology and Paleoecology. Vol. 1, Ecology. Edited by Joel W. Hedgpeth, Geological Society of America Memoir No. 67, Washington, D.C., pp 561-534.

2.2-3. Frederik H. Nicols (1973), "A Review of the Benthic Faunal Surveys in San Francisco Bay", Geological Survey Circular No. 677, Washington, D.C., 20 pages.

2.2-4. William C. Jerome, et al (1966), A Study of the Marine Resources of Quincy Bay, Division of Fisheries, Massachusetts Department of Natural Resources, Monograph Series No. 2, 62 pages.

2.2-5. Lawrence Birkett (1957), "Flotation Techniques for Sorting Grab Samples", J. Conseil, Conseil Perm. Intern. Espl. Mer., 22:289-292.

2.2-6. Thomas J. Peeling, J. G. Grovhoug and Evan C. Evans III (August, 1972), "Pearl Harbor Biological Survey - A Summary Report for First Survey Cycle", Naval Undersea Center TN-801, 218 pages.

2.2-7. Charles H. Edmondson (1944), "Incidence of Fouling in Pearl Harbor", Bernice P. Bishop Occasional Papers, 18:1, 34 pages.

MICROMOLLUSCAN SURVEY

E. Alison Kay
Evan C. Evans III

GENERAL INFORMATION

During the period 18 to 31 January 1972, sediment samples were taken at 18 locations in Pearl Harbor (see Figure 2.3-1) using the bottom sampler described in Section 2.2. This device collects a sample 1 foot square and 4 inches deep, 1/3 ft^3 or 0.0094 m^3. An aliquot of approximately 500 cm^3 was removed from each sample and given to Prof. E. Alison Kay, University of Hawaii, for micromolluscan analysis. The remaining material in 10 of these samples was processed for bottom infauna, see Section 2.2. Due to limited funds and manpower, eight of the bio-stations were discontinued in February 1972. No further sediment processing, other than micromolluscan analysis, was performed. Field data on all micromolluscan sediment samples are summarized in Table 2.3-1; if samples were also processed for bottom infauna, the same sample number appears in Table 2.2-1. Micromolluscan analysis, therefore, represents a broader coverage of Pearl Harbor than that afforded by other sections of this report. The samples include one from deep inside West Loch, three from Middle Loch, and an interesting pair of samples taken from the cold or intake side and the warm or outfall side of the Hawaiian Electric Company's (HECO) Waiau power plant (temperature rise across the condensers is 5.5 to 7.2°C or 10 to 13°F, Reference 2.3-1). Sample BM-16 was taken within 50 feet of the Pearl City sewage treatment plant diffuser heads and contained no micromollusca. This sample together with BM-08, BM-07, and BC-11, probably reflects sewage exposure affects.

Micromollusca are those mollusca whose shells measure less than 10mm in greatest dimension and are considered by some persons to be good potential indicators of water quality. Volumetrically they may constitute as much as 1/3 of the sediments from reefs and subtidal waters in the Hawaiian Islands. These sediment assemblages include not only juveniles of species which will eventually attain dimensions far greater than 10 mm and adults which mature at sizes as small as 0.5 mm in diameter, but they appear to represent most of the spatial and trophic components of molluscan communities in the immediate area of the sample, that is benthic, epifaunal and sessile mollusca. Analysis of assemblages in the manner utilized for Foraminifera, ostracod, cladoceran, and pollen grain studies* provides quantitative and qualitative data on abundance, species composition and diversity. The advantages of the utilization of microbiota for ecological studies are well known: the techniques are utilizable in any area having unconsolidated sediments, and large numbers of species can be sampled with a minimum of effort, thus quantitative and qualitative inter-area comparisons are facilitated. These advantages are enhanced by the use of mollusca because of the great body of information which is available on the habits and habitats of these animals. The disadvantages of the technique, notably inability to distinguish between living and dead shells and the effects of transport, may be overcome by appropriate interpretation of the results.

Seventy-one species of micromollusca were recovered from the sediment samples; these are listed in Table 2.3-2. The taxonomic arrangement of the list follows Taylor & Sohl (Reference 2.3-2) and HCZDB computer address codes are given together with generalized feeding and attachment information. As in the other sections, the phyletic listing is followed by an alphabetic listing, Table 2.3-3. Again phyletic position may be found in Table 2.3-2 by using the

* Namely, picking over standardized volumes (or weights) of sediments for their biotic components.

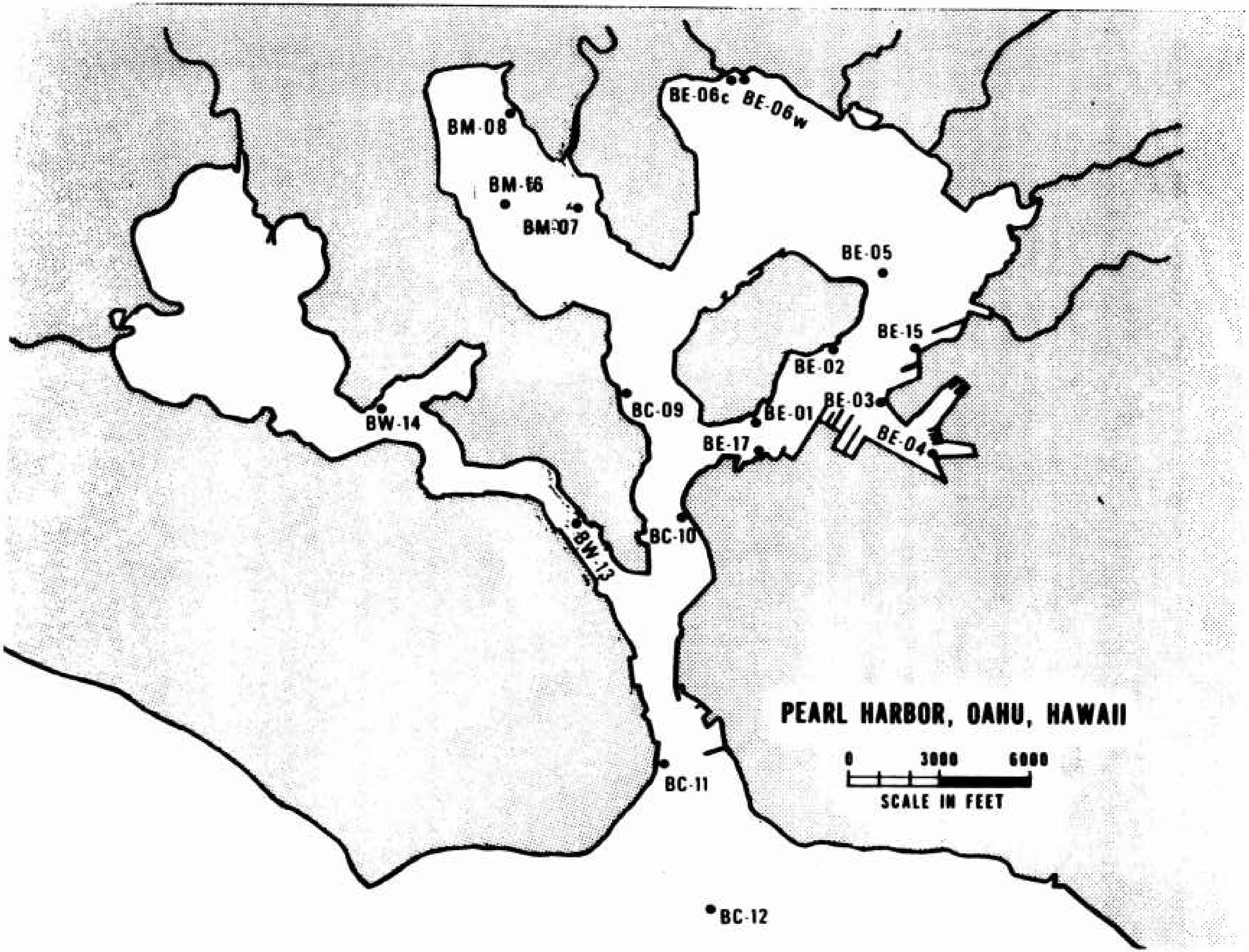


Figure 2.3-1. LOCATION OF MICROMOLLUSCAN COLLECTIONS, 18-31 JANUARY 1973

Table 2.3-1. MICROMOLLUSCA SAMPLING: FIELD NOTES

Bio-station	Sample #	Collection Time/Date '72	Depth (ft.)	General Description of the Bottom
BE-01 D*	03302	0910/19 Jan	30	soft mud and shell fragments
BE-02	03403	1025/20 Jan	25	very soft mud with Vermetid tube debris
BE-03	04405	1152/27 Jan	38	medium to coarse mud with rock rubble and shell debris
BE-04	05102	0842/31 Jan	28	very soft mud, small amount of Vermetid tube debris
BE-05	03202	1032/18 Jan	15	coarse sand and shell debris
BE-06_C D	03106	1108/17 Jan	12	coarse mud with rocks, from Waiau power plant intake side (cold)
BE-06_W D	03102	0935/17 Jan	10	mud with polychaete worm tube matting, Waiau outfall (warm)
BM-07	04302	0829/26 Jan	38	very dark mud (anoxic), oyster shell and hydroid debris
BM-08 D	04304	1010/26 Jan	15	mud with shell fragments
BC-09	04212	1245/25 Jan	28	soft mud and shell debris, sponges
BC-10	03304	1114/19 Jan	36	soft mud, some rock rubble
BC-11	04102	0933/24 Jan	12	coarse sand with shell debris
BC-12 D	05104	1106/31 Jan	30	sand pocket amid coral heads
BW-13	03503	1025/21 Jan	25	soft dark mud (anoxic) with oyster and hydroid debris
BW-14 D	04502	0945/28 Jan	22	soft mud and shell fragments
BE-15 D	04504	1246/28 Jan	38	mud and calcareous debris
BM-16 D	04201	0801/25 Jan	36	very soft dark mud (anoxic)
BE-17	04401	0805/27 Jan	25	very soft mud, scrap metal

*D = bio-station discontinued, February 1972.

Table 2.3-2. PHYLETIC CHECKLIST OF MICROMOLLUSCA
(PEARL HARBOR)

Gastropoda		
Archaeogastropoda		
Scissurellidae		
Scissurella aequatoria	7021020101	H
Fissurellidae		
Diodora granifera	7021050302	C-FG
Trochidae		
Trochus histrio	7021120101	H
Euchelus gemmatus	7021120403	H
Turbinidae		
Leptothyra rubricincta	7021140201	H
Leptothyra candida	7021140203	H
Phasianellidae		
Tricolia variabilis	7021160101	H
Phenacoleapididae		
Phenacolepas sp.	7021230100	
Mesogastropoda		H
Rissoidae		
Rissoina gracilis	7022260103	H
Rissoina ambigua	7022260104	H
Rissoina turricula	7022260105	H
Rissoina miltozona	7022260109	H
Merelina sp.	7022260400	H
Zebina tridentata	7022260501	H
Cithna sp.	7022260600	H
Parashiela beetsi	7022260701	H
Vitrinellidae		
Cyclostremiscus minutissimus	7022290101	H
Cyclostremiscus emeryi	7022290102	H
Cyclostremiscus sp. A	70222901xx	H
Cyclostremiscus sp. B	70222901xx	H
Cyclostremiscus sp. C	70222901xx	H
Cyclostremiscus sp. D	70222901xx	H
Rissoellidae		
Risoella spp.	7022330100	H
Architectonicidae		
Heliacus sp.	7022380300	C-FG
Vermetidae		
Vermetus sp.	7022430400	S
Diastomidae		
Diala varia	7022530101	H
Alaba goniochila	7022530201	H
Obtortio fulva	7022530301	H
Obtortio perparvulum	7022530302	H
Cerithiidae		
Cerithium nesioticum	7022540103	H
Bittium hiloense	7022540201	H
Bittium zebrum	7022540202	H
Bittium impendens	7022540204	H
Bittium parcum	7022540205	H

Table 2.3-2 (Continued)

Gastropoda		
Mesogastropoda		
Cerithiopsidae		
Cerithiopsis sp. A	70225501xx	C-FG
Cerithiopsis sp. B	70225501xx	C-FG
Triphoridae		
Triphora spp.	7022560100	C-FG
Eulimidae		
Balcis sp.	7022620600	C-FG
Leiostraca sp.	7022620700	C-FG
Hipponicidae		
Hipponix spp.	7022720100	H
Calyptraeidae		
Crucibulum spinosum	7022750101	S
Crepidula aculeata	7022750201	S
Naticidae		
Natica sp.	7022910100	C-AP-B
Neogastropoda		
Muricidae		
Aspella producta	7023010901	C
Buccinidae		
Cantharus farinosus	7023070401	C-AP
Engina sp.	7023070500	C
Fasciolariidae		
Peristernia chlorostoma	7023120201	C
Marginellidae		
Kogomea sandwicensis	7023210301	C-FG
Cysticus sp.	7023210400	C-FG
Turridae		
Carinapex sp.	702331xx00	C
Turrid sp.	702331xx00	C
Entomotaeniata (Pyramidellacea)		
Pyramidellidae		
Odostomia patricia	7031010201	C-E
Odostomia stearnsiella	7031010207	C-E
Odostomia eclecta	7031010202	C-E
Odostomia indica	7031010203	C-E
Odostomia oodes	7031010204	C-E
Odostomia paulbartschi	7031010205	C-E
Odostomia scopulorum	7031010206	C-E
Odostomia sp.	7031010200	C-E
Turbonillia sp.	7031010300	C-E
Juliidae		
Julia exquisita	7039160101	H

Table 2.3-2. (Continued)

Bivalvia		
Arcoida		
Arcidae		
Acar plicata	7053010101	S-b
Barbatia nuttingi	7053010202	S-b
Arca sp.	7053010600	S-b
Mytiloida		
Mytilidae		
Brachidontes sp.	7054010300	S-b
Pterioida		
Ostreidae		
Ostrea spp.	7055060200	S-c
Anomiidae		
Anomia nobilis	7055200101	S-c
Veneroida		
Lucinidae		
Ctena bella	7056290101	S-B-f
Pillucina spaldingi	7056290301	S-B-f
Chamidae		
Chama sp.	7056470100	S-c
Myoida		
Gastrochaenidae		
Rocellaria sp.	7057060100	S-f
Hiatellidae		
Hiatella hawaiensis	7057100101	S-m

Key:

first letter
C = carnivore
H = herbivore
S = suspension feeder

second/third letter
AP = active predator
B = benthic habitat
E = ectoparasite
FG = faunal grazer
b = byssal thread forming
c = cement forming
f = free
m = mat forming

Table 2.3-3. ALPHABETIC CHECKLIST OF MICROMOLLUSCA (PEARL HARBOR)

Acar plicata	BB	53010101
Alaba goniochila	MG	22530201
Anomia nobilis	BC	55200101
Arca sp.	BB	53010600
Aspella producta	NG	23010901
Balcis sp.	MG	22620600
Barbatia nuttingi	BB	53010202
Bittium hiloense	MG	22540201
Bittium impendens	MG	22540204
Bittium parcum	MG	22540205
Bittium zebrum	MG	22540202
Brachidontes sp.	BB	54010300
Cantharus farinosus	NG	23070401
Carinapex sp.	NG	2331xx00
Cerithiopsis sp. A	MG	225501xx
Cerithiopsis sp. B	MG	225501xx
Cerithium nesioticum	MG	22540103
Chama sp.	BC	56470100
Cithna sp.	MG	22260600
Crepidula aculeata	MG	22750201
Crucibulum spinosum	MG	22750101
Ctena bella	BF	56290101
Cyclostremiscus kennyi	MG	22290102
Cyclostremiscus minutissimus	MG	22290101
Cyclostremiscus sp. A	MG	222901xx
Cyclostremiscus sp. B	MG	222901xx
Cyclostremiscus sp. C	MG	222901xx
Cyclostremiscus sp. D	MG	222901xx
Cysticus sp.	NG	23210400
Diala varia	MG	22540601
Diodora granifera	AG	21050302
Engina sp.	NG	23070500
Euchelus gemmatus	AG	21120403
Heliacus sp.	MG	22380300
Hiatella hawaiensis	BM	57100101
Hipponix spp.	MG	22720100
Julia exquisita	PP	39160101
Kogomea sandwicensis	NG	23210301
Leiostraca sp.	MG	22620700
Leptothyra candida	AG	21140203
Leptothyra rubricincta	AG	21140201
Merelina sp.	MG	22260400
Natica sp.	MG	22910100
Obtortio fulva	MG	22530301
Obtortio perparvulum	MG	22530302
Odostomia eclecta	PP	31010202
Odostomia indica	PP	31010203
Odostomia oodes	PP	31010204
Odostomia patricia	PP	31010201
Odostomia paulbartschi	PP	31010205
Odostomia scopulorum	PP	31010206
Odostomia stearnsiella	PP	31010207
Odostomia sp.	PP	31010200

Table 2.3-3. (Continued)

Ostrea spp.	BC	55060200
Parashiela beetsi	MG	22260701
Peristernia chlorostoma	NG	23120201
Phenacolepas sp.	MG	21230100
Pillucina spaldingi	BF	56290301
Risoella spp.	MG	22330100
Rissoina ambigua	MG	22260104
Rissoina gracilis	MG	22260103
Rissoina miltozona	MG	22260109
Rissoina turricula	MG	22260105
Rocellaria sp.	BF	57060100
Scissurella aequatoria	AG	21020101
Tricolia variabilis	AG	21160101
Triphora spp.	MG	22560100
Trochus histrio	AG	21120101
Turbonilla sp.	PP	31010300
Turrid sp.	NG	2331xx00
Vermetus sp.	MG	22430400
Zebina tridentata	MG	22260501

Key:
- AG = archeogastropod
- BB = bivalve, byssal thread forming
- BC = bivalve, cement forming
- BF = bivalve, free
- BM = bivalve, mat forming
- MG = mesogastropod
- NG = neogastropod
- PP = pyramidellid

HCZDB number listed in Table 2.3-3; in the latter table, the prefix 70, indicating mollusc, has been dropped.

METHODS

Sediment samples were subsampled in volumes of 25 cm^3 (or lesser volumes, if appropriate); all data are, however, reported for the standard volume. The subsamples were picked over under a dissecting microscope for all the small mollusca they contained; the shells were identified to species and counted. Because of the extremely silty nature of the sediments, the shells were usually covered by a thin coat of mud which rendered them nearly indistinguishable from other non-molluscan components. The samples were, therefore, treated with a 0.3% solution of hydrogen peroxide. This treatment provided sufficient agitation to remove the mud coating thus facilitating identification.

In the analyses, the number of bivalve shells counted in each sample was divided by two to obtain the number of individuals at each bio-station.

DATA/RESULTS

A total of 37 species were identified at bio-stations within Pearl Harbor and 53 species were found at bio-station BC-12 located just outside the harbor; 18 species were common to both. These common species and also those found only within the harbor or only at BC-12 are presented in Table 2.3-4. The species and numbers present at each bio-station (except BM-16 which had no living organisms) are presented in Table 2.3-5. Also presented in Table 2.3-5 are the total number of species and individuals at each bio-station together with the number of mollusca per unit volume of sediment. The mean molluscan density for all bio-stations within Pearl Harbor is 6.4/cm^3 (6.1/cm^3 if BM-16 is included), with values ranging from 0.8/cm^3 at BM-08 (0/cm^3 at BM-16) to 32.3/cm^3 at BE-06w, the thermal outfall from the Waiau power plant. The density at BC-12 outside Pearl Harbor is 13.5/cm^3.

The percentage composition for those species representing more than 1% of the individuals in the micromolluscan assemblage is given for each bio-station in Table 2.3-6. Dominant members of these assemblages are also mapped in Figure 2.3-2. Note BC-12 stands as a unique assemblage. Note also the absence of micromullusca at BM-16.

The most abundant species, which are also the most widely distributed within the harbor, are the bivalve *Hiatella hawaiensis*, the pyramidellids *Odostomia oodes* and *O. indica*, and the mesogastropod limpet *Crepidula aculeata*. For bio-stations within the harbor (excluding BM-16), *Hiatella* constitutes 8 to 97% of the assemblages with an average of 36%; *Odostomia oodes*, 3 to 63% with an average of 25%; *O. indica*, 0 to 34% with an average of 10%; and *Crepidula*, 0 to 63% again with an average of 10%. *Hipponix* spp. and *O. stearnsiella* are common, both occurring at 10 bio-stations within the harbor. All six species also occur at BC-12 (see Tables 2.3-4 and 2.3-5), but their numbers are such that they constitute 1% or less of the total assemblage.

Table 2.3-4. DISTRIBUTION OF MICROMOLLUSCAN SPECIES BETWEEN PEARL HARBOR BIO-STATIONS AND BC-12

PEARL HARBOR ONLY

Anomia nobilis	BB-S-c
Arca sp.	BB-S-b
Bittium zebrum	MG-H
Cantharus farinosus	NG-C-AP
Cerithiopsis sp. A	MG-C-FG
Chama sp.	BB-S-c
Crucibulum spinosum	MG-S
Ctena bella	BB-S-B-f
Cyclostremiscus sp. B	MG-H
Engina sp.	NG-C
Hiatella hawaiensis	BB-S-m
Natica sp.	MG-C-AP-B
Obtortio fulva	MG-H
Odostomia sp.	PP-C-E
Peristernia chlorostoma	NG-C
Pillucina spaldingi	BB-S-B-f
Rocellaria spp.	BB-S-f
Trochus histrio	AG-H
Turrid sp.	NG-C

total = 19

COMMON SPECIES

Aspella producta	NG-C
Balcis sp.	MG-C-FG
Bittium parcum	MG-H
Brachidontes sp.	BB-S-b
Crepidula aculeata	MG-S
Diala varia	MG-H
Euchelus gemmatus	AG-H
Heliacus sp.	MG-C-FG
Hipponix spp.	MG-H
Leptothyra rubricincta	AG-H
Odostomia oodes	PP-C-E
Odostomia paulbartschi	PP-C-E
Odostomia stearnsiella	PP-C-E
Odostomia indica	PP-C-E
Ostrea sp.	BB-S-c
Risoella spp.	MG-H
Triphora sp.	MG-C-FG
Turbonilla sp.	PP-C-E

total = 18

BC-12 ONLY

Acar plicata	BB-S-b
Alaba goniochila	MG-H
Barbatia nuttingi	BB-S-b
Bittium hiloense	MG-H
Bittium impendens	MG-H
Carinapex sp.	NG-C
Cerithiopsis sp. B	MG-C-FG
Cerithium nesioticum	MG-H
Cithna sp.	MG-H
Cyclostremiscus emeryi	MG-H
Cyclostremiscus minutissimus	MG-H
Cyclostremiscus sp. A	MG-H
Cyclostremiscus sp. C	MG-H
Cyclostremiscus sp. D	MG-H
Cysticus sp.	NG-C-FG
Diodora granifera	AG-C-FG
Julia exquisita	PP-H
Kogomea sandwicensis	NG-C-FG
Leiostraca sp.	MG-C-FG
Leptothyra candida	AG-H
Merelina sp.	MG-H
Obtortio perparvulum	MG-H
Odostomia electa	PP-C-E
Odostomia patricia	PP-C-E
Odostomia scopulorum	PP-C-E
Parashiela beetsi	MG-H
Phenacolepas sp.	MG-H
Rissoina ambigua	MG-H
Rissoina gracilis	MG-H
Rissoina miltozona	MG-H
Rissoina turricula	MG-H
Scissurella sp.	AG-H
Tricolia variabilis	AG-H
(*Vermetus* sp.)*	MG-S
Zebina tridentata	MG-H

total = 35

* known to occur in Pearl Harbor but found only in BC-12 assemblage.

Key: AG = archaeogastropod, AP = active predator; B = benthic habitat; b = byssal thread forming; BB = bivalve; C = carnivore; c = cement forming; E = ectoparasite; f = free; FG = faunal grazer; H = herbivore; MG = mesogastropod; m = mat forming; NG = neogastropod; PP = pyramidellid; S = suspension feeder.

Table 2.3-5. PEARL HARBOR MICROMOLLUSCA, SPECIES AND NUMBERS

Bio-Stations	BE 01	BE 02	BE 03	BE 04	BE 05	BE 06c	BE 06w	BM 07	BM 08	BC 09	BC 10	BC 11	BC 12	BW 13	BW 14	BE 15	BE 17
No. Species	6	18	6	7	17	13	2	5	3	14	7	12	54	9	14	9	5
No./cm^3	4.2	6.5	2.4	2.0	9.5	5.0	32.3	3.7	0.8	6.4	3.6	11.4	13.5	3.7	4.4	4.7	1.9
No. Individuals	106	162	59	60	237	99	129	84	11	168	90	278	344	72	111	85	30
Acar plicata	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Alaba goniochila	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-
Anomia nobilis	-	-	-	-	1	1	-	-	-	1	-	-	-	-	5	-	-
Arca sp.	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Aspella producta	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-
Balcis sp.	-	-	-	-	-	-	-	-	-	1	-	-	1	-	2	-	-
Barbatia nuttingi	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Bittium hiloense	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Bittium impendens	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Bittium parvum	-	-	-	-	-	-	-	-	-	-	-	3	16	-	-	-	-
Bittium zebrum	-	29	-	-	40	19	-	-	-	31	-	-	-	-	4	-	2
Brachidontes sp.	-	-	-	-	-	-	-	-	-	-	-	1	1	-	3	-	-
Cantharus farinosus	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Carinapex sp.	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Cerithiopsis sp. A	-	7	-	-	2	-	-	-	-	7	-	-	-	-	-	-	-
Cerithiopsis sp. B	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-	-	-
Cerithium nesioticum	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Chama sp.	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
Cithna sp.	-	-	-	-	-	-	-	-	-	-	-	-	41	-	-	-	-
Crepidula aculeata	6	1	5	-	1	5	-	1	-	5	15	176	1	26	9	13	1
Crucibulum spinosum	-	-	-	-	-	2	-	-	-	-	-	1	-	2	2	-	-
Ctena bella	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Cyclostremiscus kennyi	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-
Cyclostremiscus minutissimus	-	-	-	-	-	-	-	-	-	-	-	-	15	-	-	-	-
Cyclostremiscus sp. A	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-
Cyclostremiscus sp. B	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyclostremiscus sp. C	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-
Cyclostremiscus sp. D	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-

Table 2.3-5. (Continued)

Bio-Stations	BE 01	BE 02	BE 03	BE 04	BE 05	BE 06c	BE 06w	BM 07	BM 08	BC 09	BC 10	BC 11	BC 12	BW 13	BW 14	BE 15	BE 17
Cysticus sp.	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Diala varia	-	2	-	-	-	-	-	-	-	-	-	-	9	-	-	-	-
Diodora granifera	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Engina sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Euchelus gemmatus	-	-	-	-	1	-	-	-	-	-	-	-	7	-	-	-	-
Heliacus sp.	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-
Hiatella hawaiensis	53	16	21	21	49	26	125	72	3	13	30	60	-	6	18	30	19
Hipponix spp.	1	2	1	8	-	3	-	-	-	2	-	5	1	6	1	23	-
Julia exquisita	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-
Kogomea sandwicensis	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-
Leiostraca sp.	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Leptothyra candida	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-
Leptothyra rubricincta	-	-	-	-	-	-	-	-	-	-	1	-	12	-	-	-	-
Merelina sp.	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Natica sp.	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Obtortio fulva	-	3	-	-	-	1	-	-	-	6	-	-	-	-	-	-	-
Obtortio perparvulum	-	-	-	-	-	-	-	-	-	-	-	-	13	-	-	-	-
Odostomia eclecta	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Odostomia indica	24	9	10	11	15	2	4	6	-	7	31	12	2	2	6	7	6
Odostomia oodes	21	71	21	3	97	34	-	3	7	81	10	10	4	25	52	7	2
Odostomia patricia	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Odostomia paulbartschi	-	-	-	-	-	-	-	-	-	-	-	6	10	-	-	-	-
Odostomia scopulorum	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Odostomia stearnsiella	-	2	-	-	17	2	-	-	1	4	2	2	4	3	3	1	-
Odostomia sp.	-	-	-	6	-	-	-	-	-	-	-	1	-	-	-	2	-
Ostrea spp.	-	1	-	1	3	2	-	2	-	1	1	-	1	1	-	1	-
Parashiela beetsi	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Peristernia chlorostoma	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Phenacolepas sp.	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Pillucina spaldingi	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Risoella spp.	-	11	-	-	-	1	-	-	-	-	-	-	3	-	4	1	-

Table 2.3-5. (Continued)

Bio-Stations	BE 01	BE 02	BE 03	BE 04	BE 05	BE 06c	BE 06w	BM 07	BM 08	BC 09	BC 10	BC 11	BC 12	BW 13	BW 14	BE 15	BE 17
Rissoina ambigua	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-
Rissoina gracilis	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Rissoina miltozona	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-
Rissoina turricula	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-
Rocellaria sp.	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scissurella aequatoria	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Tricolia variabilis	-	-	-	-	-	-	-	-	-	-	-	-	90	-	-	-	-
Triphora spp.	-	2	-	-	4	-	-	-	-	-	-	1	13	-	-	-	-
Trochus histrio	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Turbonilla sp.	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Turrid sp.	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vermetus sp.	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-
Zebina tridentata	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Bivalve spp.	-	2	-	-	-	-	-	-	-	-	-	-	17	-	1	-	-

Table 2.3-6. PERCENTAGE COMPOSITION OF MICROMOLLUSCAN ASSEMBLAGES

Bio-Stations	BE 01	BE 02	BE 03	BE 04	BE 05	BE 06c	BE 06w	BM 07	BM 08	BC 09	BC 10	BC 11	BC 12	BW 13	BW 14	BE 15	BE 17
Bittium parcum	-	-	-	-	-	-	-	-	-	-	-	1	5	-	-	-	-
Bittium zebrum	-	18	-	-	17	19	-	-	-	18	-	-	-	-	4	-	7
Cithna sp.	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	-
Crepidula aculeata	6	1	8	-	-	5	-	1	-	3	17	63	-	36	8	15	3
Cyclostremiscus minutissimus	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-
Cyclostremiscus sp. B	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-
Hiatella hawaiensis	50	10	36	35	21	26	97	86	27	8	34	22	-	8	16	35	63
Hipponix spp.	-	1	2	13	-	3	-	-	-	1	-	2	-	8	1	27	-
Leptothyra rubricincta	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-
Obtortio perparvulum	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-
Odostomia indica	23	6	17	18	6	2	3	7	-	4	34	4	1	3	5	8	20
Odostomia oodes	20	44	36	5	41	34	-	4	63	48	11	4	1	35	47	8	7
Odostomia stearnsiella	-	1	-	-	7	2	-	-	9	2	2	1	1	4	3	1	-
Tricolia variabilis	-	-	-	-	-	-	-	-	-	-	-	-	26	-	-	-	-
Triphora spp.	-	1	-	-	2	-	-	-	-	-	-	-	4	-	-	-	-
TOTAL	99	82	99	88	94	91	100	98	99	84	98	97	62	94	84	94	100

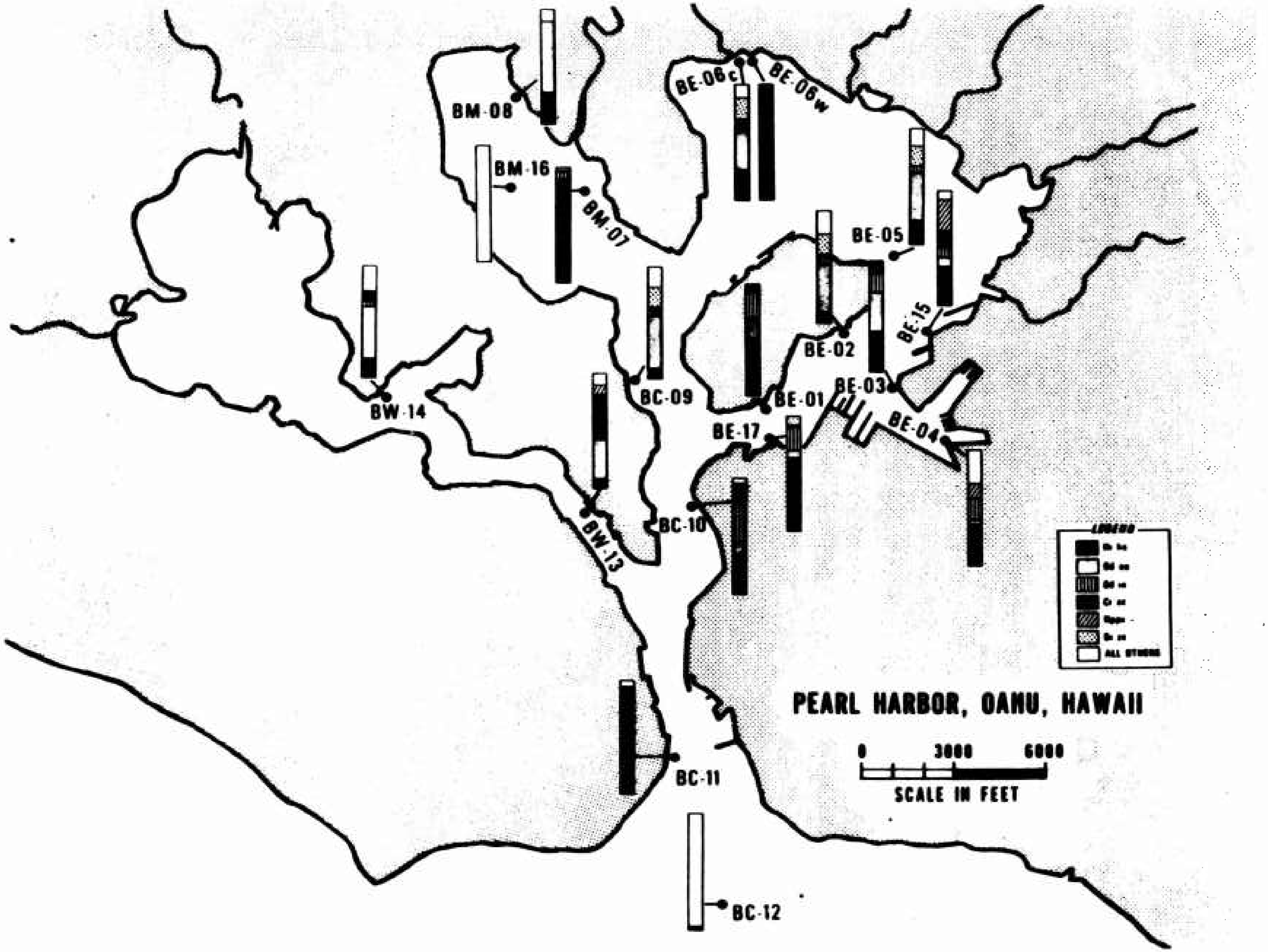


Figure 2.3-2. TYPES OF BIO-STATIONS, PERCENTAGE BY DOMINANT MICROMOLLUSCAN SPECIES

Four patterns are distinguishable among the bio-stations on the basis of species composition and number of species (Figure 2.3-3): *Hiatella/Odostomia indica* dominated assemblage with relatively few species (2 to 9); an *Odostomia oodes* dominated assemblage with in general relatively more species (13 to 18); a *Crepidula* dominated station with 12 species; and a varied *Tricolia/Cithna* assemblage with more than 50 species. The *Hiatella/O. indica* assemblage is found at BE-01, BE-03, BE-04, BE-06w, BM-07, BC-10, BE-15, and BE-17, a group of bio-stations located for the most part on the southeastern periphery of East and Middle Lochs. The *O. oodes* assemblage is found at BE-02, BE-05, BE-06c, BM-08, BC-09, BW-13, and BW-14, a group of bio-stations variously distributed throughout the harbor, many of which are, however, located on northwestern shorelines. Bio-stations BC-11 and BC-12 are unique. Bio-station BC-11, near the Iroquois Point sewage treatment plant diffusers, is the *Crepidula*-dominated assemblage; however, if this dominant species is omitted, the remainder of the assemblage resembles both in species and numbers the *O. oodes* assemblage. Bio-station BC-12, outside the entrance channel to Pearl Harbor, has a micromolluscan assemblage distinctly different from those within the harbor. Seven species representing almost 60% of the assemblage at BC-12 are either non-existent or a very minor component of the assemblages within the harbor (see Table 2.3-6).

The assemblages were further analyzed in terms of the proportion of gastropods relative to bivalves present (Table 2.3-7); in terms of the gastropod component, that is the proportion of archaeogastropods, mesogastropods, neogastropods, and pyramidellids present in an assemblage (Figure 2.3-4); and in terms of epifaunal and sessile components of the assemblage (Figure 2.3-5). Whether considered by number of species or by number of individuals, the gastropod element is dominant in most assemblages; however, the proportion of bivalves is approximately 3 to 6 times larger, depending on whether species or numbers are considered, within Pearl Harbor than at BC-12, compare the last two rows in Table 2.3-7. Note the reversal of this situation at bio-stations BE-06w, BM-07, and BE-17. The first of these bio-stations is located in the warm water outfall of the Waiau power plant; the remaining two are very probably being influenced by sewer outfalls. Among the gastropods (Figure 2.3-4), a higher proportion of pyramidellids relative tc mesogastropods occurs at most of the bio-stations within Pearl Harbor (exceptions BC-11, BE-15, and BW-13), and both archaeogastropods (here predominantly herbivorous) and neogastropods (here carnivorous) are nearly absent. Pyramidellids are well known as ectoparasites on oysters, gastropods and other sedentary invertebrates and are frequently found in places of high environmental stress, like the southeastern basin of Kaneohe Bay, for instance. Archaeogastropods and neogastropods are present in locations having high species diversity. In contrast to the bio-stations within Pearl Harbor, BC-12 has a lower proportion of pyramidellids and a higher proportion of the other three micromolluscan orders. *Tricolia variabilis*, representing 26% of the BC-12 assemblage is usually associated with frondose algae in Hawaii. No frondose algae have been observed in Pearl Harbor which may account for the absence of this archaeogastropod there. Within Pearl Harbor (Figure 2.3-5), 22 species representing 66% of the assemblages are epifaunal (for example, *Odostomia* spp. and *Bittium zebrum*), 10 species representing 35% of the assemblages are sessile (*Hiatella* and *Crepidula*), and the benthic component is restricted to 4 species (*Narica* sp., *Ctena bella*, *Pillucina spaldingi*, and an unidentified bivalve) representing less than 1% of the assemblages. Although the benthic micromolluscan fauna tends to be relatively poor in the Hawaiian Islands, the very small representation in Pearl Harbor may be due to chemically toxic conditions, to im-

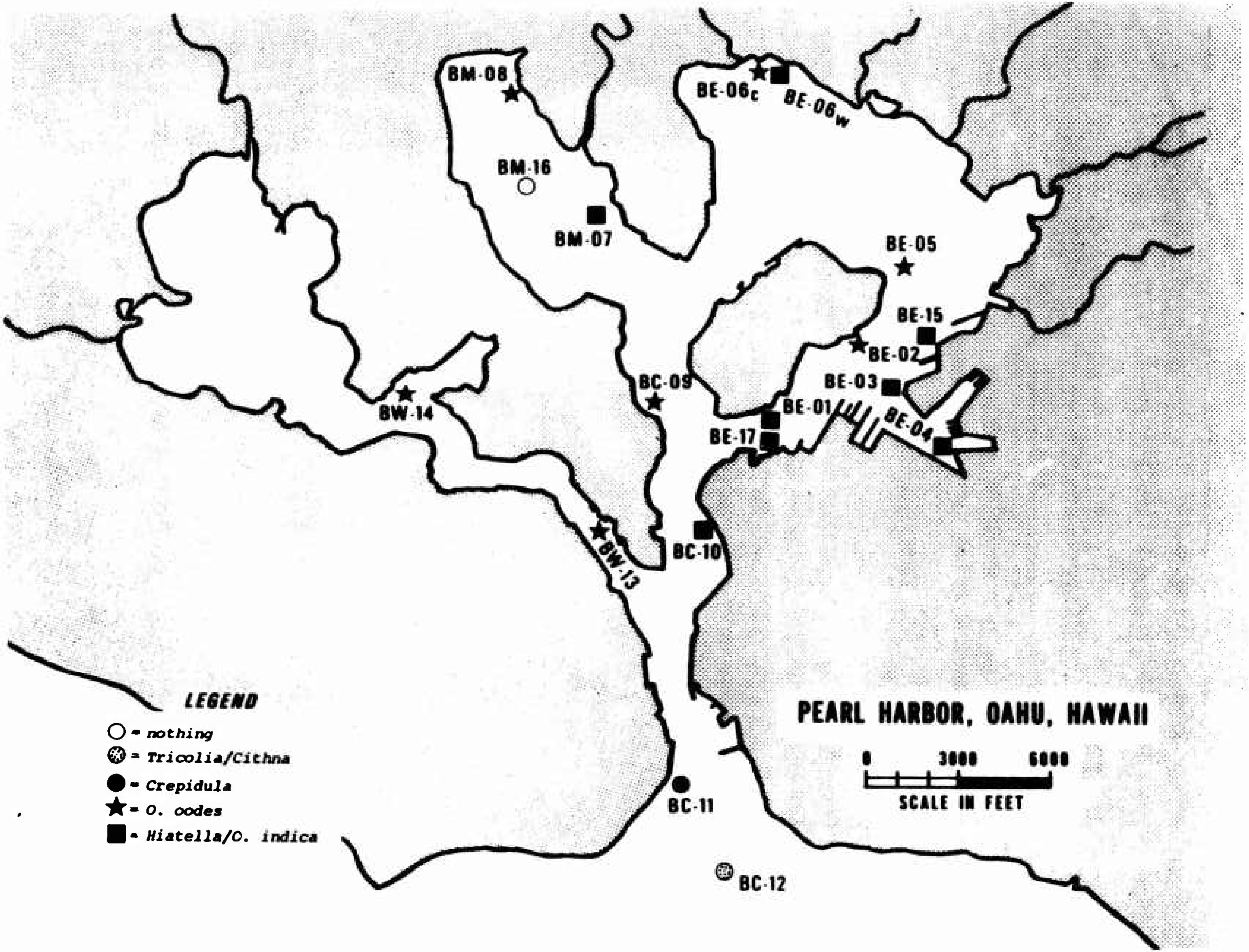


Figure 2.3-3. TYPES OF BIO-STATIONS, PATTERNS OF MICROMOLLUSCAN SPECIES COMPOSITION

Table 2.3-7. RELATIVE PROPORTION OF GASTROPODS TO BIVALVES

	By No. of Species		By No. of Individuals	
	% Gastropods	% Bivalves	% Gastropods	% Bivalves
BE-01	83	17	50	50
BE-02	78	22	88	12
BE-03	83	17	64	36
BE-04	71	29	63	37
BE-05	71	29	76	24
BE-06c	69	31	69	31
BE-06w	50	50	3	97
BM-07	60	40	12	88
BM-08	66	33	73	27
BC-09	64	36	86	14
BC-10	71	29	66	34
BC-11	83	17	78	22
BC-12	91	9	94	6
BW-13	78	22	90	10
BW-14	71	29	76	24
BE-15	78	22	64	36
BE-17	80	20	37	63
P.H. mean	72±9	27±9	62±25	38±25
First standard deviation				
BC-12	91	9	94	6

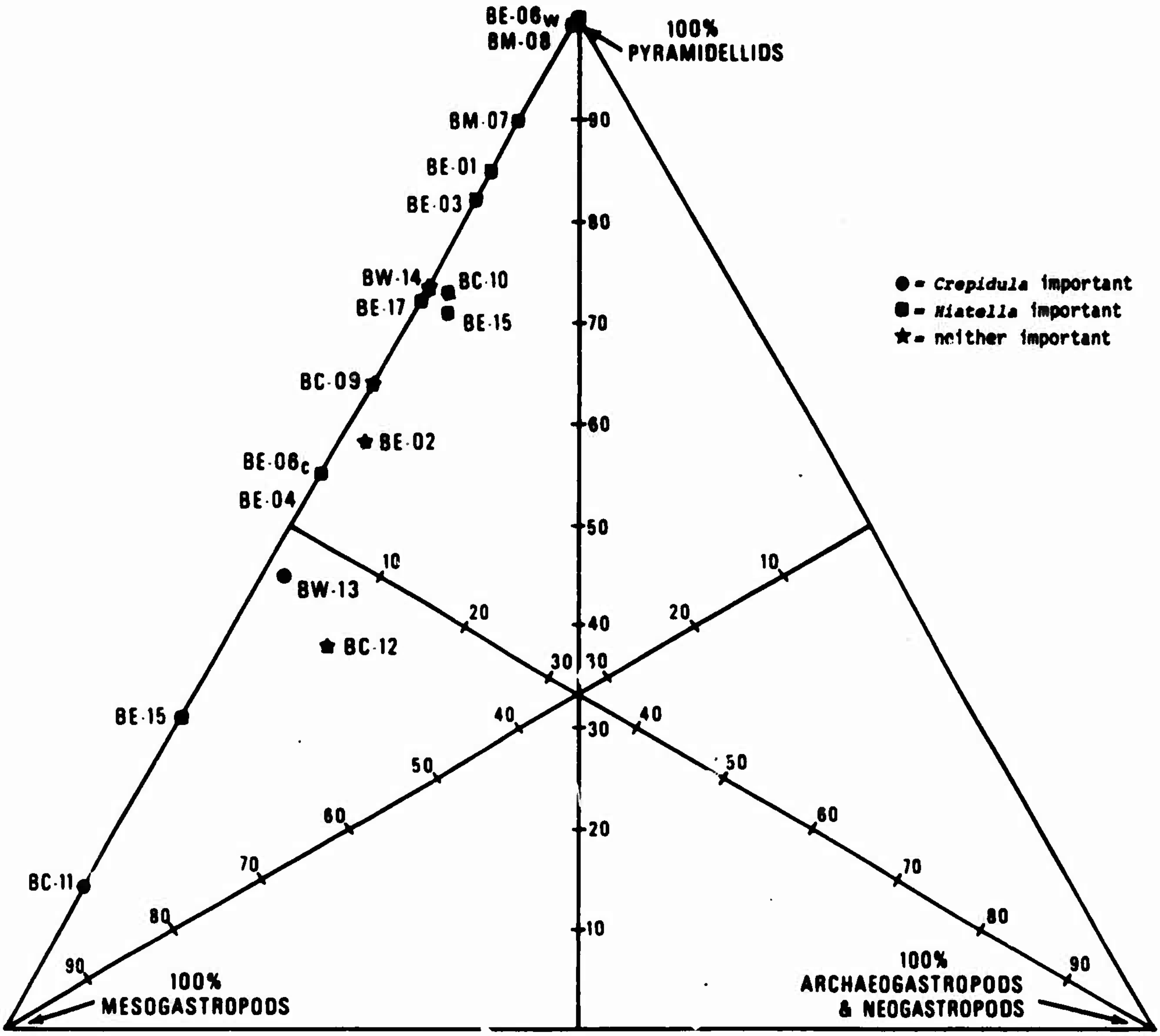


Figure 2.3-4. GASTROPOD COMPONENTS OF MICROMOLLUSCAN ASSEMBLAGES (percentage of total gastropods)

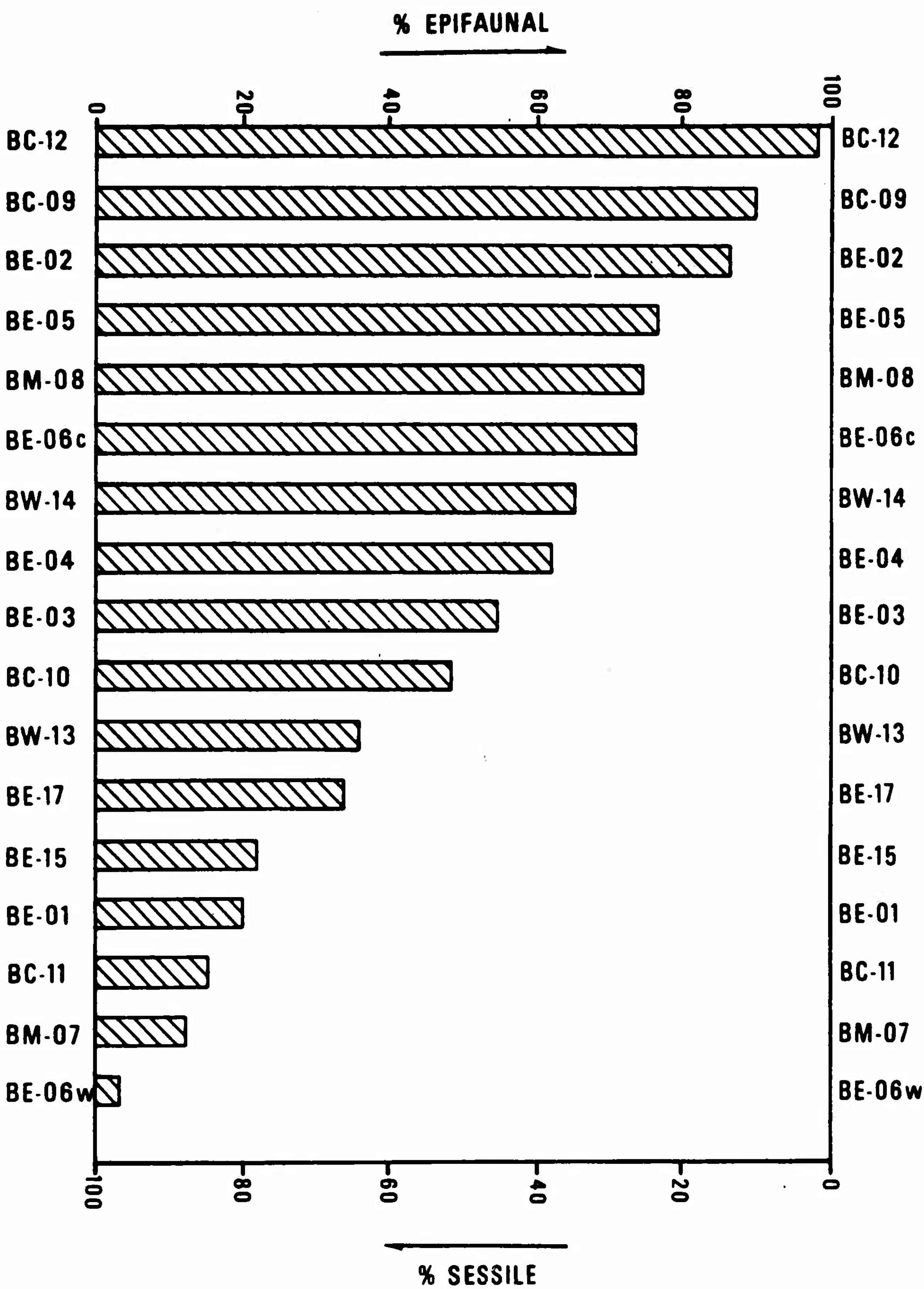


Figure 2.3-5. SESSILE AND EPIFAUNAL COMPONENTS OF MICROMOLLUSCAN ASSEMBLAGES

proper sediment composition (porosity, grain size, etc.), or to other causes. Bio-station BC-12 ranks highest in epifaunal species, while the sewage or thermally stressed bio-stations (BE-06w, BM-07, BE-10, and BC-11) rank highest in sessile species, see Figure 2.3-5.

Further consideration of the habits of the dominant mollusca are of interest because they reflect trophic structure. Analysis of the feeding habits of the assemblages (Figure 2.3-6) indicates that a great proportion of the micromolluscan fauna within the harbor consists of suspension-feeding herbivores, that is, organisms which are dependent on the primary productivity of the water column rather than on that of the substrate. The habits of the micromolluscan assemblage at BC-12 are more varied and show little or no dependence on the primary productivity of the water column, as is reflected in the virtual absence of suspension feeding forms and a carnivorous element that is epifaunal rather than ectoparasitic (see Table 2.3-4). Note that the West and East Loch bio-stations in Figure 2.3-6 tend to form a central mass between carnivores and the suspension feeders in the triangular plot, while the channel stations, BC-09, BC-10, BC-11, and BC-12, tend to be distributed around the periphery of this mass with BC-12 being by far the most distant from it. Note also that the thermally-stressed BE-06w is closely associated with the sewage-stressed BM-07 and BC-11, reflecting the high proportion of suspension feeders due to the high nutrient status of the waters resulting either from dead organisms or sewage. The thermally-stressed BC-10 is not part of this group due to the larger proportion of carnivores, but approaches the group in Figure 2.3-5 where the proportion of sessile organisms is shown. In Figure 2.3-4, bio-stations BE-06w, BM-07, and BC-10 form a looser association together with BM-08 and BE-17 (both probably influenced by sewage) and several other bio-stations, but BC-11 is quite distant due to its large population of the mesogastropod *Crepidula aculeata* instead of the sessile suspension-feeding bivalve *Hiatella hawaiensis* prominent at the first three bio-stations. In fact, *Crepidula* only becomes the dominant of the pair at bio-stations near or outside the channel entrance (BC-11, BW-12, and BW-13). *Crepidula* is a well known ciliary or suspension feeder, often recognized as an associate of oysters. It has been recorded from numerous localities in the Islands and is especially characteristic of bay or harbor areas (Kahului Bay, Maui; Hilo Bay, Hawaii; and Kaneohe Bay, Oahu). *Hiatella hawaiensis* was described from Hawaii by Dall, Bartsch, & Rehder in 1938 (Reference 2.3-3), and since has been recorded from various localities in the Islands. It is endemic to the Islands and is common though not abundant in Kaneohe Bay. The genus as recently described by Yonge (Reference 2.3-4) includes species which are bysally attached and which may or may not bore into the substrate. *Hiatella* in Pearl Harbor is a non-boring form which makes dense mats, most noticeable in the thermal outfall region near the Waiau power plant (BE-06w), but also at BE-01, BE-05, and BM-07.

The micromolluscan assemblages within Pearl Harbor represent an almost classic example of a situation where relatively few species occur in large numbers and where the organisms are in large part dependent for subsistence on the primary productivity of the water column rather than the substrate. The assemblages suggest a situation favoring sedentary organisms characteristic of fouling communities with an almost complete absence of organisms characteristic of epifaunal and benthic habitats. The high proportion of bivalves and suspension feeders are the indicators of dependence on primary productivity of the water column. The abundance of pyramidellids also suggests the dense con-

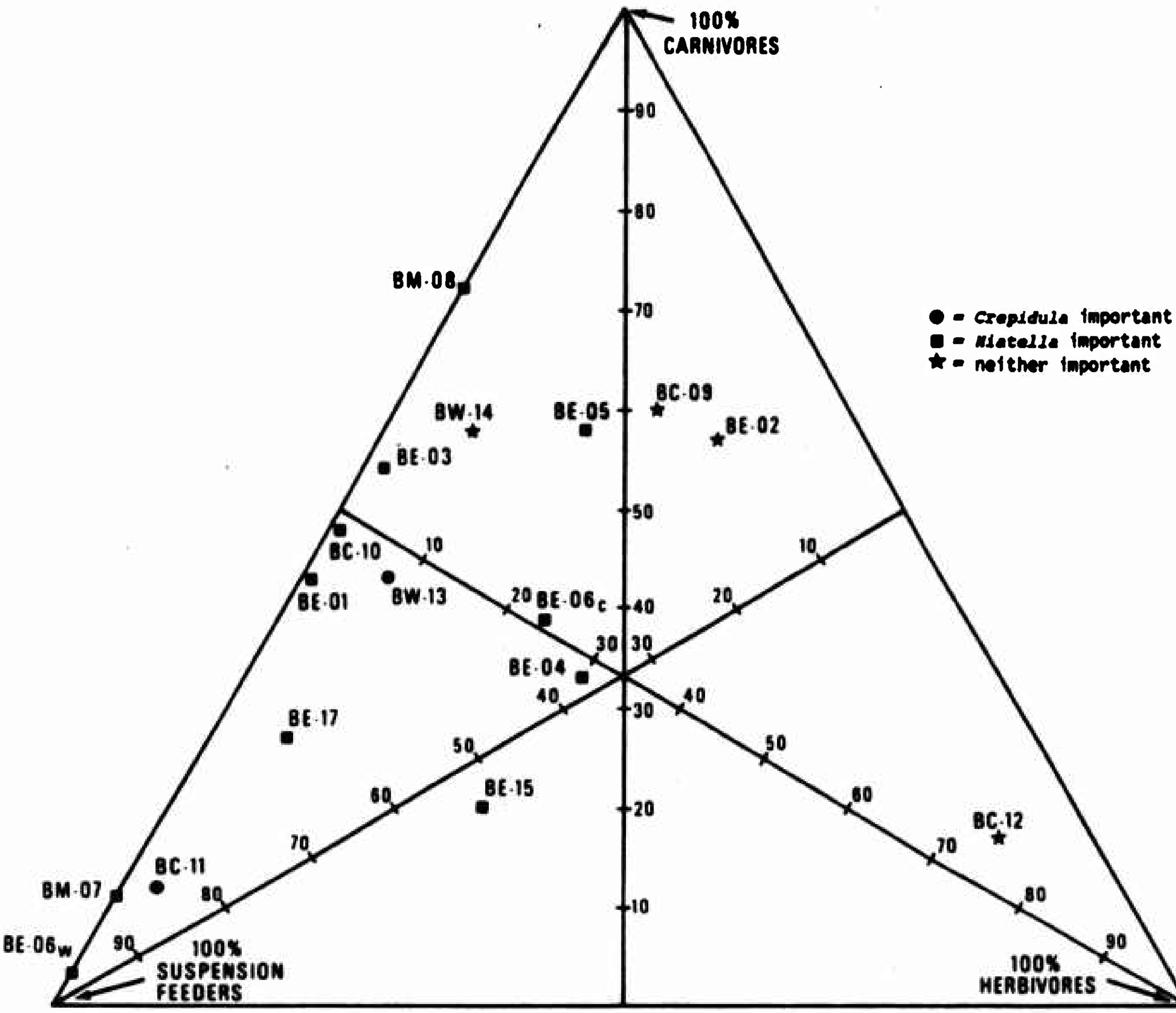


Figure 2.3-6. FEEDING HABITS OF MICROMOLLUSCAN ASSEMBLAGES (percentage of total molluscs)

centrations of sedentary invertebrates which serve as hosts. The absence of epifaunal and benthic micromolluscs indicates a somewhat unstable substratum throughout the harbor.

On the other hand, BC-12 outside the channel to Pearl Harbor represents a more typical subtidal habitat characteristic of the leeward shores of Oahu. The variety of species occurring at this bio-station, none of which dominates the assemblage, and the varied feeding types and habits indicate a habitat with stable substrates and where the animals' subsistence is derived from the productivity of the substrate rather than the water column.

Further analysis of these micromolluscan observations is presented in Section 4.5.

REFERENCES

2.3-1. John C. McCain (1974), Environmental Survey - Waiau Generating Station, Hawaiian Electric Company report, p 5.

2.3.2. Taylor and Sohl (1962), Malacologia 1, pp 7-32.

2.3-3. W. H. Dall, P. Bartsch, and H. A. Rehder (1938), A Manual of the Recent and Fossil Marine Pelecypod Mollusks of the Hawaiian Islands, B. P. Bishop Museum Bulletin 153.

2.3-4. C. M. Yonge (1971), "On Functional Morphology and Adaptive Radiation in the Bivalve Superfamily Saxicavaea (*Hiatella (=Saxicava), Saxicavella, Panomya, Panope, Cyrtodaria*)", Malacologia 11, pp 1-44.

PILING SURVEY

J. Geoffrey Grovhoug

GENERAL INFORMATION

Marine organisms inhabiting vertical substrata such as wooden or concrete pilings, bulkheads, ship hulls, metal surfaces, channel ledges, etc. are a significant component of the Pearl Harbor ecosystem. Piling organisms are predominantly epifaunal invertebrates, however, small fish and algae are also included in this group. Since these organisms are subjected to various stresses (either chronic or pulsed), especially in the surface layers, they may provide a useful combination of parameters with which to assess a given environment. In order to inventory these organisms as part of the base-line environmental study, a series of piling samples were collected in May and June 1972 and again in November 1972 from nine bio-stations in Pearl Harbor, Oahu (Figure 1.0-1). Bio-station BC-09 was excluded from the piling survey because no vertical substrata were available at that location.

In view of the base-line nature of this survey, a study of piling organisms which inhabit existing vertical substrata was selected rather than a fouling panel study such as the investigation recently conducted by Hawaiian Electric Company at the Pearl Harbor Waiau Power Plant (McCain, Reference 2.4-1). Future studies utilizing a new concept in fouling panels are planned for Pearl Harbor and other Hawaiian waters as part of the NUC/MEMO Environmental Range Program.

The piling survey describes epifaunal organisms inhabiting vertical substrata but was not designed to collect quantitative information concerning boring organisms such as *Teredo, Bankia* or *Limnoria* extant in Pearl Harbor. A general introduction to these and other groups of boring organisms is presented in Chapter 12 of Ricketts and Calvin (Reference 2.4-2); a multitude of additional information on boring and fouling organisms has been compiled in various technical reports from several Naval laboratories (NSRDC, NAVOCEANO, NCEL, ONR, etc.). Authorities such as Turner (Reference 2.4-3), Edmondson (References 2.4-4 and 2.4-5) and Long (Reference 2.4-6) provide information directly applicable to Pearl Harbor. A comprehensive bibliography on marine borers (Reference 2.4-7) is also available.

METHODS

All piling samples were collected with a sampling device designed by bio-survey field team members, T. J. Peeling and J. G. Grovhoug. The sampler consisted of a 6" x 6" x 6" stainless steel wire frame (Figure 2.4-1) to which a cotton cloth bag was securely attached by drawstrings, a sharpened metal chiseling/scraping plate (dimensions: 6" x 5-7/8" x 1/8") and a geologist's pick hammer. Two SCUBA divers operating together obtained the piling sample. One diver held the frame (with cloth bag attached) firmly against the area to be sampled on the piling or other vertical substratum. The second diver then drove the chiseling plate through the organic piling community in a perpendicular plane down to the piling surface. Where marine growth was greater than several inches thick, three preliminary cuts (bottom and each side) were necessary to collect an exact and complete sample. The plate was then driven downward along the piling surface and the resulting sample was manipulated into the cloth bag with the aid of the plate. The sample was brought to the surface, the bag detached from the wire frame (with drawstrings pulled and tied) and transferred with the sample inside to a covered plastic one-gallon container. Pertinent field observations, such as sample thickness and exact collection location, were logged in a field notebook.

(Text continued on page 2.4-3)

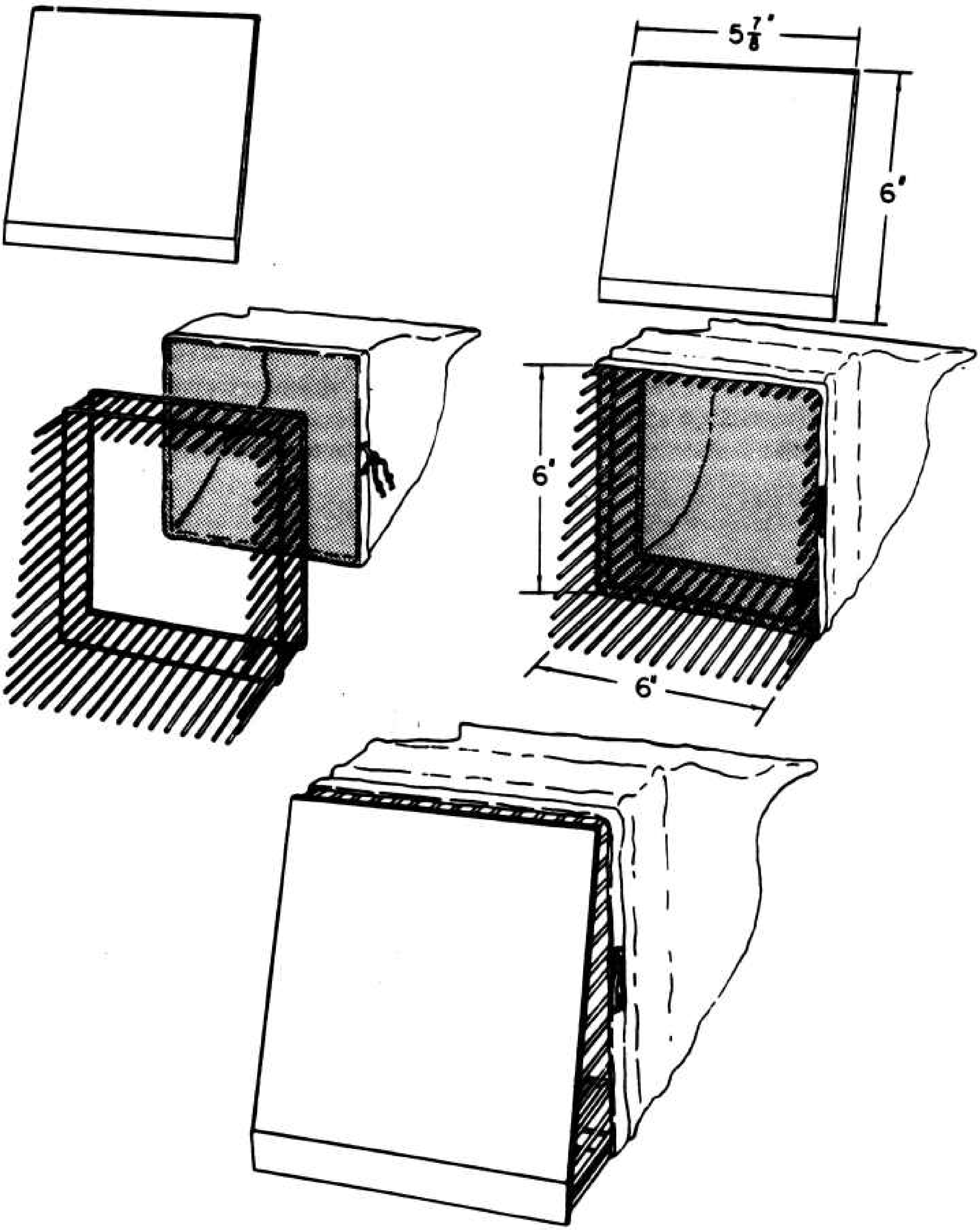


Figure 2.4-1. PILING SAMPLE DEVICE.

Piling samples collected in May and June 1972 were weighed and refrigerated at the end of each field day and stored until rough sorting and preservation could be accomplished (usually the next day, but always within three days of collection). All November 1972 piling samples were frozen at the end of each sampling day. Note that all November piling samples were collected during a two-day period due to ongoing fish survey field requirements. Live wet weights were not taken for the November sample series.

The piling sampling device operated with equal facility on wood, concrete and metal vertical surfaces; uneven rock ledge surfaces proved more difficult. However, average sample losses are estimated to be minimal (less than 5% of the total organisms per sample). The mesh in the cloth bag was finer than the 420 micron standard sieve used in screening all benthic and piling samples. Highly motile organisms such as fish, shrimp, amphipods and crabs were often collected in the piling samples.

Piling samples were collected from three depths at nine bio-stations: surface (taken at the lower barnacle line which approximates the midtidal level in subtropical environments, Reference 2.4-8), 10-foot and 20-foot depths. Additional samples (30-foot) were collected at bio-stations BM-07 and BC-11, the only two bio-stations having vertical substrata available at this depth. Piling samples were collected from rock ledges at bio-stations BE-05 (20-foot) and BC-10 (10- and 20-foot) and from a large anchor chain at BE-05 (10-foot), where these were the only available vertical substrata at these locations. All depths were verified with a diver's depth gauge. The area sampled was the same at all sample sites: 6" x 6" x D, where "D" equals the thickness of the sample (Table 2.4-1).

Thirty-six piling samples (collected from surface and 10-foot depths at nine bio-stations in May and June 1972 and again in November 1972) have been completely analyzed (separated, identified, weighed and counted) and are presented in this section of the report. Pertinent field collection data are summarized in Table 2.4-1. The decision to concentrate on only surface and 10-foot piling samples at this time was made based upon experience gained during the benthic faunal analyses (see Section 4.4). The greatest variability of benthic organisms appears at shallow (0-15 foot) depths within the Pearl Harbor ecosystem.

Laboratory workup of the piling samples began once the samples were removed from cold storage. Rough sorting into major groups (usually phyla) was conducted initially. Each sample was placed in several large (8-inch diameter) wash dishes, covered with tap water and examined through an illuminated magnifier. Organisms were hand separated with forceps and placed into vials containing either 5% formalin (fish and polychaetes) or 70% ETOH/isopropyl alcohol (all other groups such as crustaceans, sponges, algae, bryozoans, tunicates, etc.). Secondary rough sorting was performed by closer examination of the remaining sample, portions of which were placed in small (4-inch diameter) wash dishes and viewed through a variable power (10x-70x) dissecting microscope. The carbon tetrachloride flotation technique (Figure 2.2-4) was not utilized in the piling sample separation since the sample consisted almost entirely of organic material (which is floatable in CCl_4) and only small amounts of silt and fine sediment were occasionally present. All final taxonomic identifications were performed by Eric Guinther, HIMB (Environmental Consultants, Inc.). Most organisms were identified to the generic or specific level. Cost and time estimates for the piling sample analysis are similar to those listed for benthic sample processing (see page 2.2-11).

(Text continued on page 2.4-5)

Table 2.4-1. PILING FAUNAL SURVEY FIELD NOTES AND REMARKS.

Bio-station	Sample #	Collection (Time/Date)*	Depth (feet)	Substratum***	Estimated Thickness (in.)
BE-02	20406	0923/18 V	0**	CP	2
"	20405	0912/18 V	10	CP	4
"	46303	1405/15 XI	0**	CP	2
"	46302	1358/15 XI	10	CP	3
BE-03	20101	0908/15 V	0**	CP	1
"	20102	0928/15 V	10	CP	4
"	46420	1147/16 XI	0**	CP	1
"	46419	1133/16 XI	10	CP	2
BE-04	20403	0824/18 V	0**	CP	6
"	20402	0815/18 V	10	CP	4
"	46306	1506/15 XI	0**	CP	4
"	46305	1450/15 XI	10	CP	3
BE-05	23107	1245/05 VI	0**	CB	1
"	23106	1235/05 VI	10	MAC	4
"	46421	1232/16 XI	0**	CB	½
"	46423	1251/16 XI	10	MAC	3
BM-07	23104	1150/05 VI	0**	WP	1
"	23103	1138/05 VI	10	WP	6
"	46404	0823/16 XI	0**	WP	2
"	46403	0818/16 XI	10	WP	3
BC-10	21106	1140/22 V	0**	CB	1
"	21105	1131/22 V	10	RL	4
"	46414	1037/16 XI	0**	CB	3
"	46413	1024/16 XI	10	RL	3
BC-11	21104	1102/22 V	0**	MPP	1
"	21103	1050/22 V	10	MPP	6
"	46408	0928/16 XI	0**	MPP	3
"	46407	0924/16 XI	10	MPP	5
BW-13	21503	0832/26 V	0**	WP	1
"	21502	0825/26 V	10	WP	3
"	46411	0959/16 XI	0**	WP	3
"	46410	0952/16 XI	10	WP	2
BE-17	22303	1440/31 V	0**	WP	½
"	22302	1425/31 V	10	WP	4
"	46417	1108/16 XI	0**	WP	2
"	46416	1059/16 XI	10	WP	1

* All piling samples were collected during calendar year 1972.

** All surface/shallow piling samples were collected at lower barnacle line.

*** Substrata Legend: CP = Concrete Pilings; CB = Concrete Block; MAC = Metal Anchor Chain; WP = Wooden Pilings; RL = Rock Ledge; MPP = Metal Diffuser Pipe (30" dia.) at BC-11.

DATA/RESULTS

A phyletic checklist of all organisms collected during the piling survey is presented in Table 2.4-2. Hawaii Coastal Zone Data Bank (HCZDB) identification numbers and generalized feeding/habitat type for each organism have been incorporated into this list. To facilitate rapid crossreferencing of organisms, an alphabetical listing (by genera, with HCZDB numbers and adjective identifiers) is also provided (Table 2.4-3). A total of 88 genera and/or species have been positively identified from 36 piling samples. Presence/absence and abundance data for 113 taxa (species, genera and higher taxa) are provided in Table 2.4-4. Wet weights are listed for all sponges (porifera). The symbol "#" indicates that the number is uncertain for colonial organisms (such as bryozoans and tunicates) and for other species which have been placed in larger groups, e.g., miscellaneous polychaeta, miscellaneous amphipoda, etc. Again, it is significant to note that 21 taxa are unique to bio-station BC-11 (or 24% of the 88 genera/species). Of these 21 taxa collected only at BC-11, 12 were crustaceans (including 7 species of Alpheid shrimp), 6 were mollusca, 2 were polychaetes and 1 was the Eleotrid fish, *Asterropteryx semipunctatus*.

Summary data for piling organisms (by station) may be found at the end of Table 2.4-4 and are also displayed geographically in Figures 2.4-2 through 2.4-5. Bio-stations BC-11, BW-13, BC-10 and BE-03 represent the most diverse piling faunas (i.e., greatest numbers of species and individuals). As may be seen in Table 2.4-1, the substrata differ at each of these four most prolific bio-stations; concrete and wooden pilings, metal and rock ledge vertical surfaces are all represented at these bio-stations.

The distribution of porifera (sponges) collected during the piling survey is presented in Figure 2.4-6. No particular dependence on either substrata (wood, concrete, metal or rock ledges) or depth is apparent. Sponge growth was sorted from all collections and weighed (wet weight, grams). Bio-stations BE-02, BE-05, BM-07 and BC-11 exhibited the greatest amount of sponge growth; however, the number of epifaunal organisms living in or on the piling sponges was less than those observed on the benthic sponges. Furthermore, their number did not appear to be directly related to the amount of sponge present as was the case with the benthic sponges (see page 2.2-21). This observation may, however, be a function of sample size (see Section 4.6).

Eleven organisms (or groups of organisms, i.e., families) have been selected to illustrate some distributional patterns of piling biota throughout the harbor. Relevant summary data for these selected organisms is provided in Table 2.4-5. *Hiatella hawaiiensis*, the nestling bivalve mollusc, was (as observed during the benthic faunal survey) collected in more piling samples (27, or 75% of the 36 samples) than any other single organism.

Distributional patterns for these selected species/families are mapped in Figures 2.4-7 through 2.4-17. The number of individuals for each kind of organism collected at any of the nine bio-stations is plotted at the relevant geographic location within the harbor; a "slash" separates the collections made in May and June 1972 from those made in November 1972 (May and June data are always listed first). A "dash" indicates that the organism was not collected in <u>one</u> of the piling sample series. A "zero" indicates that the organism was not collected in <u>either</u> May and June or November collections (at the given

(Text continued on page 2.4-39)

Table 2.4-2. A PHYLETIC CHECKLIST OF PILING ORGANISMS COLLECTED FROM PEARL HARBOR, OAHU

Species/Group	HCZDB #	Feeding/Habitat Type*
Porifera		
Demospongiae	352XXXXXXX	S-s
Cnidaria		
Anthozoa		
Actinaria	3742XXXXXX	C-s
Platyhelminthes		
Turbellaria		
Polycladida	4137XXXXXX	C-f
Nematoda	51XXXXXXXX	0-p/f
Annelida		
Polychaeta		
Errantia		
Aphroditidae		
Paralepidonotus ampulliferus	5511012201	C-f
Amphinomidae		
Eurythoe complanata	5511040201	0-m/f
Phyllodocidae	5511060000	0-f
Syllidae		
Syllis(Typosyllis)variegata	5511140107	0-f
Nereidae		
Ceratonereis sp.	5511160100	C-f
Nereis sp.	5511160400	C-f/t
Nereis (Neanthes) caudata	5511160410	C-f
Platynereis sp.	5511160600	C-f
Perinereis cultrifera	5511160803	0-f
Eunicidae		
Eunice antennata	5511200102	C-f
Eunice filamentosa	5511200105	0-f
Eunice vittata	5511200108	0-f/m
Eunice(Palolo) siciliensis	5511200109	0-f
Eunice(Nicidion) sp.	5511200111	C-f
Lysidice collaris	5511200201	0-f
Nematonereis unicornis	5511200401	0-f
Oenone fulgida	5511204201	0-f
Lumbrinerid sp.	5511206201	D-f
Dorvillea sp.	5511209100	0-f
Sedentaria		
Cirratulidae	5521040000	D-b/m/f
Terebellidae	5521220000	S-t/s
Sabellidae	5521230000	S-t
Serpulidae		
Hydroides norvegica	5521244201	S-s/c/t
Hydroides crucigera	5521244203	S-s/c/t
Hydroides lunulifera	5521244204	S-s/c/t

Table 2.4-2. (Continued)

Sipuncunculida		
Phascolosoma dentigerum	5611010103	D-b/f
Arthropoda		
Pycnogonida	639XXXXXXX	C-f
Crustacea		
Ostracoda	643XXXXXXX	S-f
Cirripedia		
Thoracica		
Balanus amphitrite amphitrite	6451070101	S-s
Balanus eburneus	6451070103	S-s
Balanus trigonus	6451070106	S-s
Malacostraca		
Mysidacea	6466XXXXXX	S-f
Tanaidacea		
Apseudes sp. 2	6468010103	C-f
Leptochelia dubia	6468130101	C-f
Anatanais insularis	6468140201	C-f
Isopoda		
Mesanthura hieroglyphica	6471060201	C-f
Limnoria sp.	6471210100	O-b
Limnoria tripunctata	6471210103	O-b
Sphaeroma walkeri	6471220101	C-f
Paracerceis sculpta	6471220201	C-f
Dynamenella sp.	6471220300	O-f
Amphipoda		
Lembos sp.	6473080400	S-t/f/b
Corophium baconi	6473180101	D-t/f
Corophium acherusicum	6473180103	D-t
Ericthonius brasiliensis	6473180201	S-t/f
Elasmopus rapax	6473250209	D-f
Photis hawaiensis	6473320302	D-f
Leucothoe sp.	6473380100	D-f
Leucothoe hyhelia	6473380101	D-f
Podocerus brasiliensis	6473510201	D-f
Decapoda/Natantia		
Alpheopsis equalis	6483410601	D-t/b
Alpheus sp.	6483411000	D-t/b
Alpheus gracilis simplex	6483411016	D-t/b
Alpheus paralcyone	6483411023	D-t/b
Alpheus paracrinitus	6483411024	D-t/b
Alpheus gracilipes	6483411028	D-t/b
Alpheus heeia	6483411036	D-t/b
Synalpheus thai	6483411202	D-t/b
Synalpheus bituberculatus	6483411212	D-t/b
Synalpheus coutierei	6483411213	D-t/b
Decapoda/Reptantia		
Thalamita integra	6488313301	D-f
Metapograpsus thukuhar	6488320301	D-f
Platypodia eydouxi	6488330504	D-f
Madaeus simplex	6488330801	D-f
Carpilodes bellus	6488331404	D-f

Decapoda/Reptantia (continued)		
Panopeus pacificus	6488332201	D-t
Liocarpilodes integerrimus	6488332501	D-t
Pilumnus oahuensis	6488335806	D-f
Glabropilumnus seminudus	6488335901	D-f
Stomatopoda		
Gonodactylus falcatus	6489010201	C-f/t
Mollusca		
Gastropoda		
Archaeogastropoda		
Fissurellidae		
Diodora granifera	7021050302	H-f
Mesogastropoda		
Vermetidae		
Dendropoma ?psarocephala	7022430104	S-t/c
Vermetus alii	7022430401	S-t/c
Hipponicidae		
Hipponix pilosus	7022720101	H-f
Calyptraeidae		
Crepidula aculeata	7022750201	H-f
Neogastropoda		
Pyrenidae		
Mitrella zebra	7023060101	C-f
Mitridae		
Mitra sp.	7023260100	C-f
Entomotaeniata		
Pyramidellidae		
Odostomia pupu	7031010202	C-p/f
Basommatophora		
Siphonariidae		
Siphonaria normalis	7037100101	H-f
Nudibranchia	7044XXXXXX	H-f
Bivalvia		
Mytiloida		
Mytilidae		
Brachidontes(=Hormomya) crebristriatus	7054010301	S-s
Pterioida		
Isognomonidae		
Isognomon perna	7055020103	S-s
Ostreidae		
Crassostrea virginica	7055060102	S-s/c
Anomiidae		
Anomia nobilis	7055200101	S-s/c
Myoida		
Hiatellidae		
Hiatella hawaiiensis	7057100101	S-b/m/t
Ectoprocta		
Gymnolaemata		
Ctenostomata		
Vesiculariidae		
Amathia distans	7511010101	S-s
Cheilostomata		
Bicellariellidae		
Bugula neritina	7513060101	S-s
Bugula californica	7513060102	S-s

Table 2.4-2. (Continued)

Echinodermata		
Asteroidea		
Gnathophiuridae		
Ophiactidae		
Ophiactis savignyi	7841010102	D-f/b
Amphiuridae		
Amphiopholis squamata	7841030301	D-f/b
Chordata		
Urochordata		
Ascidiacea		
Phallusidae		
Ascidia sp.	8311040100	S-s
Polyclinidae		
Polyclinum sp.	8311130200	S-s
Styelidae		
Styela sp.	8312020100	S-s
Tethyidae		
Hermandia momus	8312030201	S-s
Osteichthyes		
Perciformes		
Blenniidae		
Omobranchus elongatus	8555605301	C-f/t/b
Eleotridae		
Asterropteryx semipunctatus	8555605301	C-f/b

* For Feeding/Habitat Type Definitions See Legend, Table 2.2-2 (page 2.2-17).

Table 2.4-3. AN ALPHABETICAL LIST OF PEARL HARBOR PILING ORGANISMS COLLECTED MAY/JUNE AND NOVEMBER 1972.

Species	Common Name*	HCZDB #
Alpheopsis equalis	SS	6483410601
Alpheus gracilipes	SS	6483411028
Alpheus gracilis simplex	SS	6483411016
Alpheus heeia	SS	6483411036
Alpheus paracrinitus	SS	6483411024
Alpheus paralcyone	SS	6483411023
Alpheus sp.	SS	6483411000
Amathia distans	BR	7511010101
Amphiopholis squamata	BS	7841030301
Anatanais insularis	TA	6468140201
Anomia nobilis	BI	7055200101
Apseudes sp. 2	TA	6468010103
Ascidia sp.	AS	8311040100
Asterropteryx semipunctatus	FISH	8555605301
Balanus amphitrite	BA	6451070101
Balanus eburneus	BA	6451070103
Balanus trigonus	BA	6451070106
Bugula californica	BR	7513060102
Bugula neritina	BR	7513060101
Carpilodes bellus	TC	6488331404
Ceratonereis sp.	EP	5511160100
Cirratulid sp.	SP	5521040000
Corophium acherusicum	AM	6473180103
Corophium baconi	AM	6473180101
Crassostrea virginica	BI(oyster)	7055060102
Crepidula aculeata	GA	7022750201
Dendropoma ?psarocephala	GA	7022430104
Diadora granifera	GA	7021050302
Dorvillea sp.	EP	5511209100
Dynamenella sp.	IS	6471220300
Elasmopus rapax	AM	6473250209
Erichthonius brasiliensis	AM	6473180201
Eunice antennata	EP	5511200102
Eunice filamentosa	EP	5511200105
Eunice (Palolo) siciliensis	EP	5511200109
Eunice vittata	EP	5511200108
Eunice (Nicidion) sp.	EP	5511200111
Eurythoe complanata	EP	5511040201
Glabropilumnus seminudus	TC	6488335901
Gonodactylus falcatus	MS	6489010201
Hermandia momus	AS	8312030201
Hiatella hawaiiensis	BI	7057100101
Hipponix pilosus	GA	7022720101
Hormomya(Brachidontes) crebristriatus	BI	7054010301
Hydroides crucigera	SP	5521244203
Hydroides lunulifera	SP	5521244204
Hydroides norvegica	SP	5521244201
Isognomon perna	BI	7055020103
Lembos sp.	AM	6473080400
Leptochelia dubia	TA	6468130101

Table 2.4-3. (Continued)

Species	Common Name*	HCZDB #
Leucothoe hyhelia	AM	6473380101
Leucothoe sp.	AM	6473380100
Limnoria tripunctata	IS	6471210103
Limnoria sp.	IS	6471210100
Liocarpilodes integerrimus	TC	6488332501
Lumbrinerid sp.	EP	5511206201
Lysidice collaris	EP	5511200201
Madeus simplex	TC	6488330801
Mesanthura hieroglyphica	IS	6471060201
Metapograpsus thukuhar	TC	6488320301
Mitra sp.	GA	7023260100
Mitrella zebra	GA	7023060101
Nematonereis unicornis	EP	5511200401
Nereis (Neanthes) caudata	EP	5511160410
Nereis sp.	EP	5511160400
Odostomia pupu	GA	7031010202
Oenone fulgida	EP	5511204201
Omobranchus elongatus	FISH	8555340701
Ophiactis savignyi	BS	7841010102
Ostreid sp.	BI(oyster)	7055060000
Panopeus pacificus	TC	6488332201
Paralepidonotus ampulliferus	EP	5511012201
Paracerceis sculpta	IS	6471220201
Perinereis cultrifera	EP	5511160803
Phascolosoma dentigerum	PW	5611010103
Photis hawaiensis	AM	6473320302
Phyllodocid sp.	EP	5511060000
Pilumnus oahuensis	TC	6488335806
Platynereis sp.	EP	5511160600
Platypodia eydouxi	TC	6488330504
Podocerus brasiliensis	AM	6473510201
Polyclinum sp.	AS	8311130200
Portunid sp.	TC	6488310000
Sabellid sp.	SP	5521230000
Siphonaria normalis	GA	7037100101
Sphaeroma walkeri	IS	6471220201
Styela sp.	AS	8312020100
Syllis (Typosyllis) variegata	EP	5511140107
Syllid sp.	EP	5511140000
Synalpheus bituberculatus	SS	6483411212
Synalpheus coutierei	SS	6483411213
Synalpheus thai	SS	6483411202
Terebellid sp.	SP	5521040000
Thalamita integra	TC	6488313301
Vermetus alii	GA	7022430401
Vermetid sp.	GA	7022430000
Xanthid sp.	TC	6488330000

* For Common Name/Adjective Identifier, See Key, Table 2.2-3 (page 2.2-20).

Table 2.4-4. PILING ORGANISMS PRESENT IN SAMPLES FROM NINE BIO-STATIONS IN PEARL HARBOR, OAHU. NUMBERS OF INDIVIDUALS ARE LISTED BY DEPTH (SURFACE & TEN FEET) FOR ORGANISMS COLLECTED IN MAY&JUNE 72 &/or NOVEMBER 72 (SEPARATED BY A "SLASH" IN THE TABLE). VALUES IN PARENTHESES ARE WET ALCOHOL WEIGHTS (IN GRAMS). # INDICATES NUMBER UNCERTAIN, AS FOR COLONIAL ORGANISMS; ## INDICATES NUMBER IS LARGE, MANY INDIVIDUALS; - INDICATES NOT PRESENT IN THE SAMPLE. S = SURFACE PILING SAMPLE.

		Bio-Station								
Species/Group	Depth	BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17
Porifera/Demospongiae	S May	(.65)/	(54.97)/	- /	(.19)/	- /	(.63)/	(49.93)/	- /	- /
	S Nov	-	-	-	(40.05)	(136.67)	(11.02)	-	(18.37)	(.86)
	10'May	(47.55)/	- /	- /	(123.78)/	(116.15)/	(11.82)/	(112.67)/	(7.06)/	- /
	10'Nov	(142.65)	(42.35)	(9.42)	(70.57)	(31.85)	(3.42)	(102.20)	(30.43)	(19.66)
Cnidaria/Actinaria	S	-	-	-	-/8	-	-	-	-	-
	10'	-/1	-	-	-	7/1	-	-	-	-/1
Platyhelminthes /Polycladida	S	-	-	-	-	1/-	-	-	-	-
Aschelminthes/Nematoda	S	-	5/-	-	-	-	-	-	3/-	-
	10'	-	-	-	-	-	-	-	-	-/15
Annelida/Polychaeta (misc. fragments)	S	5/3	#/3	-	-/#	-/6	7/4	#/#	8/3	-/1
	10'	#/#	4/#	-/#	1/11	#/3	6/#	#/#	2/25	#/2
/Aphroditidae *Paralepidonotus ampulliferus*	10'	-	-	-	-	-	-	2/-	-	-
/Amphinomidae *Eurythoe complanata*	10'	-	-	-	-	3/-	-	3/18	-	-
/Phyllodocidae	S	-	2/-	-	-	-	-	-	-	2/-
/Syllidae	S	-/5	86/8	-	-	-	-/17	74/17	-/5	13/13
	10'	##/-	60/103	4/96	2/7	15/12	7/#	70/47	4/6	7/-
		BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17

Table 2.4-4 (Continued)

Species/Group	Depth	BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17
					Bio-Station					
/Syllidae *Syllis (Typosyllis) variegata*	S	-	#/3	-	-/2	-	-/16	1/#	1/5	4/-
	10'	-	-/#	-	-	-	-	-	-	1/-
/Nereidae *Ceratonereis* sp.	S	-	-	-	-/4	-	-	-	-	-
	10'	3/1	-/1	-/2	2/-	-	1/2	-/3	-	-
/Nereidae *Nereis* sp.	S	-	-	-	-	-	-/1	-	-	-
/Nereidae *Nereis (Neanthes) caudata*	S	-	-	62/-	-	-	-	-	4/-	-
	10'	-	-	5/	-	-	-	-	-	-
/Nereidae *Platynereis* sp.	S	-	-/2	-	-	-	-/3	-	-	-
/Nereidae *Perinereis cultrifera*	S	21/42	-/2	-	1/-	-	2/2	-	-/5	-/2
/Eunicidae *Eunice antennata*	S	2/-	-	-	-/1	-	2/4	-	-/1	-
	10'	1/2	-/1	1/-	3/-	-	-	2/-	-	5/-
/Eunicidae *Eunice filamentosa*	S	-	-	-	-	-	-/1	1/-	-	-
	10'	-	-/1	-	-/1	-	-	8/11	-	-
/Eunicidae *Eunice vittata*	10'	-	-	-	-	-	-	13/-	-	-
/Eunicidae *Eunice (Palolo) siciliensis*	10'	-	-	-	-/1	-	-	-	-	-
/Eunicidae *Eunice (Nicidion)* sp.	S	-	-/1	-	-/4	-	-/8	9/-	-	-
	10'	-	9/3	-	1/1	-	5/2	5/14	-	-
/Eunicidae *Lysidice collaris*	S	-	-	-	10/-	-	-	-	-	-
		BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17

Table 2.4-4. (Continued)

Species/Group	Depth	BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17
/Eunicidae	S	-	4/1	-	-/2	-	-	2/2	-	1/2
Nematonereis unicornis	10'	5/3	-/5	-	-/1	-	3/3	30/40	-	-
/Eunicidae	S	-	-	-	-	-	-	-/10	-	-
Oenone fulgida	10'	-	-	-	-	-	-	10/5	1/-	-
/Eunicidae	S	-	2/-	-	-	-	-	7/-	-	-
Lumbrinerid sp.	10'	-/1	5/2	-/4	-	1/1	2/-	2/10	-	3/5
/Eunicidae										
Dorvillea sp.	10'	-	-	-	-	2/-	1/-	-	-/1	-
/Cirratulidae	S	-	92/20	63/-	-	-	3/30	3/-	-/9	1/-
	10'	7/16	83/43	91/98	17/-	5/4	12/-	6/-	2/-	37/7
/Terebellidae	10'	-	-	-	2/-	14/1	3/-	8/11	1/-	-
/Sabellidae	S	-	2/-	-	-	-	-	-	-/4	-
	10'	6/-	56/4	-	4/-	3/1	-	-	-/29	11/14
/Serpulidae	S	-	115/-	7/-	-	-	-	-	-	348/#
Hydroides norvegica	10'	-	#/-	2/#	-	2/-	-	#/-	4/-	-
/Serpulidae										
Hydroides crucigera	10'	-	-	-	-	1/-	-	-	-	-
/Serpulidae	S	-	-	-	-	-	-	-	8/#	-
Hydroides lunulifera	10'	-	-	-	-	12/-	-	-	-/#	-
Sipunculida (misc.)	S	-	-	-	-/1	-	2/-	2/-	-	-
	10'	-	-	-	-	-	-	9/33	-	-
Sipunculida										
Phascolosoma dentigerum	S	-	-	-	-	-	-/6	-/4	-	-
	10'	-	-	-	-	-	-	-/3	-	-
		BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17

Table 2.4-4. (Continued)

Species/Group	Depth	BE-02	BE-03	BE-04	Bio-Station BE-05	BM-07	BC-10	BC-11	BW-13	BE-17
Arthropoda/Pycnogonida	S	-	6/-	7/-	-	-	-/10	-	-	4/-
	10'	-/1	-	-/2	-	-	-	-	-	-
/Ostracoda	S	-	-	-	-	-	-	-	-	5/-
/Cirripedia	S	-/3	-/4	-	-/6	50/-	59/3	1/-	260/270	46/1
Balanus amphitrite	10'	1/1	-	-	-	-	-	-	2/4	-
/Cirripedia	S	-	-	-	-	4/-	3/-	-	104/40	6/-
Balanus eburneus	10'	-	-	-	-	-/7	-	-	-/1	-
/Cirripedia *Balanus trigonus*	S	-	-	-	-	-	-	1/-	-	-
/Mysidacea	10'	-	1/2	-	-	-	-	-	-	-/1
/Tanaidacea	S	-	-	-	-/8	-	-	-	-	-
Apseudes sp. 2	10'	-	-	-	-/1	-	-	13/5	-	-
/Tanaidacea	S	-	-	-	##/49	-	-	60/-	38/-	-
Leptochelia dubia	10'	-	-	-	1/3	3/-	-	19/10	-	-
/Tanaidacea *Anatanais insularis*	S	21/-	2/2	-	-/16	2/-	-	1/1	38/-	6/-
/Isopoda	S	-	-	-	-	-	-	7/-	-	-
Mesanthura hieroglyphica	10'	-	-	-	-	-	-/3	1/2	-	-
/Isopoda *Limnoria* sp.	S	-	-	-	-	-	-	-	-	1/-
/Isopoda *Limnoria tripunctata*	S	-	-	-	-	-	-	-	-	-/3
/Isopoda *Sphaeroma walkeri*	S	1/-	2/6	-	7/30	23/5	-	-/1	33/41	2/-
		BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17

Table 2.4-4. (Continued)

Species/Group	Depth	BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17
/Isopoda *Paracerceis sculpta*	S	-	2/-	-	-	-	-	-	-	-
	10'	-	1/-	1/-	-	-	-	-	-	-
/Isopoda *Dynamenella* sp.	S	-	2/1	-	2/8	26/1	-	-	-	1/-
/Amphipoda (misc.)	S	-	145/-	-	-/1	-/4	-/1	8/4	2/1	-/31
	10'	2/4	5/-	-	2/3	-	-/5	43/1	13/-	7/-
/Amphipoda *Lembos* sp.	10'	-	-	-	-	-	-	-/37	-	-
/Amphipoda *Corophium baconi*	S	-	-	-	-	1/-	-	-	12/-	-
	10'	-	1/-	-	-/1	1/7	-	-	-/1	-
/Amphipoda *Corophium acherusicum*	S	-	19/-	-	-	-/3	-	-	-	1/-
	10'	-	-	-	-	-/1	-	-	-	1/-
/Amphipoda *Ericthonius brasiliensis*	S	-	#/-	-	-	-	-	-	-	-
	10'	-	-	-	-	1/-	1/14	-	-	-
/Amphipoda *Elasmopus rapax*	S	3/-	494/-	-	-	-	-	-	-	48/-
	10'	2/-	39/-	146/5	5/-	131/6	18/-	-/2	193/2	56/5
/Amphipoda *Photis hawaiensis*	10'	-	-	-	-	5/-	-	-	-	-
/Amphipoda *Leucothoe* sp.	10'	-	-	-	2/-	-	-	7/-	3/-	-
/Amphipoda *Leucothoe hyhelia*	S	-	-	-	-/1	-	-	#/-	-	-
	10'	-	-	-	-	2/-	-/1	14/-	8/1	1/-
/Amphipoda *Podocerus brasiliensis*	S	-	21/-	-	-	-	-	-	-	-
		BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17

Table 2.4-4. (Continued)

Species/Group	Depth	BE-02	BE-03	BE-04	Bio-Station BE-05	BM-07	BC-10	BC-11	BW-13	BE-17
/Decapoda(Natantia) (misc. Caridea)	10'	-	1/-	-/4	-	3/-	2/2	5/1	-/6	-
/Decapoda *Alpheopsis equalis*	10'	-	-	-	-	-	-	-/13	-	-
/Decapoda *Alpheus* sp.	10'	-	-	-	-	-	3/-	-	-	-
/Decapoda *Alpheus gracilis simplex*	10'	-	-	-	-	-	-	-/1	-	-
/Decapoda *Alpheus paralcyone*	10'	-	-	-	-	-	-	7/3	-	-
/Decapoda *Alpheus paracrinitus*	10'	-	-	-	-	-	-	-/1	-	-
/Decapoda *Alpheus gracilipes*	10'	-	-	-	-	-	-	1/1	-	-
/Decapoda *Alpheus heeia*	10'	-	-	-	-	-	-	-/1	-	-
/Decapoda	S	-	-	-	-/1	-	-	-	-	-
Synalpheus bituberculatus	10'	-	1/-	-	2/-	-	-	2/12	-	-
/Decapoda	S	-	-	-	-	-	-	2/-	-	-
Synalpheus thai	10'	-	-	-	-	-	-	-/1	-	-
/Decapoda *Synalpheus coutierei*	10'	-	-	-	1/-	-	-	-	-	-
/Decapoda	S	-	-	-	-/4	-	-	-	-	-
(misc. Reptantia)	10'	-	-/1	-	-	1/-	-	-	-	-
		BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17

Table 2.4-4. (Continued)

Species/Group	Depth	BE-02	BE-03	BE-04	Bio-Station BE-05	BM-07	BC-10	BC-11	BW-13	BE-17
/Portunidae	10'	-	-	-	-	-	-/1	-	-	-
/Portunidae *Thalamita integra*	10'	-/1	-	-	-	4/3	-	-	-/2	3/-
/Grapsidae *Metapograpsus thukuhar*	S	-	-	-	-	-	-	1/-	-/1	-/1
/Xanthidae (misc.)	S	-	-	-	-	-/6	-	-	-	-
	10'	-	-	-	-	-	-	4/3	-	-
/Xanthidae *Platypodia eydouxi*	S	-	-	-	-	-	-	3/-	-	-
	10'	-	-	-	-	-	1/-	1/-	-	-
/Xanthidae *Madaeus simplex*	10'	-	-	-	-	-	-	1/-	-	-
/Xanthidae *Carpilodes bellus*	10'	-	-	-	-	-	-	2/-	-	-
/Xanthidae *Panopeus pacificus*	S	3/2	-/1	-	2/-	-/9	13/2	-	7/26	1/-
	10'	-	-	-	-	1/1	-	-	-	-
/Xanthidae *Liocarpilodes integerrimus*	S	-	-	-	-	-	-	1/-	-	-
/Xanthidae *Pilumnus oahuensis*	S	1/-	3/1	-	-/25	-	-/2	-	-	-
	10'	-/1	-/4	2/7	10/17	4/2	8/5	5/1	2/3	2/2
/Xanthidae *Glabropilumnus seminudus*	10'	-	1/-	-	-/1	-	-	1/-	-	-
/Stomatopoda *Gonodactylus falcatus*	10'	-	-	-	-	-	1/-	3/4	-	-
		BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17

Table 2.4-4. (Continued)

Species/Group	Depth	BE-02	BE-03	BE-04	Bio-Station BE-05	BM-07	BC-10	BC-11	BW-13	BE-17
Mollusca (Gastropoda)										
/Fissurellidae										
Diodora granifera	10'	1/-	-	-	-	-	-	-	-	-
/Vermetidae	S	7/15	1/10	1/1	-/1	-	4/5	2/-	-	-
(misc.)	10'	-/2	4/3	7/8	-/1	-	-	-	-	3/-
/Vermetidae	S	-	-	-	-	-	-	1/-	-	-
Dendropoma ?psarocephala										
/Vermetidae	S	12/-	-/4	-	-	-	-	-	-	-
Vermetus alii	10'	-	1/-	-	-	-	-	-	-	-
/Hipponicidae										
Hipponix pilosus	10'	-	1/-	1/-	-	-	-/1	-	-	-
/Calyptraeidae	S	3/-	-	-	-/4	-	7/-	20/29	23/3	-
Crepidula aculeata	10'	6/3	10/5	1/-	1/1	4/-	1/11	1/-	-/2	7/[illegible]
/Pyrenidae	S	-	-	-	-	-	-	-/2	-	-
Mitrella zebra										
/Mitridae										
Mitra sp.	10'	-	-	-	-	-	-	-/2	-	-
/Pyramidellidae										
Odostomia pupu	10'	-	3/-	-	-	1/1	15/-	-	5/-	1/-
/Siphonariidae	S	-	-	-	1/6	-	1/1	-	-	-
Siphonaria normalis										
/Nudibranchia	10'	-	-	-	-	-	-	-/1	-	-
		BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17

Table 2.4-4. (Continued)

Species/Group	Depth	BE-02	BE-03	BE-04	Bio-Station BE-05	BM-07	BC-10	BC-11	BW-13	BE-17
/Bivalvia (misc.)	10'	-	-	-/2	-	-	-	-/1	-	-
/Mytilidae *Brachidontes (=Hormomya) crebristriatus*	S	-	-	-	-	-	-	2/5	-	-
/Isognomidae *Isognomon perna*	10'	-	-	-	-	-	-	9/-	-	-
/Ostreidae (misc.)	S	3/5	-	-	-/1	-	4/3	1/2	-/3	-/1
	10'	-	-	-	4/1	3/-	-	-/1	-	-
/Ostreidae *Crassostrea virginica*	S	-	-	-	-	1/-	-	-	-	-
/Anomiidae	S	-	-	-	-/1	-	-	-	-	-
Anomia nobilis	10'	-	-	-	-	1/-	-	-	-	-
/Hiatellidae	S	10/1	18/8	-	-/8	-/21	64/22	7/1	113/26	-/10
Hiatella hawaiiensis	10'	5/-	1/-	-	2/-	35/39	1/1	1/-	2/2	-/4
Ectoprocta/Bryozoa	S	-	-/#	-	-	-	-	-	-	-
(misc.)	10'	#/-	-	-	-	#/#	-	#/-	-	-
/Vesiculariidae	S	-	-	-	-	-	#/#	-	-	-
Amathia distans	10'	-	-/#	-/#	-/#	#/-	#/#	-	-	-
/Bicellariellidae	S	-	#/-	-	-	-	-	-	#/#	-/#
Bugula neritina	10'	-	-	-	-	#/#	-	-	-/#	-
/Bicellariellidae	S	-	-/#	-	-	-	-	-	-	-
Bugula californica	10'	-	-/#	-/#	-	-	#/-	-	-	-
Echinodermata (Ophiuroidea)										
/Ophiactidae	S	-	-	-	-/1	-	-/9	6/-	12/229	-
Ophiactus savignyi	10'	-/1	-	-	-	-	-	791/414	137/179	-
		BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17

Table 2.4-4. (Continued)

Species/Group	Depth	BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17
		Bio-Station								
/Amphiuridae	S	-	-	-	-/1	-	-	-	1/-	-
Amphiopholis squamata	10'	-	-	-	-	-	-	-	4/-	-
Urochordata/Ascidacea	S	-	-	-	-	-	-/#	-	#/-	-
(misc.)	10'	#/#	-/#	-/#	-/#	#/-	-/#	#/#	#/#	-/#
/Phallusidae	S	-	-	-	-	-	-	1/-	-	-
Ascidia sp.	10'	-	-	-	-	3/-	1/-	2/2	-	-
/Polyclinidae										
Polyclinum sp.	10'	-	-	-	-	-	##/-	-	-	-
/Styelidae	S	7/9	-/1	-	-/5	-/1	15/6	-	1/270	-/20
Styela sp.	10'	2/-	-	-	-/10	13/28	-	-/7	-/5	-/2
/Tethyidae										
Hermandia momus	10'	-	-	-	-/1	-	1/-	4/-	1/-	-
Chordata/Osteichthyes										
/Blenniidae	S	-	-	-	-	-	-	-	1/-	-
Omobranchus elongatus										
/Eleotridae										
Asterropteryx semipunctatus	10'	-	-	-	-	-	-	1/-	-	-
TOTAL species (minimum)	@ S	15/9	25/20	5/1	8/29	8/10	16/25	30/14	21/21	17/14
TOTAL species (minimum)	@ 10'	17/18	21/20	11/16	19/20	35/20	25/18	41/39	19/20	16/14
TOTAL individuals	@ S	99/85	1023/78	140/1	23/99	108/56	186/156	224/78	669/943	490/65
TOTAL individuals	@ 10'	41/38	287/178	261/228	62/62	281/118	93/51	1106/722	384/269	145/59
		BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17

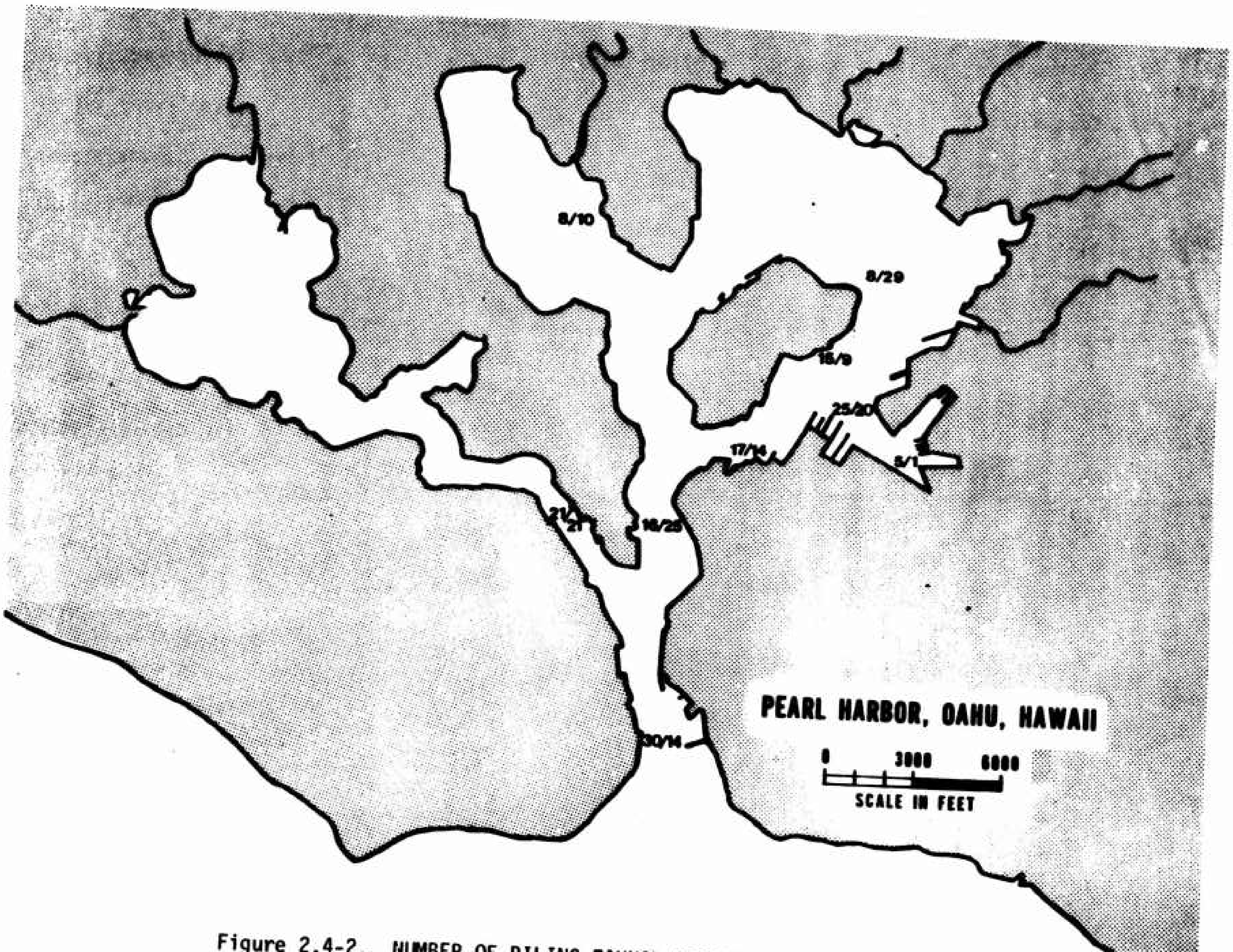


Figure 2.4-2. NUMBER OF PILING FAUNAL SPECIES PER STATION. (SURFACE SAMPLES MAY/NOVEMBER 1972)

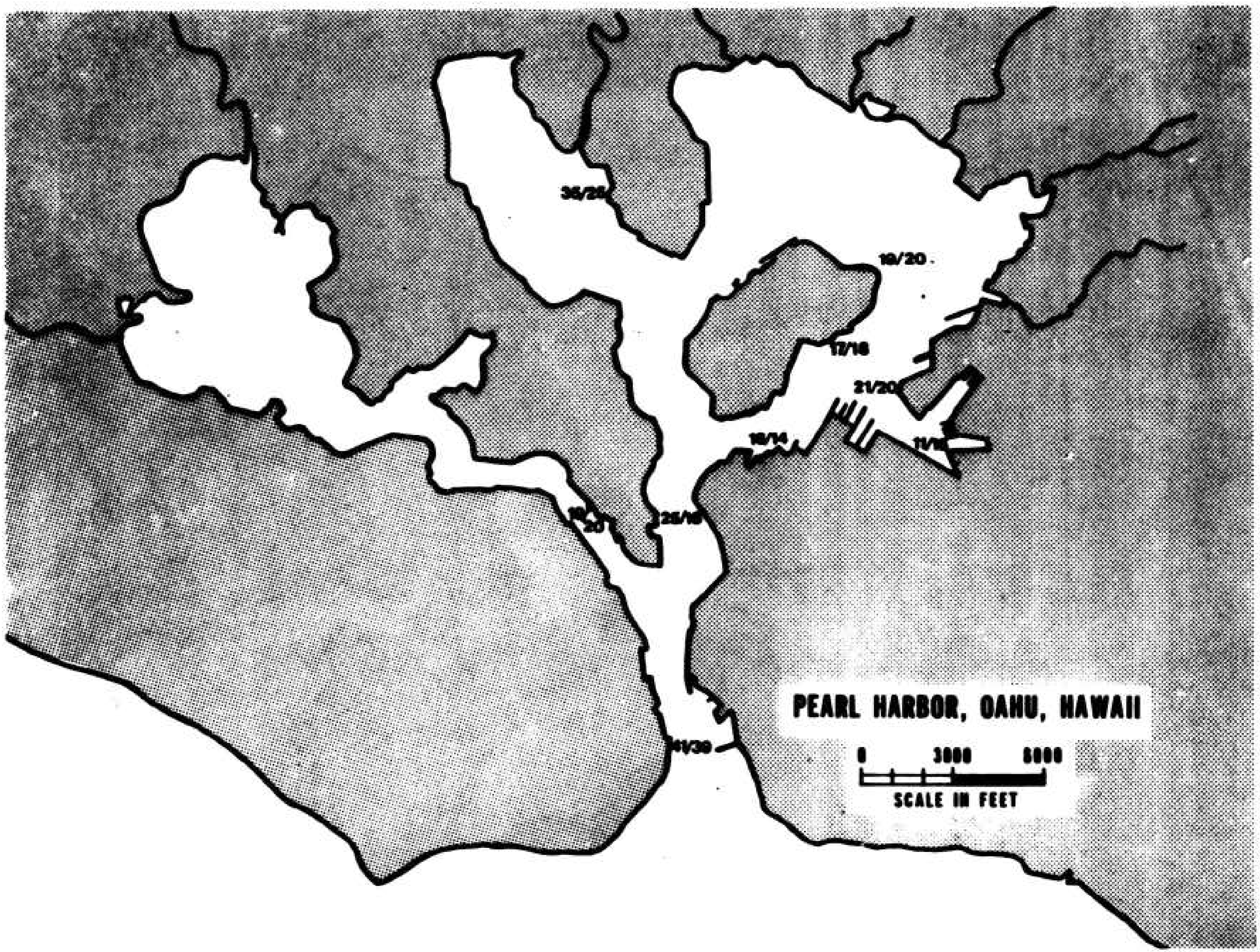


Figure 2.4-3. NUMBER OF PILING FAUNAL SPECIES PER STATION. (10-FOOT SAMPLES MAY/NOVEMBER 1972)

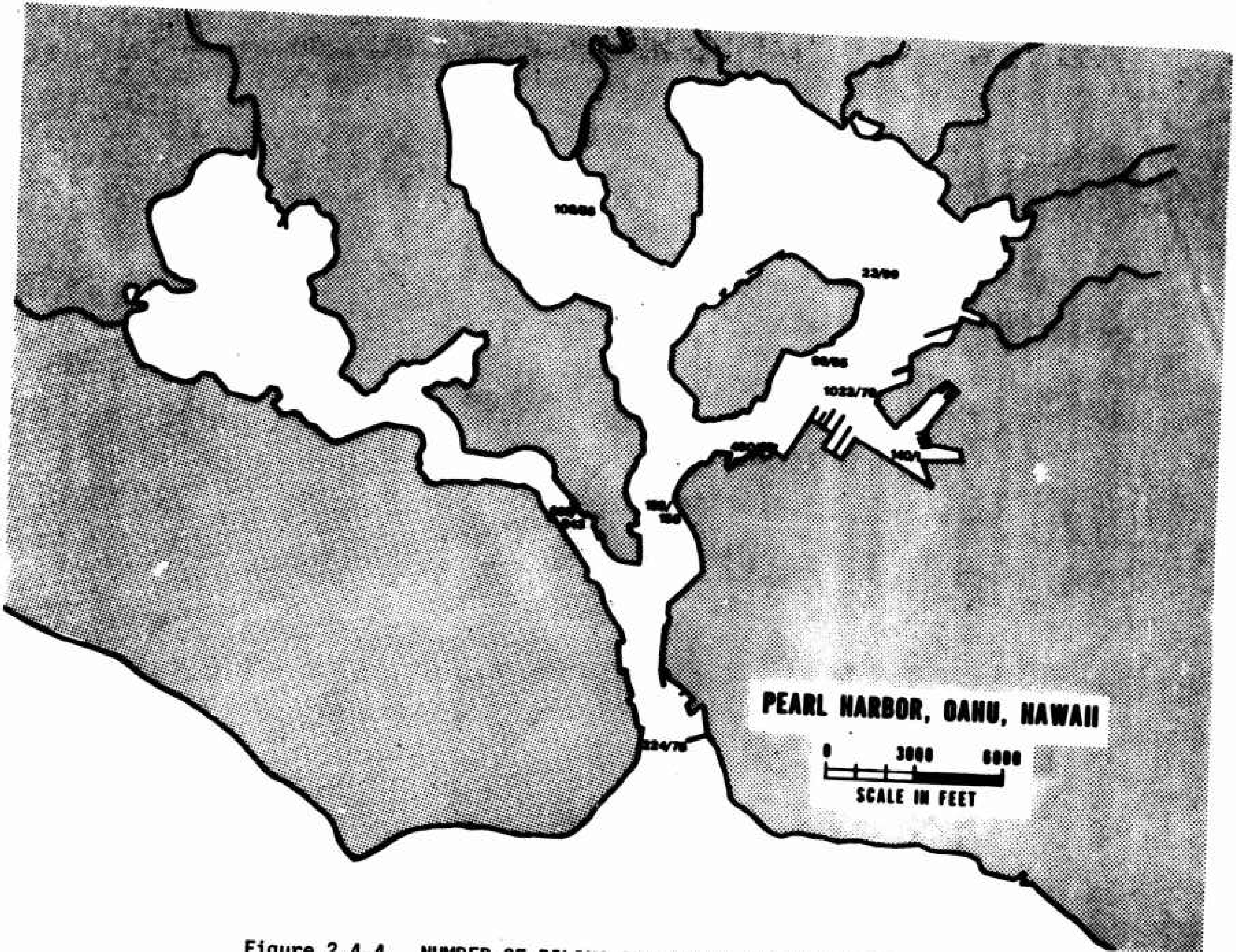


Figure 2.4-4. NUMBER OF PILING INDIVIDUAL ORGANISMS PER STATION. (SURFACE SAMPLES COLLECTED MAY/NOVEMBER 1972)

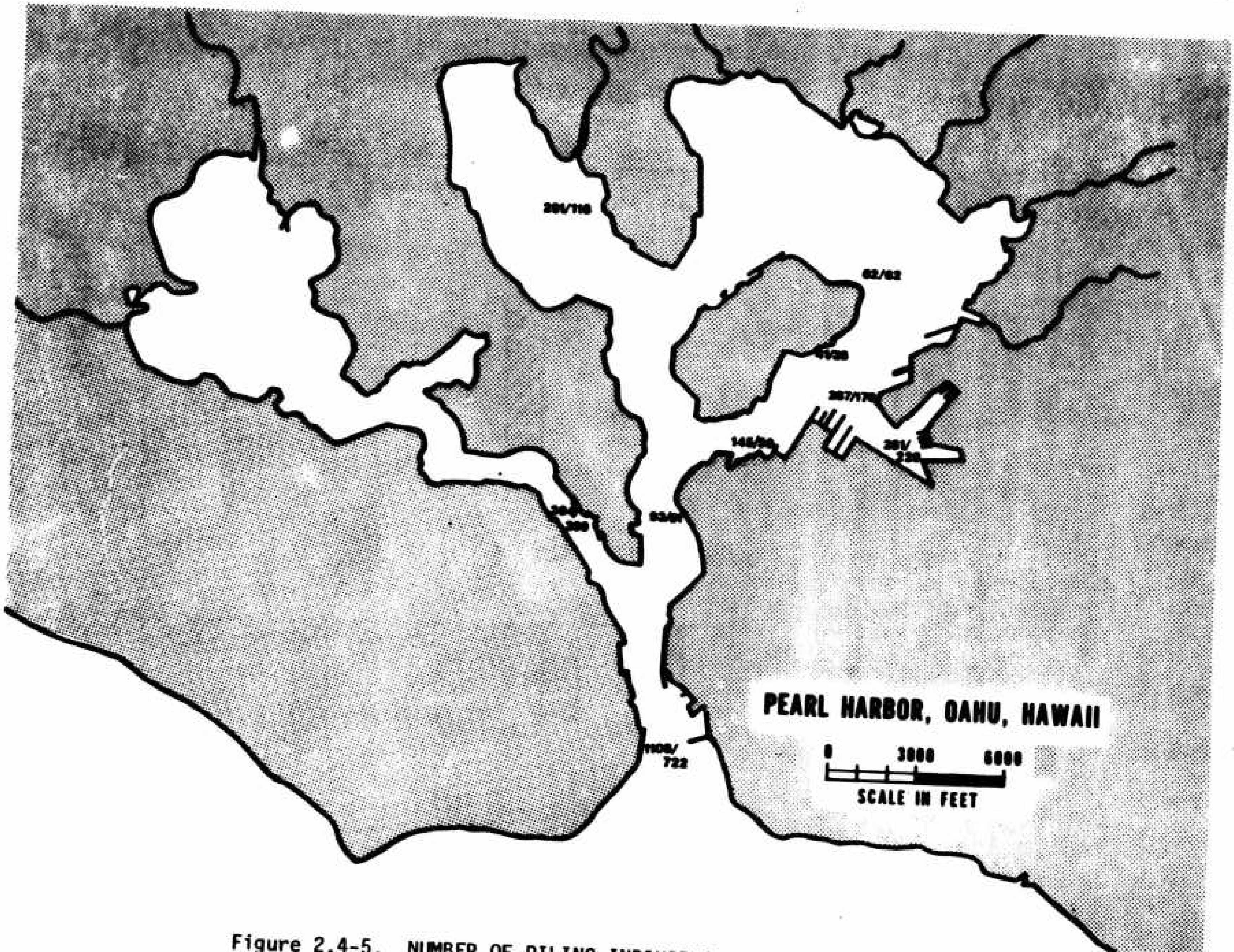


Figure 2.4-5. NUMBER OF PILING INDIVIDUAL ORGANISMS PER STATION. (10-FOOT SAMPLES COLLECTED MAY/NOVEMBER 1972)

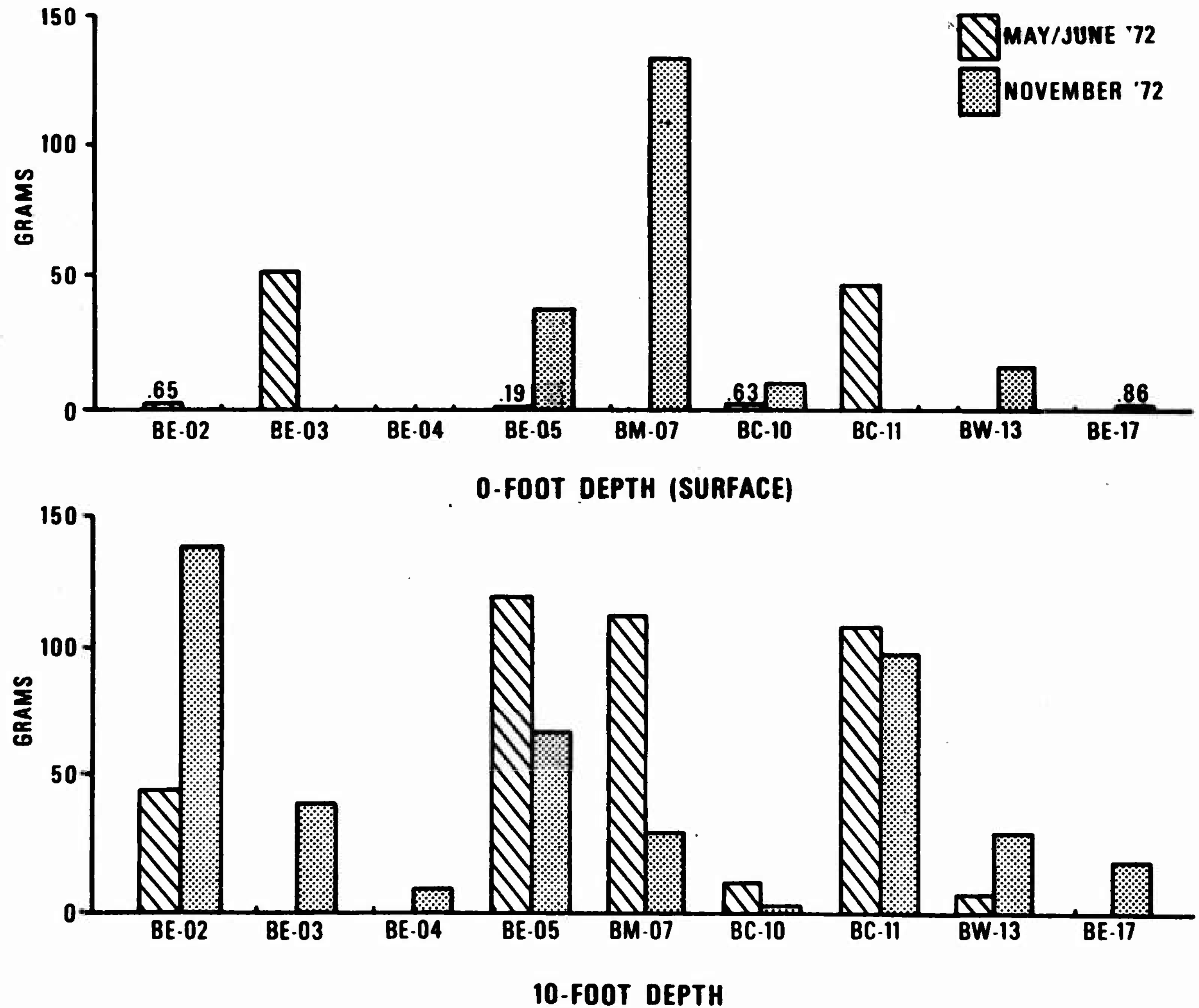


Figure 2.4-6. DISTRIBUTION OF PORIFERA (WET WEIGHT IN GRAMS) COLLECTED IN PILING SAMPLES FROM PEARL HARBOR, OAHU.

Table 2.4-5. SELECTED COMMON PILING FAUNAL ORGANISMS PRESENT IN SAMPLES FROM PEARL HARBOR, OAHU.

Species/Family	Common Name	# samples containing organism	# bio-stations containing organism	Depth preference
Hiatella hawaiiensis	BI	27	8	S
Syllidae	EP	25	9	TT
Cirratulidae	SP	22	9	TT
Crepidula aculeata	GA	21	9	T
Pilumnus oahuensis	TC	21	9	TT
Styela sp.	AS	17	8	S/T
Vermetidae	GA	17	7	S
Elasmopus rapax	AM	16	9	TTT
Balanus amphitrite	BA	15	8	SSS
Ophiactis savignyi	BS	10	5	TT
Bugula spp. (2)	BR	10	6	S/T

* Legend for Common Names may be found in Table 2.2-3 (page 2.2-20).

** Legend for depth preference:

S = weak surface depth preference, SS = moderate surface depth preference
SSS = strong surface depth preference; T = weak 10' depth preference,
TT = moderate 10' depth preference, TTT = strong 10' depth preference;
S/T = no preference observed for either depth.

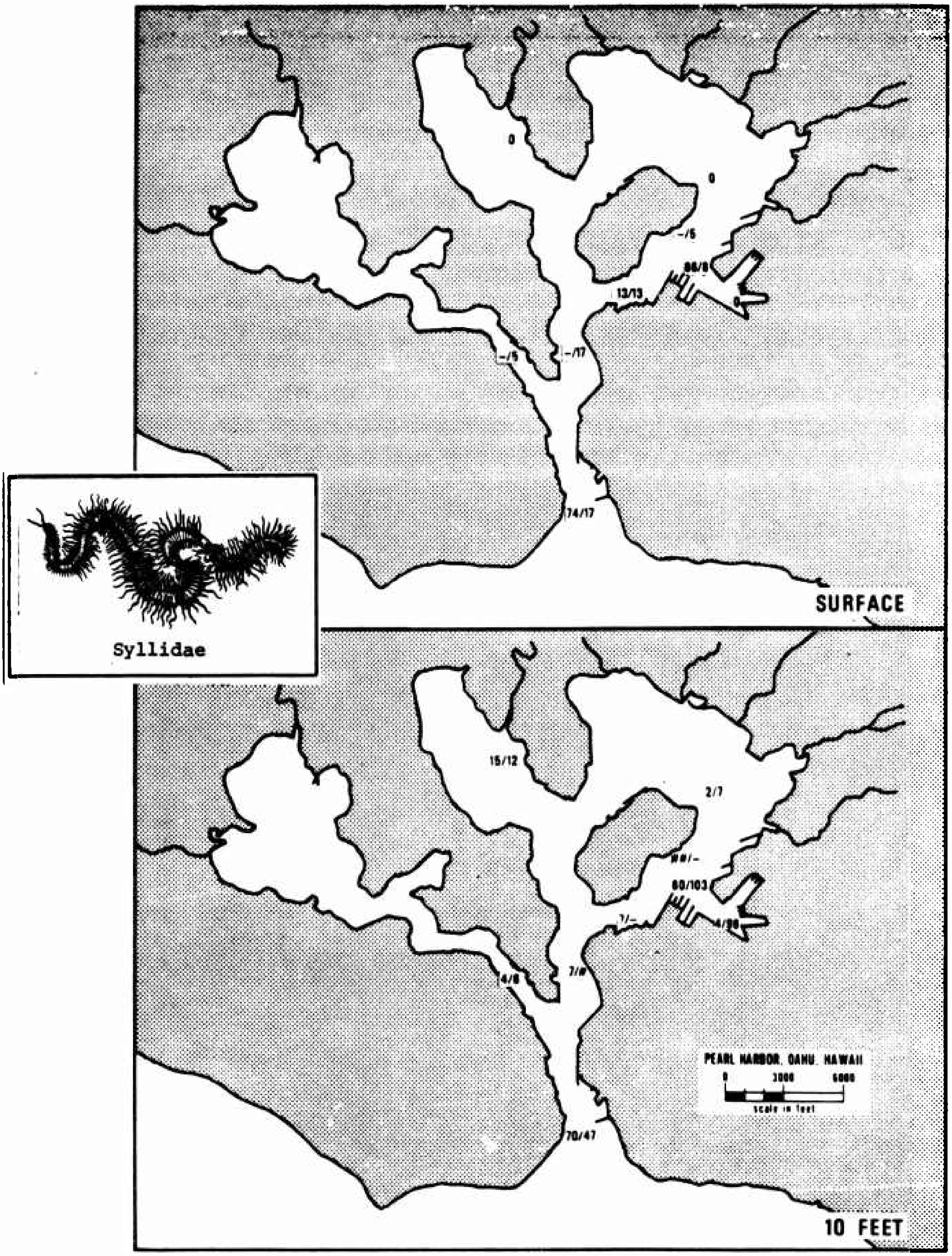


Figure 2.4-7. Syllidae

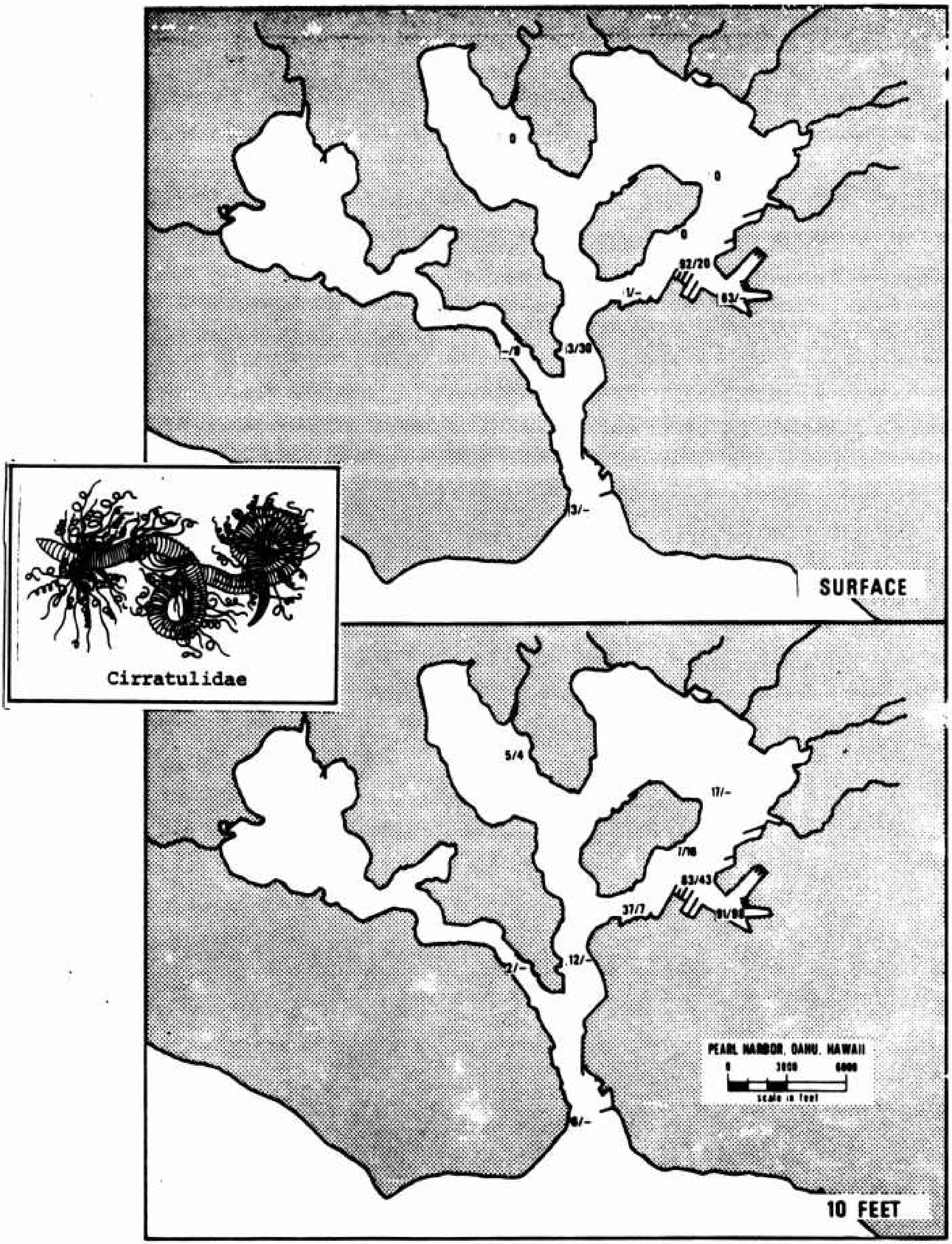


Figure 2.4-8. Cirratulidae

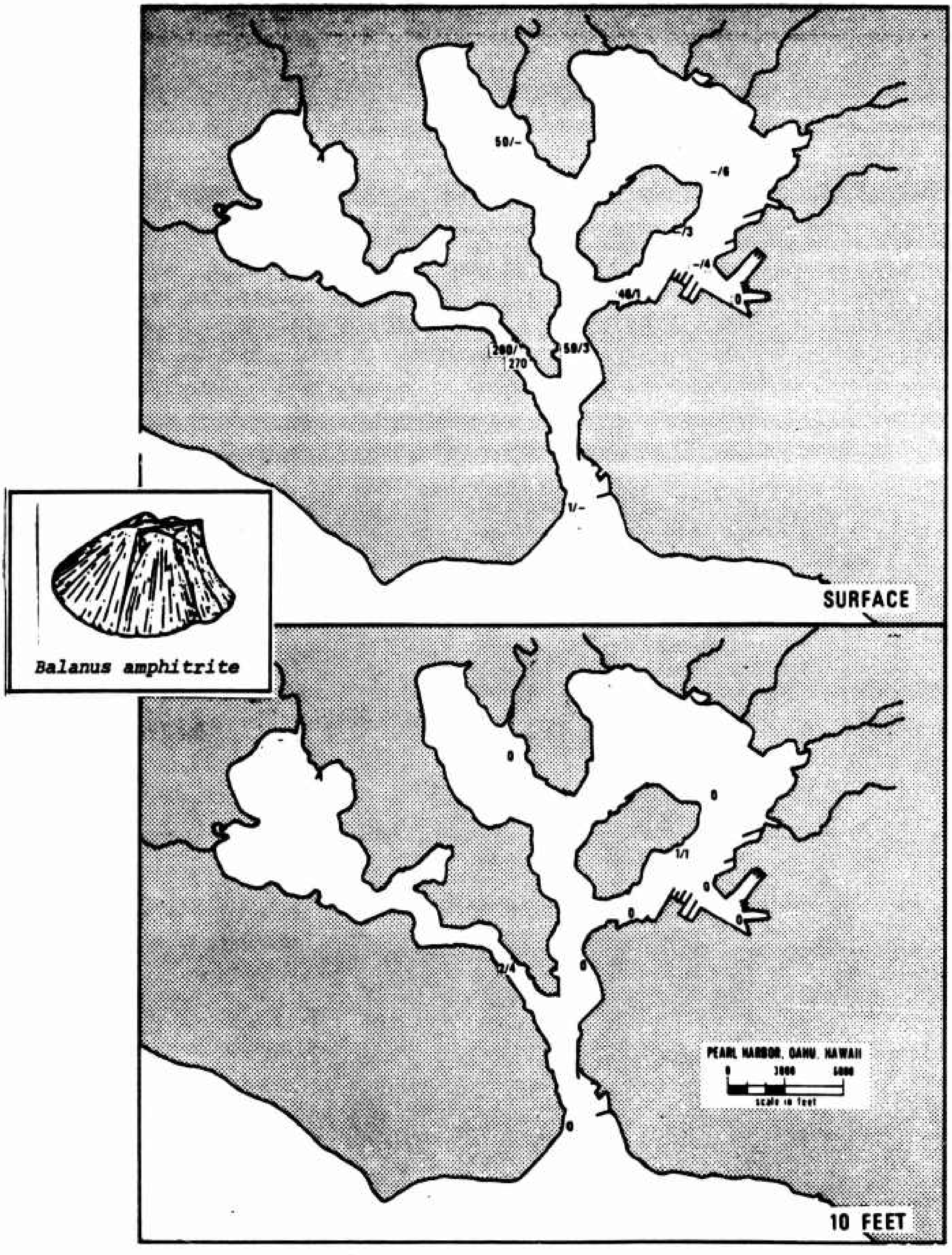


Figure 2.4-9. *Balanus amphitrite*

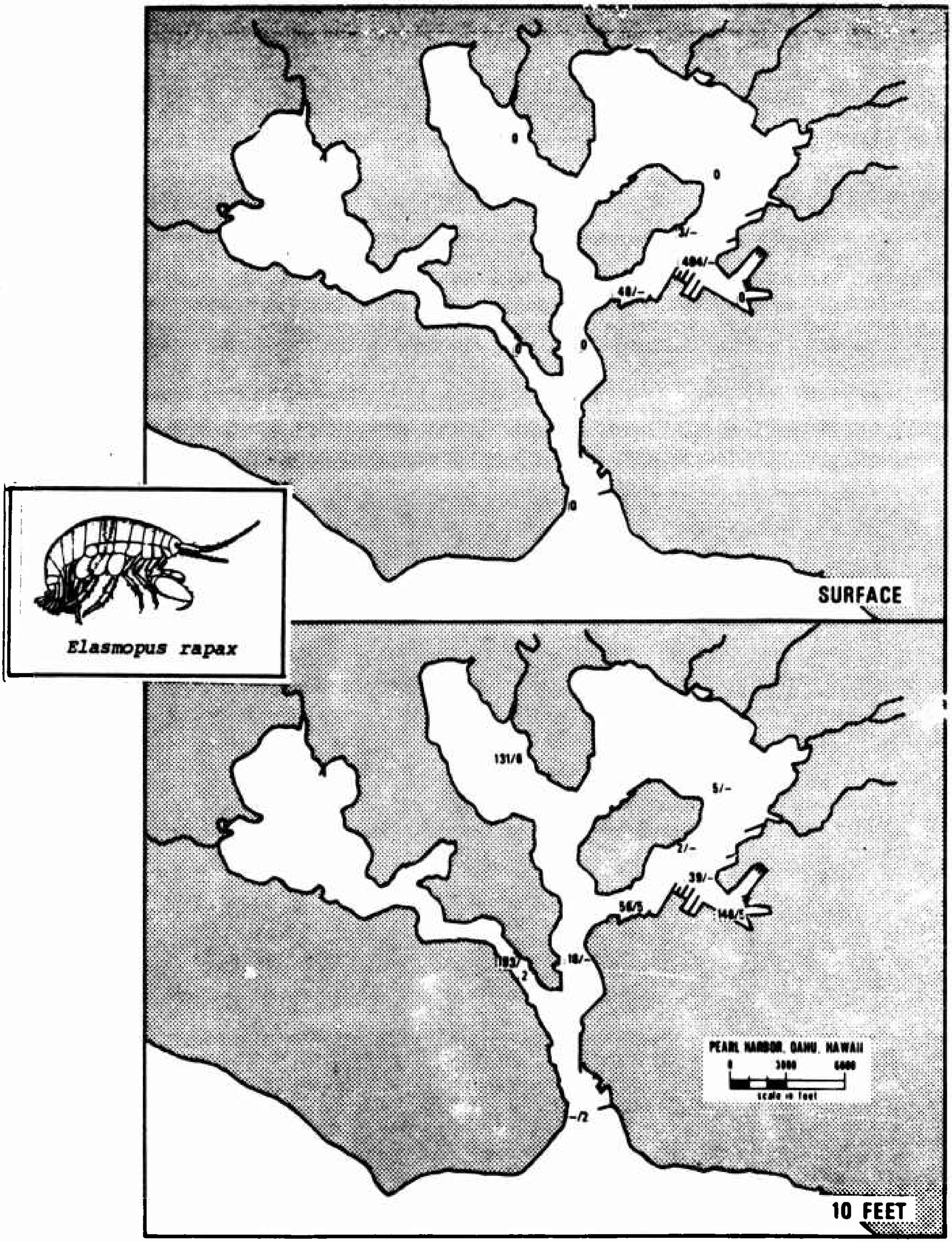


Figure 2.4-10. *Elasmopus rapax*

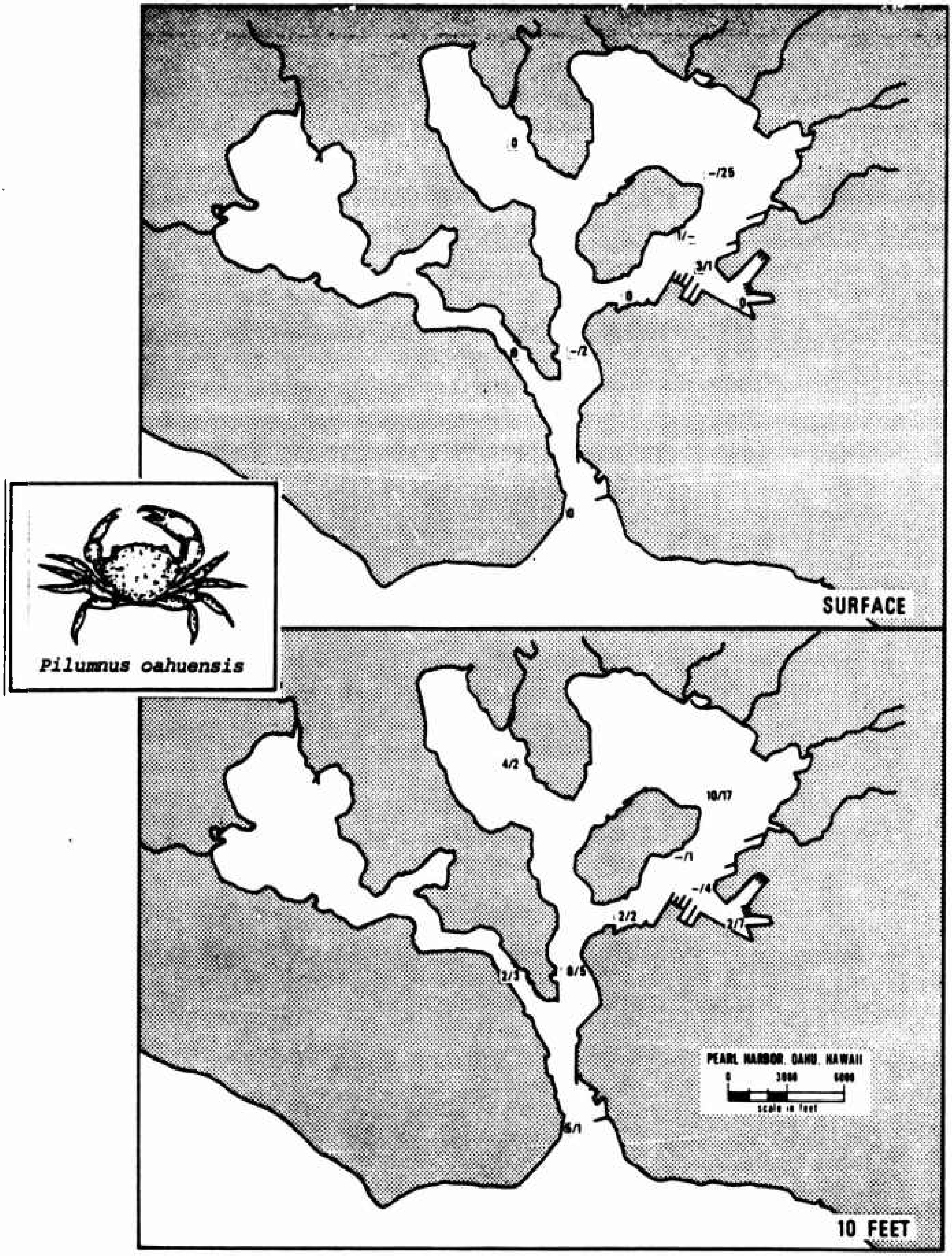


Figure 2.4-11. *Pilumnus oahuensis*

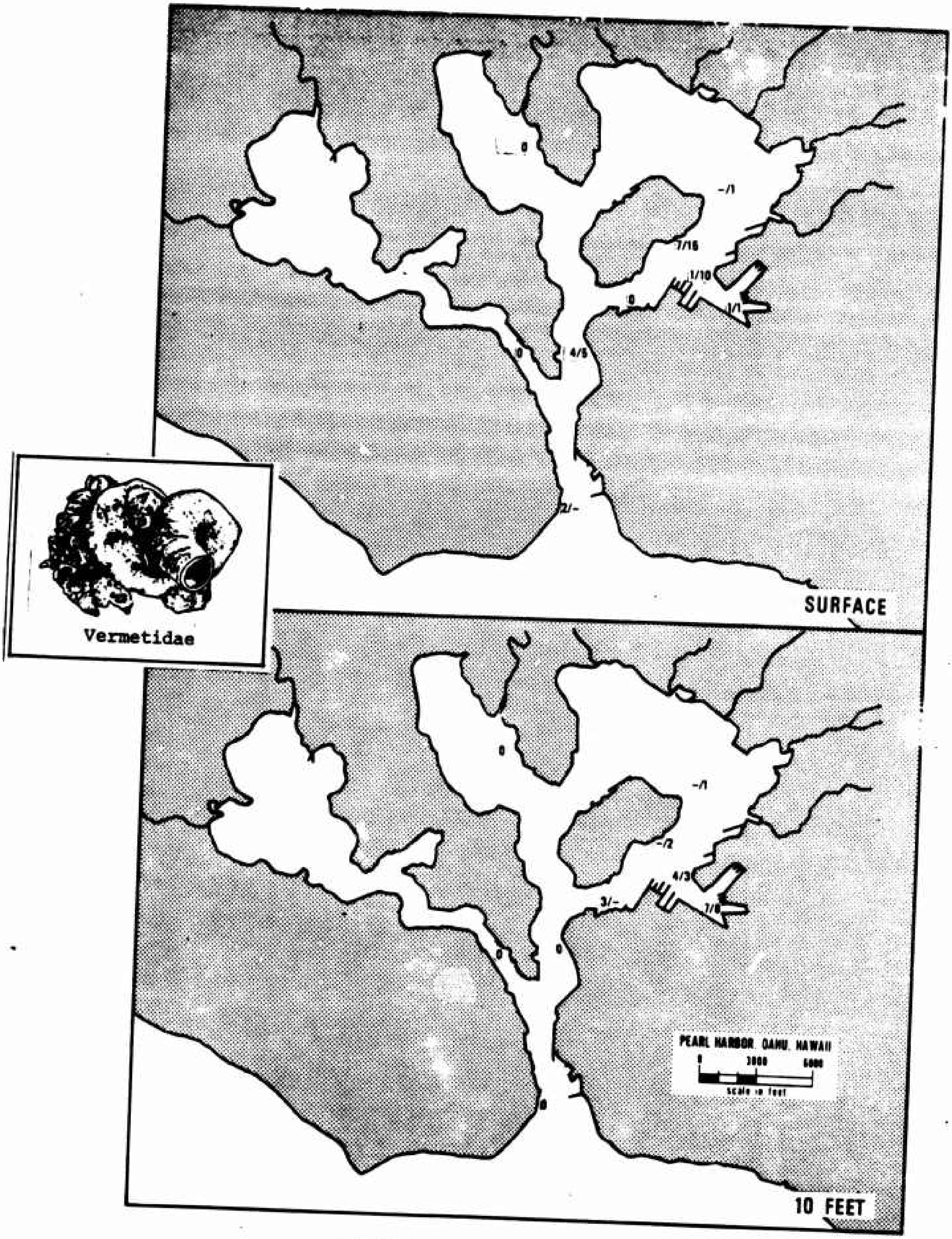


Figure 2.4-12. Vermetidae

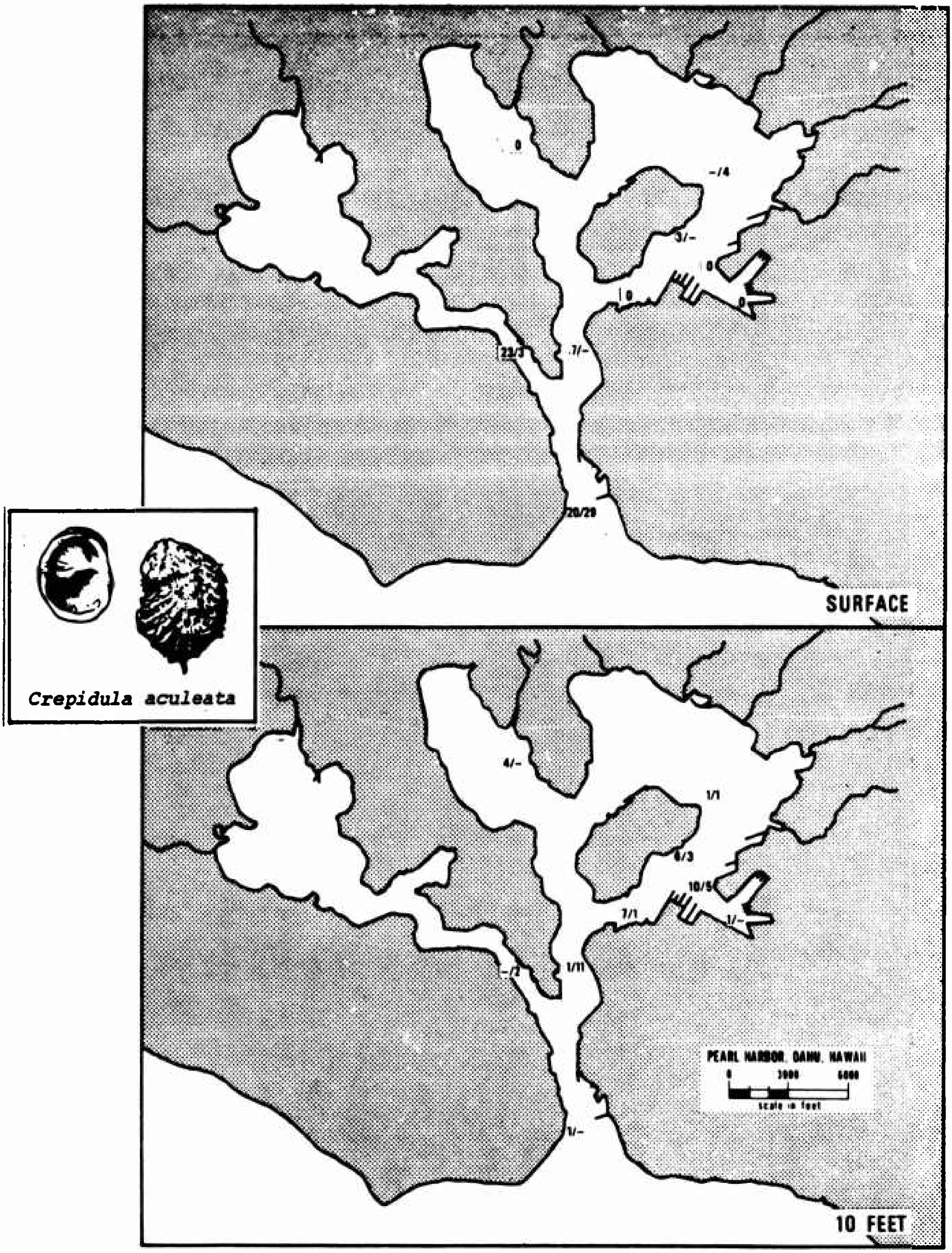


Figure 2.4-13. *Crepidula aculeata*

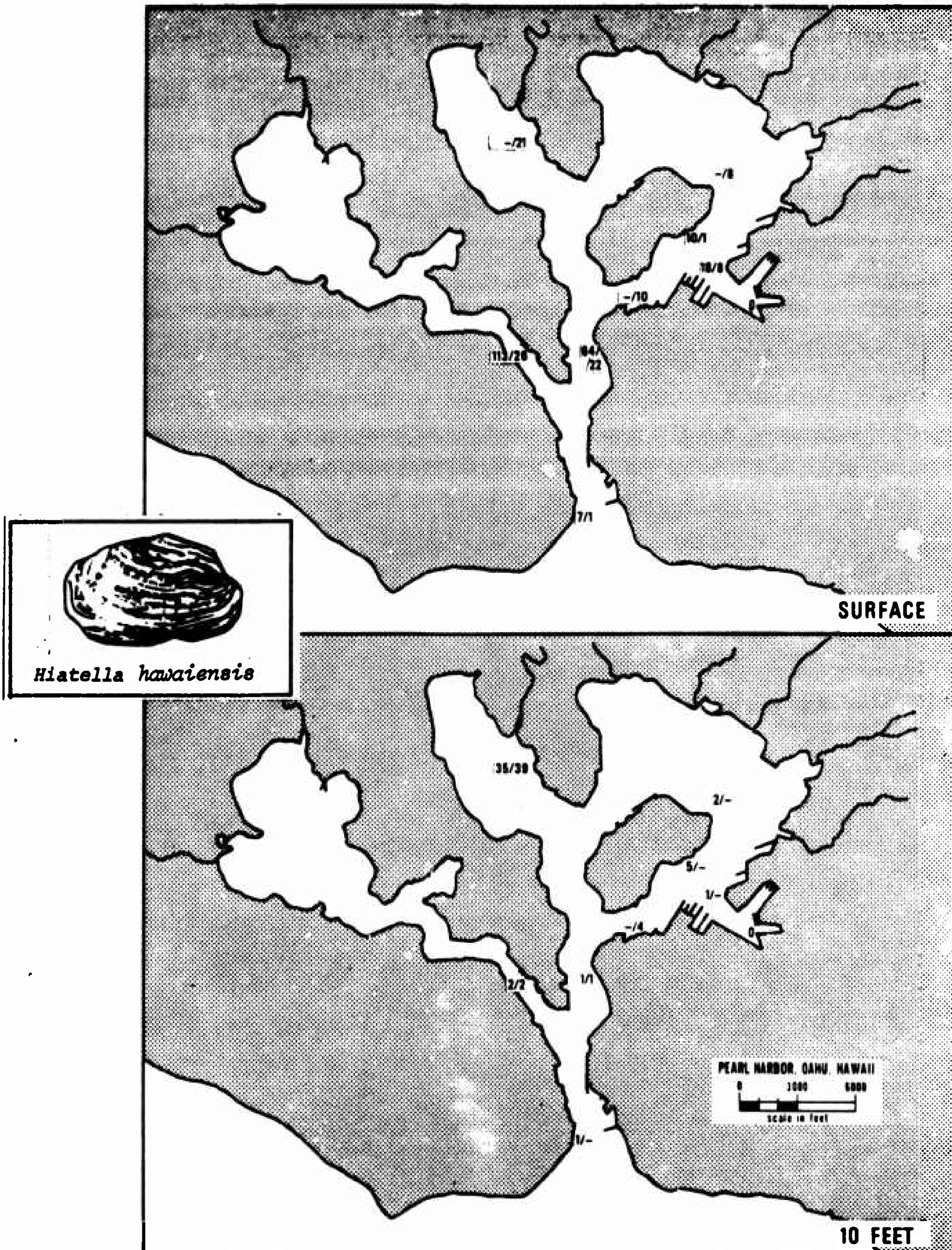


Figure 2.4-14. *Hiatella hawaiensis*

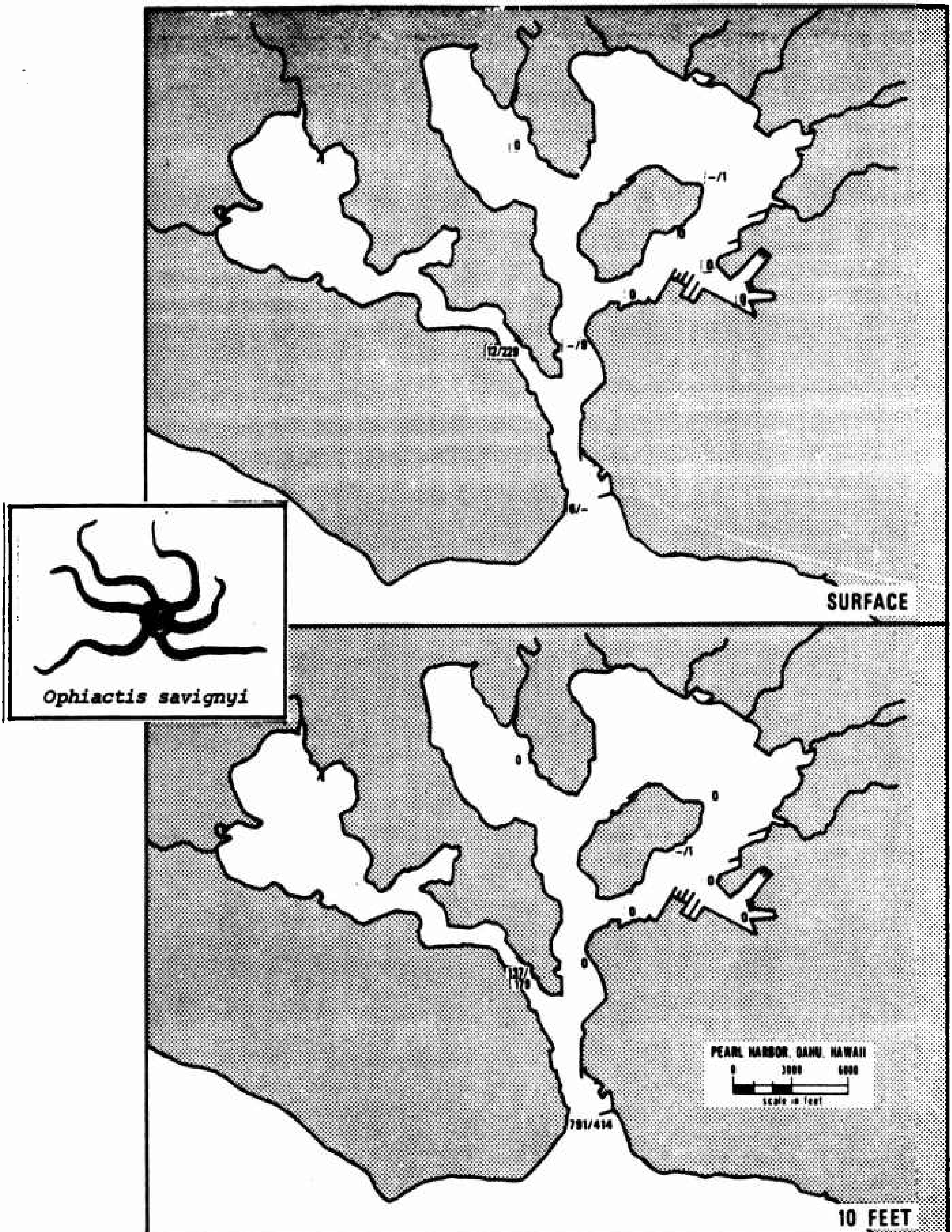


Figure 2.4-15. *Ophiactis savignyi*

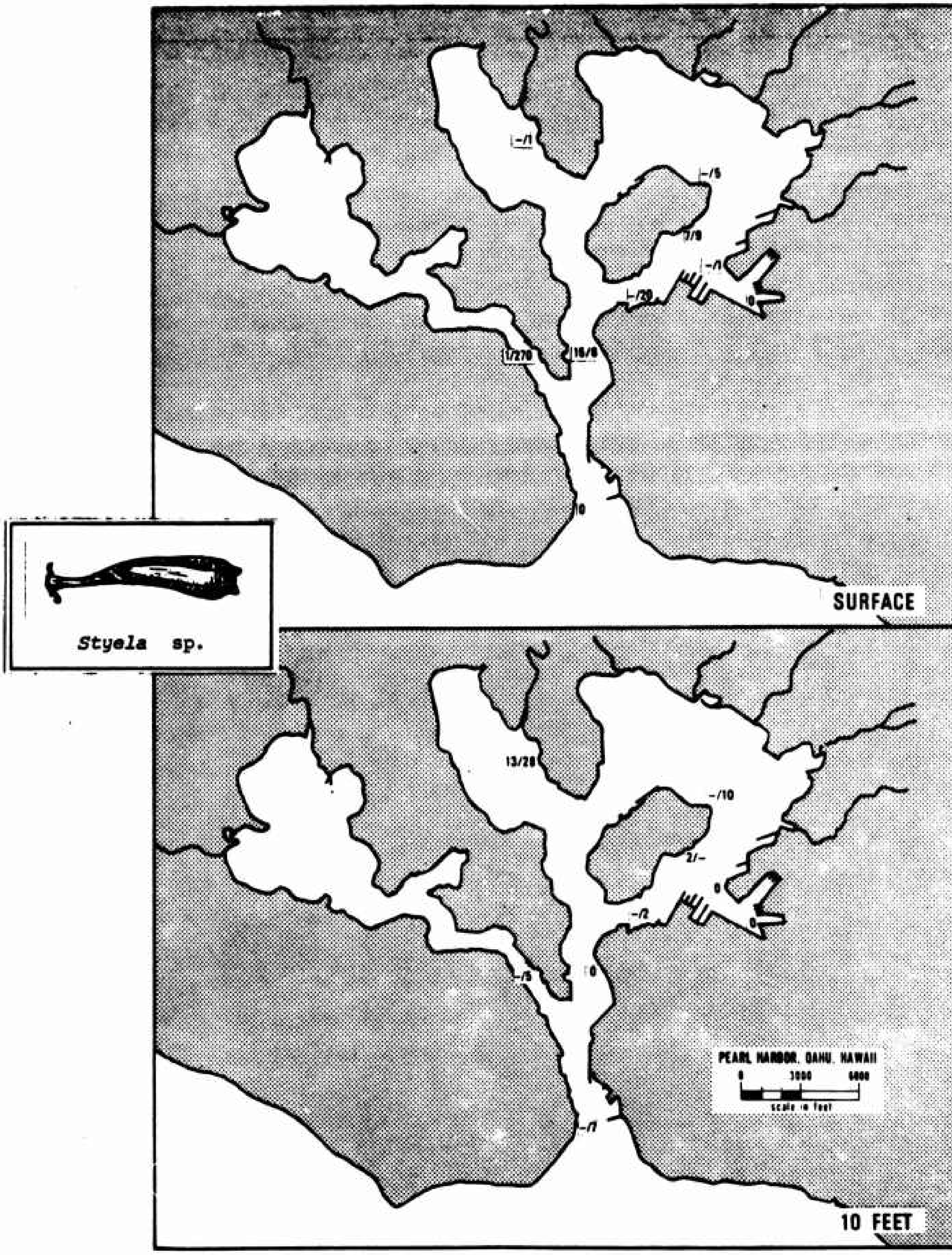


Figure 2.4-16. *Styela* sp.

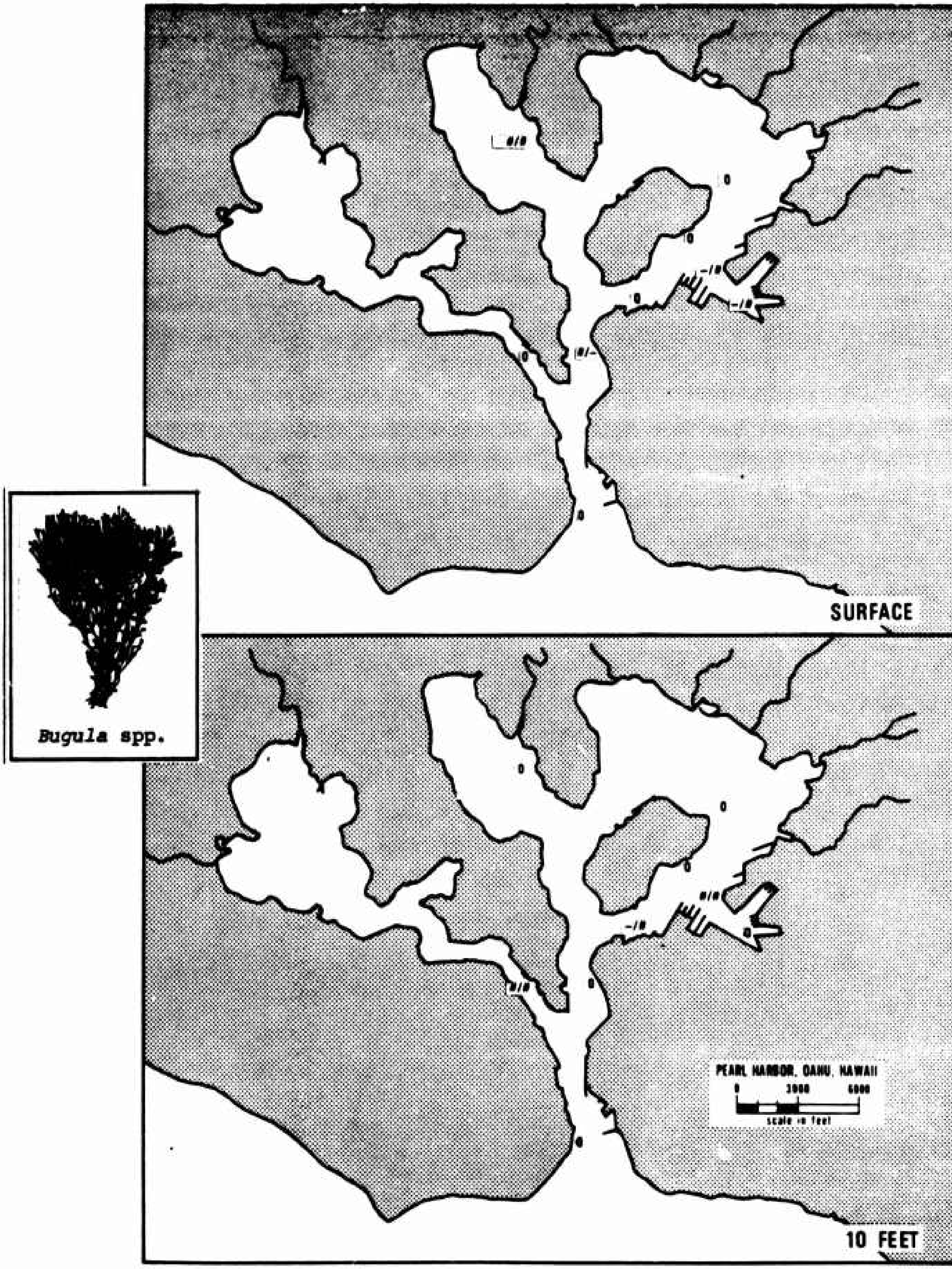


Figure 2.4-17. *Bugula* spp.

depth). "#" indicates that the organism is present, however, the actual number is uncertain, i.e., colonial organisms like *Bugula*. "##" indicates that the number is large, i.e., many individuals. Surface piling data are displayed in the upper map on each figure (2.4-7 through 2.4-17); the lower map displays piling data for 10-foot depths.

Two families of polychaetous annelids, Cirratulidae and Syllidae (shown in Figures 2.4-7 and 2.4-8, respectively), are seen to be present at all nine bio-stations sampled in Pearl Harbor. Both families show a tendency to be more numerous in the 10-foot collections. The numbers of individuals of cirratulids are greatest in 10-foot depth samples at bio-stations BE-04, BE-03 and BE-17, suggesting a specificity for the more stressed Southeast Loch area. Syllids, by contrast, are most numerous in collections for both surface and 10-foot depths at bio-stations BE-03, BC-11, BE-04 and BM-07, suggesting no apparent preference for location or environmental status within the harbor.

Examining the distribution of the barnacle, *Balanus amphitrite*, (Figure 2.4-9) in piling collections, a strong tendency is revealed for this organism to occur in surface samples at all but the presumably most stressed bio-station, BE-04. Several individuals were collected at 10-foot depths at bio-stations BE-02 and BW-13, however. *Balanus amphitrite* was most numerous in surface samples at BW-13 which suggests that high nutrient levels in the surface waters of West Loch are significantly elevating the standing crop of this organism (five times as many individuals were collected at BW-13 as were collected at any other bio-station).

The amphipod, *Elasmopus rapax*, is ubiquitous throughout the harbor as observed in 10-foot piling samples (Figure 2.4-10). This is the only piling organism selected which shows a moderate tendency for increased abundance in the May and June collections, compared to much lower numbers in the November collections. With the exception of nearly 500 individuals collected in the surface sample (in May) at BE-03, *Elasmopus rapax* was consistently more abundant in the 10-foot depth samples. This amphipod has an affinity for sponge-tunicate-bryozoan growth.

Pilumnus oahuensis, a xanthid crab which was also selected for distributional display during the benthic faunal survey (Figure 2.2-15 and page 2.2-41 for discussion), occurred at all 9 piling sample locations. The greatest abundance of this organism was observed at bio-station BE-05 (Figure 2.4-11) in both surface and 10-foot samples. It was suggested during the benthic faunal discussion that some seasonal variations may occur in this species. However, no seasonal indications are present in data from the May/June and November piling collections.

The tubiculous mollusca in the family Vermetidae exhibit a definite substrata specificity for concrete, rock or other hard surfaces. Figure 2.4-12 illustrates that vermetids are most abundant at bio-stations in the Southeast Loch complex (at surface and 10-foot depths) indicating a tolerance (and possibly, even a preference) for this stressed environment. The abundance of growth that these filter-feeding organisms exhibit at bio-station BE-02 is truly impressive (see description in Reference 2.4-9, page 16); the concrete pilings at BE-02 (pier F-5) are completely cemented together by vermetid growth at the 2- to 10-foot depth.

(Text continued on page 2.4-40)

Another gastropod mollusc, *Crepidula aculeata*, was present in 10-foot piling samples at all nine bio-stations (Figure 2.4-13). As stated in the benthic faunal survey section (see page 2.2-41), *Crepidula aculeata* exhibited an affinity for vertical substrata and was most numerous in piling collections at bio-stations BC-11 and BW-13. Its distribution throughout the harbor indicates a tolerance for existing environmental conditions (even in Southeast Loch), however, a weak preference for channel areas is suggested.

The nestling bivalve, *Hiatella hawaiiensis*, was collected at all bio-stations except BE-04 (Figure 2.4-14). This same distributional pattern was observed during the benthic survey (Figure 2.2-18, page 2.2-51). *Hiatella hawaiiensis* was most abundant at bio-stations BW-13, BC-10 and BM-07 which further indicates its ubiquitous nature and tolerance for all but the most stressed piling environments in Pearl Harbor. This clam exhibited a weak specificity for surface depths in the piling collections.

The brittle star, *Ophiactis savignyi*, was present in significant numbers only at bio-stations nearest the entrance channel, i.e., BE-13, BC-11 and BC-10. The single individuals collected in 10-foot samples at bio-stations BE-05 and BE-02 (Figure 2.4-15) provide a weak distributional extension to data observed during the benthic faunal survey (page 2.2-41). Again, echinoderms in general were only rarely observed within the inner harbor, with the notable exception of the holothurian, *Ophiodesoma spectabilis*. *Ophiactis savignyi* occurred most abundantly in 10-foot piling collections.

The solitary tunicate, *Styela* sp., was collected from all piling sample bio-stations except BE-04 (Figure 2.4-16). No seasonal variations or depth specificity were observed for this organism.

The bryozoans, *Bugula neritina* and *Bugula californica*, are grouped together for distributional presentation (Figure 2.4-17). The colonial nature of these epifaunal organisms obviates listing numbers of individuals. However, it can be seen that *Bugula* occur throughout Southeast Loch, with a notable absence at bio-stations BE-05 and BC-11. As discussed in the benthic faunal section (page 2.2-56), *Bugula* has been recognized as a major fouling organism in Pearl Harbor.

DISCUSSION

Certain distributional patterns of piling biota have been examined in data from 36 samples collected in Pearl Harbor. The most obvious facet of this analysis is, again, the singularity of biota from bio-station BC-11. However, this pattern is not as strongly developed as that contained in data from the benthic faunal survey.

Substratum and depth specificities have been suggested for certain organisms. Some piling organisms were observed to be ubiquitous at all nine sampling locations. The only seasonal variation of moderate indication was suggested for the amphipod, *Elasmopus rapax*. A more refined, future study specifically designed to measure seasonality of certain organisms would be required to provide adequate quantitative substantiation. For further analyses of these data, see Section 4.6.

REFERENCES

2.4-1. John C. McCain (1974), "Environmental Survey: Waiau Generating Station", Hawaiian Electric Company, Environmental Department, 193 pages.

2.4-2. Edward F. Ricketts and Jack Calvin (1968), Between Pacific Tides, Fourth Edition, edited by Joel W. Hedgpeth, Stanford University Press, 614 pages.

2.4-3. Ruth D. Turner (1966), "A Survey and Illustrated Catalogue of the Teredinidae (Mollusca: Bivalvia)", Museum of Comparative Zoology, Harvard University, 265 pages.

2.4-4. Charles H. Edmondson (1944), "Incidence of Fouling Organisms in Hawaii", Occasional Papers of the B. P. Bishop Museum, Vol. 18, No. 1, 34 pages.

2.4-5. Charles H. Edmondson and William M. Ingram (1939), "Fouling Organisms in Hawaii", Occasional Papers of the B. P. Bishop Museum, Vol. 14, No. 14, 49 pages.

2.4-6. Edward R. Long (1970), "Oceanographic Cruise Summary: Second Year of Marine Biofouling Studies off Oahu, Hawaii", Naval Oceanographic Office, Washington, D. C., 12 pages.

2.4-7. William F. Clapp and Roman Kenk (1963), Marine Borers: An Annotated Bibliography, Sponsored by the Office of Naval Research, Washington, D. C., 1136 pages.

2.4-8. Joel W. Hedgpeth (Ed.) (1957), "Estuaries and Lagoons. Part II, Biological Aspects" (Chapter 23) in "Treatise on Marine Ecology and Paleoecology", Vol. 1, Ecology, Geological Society of America Memoir No. 67, Washington, D. C., pp. 693-729.

2.4-9. Evan C. Evans III, et al. (1972), "A Proximate Biological Survey of Pearl Harbor, Oahu", Naval Undersea Center TP-290, 65 pages.

PHYSICAL/CHEMICAL MEASUREMENTS

For any comprehensive assessment of marine biological status, considerable information concerning physical and chemical conditions in the water column, at the air/sea interface and at the bottom/sea interface must also be known. Much of the required data was collected as part of the complete survey of Pearl Harbor by the Naval Civil Engineering Laboratory's Environmental Protection Data Base survey teams, who were active in the harbor at the same time the biological survey was in progress. Certain factors, considered important by the biological survey team, were not, however, included in the Data Base survey activity. The PHBS, therefore, let small contracts with Sea-Test, Inc. to obtain a better knowledge of circulation and water masses, and with SEACO, Inc. to obtain a quantitative analysis of the amount and kind of ship traffic characteristic of Pearl Harbor. Both the data obtained by these contractors and a summary of Data Base results of importance to marine biology are presented in the following sections.

Since the Data Base has issued more detailed reports, their Pearl Harbor results are not presented in extensive detail. Rather, they are summarized only to the extent necessary to make biological inferences or relationships to physicochemical parameters clear. The Pearl Harbor current survey and the ship movement study are not elsewhere reported, thus these results are presented fully. The current survey is the most extensive yet attempted for Pearl Harbor, although the work of Michael Sonnen and William Norton of Water Resources Engineers, Walnut Creek, California, should be noted. The ship movement study is apparently the first of its kind and is a direct outgrowth of the biological survey team's early analysis of Pearl Harbor results (see Section 4.1).

Section 3.1 summarizes the results of the Data Base's analysis of the physical and chemical properties of the soils and sediments in Pearl Harbor and its drainage basin. Section 3.2 summarizes the results of the Data Base's water quality analyses. In addition to harbor waters, stream waters and various industrial/agricultural source waters were analyzed. Section 3.3 reports Pearl Harbor circulation in detail and presents water-mass characteristics and estimated mean residence times. Section 3.4 describes ship activity in the harbor quantitatively.

SEDIMENT MEASUREMENTS

Evan C. Evans III
Alv Dan Youngberg
Dennis T. O. Kam

GENERAL INFORMATION

Both the sediment survey and subsequent analysis for heavy-metal content were done by the Pearl Harbor Division of the Naval Civil Engineering Laboratory's Environmental Protection Data Base Office under the direction of Alv Dan Youngberg (References 3.1-1 and 3.1-2). Although all sediment measurements made at the ten bio-stations are included in Table 3.1-1, only the heavy-metal burdens found in the sediments were used in the statistical analysis (see Section 4.1). Consequently, this section emphasizes the heavy-metal data. More detailed information on the soils and sediments of the Pearl Harbor drainage basin and estuary are to be found in the Data Base report (Reference 3.1-1). In addition to heavy-metal burdens, reported values include: chemical oxygen demand (COD), oil and grease, Kjeldahl nitrogen, a physical description and a mechanical analysis. A second Data Base report on groundwaters beneath landfills adjacent to Pearl Harbor (Reference 3.1-3) may also be of interest. Certain incidental data obtained by the Pearl Harbor Biological Survey team from other sources are included in this section since they further describe Pearl Harbor sediment properties. These data include: $CaCO_3$ content, mineral composition and estimated cation exchange capacity.

SEDIMENT SAMPLING

Sediment was collected from 95 locations in Pearl Harbor (Figure 3.1-1). Samples were obtained with a Model 860 Shipek Sediment Sampler which collects an 8-inch square surface sample to a depth of approximately 4 inches. Three separate grabs were taken at each station. A representative portion (200 g) from each of these three grabs was mixed thoroughly in an agate grinder for 15 minutes, then placed in an acid-rinsed plastic bottle. Two to five gram aliquots of this mixture were taken for laboratory analysis by extracting a "core" from the center of the bottle using a 15mm glass tube. Laboratory samples were refrigerated without preservatives until they were analyzed.

LABORATORY ANALYSIS

With the exception of mercury, all heavy metals were analyzed by the acid digestion procedure given by EPA (Reference 3.1-4) for bottom sediments. The general procedure for metals is briefly outlined here; procedure for mercury is given below. A 2-5 gram aliquot of mixed sediment was oxidized using 10 ml of concentrated HNO_3 to which 0.5 ml of 30% H_2O_2 was added. The entire sample was then evaporated to dryness and ashed at 400° to 425°C for one hour. After cooling, 25 ml of aqua regia*, 20 ml of 10% (by wt.) NH_4Cl solution and 1 ml of $Ca(NO_3)_2$ solution** were added to the ash and the mixture heated gently for 15 minutes. This mixture was then allowed to cool for 5 minutes or longer before centrifuging at 6000 rpm for 15 minutes. The clear supernate was then decanted into a 250 ml volumetric and made up to volume with redistilled water. Aliquots of this final solution were analyzed by atomic absorption on a Model 120 Varian Techtron Atomic Absorption Spectrophotometer which was standardized daily.

---

* Aquaregia used was 200 ml of concentrated HNO_3 and 50 ml of HCl made up to a volume of 1 liter with redistilled water.
** 11.8 grams of $Ca(NO_3)_2 4H_2O$ made up to a volume of 100 ml with redistilled water.

(Text continued on page 3.1-5)

Table 3.1-1. SUMMARY COMPARISON OF SEDIMENT DATA WITH BIOLOGICAL PARAMETERS.
(values in mg/kg dry wt. unless otherwise noted; * = multiply by 10^3)

STA			H-E-A-V-Y		M-E-T-A-L-S							P-O-L-L-U-T-A-N-T-S				PHYS. DISCR.			M-E-C-H	A-N-A-L		BOT. INFAUNA			µMOL.	
	Ag	Cd	Cr	Cu	Fe*	Hg	Mn	Ni	Pb	Zn	TOT	COD*	Oil	Kj-N	VoSo (%)	CLR	OD	CP	gr (%)	sd (%)	c&s (%)	sp (#)	ind (#)	$\overline{ind}$ (#)	sp (#)	ind (#)
BE-02	-	1.4	24	120	15.	-	128	27	65	110	347	-	-	-	12.99	GBK	Oi	SM	36.6	45.4	18.0	30	185	21	18	162
BE-03	-	4.	100	197	37.	1.2	315	80	100	153	634	-	-	10	19.13	-	-	-	0	24.6	75.4	43	308	34	6	59
BE-04	-	ND	360	227	93.	2.6	513	200	60	137	984	-	-	10	13.53	-	-	-	0	23.6	76.4	8	24	4	7	60
BE-05	2.5	0.5	70	30	24.1	0.074	420	71	22	146	342	-	12650	-	7.73	GBR	Sa	SM	-	-	-	51	5256	584	17	237
BM-07	-	ND	150	83	17.	0.36	630	130	20	200	583	105.	6860	10	12.97	GBK	Sf	SM	1.6	8.6	89.8	21	155	26	5	84
BC-09	9.0	ND	110	99	39.	0.67	1100	110	39	280	647	-	-	110	21.71	BR	Sa	SM	0.2	5.0	94.8	70	3945	438	14	168
BC-10	5.8	1.2	96	560	43.	3.7	420	190	310	1300	2463	78.2	-	1860	21.07	GBR	NO	SS	67.6	20.3	12.1	32	85	14	7	90
BC-11	3.5	0.8	9.2	11	4.3	0.081	150	10	15	50	100	-	3920	-	7.46	GGR	Sf	SM	-	-	-	99	4968	331	12	278
BW-13	3.8	1.0	62	240	22.	2.1	770	52	110	350	819	91.	-	2480	21.25	GBK	Sf	SM	46.4	33.7	19.9	61	1923	214	9	72
BE-17	-	1.8	66	570	28.	-	165	50	530	440	1658	107.	-	-	11.74	GBK	Sf	SM	3.9	32.8	64.3	25	80	9	5	30
correlation coefficients between sediment and biological data																										
INFsp	-.06	-.03	-.60	-.45	-.54	-.50	+.14	-.57	-.34	-.20	-.44	-.43	-.45	+.32	-.05	-	-	-	+.15	-.20	-.03	+1	+.82	+.69	+.41	+.71
INFid	-.25	-.33	-.37	-.60	-.37	-.66	+.20	-.41	-.45	-.32	-.53	.20	+.23	+.06	-.33	-	-	-	-.28	-.43	+.25	+.82	+1	+.96	+.61	+.85
INF$\overline{id}$	-.14	-.36	-.31	-.56	-.29	-.62	+.35	-.32	-.44	-.28	-.48	-.20	+.61	+.06	-.22	-	-	-	-.28	-.44	+.25	+.69	+.96	+1	+.64	+.76
µMLsp	-.12	-.25	-.40	-.57	-.32	-.51	-.01	-.44	-.48	-.33	-.54	-.66	+.58	+.07	-.27	-	-	-	+.09	+.30	-.29	+.41	+.61	+.64	+1	+.77
µMLid	-.31	-.32	-.45	-.68	-.47	-.65	-.11	-.44	-.55	-.33	-.59	-.62	-.02	-.14	-.51	-	-	-	-.02	-.12	-.08	+.71	+.85	+.76	+.77	+1

Key: heavy metals, COD, Oil, and Kj-N given in mg/kg dry wt, (* indicates value should be multiplied by 10^3); VoSo and mechanical analysis given in % of total sample. Ag = silver, Cd = cadmium, CLR = color of sediment, COD = chemical oxygen demand, CP = composition of sediment, Cr = chromium, Cu = copper, c&s = clay and silt, BOT. = bottom, BR = brown, Fe = iron, GBK = grayish-black, GBR = grayish-brown, GGR = grayish-green, gr = gravel, Hg = mercury, ind = total number of individuals, $\overline{ind}$ = av. number of individuals per sample, INFid = bottom infaunal ind., INF$\overline{id}$ = bottom infaunal $\overline{ind}$, INFsp = number of bottom infaunal species, Kj-N = Kjeldahl nitrogen, MECH ANAL = mechanical analysis, Mn = manganese, ND = not detected, Ni = nickel, NO = no odor, OD = odor, Oi = oily smell, Pb = lead, PHYS. DISCR. = physical description of sediment, Sa = salty smell, sd = sand, Sf = sulfur smell, SM = sand and mud, sp = number of species, SS = shells, VoSo = volatile solids, TOT = total metals (Ag+Cd+Cr+Cu+Pb+Ni+Zn), µMLsp = number of micromolluscan sp., µMLid = total number of micromolluscan individuals, µMOL = micromollusca.

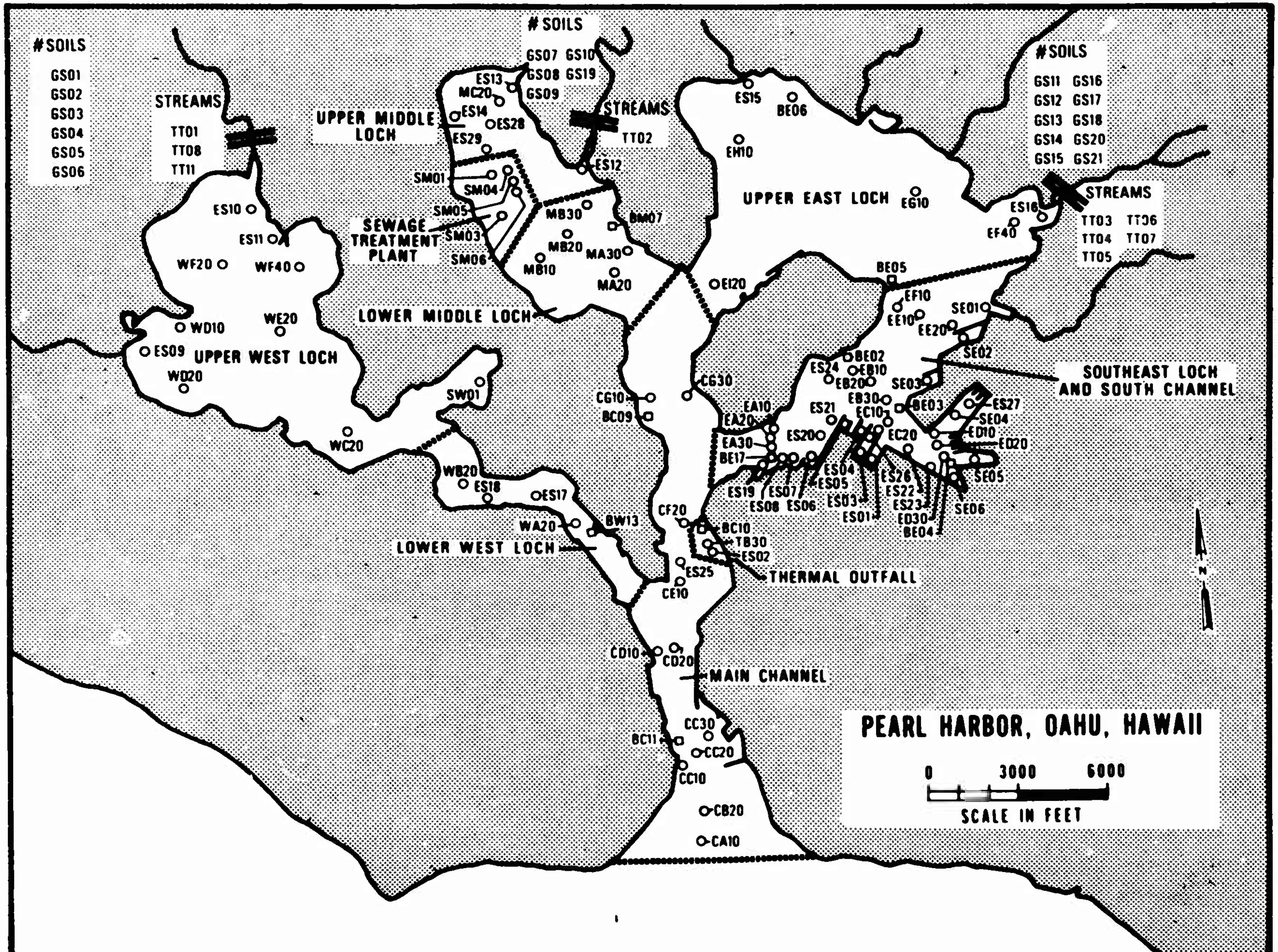


Figure 3.1-1. LOCATION OF SOIL AND SEDIMENT SAMPLES IN PEARL HARBOR DRAINAGE BASIN AND ESTUARY (STATIONS INCLUDED IN THE HARBOR SUBDIVISIONS USED IN TABLE 3.1-3 ARE BOUNDED BY DOTTED LINES).

The mercury procedure, given in Reference 3.1-5 is briefly as follows. Five gram samples for mercury analysis were placed in a 250 ml round bottom flask with 10 ml of concentrated HNO_3 and refluxed gently for 2 hours using a water-cooled reflux condenser approximately 2 feet long. After refluxing, the sample and reflux column rinse was filtered through Whatman No. 2 paper into a 100 ml volumetric and made up to volume. Aliquots of this final solution were analyzed by atomic absorption using cold vapor technique and a mercury hollow cathode lamp.

HEAVY METAL RESULTS

The results of the Data Base measurements are presented in highly condensed form in Tables 3.1-1 through 3.1-3. Table 3.1-1 presents all sediment measurements made at the bio-stations together with a summary of pertinent biological data taken from Tables 2.2-5 and 2.3-5. In the lower section of Table 3.1-1, correlation coefficients between these biological data and each of the sediment measurements are given. As reported previously (Reference 3.1-6), the benthos community shows poor to moderate negative correlation with heavy-metal burdens in the sediment. Of the 10 metals reported, Cu and Hg show the strongest negative correlation. For the remaining parameters reported by the Data Base, there seems to be little to no meaningful correlation, although a case might be made for moderate negative correlation between micromollusca and chemical oxygen demand.

Table 3.1-2 presents a ranked list of the first 10 and the first 20 highest metallic burdens for each of the metals analyzed (where several stations have the same value, alphanumeric order has been used). Incorporated into the table is the mean plus one standard deviation value for each metal (Table 4.1-1). Stations showing metallic concentrations above this value are plotted in Figures 3.1-2 through 3.1-11. These figures are discussed in the following paragraph. Referring to Table 3.1-2, it may be seen that only bio-stations BE-03, BE-04, BC-10 and BE-17 appear above the mean-plus-one standard-deviation value, which may be interpreted as indicating significantly elevated metallic burden. These are the bio-stations considered in Section 4.7 to be typical of the normal polluted condition characteristic of Pearl Harbor in general. Of the bio-stations considered representative of less polluted conditions, BE-02 shows up once in the top 20 under Cd, and BW-13 shows up once in the top 10 under Hg and five times in the next 10 under Cd, Cu, Mn, Pb and Zn. Considering metal toxicity and BW-13's position in the rankings, probably only its appearances under Cu and Hg are important. As stated in Section 4.7, BW-13 may be favored by strong tidal action. Of the 100 stations appearing in the top 10, 61% are located in Southeast Loch or along the shoreline of the Pearl Harbor Naval Shipyard, 19% in Middle Loch, 17% in West Loch, with the remaining 3% being located either in the outer Main Channel or in upper East Loch. Repeat stations in the top 10 are listed at the bottom of Table 3.1-2.

Table 3.1-3 presents the average heavy-metal content for various locations in Pearl Harbor. In the preparation of this table, all Data Base stations were grouped as indicated in Figure 3.1-1. Basically the lochs and their individual drainage basins were treated separately; furthermore, the lochs themselves were subdivided where reasonable into upper, central and

(Text continued on page 3.1-19)

Table 3.1-2. HIGHEST 20 STATIONS, PEARL HARBOR SEDIMENT ANALYSIS.
(values in mg/kg dry wt.; * = multiply value by 10^3)

Ag STA	Ag METL	Cd STA	Cd METL	Cr STA	Cr METL	Cu STA	Cu METL	Fe* STA	Fe* METL	Hg STA	Hg METL	Mn STA	Mn METL	Ni STA	Ni METL	Pb STA	Pb METL	Zn STA	Zn METL	TOTAL STA	TOTAL METL
ES03	21.	ES08	11.	→BE04	360	ES06	1200	→BE04	93.	ES06	9.5	WC20	4800	SM01	930	SE05	1700	ES08	1900	ES08	3777
ES08	19.	SE04	10.	SM01	220	ES08	840	SE05	84.	SE05	5.3	WB20	3000	SM06	830	ES06	800	→BC10	1300	ES06	3497
$\bar{X}+\sigma$ =	14.3	ES22	8.8	SM06	210	TB30	800	WE20	83.	ES08	4.9	ES17	1600	MB10	610	ES08	740	ES06	1300	SE05	3211
ES06	10.	SE02	5.	ED30	200	SE04	698	ES13	78.	→BC10	3.7	ES18	1600	SM03	470	→BE17	530	ES22	1100	→BC10	2463
ES28	10.	→BE03	4.	ES13	200	SE05	695	ES11	72.	SE04	2.9	SW01	1600	ES11	410	TB30	470	ES21	990	TB30	1896
→BC09	9.	SE03	4.	MB20	200	→BE17	570	SE04	72.	ES18	2.8	WD20	1200	ES10	380	ES20	380	ES20	820	ES22	1744
ES19	8.5	ES06	2.8	MC20	200	→BC10	560	WF40	72.	→BE04	2.6	$\bar{X}+\sigma$ =	1150	ES13	380	$\bar{X}+\sigma$ =	327	ES23	815	ES21	1733
ES21	7.0	$\bar{X}+\sigma$ =	2.71	SE02	200	EA30	390	ES14	69.	ES20	2.4	→BC09	1100	ES15	290	→BC10	310	ES17	566	SE04	1715
CC30	6.5	→BE17	1.8	SE04	200	SE06	372	ES10	67.	$\bar{X}+\sigma$ =	2.39	MB10	1000	ES12	280	ES21	310	$\bar{X}+\sigma$ =	543	ES20	1664
CD10	6.2	ES23	1.7	SE05	200	$\bar{X}+\sigma$ =	348	SE02	65.	ES24	2.2	SM01	970	$\bar{X}+\sigma$ =	273	EA30	300	TB30	510	→BE17	1658
ES18	6.0	ES03	1.5	$\bar{X}+\sigma$ =	160	ES02	290			→BW13	2.1	WE20	890	ES14	270	ED30	300	→BE17	440		
→BC10	5.8	ES04	1.5	ES08	180	ES20	280	ES09	65.	ES29	2.1	ES16	870	WF40	260	ES19	300	ES04	440	SM01	1649
WF40	5.7	ES19	1.5	ES11	180	ES21	260	WC20	62.	ED30	1.9	MA30	850	WE20	210	ES22	300	ES28	428	ES23	1418
ES20	5.5	ES21	1.5	ES10	170	ES28	260	WD10	61.	ES04	1.9	WF40	840	→BE04	200	SE06	300	SE05	416	$\bar{X}+\sigma$ =	1402
ES23	5.0	→BE02	1.4	ES28	170	→BW13	240	ES15	58.	ES05	1.9	WA20	800	BE06	200	ES26	240	SE04	407	MB10	1093
TB30	4.9	TB30	1.4	WE20	170	SE02	236	WD20	58.	SE06	1.9	SM06	790	MB20	200	SE04	200	ES02	390	SE06	1086
ES15	4.7	WF40	1.4	MB30	160	→BE04	227	SM05	56.	ES27	1.8	→BW13	770	SE04	200	ES02	190	ES26	383	ED30	1005
ES07	4.6	ES02	1.3	SM05	160	ES23	220	SM04	55.	ED20	1.7	CD10	770	SE05	200	ES23	190	ES27	368	ES02	996
ES22	4.5	→BC10	1.2	→BM07	150	SE03	219	SW01	55.	ES28	1.7	SM03	680	→BC10	190	ES04	120	ES19	360	ES04	959
ES02	4.3	→BW13	1.0	ES14	150	ES07	210	$\bar{X}+\sigma$ =	54.5	CF20	1.6	ES09	660	ES28	150	ES17	120	→BW13	350	EA30	950
ES05	3.9	CB20	1.0	ES29	150	ES04	200	ES29	53.4	SE01	1.6	ES24	650	ES09	140	→BW13	110	ES01	310	→BE04	924
								MB30	52.											ES19	909
→BW13	3.8	CC30	1.0	MB10	150	→BE03	197	WF20	52.	ES22	1.5	MA20	630	WF20	140	ES18	110	ED30	287	ES17	891
		CD10	1.0	SM04	150			ES28	47.1					→BM07	130	SE01	110				
		ES01	1.0	SM03	140											→BE03	100				
		ES17	1.0																		
		ES20	1.0																		
		ES26	1.0																		
		ES28	1.0																		
		CC20	0.9																		

Repeat stations in the top 10: BC09 Ag, Mn; BC10 Cu, Hg, Pb, Zn; BE04 Cr, Fe, Hg; BE17 Cd, Cu, Pb, Zn; ED30 Cr, Pb ES03 Ag, Cd; ES06 Ag, Cd, Cu, Hg, Pb, Zn; ES08 Ag, Cd, Cu, Hg, Pb, Zn; ES10 Fe, Ni; ES11 Fe, Ni; ES13 Cr, Fe, Ni; ES14 Fe, Ni; ES17 Mn, Zn; ES18 Ag, Hg, Mn; ES19 Ag, Cd; ES20 Hg, Pb, Zn; ES21 Ag, Cd, Pb, Zn; ES22 Cd, Zn; ES23 Cd, Zn; MB10 Mn, Ni; SE02 Cr, Fe; SE04 Cd, Cr, Cu, Fe, Hg; SE05 Cr, Cu, Fe, Hg, Pb; SE06 Cu, Pb; SM01 Cr, Mn, Ni; SM06 Cr, Ni; TB30 Cu, Pb, Zn; WE20 Fe, Mn.

Table 3.1-3. AVERAGE HEAVY-METAL CONTENT BY LOCATION IN THE PEARL HARBOR DRAINAGE BASIN AND ESTUARY.
(values in mg/kg dry wt.; * = multiply value by 10^3)

Metal & Loch		Soils	Streams	Upper Loch	SE Loch & S. Chan.	Thermal or STP	Lower Loch or Channel
n†	WL	6	3	10			5
	ML	5	1	6		5	6
	EL	10	5	8	39	3	16
Ag	WL	0.22±0.35	2.6±3.4	2.0±1.5			3.6 ±1.6
	ML	1.1 ±1.2	0.5	2.6±4.2[5]		1.2±1.3	0.97±1.0[3]
	EL	2.0 ±2.9	1.5±1.8	2.6±2.1[3]	6.6±6.0[15]	5.0±0.75	3.1 ±2.7[13]
Cd	WL	0.83±0.89	6.7 ±11.††	0.47±0.42			0.70±0.31
	ML	0.97±2.0	0	0.22±0.40		0 ± 0	0.15±0.25
	EL	0 ± 0	0.10± 0.15	0.06±0.18	1.7±2.7	1.3±0.10	0.45±0.41
Cr	WL	62.±43.	96.±47.	120.±39.			68.±15.
	ML	87.±48.	110.	170.±29.		150.±84.	140.±36.
	EL	55.±12.	100.±29.	100.±16.	100.±62.	67.±25.	34.±26.
Cu	WL	60.±35.	39.±27.	72.±25.			120.±71.
	ML	86.±49.	48.	120.±75.		120.± 38.	87.±15.
	EL	29.± 8.7	49.± 7.7	60.±27.	240.±240.	550.±260.	34.±27.
Fe*	WL	41.±16.	38.±7.6	65.± 9.2			27.± 6.3
	ML	49.±18.	42.	50.±23.		35.±19.	24.±17.
	EL	39.±11.	33.±5.4	28.±19.	36.±17.	28.±14.	13.±10.
Hg	WL	1.4 ±1.9	0.32±0.07	0.31±0.09			1.6 ±0.89
	ML	0.82±0.55	0.79	0.92±0.91[5]		0.41±0.19	0.36±0.19[4]
	EL	0.33±0.46	0.70±0.53	0.15±0.07[3]	2.0±1.8[30]	1.9 ±1.5	0.52±0.40
Mn	WL	1900.±1400.	600.±130.	1200.±1300.			1600.±900.
	ML	1300.±1500.	490.	5500.± 120.		720.±160.	700.±180.
	EL	370.± 360.	740.±820.	440.± 230.	390.±150.	390.± 25.	360.±280.
Ni	WL	67.± 34.	120.±58.	200.±120.			62.± 12.
	ML	240.±350.	140.	220.±110.		470.±410.	190.±210.
	EL	97.± 55.	120.± 8.4	130.± 74.	84.±43.	100.± 74.	34.± 26.
Pb	WL	7.0± 7.2	26.±40.	20.± 6.6			90.±35.
	ML	14. ±12.	22.	42.±39.		26.± 13.	20.± 7.7
	EL	13. ± 7.3	54.±43.	33.±24.	210.±300.	320.±140.	29.±21.
Zn	WL	77.± 40.	79.±62.	160.± 43.			330.±150.
	ML	130.±150.	82.	210.±110.		190.± 45.	160.± 34.
	EL	44.± 20.	100.±75.	120.± 39.	350.±400.	730.±490.	92.± 68.

† = number of stations; when there are differences, the correct number of stations is marked as a superscript immediately following the standard deviation.
†† = all stream measurements were ND (not detected) except that at the mouth of Waikele Stream which had a Cd value of 20 mg/kg dry wt.

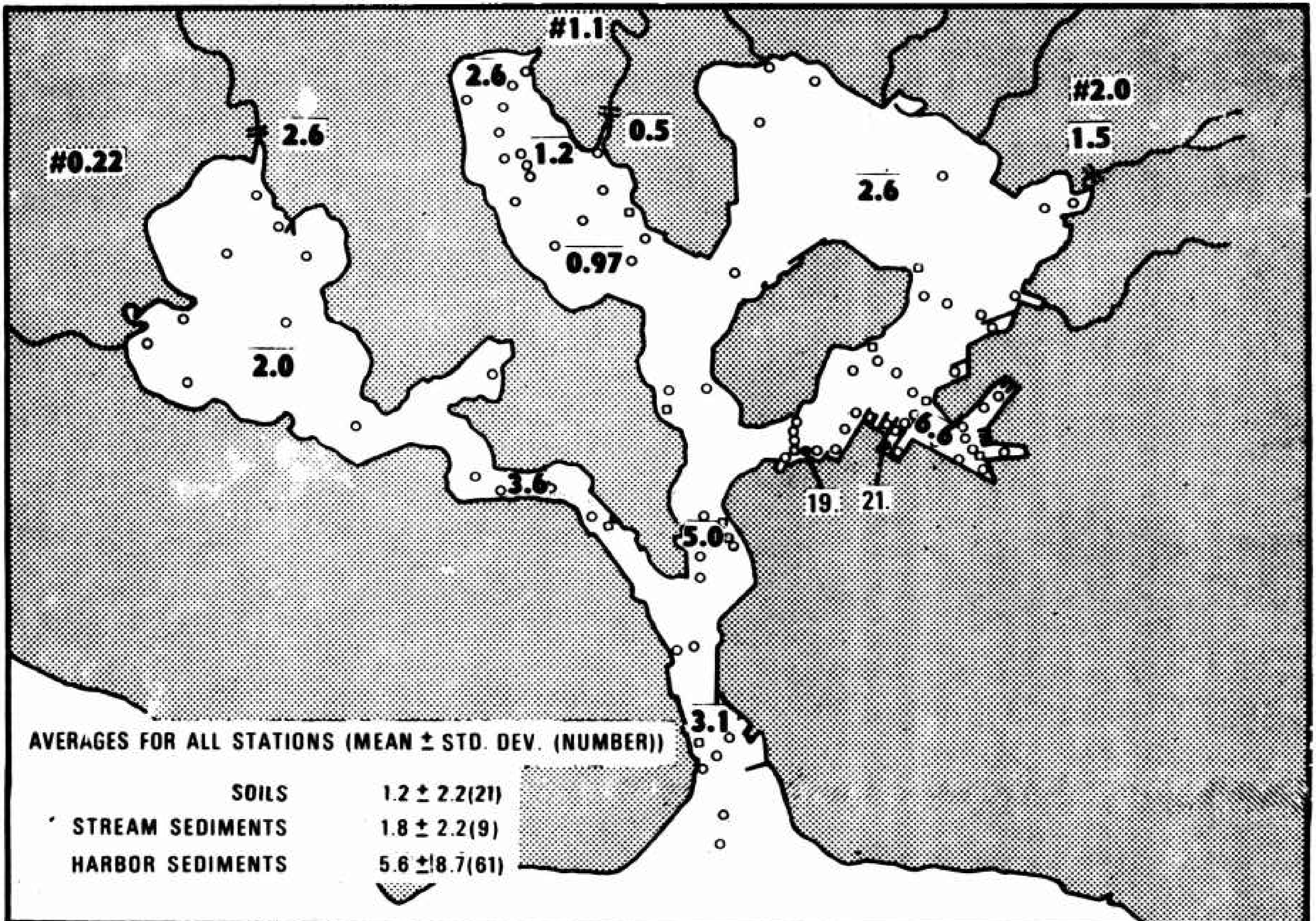


Figure 3.1-2. DISTRIBUTION OF SILVER (Ag) CONTENT OF SOILS AND SEDIMENTS, SHOWING STATIONS WITH SIGNIFICANTLY HIGH CONCENTRATIONS (VALUES IN MG/KG DRY WT.).

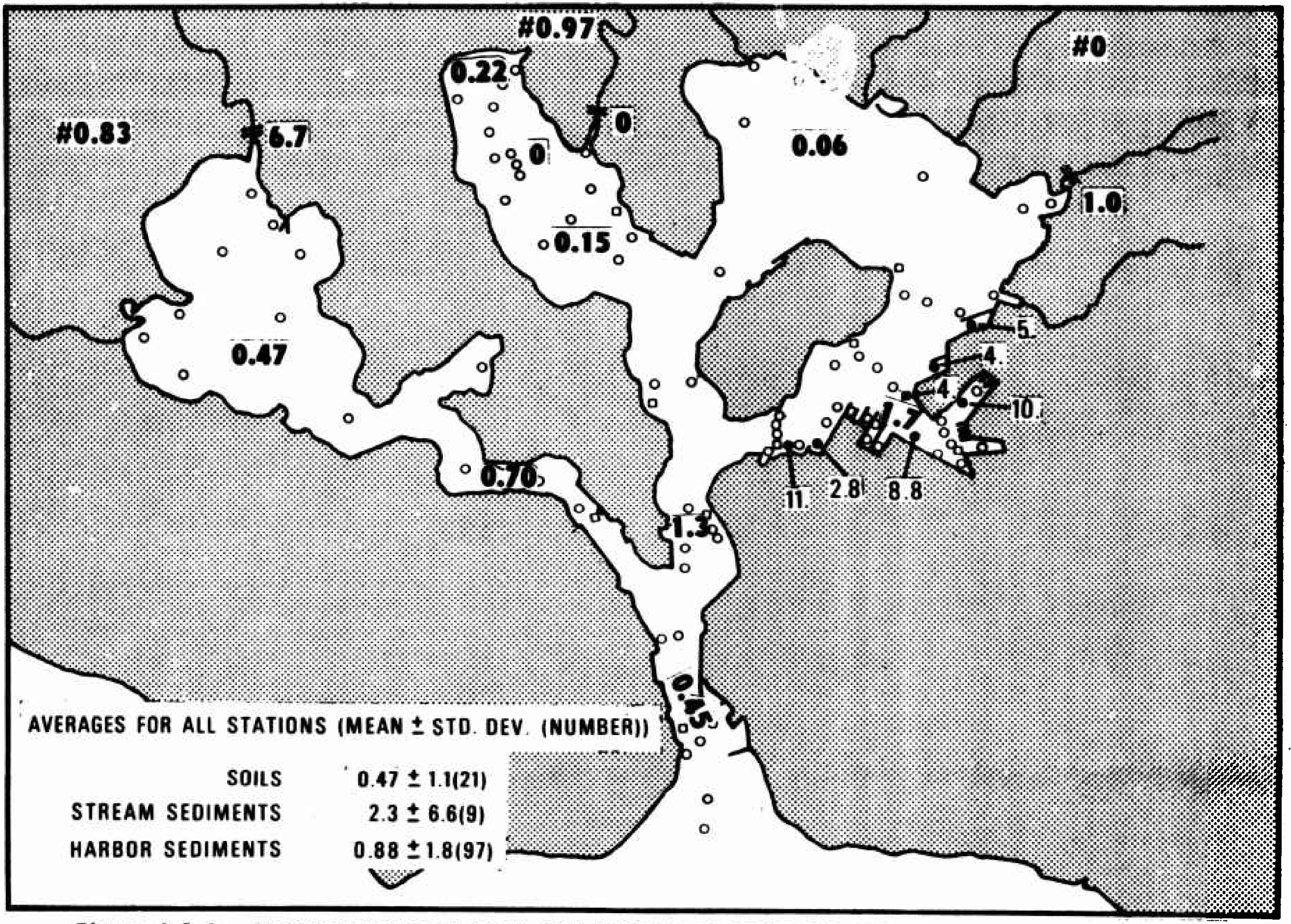


Figure 3.1-3. DISTRIBUTION OF CADMIUM (Cd) CONTENT OF SOILS AND SEDIMENTS, SHOWING STATIONS WITH SIGNIFICANTLY HIGH CONCENTRATIONS (VALUES IN MG/KG DRY WT.).

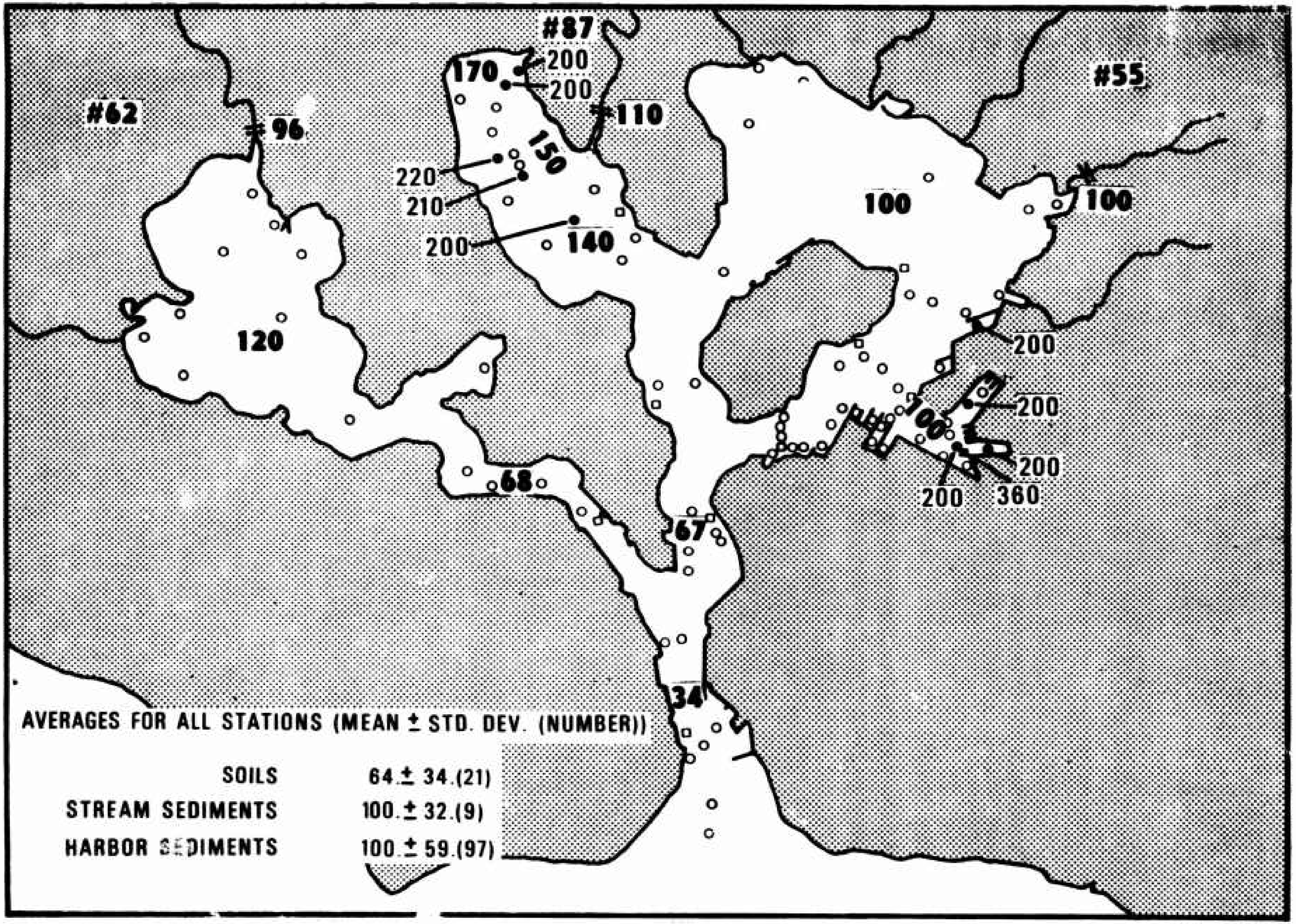


Figure 3.1-4. DISTRIBUTION OF CHROMIUM (Cr) CONTENT OF SOILS AND SEDIMENTS, SHOWING STATIONS WITH SIGNIFICANTLY HIGH CONCENTRATIONS (VALUES IN MG/KG DRY WT.).

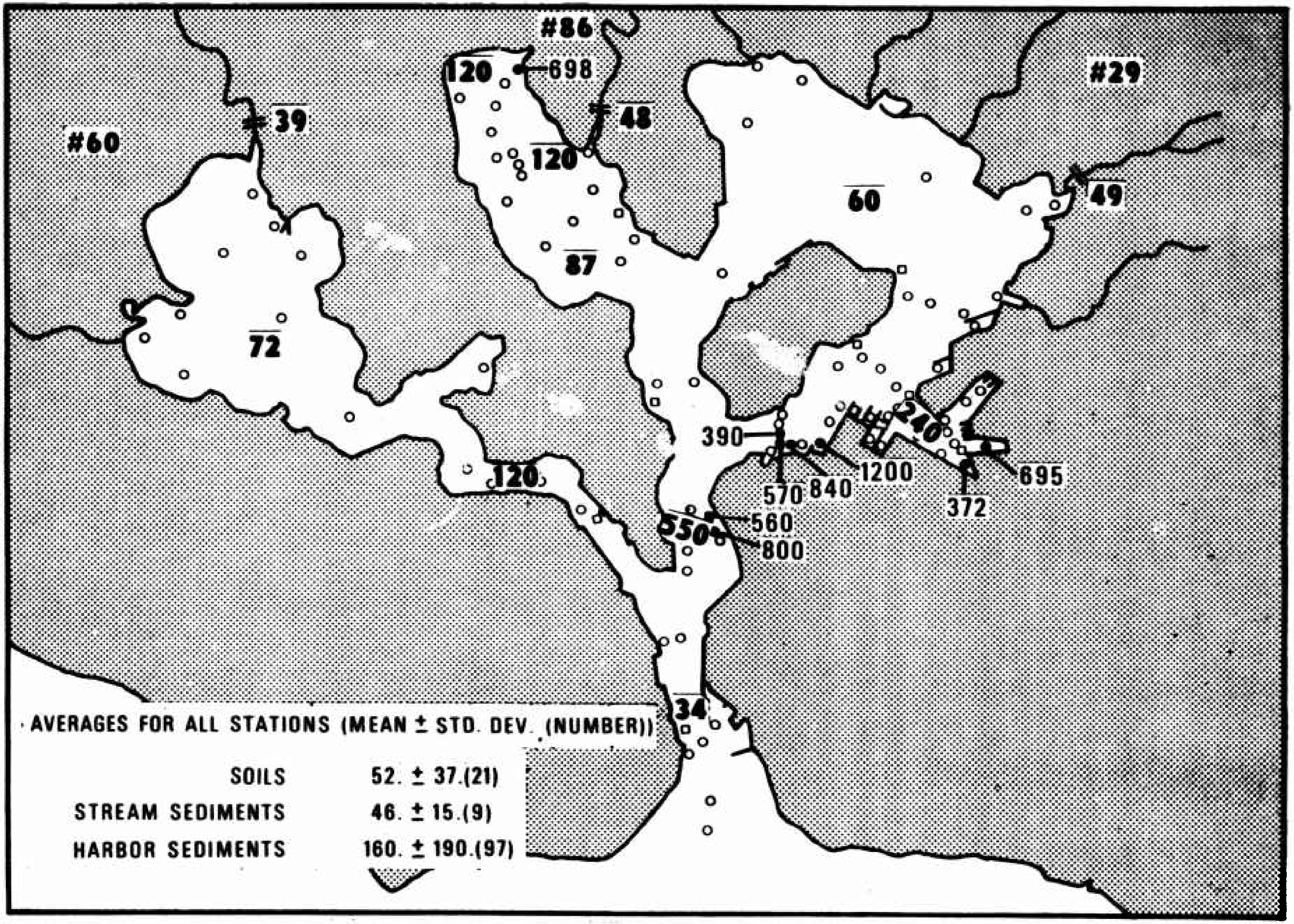


Figure 3.1-5. DISTRIBUTION OF COPPER (Cu) CONTENT OF SOILS AND SEDIMENTS, SHOWING STATIONS WITH SIGNIFICANTLY HIGH CONCENTRATIONS (VALUES IN MG/KG DRY WT.).

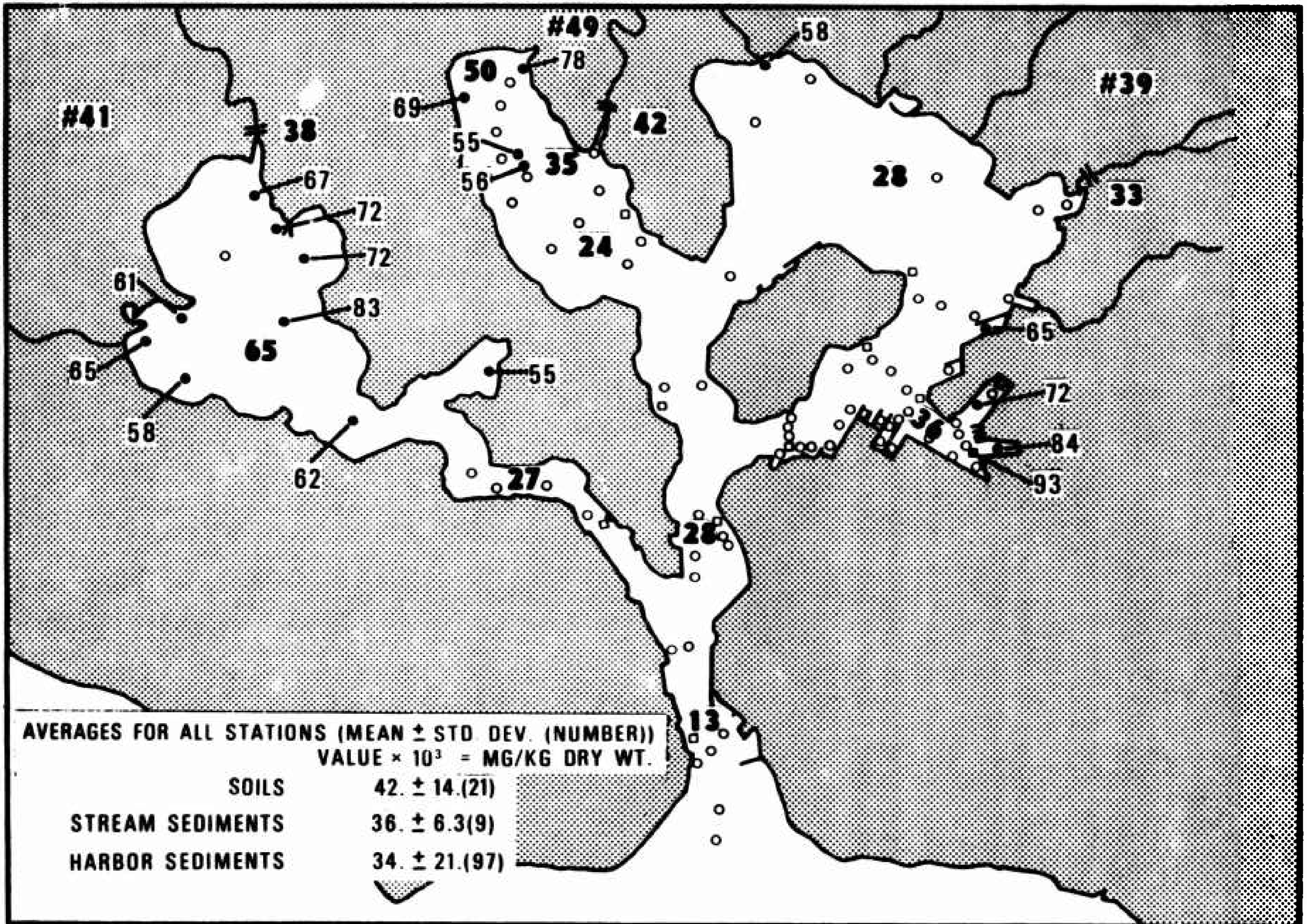


Figure 3.1-6. DISTRIBUTION OF IRON (Fe) CONTENT OF SOILS AND SEDIMENTS, SHOWING STATIONS WITH SIGNIFICANTLY HIGH CONCENTRATIONS (VALUES IN MG/KG DRY WT.). .

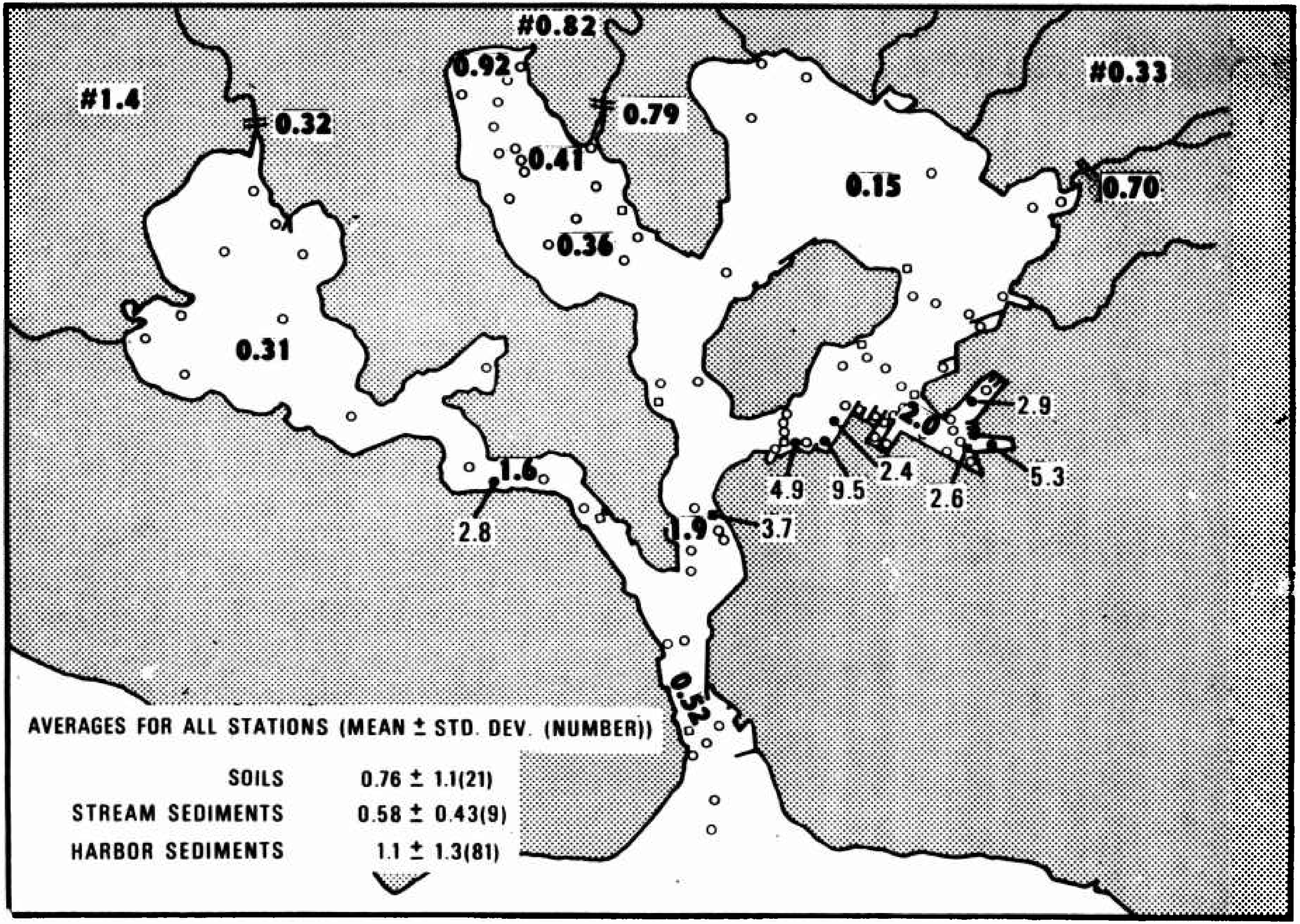


Figure 3.1-7. DISTRIBUTION OF MERCURY (Hg) CONTENT OF SOILS AND SEDIMENTS, SHOWING STATIONS WITH SIGNIFICANTLY HIGH CONCENTRATIONS (VALUES IN MG/KG DRY WT.).

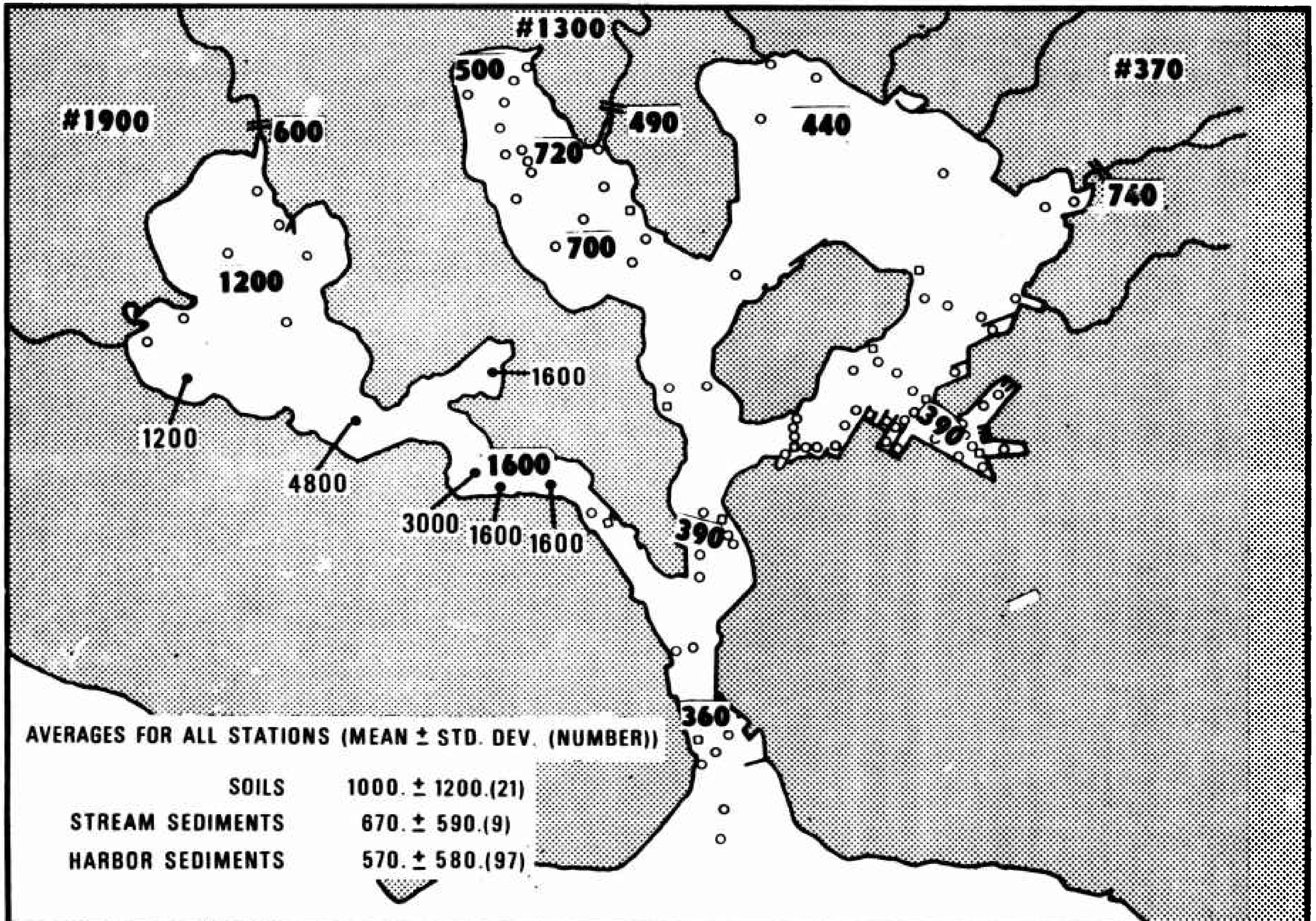


Figure 3.1-8. DISTRIBUTION OF MANGANESE (Mn) CONTENT OF SOILS AND SEDIMENTS, SHOWING STATIONS WITH SIGNIFICANTLY HIGH CONCENTRATIONS (VALUES IN MG/KG DRY WT.).

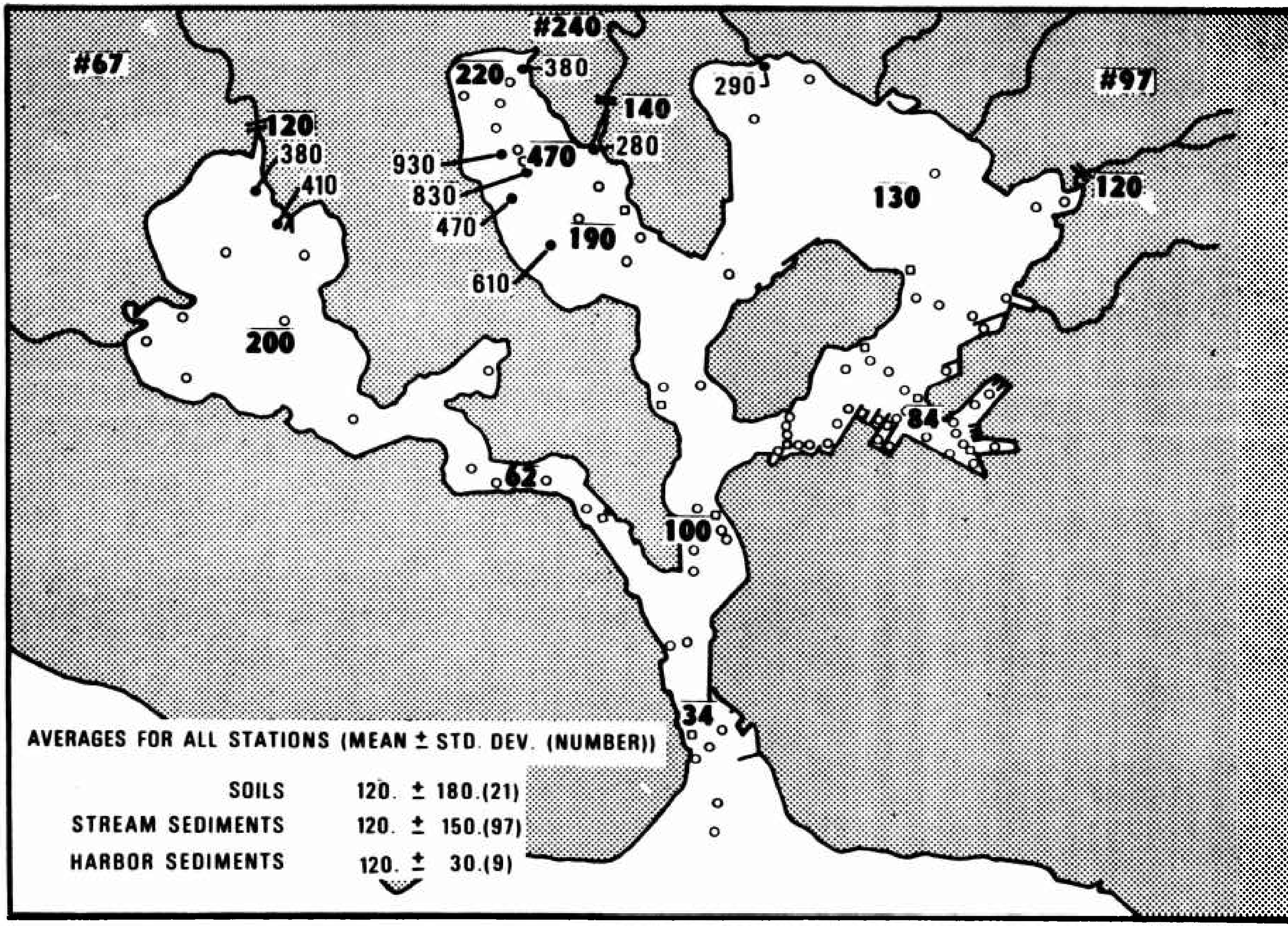


Figure 3.1-9. DISTRIBUTION OF NICKEL (Ni) CONTENT OF SOILS AND SEDIMENTS, SHOWING STATIONS WITH SIGNIFICANTLY HIGH CONCENTRATIONS (VALUES IN MG/KG DRY WT.).

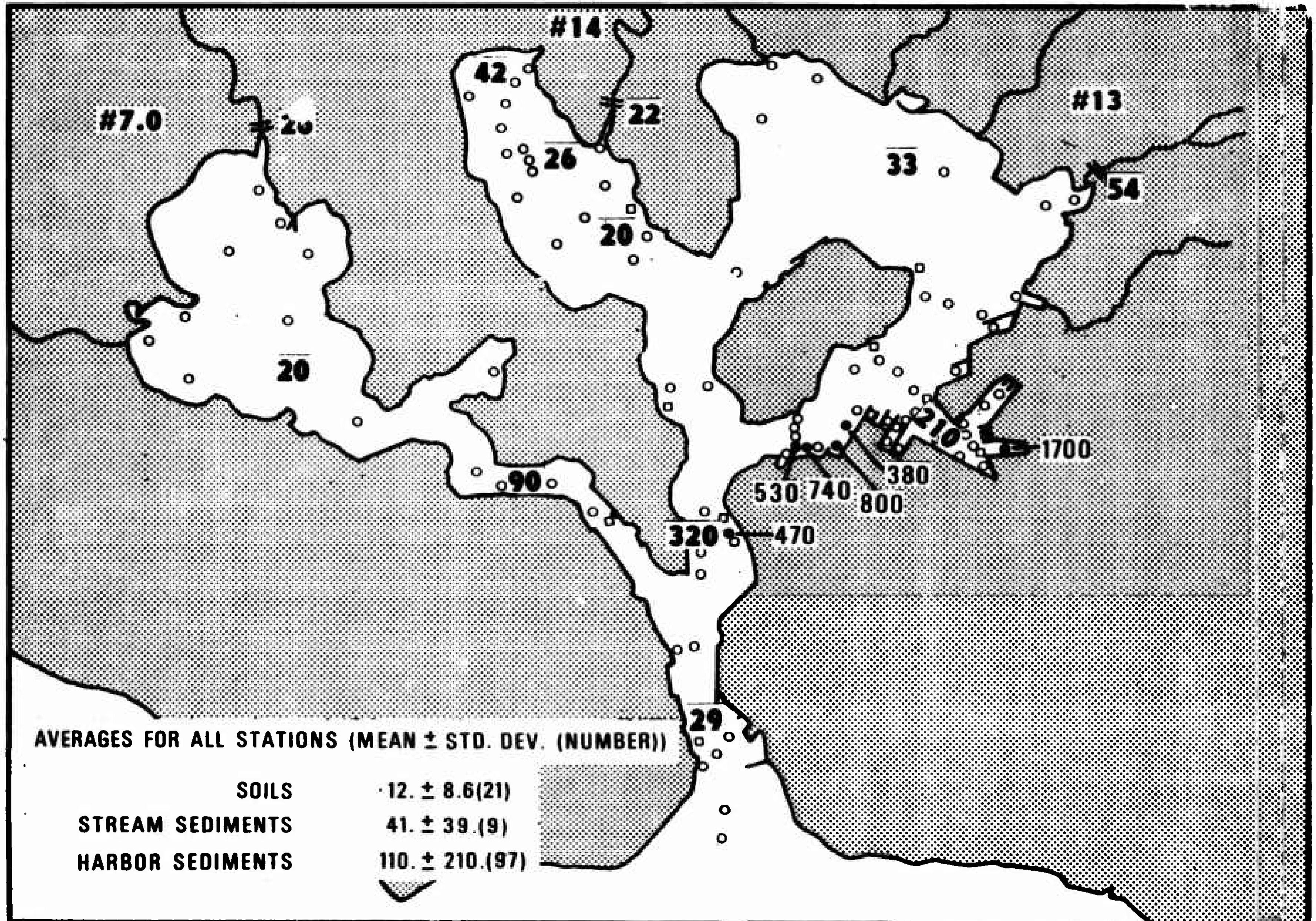


Figure 3.1-10. DISTRIBUTION OF LEAD (Pb) CONTENT OF SOILS AND SEDIMENTS, SHOWING STATIONS WITH SIGNIFICANTLY HIGH CONCENTRATIONS (VALUES IN MG/KG DRY WT.).

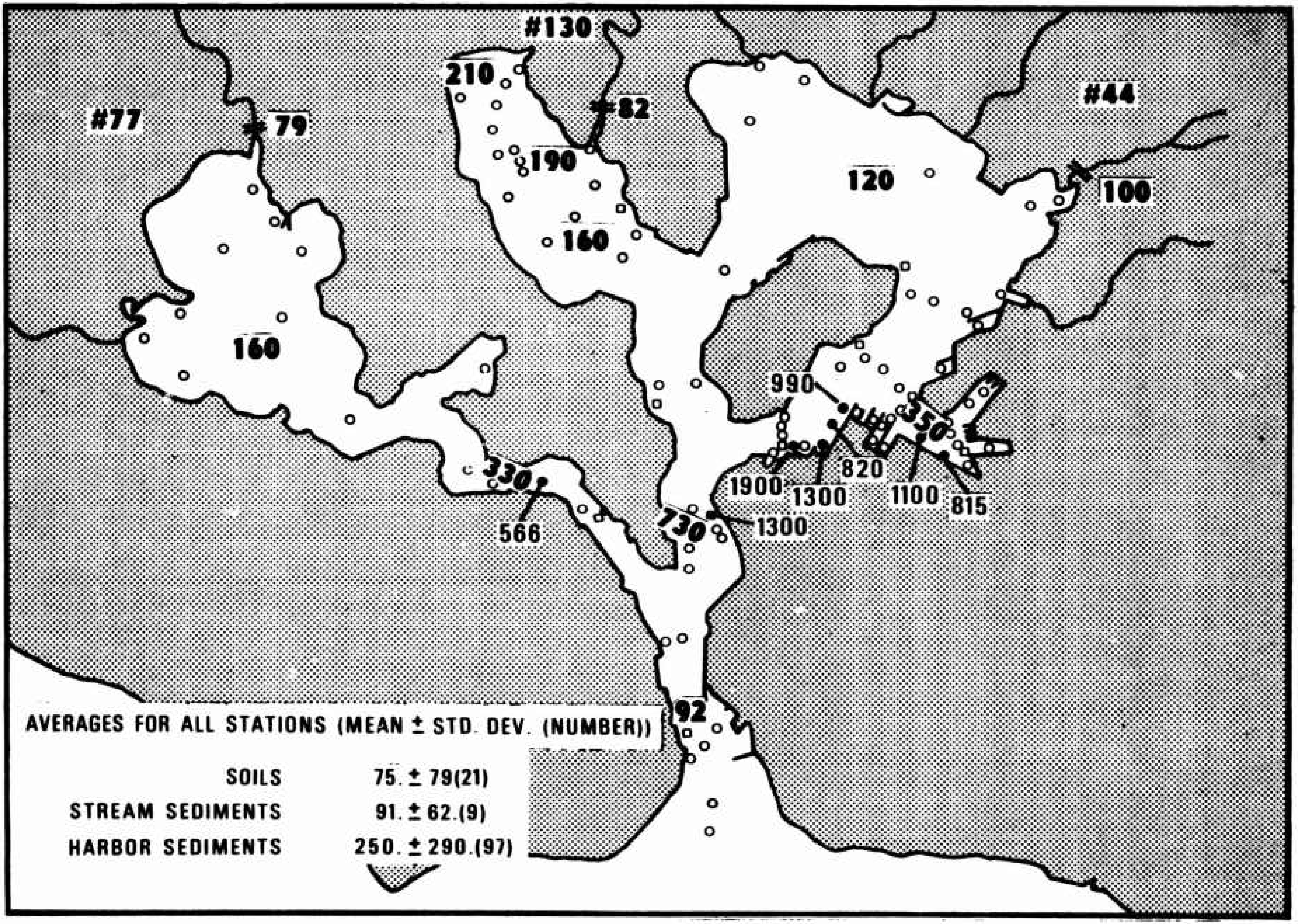


Figure 3.1-11. DISTRIBUTION OF ZINC (Zn) CONTENT OF SOILS AND SEDIMENTS, SHOWING STATIONS WITH SIGNIFICANTLY HIGH CONCENTRATIONS (VALUES IN MG/KG DRY WT.).

lower or channel regions. Where certain special features existed, such as the Pearl City STP diffusers and the Navy power plant thermal outfall, the region in the immediate vicinity was considered as a separate entity. The mean and standard deviation for each metal in each region is summarized in Table 3.1-3. The mean values for each region are shown in Figures 3.1-2 through 3.1-11 as boldface entries. An inspection of the standard deviations in Table 3.1-3 shows the data to be very "noisy" for all metals except iron. This situation makes further interpretation of the data uncertain. Nevertheless, certain trends are apparent in the data. Iron shows a fairly uniform gradient, starting high in the soils and diminishing in the sediments with distance from stream outfalls or sources of irrigation tailwaters; this trend is clearly shown in the factor analysis (see Section 4.1). The other metals loading heavily on Factor II, Cr, Mn and Ni, also show this tendency, but the picture is complicated by areas of elevated concentration probably associated with causes other than fresh-water runoff (central and upper Middle Loch for Cr, central West Loch for Mn, and central Middle Loch for Ni). The soils of West and Middle Loch drainage basins appear to contain more Cd, Cu, Hg and Zn than those of the East Loch basin. This situation may be the result of agricultural practices. Silver is low in West Loch soils and high in East Loch soils, while Ni seems high in Middle Loch soils. No explanation is offered for these possible differences. The other metals, Cr, Fe, Mn and Pb, seem fairly uniformly distributed among the soils of the three drainage basins.

With the exception of Hg in West Loch and the erratic behavior of Cd, all stream sediments exhibit metallic concentrations which are the same or higher than those characteristic of the drainage basin soils. This phenomenon is possibly due to fallout followed by surface scavenging by runoff waters.

Metallic content of sediments in the upper reaches of all lochs is roughly equivalent to that reported for the sediments of the entering streams. Generally elevated sedimentary content for the metals Ag, Cd, Cu, Hg, Pb and Zn are evident in Southeast Loch and South Channel, also to a lesser extent, near the Whiskey Docks in West Loch. The elevated Mn concentrations in West Loch sediments could be, but probably are not, associated with Navy activities at the Whiskey Docks. High Cu and Zn concentrations seem to be associated with the Navy thermal outfall into the Main Channel and the high Ni concentrations in central Middle Loch may be associated with the Pearl City STP diffusers. It is noteworthy that all average metallic concentrations in the sediment exhibit a pronounced decline in the outer portion of the Main Channel despite the presence of the Iroquois Point diffusers. It is again pointed out that all the above statements can only be considered tentative due to the very "noisy" condition of the heavy-metal data.

A comparison of metallic content of sediments from three Navy harbors is given in Table 3.1-4. Included in this table are sediment data from San Diego Bay and Apra Harbor, Guam (References 3.1-7 and 3.1-8). Again the data are "noisy", but essentially the same concentrations are found in areas of Navy activity. In areas where the Navy is less active, sediment concentrations in all three harbors tend to be lower and to show more individual variation between harbors. Probably because of the "noise" in the data, these tendencies are not statistically significant.

(Text continued on page 3.1-21)

Table 3.1-4. COMPARISON OF METALLIC CONTENT OF SEDIMENTS FROM THREE NAVY HARBORS.
(values in mg/kg dry wt., mean ± std. dev. (n))

Metal	San Diego Bay	Pearl Harbor (Southeast Loch)	Apra Harbor
		FLEET ACTIVE	
Cu	290±370(9)	240±240(39)	240±280(3)
Pb	120±100(9)	210±300(39)	200±250(3)
Zn	430±310(9)	350±400(39)	400±400(3)
		FLEET INACTIVE	
	San Diego Bay	Pearl Harbor (Middle Loch)	Apra Harbor
Cu	220±80(8)	120±50(14)	35±13(2)
Pb	62±29(7)	32±27(14)	13±8(2)
Zn	370±170(8)	200±80(14)	54±30(2)

Additional note: As reported in the Westinghouse Engineer, April 1974, sediment content (mg/kg dry wt.) for these metals in upper Chesapeake Bay are:

Baltimore Harbor	Cu 320	Pb 1500	Zn 2600
Chester River (max. obs.)	Cu 35	Pb 60	Zn 320
Rhode River (max. obs.)	Cu 120	Pb 130	Zn 80

$CaCO_3$ CONTENT

Mr. Dennis Kam analyzed sediment samples from the bio-stations for their $CaCO_3$ content using Hülsemann's gasometric technique (Reference 3.1-9). In this method, CO_2 liberated by treatment with 0.1 N HCl is measured manometrically and $CaCO_3$ is reported as percent of total dry weight. The results are presented in Figure 3.1-12. A gradient from alluvial composition to marine carbonate composition may be observed from BM-07 to BC-11. Aside from this general gradient, no striking pattern of $CaCO_3$ distribution emerges. This situation is unlike that found in Kaneohe Bay (Reference 3.1-10).

MINERALOGY AND EXCHANGE CAPACITY

The geological formations about Pearl Harbor are presented fully in Reference 3.1-1. The plain bounding the west side of Pearl Harbor is composed principally of limestone from ancient reefs; those on the east are mainly volcanic tuff. The northern boundaries are composed of volcanic basalt overlain by noncalcareous alluvial deposits. According to Youngberg (Reference 3.1-11), the general rules of clay mineralogy applied to Pearl Harbor soils suggest that basic igneous rocks and volcanic tuff will form kaolinite in areas of good drainage and high rainfall but will form montmorillonite in areas of poor drainage and low rainfall. Calcareous sedimentary rocks form illites and montmorillonites; the presence of calcium ion tends to block the formation of kaolinite. Figure 3.1-13 maps areas of kaolinite and montmorillonite formation. Table 3.1-5 summarizes the general cation exchange capacities for these minerals. Bruce Turner (Reference 3.1-12) has studied the clay mineralogy of Pearl Harbor sediments and reported that they contain kaolinite, montmorillonite, pyrite and mica. The highest fraction of montmorillonite is found in the sediments of Southeast Loch. Average mineral compositions and exchange capacities for Pearl Harbor sediments may be obtained from Turner's report, which was still in preparation when this section was being written.

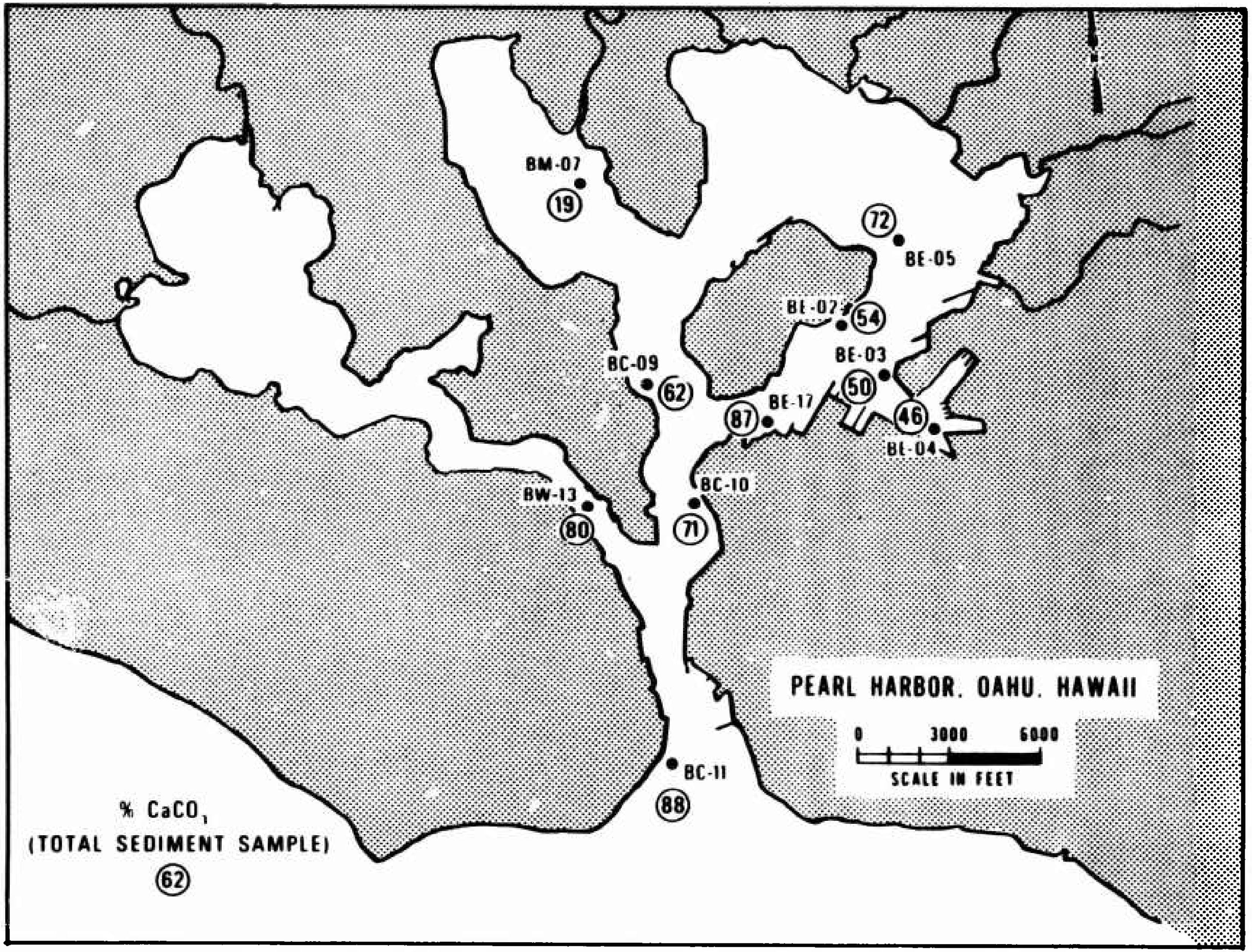


Figure 3.1-12. CALCIUM CARBONATE CONTENT (% TOTAL DRY WT.) OF SEDIMENTS COLLECTED AT PEARL HARBOR BIO-STATIONS.

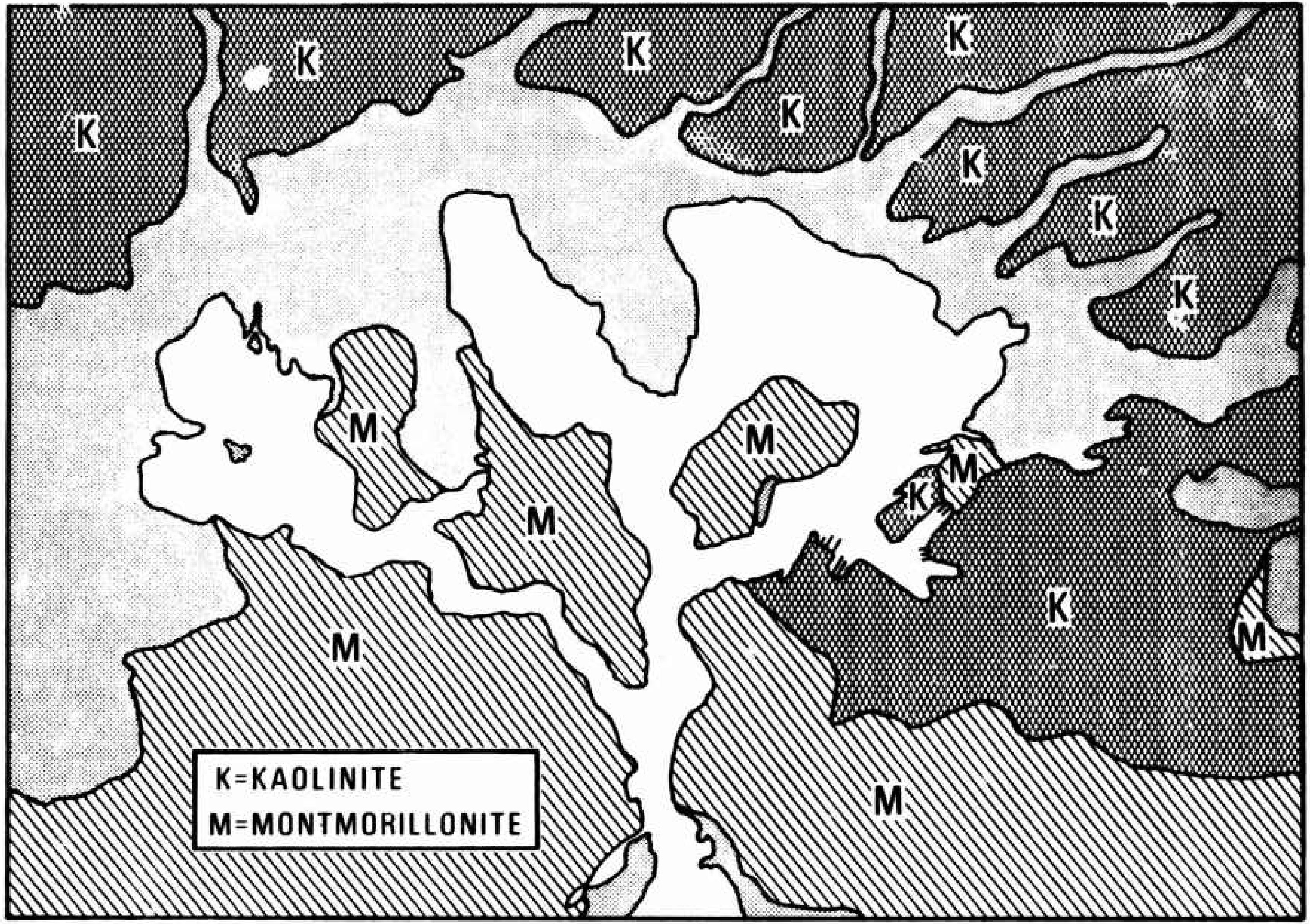


Figure 3.1-13. PRINCIPAL REGIONS OF KAOLINITE AND MONTMORILLONITE FORMATION IN THE PEARL HARBOR DRAINAGE BASIN (ACCORDING TO ALV DAN YOUNGBERG).

Table 3.1-5. GENERAL CATION EXCHANGE CAPACITIES FOR VARIOUS CLAY MINERALS FROM REFERENCES 3.1-13 AND 3.1-14. (values in milliequivalents/100 grams dry wt)

Mineral	Median Value	Range
Montmorillonite	100	80 to 150
Illite	30	10 to 40
Kaolinite	8	3 to 15
Organic Matter	150	70 to 300

REFERENCES

3.1-1. Alv Dan Youngberg (1973), A Study of Sediments and Soil Samples from Pearl Harbor Area, NCEL Report EPDB 72-062, LIMDIST.

3.1-2. D E. Morris and A. D. Youngberg (1972), Methods of Collection and Reporting of Sediment Samples from Pearl Harbor, NCEL Report EPDB 73-001, LIMDIST.

3.1-3. Alv Dan Youngberg (1973), A Study of Groundwater Contamination beneath Landfills at Pearl Harbor, NCEL Report EPDB 73-004, LIMDIST.

3.1-4. Environmental Protection Agency (1969), Chemistry Laboratory Manual: Bottom Sediments, compiled by Great Lakes Region Committee on Analytical Methods, Federal Water Quality Administration.

3.1-5. American Public Health Association (1971), Standard Methods for the Examination of Water and Wastewater, 13th Edition, p 128.

3.1-6. T. J. Peeling, J. G. Grovhoug, and E. C. Evans III (1972), "Pearl Harbor Biological Survey - Summary Report for First Survey Cycle", NUC TN-801, Table 40, p 134, LIMDIST.

3.1-7. Sachio Yamamoto (1974), NUC letter report dtd 17 June, LIMDIST.

3.1-8. E. C. Evans III, J. G. Grovhoug, and T. J. Peeling (197-), "Site Survey, Inner Apra Harbor, Guam", NUC letter report in preparation.

3.1-9. J. Hülsemann (1966), "On the Routine Analysis of Carbonates in Unconsolidated Sediments", J. Sedimentary Petrology 36:2, pp 622-625.

3.1-10. S. V. Smith, K. E. Chave, and D. T. O. Kam (1973), Atlas of Kaneohe Bay: A Reef Ecosystem Under Stress, University of Hawaii, SEAGRANT publication TR-72-01.

3.1-11. Alv Dan Youngberg (1974), personal communication, 25 March.

3.1-12. Bruce W. Turner (197-), Mineralogy of Pearl Harbor Sediments, University of Hawaii, Dept. of Geology and Geophysics, MS Thesis in preparation.

3.1-13. Lyon, Buckman, and Brady (1952), The Nature and Properties of Soils, MacMillan, p 101.

3.1-14. Black (1957), Soil-Plant Relationships, J. Wiley, p 109.

3.2 WATER QUALITY

Evan C. Evans III
Donald E. Morris

GENERAL INFORMATION

An extensive water quality survey was performed by the Pearl Harbor Division of the Naval Civil Engineering Laboratory's Environmental Protection Data Base, under the direction of Donald E. Morris (Reference 3.2-1). This survey was performed during the period October 1971 to December 1972 simultaneously with the biological survey of Pearl Harbor. The Data Base survey was intended primarily to determine Pearl Harbor water quality conditions with respect to State and Federal law and to assess the effects of Navy discharges and Navy abatement activity on the harbor as a whole. Only those aspects of water quality having important influences on living marine organisms are summarized here. Unfortunately, a lack of nighttime data precludes any thorough analysis of such biologically important parameters as dissolved oxygen. In the statistical analysis (see Section 4.1), only data from 37 of the approximately 120 stations in the harbor were used since the data from these stations* were considered most representative of water conditions at the bio-stations. No source discharge data were used as it was not available at the time the statistical analysis was performed. Where they could influence a nearby bio-station, some of these source discharge measurements are considered in this section. Considerably more information concerning source discharges and regions of Pearl Harbor distant from the bio-stations may be found in Reference 3.2-1. This reference also compares water conditions extant in Pearl Harbor with State water quality standards and makes a few source/sink inferences.

WATER QUALITY SAMPLING

Water samples were collected from a small boat at the locations shown in Figure 3.2-1. Samples were collected in one-liter polyethylene bottles which had been washed with phosphate-free detergent and acid rinsed prior to going into the field. Both a surface sample and a bottom sample were collected. The surface sample was taken 1 foot below the surface and the bottom sample was taken 1 foot above the bottom (or at a depth of 40 feet) using a self-priming bilge pump and a length of plastic hose. The pump was run for at least one minute to clear all lines before the sample was taken. Preservatives were added as required (Table III-2 of Reference 3.2-1) after the samples were returned to the laboratory. Time lag between collection and laboratory delivery usually did not exceed four hours. Van Dorn and rope-lowered sewage samplers were also used, usually for bacteriological analysis.

Field measurements included dissolved oxygen, temperature, salinity and Secchi disc readings. Dissolved oxygen was determined with a Weston and Stack Model 300 Oxygen Analyzer System; salinity with a Beckman Model RS5-3 Salinometer. Temperatures were determined using a mercury thermometer held

---

* These stations are: for BE-02, EB-10, EB-20; for BE-03, EB-30, EC-10, EC-20; for BE-04, ED-10, ED-20, ED-30; for BE-05, EF-10, EF-20, EG-30; for BM-07, MA-20, MA-30, MB-20, MB-30; for BC-09, CG-10, CG-20, CG-30; for BC-10, TA-30; for BC-11, CC-10, CC-20, CC-30; for BW-13, WA-20, WA-30; for BE-17, EA-10, EA-20, EA-30.

(Text continued on page 3.2-3)

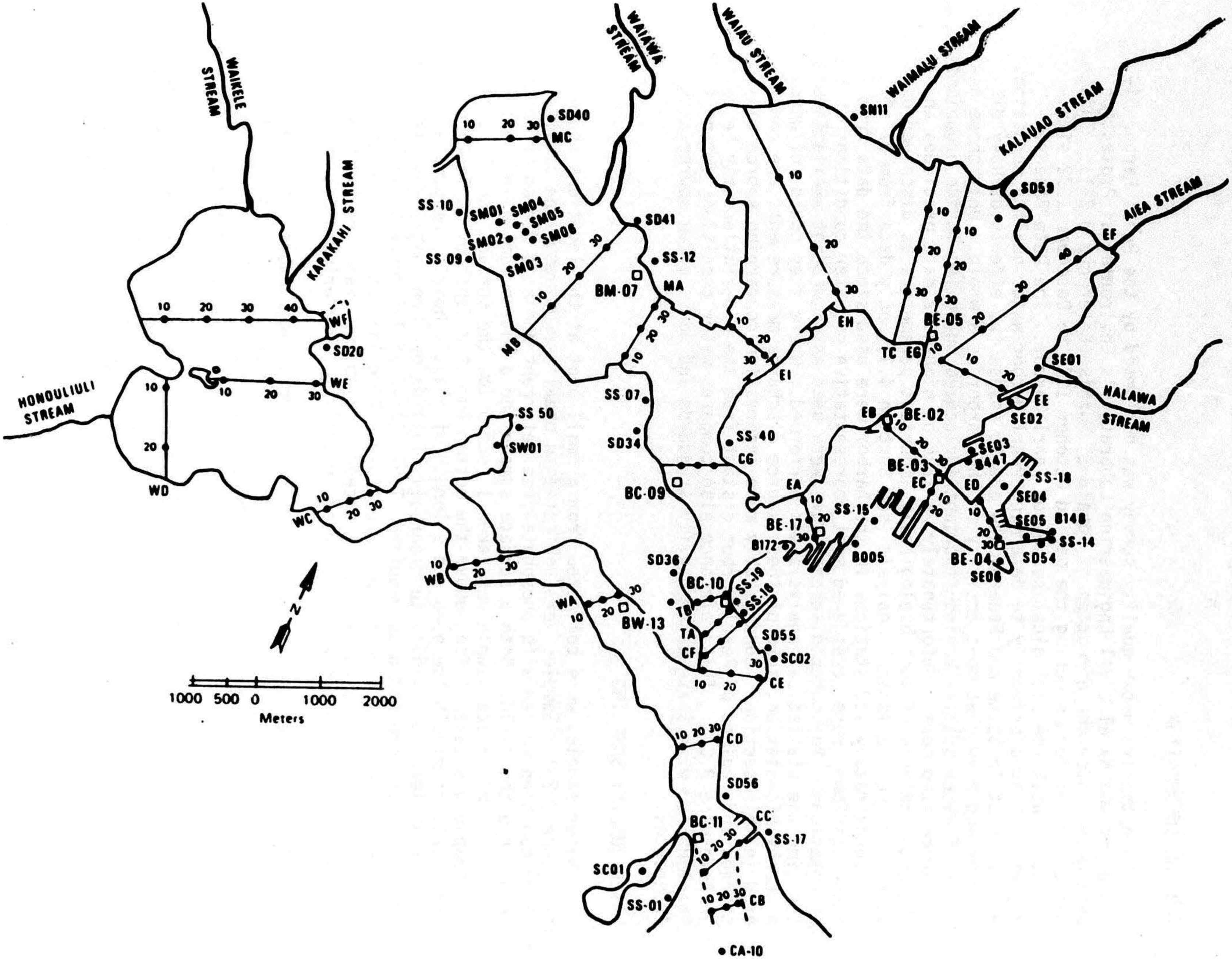


Figure 3.2-1. NCEL WATER QUALITY SAMPLING STATIONS IN PEARL HARBOR. (bio-statio[illegible]d some source locations also shown)

in the surface waters or in the bottom waters flowing from the plastic hose until equilibrium was attained.

In addition to the Pearl Harbor water samples, grab samples were taken at approximately 130 sites discharging into the harbor. These sources included sanitary and industrial effluents, irrigation tailwaters, storm-drain outflows, streams and springs. Grab samples were taken at approximately two-week intervals with more frequent sampling at major discharges. Source flow measurements were not attempted due to lack of appropriate instrumentation. Some flow data obtained from various references are presented in Table II-7 of Reference 3.2-1; additional flow information is available in References 3.2-2 and 3.2-3. Source locations are presented in Tables II-3 through II-6, and in Figures II-5 through II-8 of Reference 3.2-1 (Figure 3.2-1 shows locations of those sources specifically identified in the text). Those sources possibly influencing various bio-stations are summarized in Table 3.2-1; see also Figure 3.2-5 under the discussion of temperature below.

LABORATORY ANALYSIS

With the exception of heavy metals, a complete description of all analytical procedures is not presented; full details may be found in Section III of Reference 3.2-1. Kjeldahl nitrogen, nitrate, nitrite, ammonia, chloride and oil and grease analyses were performed on a Technicon AutoAnalyzer II, Industrial Model; phenols, total phosphate and orthophosphate on a Perkin-Elmer Coleman Model III Visible-Ultraviolet Spectrophotometer; total organic carbon on a Beckman Model 915 Total Organic Carbon Analyzer; and pesticides on a Varian Aerograph Model 2800 Gas Chromatograph. Methods followed those set forth by the Environmental Protection Agency or the American Public Health Association (References 3.2-4 through 3.2-6). An Infrared Spectrophotometer was used to check the quality of solvents. pH was determined in the laboratory using a Beckman SS-1 meter. Turbidity was also measured in the laboratory using a Hach Laboratory Turbidimeter calibrated against a Formazin standard. Suspended solids, settleable solids and residual (dissolved) solids were determined by standard methods using a Mettler Model H10 Analytical Balance. Fecal coliform and total coliform counts were made using standard membrane filter technique (Reference 3.2-6).

Heavy metals were determined by atomic absorption using a Varian Techtron Model 120 Atomic Absorption Spectrophotometer equipped with hollow cathode lamps and an accessory kit for additional elements, such as mercury. Usually water samples were nebulized directly into the spectrophotometer from the field sample bottles without any further treatment. With salt water samples, the burner head normally required cleaning every 15 samples. The simplicity of this direct analytical procedure more than compensated for this additional cleaning effort. All metal analyses were done relative to two standards; one diluted with acidified seawater obtained at station CA10 (Figure 3.2-1) and the other diluted with acidified distilled water. Seawater from station CA10 measured 0.007 ppm Cu and 0.05 ppm Zn; all other metals reported on in this section were below the detection limit of the instrument. The distilled water measured 0.1 ppm Cu, 0.02 ppm Pb and 0.07 ppm

(Text continued on page 3.2-5)

Table 3.2-1. SOURCE DISCHARGES NEAR PHBS BIO-STATIONS.

STA	DBID*	Description and Remarks
BE-02	none	many sewer lines (6" to 10", inactive); 4 storm drains (12" to 18")
BE-03	B447	work area drainage - Laundry, Warehousing and Storage areas
	none	2 sewer lines (6", inactive)
BE-04	B148	ground runoff from Sub Base area, Tool Shop, Demineralized Water Plant, Preservation and Packing area
	SD54	Quarry Loch storm drain
	SS14	raw sewage discharge - temporary during pump station repair
	SS18	Magazine Loch - Navy oil
	none	oil slicks, possible underground seepage from Navy tank farm; numerous sewer lines (4" to 12", inactive)
BE-05	none	2 sewer lines (4", inactive?)
BM-07	SD40	marsh drainage - intermittent flow
	SD41	Kaipo Canal
	SS09	sewage from Honolulu City and County oxidation ponds
	SS10	sewage from inactive fleet - extended aeration system
	SS12	no-flow line connected to Pearl City STP*
	TT02	Waiawa Stream
	none	4 sewer lines (8" to 12", inactive?)
BC-09	SD34	irrigation tailwater - DBID changed to SD32
	SD36	irrigation tailwater - DBID changed to SD36
	SS07	treated sewage from Degaussing Station
	SS40	Ford Island STP
BC-10	SD55	Dumpster wash-rack drainage
	SS16	thermal outfall and oil from Navy power plant #3
	SS19	raw sewage outfall (inactive)
	none	2 storm drains (12" lines); possible underground seepage from Navy tank farm
BC-11	SD56	storm drainage - Hammer Point
	SS01	treated sewage - NAS Housing STP, Hammer Point
	SS17	treated sewage - Hickam AFB STP
BW-13	none	discharges into upper West Loch - notably Waikele Stream, SS03, and SS04
BE-17	B172	ground runoff from Electronic/Weapons Shop and Machine Shop
	SS15	thermal outfall from Navy power plant #2
	none	work area drainage - dry docks #1, #2, and #3; numerous sewer lines (4" to 8", inactive); possible storm drainage from Electrode Plating Shop, Battery Shop, Foundry, Pipe and Copper Shop, Forge and Galvanizing Shop

*DBID = Data Base identification number; STP = sewage treatment plant.

Zn; other metals were again below detection limits. Harbor water measurements are reported relative to the "seawater" standard; stream and source water measurements are relative to the "distilled water" standard. For brackish water samples a correction was made on the basis of salinity using the two standards. Detection limits for the various metals are summarized in Table 3.2-5, appearing later in the text.

GENERAL WATER QUALITY AT BIO-STATIONS

The results of the Data Base water quality measurements are presented in highly condensed form for the ten bio-stations in Tables 3.2-2 and 3.2-3. Table 3.2-2 also includes fish and piling community data extracted from Tables 2.1-6 and 2.4-4, respectively. In the lower section of this table, correlation coefficients between the water quality and biological data are given. Although all possible combinations of the two data sets were run in the computer, only correlation coefficients representative of the fish and piling communities are included in the table. As reported previously (Table 39 of Reference 3.2-7), dissolved oxygen correlates positively with the biological data. Temperature and salinity are so uniform that little correlation would be expected. While no correlation with either total phosphate or total organic carbon is apparent, there is very high correlation between the piling community and the nitrogen content of bottom waters. Thus, some nutrients but not others elicit a biological response. Mean monthly variations in four water quality parameters are summarized in Table 3.2-3. The monthly means reported are actually those for the Data Base range* nearest the given bio-station, since there was insufficient data taken at the bio-stations themselves. The ranges are shown as straight lines in Figure 3.2-1. Temperature and salinity show moderate seasonal excursions due to insolation and fresh water runoff, which are fairly uniform throughout the harbor. Dissolved oxygen shows a slight tendency to be higher during the winter months. Total organic carbon seems to be higher at all bio-stations in January, but the seasonal record is too incomplete to attach any significance to this observation.

HEAVY-METAL RESULTS

Although a great many heavy-metal analyses were run for both harbor and source waters, the number of detections for metals of probable non-terrigenous origin (Ag, As, Cd, Cu, Hg, Pb and Zn) are so low (~11%) that, with the exception of Zn, few conclusive statements can be made. Certainly, the analysis of the water column is not an efficient way of estimating the heavy-metal insult to a marine environment; analysis of sediments (see Section 3.1) or of the tissues of resident marine organisms (Table 5 of Reference 3.2-3) would seem preferable. The results of the Data Base heavy-metal analyses are summarized in Tables 3.2-4 and 3.2-5. In the heavy-metal analyses for

* For Be-02, range EB; for BE-03, EC; for BE-04, ED; for BE-05, EE; for BM-07, MA; for BC-09, CG; for BC-10, CF; for BC-11, CC; for BW-13, WA; for BE-17, EA.

(Text continued on page 3.2-15)

Table 3.2-2. SUMMARY COMPARISON OF WATER QUALITY DATA WITH BIOLOGICAL POPULATIONS.

STA	Temperature (°C) range	Temperature (°C) mean (n)	Salinity (‰) range	Salinity (‰) mean (n)	Diss Ox (mg/l) range	Diss Ox (mg/l) mean(n)	Total P (ppm) range	Total P (ppm) mean (n)	Tot Or Car (ppm) range	Tot Or Car (ppm) mn.(n)	FISH sp	FISH ind	PILING COMM. sp Jn/Nv	PILING COMM. ind Jun/Nov
BE-02S	22.9-28.3	26.5(19)	28.8-35.5	34.1(17)	4.2- 6.8	5.2(18)	.010-.070	.030(13)	ND- 8.0	2.7(9)	31	82	15/ 9	99/ 85
B	22.9-28.1	26.1(17)	29.4-35.7	34.4(12)	3.9- 5.6	4.7(18)	.005-.050	.022(12)	ND- 5.5	2.3(8)			17/18	41/ 38
BE-03S	24.1-28.5	26.6(17)	29.9-35.8	34.2(16)	4.8- 8.6	5.9(17)	.005-.046	.015(12)	ND- 6.0	3.0(10)	29	138	25/20	1023/ 78
B	23.9-27.4	26.0(15)	34.7-36.0	35.4(14)	1.8- 8.0	4.2(15)	.005-.070	.022(12)	ND- 5.5	2.2(9)			21/20	287/178
BE-04S	24.0-28.3	26.6(18)	28.8-35.9	34.2(16)	3.7- 6.7	5.2(17)	ND-.052	.022(12)	ND-12.0	3.8(9)	10	41	5/ 1	140/ 1
B	23.5-27.8	26.0(17)	34.7-36.0	35.2(14)	3.1- 5.0	3.8(16)	ND-.060	.026(12)	ND- 5.0	2.8(8)			11/16	261/228
BE-05S	24.0-29.8	26.5(21)	31.1-35.2	34.1(18)	4.8- 6.8	5.8(19)	.005-.070	.029(14)	ND-14.0	4.5(8)	28	221	8/29	23/ 99
B	24.9-28.5	27.1(11)	33.5-35.4	34.6(10)	4.0- 6.6	5.5(13)	.010-.112	.034(12)	ND- 7.0	2.8(7)			19/20	62/ 62
BM-07S	24.6-29.9	27.4(17)	23.7-35.2	33.5(16)	4.4- 8.0	5.8(16)	.028-.200	.090(13)	ND- 5.5	2.9(9)	22	133	8/10	108/ 56
B	23.4-27.3	25.9(16)	34.6-36.9	35.8(15)	1.0- 9.4	3.9(16)	.012-.070	.040(14)	ND- 5.5	2.2(6)			35/20	281/118
BC-09S	22.8-29.1	26.4(18)	19.4-34.3	32.3(16)	4.1- 8.6	6.1(17)	.035-.270	.109(13)	ND- 5.0	2.9(9)	24	140	no data	
B	24.1-28.3	26.7(14)	31.4-35.0	33.7(13)	4.3- 6.4	5.3(14)	.008-.129	.066(12)	ND- 7.0	2.2(6)			no data	
BC-10S	22.5-40.0	32.4(18)	24.5-40.0	34.6(14)	4.9- 9.2	5.9(17)	ND-.102	.030(12)	ND- 7.0	3.0(10)	42	186	16/25	186/156
B	23.0-27.7	25.4(17)	32.4-36.6	35.2(13)	4.4- 9.1	5.4(17)	ND-.045	.019(12)	ND- 6.0	2.3(8)			25/18	93/ 51
BC-11S	23.4-29.3	26.6(17)	20.5-35.4	33.1(15)	4.8- 9.8	6.4(14)	.010-.086	.040(10)	ND-13.5	4.7(9)	70	227	30/14	224/ 78
B	23.8-27.5	26.4(14)	34.0-36.7	35.3(13)	3.8- 6.5	5.2(12)	.005-.070	.028(10)	ND- 7.0	2.3(7)			41/39	1106/722
BW-13S	21.5-29.5	26.7(18)	18.1-34.8	32.4(16)	4.4- 7.2	5.7(16)	.025-.125	.073(13)	1.0- 7.0	4.0(8)	43	65	21/21	669/943
B	21.9-28.0	25.8(17)	34.4-36.9	35.5(14)	2.9- 5.8	4.2(17)	ND-.060	.028(13)	1.0- 8.5	3.9(6)			19/20	384/269
BE-17S	25.0-28.3	26.7(17)	25.6-36.0	33.6(16)	4.7-10.0	6.2(16)	ND-.090	.037(12)	ND- 6.0	2.5(11)	19	134	17/14	490/ 65
B	24.0-27.8	26.3(15)	32.5-35.8	35.0(14)	3.6- 8.0	4.8(16)	ND-.090	.025(12)	ND- 5.0	1.6(8)			16/14	145/ 59

highest and next highest correlation coefficients (positive or negative) between water quality and biological data

FidB -0.45	PspJB +0.48	FidB +0.80	PspJS -0.43	FspS +0.52	all intercorrelations
PspNS +0.38	PidNS -0.45	FidS +0.72	PspNS -0.40	FidB -0.35	are high (0.6 to 1.0)

Key: B = bottom water, F = fish, id = individual count, J = June survey, N = November survey, S = surface water, sp = species count. These abbreviations are combined, thus FidB = fish, individual count vs bottom water quality parameter, etc. Fish were compared with both surface and bottom water quality parameters; piling surface biota were compared only to surface water quality parameters; piling 10-foot biota to bottom water quality parameters only.

Table 3.2-2. SUMMARY COMPARISON OF WATER QUALITY DATA WITH BIOLOGICAL POPULATIONS.
(continued: biological parameters in first section)

STA	pH		Turbidity (JTU)		Secchi (m)		Kjeldahl-N (ppm) ND = <.005*		Ammonia-N (ppm) ND = <.005*		Fecal Coliform (MFC/100ml)		Total Coliform (MFC/100ml)	
	range	mean(n)	range	mean (n)	range	mean(n)	range	mean(n)	range	mean(n)	range	mn(n)	range	mean (n)
BE-02S	7.9-8.5	8.1(19)	0.6- 3.3	1.6(18)	1.0-5.0	3.2(19)	ND	ND (6)	ND-.030	.008(7)	2- 20	6(4)	10- 5500	47(12)
B	8.0-8.5	8.2(17)	0.8-23.0	4.3(18)			ND-.081	.023(6)	ND-.015	.007(7)				
BE-03S	8.0-8.5	8.2(18)	0.8- 5.7	2.0(18)	1.4-4.8	3.2(17)	ND-.486	.069(7)	ND-.023	.010(7)	2- 40	11(4)	10- 2100	82(11)
B	7.9-8.5	8.1(17)	1.7-55.0	7.3(17)			ND-.050	.007(7)	.010-.028	.020(7)				
BE-04S	8.0-8.5	8.2(18)	1.2- 7.5	3.0(17)	1.5-4.8	3.1(18)	ND-.062	.009(7)	ND-.030	.012(7)	2-154	44(4)	16- 14700	460(11)
B	8.0-8.4	8.1(17)	2.1-11.0	4.0(17)			ND-.110	.016(7)	.005-.035	.020(7)				
BE-05S	6.8-8.6	7.7(23)	1.1-36.0	4.0(20)	1.1-3.4	2.0(16)	ND	ND (6)	ND-.011	.004(7)	2	2(4)	10- 430	49(10)
B	7.9-8.3	8.1(11)	2.3- 4.1	3.2(13)			ND-.078	.013(6)	ND-.023	.009(7)				
BM-07S	7.4-8.7	8.1(18)	1.8- 6.0	3.5(19)	0.6-2.5	1.6(16)	ND-.147	.061(6)	ND-.090	.015(7)	14-120	60(4)	30- 9100	400(11)
B	7.1-8.4	7.9(18)	1.5-37.0	10.7(18)			ND-.099	.026(6)	ND-.072	.022(7)				
BC-09S	7.9-9.0	8.2(18)	2.2-15.0	4.4(18)	0.7-3.0	1.7(8)	ND-.121	.063(6)	ND-.038	.015(7)	6-120	54(4)	28-107000	2800(11)
B	7.9-8.5	8.1(16)	1.1- 5.0	3.2(17)			ND-.054	.017(6)	ND-.050	.014(7)				
BC-10S	8.0-8.5	8.2(18)	1.1- 3.0	1.8(17)	2.0-4.0	2.8(18)	ND-.097	.016(6)	ND-.035	.015(7)	2- 2	2(4)	100- 2600	200(11)
B	8.0-8.6	8.2(19)	1.9- 7.9	3.3(17)			ND-.075	.015(5)	ND-.021	.014(6)				
BC-11S	8.0-8.4	8.2(17)	1.6- 9.2	2.8(17)	0.8-3.2	2.3(16)	ND-.068	.025(5)	ND-.006	.002(7)	2- 10	6(4)	8- 1710	180(11)
B	8.0-8.3	8.1(16)	2.4- 7.3	4.1(16)			ND-.445	.110(5)	ND-.309	.054(7)				
BW-13S	7.9-8.5	8.2(19)	1.4- 7.2	2.6(19)	1.0-3.5	2.2(18)	ND-.061	.010(6)	ND-.019	.004(7)	2-130	46(4)	16- 8000	240(11)
B	8.0-8.5	8.1(19)	1.1- 4.9	3.0(19)			ND-.116	.037(6)	ND-.035	.025(7)				
BE-17S	8.0-8.6	8.2(18)	1.2-14.0	2.8(18)	1.0-4.2	2.8(18)	ND-.099	.017(6)	ND-.035	.010(7)	2-110	32(4)	62- 8900	250(11)
B	8.0-8.5	8.1(17)	1.1-14.0	4.3(17)			ND-.053	.009(6)	ND-.028	.012(7)				
highest and next highest correlation coefficients (positive and negative) between water quality and biological data														
	PspNS	-0.46	PspJS	-0.64	PidJS	+0.41	PspNB	+0.95	PidJB	+0.99	PspNS	-0.61	PspNS	-0.60
	PspJB	-0.42	PidJS	-0.46	PspJS	+0.37	PidJB	+0.94	PidNB	+0.98	FidB	-0.61	PspJS	-0.60

Key: Same as first section of table.

* Means < detection limit are reported for statistical purposes.

Table 3.2-3. MONTHLY MEAN VALUES FOR BIOLOGICALLY IMPORTANT WATER QUALITY PARAMETERS.

	Jr	Fb	Mr	Ap	My	Jn	Jl	Ag	Sp	Oc	Nv	Dc
BE-02												
Tp(°C)S*	23.6	23.1	25.1	24.8	25.9	26.9	26.9	27.2	28.0	28.2	26.2	24.3
B*	23.6	22.9	22.8	24.3	25.1	26.3	26.5	26.5	27.3	27.3	25.9	24.6
Sal(‰)S	-	34.0	33.1	34.0	34.1	34.9	35.2	34.9	35.1	34.8	35.6	35.6
B	-	34.7	35.6	35.3	35.2	35.4	35.6	35.6	35.4	35.5	36.0	36.5
DO(ppm)S	6.6	7.3	6.9	6.7	7.1	5.5	4.7	5.5	7.0	5.5	6.4	5.5
B	-	6.2	-	5.3	5.3	4.0	3.8	4.6	3.7	3.4	5.2	4.4
TC(ppm)S	7.1	1.2	1.5	1.9	4.0	1.3	5.2	3.5	-	-	-	-
B	7.7	1.8	-	1.1	3.6	2.0	3.0	-	-	-	-	-
BE-03												
Tp(°C)S	23.6	23.2	25.0	25.3	25.8	26.5	26.7	27.2	28.1	28.4	26.0	24.4
B	23.6	22.9	22.8	24.5	25.1	26.6	26.6	26.6	27.3	27.3	25.7	24.5
Sal(‰)S	-	34.1	33.4	34.2	34.2	35.4	35.4	35.1	35.0	34.9	35.8	35.5
B	-	34.6	35.7	35.5	35.2	35.7	35.7	35.8	35.6	35.6	36.3	36.3
DO(ppm)S	6.7	7.4	6.0	6.3	6.8	4.5	4.0	5.5	6.4	5.3	5.5	4.7
B	-	-	-	5.0	4.9	3.2	3.6	4.6	3.5	3.3	4.4	4.2
TC(ppm)S	5.6	1.1	3.0	2.0	4.7	1.2	3.5	3.0	-	-	-	-
B	6.0	0.9	-	1.4	4.2	1.0	2.5	-	-	-	-	-
BE-04												
Tp(°C)S	23.7	23.3	25.3	24.9	25.8	27.0	27.1	27.2	27.9	28.2	26.1	24.5
B	23.7	23.2	22.9	24.6	25.2	26.7	26.8	26.7	27.3	27.3	25.8	24.6
Sal(‰)S	-	34.2	33.2	34.9	34.6	35.9	35.6	35.3	35.2	34.8	35.9	35.6
B	-	34.7	35.4	35.7	35.1	35.6	35.7	35.8	35.5	35.6	36.0	36.2
DO(ppm)S	6.1	6.1	5.7	6.0	5.5	3.7	4.0	5.7	6.3	4.8	5.2	4.9
B	-	5.7	5.0	4.1	4.3	3.6	3.5	4.7	2.8	3.0	4.0	3.3
TC(ppm)S	9.9	1.6	2.5	1.4	4.5	1.5	3.0	1.5	-	-	-	-
B	8.4	2.2	-	1.1	4.2	1.0	3.8	-	-	-	-	-
BE-05												
Tp(°C)S	23.9	23.2	25.4	24.9	26.0	26.9	26.8	27.2	28.1	28.1	26.1	24.5
B	23.6	22.8	22.9	24.3	25.2	25.9	26.4	26.5	27.2	27.2	25.7	24.8
Sal(‰)S	-	34.0	32.4	34.8	34.0	35.0	35.1	34.9	34.9	34.9	35.7	35.3
B	-	35.0	35.6	35.5	34.8	35.0	35.8	35.8	35.5	35.6	36.3	36.4
DO(ppm)S	7.0	7.2	7.2	6.4	7.2	5.0	4.4	5.8	5.8	5.8	6.1	5.2
B	5.4	6.4	-	4.0	4.7	4.0	4.0	4.4	2.4	3.8	4.8	3.6
TC(ppm)S	12.6	1.0	2.5	2.0	3.8	1.7	3.5	5.5	-	-	-	-
B	3.3	-	-	2.7	4.2	1.2	2.2	5.0	-	-	-	-

* B = bottom water; S = surface water.

Table 3.2-3. MONTHLY MEAN VALUES FOR BIOLOGICALLY IMPORTANT WATER QUALITY PARAMETERS (continued)

	Jr	Fb	Mr	Ap	My	Jn	Jl	Ag	Sp	Oc	Nv	Dc
BM-07												
Tp(°C)S*	23.7	23.[illegible]	24.5	25.2	27.2	27.6	27.8	27.5	28.6	28.6	26.2	24.3
B*	23.4	22.0	22.8	24.3	25.5	26.5	26.5	26.8	27.3	27.1	26.1	24.5
Sal(‰)S	-	32.4	32.3	32.8	33.7	34.1	34.6	32.9	33.6	33.3	34.2	34.9
B	-	35.7	35.7	35.2	34.9	35.4	35.7	35.7	35.8	35.5	36.2	36.4
DO(ppm)S	7.2	8.3	7.3	7.4	8.0	8.9	5.1	6.6	6.2	6.0	6.7	4.4
B	5.2	5.8	4.9	4.3	4.3	3.0	3.2	4.2	2.5	2.3	2.9	4.4
TC(ppm)S	-	2.9	2.3	2.2	5.9	2.7	3.9	-	-	-	-	-
B	1.0	3.1	1.7	0.7	4.9	3.0	2.5	-	-	-	-	-
BC-09												
Tp(°C)S	23.8	22.9	25.5	25.0	26.5	26.8	27.6	27.1	28.1	28.1	27.0	23.9
B	23.8	22.8	23.0	24.2	25.4	26.0	26.8	26.5	27.3	27.2	26.6	24.4
Sal(‰)S	-	33.3	33.4	32.9	33.4	33.6	34.5	33.6	33.6	34.0	35.0	34.5
B	-	34.9	35.1	33.5	35.0	35.4	35.8	35.8	35.7	35.5	36.6	36.3
DO(ppm)S	7.1	7.8	7.8	6.7	8.7	7.6	6.3	6.8	6.5	5.4	5.9	5.4
B	5.6	6.4	5.6	5.2	5.5	4.7	5.2	5.4	5.0	4.2	4.5	3.4
TC(ppm)S	5.9	2.3	2.2	2.8	4.9	2.7	2.2	8.5	-	-	-	-
B	7.5	3.0	-	0.8	4.9	2.2	3.2	5.0	-	-	-	-
BC-10												
Tp(°C)S	24.4	23.3	25.4	25.6	26.4	27.1	27.9	27.6	28.4	28.4	26.7	23.7
B	24.1	22.9	22.7	24.6	25.5	25.7	26.5	26.4	27.2	27.2	26.1	24.4
Sal(‰)S	-	33.0	32.2	32.7	33.9	33.3	34.8	33.6	34.6	33.6	35.3	-
B	-	34.7	35.7	35.7	35.1	35.0	35.9	34.5	35.8	35.7	36.4	-
DO(ppm)S	7.3	8.1	8.4	7.4	7.8	7.7	6.8	7.6	7.0	5.8	4.9	5.0
B	6.3	7.3	6.1	4.9	6.2	5.2	5.8	6.4	5.4	4.6	4.9	4.9
TC(ppm)S	8.3	1.0	2.0	1.5	4.4	3.0	1.8	-	-	-	-	-
B	2.2	0.5	4.0	0.8	4.4	1.5	4.0	-	-	-	-	-
BC-11												
Tp(°C)S	23.3	22.6	24.3	25.1	25.5	26.8	27.5	27.4	28.0	28.0	26.7	23.8
B	23.6	22.9	22.9	24.2	25.2	25.7	26.4	26.4	27.2	27.2	25.9	24.3
Sal(‰)S	-	32.8	33.4	31.1	34.1	34.8	35.0	34.2	34.7	34.2	35.7	35.2
B	-	34.7	35.8	35.0	35.5	35.4	35.9	35.1	32.7	35.5	36.6	36.3
DO(ppm)S	6.8	7.7	7.8	8.4	7.6	7.7	6.0	6.2	6.1	5.8	6.0	5.4
B	-	7.3	7.2	5.9	6.5	5.4	5.7	6.1	4.7	5.6	5.5	5.2
TC(ppm)S	9.1	2.1	3.1	3.7	4.8	1.9	1.0	-	-	-	-	-
B	6.2	1.4	2.0	1.8	4.3	1.6	-	-	-	-	-	-

* B = bottom water; S = surface water.

Table 3.2-3. MONTHLY MEAN VALUES FOR BIOLOGICALLY IMPORTANT WATER QUALITY PARAMETERS (continued)

	Jr	Fb	Mr	Ap	My	Jn	Jl	Ag	Sp	Oc	Nv	Dc
BW-13												
Tp(°C)S*	23.0	22.7	24.6	25.7	26.4	27.2	27.1	28.1	28.1	27.8	25.8	23.6
B*	23.8	22.7	23.2	24.7	25.3	26.6	26.8	26.7	27.7	27.3	26.1	24.5
Sal(‰)S	-	29.5	31.9	29.8	32.4	33.4	34.0	33.6	33.1	32.7	33.1	35.3
B	-	32.7	34.8	35.5	35.1	35.0	36.2	35.1	35.1	35.8	36.2	36.5
DO(ppm)S	7.6	8.6	7.7	7.9	7.1	5.0	4.9	6.6	8.1	6.2	6.3	4.8
B	5.8	6.7	5.6	3.8	6.0	4.3	4.8	5.8	6.8	4.3	4.3	5.5
TC(ppm)S	6.7	2.5	3.5	3.0	3.5	1.7	3.1	8.2	-	-	-	-
B	4.6	1.3	-	1.2	3.0	2.0	3.5	4.8	-	-	-	-
BE-17												
Tp(°C)S	23.4	23.1	25.1	25.0	26.1	27.5	27.2	27.3	28.2	28.6	25.8	24.4
B	23.5	22.8	22.7	4.4	25.1	26.0	26.5	26.8	27.4	27.4	25.5	24.4
Sal(‰)S	-	33.6	32.1	34.1	34.0	34.2	34.9	35.3	34.7	34.4	35.4	35.3
B	-	34.6	35.7	35.4	35.1	35.2	35.8	35.9	35.5	35.6	36.2	36.4
DO(ppm)S	6.9	7.5	7.2	7.1	7.0	5.6	4.7	5.9	6.9	5.9	6.1	5.4
B	-	-	6.4	4.6	5.4	4.0	3.8	4.7	3.8	4.6	4.8	4.7
TC(ppm)S	6.4	1.7	1.5	2.4	5.1	3.6	1.5	2.2	-	-	-	-
B	2.5	2.1	-	1.0	4.5	3.0	2.2	-	-	-	-	-

* B = bottom water; S = surface water.

Table 3.2-4. SUMMARY OF HEAVY-METAL WATER ANALYSIS FOR BIO-STATIONS. (number of detections/number of analyses; max value (ppm) given whenever a detection is reported)

STA	Ag	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn	Summary of Metals Detected
BE-02S*	0/1	0/1	0/4	1/9 .02	1/2 .50	0/2	0/4	-	0/4	0/8	Cu, Fe
B*	0/2	0/1	0/4	2/8 .03	0/3	0/2	0/4	-	0/4	4/8 .04	Cu, Zn
BE-03S	0/1	0/1	0/4	0/9	1/3 .02	0/2	0/4	-	1/6 .10	1/8 .05	Fe, Pb, Zn
B	0/2	0/1	0/4	2/8 .03	2/4 .15	0/2	0/4	-	1/5 .10	2/8 .05	Cu, Fe, Pb, Zn
BE-04S	0/1	0/1	1/5 .26	0/8	0/2	0/2	0/4	-	1/6 .10	0/7	Cr, Pb
B	0/2	0/1	1/3 .26	1/6 .04	0/1	0/2	0/4	-	0/4	4/7 .23	Cr, Cu, Zn
BE-05S	0/1	0/1	0/4	0/7	0/3	0/3	0/4	-	0/5	0/8	no detections
B	0/1	0/1	0/4	1/6 .04	0/5	0/2	0/4	-	0/4	4/8 .09	Cu, Zn
BM-07S	0/1	0/2	0/4	0/9	1/2 .11	0/2	1/5 .04	-	0/6	0/9	Fe, Mn
B	0/2	0/3	0/4	0/8	2/3 .15	0/2	1/5 .04	-	0/4	5/9 1.1	Fe, Mn, Zn
BC-09S	0/1	0/1	0/4	0/8	0/3	0/2	0/4	-	1/5 .10	0/8	Pb
B	0/2	0/1	0/4	0/6	0/3	0/2	0/4	-	0/4	3/8 .17	Zn
BC-10S	0/1	0/1	0/4	0/8	0/3	0/2	0/4	-	0/6	1/8 .04	Zn
B	0/2	0/1	0/4	0/6	0/3	0/2	0/4	-	0/4	4/8 .14	Zn
BC-11S	0/1	0/1	0/4	0/7	0/3	0/2	0/3	-	0/6	0/8	no detections
B	0/2	0/1	0/4	1/5 .07	0/3	0/2	0/3	-	0/4	5/8 .27	Cu, Zn
BW-13S	0/2	0/1	0/4	0/8	1/3 .20	0/2	1/5 .04	-	0/6	0/8	Fe, Mn
B	0/4	0/1	0/4	0/6	0/5	0/2	0/4	-	0/4	4/8 .10	Zn
BE-17S	0/1	0/1	0/4	0/9	0/2	0/2	1/5 .04	-	0/4	0/8	Mn
B	0/2	0/1	0/4	1/8 .04	2/3 .11	0/2	0/4	-	0/4	4/8 .11	Cu, Fe, Zn
TOTALS	0/11	0/11	1/41 .26	1/82 .02	4/26 .50	0/21	3/42 .04	-	3/56 .10	2/80 .05	Cr, Cu, Fe, Mn, Pb, Zn
B	0/21	0/12	1/39 .26	8/68 .07	6/33 .15	0/20	1/40 .04	-	1/41 .10	39/80 1.1	Cr, Cu, Fe, Mn, Pb, Zn

* B = bottom water; S = surface water.

Table 3.2-5. SUMMARY OF WATER ANALYSIS FOR HEAVY METALS.

Mt	Seawtr Conc* (ppm)	Det Lim	Pearl Hbr Waters An	Dt	M ppm	I-n-f-l-u-e-n-t Drains/Ind Only An	Dt	M ppm	S-o-u-r-c-e-s Streams Only An	Dt	M ppm
Ag	.00015-.00003	.04	456	0	-	64	0	-	32	0	-
As	.003-.024	.02	20	0	-	41	0	-	8	0	-
Cd	.00011**	.005-.04	271	0	-	66	2	0.9	24	1	0.04
Cr	.00005**	.10-.20	763	20	0.26	181	7	0.46	43	0	-
Cu	.001-.09	.02-.06	1442	70	0.15	152	28	0.46	74	4	0.23
Fe	.002-.02	.04-.02	801	241	3.0	111	86	19.6	86	70	70.4
Hg	.0003	.002-.005	123	5	.003	106	0	-	31	0	-
Mn	.001-.01	.02-.05	1021	215	1.10	52	15	2.35	80	56	2.86
Ni	.0001-.0005	.04	-	-	-	19	2	0.04	15	2	0.18
Pb	.004-.005	.04-.4	628	7	0.10	174	10	4.1	58	0	-
Zn	.005-.014	.02	1450	342	1.6	162	111	1.7	54	10	0.10

Key: An = number of analyses, Dt = number of detections, M = maximum value.

* Handbook of Chemistry and Physics, 53rd ed, p F169
** H. J. M. Bowen, Trace Elements in Biochemistry, Academic Press (1966)

the bio-stations (Table 3.2-4), Zn shows up very frequently in water samples from the bottom (95% of all detections and 24% of all analyses are bottom samples). A similar, but somewhat weaker trend, is shown by Cu. Iron and Mn, however, tend to be more evenly distributed throughout the water column. Excluding Ag, Cd and Hg, which are not detected at all at the bio-stations, the metals generally tend to be reported in bottom samples (19% of all analyses) as opposed to surface samples (4%).

Table 3.2-5 presents heavy-metal data for Pearl Harbor as a whole and again the same general tendencies shown in the bio-station data appear. Cu and Zn are more frequently reported in bottom samples, while Fe and Mn are more generally distributed throughout the water column.* Specific calculations were made only for representative metals in each category. In 91% of all detections, or 21% of all analyses, Zn shows up in a bottom sample. Correspondingly, 62% of the Fe detections are in bottom samples and 38% in surface samples (percentages on the basis of total analyses are 18% and 11%, respectively). Were it not for the more uniform distribution of Mn and Fe, contamination of the bottom water samples with sediment might be suspected. Although there is little data on Cr, this metal is reported more frequently in surface waters. This observation further excludes possible bottom contamination.

For purposes of general discussion, the distribution of heavy metals is most easily seen in Table 3.2-6.

Table 3.2-6. DISTRIBUTION OF METALS IN HARBOR AND SOURCE WATERS.
(detections as percent of total analyses in each water category)

Metal	Harbor Waters	Storm Drains and Industrial Sources	Streams
Ag	0	0	0
As	0	0	0
Cd	0	3	4
Cr	3	2	0
Cu	5	18	5
Fe	30	78	81
Hg	4	0	0
Mn	21	29	70
Ni	-	10	13
Pb	1	6	0
Zn	24	68	18

*This statement is made in spite of the statement on page 227 of Reference 3.2-1 that copper is "uniformly distributed in both the surface and bottom waters..." Cu appears in bottom waters in 86% of the detections reported.

Since silver (Ag) and arsenic (As) were nowhere detected, these metals may be excluded from further discussion. Ag was found in Pearl Harbor sediments (see Section 3.1), but in significantly high concentrations only in South Channel near Dry Docks #1 through #3.

Cadmium (Cd) was nowhere detected in the harbor, but found in two storm drains entering East Loch and in Waimalu Stream. Highest source concentration for Cd (0.09 ppm) is reported for a 30" storm drain entering East Loch near Kalauao Stream (SD59).

Chromium (Cr) concentrations in harbor waters were highest in the northwestern section of East Loch. These locations do not match reported high concentrations of Cr in the sediments. The metal was detected five times in storm drains entering South Channel and Southeast Loch; the highest concentration (0.46 ppm) was found in B447, a location which might affect bio-station BE-03 (Table 3.2-1). Concentrations of Cr in surface waters would appear, at least in part, to be associated with this source. No Cr was detected in streams.

Copper (Cu) is fairly uniformly distributed throughout the bottom waters of the harbor; the highest harbor water concentration (0.15 ppm) was found in the upper reaches of Middle Loch. In the source waters, relatively high Cu concentrations are found in storm drains entering South Channel and Southeast Loch, with the highest (0.46 ppm) again in B447 (see Cr above). Cu detections are also reported for a number of streams, 0.03 ppm in Honouliuli, 0.06 ppm in Halawa, 0.15 ppm in Waikele, and the highest, 0.23 ppm, in Waiau Stream. Cu in bottom waters correlates well with significantly high burdens of Cu reported in the sediments.

Iron (Fe) is distributed generally throughout the waters of Pearl Harbor with the highest water concentrations (3.0 ppm) occurring in West Loch. Water detections in Middle Loch and Southeast Loch as well as West Loch correspond well with high concentrations of Fe in the sediment. Streams show a high percentage of Fe detections with water concentrations ranging from a low of 0.3 ppm in Aiea to a high of 16 ppm in Waiau Stream. Storm drains emptying into South Channel and Southeast Loch characteristically have Fe concentrations lower than the streams.

Mercury (Hg) was found only in the harbor waters. Although the detection of Hg in the waters of South Channel and near the Whiskey Docks is noted, the Hg data (5 detections) are considered too sparse for any comparison with sediment burden. Hg in the surface waters of Walker Bay (SW01) may be associated with agricultural runoff.

Manganese (Mn), like Fe, is generally distributed throughout the waters of Pearl Harbor with higher concentrations in West and Middle Lochs. Streams are high in Mn, with Waimalu Stream highest (2.86 ppm). Storm drains in Southeast Loch are characteristically low in Mn and water concentrations correlate well with sediment burdens.

No analyses for nickel (Ni) were performed on harbor waters. Highest Ni detection (0.18 ppm) is reported for Waimalu Stream. Ni was also found in Kapakahi Stream waters, a fact which might explain the significantly high Ni burdens in the sediment of upper West Loch. Ni was detected in waters entering Middle Loch from the City and County oxidation ponds on Waipio Peninsula; the significantly high burdens of Ni found in Middle Loch sediments may be related.

Lead (Pb) was not detected in the waters of West Loch or upper East Loch. It was found in Middle Loch and Main Channel waters and at several bio-stations located in Southeast Loch. Pb is reported in storm drains entering South Channel and Southeast Loch with the highest concentration (4.1 ppm) again in B447 (see Cr and Cu above). Pb concentrations in these source waters correlates well with high burdens in the sediment. No Pb was detected in stream waters.

Zinc (Zn) is fairly uniformly distributed throughout the bottom waters of the harbor; however, there is a higher frequency of Zn detections in West Loch and in the outer Main Channel. The highest harbor water concentration (1.6 ppm) was found in bottom waters at the channel entrance to Pearl Harbor (CA). Zn was detected in storm drains entering South Channel and Southeast Loch; however, the highest source water concentration (1.7 ppm) was found in the inactive fleet sewage outfall (SS10). Zn was frequently detected in all sewage outfalls at mean levels of approximately 0.03 ppm. Zn also was detected in most streams at 0.03 ppm levels or below. The significantly high Zn burdens in the sediments of South Channel, Southeast Loch and near the Whiskey Docks correspond to frequent Zn detection in bottom waters at these same locations.

In summary, heavy metals are, with the exception of Hg, more frequently detected in source water from storm drains, sewers and industrial outfalls than in harbor waters. The metals Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn are all detected in storm drains entering South Channel and Southeast Loch. One such drain (B447) entering South Channel near bio-station BE-03 registers the highest detected concentrations for three metals (Cr, Cu and Pb). With the exception of Mn and Fe, streams entering Pearl Harbor are low in heavy metals, although Cd, Cu, Ni and Zn are detected. Cd was detected only in Waimalu Stream, which also registers the highest source concentrations of both Mn (2.86 ppm) and Ni (0.18 ppm). Waiau Stream registers moderately high Cu concentrations (0.23 ppm). With the exception of Cd, metallic detections in harbor waters correlate fairly well with significantly high metallic burdens in the sediments. Insufficient water detections existed, however, for Ag, Cd, Hg and Ni.

PHYSICAL PARAMETERS

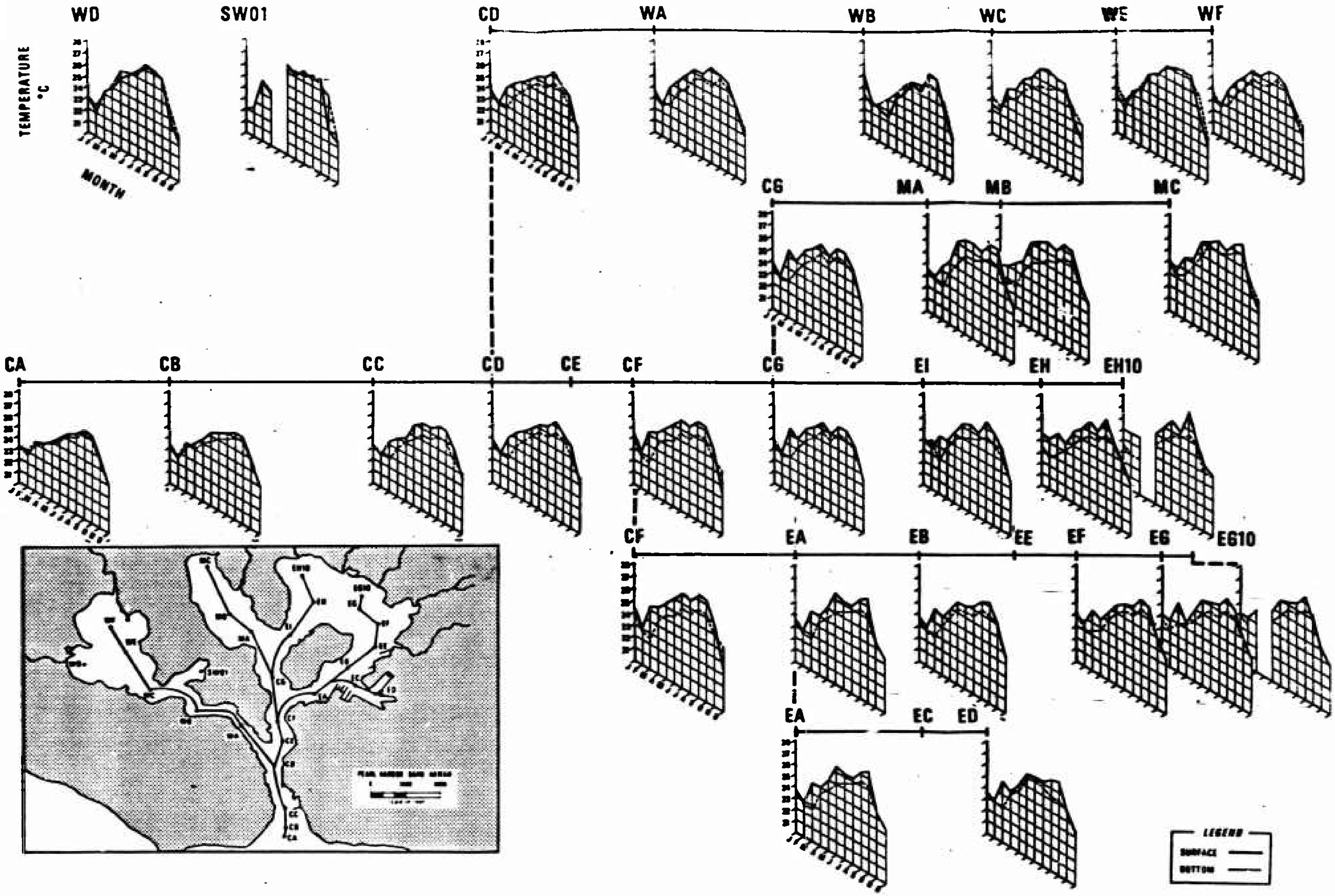
Included in these parameters are: temperature, salinity, dissolved oxygen, water clarity, turbidity and pH. Values for these parameters at the ten bio-stations have been summarized in Table 3.2-2. Variations of these parameters for Pearl Harbor as a whole are discussed here. Where appropriate, their possible influence on the marine communities at specific bio-stations will be pointed out. The various parameters are covered in the order given above.

The temperature regime for Pearl Harbor is shown in Figure 3.2-2. In this figure, monthly mean temperatures are plotted by range. All stations appearing on the straight lines shown in Figure 3.2-1 constitute a range. The ranges themselves are displayed according to the lochs of Pearl Harbor in order of the range center's approximate distance from the channel entrance, see insert in lower left-hand corner of Figure 3.2-2. A few singular stations (EG10, EH10, SW01 and range WD) are also included, since they represent conditions in the uppermost regions of the lochs. An inspection of Figure 3.2-2 shows the seasonal temperature regime of the harbor as a whole to be fairly uniform. Water temperatures in the upper reaches of all lochs tend to show slightly greater summer temperature excursions due to insolation than stations in the Main Channel or in the lower portion of the lochs. This difference in temperature excursion is more apparent when bottom-water temperatures for channel and upper loch stations are compared. During the fall, cooling of bottom waters apparently lags slightly behind that of the surface waters. Note that because of their location, temperature excursions at the bio-stations are always less than the extremes found in the upper reaches of the lochs. In Figure 3.2-3, a simplified range format is used to display the mean annual surface temperature and the surface temperature range. In this figure, the slight increases in mean temperature shown at locations EH10, EG and EG10 may reflect the anomalous heat source introduced into East Loch by the Hawaiian Electric Company's Waiau power plant. This plant discharges approximately 530 mgd of coolant waters which are 5.5° to 7.2°C above ambient (Reference 3.2-8). The seasonal surface temperature excursion for Pearl Harbor as a whole is summarized in Figure 3.2-4. The highest average surface temperature (28.2°C) occurred in September, and the lowest (23.1°C), in February.

On the basis of the uniform temperature regime throughout the harbor, little differential response at the ten bio-stations would be expected. Indeed, none is shown (Table 3.2-2). Certain anomalous temperature situations, summarized in Figures 3.2-5 and 3.2-6, might be expected to elicit some sort of biologic response. BC-10 is the only active bio-station located near one of these thermal disturbances. BE-17 is probably too distant from the thermal plume generated by Navy power plant #2, and BE-06, near the Waiau plant, was discontinued due to lack of funds. Figures 3.2-6 A, B and C indicate the extent of the surface thermal plumes resulting from the two Navy power plant discharges. Inspection of Tables 3.2-2 and 3.2-3 shows that the thermal anomaly is not apparent in the deeper waters at BC-10, and probably not even in the surface waters. Although BC-10 is rated as a relatively "poor" bio-station and the presence of the thermal outfall is noted in Section 4.7, its biological condition is probably not a direct response to the thermal anomaly.

The salinity regime for Pearl Harbor as a whole is shown in Figure 3.2-7. Presentation is exactly similar to that just described for temperature.

(Text continued on page 3.2-26)



GENERAL LAYOUT OF PEARL HARBOR SHOWING MEAN MONTHLY TEMPERATURE VARIATION BY RANGE FOR SURFACE AND BOTTOM WATERS.

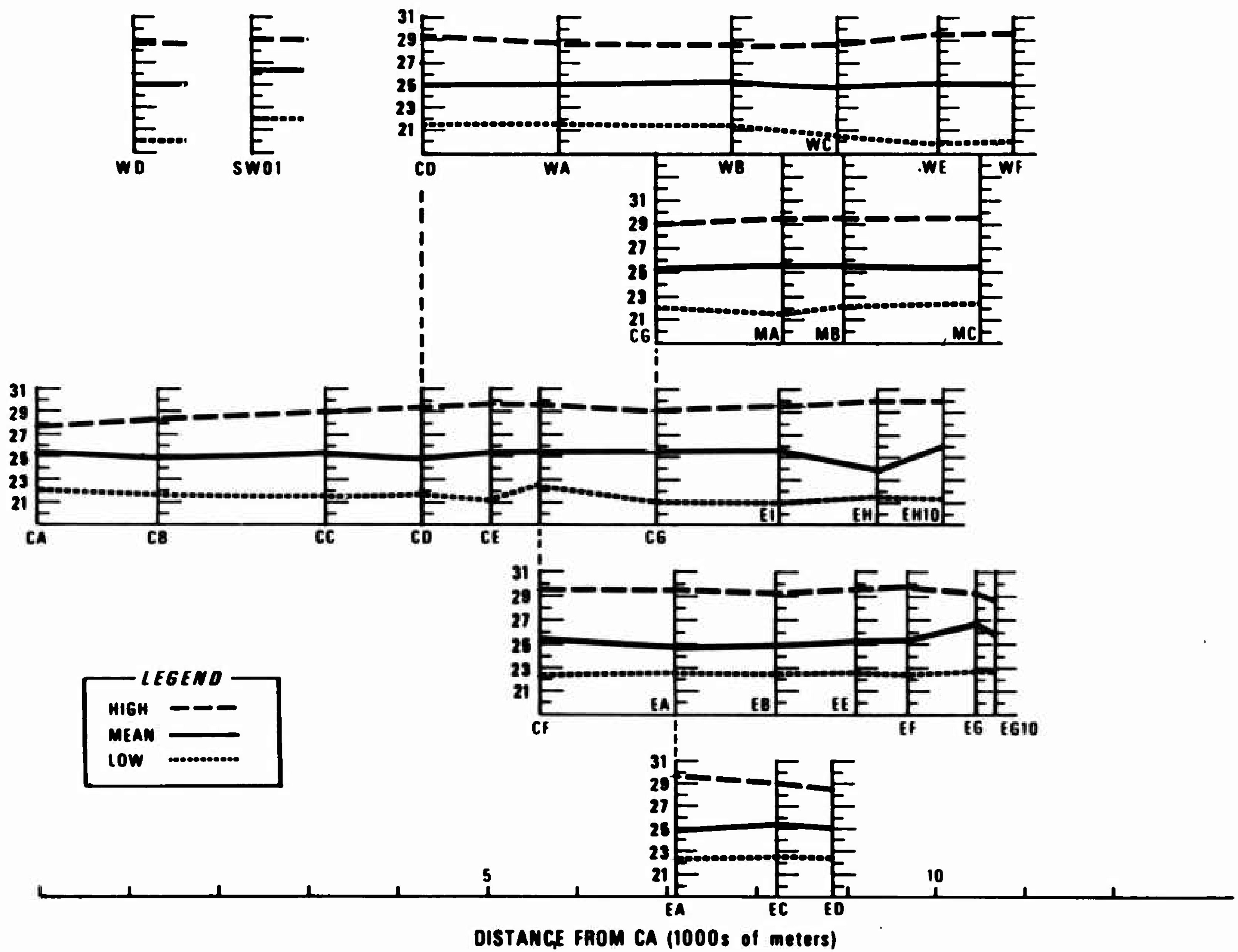


Figure 3.2-3. MEAN ANNUAL SURFACE WATER TEMPERATURE (°C) BY RANGE. (annual minimum and maximum temperatures also given)

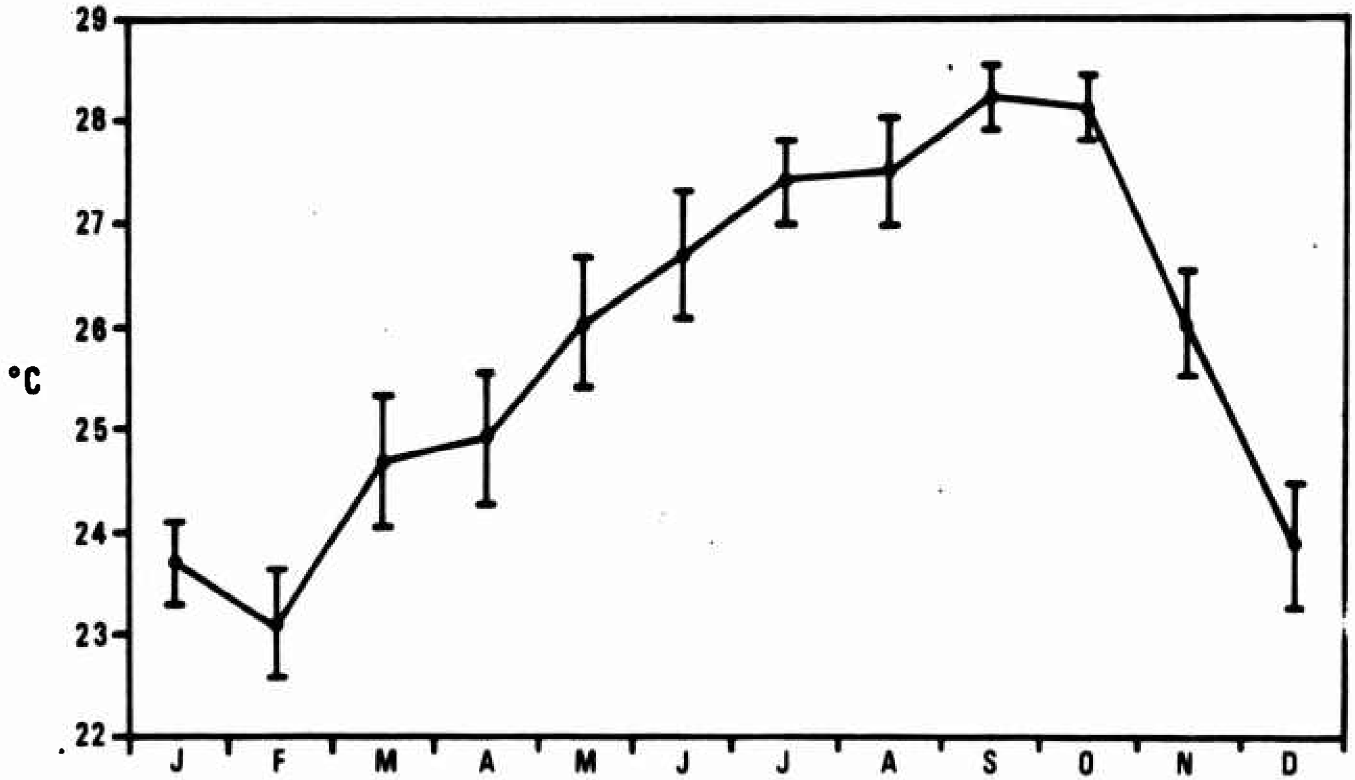


Figure 3.2-4. VARIATION OF AVERAGE MONTHLY TEMPERATURES (°C) in PEARL HARBOR. (mean ± one standard deviation shown)

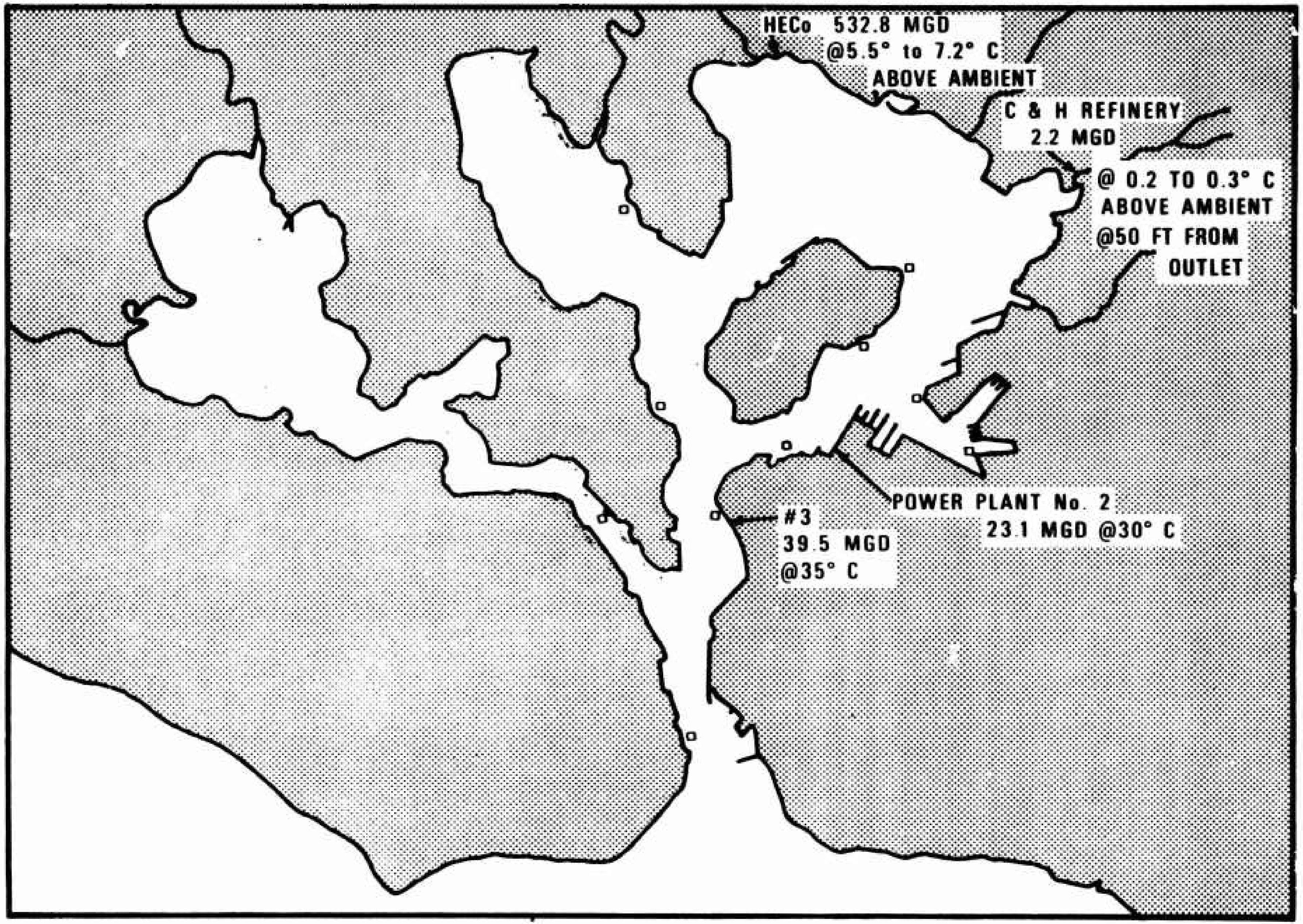
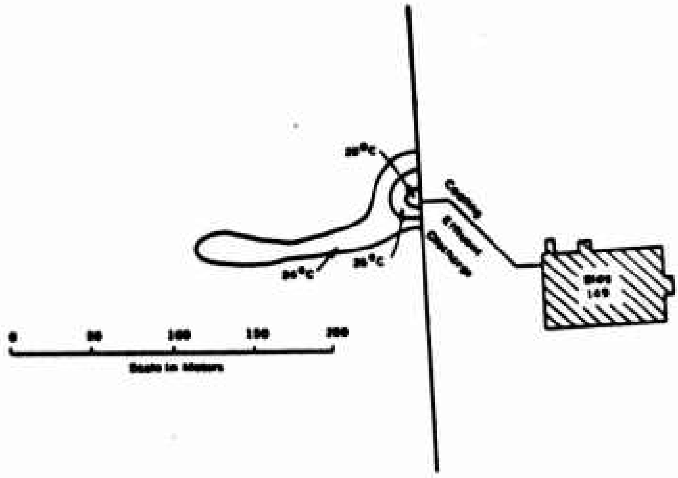
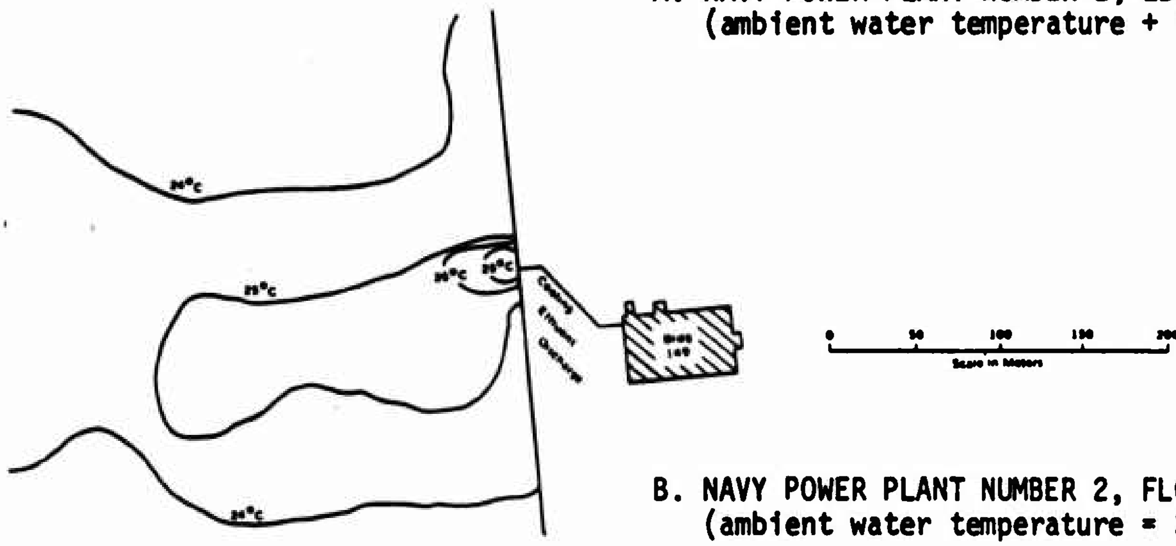


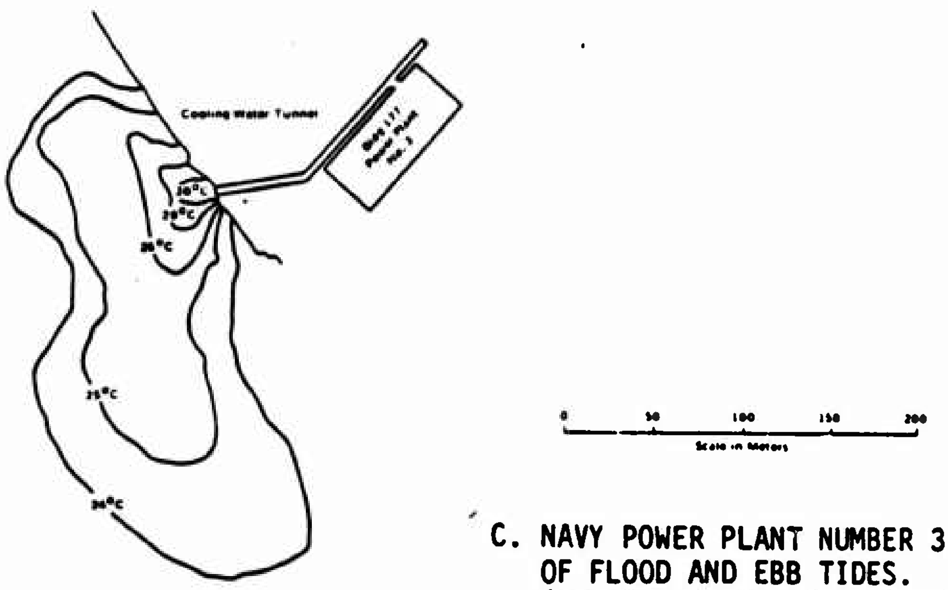
Figure 3.2-5. LOCATION OF ANOMALOUS THERMAL SOURCES IN PEARL HARBOR.



A. NAVY POWER PLANT NUMBER 2, EBB TIDE.
(ambient water temperature + 23°C)



B. NAVY POWER PLANT NUMBER 2, FLOOD TIDE
(ambient water temperature = 24°C,



C. NAVY POWER PLANT NUMBER 3, COMPOSITE OF FLOOD AND EBB TIDES.
(ambient water temperature = 23°C)

Figure 3.2-6. SURFACE WATER TEMPERATURE CONTOURS FOR NAVY THERMAL DISCHARGES.

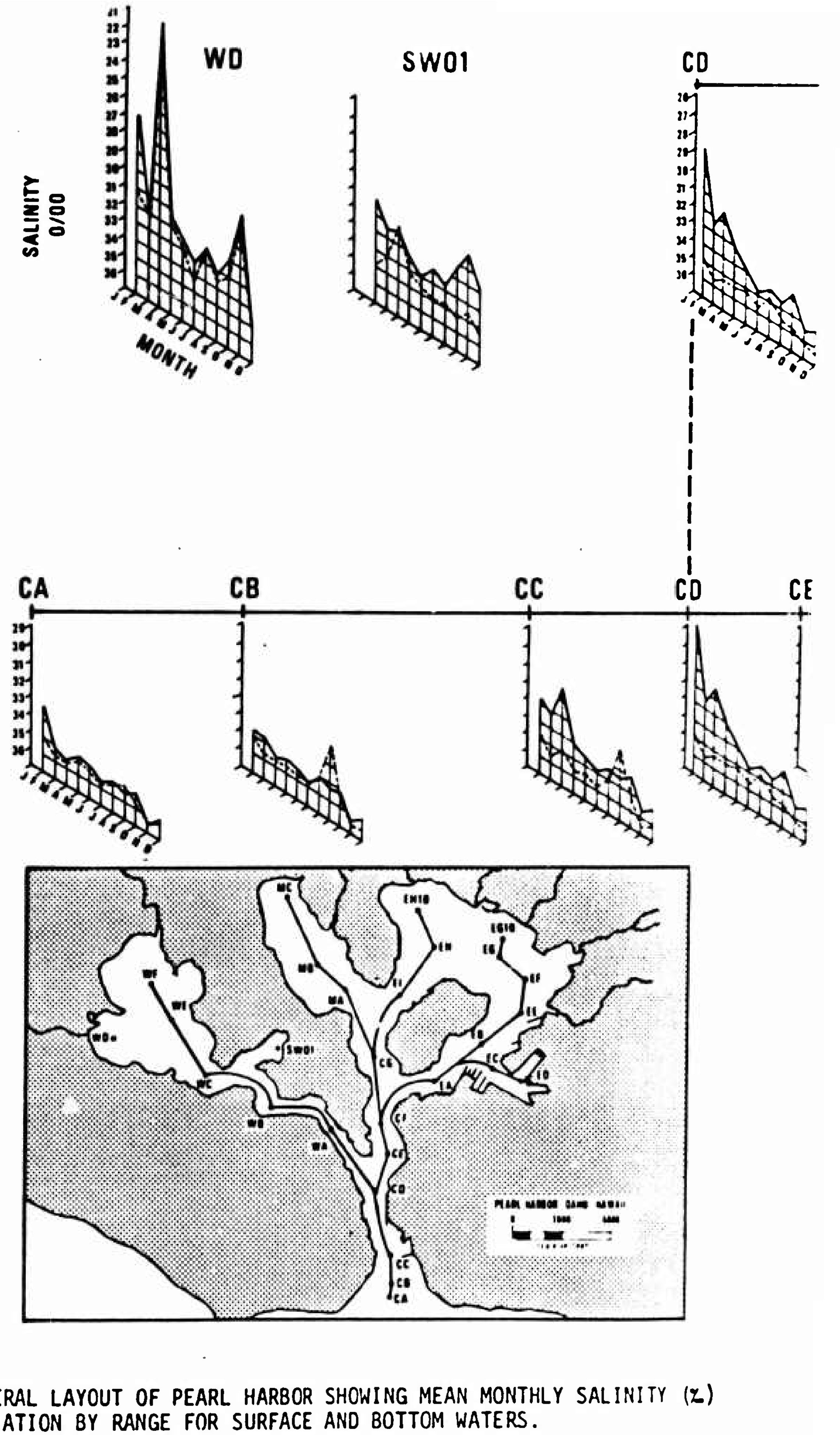
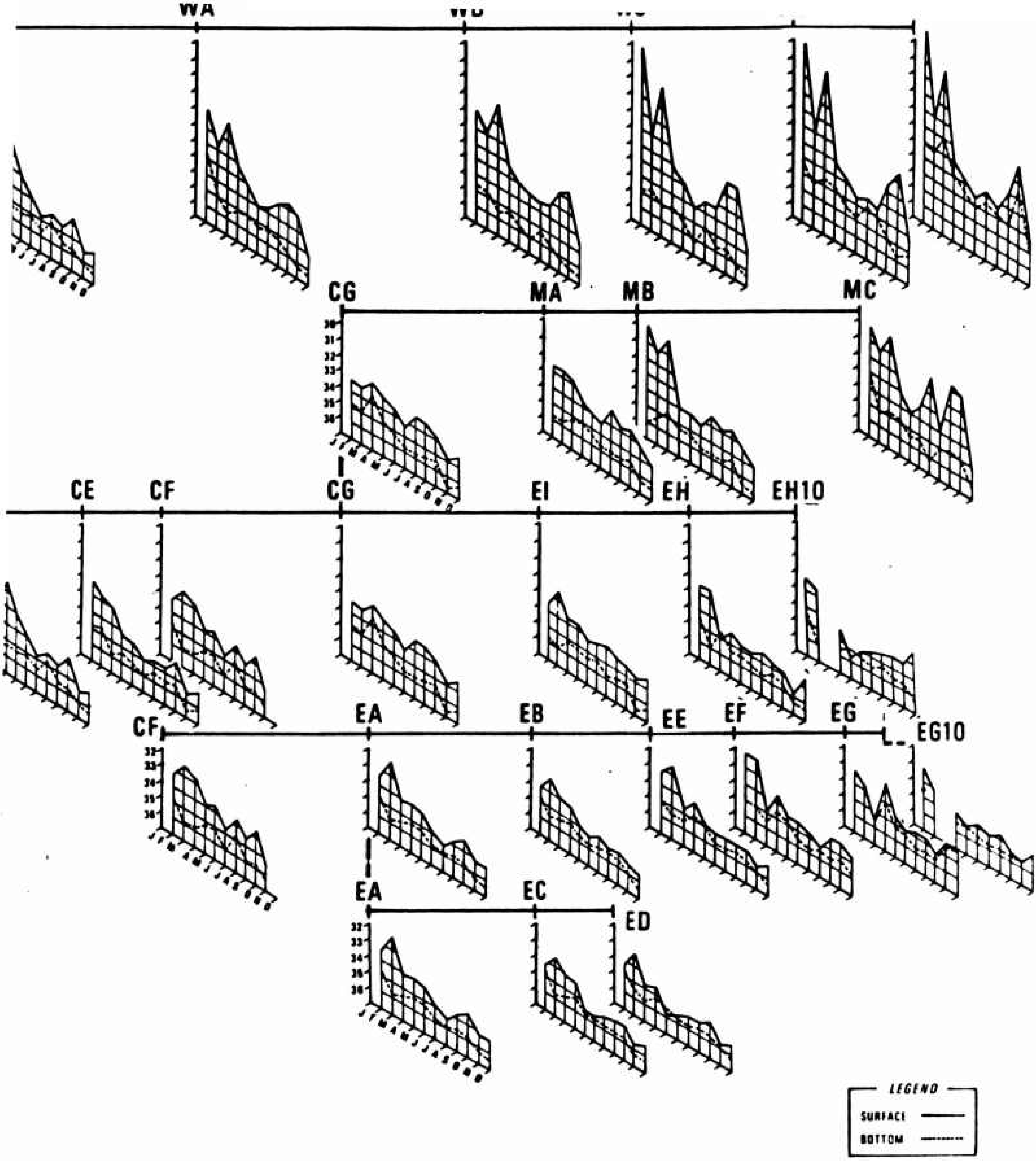


Figure 3.2-7. GENERAL LAYOUT OF PEARL HARBOR SHOWING MEAN MONTHLY SALINITY (‰) VARIATION BY RANGE FOR SURFACE AND BOTTOM WATERS.


WA
CG
MA
MB
MC
CE
CF
CG
EI
EH
EH10
CF
EA
EB
EE
EF
EG
EG10
EA
EC
ED
LEGEND
SURFACE
BOTTOM

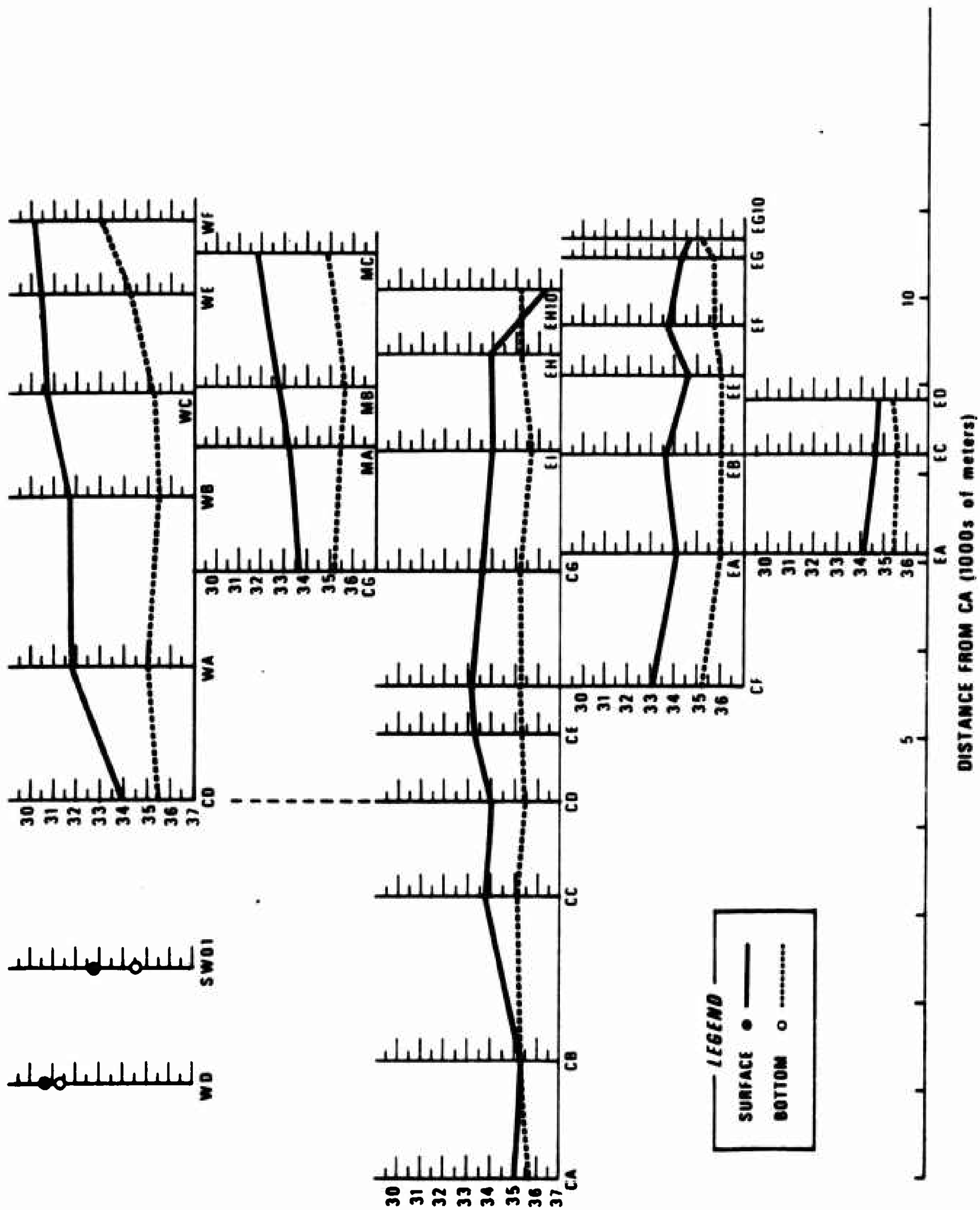
In this figure, the salinity scale has been reversed, since this procedure lends itself to clearer presentation of a salt-wedge estuary (see Section 3.3). The influence of fresh water runoff on surface salinities is especially apparent during the winter months in West Loch and somewhat less so in Middle Loch. The salinity of bottom waters in West Loch also responds to winter runoff, especially in the upper reaches of the loch. The influence of West Loch may even be seen in the Main Channel where West Loch joins it at range CD. Seasonal salinity variations in the remainder of Pearl Harbor are not as great. Mean annual surface and bottom salinities for the harbor as a whole, presented in the simplified format used for temperature, are shown in Figure 3.2-8. In this figure, the surface brackish layer overlying oceanic waters is apparent (oceanic mean is 35‰). Not shown in the figure are the extremes in salinity. Surface salinities in the upper lochs reach lows due to runoff of 14.1‰ and 14.3‰, respectively, on ranges WD and WF; these same ranges also show bottom water lows of 15.8‰ and 17.3‰. The surface low of 19.4‰ at BC-09 (Table 3.2-2) should be noted. Since such an extreme is not seen in the remainder of Middle Loch, the low at BC-09 is probably due to irrigation tailwaters. The highest salinity (37.5‰) was recorded for bottom water at the channel entrance (range CA). High surface salinities due to evaporation are not apparent in the harbor.

Again, on the basis of their location, none of the bio-stations experience maximum seasonal excursions in salinity (Tables 3.2-2 and 3.2-3). Little differential biologic response would be expected and, indeed, none is shown (Table 3.2-2).

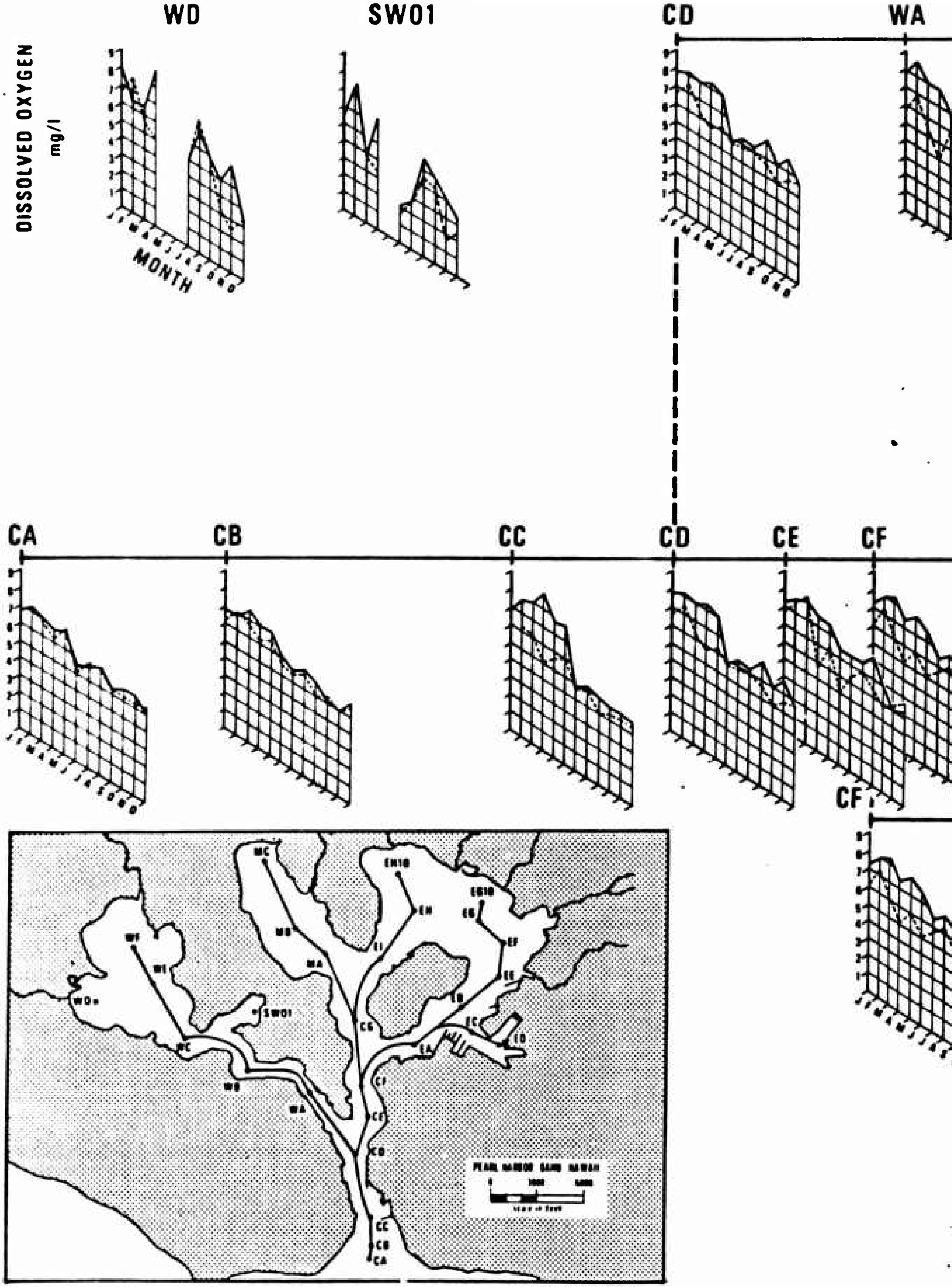
Using the same format, the daytime dissolved oxygen (DO) regime for Pearl Harbor as a whole is shown in Figure 3.2-9. Due to the sampling schedule used by the Data Base team, DO measurements were taken principally during the morning hours, thus the full diurnal regime is not reflected in this figure. Surface water DO levels generally remain above 6 ppm, being highest in the late winter and spring, declining during the summer, and reaching lows close to the 6 ppm value during the early winter. DO levels in the bottom waters are everywhere depressed, but are close to or above the 6 ppm value for all channel ranges and most of the ranges in East Loch. Bottom-water levels in upper West and Middle Loch are considerably depressed below the surface levels and often fall below the 6 ppm level. Extreme lows of 0.1 ppm are reported for the bottom waters of both lochs. Annual mean DOs by range are presented in simplified format in Figure 3.2-10. In this figure, the extreme lows do not show up; however, the depressed oxygen levels in the bottom waters of the upper regions of all lochs, including Southeast Loch, are quite apparent. Mean lows for mid-morning DOs of 3.5 and 2.8 ppm are reported in Middle Loch and West Loch, respectively. Bottom conditions in Middle Loch around the Pearl City STP diffusers are even lower than those plotted for the ranges; stations SM01 through SM06 exhibit mean lows for bottom waters ranging from 1.4 to 2.5 ppm with a mean mean for these stations of 1.5 ppm. It is again emphasized that these are mid-morning DO values.

The lack of data on the complete diurnal cycle of DO levels are regrettable. Some observations of diurnal changes from early morning (0700) to early afternoon (1430) were obtained during the fall months. Data for the

(Text continued on page 3.2-31)

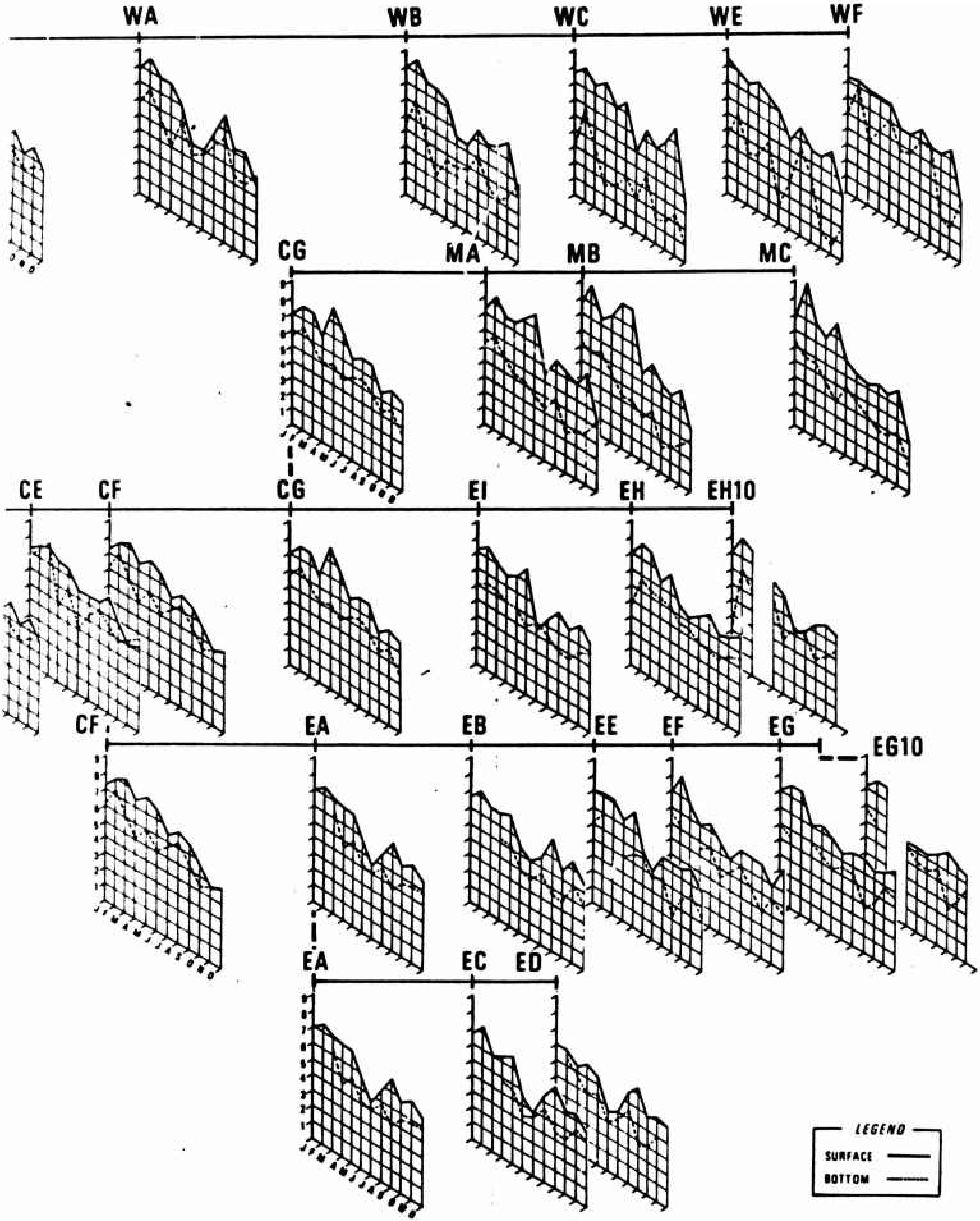


LEGEND
SURFACE ● ——
BOTTOM ○ ------
DISTANCE FROM CA (1000s of meters)
5
10
CA
CB
CC
CD
CE
CF
CG
WD
SW01
WA
WB
WC
WE
WF
MA
MB
MC
EI
EH
EH10
EA
EB
EE
EF
EG
EG10
EC
ED
30
31
32
33
34
35
36
37



e 3.2-9. GENERAL LAYOUT OF PEARL HARBOR SHOWING MEAN MONTHLY DISSOLVED OXYGEN (ppm) VARIATION BY RANGE FOR SURFACE AND BOTTOM WATERS. (dissolved oxygen determinations for morning hours only)

1 of 2


WA
WB
WC
WE
WF
CG
MA
MB
MC
CE
CF
CG
EI
EH
EH10
CF
EA
EB
EE
EF
EG
EG10
EA
EC
ED
LEGEND
SURFACE
BOTTOM

342

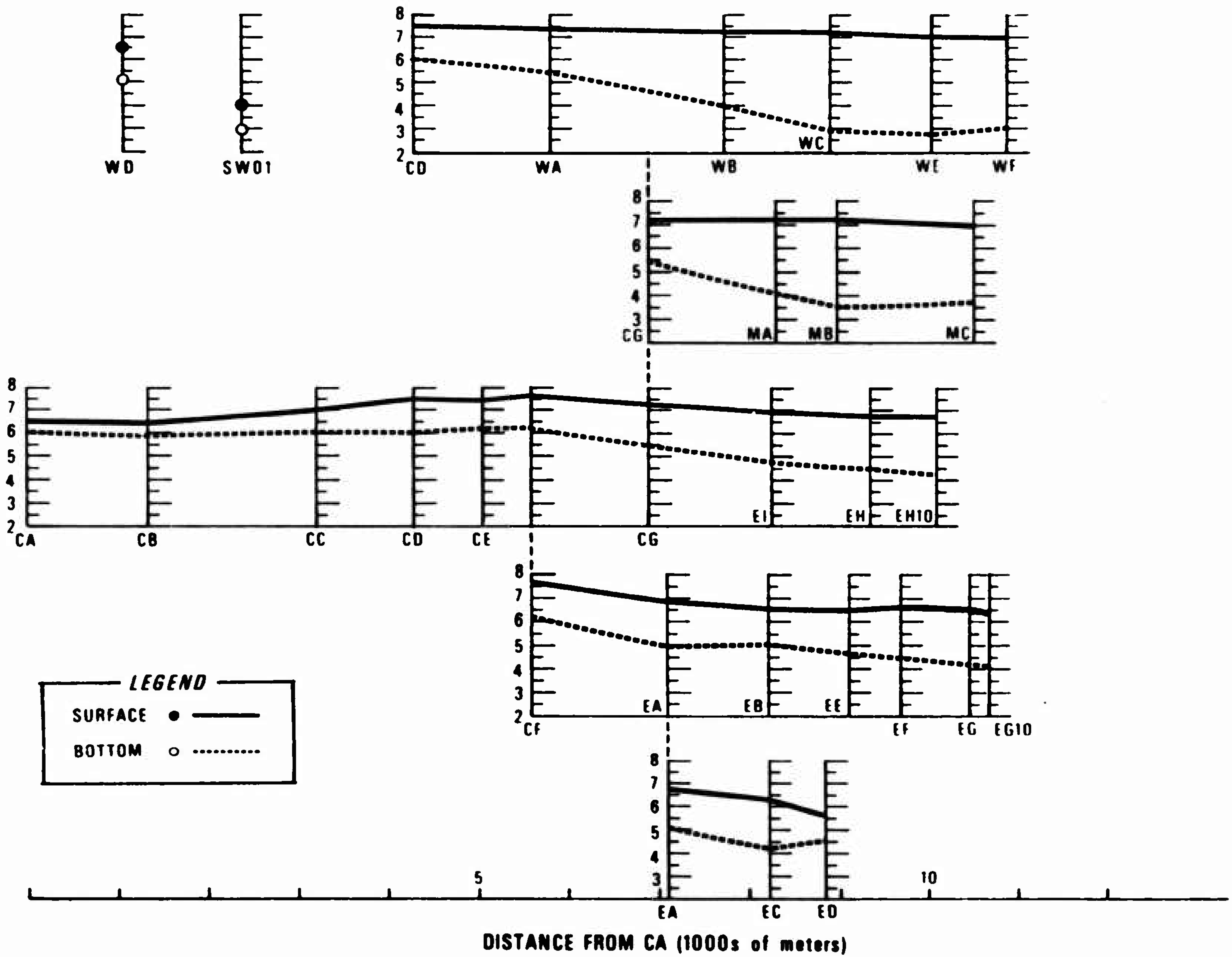


Figure 3.2-10. MEAN ANNUAL SURFACE AND BOTTOM DISSOLVED OXYGEN LEVELS (ppm) BY RANGE. (dissolved oxygen determinations for morning hours only)

main body and the upper reaches of each of the lochs are presented in Figure 3.2-11. The bottom waters of all lochs exhibit early morning lows undoubtedly reflecting nighttime depression in DO level. Early morning surface and subsurface DO values of 0 ppm have been reported for many locations in Pearl Harbor (page 23 of Reference 3.2-9). It is probable that the subsurface waters of most West and Middle Lochs and the upper regions of East Loch can become severely depleted in oxygen during the night. Outer Main Channel bottom waters show no morning depression in Figure 3.2-11 and probably do not suffer oxygen depletion during the night. Interestingly, a mid-depth layer in the neighborhood of the Whiskey Docks exhibits DO levels which are lower than the bottom waters at the same location. The bottom waters in the lower portions of the lochs (and in the shallow waters of upper West Loch) usually show a characteristic increase in oxygen level as the day progresses. Such increases were not observed in the bottom waters of Middle Loch or in the deeper, upper reaches of East Loch; however, they probably do occur.

The mean DO levels measured in source waters range from a low of 0.8 ppm from a drain emptying near Halawa Stream (SD58) to a high of 10.3 ppm reported for Halawa Stream itself. Oxygen levels in streams average around 6.7 ppm (n = 210) with a range from 1.1 ppm measured in Honouliuli to 18.8 ppm measured in Halawa Stream. The depressed oxygen levels in the bottom waters of Middle Loch are almost certainly the result of discharges from the City and County's sewage oxidation ponds on Waipio Peninsula and from the Pearl City sewage treatment plant. Conditions in West Loch appear to have improved since a survey done in 1969 (Reference 3.2-9), possibly because raw sewage from Waipahu is no longer discharged into this loch. Black and septic wastewater from Oahu Sugar Company's oxidation ponds (SS50) is, however, being discharged into Walker Bay. Their effect may be seen at station SW01 (Figure 3.2-10).

As reported above, both the fish and the piling communities at the biostations show a response to mean DO levels. A correlation coefficient of +.72 was found between mean DO and total number of fish. Similar positive correlations are found for the other biological data summarized in Table 3.2-2. These correlations were discovered and reported (Reference 3.2-7) in an earlier analysis of the data. Although such correlations are gratifying, they can hardly be considered unexpected.

Several different measurements of water clarity were made by the Data Base team. These included routine Secchi disc casts made in the field and water turbidity measured in the laboratory with a Hach turbidimeter. In addition, a number of casts were made with a transmissometer and there are many verbal descriptions of water clarity made by SCUBA divers on the biological survey team. The transmissometer data, summarized in Figure 3.2-12, and the reports of the divers indicate that there is a turbid surface layer in West and Middle Lochs. Under this surface layer water clarity increases. This surface "turbidity" is due primarily to suspended silt introduced into the harbor by streams. The net effect of suspended silt on water clarity is correctly shown by the Secchi disc readings which are summarized by range in Figure 3.2-13. Secchi disc readings, which are an inverse measure of surface water clarity, drop from a high of 17.4 meters at the channel entrance to lows of 0.9 and 0.7 meters, respectively, in the upper reaches of West Loch and Walker Bay (SW01). Hach turbidimeter readings, which report

(Text continued on page 3.2-35)

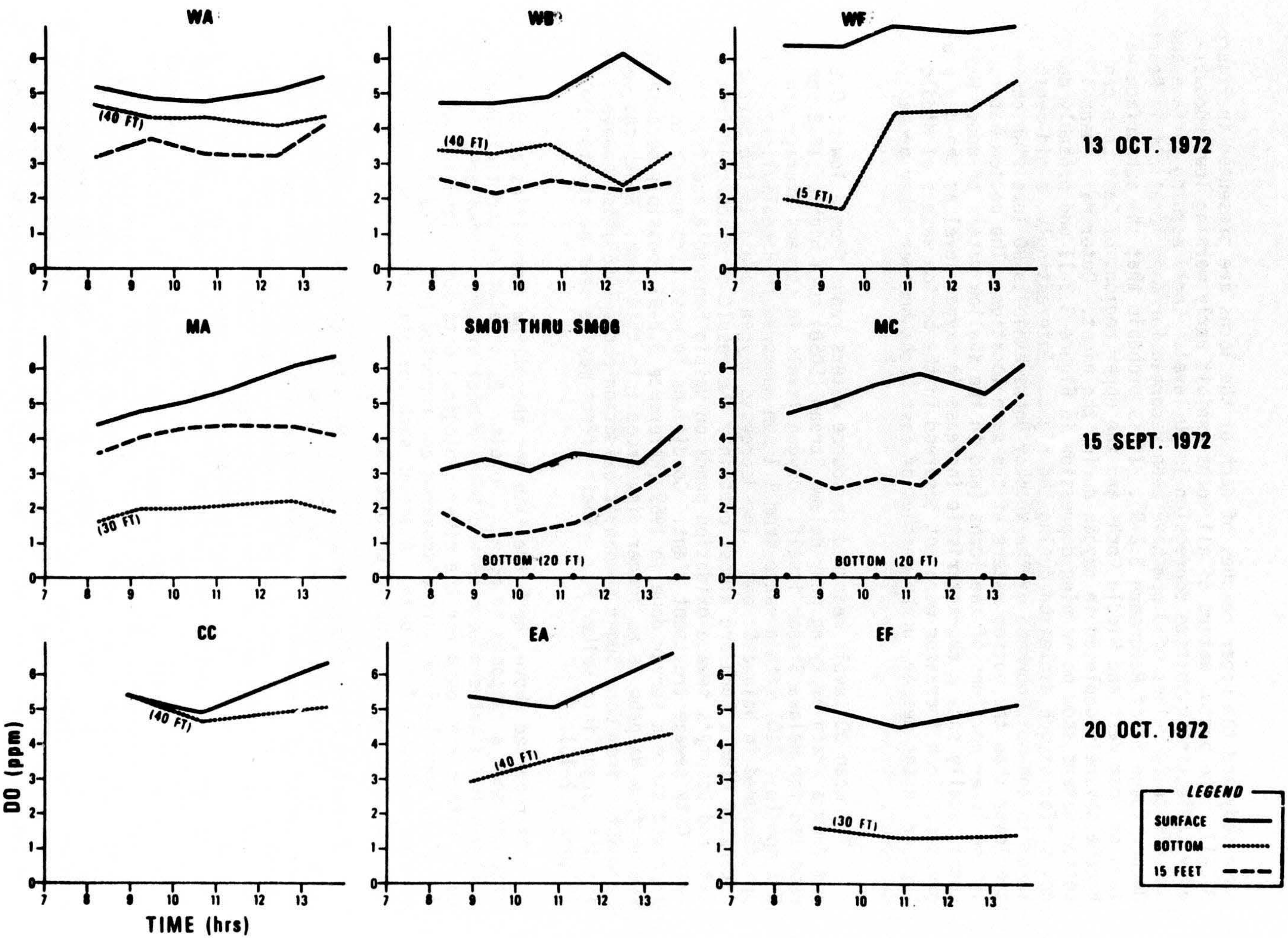
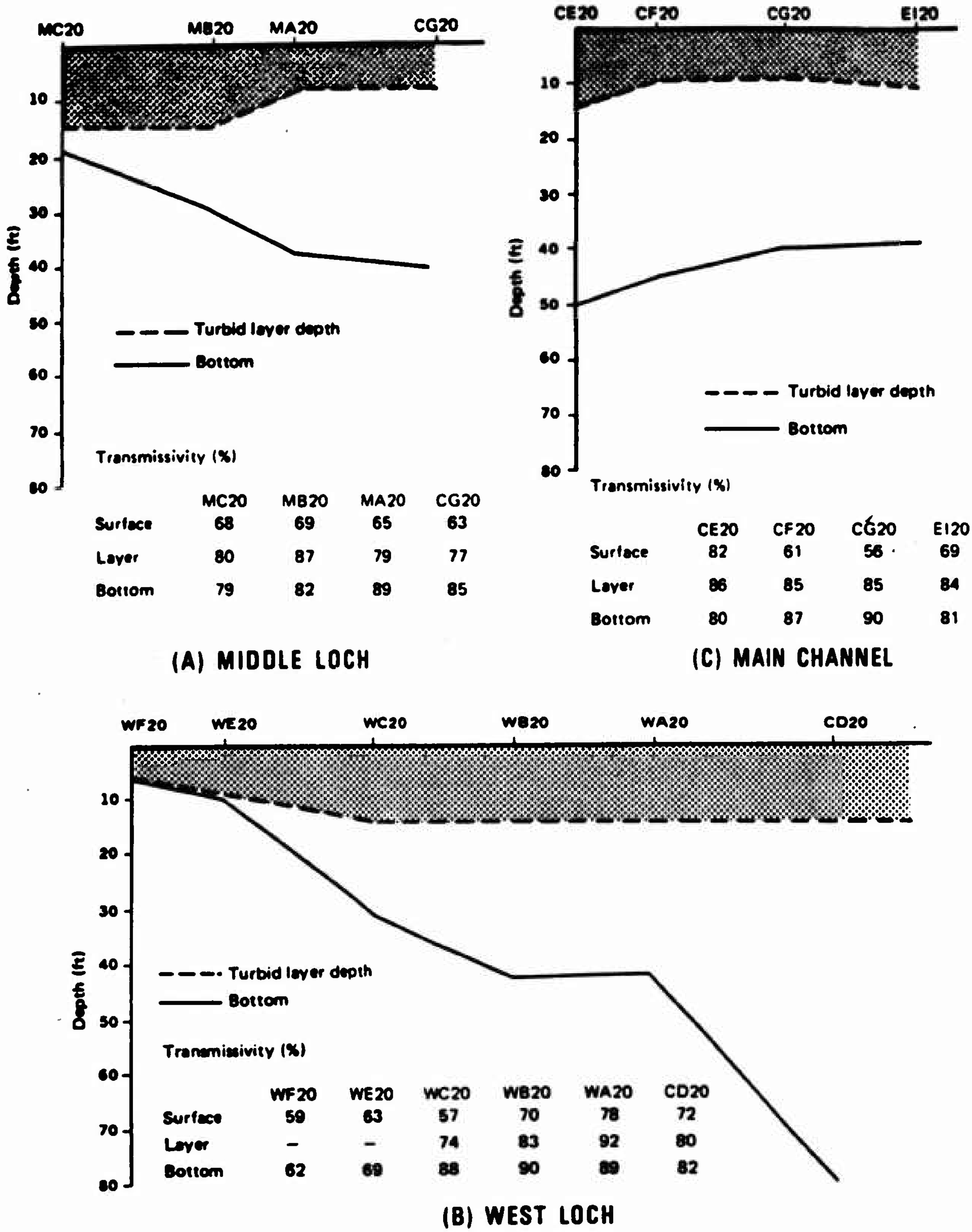


Figure 3.2-11. VARIATION IN DISSOLVED OXYGEN LEVELS (ppm) DURING THE DAY FOR SELECTED LOCATIONS IN PEARL HARBOR.



(A) MIDDLE LOCH — Transmissivity (%)

	MC20	MB20	MA20	CG20
Surface	68	69	65	63
Layer	80	87	79	77
Bottom	79	82	89	85

(C) MAIN CHANNEL — Transmissivity (%)

	CE20	CF20	CG20	EI20
Surface	82	61	56	69
Layer	86	85	85	84
Bottom	80	87	90	81

(B) WEST LOCH — Transmissivity (%)

	WF20	WE20	WC20	WB20	WA20	CD20
Surface	59	63	57	70	78	72
Layer	–	–	74	83	92	80
Bottom	62	69	88	90	89	82

Figure 3.2-12. CROSS SECTIONAL PLOTS OF TRANSMISSOMETER READINGS TAKEN ON 2 JUNE 1972. (surface turbid layer and bottom contours shown)

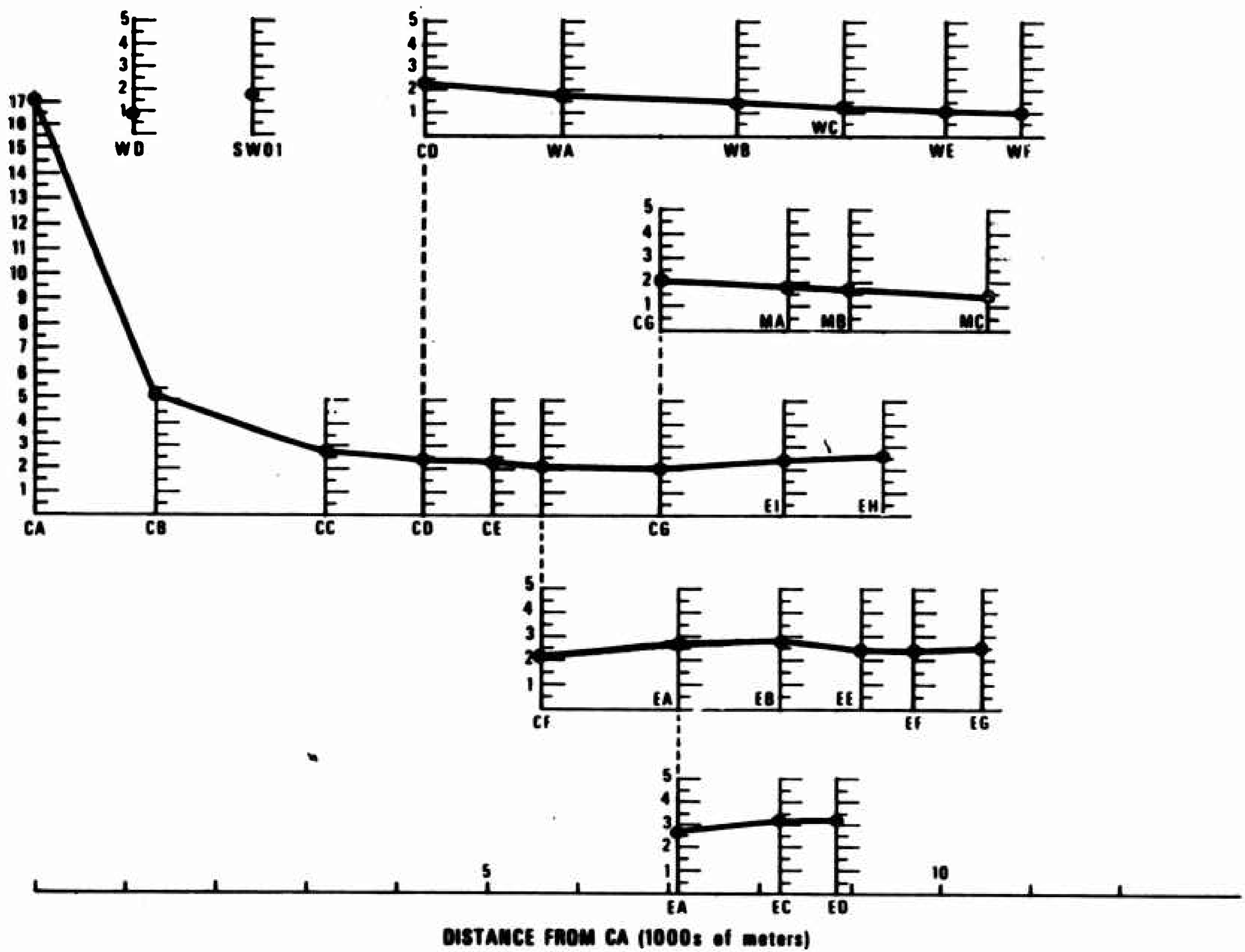


Figure 3.2-13. MEAN ANNUAL SECCHI DISC READINGS (meters) BY RANGE.

90° scattered light intensity in Jackson Turbidity Units (JTU), are summarized by range in Figure 3.2-14. Both turbidimeter and Secchi disc readings are given for the bio-stations in Table 3.2-3. Although there is a strong negative correlation (-.80) between these two readings for the bio-station data, readings in the harbor as a whole show only moderate negative correlation (-.40). This fact suggests that silt may be an interfering factor in the correlation since all the bio-stations are located in relatively clear waters when compared to the upper reaches of the lochs. Due to the nature of the two measures, negative correlation coefficients would be expected.

It is also apparent both from Table 3.2-3 and Figure 3.2-14 that bottom waters consistently give higher turbidity readings than surface waters, a fact which apparently is inconsistent with the diver reports, Secchi disc readings and transmissometer readings. All measurements are, however, correct and the apparent inconsistency illustrates an important point. Diver estimations of water clarity, Secchi disc readings and transmissometer readings are all long-light-path measures of transmitted light. The turbidimeter reading is a short-light-path measure of scattered (not transmitted) light, which apparently does not give high readings for the amounts of silt normally suspended in the surface waters of Pearl Harbor. The progressive increase in turbidity shown for West Loch as the upper ranges are approached may, however, be such a response to silt (see upper plot in Figure 3.2-14). In addition to silt, the turbidimeter also measures reflected light from suspended matter such as finely divided organic material and microorganisms which appear transparent to the diver under transmitted light. Underwater flash photographs taken in apparently clear water well illustrate this problem, note backscatter around yellow jack *Gnathanodon specioseus* in Figure 3.2-15. Turbidimeter readings, therefore, are a measure of the amount of suspended organic and living particulates. Unfortunately, the measure in Pearl Harbor is confounded by the presence of silt. The higher readings for bottom waters suggest that they contain more living, or at least organic, matter than the surface waters. This difference may be real, since pollutants, fresh water (which is toxic to many marine forms) and suspended silt are all more abundant in the surface waters. The possibility of sediment contamination in the bottom samples is fairly well ruled out by the differences in the distribution of heavy metals discussed above.

The seasonal variations in both Secchi disc and turbidimeter readings are erratic, especially so for the turbidimeter readings. Secchi disc readings in the Main Channel show a slight tendency to increase during the dry months and to decrease during the rainy months. For all seasons, Secchi disc readings are lower and turbidimeter readings are higher in West and Middle Lochs than in the Main Channel and East Loch. The lowest mean turbidimeter readings (1.0 JTU with a range of 0.2 to 5.0) are reported for the surface waters at the channel entrance (range CA), the highest mean readings (27.9 JTU with a range of 3.0 to 280) are reported for the bottom waters at station SM02. Secchi disc readings were not taken in source waters, but turbidimeter readings were. Streams showed a mean turbidity of 20.8 JTU (n = 266) with a range from 1.1 JTU to 240 JTU, both in Kalauao Stream. Most streams showed similar wide ranges in turbidity, probably reflecting the amounts of silt being transported by runoff. Both low (0.6 JTU) and high (180 JTU)

(Text continued on page 3.2-38)

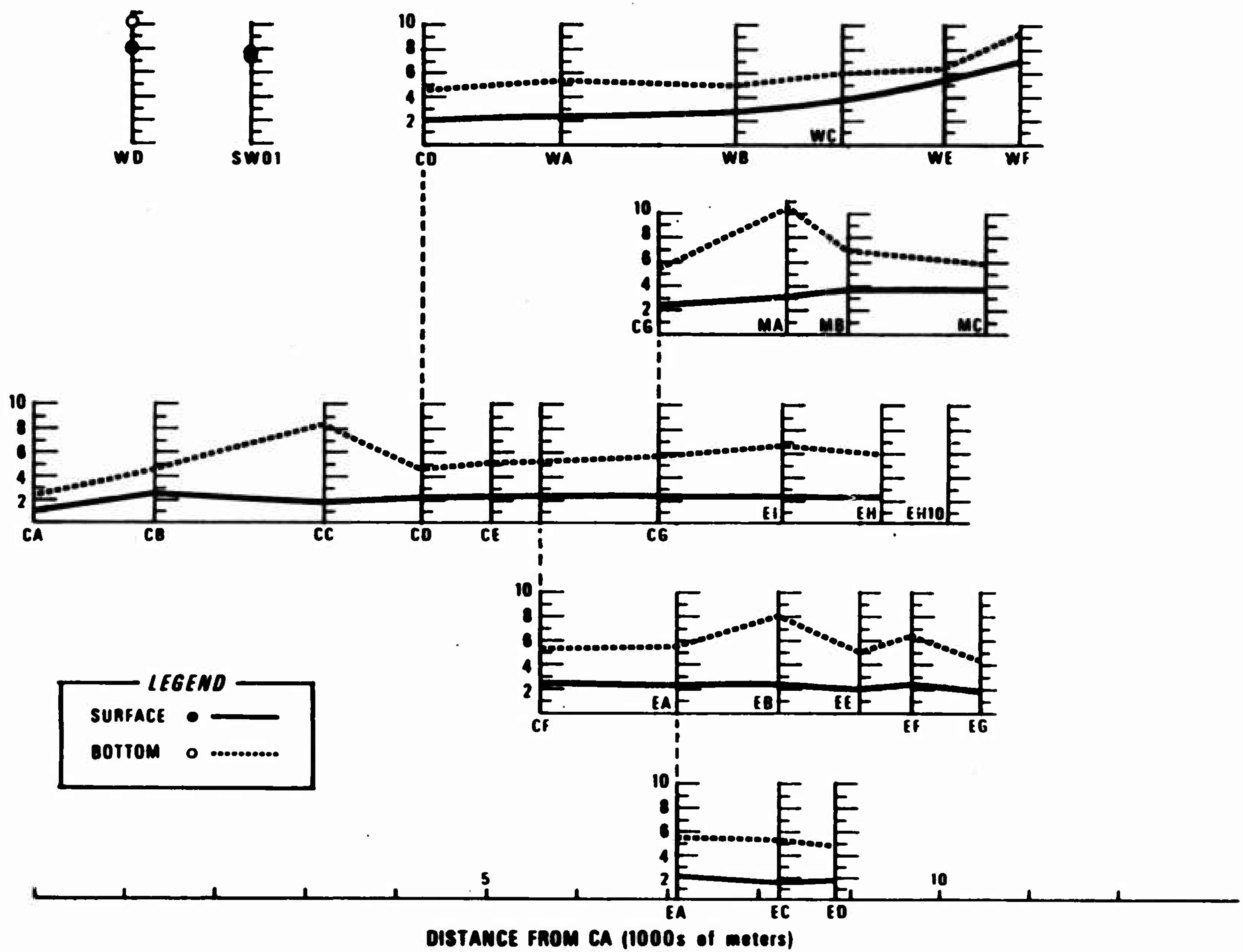


Figure 3.2-14. MEAN ANNUAL SURFACE AND BOTTOM TURBIDIMETER READINGS (JTU) BY RANGE.

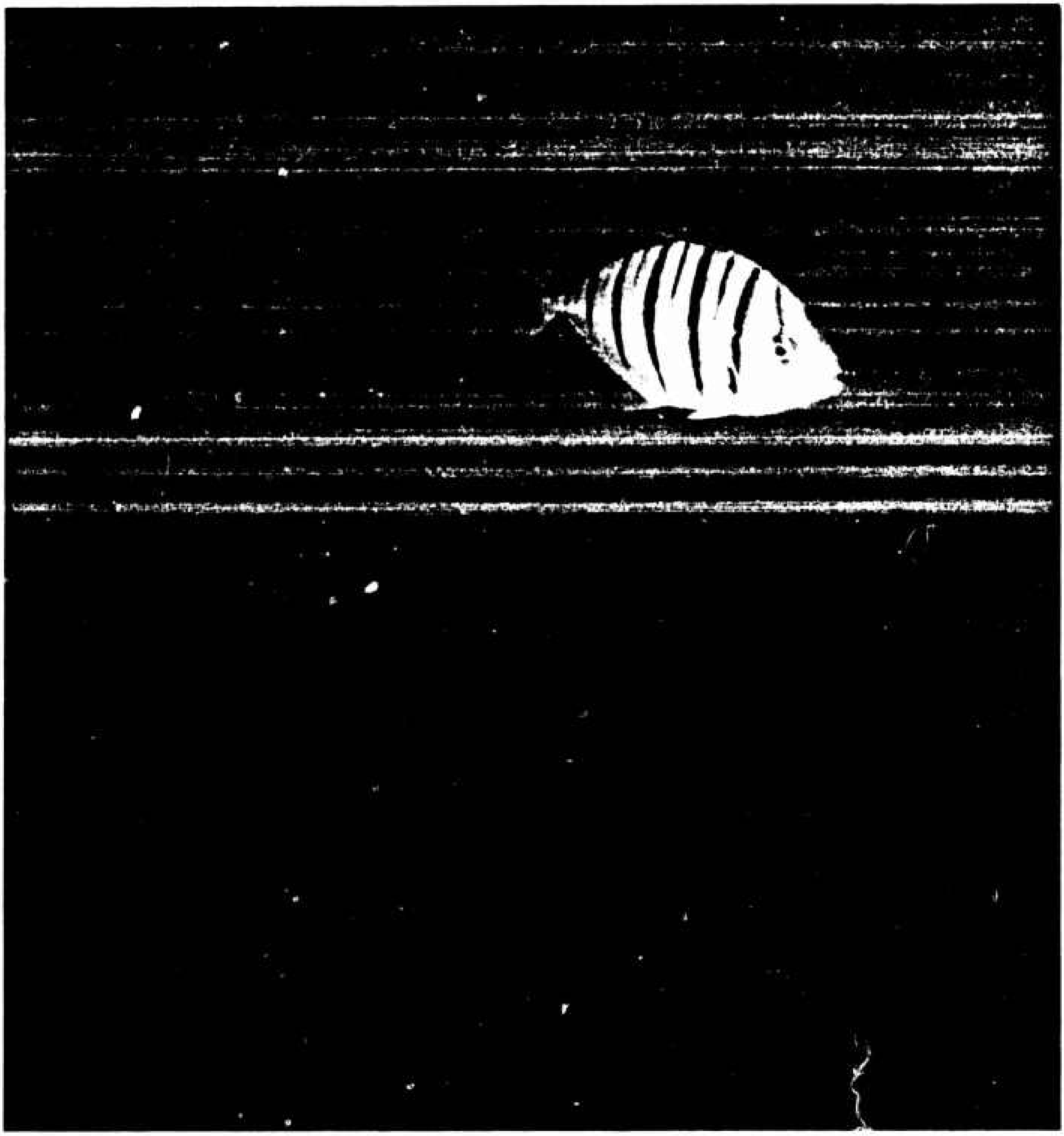


Figure 3.2-15. UNDERWATER FLASH PHOTOGRAPHS OF YELLOW JACK (*Gnathanodon speciosus*) TAKEN IN APPARENTLY CLEAR WATER BY TRANSMITTED LIGHT.

values of turbidity were found in storm drains entering South Channel and Southeast Loch. The highest source turbidity (mean of 146 JTU with a range from 10 to beyond the capacity of the instrument) was found in the discharge from the City and County oxidation ponds on Waipio Peninsula (SS09).

Although biological responses to turbidity are suggested in the discussion above, no significant correlations with the biological data are shown in Table 3.2-3. There are a number of possible explanations for this lack of correlation. Interference due to silt may be a factor. The material causing the reported higher turbidities in bottom waters may be largely inert or simply not suitable as food for filter feeding organisms.

The last of the physical parameters is hydrogen ion concentration or pH. Although this parameter can be important biologically, it is hardly so in a well buffered medium such as the ocean. Nearly 4000 pH measurements were routinely taken by the Data Base team. Throughout the harbor mean pH values were close to the oceanic mean, 8.2. Values ranged from a low of 6.0 reported for the bottom waters at ranges CD and ED, to a high of 9.0 reported in the surface waters at bio-station BC-09. Bottom waters tended to be 2 to 3 tenths less alkaline than surface waters. Source waters showed a much wider range of pH values. The lowest mean pH of 4.2 (with a range of 3.4 to 6.0) was reported for the aerated sewage discharge from the inactive fleet (SS10). The highest mean pH of 8.6 (with a range of 7.4 to 10.1) was reported for a storm drain entering South Channel near Dry Dock #1 (B005). This is drainage from the area of the Pipe and Copper Shop and the Forge and Galvanizing Shop. Streams were slightly more acid than seawater, averaging 7.6 (n = 148) and ranging from 6.0 in Kalauao to 9.6 in Halawa Stream.

NUTRIENTS

The Data Base survey included the analysis of water samples for the following nutrients: total phosphorous, total Kjeldahl nitrogen, nitrate nitrogen, nitrite nitrogen and ammonia nitrogen. Since statistical analysis (see Section 4.2) of the nutrient data showed little useful correlation to the biological data, only a few nutrients are summarized here as an example on nutrient conditions in Pearl Harbor. For information on the other nutrient measures, see Reference 3.2-1. Although not strictly a nutrient, total organic carbon (TOC) is also included as a biologically active constituent.

The total phosphorous content of Pearl Harbor waters (reported as elemental P in ppm) is summarized by range in Figure 3.2-16 and is also mapped for the harbor as a whole in Figure 3.2-17. The higher phosphorous values in surface waters of West and Middle Lochs are readily apparent, as are the highs associated with sewage outfalls from Ford Island and Hammer Point. In Figure 3.2-16, the elevated mean concentrations at ranges CD and CG probably reflect the confluence of waters from West and Middle Lochs at these locations. Seasonal variations in phosphorus content show a high for both West and Middle Lochs in June 1972 and also an increase in both lochs during the fall months (Figure 3.2-18). The Main Channel and East Loch show little seasonal variation in total P.

(Text continued on page 3.2-42)

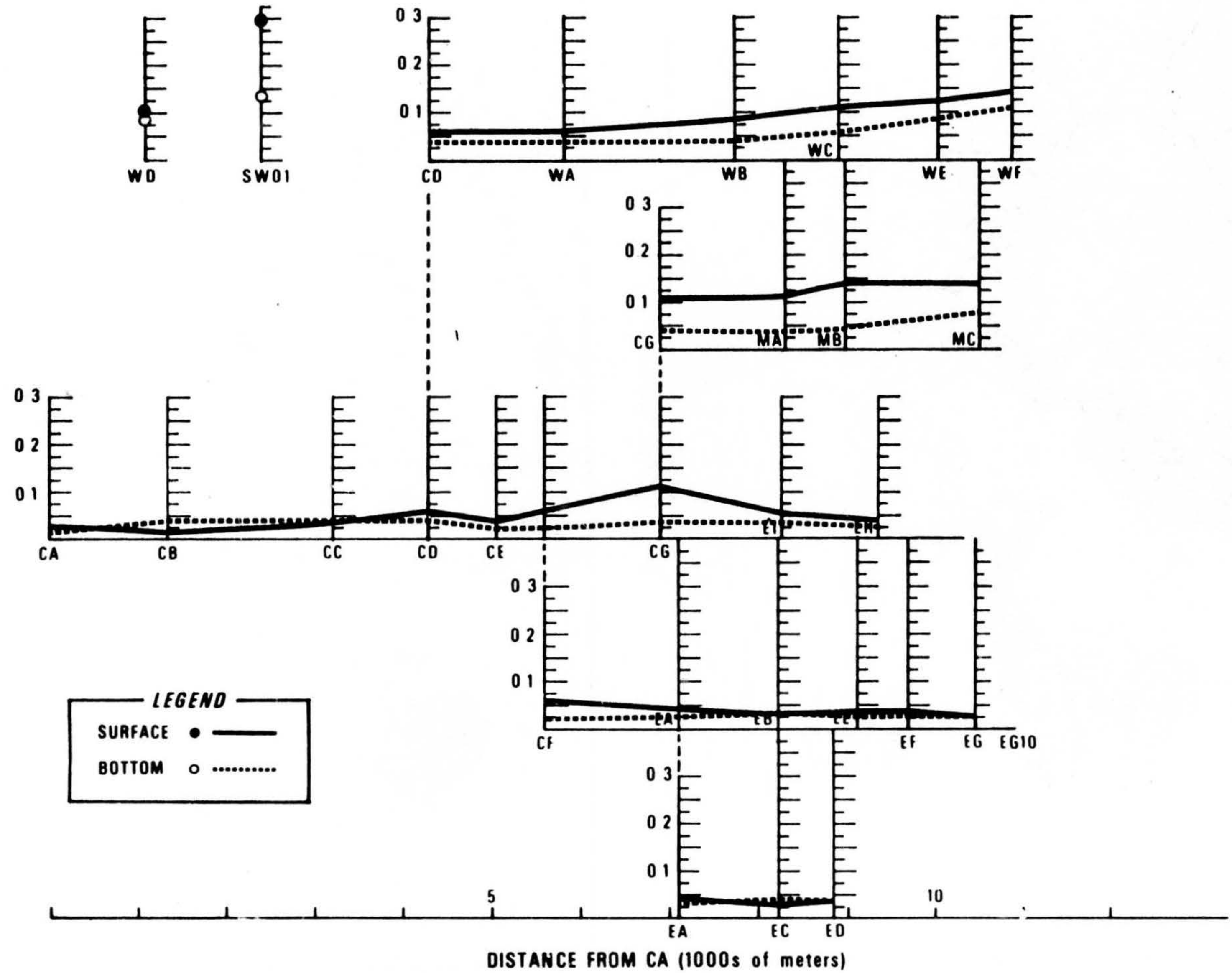
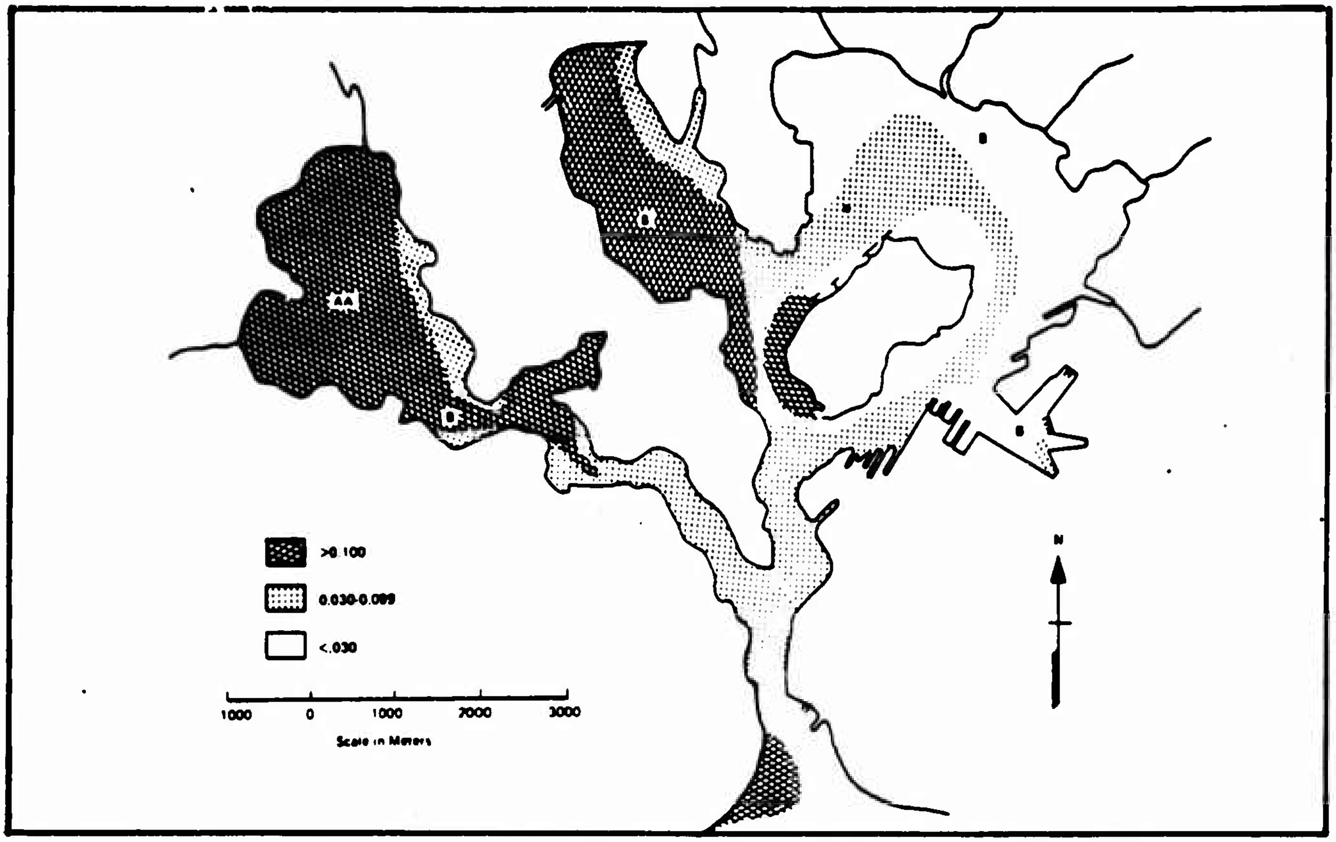
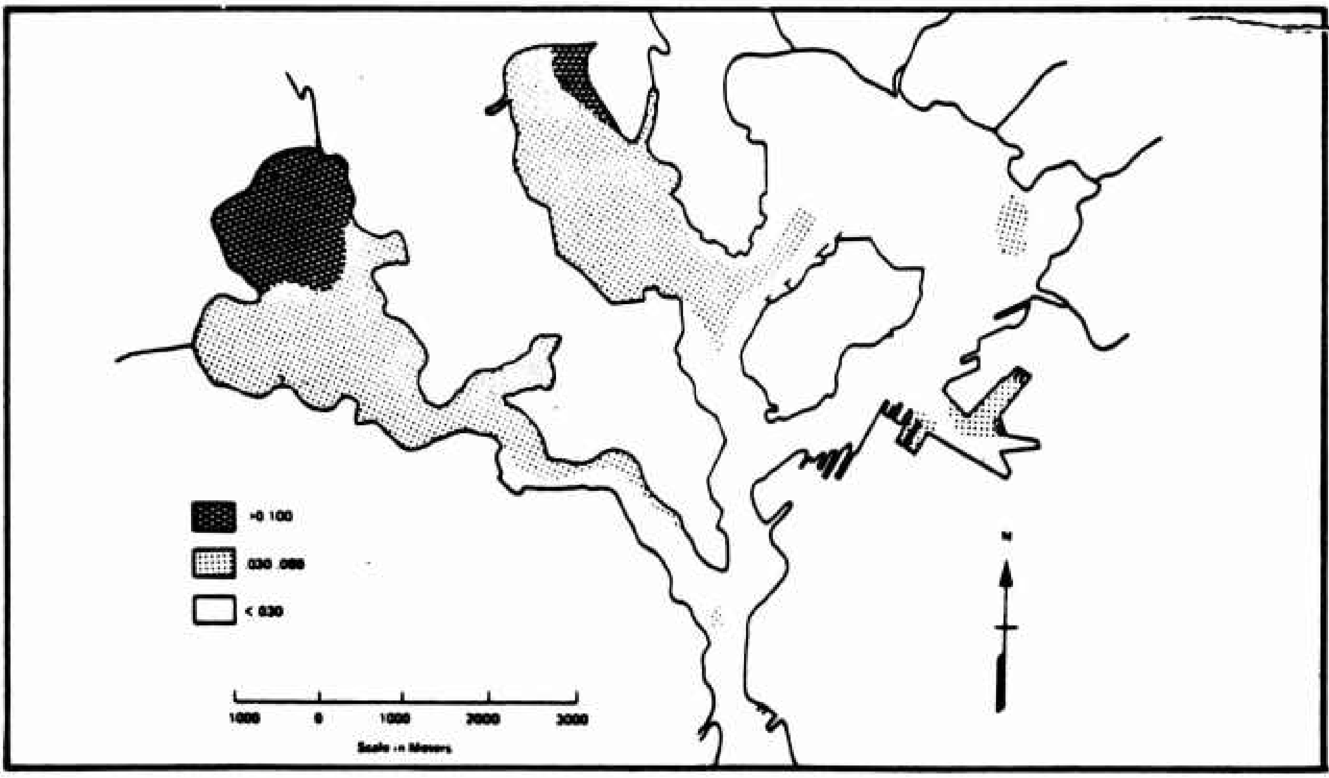


Figure 3.2-16. MEAN AN...AL TOTAL PHOSPHOROUS CONTENT (ppm) IN SURFACE AND BOTTOM WATERS BY RANGE.



A. SURFACE WATERS



B. BOTTOM WATERS

Figure 3.2-17. DISTRIBUTION OF TOTAL PHOSPHOROUS IN THE WATERS OF PEARL HARBOR.

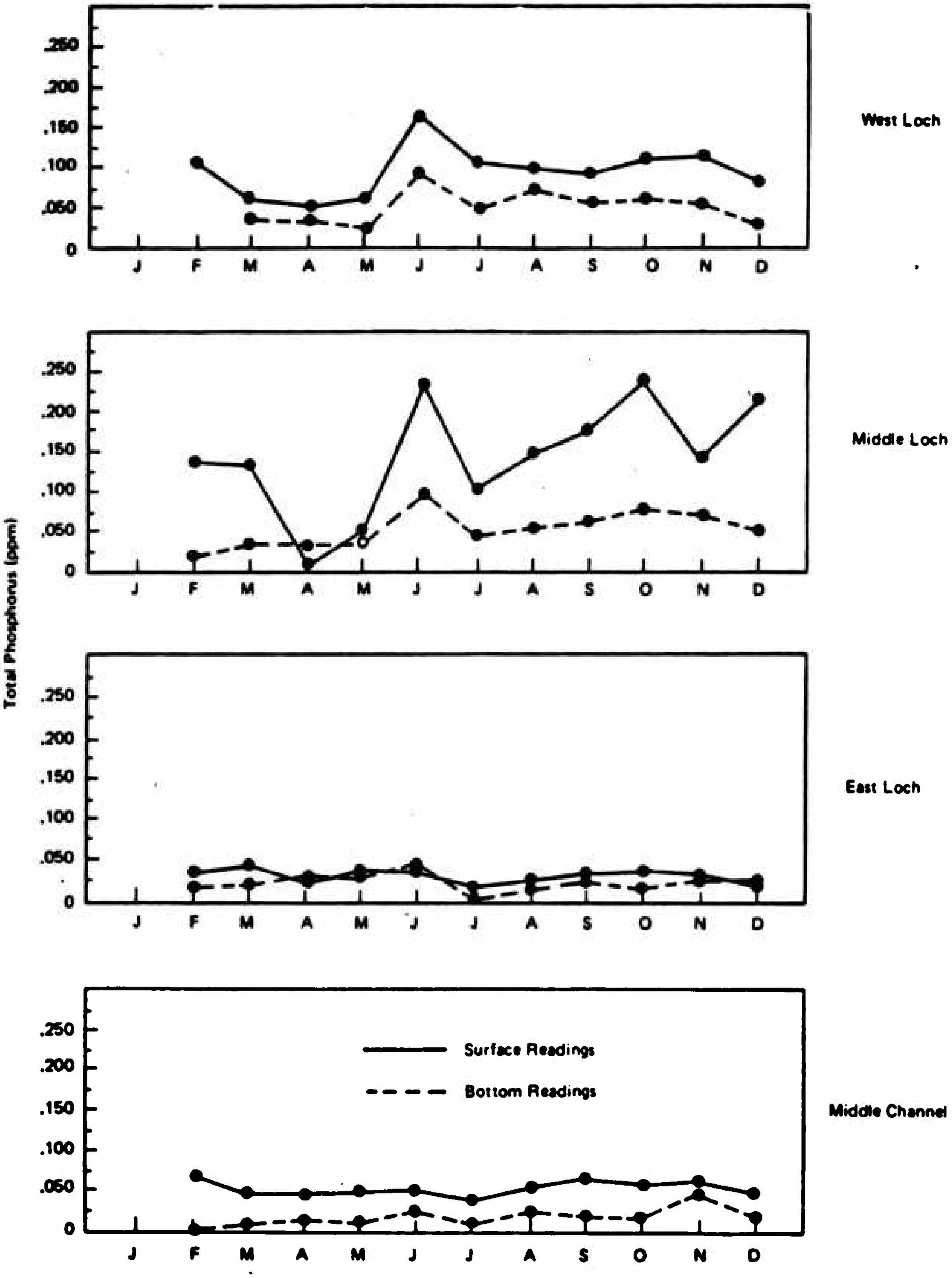


Figure 3.2-18. MONTHLY VARIATION IN TOTAL PHOSPHOROUS CONTENT (ppm) IN THE LOCHS OF PEARL HARBOR.

Lowest mean phosphorous content (0.014 ppm with a range from below detection to 0.100) was found in the bottom waters at the channel entrance (range CA), while the highest mean (0.292 ppm with a range of 0.07 to 1.36) was found in the surface waters of Walker Bay (SW01). For source waters, the lowest mean (0.023 ppm with a range from below detection to 0.04) was found in the drainage from Hawaiian Electric's ponds (SN11) and the highest mean (2.69 ppm with a range from 1.87 to 4.04) for the discharge from Ford Island STP (SS40). A more precise analysis of phosphorous distribution is presented in Table 3.2-7. In this table, various sources have been combined on the basis of the loch into which they flow. Note that both the storm drains and the streams emptying into West Loch average higher in total P than the remainder of the sources. The very high phosphate content (0.858 ppm, n = 18) of Waiau Stream should, however, be noted.

Both Kjeldahl nitrogen and ammonia nitrogen (reported as elemental N in ppm) are summarized in similar manner (Tables 3.2-8 and 3.2-9), since the nitrogen content in bottom waters shows very high correlation (+0.92) with the piling community. The surface waters of Middle Loch are seen to be highest in both nitrogen and total phosphorus. Although bottom waters are lower than the surface, Middle Loch again shows the highest concentration for the two nitrogens; phosphorus is highest in the bottom waters of West Loch. West Loch source waters are again highest in nitrogen as they were for phosphorus, streams flowing into West Loch being especially high. Source waters flowing into Southeast Loch are next highest in all three nutrients. For Pearl Harbor as a whole, there is little variation in nitrogen content (Figures 3.2-19 and 3.2-20), except that the heads of West and Middle Lochs are notably high. There is a slight elevation in Kjeldahl nitrogen where West Loch joins the Main Channel at range CD; the peak in bottom waters at range CB could be due to the Hammer Point STP diffusers, but if so, range CC should also be high. Some additional data on the four forms of nitrogen are presented in Table 3.2-10. Although the piling communities show high correlation with two forms of nitrogen, factor analysis of neither the water quality means nor the piling community does not offer any explanation (cf. Figures 4.2-3 and 4.6-6). Perhaps the correlation is spurious, although this seem unlikely. In any event, additional field data would be required to resolve the question.

The total organic carbon (TOC) content of Pearl Harbor waters is summarized by range in Figure 3.2-21. TOC in seawater is reported to range between 0.02 and 4.0 ppm (Reference 3.2-10); the mean value for Pearl Harbor as a whole was 3.8 ppm with a range from below detection limits (0.5 ppm) to 62 ppm in Main Channel surface waters (range CD). As seen in Figure 3.2-21, harbor surface waters generally tended to be higher in TOC than bottom waters. Annual mean concentrations show a low of 0.7 ppm with a range from 0.5 to 1.0 in bottom waters at SM03 and a high of 7.3 ppm with a range from below detection limits to 17 in surface waters at SE01. There is no significant correlation (-.31) between mean TOC and mean turbidity of bottom waters from Pearl Harbor. For source waters, TOC values range from below detection limits to a mean high of 395 ppm (range 50 to 828) found in irrigation waters draining into Walker Bay (SS50). Streams averaged 5.0 ppm (n = 132) with TOC values ranging from below detection limits in a number of streams to 118 ppm in Aiea Stream.

(Text continued on page 3.2-50)

Table 3.2-7. MEAN PHOSPHOROUS CONTENT OF HARBOR AND SOURCE WATERS.

Pearl Harbor (elemental P in ppm (n)) Location	Surface	Bottom
West Loch (incl. SW01)	0.116 (232)	0.075 (219)
Middle Loch	0.161 (193)	0.064 (168)
East Loch	0.035 (299)	0.028 (279)
Southeast Loch	0.029 (53)	0.026 (51)
Main Channel	0.053 (268)	0.031 (222)
Bio-Stations	0.047 (136)	0.032 (121)
Source Waters (elemental P in ppm (n))		
Sewage Discharges	1.972 (68)	
Industrial Discharges	0.258 (21)	
Storm Drains		
West Loch	0.481 (47)	
Middle Loch	0.109 (34)	
East Loch	0.189 (13)	
Southeast Loch	0.212 (82)	
Main Channel	0.044 (11)	
Streams and Springs		
West Loch	0.498 (61)	
Middle Loch	0.167 (39)	
East Loch	0.200* (136)	

* note high of 0.858 (18) on Waiau Stream

Note: Sewage Discharges: SS01, SS07, SS09, SS10, SS11, SS17, SS19, SS40, SS50; Industrial Discharges: SS02, SS04, SS15, SS16, SS30; Storm Drains, West Loch: SD03, SD15, SD17, SD18, SD20, SD22, SD23, SD24; Storm Drains, Middle Loch: SD-30, SD31, SD32, SD37, SD41; Storm Drains, East Loch: SD45, SD51, SD58, SD59, SD60; Storm Drains, Southeast Loch: B003, B004, B005, B33, B67, B100, B148, B172, B296, B447, B471, B472, B475, B476, B482, B641, B650, SD54; Springs and Streams, West Loch: SN01, SN02, SN03, TT01, TT08, TT11; Springs and Streams, Middle Loch: SN04, SN05, TT02; Springs and Streams, East Loch: SN06, SN07, SN-08, SN09, SN10, SN11, TT03, TT04, TT05, TT06, TT07, TT16.

Table 3.2-8. MEAN KJELDAHL NITROGEN CONTENT OF HARBOR AND SOURCE WATERS.

Pearl Harbor (elemental N in ppm (n)) Location	Surface	Bottom
West Loch (incl. SW01)	0.072 (116)	0.047 (117)
Middle Loch	0.128 (100)	0.098 (97)
East Loch	0.019 (98)	0.023 (96)
Southeast Loch	0.048 (82)	0.021 (80)
Main Channel	0.019 (104)	0.020 (97)
Bio-Stations	0.027 (61)	0.026 (60)
Source Waters (elemental N in ppm (n))		
Sewage Discharges	1.104 (13)	
Industrial Discharges	0.753 (10)	
Storm Drains		
West Loch	0.510 (24)	
Middle Loch	0.258 (18)	
East Loch	0.164 (13)	
Southeast Loch	0.354 (65)	
Main Channel	0.052 (8)	
Streams and Springs		
West Loch	2.501 (31)	
Middle Loch	0.438 (20)	
East Loch	0.112 (69)	

Note: See note, Table 3.2-7.

Table 3.2-9. MEAN AMMONIA NITROGEN CONTENT OF HARBOR AND SOURCE WATERS.

Pearl Harbor (elemental N in ppm (n)) Location	Surface	Bottom
West Loch	0.014 (81)	0.021 (105)
Middle Loch	0.091 (102)	0.073 (100)
East Loch	0.005 (105)	0.014 (106)
Southeast Loch	0.021 (81)	0.016 (81)
Main Channel	0.002 (112)	0.009 (113)
Bio-Stations	0.010 (70)	0.020 (69)
Source Waters (elemental N in ppm (n))		
Sewage Discharges	6.576 (38)	
Industrial Discharges	0.272 (11)	
Storm Drains		
West Loch	0.221 (26)	
Middle Loch	0.076 (18)	
East Loch	0.154 (4)	
Southeast Loch	0.215 (67)	
Main Channel	0.015 (8)	
Streams and Springs		
West Loch	2.158 (29)	
Middle Loch	0.264 (20)	
East Loch	0.064 (69)	

Note: See note, Table 3.2-7.

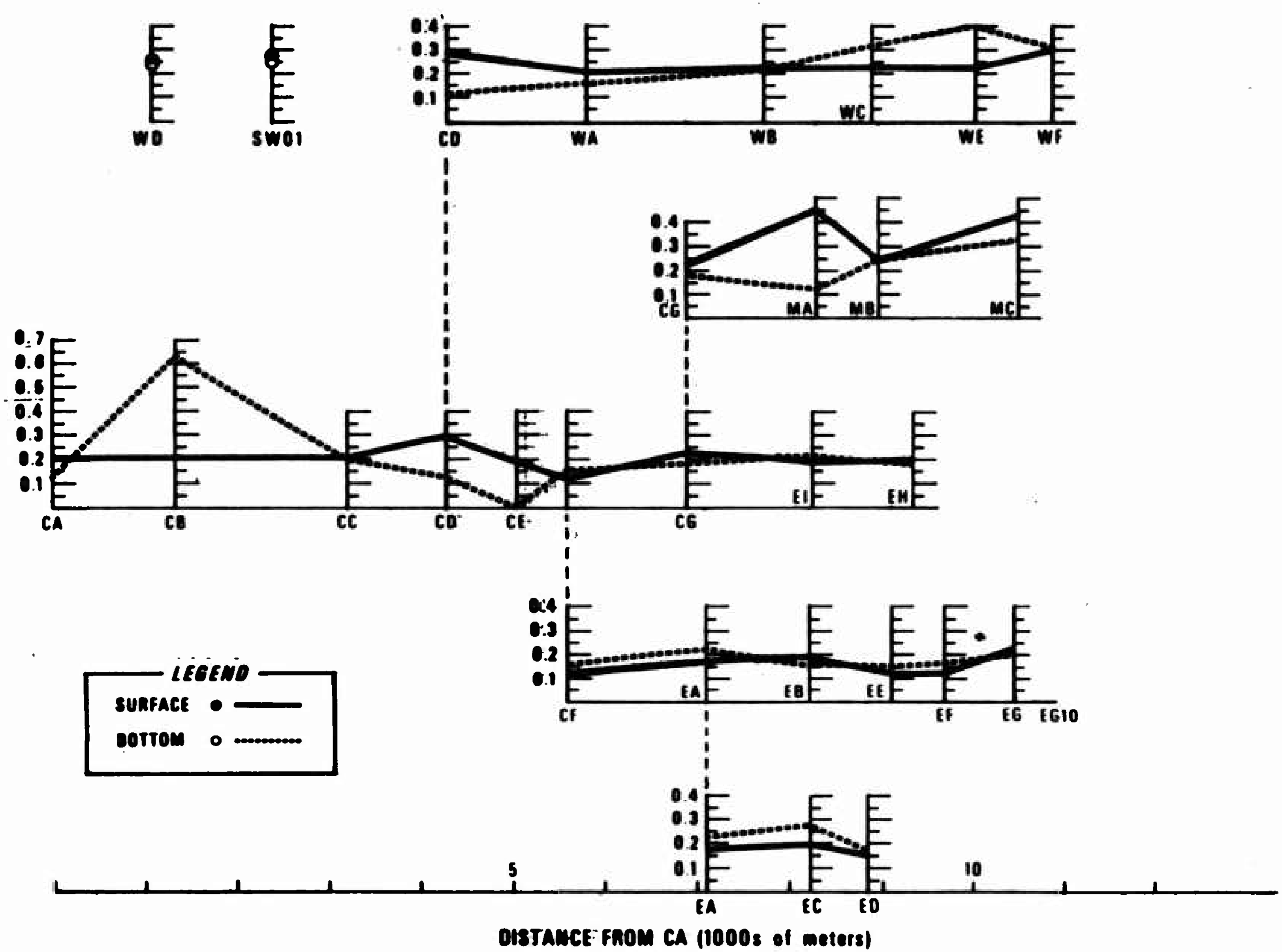


Figure 3.2-19. MEAN ANNUAL KJELDAHL NITROGEN CONTENT (ppm) IN SURFACE AND BOTTOM [illegible]S BY RANGE

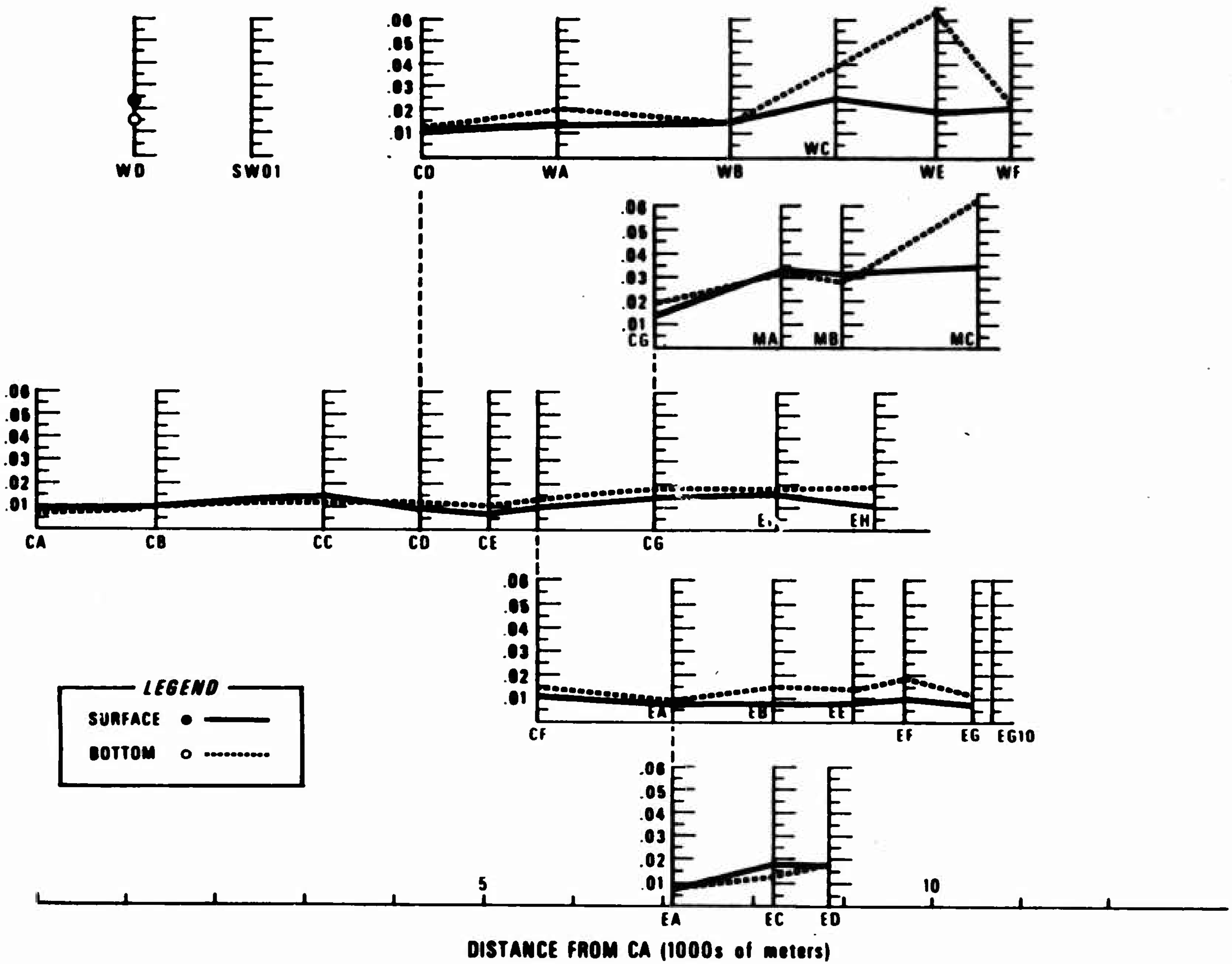
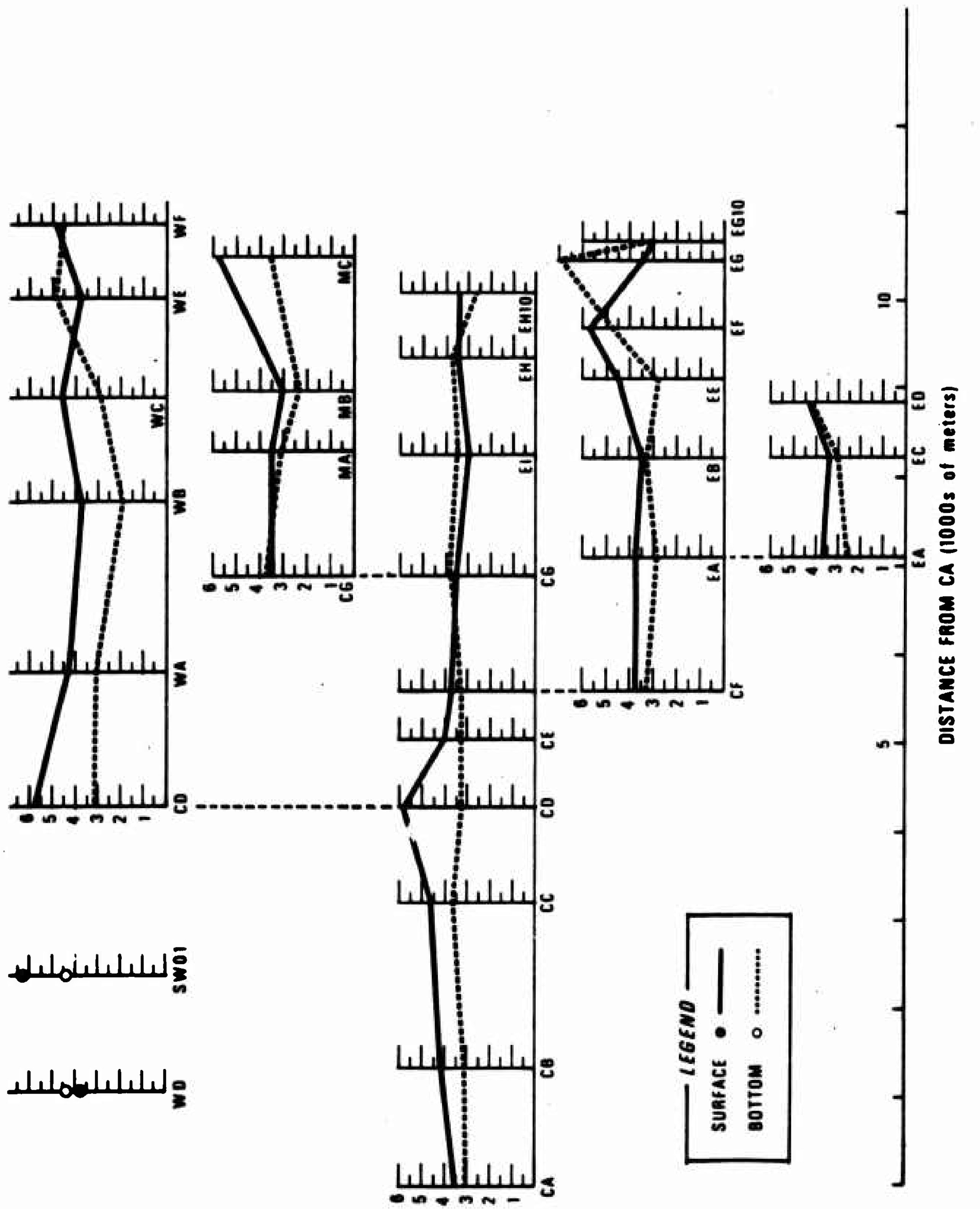


Figure 3.2-20. MEAN ANNUAL AMMONIA NITROGEN CONTENT (ppm) IN SURFACE AND BOTTOM WATERS BY RANGE

Table 3.2-10. SUMMARY OF LOW AND HIGH NUTRIENT LEVELS IN HARBOR AND SOURCE WATERS, PEARL HARBOR.

	Low Mean station	mean	range	High Mean station	mean	range
Kjeldahl Nitrogen (N in ppm, ND = below 0.050 ppm)						
harbor waters	CD(B)	0.054	ND - 0.056	SM05(S)	0.854	ND - 1.339
source waters	SN10	0.080	ND - 0.108	SS10	33.089	27.578 - 38.600
Nitrate Nitrogen (N in ppm, ND = below 0.002 to 0.005)						
harbor waters	WC(S)	0.003	ND - 0.003	WA(S)	0.278	ND - 0.926
source waters	SS50	0.006	ND - 0.008	SS10	29.560	0.263 - 58.233
Nitrite Nitrogen (N in ppm, ND = below 0.001 ppm)						
harbor waters	CG(S)	0.002	ND - 0.004	MC(B)	0.021	ND - 0.096
source waters	SD52	0.003	ND - 0.003	SD45	0.948	ND - 1.890
Ammonia Nitrogen (N in ppm, ND = below 0.005 ppm)						
harbor waters	CB(S)	0.010	ND - 0.013	SM05(S)	0.760	ND - 1.275
source waters	B004	0.024	0.007 - 0.057	SS11	29.775	26.750 - 32.800


WF
WE
WC
WB
WA
CD
SW01
WD
MC
MB
MA
CG
EH10
EH
EI
CE
CC
CB
CA
EG10
EG
EF
EE
EB
EA
CF
ED
EC
LEGEND
SURFACE
BOTTOM
DISTANCE FROM CA (1000s of meters)
5
10

MICROORGANISMS

Both total coliform and fecal coliform bacteria were reported by the Data Base as membrane filter count (MFC) per 100 ml of sample water. Median coliform counts in surface waters are summarized by range in Figure 3.2-22 and the distribution of fecal coliforms in surface waters is mapped in Figure 3.2-23. As might be expected, high counts are found in West and Middle Lochs, and also near the outfalls of the Ford Island and Hammer Point sewage treatment plants. For total coliform, harbor waters show a low median of 10 MFC with a range of 2 to 160 for surface waters at SC01 and a high median of 30,500 MFC with a range of less than 1000 to 209,000 for surface waters in Walker Bay (SW01). Source waters show a low median of less than 10 MFC (range <2 to <10) at B476, and a high median of 5,800,000 MFC (range >800,000 to 19,000,000) in drainage waters from the City and County's oxidation ponds (SS09). Similarly for fecal coliform in harbor surface waters, a low median of <2 MFC is reported for BE-05 and a high median of 42,500 MFC (range 10 to 110,000) for SC02. For source waters the reported low median is again <2 MFC for B004, and the high median is >600,000 MFC (range <10,000 to >600,000) for sugar cane irrigation and holding pond water discharging into West Loch (SD20). No correlation is found between biological data and either of these counts.

MISCELLANEOUS DATA

In addition to all measures reported on above, the Data Base analyzed both harbor and source waters for the following: phenols, oil and grease, chlorides, settleable solids, suspended solids and residual solids. To a limited extent, they also determined chemical oxygen demand (COD) and biological oxygen demand (BOD). These last two determinations were dropped due to salt water interference or lack of manpower. Chloride determinations closely parallel the salinity data already presented and are therefore not presented. Table 3.2-11 summarizes representative low and high determinations for the remainder of these parameters.

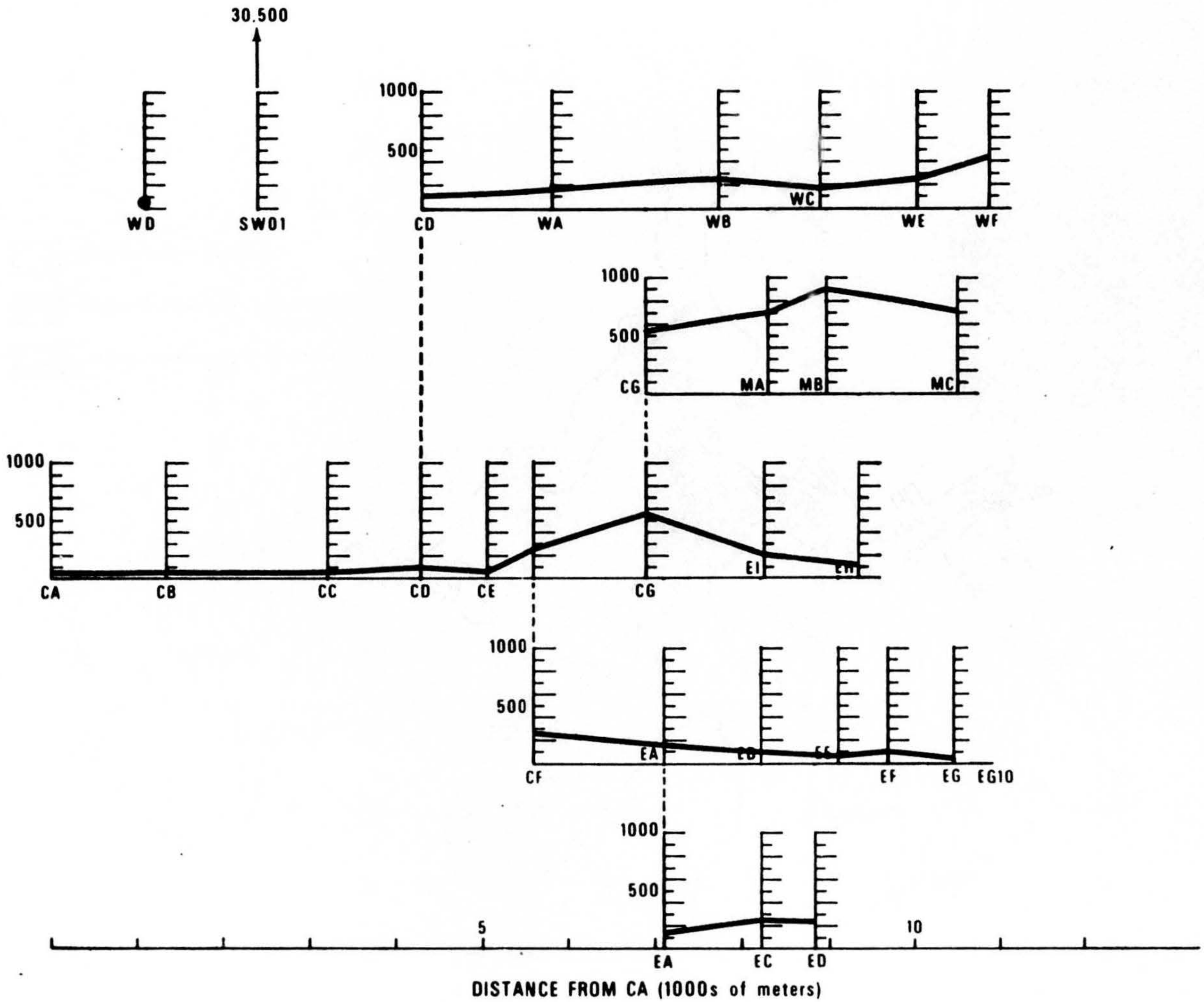


Figure 3.2-22. MEDIAN TOTAL COLIFORM COUNT (MFC/100 ml) IN THE SURFACE WATERS OF PEARL HARBOR.

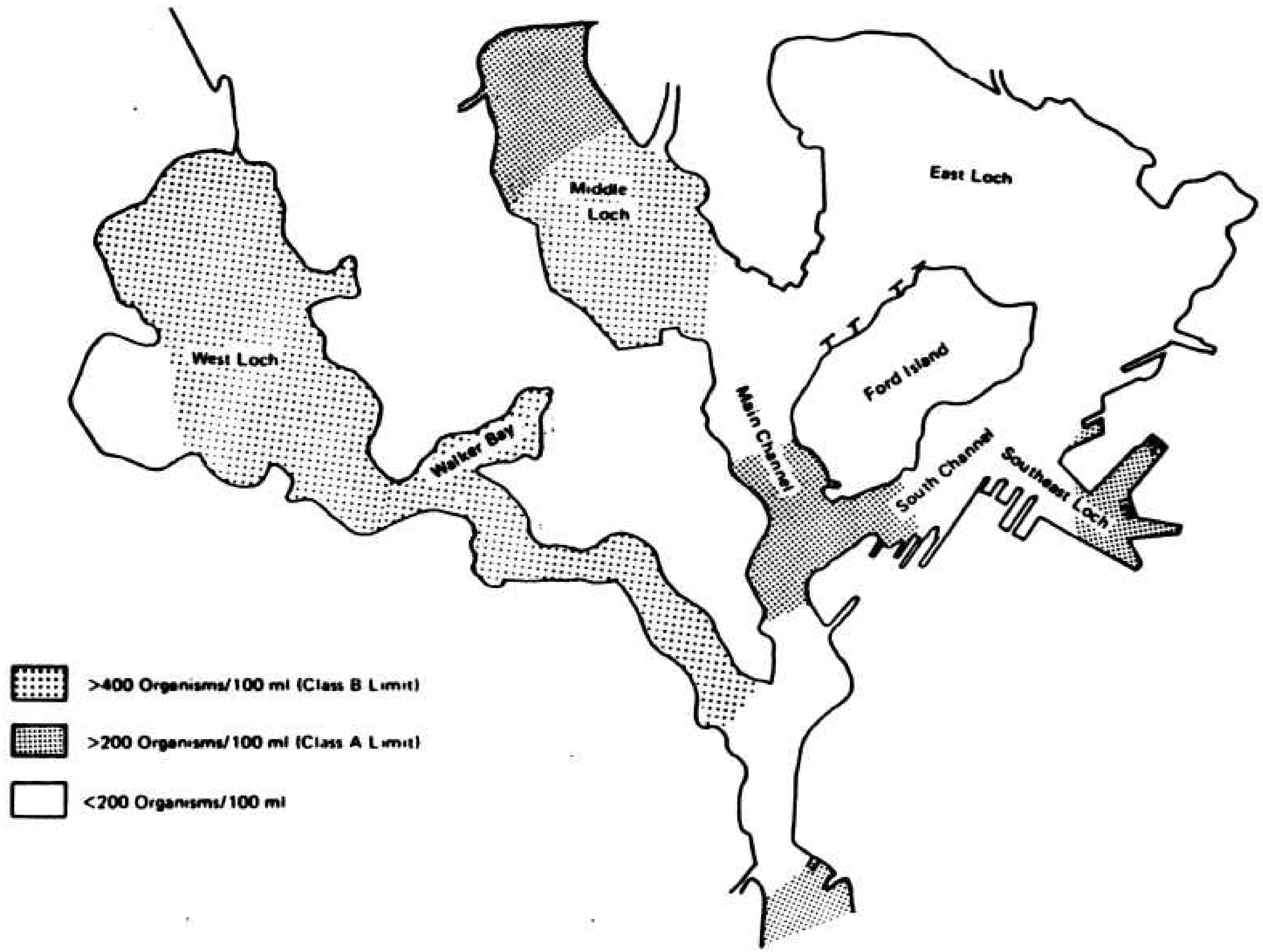


Figure 3.2-23. DISTRIBUTION OF FECAL COLIFORM IN THE SURFACE WATERS OF PEARL HARBOR. (1971-1972)

Table 3.2-11. SUMMARY OF LOW AND HIGH VALUES FOR VARIOUS MISCELLANEOUS PARAMETERS.

	Low Mean and Range			High Mean and Range		
	station	mean	range	station	mean	range
Phenols (in ppb, DN = below 0.05 ppb)						
harbor waters	SE02(S)	0.5	ND - 1.0	EE(S)	21.1	1.0 - 62.0
source waters	TT08	12.6	4.1 - 22.9	SS50	89.1	12.0 - 193.6
Oil and Grease (in ppm, ND = below 0.1 ppm)						
harbor waters	CA(S)	0.1	0.1	EC(S)	24.2	0.1 - 96.5
source waters	SD41	4.3	4.3	SS11	2014.2	2014.2
Chemical Oxygen Demand (in ppm, ND = below 20 ppm)						
harbor waters			approx. 370 ppm			
source waters	SS15	61.3	61.3	SS50	1463.5	117 - 2810
Biochemical Oxygen Demand (in ppm)						
harbor waters	WD(S)	1.0	1.0	EE(S)	2.0	1.9 - 2.1
Settleable Solids (in ppm, ND = below 1 ppm)						
harbor waters			approx. 100 ppm			
source waters	SD25	ND		SS04	3783	2506 - 5060
Suspended Solids (in ppm, ND = below 1 to 10 ppm)						
harbor waters	SE05(S)	2	2	TB(S)	220	ND - 310
source waters	B482	3	ND - 4	SS04	2035	594 - 3476
Residual Solids (in ppm, ND = below 10 ppm)						
harbor waters				SM06(B)	39940	39940
source waters	TT01	320	130 - 450	SD41	9630	3970 - 20070

B = bottom water; S = surface water.

REFERENCES

3.2-1. D. E. Morris, S. W. Surface and J. P. Murray (1973), "Completion Report for the Pearl Harbor, Hawaii Study Covering the Test Period Through Calendar Year 1972", NCEL Report EPDB 73-005, LIMDIST.

3.2-2. COMPACNAVFACENGCOM (1971), "Pearl Harbor Pollution Model Study", Report prepared by OICC, MICPAC and DCE (COMFOURTEEN) Staffs, LIMDIST.

3.2-3. Evan C. Evans III, A. Earl Murchison, Thomas J. Peeling and Q. Dick Stephen-Hassard (1972), "A Proximate Biological Survey of Pearl Harbor, Oahu", NUC TP-290.

3.2-4. Environmental Protection Agency (1971), "Methods for Chemical Analysis of Water and Wastes", Analytical Quality Control Laboratory, Cincinnati, Ohio.

3.2-5. Environmental Protection Agency (1969), "Chemistry Laboratory Manual - Bottom Sediments", compiled by Great Lakes Region, Committee on Analytical Methods.

3.2-6. American Public Health Association (1971), "Standard Methods for the Examination of Water and Wastewater", 13th Edition, Washington D.C.

3.2-7. Thomas J. Peeling, J. Geoffrey Grovhoug and Evan C. Evans III (1972), "Pearl Harbor Biological Survey - Summary Report for First Survey Cycle", NUC TN-801, LIMDIST.

3.2-8. John C. McCain (1974), "Environmental Survey - Waiau Generating Station", Hawaiian Electric Company Report.

3.2-9. Federal Water Pollution Control Administration (1969), "Report on Pollution of the Navigable Waters of Pearl Harbor", Pacific Southwest Region Report.

3.2-10. Chemical Rubber Company (1971), "Handbook of Chemistry and Physics", 42nd Edition.

TIDES, RUNOFF AND CURRENTS

Norman L. Buske
Evan C. Evans III

INTRODUCTION

Studies of the physical processes of Pearl Harbor have been short in duration and modest in spatial coverage (References 3.3-1 through 3.3-8). Physical data have been limited to several drogue observations, current meter records which are not correlated with meteorological and oceanographic conditions, dye studies for prediction of effluent distributions, and occasional temperature and salinity measurements related to specific studies. This material was not considered sufficient for a sensitive interpretation of the biological survey results; therefore a year-long study conducted concurrently with the marine biological survey was initiated in June 1972. The purpose of this study was to provide an initial and approximate understanding of the general circulation of Pearl Harbor, exclusive of West Loch. The field observations appear in four data reports (References 3.3-9 through 3.3-12). This section consists of an analysis of these data and some additional material, resulting in a preliminary description of the important physical oceanographic processes for the area shown in Figure 3.3-1. The area of primary coverage is hatched; dotted lines indicate the maximum limits of field observation. Thus, in addition to West Loch, the upper reaches of the other lochs have no coverage. Furthermore, no data are available for strong southerly (Kona) wind conditions, and the rainfall was abnormally low for the entire survey period. Thus, the degree of coverage is adequate only for a preliminary estimate of daytime circulation patterns under tradewind or calm conditions during a dry year. With the exception of the low rainfall, such conditions prevail a little more than half the time in Pearl Harbor. Circulation under other conditions can, of course, be estimated with a reduced degree of confidence from the model.

First a general description of the scalar properties, uses, and driving mechanisms affecting the harbor is given. The methods of obtaining current data, salinity profiles, and temperature profiles are next described. These data are then used to construct a preliminary current model for Middle and East Lochs, after which the driving forces are discussed in greater detail in the light of this model and other field observations. The effects of mixing by ships traversing the harbor (see also Section 3.4) are given special attention, since many physical properties of the harbor are strongly affected by this activity. Water masses are then briefly discussed. The section is concluded with a summary of important results. A sample calculation illustrating the fitting procedure used to create the current model and a list of the drogue tracks used in this process is given in Appendix D.

GENERAL BEHAVIOR AND USES OF PEARL HARBOR

Pearl Harbor is apparently an old feature of the island of Oahu, dating from the Koolau eruptions. Subsequent to its initial formation, stream deposition, variations in sea level, growth of coral reefs, and the effects of wave action have determined the present nature of the harbor (Figures 3.3-2 and 3.3-3). The harbor is divided into three embayments, called "lochs", and a main channel. A fourth loch, Southeast Loch, and two subdivisions of the main channel are often recognized, see Figure 3.3-3. The physical scales of these major harbor divisions have been calculated from the tidal datum level, mean lower low water (Reference 3.3-13) and are presented in Table 3.3-1. The ma-

(Text continued on page 3.3-6)

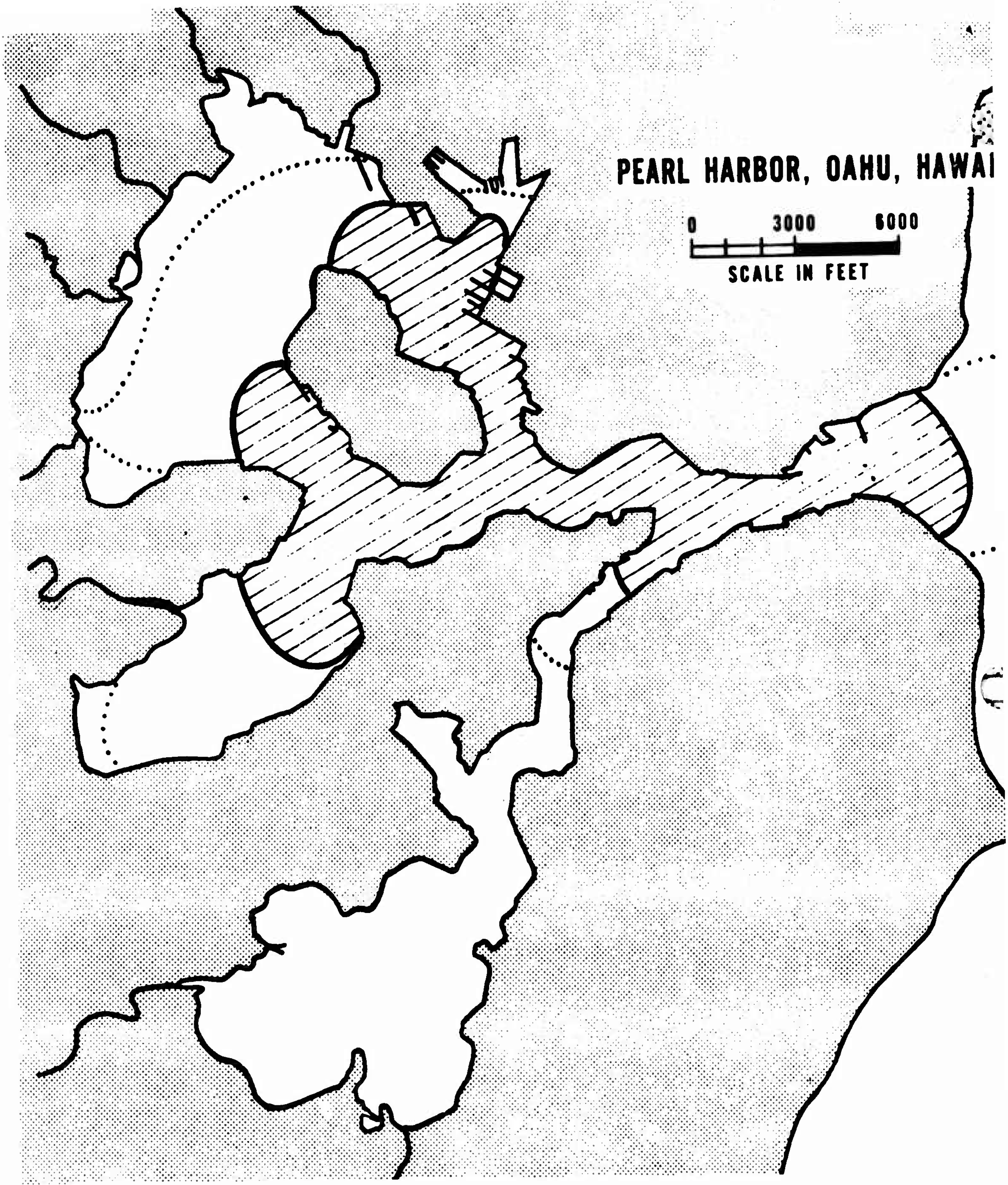


Figure 3.3-1. TYPICAL AREA OF 1972-1973 SURVEY COVERAGE. REGIONS OF SURVEY HATCHED - MAXIMUM EXTENT OF SURVEY SHOWN AS DOTTED BOUNDARY.

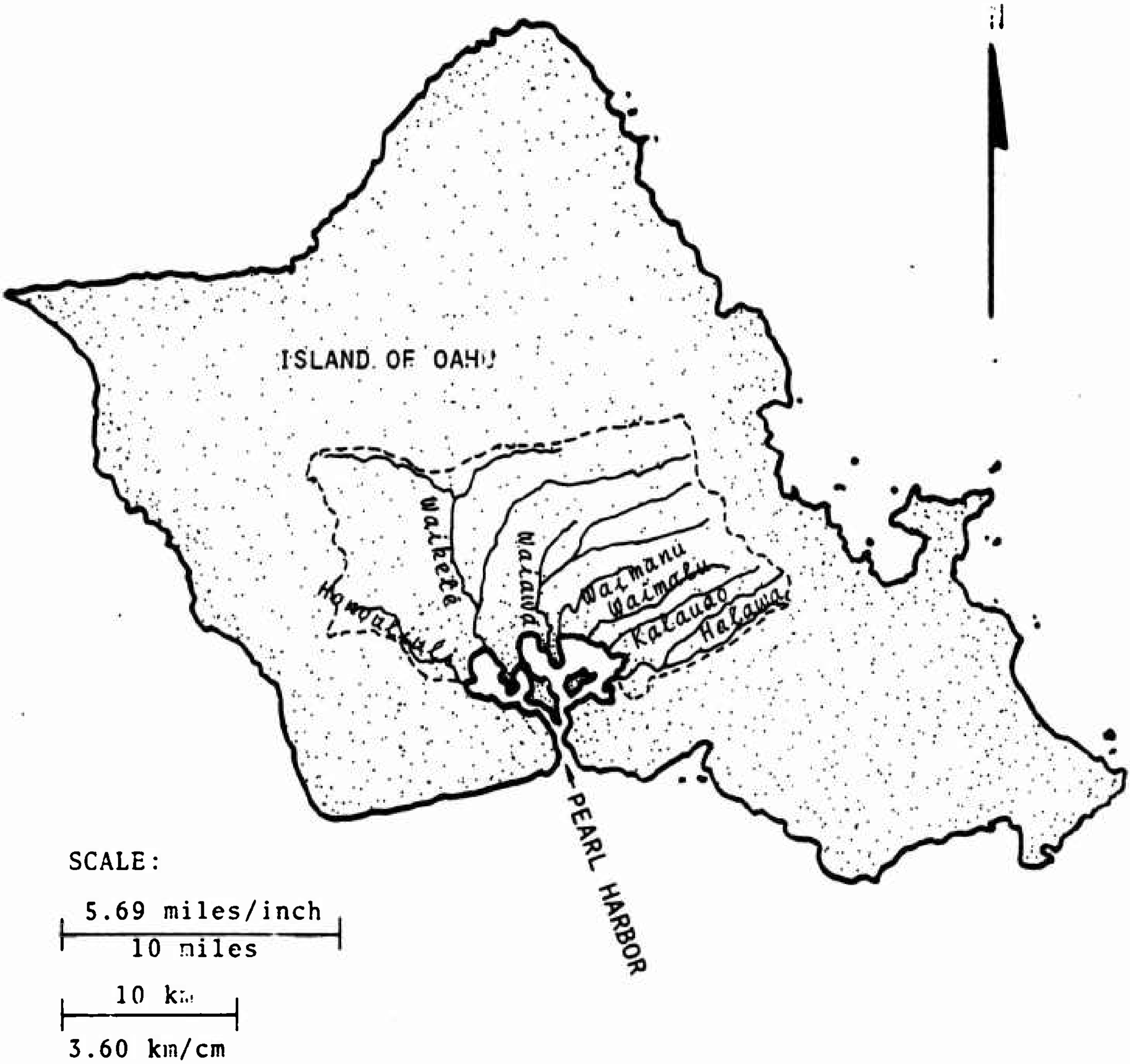


Figure 3.3-2. LOCATION MAP SHOWING PEARL HARBOR DRAINAGE BASIN AND MAJOR STREAMS ENTERING PEARL HARBOR.

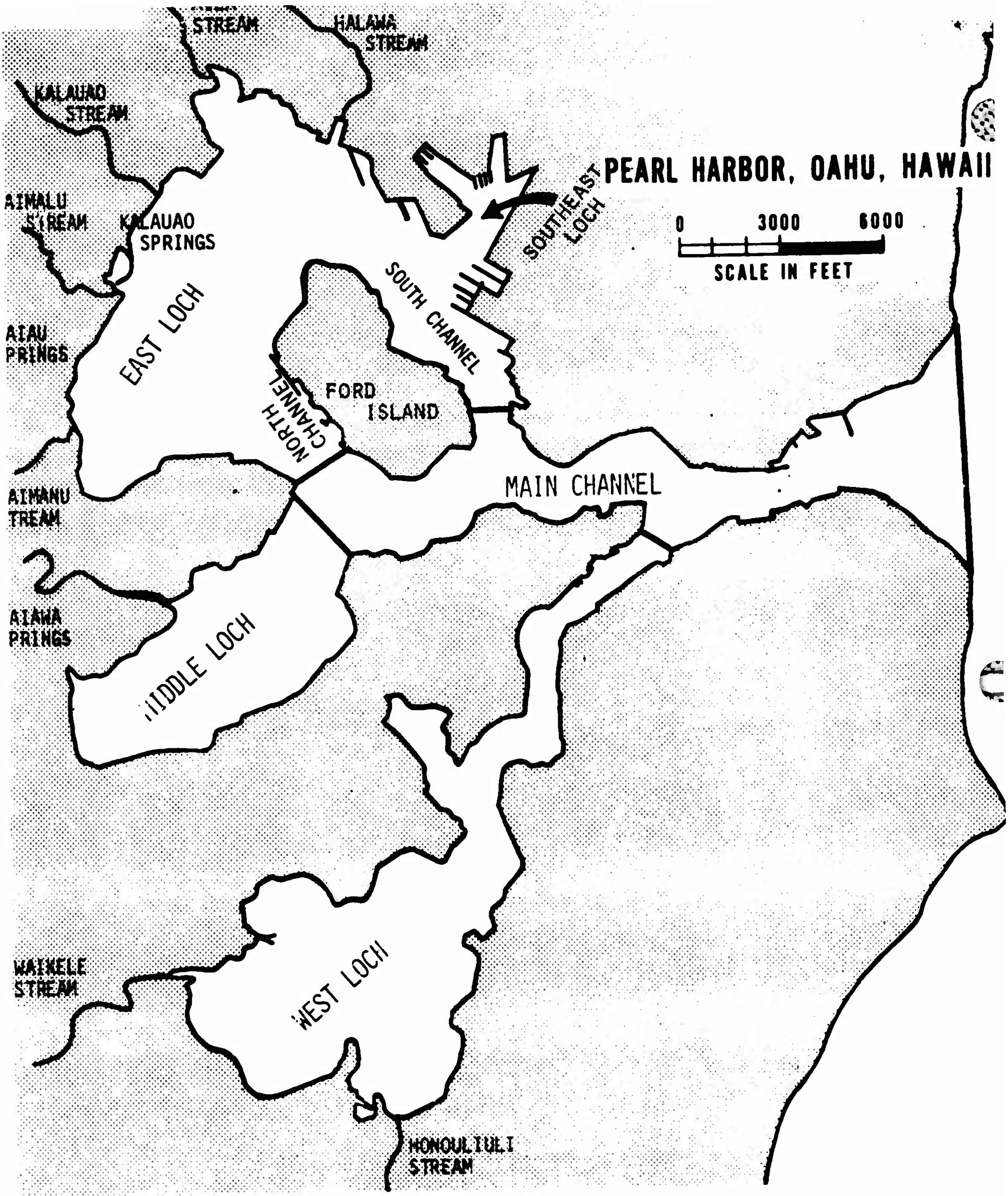


Figure 3.3-3. MAJOR DIVISIONS AND FRESH WATER SOURCES OF PEARL HARBOR.

Table 3.3-1. SCALES OF PEARL HARBOR. (ON MLLW)

LOCATION	MEAN DEPTH m	AXIAL LENGTH km	SURFACE AREA km^2	VOLUME km^3
East Loch	8.5	4-7	7.6	0.065
Middle Loch	5.8	3.0	2.8	0.017
West Loch	4.9	6.6	5.4	0.028
Main Channel	8.5	6.0	4.3	0.037
PEARL HARBOR	7.2	10	20.1	0.144

jor divisions have length:width:depth ratios of roughly 5000:2000:7, which are not atypical of coastal plain estuaries; however, few such estuaries are as dendritic as Pearl Harbor.

Although Pearl Harbor can generally be described as a two-layer-flow estuary with vertical mixing (Reference 3.3-14), the circulation processes which occur in the harbor vary greatly between the different lochs and the main channel. Thus, Pearl Harbor might be considered as three separate, but interacting, estuaries which are connected to the Pacific Ocean by a common, main channel. Two other physical features of the harbor system are noteworthy. First, Ford Island permits a gyral circulation around it in East Loch. Second, the bathymetric profiles of the channels and lochs are exceptionally rectangular as a result of extensive dredging of ship routes combined with unmodified sedimentation elsewhere. The influx of sediment is associated with farming and land development in the drainage basin of the five major streams which flow into the harbor. Operational areas are typically maintained at depths of 11 to 15 meters. The peripheral areas are apparently shoaling, particularly near the mouths of streams (References 3.3-2, 3.3-4, and 3.3-7). For example, over the last four years a small island has formed off the mouth of Waimanu Stream, indicating sedimentation in excess of 0.1 meter/year.

In the portion of Pearl Harbor studied, the temperature and salinity characteristics of the water layer below the thermocline are quite stable and are similar to oceanic values. If both streams and springs are considered, equal amounts of fresh water flow into the heads of East and Middle Lochs, and almost 30% of the total fresh water volume entering the harbor flows into the head of West Loch. The main thermocline and main halocline are normally at 1½ to 5½ meters depth. Pronounced estuarine profiles are also seen along the western side of the Main Channel due to fresh water outflows from West Loch. Diurnal temperature ranges can exceed 2°C in undisturbed shoal areas. Oil films in the harbor can, however, influence net radiation balance and heat budgets.

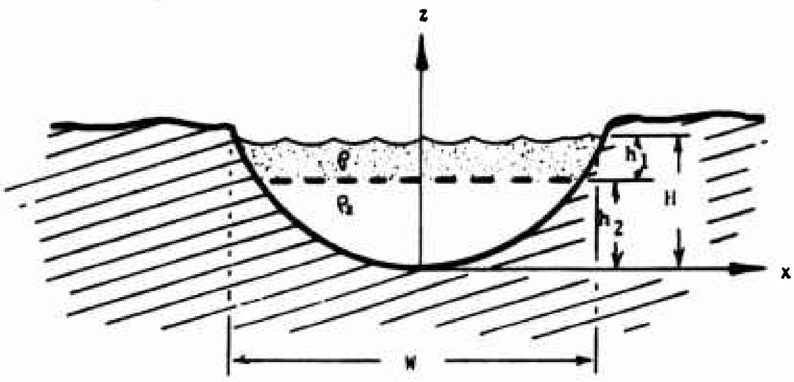
Circulation in Pearl Harbor is driven by several major mechanisms: tide, fresh water influx, salt water influx, mixing processes, wind stress, and both spatial and temporal derivatives of wind stress. Other factors also may affect circulation but do not receive detailed consideration in this section. Tides increase water depths in the harbor by about 0.6 meters (2 ft.) and cause oscillatory currents under a generally constant surface outflow (Reference 3.3-1). Tidal current reversals occur at peak tidal amplitudes. Either cyclonic or anticyclonic circulations around Ford Island can be observed. This reversing gyre appears to be associated with tidal currents and with spatial differences in wind stress, flood currents being most often associated with cyclonic circulation. Currents in Pearl Harbor are generally almost parallel to the shoreline.

The winds tend to follow the channels and wind speeds are greatest where a considerable fetch is aligned with the wind aloft. Under tradewind conditions, wind-induced currents in North Channel, in the entrance to Middle Loch, and in South Channel are normally strongest and set toward the harbor entrance. The usually high relief of Pearl Harbor shorelines causes marked cross-channel differences in wind velocity and induced current velocity. In fact, currents on the upwind side of the channel are often opposite those on the downwind side. With a sustained cross-channel wind, the surface water moves across the channel as well as axially along the channel. •Cross-channel flows are normally less than 20% of axial flows. With sufficient velocity, a sustained wind stress can tilt the thermocline and halocline such that the boundary between the two water layers contacts the water surface. Surface flows are compensated by upwelling along the upwind side of the channel. A typical example of such circulation in the Main Channel is shown diagramatically in Figure 3.3-4. The mean maximum surface current is about 0.2 m/sec and the mean maximum current in the lower layer is about 0.05 m/sec.

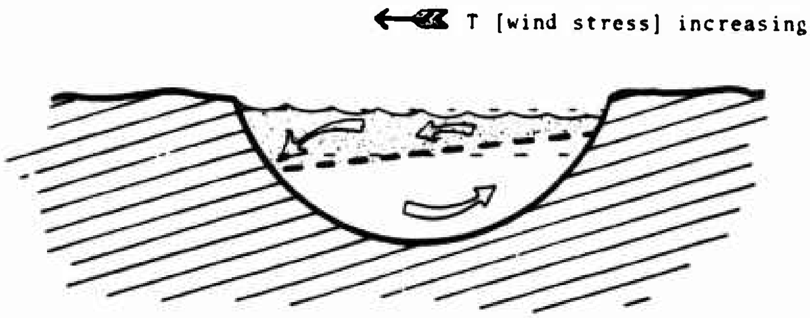
With decreased vertical stratification (often typical of winter conditions) wind derivative currents (those caused by changes in wind speed or velocity differences between two locations) can be several times stronger than tidal or normal wind stress currents. Wind derivative current velocities up to 0.3 m/sec have been observed. Such derivative currents are particularly important in Middle Loch where wind driven cross-loch flows are often dominant. Under tradewind conditions, Middle Loch exhibits a three-layered circulation with surface (0 to 0.3 m depth) and bottom (5 to 10 m depth) flows toward the upper reaches of the loch and with a return flow at mid-depth. Middle Loch normally has a sluggish gyral surface circulation; however, under changing wind conditions, surface velocities of 0.1 m/sec are often observed. When the tradewinds diminish, surface outflow from Middle Loch often occurs, particularly on ebb tides.

Mixing in Pearl Harbor is, of course, determined by the vertical stability of the water column, by winds, and by tides; but, in addition, the movement and positioning of ships is a very important factor in East Loch, Southeast Loch, and the Main Channel (although not observed on this study, it is also possibly important around the Whiskey docks in West Loch, Reference 3.3-15). Water column stability determines the mixing efficiency of various driving mechanisms. Elevated temperatures and fresh water in the surface layers generally increase stability; however, winter solar heating of the upper layer can decrease the stability of the water column near the heads of the lochs because stream influx is cooler than the harbor waters. Tides and winds result in classical estuarine mixing in certain regions of the harbor, but in Southeast Loch, South Channel, and the Main Channel mixing is predominantly caused by ship movement. The generally clearer waters of South Channel and around Ford Island may be a result of this efficient mixing although wind-driven upwelling could also be contributory. Increased mixing increases mean salinity and diffusive mixing, influences advective circulation first positively then negatively, and decreases mean residence time of water masses in the harbor as shown diagrammatically in Figure 3.3-5. The importance of ship's energy to this mixing process is discussed in detail later.

Seiche modes (harbor resonance) due to wind stress were not investigated in detail since they were not considered important to the general circulation of the harbor. They do exist, however. A strong 5th harmonic of the tidal period has been observed in the upper reaches of East Loch by Robert H. Dale in 1967 (Reference 3.3-16). It had a period of about 2 hours and an amplitude of 0.02 cm. Mr. Dale's records have been turned over to Lt. William Hall, University of Hawaii, who plans to use the material in his PhD Thesis.



SIMPLE BASIN WITH TWO LIQUIDS, NO WIND STRESS.



CASE OF INCREASING WIND STRESS. ARROWS INDICATE CIRCULATION.
LIGHT DASHED LINES INDICATE LEVELS OF FREE SURFACE AND INTERFACE.

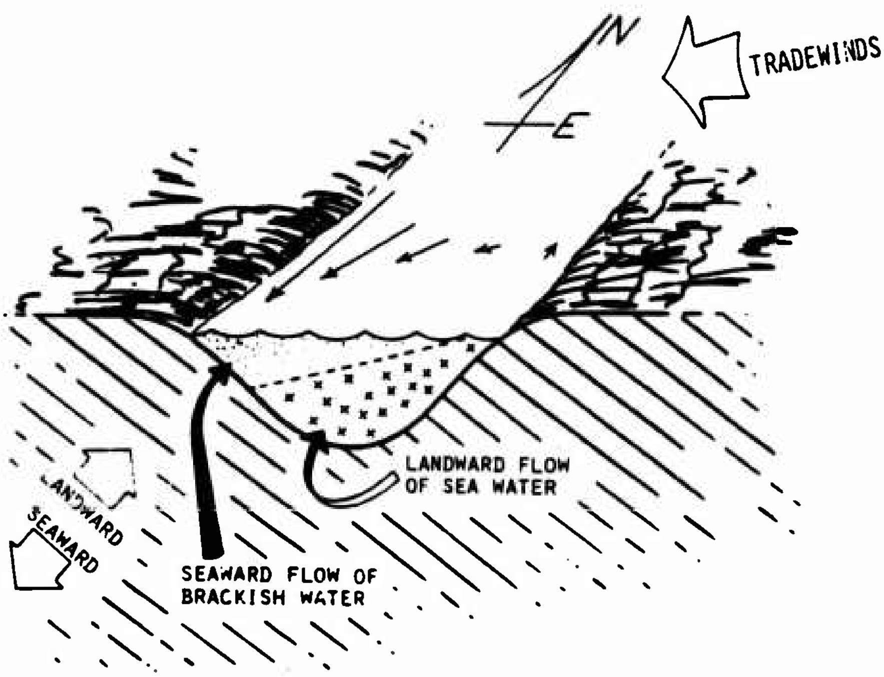


Figure 3.3-4. TYPICAL FLOW PATTERN IN THE MAIN CHANNEL UNDER TRADEWIND CONDITIONS. ARROWS INDICATE DIRECTIONS AND INTENSITIES OF CURRENTS AT ONE FOOT DEPTH.

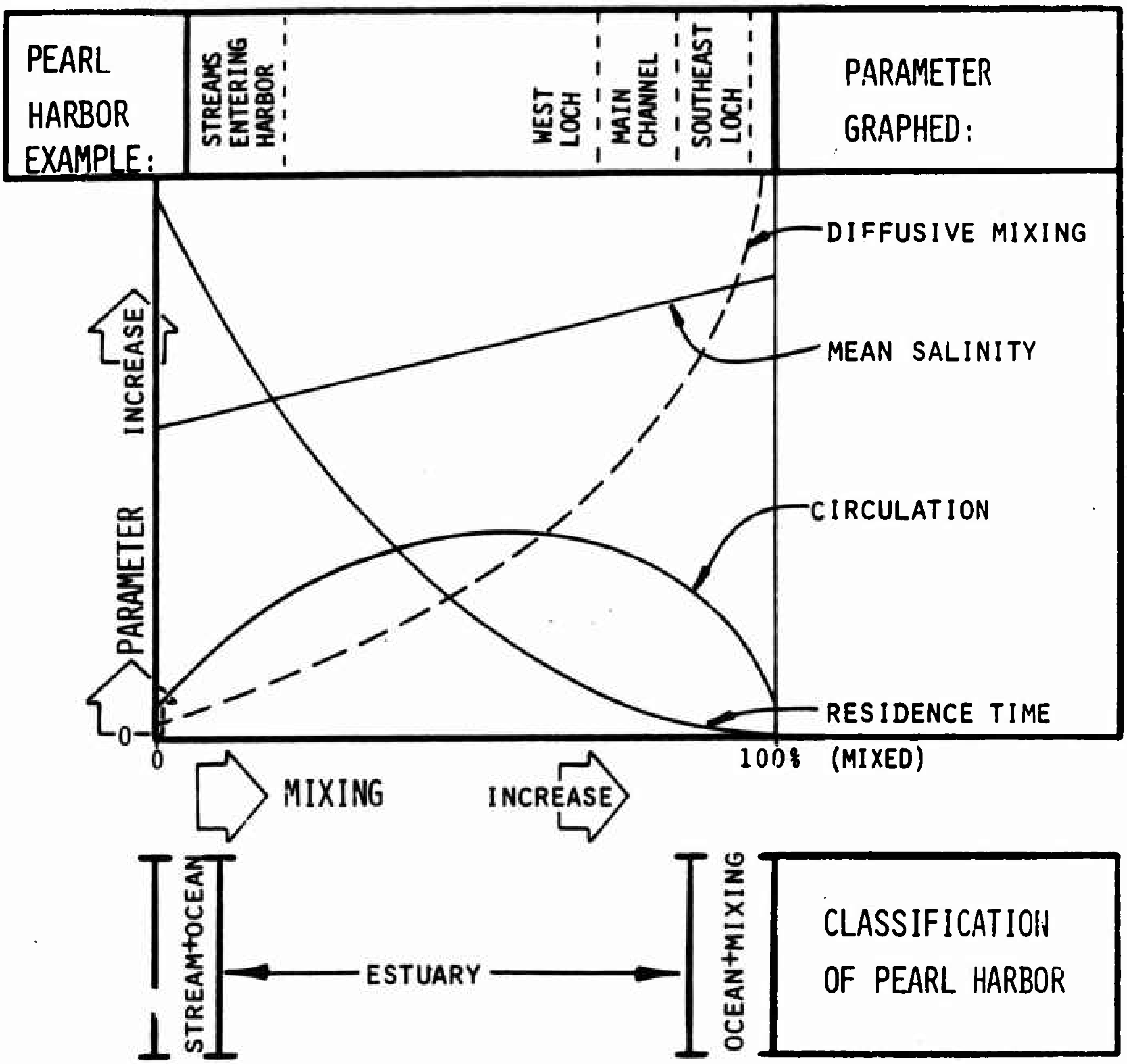


Figure 3.3-5. EFFECTS OF INCREASED MIXING IN PEARL HARBOR, GRAPHS ARE QUALITATIVE ONLY. AS MIXING IS INCREASED, MOST OF PEARL HARBOR WOULD BECOME MORE "OCEANIC".

The dominant current-driving mechanisms for various regions in Pearl Harbor are summarized in Figure 3.3-6. The indicated boundaries are only approximate and at a given time may be quite different. A small region which is influenced by the intake and discharge of the Hawaii Electric Company's Waiau Power Plant has been included in the figure (see also Section 2.3). More detailed discussion of these driving mechanisms follows the development of the current model.

Pearl Harbor is used primarily as a naval base servicing mainly the smaller ships in the fleet. Typically, about 30 ships are in port at any given time, and there are 4 ship arrivals and 4 ship departures daily; see Section 3.4 for a more detailed description of these movements and those of smaller boats within the harbor. Besides ship movement, other military influences on the harbor include: introduction of sewage and corrosion products (Reference 3.3-17), release of oil and flotsam, acoustic testing of sonar equipment, and the addition of heat (see Figure 3.3-7). On 23 and 24 November 1973, the Knox tested sonar equipment in Southeast Loch; sound levels in air were audible over a 60 horsepower Mercury outboard operating at full throttle 3 feet from the observer, even though tranmission losses from water to air are 29.5 db (Reference 3.3-10). The Navy Power Plants #2 and #3 produce heated effluent waters (5 to 8°C above ambient) which e‹ er the harbor 800 meters north of bio-station BE-17 and at BC-10, respectively.

Pearl Harbor also receives irrigation tailgate waters from the Oahu Sugar Company, industrial waste waters from the Primo Brewery, and heated waters from the Hawaiian Electric Power Plant (Reference 3.3-11). Pesticides and silt have been noted in the agricultural wastes (Reference 3.3-4). There are over 100 sewer outfalls entering the harbor (References 3.3-15 and 3.3-17), most of which are no longer in use. The largest with a discharge of about 0.2 m^3/sec (Reference 3.3-15) from the Pearl City Sewer Treatment Plant enters Middle Loch and is still in active use (see Figure 3.3-7). Only this outfall and the heated discharge from the Waiau Plant were detectable in this physical oceanographic survey. Considerable commercial and recreational fishing occurs in Pearl Harbor. About one-third of the State's nehu (*Stolephorus purpureus*), an important bait fish, are taken in Pearl Harbor (Reference 3.3-4). Areas used by the commercial nehu boats and recreational shoreline fishermen are also shown in Figure 3.3-7.

METHODS

Field data were collected on 28 days over a one year period, June 1972 to May 1973, under conditions which are summarized in Table 3.3-2. The original data for these dates are found in References 3.3-9 through 3.3-12. The following systematic observations were made:

- current velocity at various depths (1100 observations)
- temperature and salinity profiles (370 observations)
- wind velocity at 2½ meters elevation
- wet and dry bulb air temperatures
- estimated percent cloud cover.

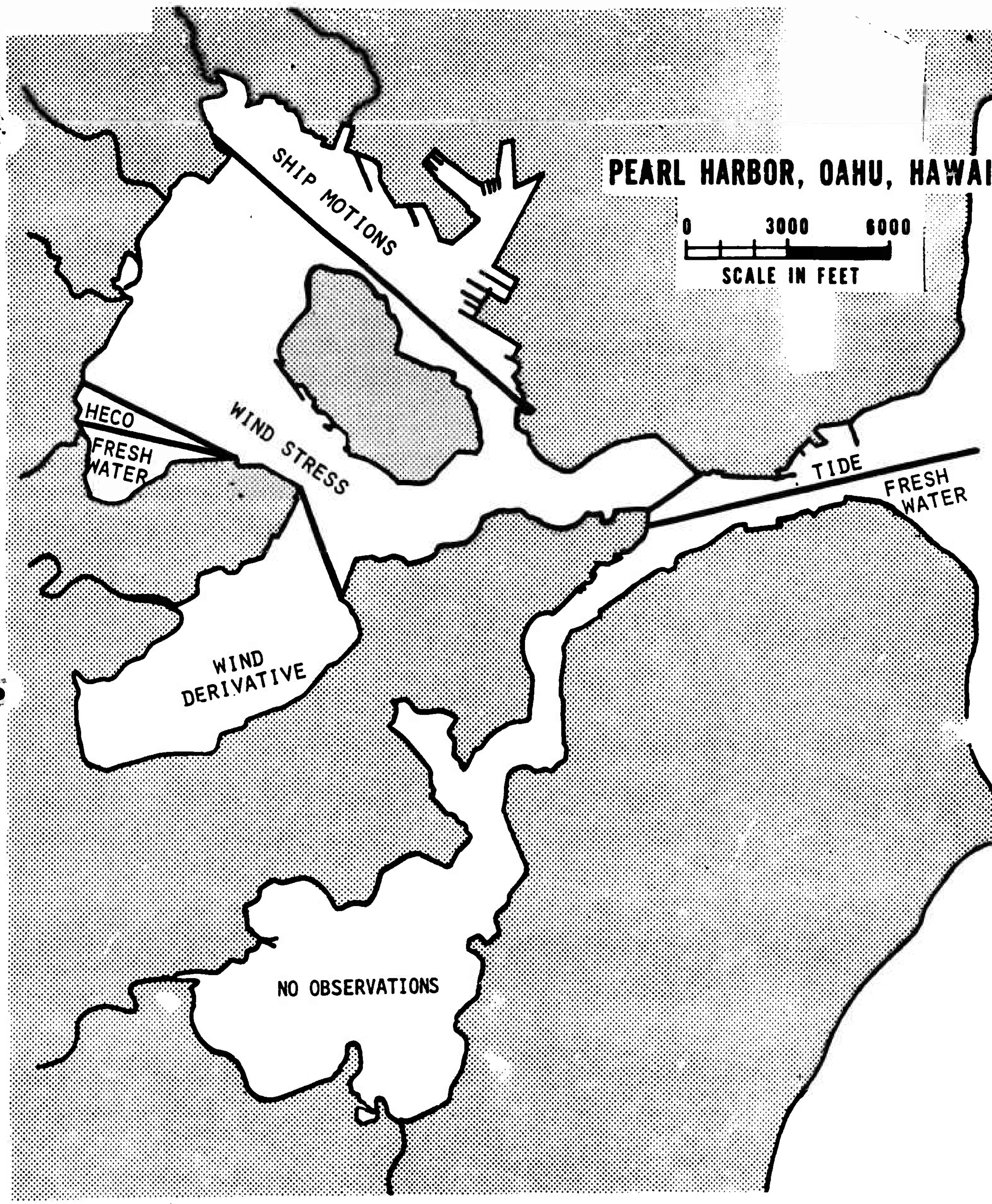


Figure 3.3-6. DOMINANT CIRCULATION DRIVING MECHANISMS.

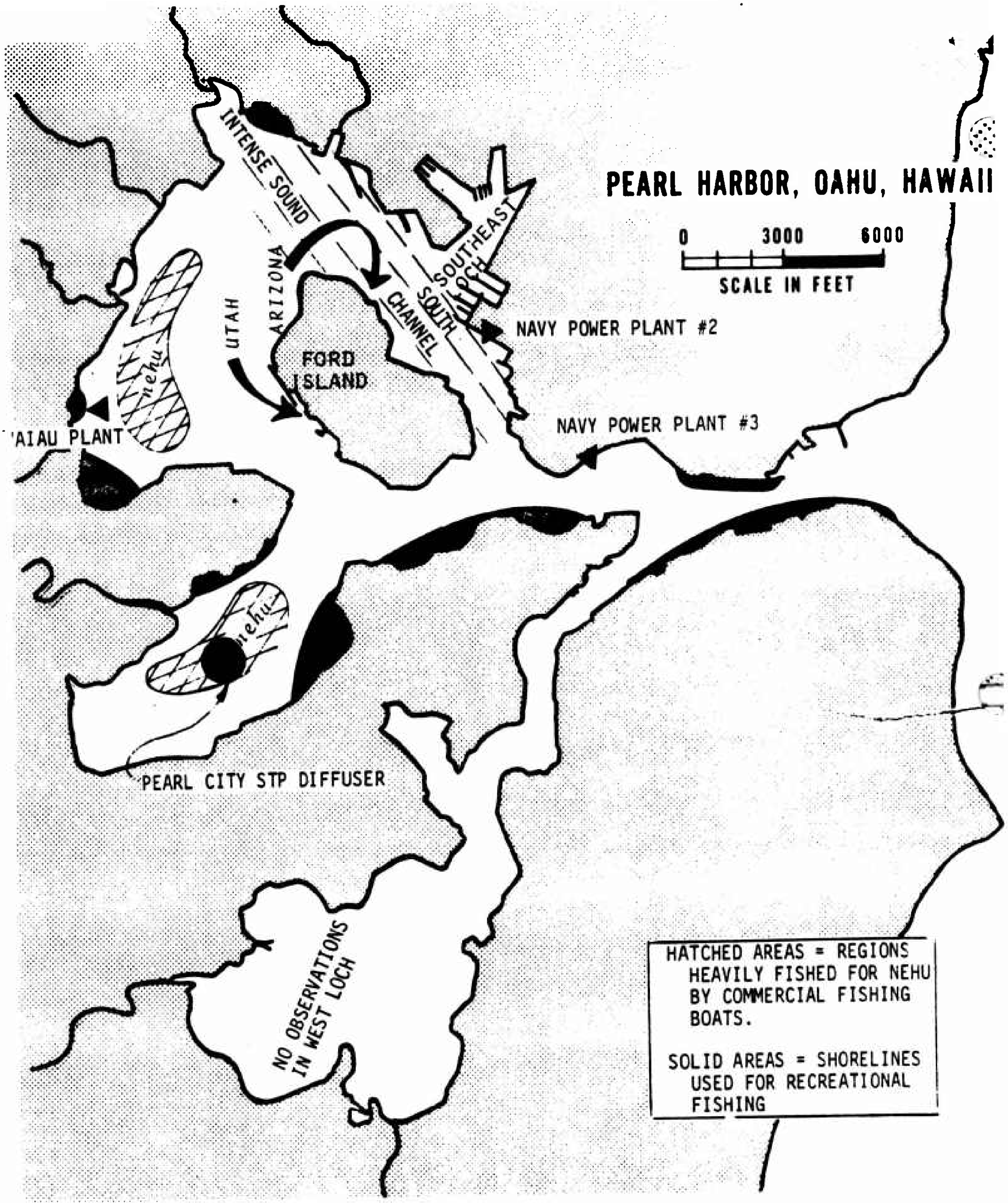


Figure 3.3-7. OBSERVED FISHING AREAS AND POINTS OF INTEREST.

TABLE 3.3-2. 1972 - 1973 FIELD STUDY DAYS.

DATE	TIDE	WIND	ΔS*
JUN 05	HIGH	CALM	2.1
06	FLOOD/EBB	CONVERGENT**	2.1
26	FLOOD/HIGH	TRADE, CONVERGENT	1.1
27	FLOOD	TRADE	(1.1)
JUL 20	FLOOD/EBB	TRADE	2.1
21	FLOOD/EBB	TRADE	(2.1)
AUG 18	FLOOD/EBB	TRADE	1.2
SEP 06	LOW/FLOOD	VARIABLE, CONVERGENT	0.8
26	EBB	TRADE, CONVERGENT	1.1
OCT 10	EBB/LOW	WEAK KONA	1.8
19	FLOOD/HIGH	WEAK TRADE	1.5
23	EBB/FLOOD	TRADE	(1.5)
25	EBB	TRADE, CONVERGENT	(1.5)
NOV 23	EBB	TRADE, CONVERGENT	1.6
24	EBB	WEAK KONA	2.6
DEC 21	EBB	TRADE	LARGE***
JAN 27	EBB	TRADE	1.1
29	VARIOUS	TRADE	(1.1)
FEB 06	EBB/FLOOD	TRADE	(1.5)
16	FLOOD/EBB	VARIABLE, CONVERGENT	(1.6)
17	EBB/FLOOD	TRADE, CONVERGENT	1.6
MAR 06	EBB/FLOOD	STRONG TRADE	1.1
07	FLOOD	TRADE	(1.1)
APR 26	FLOOD/EBB	TRADE	1.1
27	SLIGHT	TRADE	(1.1)
29	FLOOD/HIGH	TRADE	2.5
MAY 01	VARIOUS	TRADE	(0.7)
02	EBB/LOW	TRADE	0.7

*ΔS is the difference in salinity [in parts/1000] between surface and bottom. Parentheses indicate interpolated values. Measurements were made near the west side of the lower entrance channel of Pearl Harbor. Large values indicate large fresh water influx due to runoff.

**A sea breeze was often noted to the south of Ford Island. The wind velocity fields and surface currents converged to the south side of Ford island. The effect was greatest shortly after noon, as would be expected.

***The salinometer was inoperative on this date; no salinity values were obtained.

The area of coverage is shown in Figure 3.3-1; drogue transect lines and stations are shown in Figure 3.3-8. The circuit distance for this array was approximately 20 km. A 5-meter Reinell equipped with a 60 HP Mercury outboard was used for tending the drogue array; typical circuit time including necessary operational activities was about 1½ hours. Positions were obtained using a K&E sextant which was maintained at an accuracy of 20" arc. Convex sets of targets, which provide excellent resolution, are found almost everywhere in Pearl Harbor (Reference 3.3-13). Where uncertainties occurred, redundant angles were obtained to verify the positions. In general, position uncertainty was less than 10 meters. Locating a given drogue, obtaining a position reading, and recording this information required slightly less than 2 minutes.

Current velocities at various depths (approximately 0.3, 0.6, 1.2, 2.4, 7, 10, and 12 meters) were measured with Sea-Test drogues (see Figure 3.3-9). These drogues are collapsible and are contructed of crossed 1x2 ft sheets of oil-treated Masonite peg board (wing area is about 0.1 m^2). They are weighted with 10 ounce (284 gram) fishing weights to maintain depth and attitude, and they use very small (15 cm diameter) orange marker-floats. The effect of wind stress on the float-marker was calibrated by observing redundant drogues (one with a single float and the other with a double float) in known wind fields. Since wind stress causes the double float to orient normal to the wind, the wind drag is nearly doubled. The differences in velocities between these redundant drogues permitted an estimation of the wind drag coefficient. For wind velocities in the 5 to 10 m/sec range (measured 2.3 m above the water surface), the drag coefficient is 1.4×10^{-3} times wind speed and acts in a direction 50° to the left of the wind heading. The rotation is due to the Ekman effect (Reference 3.3-18).

The drag coefficient is variable and depends on the detailed wind velocity profile. Because of this variability, it is impossible to remove all drag effects unless each measurement is calibrated. Thus, the approach of using drogues with such small drag coefficients that drag corrections would generally be negligible. With Sea-Test drogues, the uncorrected wind-drag errors are normally less than 10% of the wind-induced current velocity. The drogue paths used in this study were not corrected for wind drag because the effect is no greater than the sensitivity of the analysis. Middle Loch may be an exception due to the weak circulation observed there. If more accurate velocity determinations are required, the corrections can be applied to the field data presented in References 3.3-9 through 3.3-12.

Double line experiments with these drogues have demonstrated negligible current drag for line lengths up to at least 10 meters. Furthermore, the current shear and wind drags were small enough so that drogue lines (and therefore the drogues) were never observed to be more than 5° from vertical in Pearl Harbor. About 5% of the drogue measurements showed evidence of ship interference. At dragging speeds or contact speeds greater than about 0.5 m/sec, various kinds of destructive failures occur. Thus, important ship contacts are obvious, and the velocity measurement is discarded. Occasionally drogues lost their floats, vitiating the resulting measurements. Wind-driven circulation frequently carried surface drogues ashore and again the measurement was lost. Wherever there was a suspicion that the drogues had been tampered with, the measurement was discarded. All drogue tracks used in the analysis are tabulated in Appendix D.

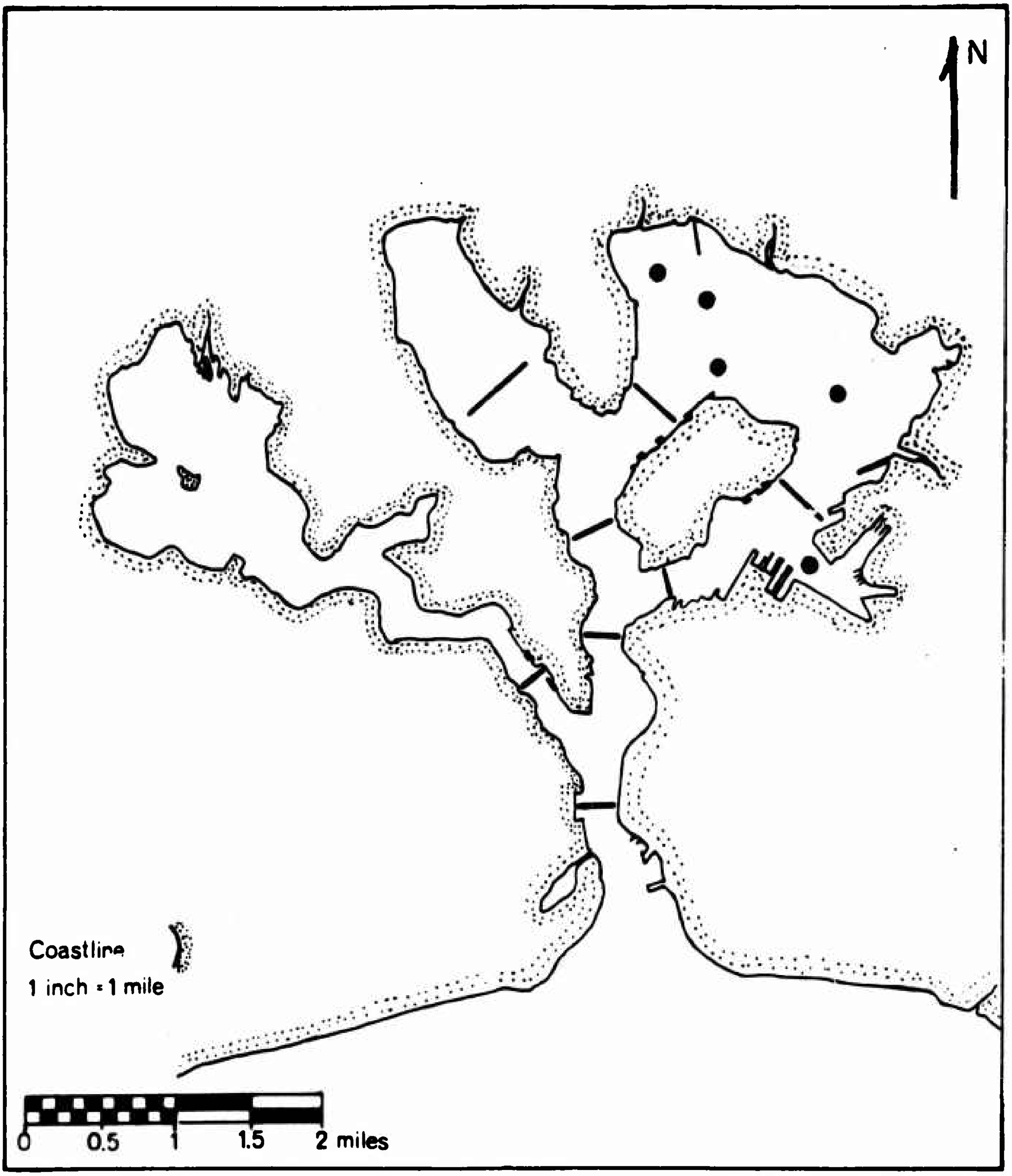


Figure 3.3-8. APPROPRIATE LOCATIONS OF SECTIONS AND STATIONS.

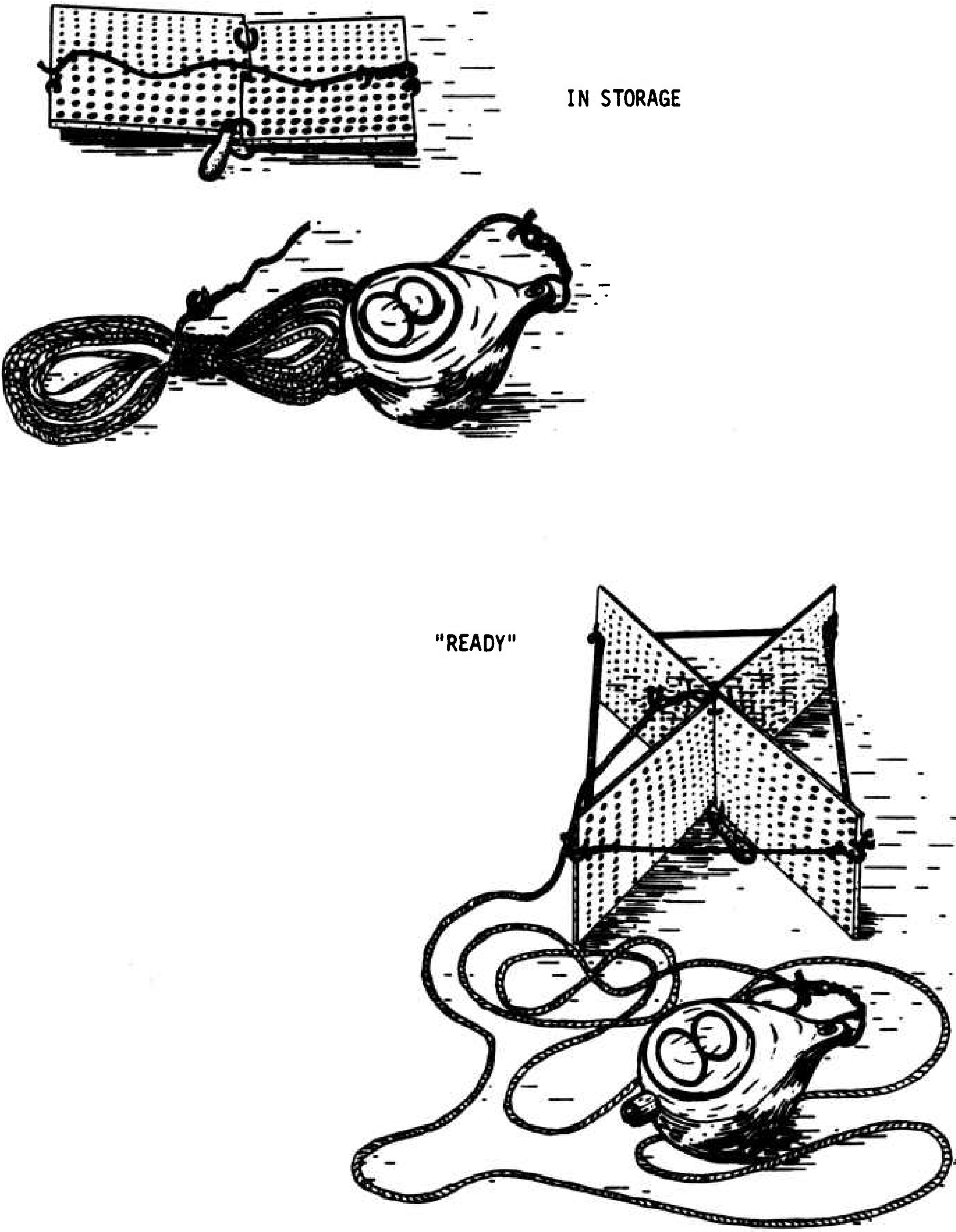


Figure 3.3-9. COLLAPSIBLE CURRENT DROGUE (MODEL 2).

Water temperature and salinity measurements were obtained with Beckman RS5-3 inductive salinometers which were calibrated against a seawater substandard by titration. Samples at two temperatures and two salinities were used for each calibration in order to check the salinity computation mechanism of the instrument. Temperature calibrations were obtained with 0.05°F mercury thermometers. Field checks of the instruments were made with mercury thermometers and an AO Goldberg refractive salinometer.

Observations of wet and dry bulb air temperature were made approximately hourly with matched Taylor sling psychrometers. Wind speed was measured at about 2.3 meters above the water surface, away from boat obstructions, using a corrected Sims Model BT electronic wind meter. Wind measurements were made at least hourly; however, many additional measurements were made in order to estimate temporal and spatial variations in wind velocity. The measurements represent approximately 2-minute averages. Wind direction was obtained with a compass adjusted to True and is reported conventionally (direction from which the wind comes). Visual estimates of percent cloud cover were also made. Rainfall and stream flow data were obtained from the U.S. Geologic Survey, Water Measurement Branch, in Honolulu.

CURRENTS - VELOCITY ANALYSIS

The major mechanisms (or forcing functions) which drive the Pearl Harbor circulation were generally outlined in an earlier section (see Figure 3.3-6). Even if these mechanisms are simplified to linear, independent equations, 7 free coefficients result. Yet, for most sites within the main survey area (Figure 3.3-1), only about 20 independent, well-defined velocity measurements exist. Thus, there is too much freedom in the fitting procedure for high confidence in the results.

In order to assure that the analytical results are physically real, a very restrictive analytical technique has been employed. With the approach used, less than 25% of the data for one current velocity component at one site were selected for fitting by *differences* in a single (apparently important) forcing function; an example of the fitting procedure is given in full for one location in Appendix D. Only a brief description of the process is presented here.

All the field data for a given location were first inspected in order to determine which would be used in the fitting procedure and also to determine the order in which the driving functions would be removed. This order was not necessarily the same at all locations. Pairs of data, which were nearly invariant except for the velocity component and the forcing function under consideration, were selected. An initial assumption of zero dependence was made. A trial value of the parameter was obtained as the mean of the sample difference values. This trial value was then applied to the entire data set to determine reduction of the residual $|\overline{R}|$, see Equation 3.3-1. If $|\overline{R}|$ was appreciably decreased, then the trial value of the parameter was used throughout the data set to remove the effect of the first forcing function. A second trial parameter was then fitted, as described above. When a second trial parametric fit had been accepted, a third parameter was considered, and so forth. When all parameters were thus trial fitted, the entire procedure was repeated once in order to obtain final fit values. This technique is designed to avoid spurious correlations rather than to retrieve all possible information from the field data. The method requires a minimum of about 16 independent observations per velocity component per site.

In order to enhance the sensitivity of the analysis, local coordinates were selected for each of the 10 locations analyzed (see Figure 3.3-10). The u velocity component is directed axially up-channel, as shown in the figure; large numerals designate the reference site, the arrows and the smaller 3-digit numbers indicate the True heading (or the positive direction) of the u component. The v component is orthogonal to the u component with its positive direction to the right. At each location in Figure 3.3-10, velocities in the surface layer (0.3 m depth) and in the bottom layer (5.5 to 7.2 m depth) were analyzed. There was an additional mid-depth (1 to 2 m depth) analysis at Location 9 in Middle Loch.

The general fitting equation is:

$$u,v = \mu U + \nu V + \Delta\mu(\Delta U) + \Delta\nu(\Delta V) + \Sigma\Delta S - \tau\frac{\Delta H}{\Delta T}\sin\left(\frac{\pi t}{\Delta T}\right) + \delta + R \qquad \text{Eq. 3.3-1}$$

where the Greek letters represent the linear coefficients to be fitted, and:

U = axial wind speed, parallel to u

V = orthogonal wind speed, parallel to v

ΔU = hourly change in U

ΔV = hourly change in V

ΔH = the appropriate tidal range

ΔT = time interval corresponding to ΔH

t = time from the previous tidal extreme, + if high water, - if low water

ΔS = the vertical salinity difference, bottom to top

δ = the functional mean current component

R = residual (unfitted) velocity

In this analysis, the functional mean current, δ, is the mean remainder, and it is the final quantity which is removed before R is calculated. Since the fitting technique employs differences, δ is a functional mean, and not a statistical mean *sensu stricto*. All fit parameters are nondimensional except Σ, δ, and R, all of which have the units of speed (m/sec).

All water velocity data at the locations shown in Figure 3.3-10 were used in the analyses, with the following exceptions. Consecutive, redundant data covering essentially one meteorological and oceanographic condition were excluded. Data were also excluded wherever important meteorological or oceanographic functions were not defined. One observation in South Channel was omitted because of possible tampering with the drogue. Observations with probable shoreline interference were discarded. The remaining observations, which are listed in Appendix D, were used.

In addition to the formal analyses, estimates of divergence of the wind velocity field, a quadrature tidal term, and an entry for current reversal

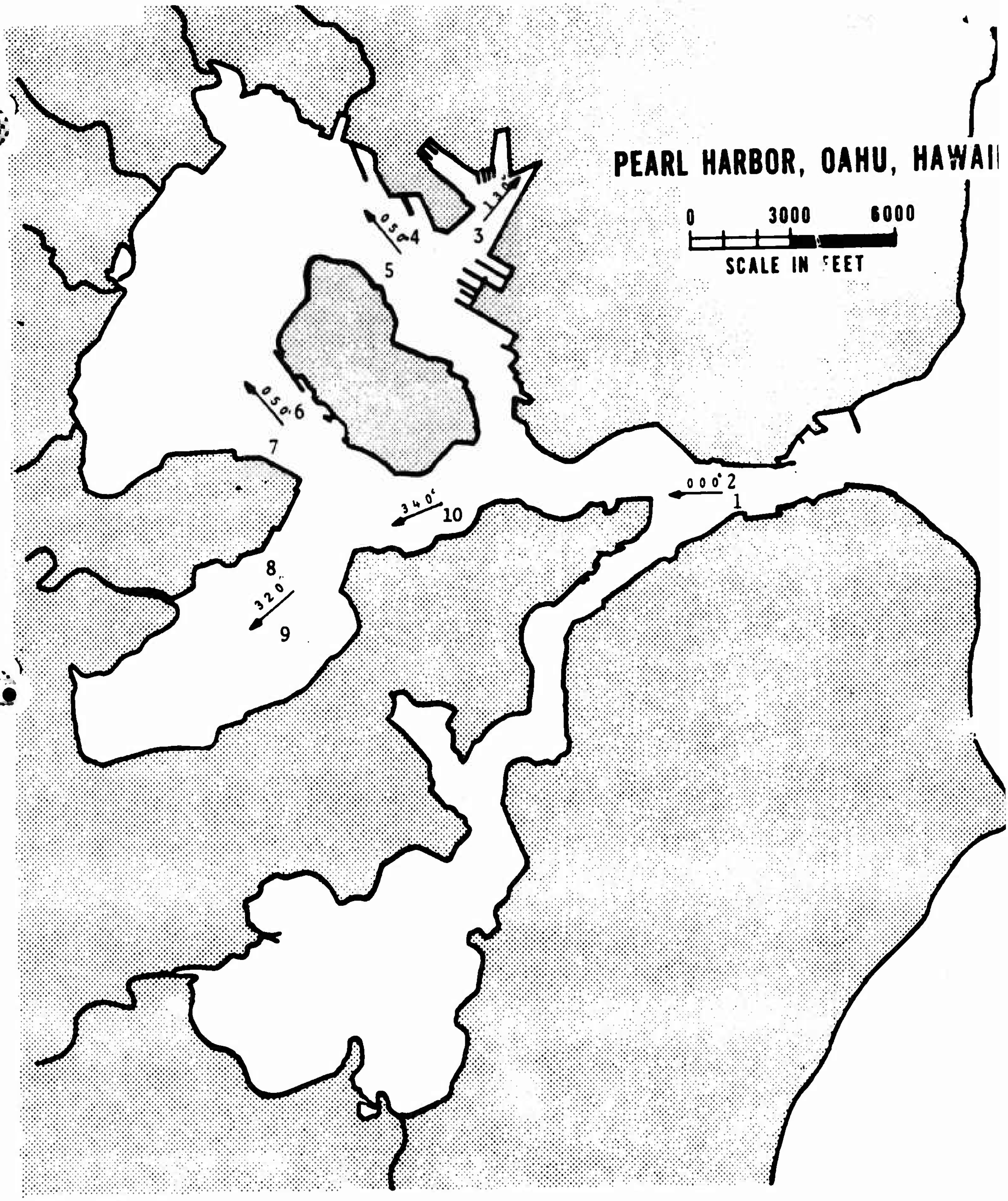


Figure 3.3-10. LOCATIONS OF SITES FOR ANALYSES OF CURRENT VELOCITIES. (DIRECTIONS ARE DEGREES TRUE).

were carried through the analysis. Too few data, however, were available to demonstrate any of these or ΔV dependences. Qualitative comments on some of these effects are presented later in the detailed discussion of the driving mechanisms.

The fitted values of the coefficients of Equation 3.3-1 which resulted from this analysis are listed in Table 3.3-3. The small zeros are entered as a reminder that the analysis did not demonstrate an effect so that the proper coefficient in Equation 3.3-1 for that effect at that location is zero. Water velocities at any of the study locations may be obtained by entering the coefficients tabulated for that location in Table 3.3-3 into Equation 3.3-1. If the forcing functions for that location are then specified, the two components of the current velocity (u,v) are determined. The first column of Table 3.3-3 identifies the locations in Figure 3.3-10 and also the applicable velocity component, u or v. The second column presents the number of observation sets that were employed in the analysis. The next six columns present the coefficients for the wind (columns 3, 4, and 5), for salinity difference (column 6), for the tide (column 7), and for the functional mean current (column 8). The ninth column presents the means of the absolute values of the residuals, the term that the analytical procedure attempted to minimize. The last column gives the percentage decrease in residuals achieved by the analysis. With the inherent errors and uncertainties in the several steps involved in data acquisition, a removal of 70% is considered to be nearly perfect, i.e. 30% of the residuals may fairly be attributed to "observational noise". Such "perfect scores" can only occur if turbulent velocities are small, if higher order and nonlinear effects are small, and if all important driving forces have been accommodated by the analysis.

An inspection of the coefficients tabulated in Table 3.3-3 shows that bottom layer behavior is less well defined than that of the surface layer. Furthermore, the orthogonal (or cross-channel) components, v, are only slightly dependent on the driving functions considered. The cross-channel residual velocity terms are, however, usually smaller than the axial residuals, so this lack of dependence is not a real problem. Such is not the case at Locations 3, 8, 9, and 10. Possible reasons for this situation may be found in the sluggish circulation of Middle Loch (already mentioned), complexities due to downwelling (see Figure 3.3-20), and ship traffic in Southeast Loch.

Equation 3.3-1 and the tabulated coefficients constitute a simple, empirical, 3-dimensional, hydrodynamic model of Pearl Harbor exclusive of West Loch. As indicated in the introduction, the model is most accurate for daytime circulation under tradewind or calm conditions; furthermore the significantly reduced rainfall during the period of study should be borne in mind. In order to gain familiarity with the model and with the basic features of Pearl Harbor circulation, five idealized conditions are considered in some detail.

First, all driving functions in Equation 3.3-1 are "turned off". In this case, only the functional mean components (column 8 or δ) remain. Since these mean flows result from interactions of the other driving functions, the functional means should ideally vanish; practically, they do not. They remain as constants which contain part of the tidal (column 7 or τ) and estuarine (column 6 or Σ) circulation and other constants of the harbor not linked to forcing functions by the analysis. The functional mean circulation, δ, is pre-

Table 3.3-3. WATER VELOCITY COEFFICIENTS.

LOCATION	NO. OBS	μ	Δμ HOURS	ν	Σ m/s	τ (10^3)**	δ m/s	$\overline{\lvert R \rvert}$ m/s	% REMOVED
1S u	14	0.036	0	0	-41	3	0	0.05	41
v	"	0	0	0.008	10	0	-0.01	0.02	5
B u	14	0.010	0	0	15	3	-0.01	0.03	24
v	"	0	0	0	0	0	0	0.01	0
2S u	18	0.021	0.012	0	-77	3	0.03	0.03	76
v	"	0	0	0	0	0	0	0.03	0
B u	22	0.014	0	0	15	6	-0.02	0.05	39
v	"	0	0	0	0	0	0	0.02	0
3S u	19	0	0	0	0	0	-0.01	0.03	9
v	"	0	0	0.007	0	-2	0	0.02	35
B u	15	0	0	0	0	0	-0.01	0.02	7
v	"	0	0	0	0	0	0.01	0.01	29
4S u	28	0.018	0	0	0	3	0.01	0.06	18
v	"	0	0	0	0	0	-0.01	0.02	8
B u	30	0	0	0	0	0	0	0.02	0
v	"	0	0	0	0	0	0	0.01	0
5S u	29	0.020	0	0	-20	2	0.02	0.04	51
v	"	0	0	0.010	0	0	0.02	0.02	6
B u	30	0.003	0	0	0	0	0.01	0.02	5
v	"	0	0	0	0	0	0	0.01	0
6S u	21	0.017	0	0	0	0	0.01	0.04	54
v	"	0	0	0	0	0	-0.02	0.02	7
B u	23	0	0	0	0	0	-0.01	0.02	2
v	"	0	0	0	0	0	0	0.01	0
7S u	24	0.022	0	0	-41	1	0	0.04	70
v	"	0	0	0	0	0	0.01	0.03	-5
B u	23	0.008	0	0	0	0	-0.02	0.02	57
v	"	0	0	0	0	0	0.01	0.02	0
8S u	20	0	0.04*	0	0	1	-0.02	0.03	41
v	"	0	0	0.009	0	0	0	0.04	49
B u	20	0	0	0	0	0	0.02	0.02	37
v	"	0	0	0.003	0	0	0	0.01	42
9S u	17	0	0.03*	0.006	0	0	-0.01	0.03	38
v	"	0	0	0.010	0	0	-0.01	0.03	47
M u	10	0	0	0	0	(1)	(0.01)	(0.02)	31
v	"	0	0	(0.008)	0	0	0	(0.02)	12
B u	17	0.007	-0.01*	0	0	0	0.01	0.02	27
v	"	0	0	0.004	0	0	0	0.02	35
0S u	16	0.024	0	0	0	1	-0.04	0.03	57
v	"	0	0	0.006	0	0	-0.02	0.02	38
B u	17	0.018	0	0	0	1	-0.02	0.03	36
v	"	0	0	0.012	0	0	0.01	0.02	25

*A 3-hour lag in this effect. ( ) indicates too few data. **Multiply numbers in this column by 10^3.

sented in Figure 3.3-11, which represents that part of the model which cannot be "turned off", even though no forcing function is explicitly stated.

Several features of Figure 3.3-11 are of interest. First, typical estuarine circulation (i.e. inflow along the bottom and outflow on the surface) appears in Middle Loch. The estuarine flows appear in the functional means because ΔS is intimately tied to the dominant, time derivative circulation of Middle Loch. Second, a cyclonic gyre about Ford Island is apparent, which is consistent with the observations of Au (Reference 3.3-1). Third, the surface flows in North and South Channels converge toward the centers of the channels. This situation was often observed in the field, however, no explanation is offered here. Fourth, there is a weak net flow into East Loch in the bottom layer. This bottom flow may be a reaction to the tradewind-driven surface outflow (see Figure 3.3-13). Fifth, there is a mean inflow at the surface of the harbor entrance, which is matched by an outflow below. This situation is, of course, the reverse of that specified by Cox or Au (References 3.3-1 and 3.3-4); it should, however, be remembered that all fresh water has been "turned off" in this particular illustration. In general, the functional mean flows seem to satisfy continuity requirements across all of these sections.

Next, suppose that rainfall and runoff are so intense that ΔS is increased to 10 ‰ in the harbor; this might be called the "deluge" model. Again all other driving forces, including the functional mean δ, are turned off. The resulting "deluge" model circulation (column 6 or Σ) is shown in Figure 3.3-12. Typical estuarine circulation is seen at the harbor entrance, now agreeing with that specified by Cox and Au (References 3.3-1 and 3.3-4). Presumably, the surface current on the west side of the entrance is displaced to the east because of a strong surface efflux from West Loch. In both North and South Channels, the surface outflow is concentrated on the west sides of the channels. The flow in North Channel predominates and reflects the presence of Waimanu Stream. A surface outflow would, in reality, also occur in Middle Loch; however, this effect has been masked in the model by the wind derivative effect. The results of the "deluge" model are also consistent with mass balance for all regions of the harbor.

Next, the water is turned off and the wind (columns 3 and 5, μ and ν) is turned on. The mean wind at 7.6 m above the ground at Honolulu Airport is 5.2 m/sec from about 70° True (Reference 3.3-18). Comparisons between the Honolulu Airport data and Pearl Harbor survey data (Reference 3.3-9) suggest that wind speeds 2.3 m above the water surface are generally about 20% lower but from approximately the same direction. Thus, an appropriate wind velocity for the Pearl Harbor mean "wind-driven" model is 4 m/sec from 70° True. The results appear in Figure 3.3-13; also included in the figure is the wind summary for leeward Oahu prepared by Bathen (Reference 3.3-19). If the functional mean component (column 8 or δ) is added to the wind, Figure 3.3-14 results. The velocities shown in this figure more closely resemble those observed under typical field conditions. The figure also identifies the areas where surface drogues often struck the shore, viz. the southern shores of Middle Loch and NW of Location 10. Addition of δ also creates the surface convergence in North and South Channels mentioned earlier and often observed in the field. One disturbing feature of Figures 3.3-13 and 3.3-14 is that continuity is not immediately satisfied for East Loch or for the entire harbor as viewed from the entrance. In both cases there is an obvious net efflux of water, es-

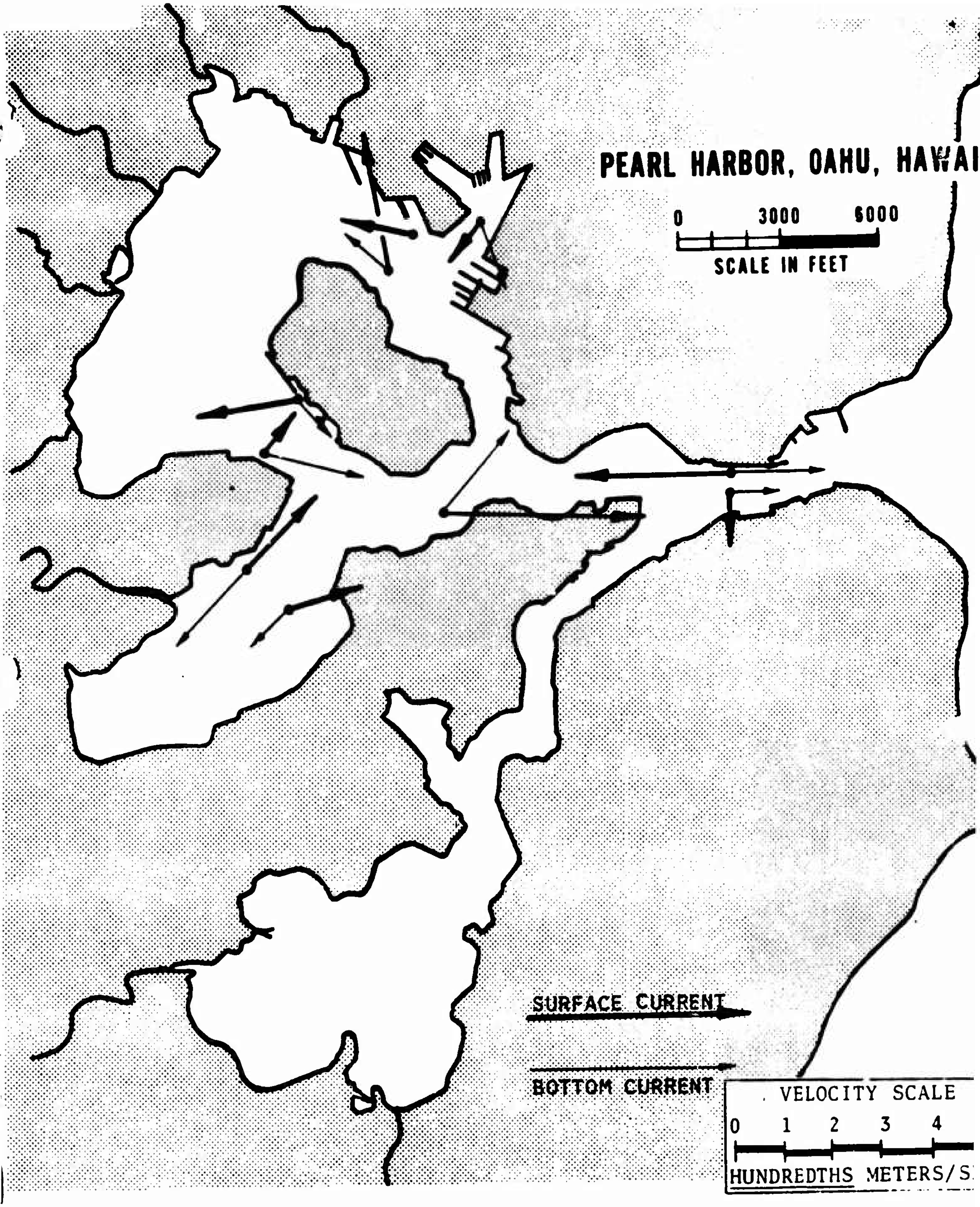


Figure 3.3-11. "DEAD" MODEL CIRCULATION.

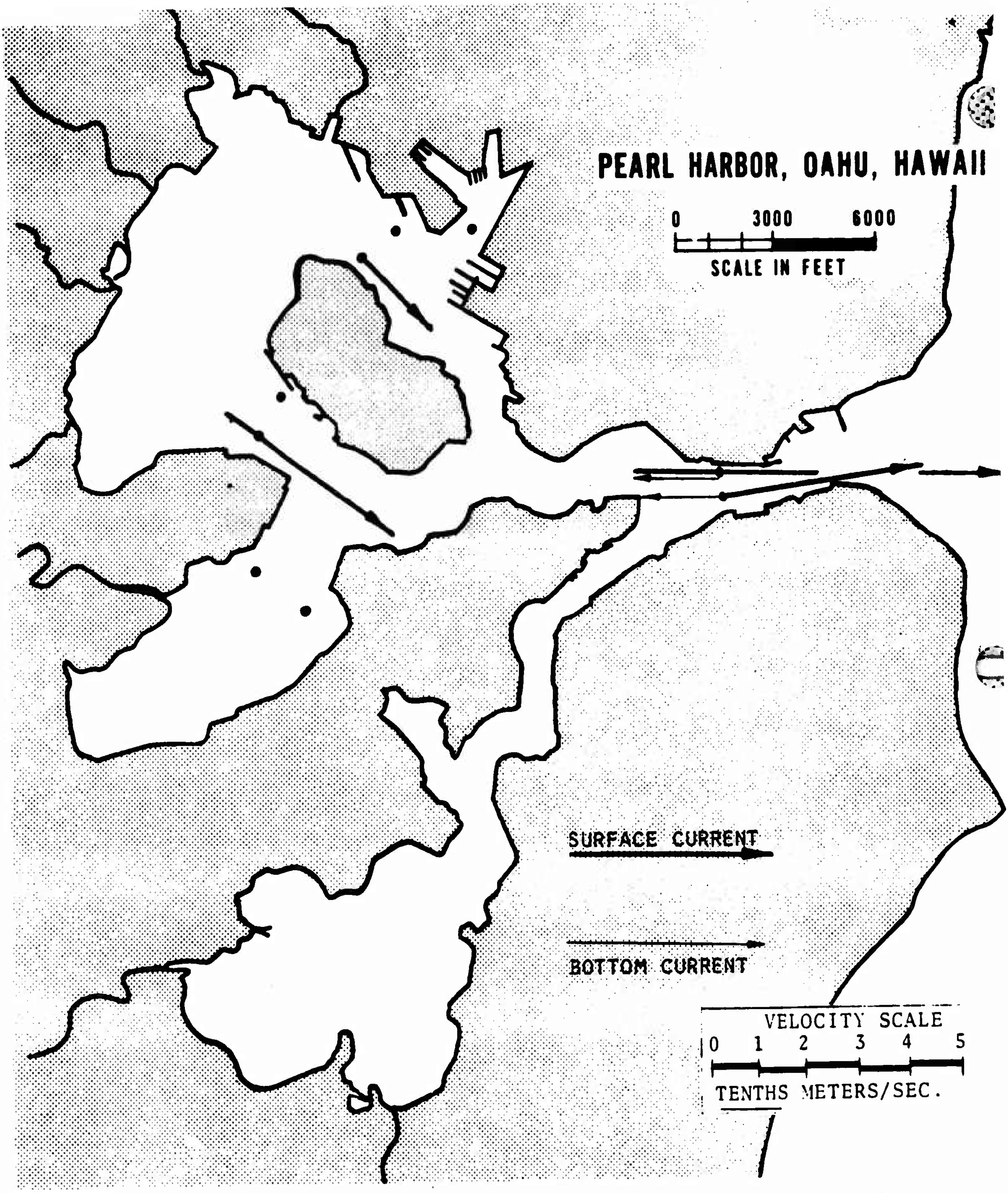


Figure 3.3-12. SIMPLE "DELUGE" MODEL CIRCULATION.

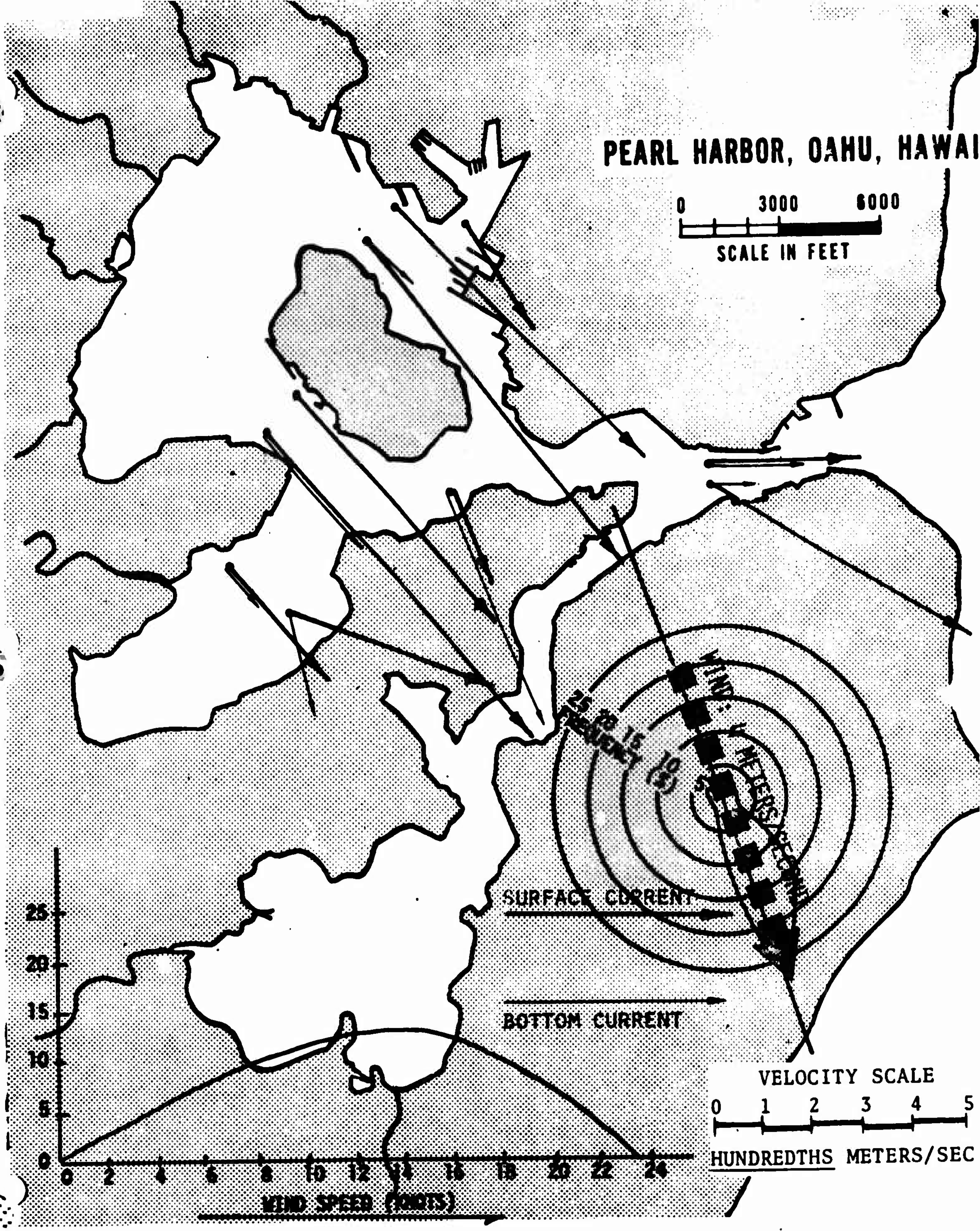


Figure 3.3-13. "WIND-DRIVEN" MODEL CIRCULATION. (DATA FROM REFERENCE 3.3-20).

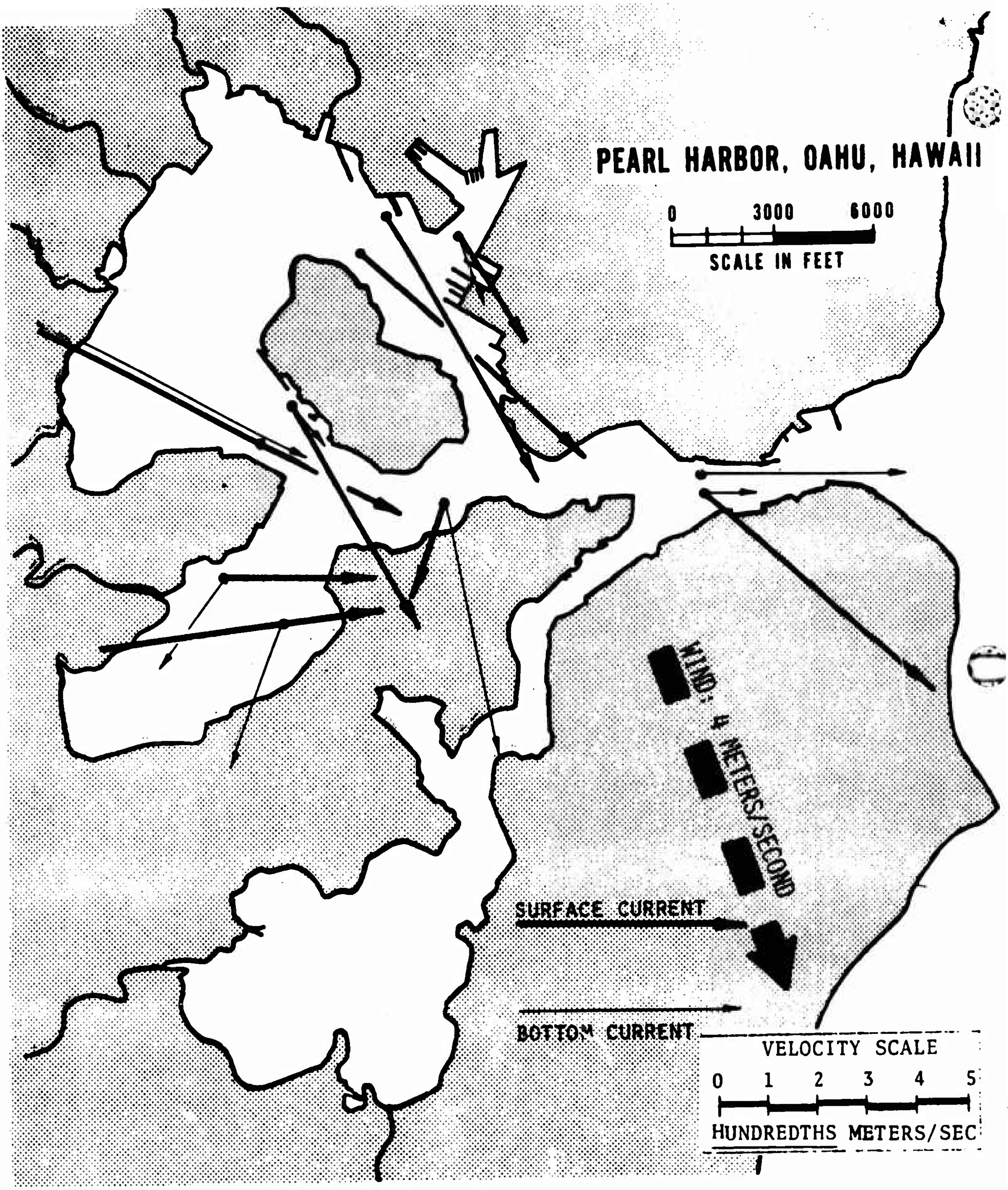


Figure 3.3-14. "WIND-DRIVEN" MODEL CIRCULATION.

pecially in the surface layer. Such a situation cannot be long sustained. For example, the average wind-driven efflux at the harbor entrance is -0.03 m/sec (the negative sign here indicates flow out of the harbor), which would result in a total volume flow of roughly 100 m^3/sec. Such a flow would entirely drain Pearl Harbor in about 2 weeks. Four possible explanations of this violation of continuity are offered. First, variations in the local wind field are not included in the illustration; Figures 3.3-13 and 3.3-14 represent the results of an invariant wind blowing continuously. Such a condition is quite artificial and is discussed later in the section on driving forces. Second, the outflow may be an artifact of the survey's sampling procedure. For example, the mean hourly wind speed at Honolulu Airport is 6.8 m/sec at 1300 hours and only 3.5 m/sec at 0400 hours (calculated from data in Reference 3.3-20), but current measurements were confined to the daylight hours. With any sort of landward component, even this daytime model will show a wind-driven flow into the harbor; thus compensating nighttime flows into the harbor are quite probable. Interestingly, such transitory daytime losses from the harbor are at least consistent with tidal deviations observed at the Waiau Power Plant; see Figure 2-8 of Reference 3.3-7 in which tidal deviations as large as 15 cm are shown. According to Dale (Reference 3.3-21), 24-hour filtered records of tidal height at the CINCPACFLT landing show negative and positive deviations as large as 6 to 9 cm. The net wind-driven efflux predicted by the daytime model could cause such depressions in 3 to 5 hours of flow. Third, isolated return-flow jets are possible although such compensation is considered unlikely. Such jets could only exist if no drogues had been placed in a jet or if all drogues so placed had been lost. Fourth, return flow may occur below 8 meters depth; that is, the return flow may be a bottom current. The few drogue measurements obtained near the bottom (12 m depth) in the harbor entrance did not, however, show such bottom currents. Additionally, such bottom currents would probably be identifiable in the temperature and salinity profiles. Therefore, this possibility is also considered unlikely.

Next, the wind is turned off, and the tide (column 7 or τ) is turned on. The mean tidal speed is

$$\bar{u} = \frac{2\Delta H}{\pi \Delta T}\,\tau \qquad \text{Eq. 3.3-2}$$

Tidal data for Pearl Harbor are given in Table 3.3-4. The standard tidal period is 12.4 hours, thus $\overline{\Delta T} \approx 2.2 \times 10^4$ seconds and $\bar{u} = 1.0 \times 10^5$ (m/sec)τ for any location within the harbor, and τ is given in Table 3.3-3. The mean, model tidal velocities for the selected locations appear as double arrows in Figure 3.3-15. The mean flood and the mean ebb velocities are indicated by the full length of the arrows (point to point) in the figure; other tidal velocities may be obtained from Figure 3.3-15 by multiplying the plotted values by the appropriate scaling factor given in Table 3.3-5. Thus, the peak ebb tidal velocities for 1973 could be modeled by lengthening the arrows in Figure 3.3-15 by a factor of 3.2 and pointing them only in the seaward direction. The tidal circulation is harmonic and thus automatically satisfies the continuity requirement.

Changes in wind speed or the wind-derivative coefficient (column 4 or $\Delta\mu$) are important only for Middle Loch where all other coefficients tend to be small or nonexistent. Rates of change on the order of 2 m/sec per hour are not uncommon. Resultant surface velocities in Middle Loch would be about

TABLE 3.3-4. TIDAL ELEVATIONS AND RANGES.

ELEVATION	METERS	RANGE	METERS
1973 MAXIMUM HIGH WATER	+0.8	1973 MAXIMUM	0.85
MEAN HIGHER HIGH WATER	+0.6	DIURNAL	0.58
MEAN LOWER HIGH WATER	+0.3	MEAN	0.37
MEAN WATER	+0.2	MINIMUM	~~0.10~~ 0.0
MEAN HIGHER LOW WATER	+0.1		
MEAN LOWER LOW WATER	0.0	(MLLW=DATUM LEVEL)	
1973 MINIMUM LOW WATER	-0.1		

Table 3.3-5. TIDAL VELOCITY SCALES. (MULTIPLICATION FACTORS TO BE USED WITH Figure 3.3-15).

TIDAL RANGE	FACTOR (MEAN SPEED/PEAK SPEED)
Mean	1.0/1.6
Diurnal	1.6/2.5
1973 Maximum	2.0/3.2

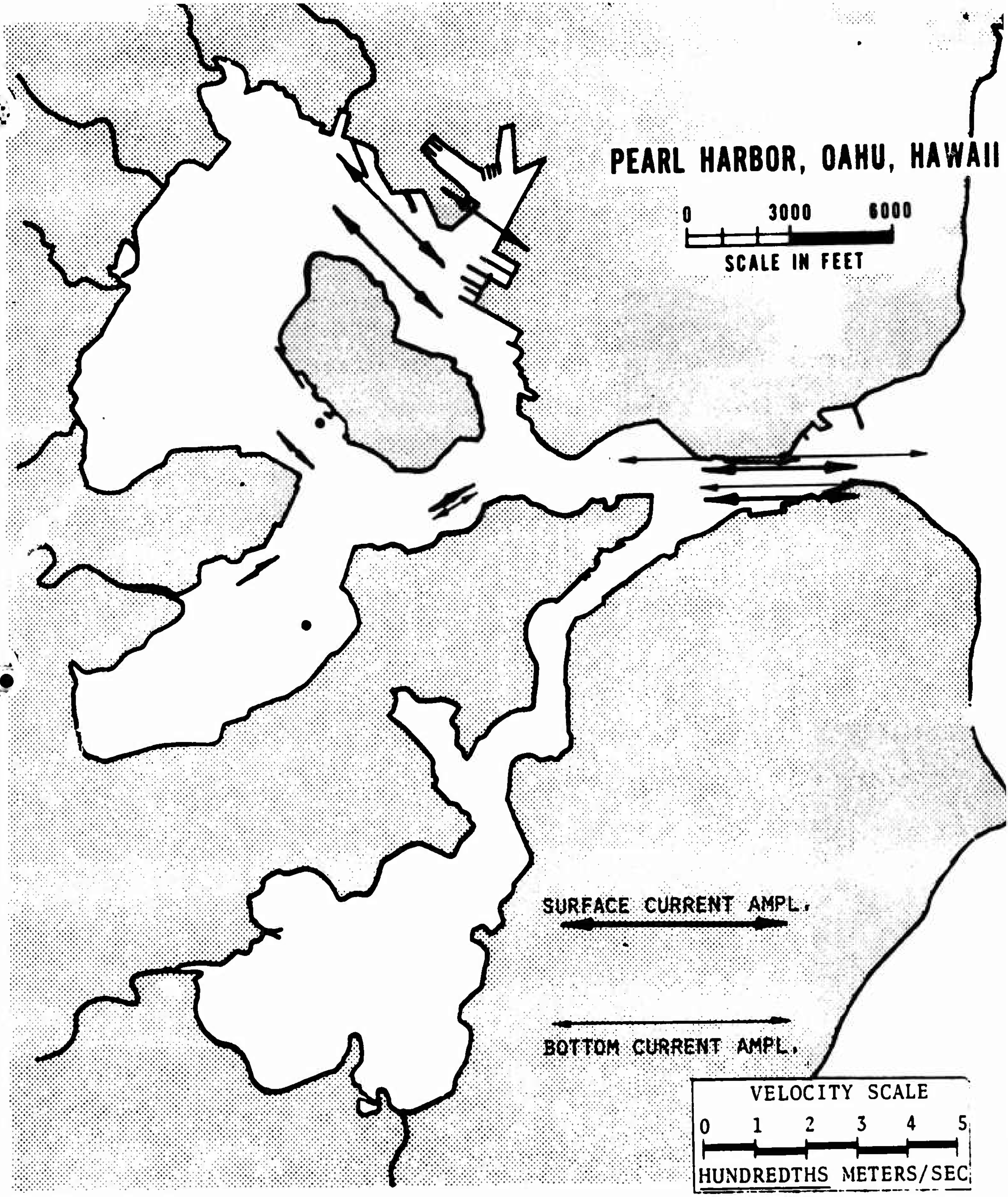


Figure 3.3-15. "TIDAL" MODEL CIRCULATION. (MEAN SPEEDS).

0.07 m/sec and directed axially with a 3 hour time lag according to Table 3.3-3. Continuity is necessarily satisfied. The phenomenon of currents driven by temporal changes in wind stress is discussed at greater length in the section on driving mechanisms or forces.

Finally, the residual current velocities (column 9 or $|\overline{R}|$) are considered. The percentage residual is obtained by subtracting the value in the last or tenth column from 100; as noted previously, random errors in data aquisition account for about 30% of this residual. Thus, the percent residual minus 30 becomes an estimate of the magnitude of turbulent velocity. The axial or u components (surface/bottom) of this estimated turbulence are given in Figure 3.3-16. The relatively great uncertainty in the wind derivative driving function in Middle Loch increases the plotted values there. Also, the bottom layer value at the east side of North Channel reflects variability associated with a local convergence condition, discussed later (see Figure 3.3-11). Higher turbulence values shown on the west side of the Main Channel are probably associated with switching effects (variable reversing currents resulting from differences in driving functions for West and East Lochs) at the branching of the channels. Most important is the fact that the highest residual percentages occur in South Channel and Southeast Lochs, suggesting that more than half the water velocities, surface and bottom, are random. This region (and also the east side of North Channel) experiences a great deal of ship traffic (see Figures 3.4-6 and 3.4-8). Turbulent velocities due to the movement of ships may be responsible for these large residual percentages, see later discussion in section on driving forces.

CURRENTS - CIRCULATION

The 1972-1973 study has provided enough data for a basic understanding of the circulation of Pearl Harbor except for West Loch. As previously indicated, the results cover only fairly typical daytime conditions during a dry year. Therefore, caution is advised if conditions differ significantly from those prevailing during the survey.

To use the model (Equation 3.3-1 and Table 3.3-3) to estimate circulation patterns in Pearl Harbor, the following environmental parameters must be known:

- Wind Field
- Tidal Stage
- Fresh Water Influx (as ΔS)

These parameters may be temporally and spatially varied if representation of a particular circulation pattern is required of the model. The most critical parameters for the various regions of Pearl Harbor have been indicated in Figure 3.3-6. The data in References 3.3-9 through 3.3-12 may be used to estimate the above listed parameters for several general conditions. Approximate circulation models may be obtained by providing simple, constant driving functions. In the previous section, 6 idealized circulation models were provided as Figures 3.3-11 through 3.3-16. In this section, 2 more realistic model-derived circulation patterns are presented. The first shows the currents under calm wind conditions at slack tide for the 1972-1973 fresh water influx (mean ΔS = 1.5 ‰); that is the circulation is determined using columns 6 and 8 (Σ and δ) of Table 3.3-3. The result is Figure 3.3-17; the 10 locations are shown as dots and the currents again are represented by vectors. An estuarine

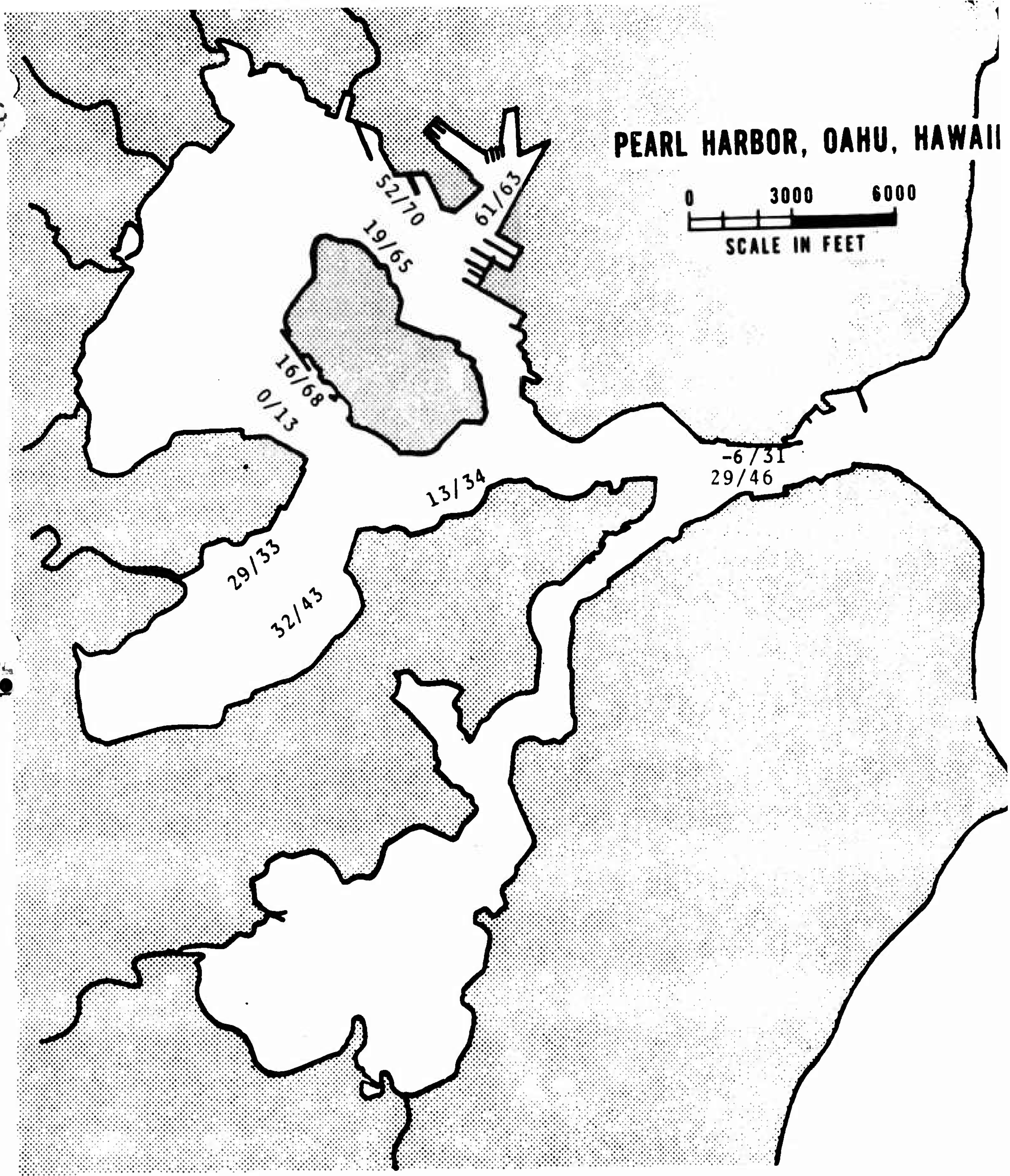


Figure 3.3-16. PERCENT u RESIDUALS MINUS 30: SURFACE/BOTTOM LAYER. (30% IS CONSIDERED "OBSERVATIONAL" NOISE, SEE TEXT).

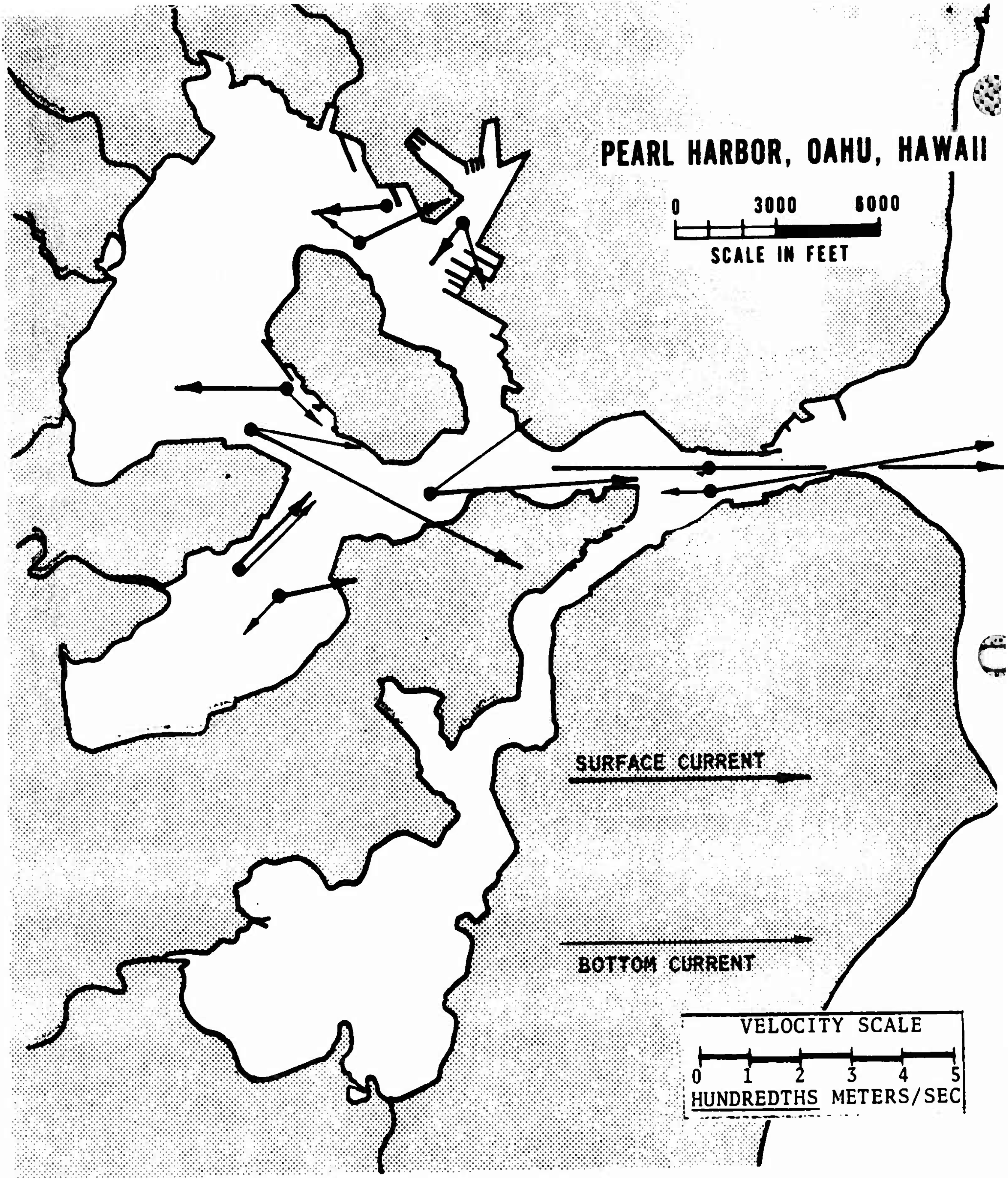


Figure 3.3-17. 1972-1973 MEAN CURRENTS WITHOUT WIND OR TIDE.

circulation pattern, with surface outflow and bottom inflow, is conspicuous. If the mean tradewind (4 m/sec from 70° True) is added to the model (columns 3 and 5, or μ and ν), the "simple mean model" shown in Figure 3.3-18 results; the reduced velocity scale in Figure 3.3-18 should especially be noted. Figure 3.3-18 is also the vector sum of Figures 3.3-13 and 3.3-17. Mean conditions for flood or ebb tide may be obtained by vector addition of tidal velocities obtained from Figure 3.3-15 to those obtained from Figure 3.3-18 (again noting differences in scale between the two figures). Since about 60% of winds on leeward Oahu have speeds between 2 and 8 m/sec and directions between 0° and 90° True (Reference 3.3-20, see also insert to Figure 3.3-13), the combination of Figures 3.3-15 and 3.3-18 is fairly representative of the harbor over half the time. The combination of Figures 3.3-15 and 3.3-17 accounts for another 5% of the time. A wide variety of conditions exist during the remainder of the time; however, circulation patterns may be estimated in the same manner as that done above.

The data in Figure 3.3-18 have also been considered in conjunction with other current observations made in the 1972-1973 study to generate a qualitative surface circulation pattern shown in Figure 3.3-19. The resulting "typical" circulation pattern resembles that of Au (Reference 3.3-1); the arrow lengths in this figure are intended to indicate the strength of the currents only in a qualitative sense; they do not have specific scalar meaning as in the earlier modeled circulations.

CURRENTS - CONVERGENCE

From Figures 3.3-18 and 3.3-19, it is apparent that there are local regions within Pearl Harbor in which vertical water motions are important. Typical regions of upwelling and downwelling are shown in Figure 3.3-20. Upwelling is generally obvious from the divergence of surface drogues, the convergence of bottom drogues, and plumes of clear green water visible on the surface. Upwelling in Middle Loch, however, produced milky green waters which were quite odiferous. Downwelling is associated with the opposite in drogue behavior and is not associated with any unusual surface water coloration. Typically upwelling and downwelling (as distinguished from vertical mixing) are probably wind driven since overturning is seen to increase markedly with increased wind velocity (see Figure 3.3-4). Also, upwelling and downwelling are most evident when the water column is least stably stratified, as would be expected. Ship-induced mixing in South Channel and Southeast Loch, therefore, could be largely responsible for the extensive upwelling at the head of East Loch. Thus, second-order effects related to ship mixing would appear possible.

RESIDENCE TIMES

Typical residence times for waters in the upper layer (0.3 m) of Pearl Harbor can be estimated from Figures 3.3-18 and 3.3-19. Following the general current track in Figure 3.3-19 from the head of East Loch to the harbor entrance, a distance of about 8000 meters is obtained. From Figure 3.3-18, an average surface current of about 0.07 m/sec may be obtained; thus a total transit time of about 30 hours can be estimated from the upper reaches of East Loch. Assuming that only half the volume of a given water mass starting at this location actually travels at this average speed to the harbor entrance,

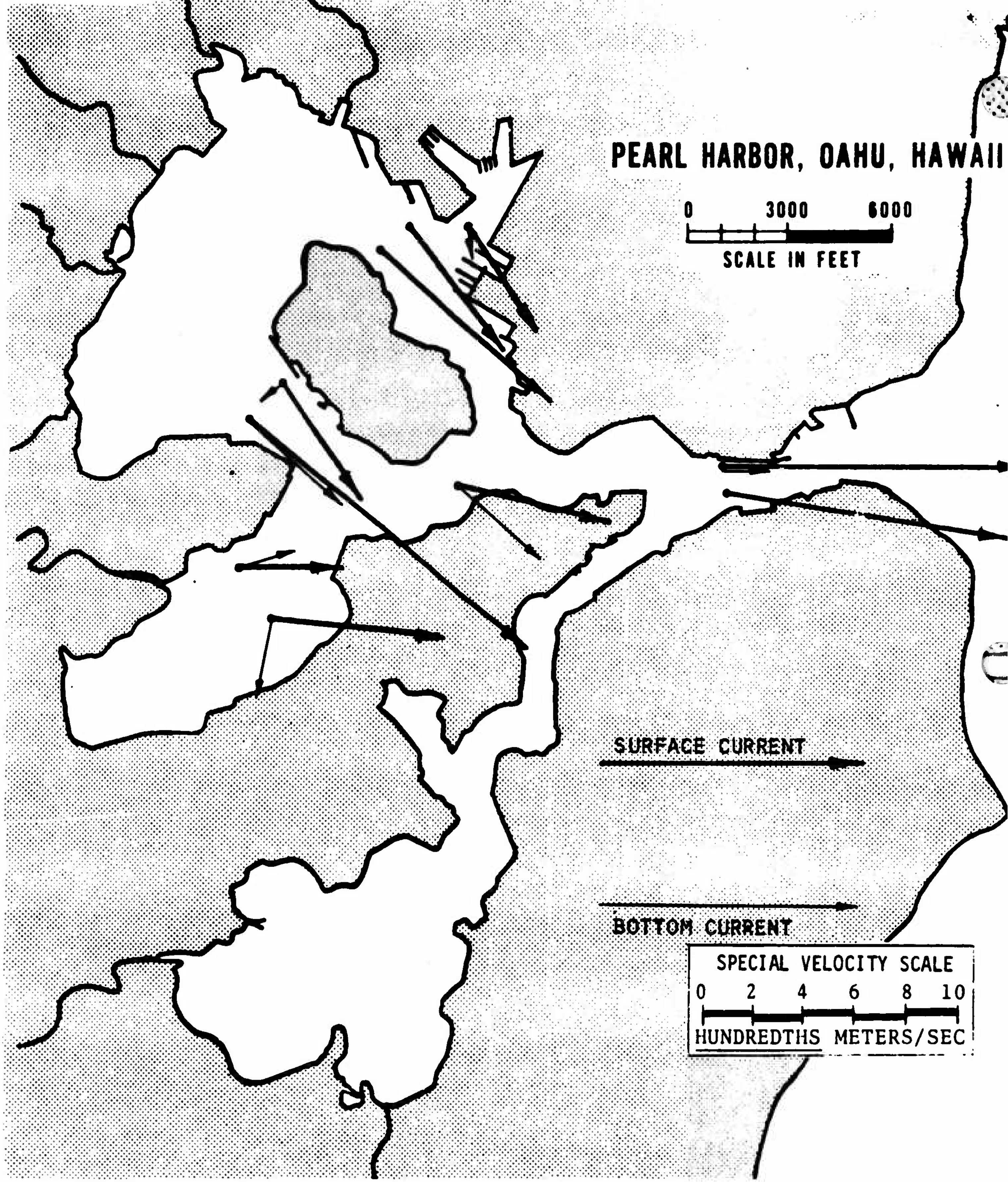


Figure 3.3-18. "SIMPLE MODEL MEAN" CIRCULATION.

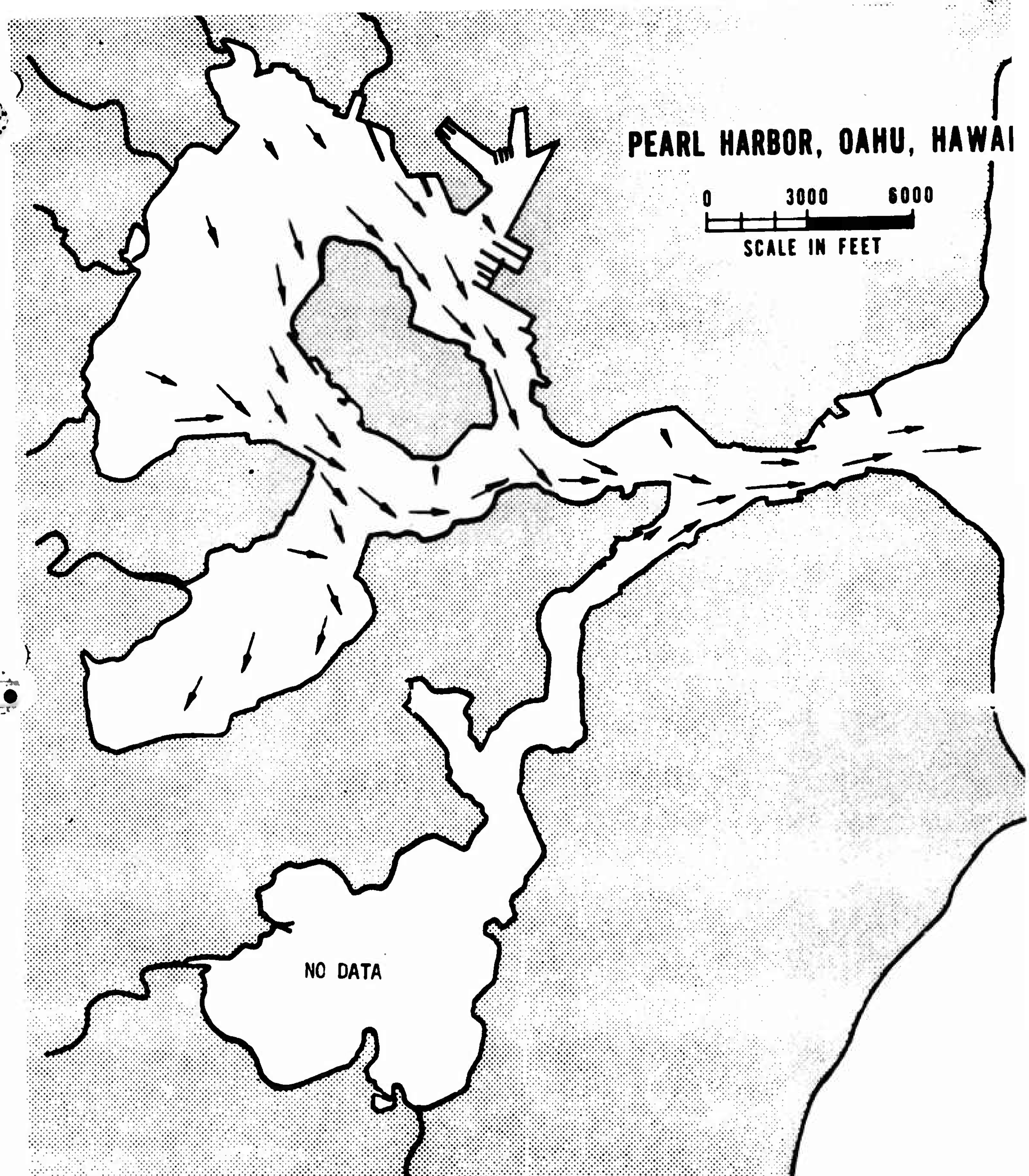


Figure 3.3-19. TYPICAL SURFACE CIRCULATION PATTERN.

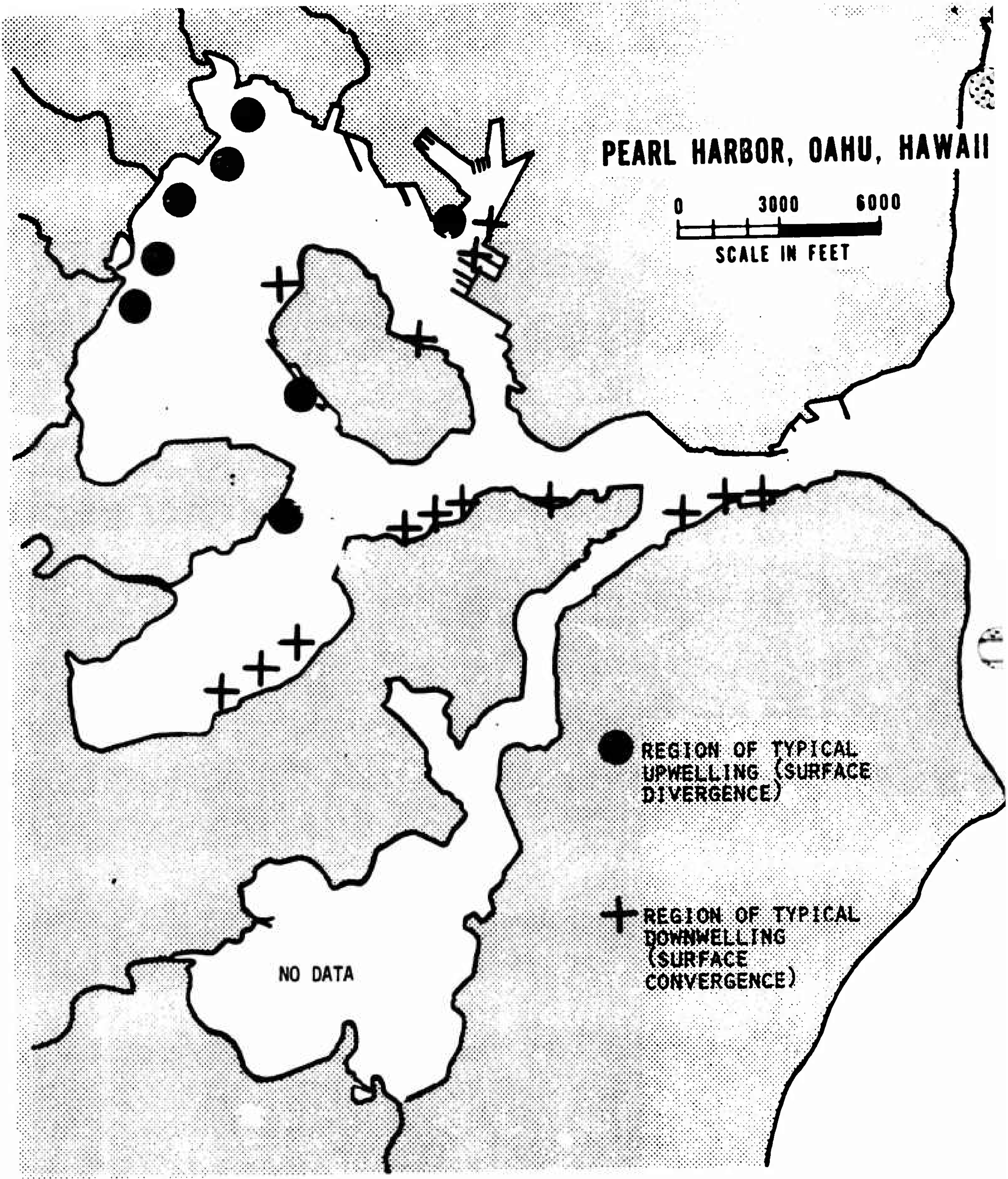


Figure 3.3-20. REGIONS OF TYPICAL UPWELLING AND DOWNWELLING.

this calculation may be taken as a crude estimate of surface water residence time. Similar calculations were made for other regions in Pearl Harbor and the results are given in Figure 3.3-21. Upper East Loch and Middle Loch in general exhibit the slowest surface layer flushing; an independent estimate of surface layer flushing times is also given in the section on water masses.

Residence times of bottom waters are more difficult because the bottom water well within the harbor must be carried to the surface layer by mixing or by upwelling before rapid exit from the harbor is probable. Vertical transport, which cannot be well documented by this study, thus becomes important. Based on the limited data available (Figures 3.3-17 and 3.3-18, and the residual velocities, $|\overline{R}|$, given in Table 3.3-3) residence times for the lower layer have been estimated and are presented in Figure 3.3-22. These estimates are considered very preliminary and are generally shorter than the 6½ day half-life for Southeast Loch waters which can be calculated from Fisher's dye studies (Reference 3.3-8). There are several possible reasons for the differences. Fisher's dye samples were taken from depths of 2 to 8 meters, and therefore not from truly surface waters; furthermore, the present estimates consider vertical mixing which can have pronounced effects on residence times. However, surface residence times estimated from other data do show good agreement with Fisher, see later section on water masses. Again considering bottom waters, if a track along the bottom from Southeast Loch around the north end of Ford Island and out North Channel to the entrance is measured, the track length is approximately 10,000 meters. Again from Figure 3.3-18, a bottom current of 0.01 m/sec can be estimated for the first 5000 m of this track and 0.03 m/sec for the last 5000 meters. If the track and speed estimates are accepted, a total transit time of about 8 days is obtained, a value which is similar to Fisher's residence times. Regardless of exact values, several general observations seem true. Middle Loch appears to be relatively stagnant (wind flushing times are estimated as equivalent to 5 or more tidal cycles or at least 2½ days). Minimum flushing times are expected for the upper reaches of East Loch because of the frequent wind-induced upwelling in that region (see Figure 3.3-20). The effects of ship-induced turbulence and thus enhanced vertical mixing due to the reduction of vertical stability are expected to reduce bottom flushing times for Southeast Loch and the region north of Ford Island.

Residence times for various regions of Pearl Harbor depend strongly on the prevailing meteorological and oceanographic conditions. For situations in which the residence time is critical, special evaluations are recommended.

DRIVING MECHANISMS

As stated earlier in this section, Pearl Harbor is driven by several major mechanisms: tide, fresh water influx, salt water influx, various mixing processes, wind stress, and both temporal and spatial derivatives of wind stress. Each of these driving mechanisms is now discussed in detail in the light of the 1972-1973 field observations and of the current model developed from them. Several other factors also affect the harbor. These include net radiation balance and heat budget for the harbor, evaporation from the water surface, and wind setup (or buildup) on the shelf off the entrance of Pearl Harbor. In addition, factors such as tsunami and hurricane storm surge may be important on very rare occasions. However, all of these factors are

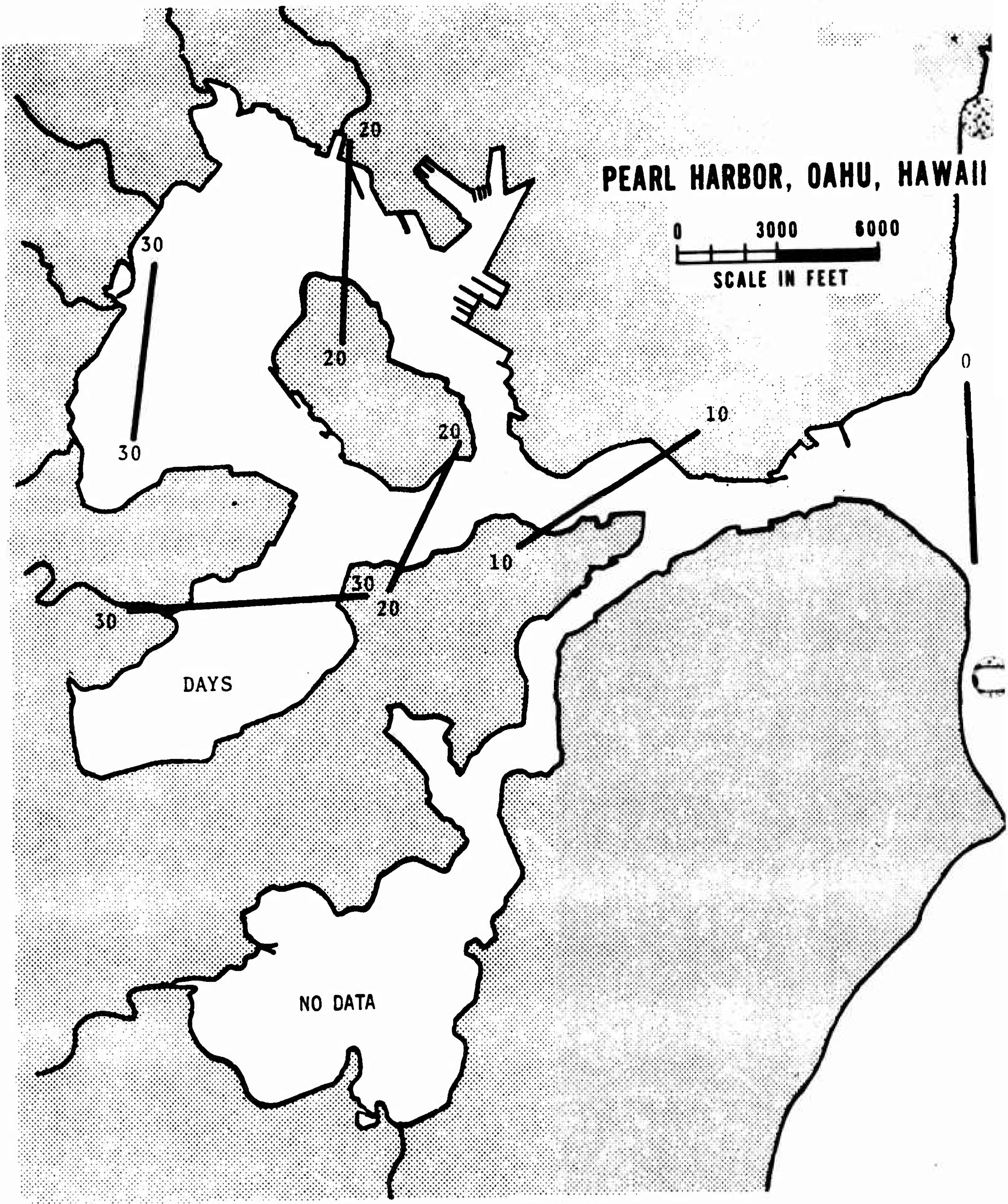


Figure 3.3-21. TYPICAL UPPER LAYER RESIDENCE TIMES (HOURS).

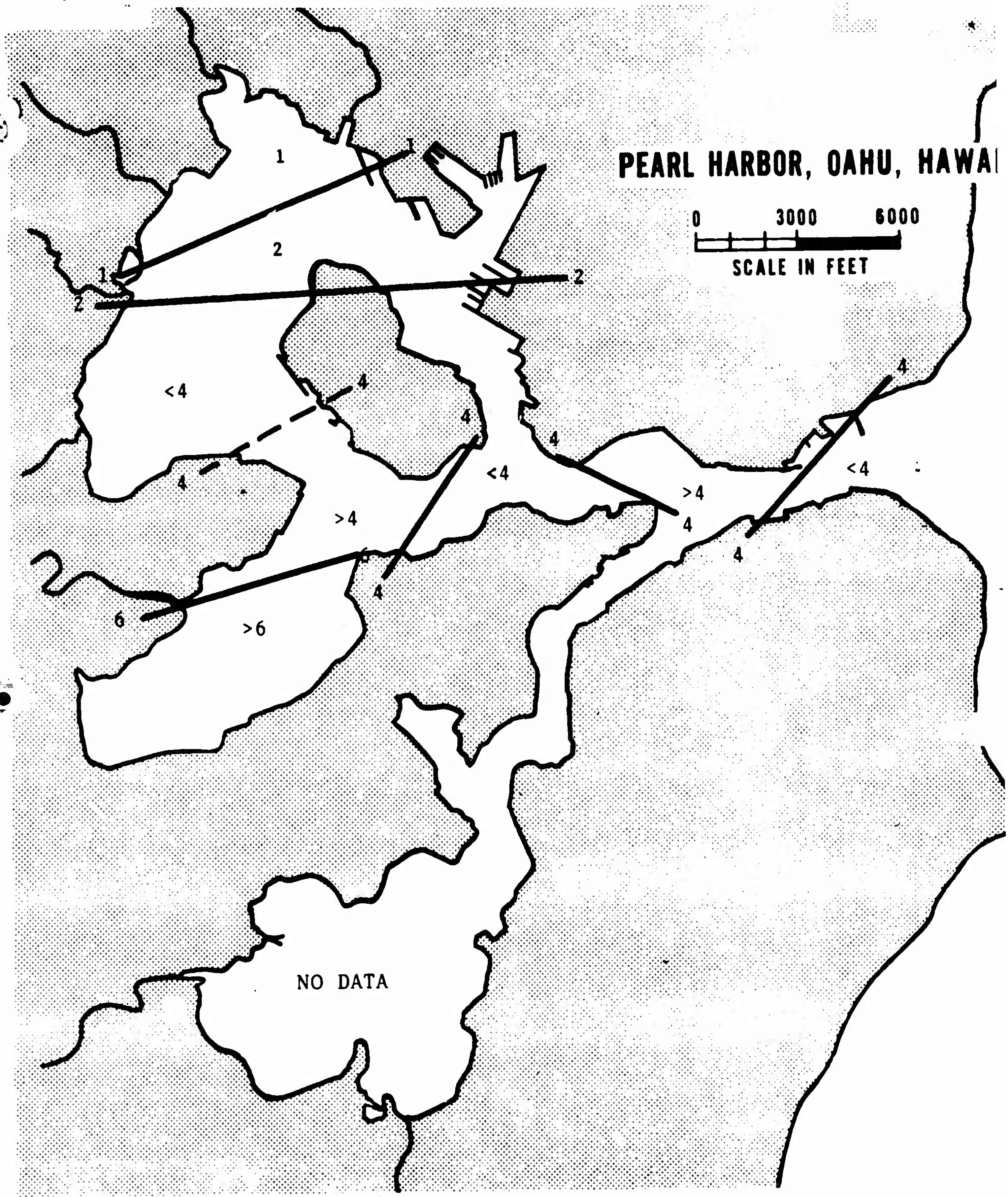


Figure 3.3-22. ESTIMATED TYPICAL LOWER LAYER RESIDENCE TIME (DAYS).

probably less important than the uncertainties which are associated with the major factors here considered in detail. Each major force is first treated separately and then related to the model already described where appropriate.

DRIVING MECHANISMS - TIDE

Previous studies of currents in Pearl Harbor have been mainly concerned with tidal effects (References 3.3-3 and 3.3-5), presumably because the tidal driving function can be well defined (References 3.3-6, 3.3-22 and 3.3-23) without special field measurements. Both calculations with the shallow water wave theory and tidal observations within Pearl Harbor (Reference 3.3-7) show a lag of only a few minutes relative to the tidal stage in Honolulu. Thus, Pearl Harbor may be considered to be practically cotidal with water elevation at that stage. Important tidal elevations and ranges from References 3.3-13 and 3.3-22 have been presented in Table 3.3-4. Pearl Harbor has a "mixed tide" with strong diurnal and semidiurnal components.

The axial velocity component, u, in a cotidal channel is:

$$u = (\sigma/A)dH/dt \qquad \text{Eq. 3.3-3}$$

where σ is the water surface area upstream of the channel cross section, A, and dH/dt is the time rate of change of water elevation. Assuming a sinusoidal variation in water height, ΔH, over a time ΔT between successive extrema,

$$u = -\left(\frac{\pi\sigma}{2A}\right)\frac{\Delta H}{\Delta T}\sin\frac{\pi t}{\Delta T} \qquad \text{Eq. 3.3-4}$$

The quantity in parentheses is a shape factor which depends on the form of the upstream channel. The quantity outside the parentheses represents the driving function. In the model analysis, the quantity τ, where

$$\tau \equiv \pi\sigma/2A \qquad \text{Eq. 3.3-5}$$

was fit to the drogue velocity data for the following locations, see Figure 3.3-10:

(1) across the harbor entrance, Locations 1 and 2
(2) across South Channel into East Loch, Locations 4 and 5
(3) across North Channel into East Loch, Locations 6 and 7
(4) across the entrance to Middle Loch, Locations 8 and 9.

According to Equation 3.3-5, the cross channel mean τ should equal a geometric quantity which may be calculated from a chart of the harbor, Reference 3.3-13. A comparison of the calculation from harbor geometry with the model value of τ (column 7 of Table 3.3-3) is given in Table 3.3-6 (see columns 4 and 5). Considering the coarseness of the grids employed for the model analysis, the agreement is quite good. The mean tidal current speeds $|\bar{u}|$ for these sections are also estimated in Table 3.3-6, and again check roughly with those given in Figure 3.3-15.

In the individual drogue paths there was an obvious tendency for flood tide to occur on the eastern sides of the channels and for ebb tide to be concentrated on the opposite side. The net result of these patterns was a tidally-induced cyclonic circulation around Ford Island, reported by Au (Reference 3.3-1). Such a pattern may also be inferred from the cross channel differences in the functional mean current δ (column 8 of Table 3.3-3, see also

TABLE 3.3-6. COMPARISONS OF GEOMETRIC AND DATA-FIT VALUES OF τ.

LOCATION	$A[10^3 m^2]$	$\sigma[10^6 m^2]$	$\frac{\pi\sigma}{2A}$ $[10^3]$		data-fit τ*	$\lvert u \rvert$ [m/s]
ENTRANCE	4.3	18.0	6.6	$\leftrightarrow$	3.8	0.05
EAST LOCH	10.8	6.0	0.9	$\leftrightarrow$	0.9	0.009
MIDDLE LOCH	11.0	2.3	0.3	$\leftrightarrow$	0.4	0.003

*A simple mean, across channel, of data in Table 3.3-3 is used.

Figure 3.3-11). For example, a cyclonic (counterclockwise) mean flow of 0.1 m/sec appears around Ford Island. This effect is partly attributable to the Coriolis acceleration (Reference 3.3-18), although wind stress is also a contributing factor.

Table 3.3-3 shows that tidal currents at the harbor entrance are slightly more intense in the bottom layer than in the surface layer, see section on water masses for definition of these layers. Near the entrances to Middle and East Lochs, the tidal currents are, however, concentrated in the surface layer. This suggests a vertical, tidal velocity shear and resultant vertical mixing in the upper reaches of Pearl Harbor.

Tidal currents are apparently more intense along the eastern sides of the channels than along the western sides. For example, some two-thirds of the tidal exchange with East Loch occurs through South Channel, according to the model. No general explanation of this phenomenon is apparent.

The tidal excursion X is obtained by integrating Equation 3.3-4 over half a tidal period, $0 \le t \le \Delta T$:

$$X = \frac{\sigma}{A}H = \frac{2}{\pi}\tau\Delta H \qquad \text{Eq. 3.3-6}$$

From Tables 3.3-4 and 3.3-6, X is calculated to be about 1.5 km at the harbor entrance, 200 meters near the entrances to East Loch, and only 80 meters in Lower Middle Loch for the mean tidal range. Tidal excursions would be even smaller near the heads of the lochs. Thus, there is very little tidal action throughout most of Pearl Harbor, and tidal flushing can be appreciable only near the harbor entrance.

DRIVING MECHANISMS - FRESH WATER

The influx of fresh water into a semi-enclosed body of water results in a special kind of circulation which is often called estuarine. In the absence of effects other than moderate mixing, a seaward flow occurs in the surface water layer (which has a relatively low salinity), and a landward flow occurs in the bottom layer (which has oceanic or higher salinity). Four types of estuarine circulation are recognized (Reference 3.3-14). These are: (1) salt wedge in which river flow is dominant, (2) two-layer flow with entrainment in which river flow is modified by tidal currents, (3) two-layer flow with vertical mixing in which more or less river-flow and tidal mixing occurs, and (4) vertically homogeneous in which tidal currents predominate. Pearl Harbor circulation most closely resembles the third type; however, in East and Southeast Lochs, mixing due to ship activity predominates. In stratified estuaries, the mass transport of surface waters seaward and bottom waters landward induced by the fresh water influx can be an order of magnitude greater than the fresh water flow rate producing the circulation.

The Pearl Harbor drainage basin and the major streams entering the harbor are shown in Figure 3.3-2. The total drainage basin lies on the southwestern side of the island of Oahu and covers an area of about 290 km^2. The basin extends from near the shore, with an annual rainfall of about 50 cm, to the ridge of the Koolau Mountains, with an annual rainfall of almost 600 cm; mean annual rainfall for the basin as a whole is reported as 212 cm (Reference 3.3-

27). The complex topography and geology of this basin (Reference 3.3-26) result in a complex of streams, springs, and aquifers supplying fresh water to Pearl Harbor, which has been generally summarized in References 3.3-2 and 3.3-4. Surface runoff is estimated at 15% (Reference 3.3-15) and flow rates together with other pertinent data are given for the 5 major streams entering Pearl Harbor in Table 3.3-7. In addition 3 major springs provide fresh water flows of about 0.4 m^3/sec each; these are Kalauao and Waiau Springs flowing into East Loch and Waiawa Spring flowing into Middle Loch (Reference 3.3-15). The extrapolated mean flow rate for all streams entering the harbor is 3.33 m^3/sec; if the 3 springs are added this becomes 4.5 m^3/sec, which is very close to that reported by Cox, viz. 4.4 m^3/sec (Reference 3.3-4).

Although the U. S. Geological Survey monitors stream flows on several of the streams entering the harbor, these data are not adequate to estimate the total fresh water input to the harbor. Two independent calculations, one based on rainfall and the second on oceanographic parameters, are presented to estimate this fresh water input.

Stream flow per unit of rainfall data may be obtained from the U. S. Weather Bureau in Honolulu. Table 3.3-8 presents a summary of such data for Waikele and Waiawa Streams, which were selected for their nearly continuous flow records. The response of these 2 streams to the 3 October 1972 storm is shown in Figure 3.3-23. This storm was selected because over 2.4 cm of rain fell in one day without a trace of rainfall for the previous month and without subsequent rainfall for at least 10 days (next rain occurred on 28 October). The response time of the 2 streams is roughly one day and flows return to normal for the dry period within about 4 days. Integrating under the flow curve and subtracting out the normal dry-period flow, flow rates for 2.4 cm of rain are estimated at 8 m^3/sec for the Waikele and 10 m^3/sec for the Waiawa. Using their respective drainage basin areas (Table 3.3-7), flows per unit of rainfall of 0.24 and 0.55 $10^6 m^3$/cm of rain are obtained for the Waikele and the Waiawa respectively; by comparing these values with the theoretical stream flow coefficients (column 4 of Table 3.3-8), respective runoff for the 2 streams is seen to be 21% and 81%. These runoff values are undoubtedly high, since rainfall over the entire drainage basin could have been less than 2.4 cm; nevertheless they are sufficiently greater than the reported 15% to indicate that high surface runoff is possible. Nevertheless, using this 15% runoff value, the extrapolated drainage basin area for Pearl Harbor (column 7, Table 3.3-7), and the reported annual rainfall (212 cm/year), a total mean flow for the 5 major streams of 2.92 m^3/sec can be calculated, a value which is in good agreement with that given in Table 3.3-7. This is only surface runoff, however. Using the same calculational procedure, the total mean flow delivered to Pearl Harbor would be about 19½ m^3/sec if all rain falling into the drainage basin arrived there. Considering loss by evaporation, diversion, and loss to aquifers surfacing elsewhere, about half or 10 m^3/sec might be expected. Thus, perhaps twice the reported mean fresh water flows might be expected.

Fresh water influx into Pearl Harbor may also be estimated from oceanographic data collected at the harbor entrance during the 1972-1973 survey year. Net fresh water influx can be calculated from equations of continuity for salt and for the water mass, which reduce to:

$$R = \frac{\Delta S}{S_b} u_u A_u \qquad \text{Eq. 3.3-7}$$

where R is the fresh water influx rate, ΔS is the salinity difference between

TABLE 3.3-7. MAJOR STREAMS ENTERING PEARL HARBOR. (FROM REFERENCE 3.3-27)

STREAM NAME	U.S.G.S. NUMBER	FLOW RATES m^3/s MEAN	MAX.	MIN.	RECORD YEARS	DRAINAGE AREA km^2
WAIKELE	162130	1.10	385	0.1	17	118
WAIAWA	162160	0.92	663	0.06	18	68
WAIMALU	162230	0.23	227	NONE	16	16
KALAUAO	162245	0.09	73	NONE	13	7
N. HALAWA	162260	0.16	188	NONE	20	9
TOTAL OF 5 STREAMS:		2.50	WITH AN AREA OF:			218
EXTRAPOLATED TOTALS FOR PEARL HARBOR:		3.33	BASED ON AREA OF:			290

TABLE 3.3-8. STREAM FLOW PER UNIT OF RAINFALL [$10^6 m^3$/cm of rain]

STREAM NAME	RECORD MEAN	1972 - 1973 YEAR	3 OCT. STORM	CALCUL.* HONOLULU RAINFALL
WAIKELE	0.624	0.633	0.24	1.18
WAIAWA	0.520	0.329	0.55	0.68

*The drainage area in hundreds of square kilometers, this may be considered a "theoretical" stream-flow coefficient.

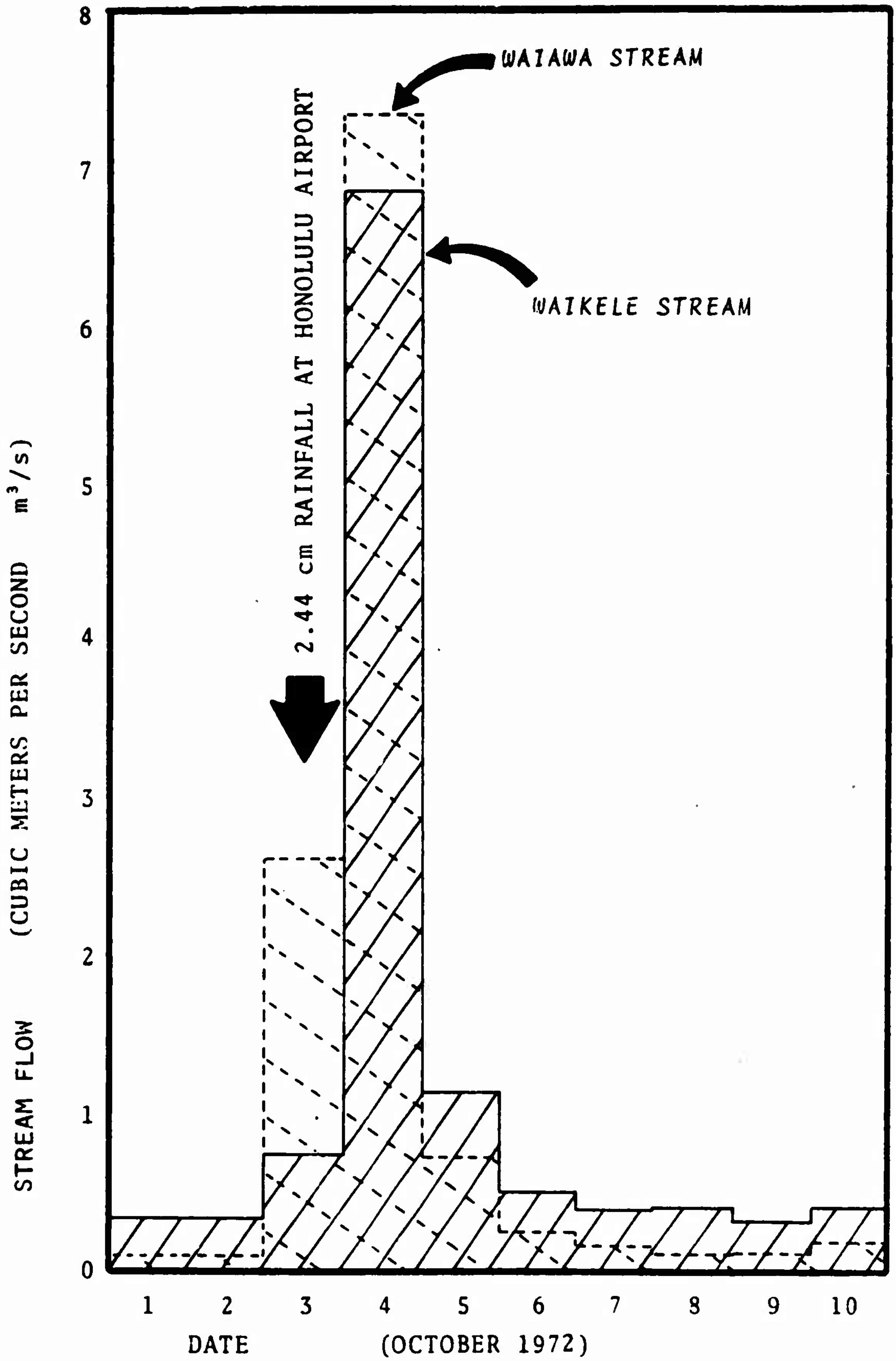


Figure 3.3-23. STREAM FLOWS ASSOCIATED WITH STORM OF 3 OCTOBER 1972. (RAINFALL OF 2.4 CM RECORDED AT HONOLULU AIRPORT FOR 3 OCTOBER)

upper and bottom layers, S_b is the salinity of the bottom layer, u_u is the mean water speed of the upper layer, and A_u is the cross sectional area of the upper layer. The mean monthly average salinity profiles for the harbor entrance indicate that ΔS is 1.5 ‰ and S_b is 34.5 ‰. Considering the axial components only and a mean wind of 4 m/sec from 70° True, the following mean flows at the harbor entrance are obtained from the model (Equation 3.3-1 and Table 3.3-3; negative values indicate flows out of the harbor):

Location	functional mean (δ)	estuarine vel. (Σ)	wind stress (μ)
1S	0.0	-0.06	-0.05
2S	+0.03	-0.12	-0.03
MEAN	+0.015	-0.09	-0.04

These axial velocities sum to -0.115 m/sec, which is the scalar mean of the velocities shown in Figure 3.3-18. The mean halocline depth at the entrance is about 3 meters and the channel width is about 300 meters. Thus,

$$R_{72/73} = \frac{1.5\text{ ‰}}{34.5\text{ ‰}}(0.115\text{ m/sec})(300\text{ m})(3\text{ m}) = 4.5\text{ m}^3\text{/sec} \qquad \text{Eq. 3.3-8}$$

Figure 3.3-24 summarizes the rainfall and stream flow for the survey period. As may be seen from the figure, stream flows and rainfall are about half that for a normal year. Thus, $R_{72/73}$ is doubled to obtain 9 m^3/sec as the estimated fresh water influx for a normal year. This value compares quite favorably with the 10 m^3/sec obtained from rainfall data.

After the introduction of fresh water into Pearl Harbor, the water column responds in a characteristic manner. The fresh water mixes downward while it is being flushed out of the harbor; such downward mixing is shown diagrammatically in Figure 3.3-25. This mixing process was observed following 1.0 cm of rain (at Honolulu) on 3 June 1972. These observations are presented in Table 3.3-9 and Figures 3.3-26 through 3.3-30. The table and the first figure summarize pertinent observational data, while the remaining figures present the salinity profiles. These profiles demonstrate increasing rapid mixing of fresh water, considering the regions in numerical sequence. Values of the salinity differential ΔS between the surface and bottom are plotted against time elapsed since the 3 June rain in Figure 3.3-31. Except for very small values of ΔS, isopleths of ΔS may be contoured, as suggested by the 0.5 ‰ ΔS contour interval which appears diagonally in the figure. For values of ΔS greater than 0.5 ‰, a uniform contour interval implies an initial logarithmic decay for ΔS. If the differences in the rates of decay of ΔS in Figure 3.3-31 are primarily due to diffusive mixing, then an ordering of diffusive coefficients is suggested in the box at the top of the figure. Since the vertical ΔS is relatively constant throughout the harbor, the relative diffusivity between two regions is inversely proportional to the elapsed time between two isopleths in Figure 3.3-31. Thus, setting the apparent diffusivity of Region #1 equal to 1D, the relative diffusivity of the other regions is estimated as shown in the upper box. In an estuary of this type a decrease in ΔS and hence vertical stability and an increase in tidally driven mixing are normally expected as the harbor entrance is approached (see Figure 3.3-5). As may be seen in Figure 3.3-26, this is decidedly not the case. Progressing from the Main Channel into Southeast Loch, the apparent diffusivity increases by nearly two or-

(Text continued on page 3.3-53)

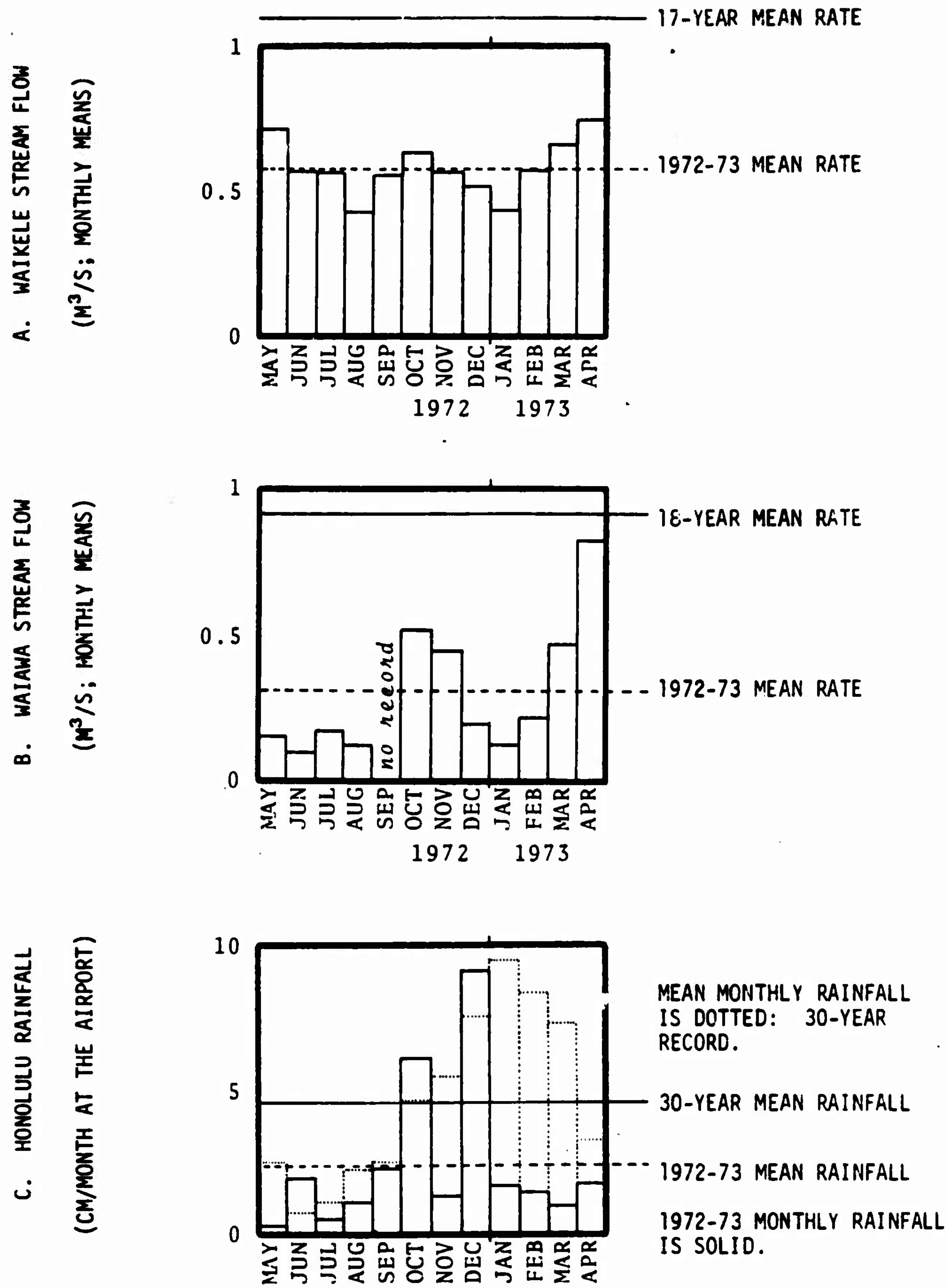


Figure 3.3-24. STREAM FLOW AND RAINFALL FOR THE STUDY PERIOD AND MEAN CONDITIONS.

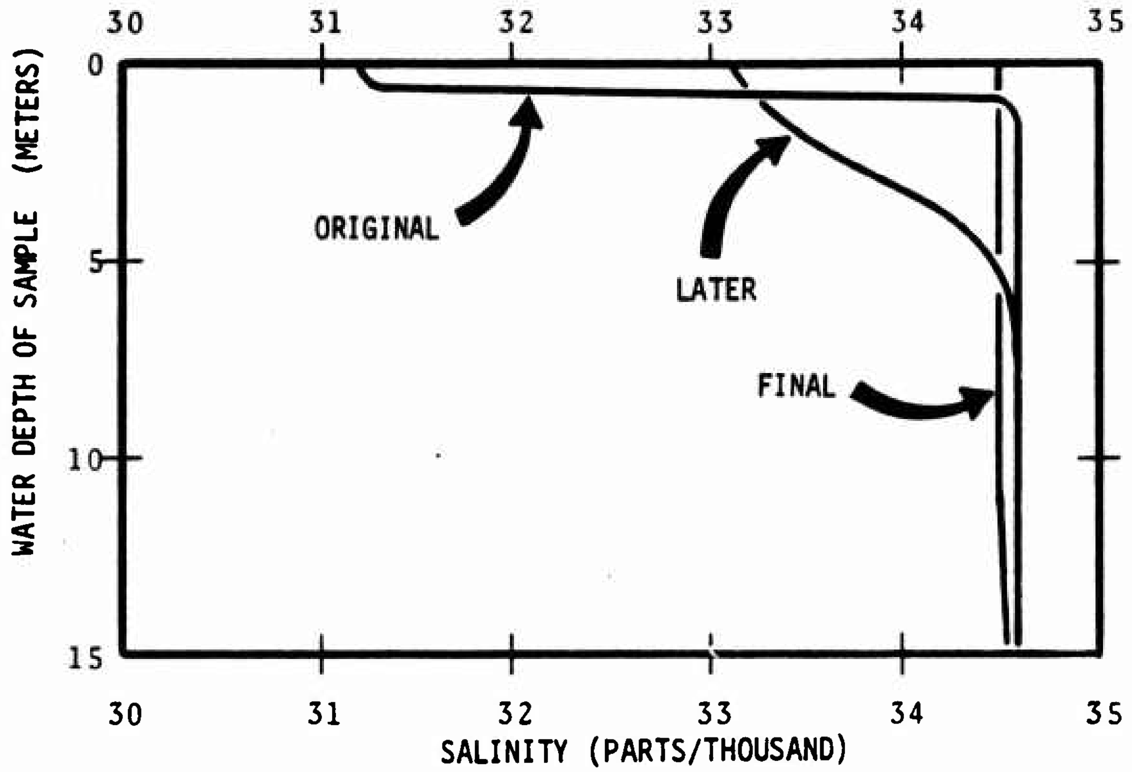


Figure 3.3-25. DEVELOPMENT OF SALINITY PROFILE AFTER INTRODUCTION OF FRESH WATER. DIAGRAMMATIC SKETCH. ΔS IS THE DIFFERENCE BETWEEN THE BOTTOM SALINITY AND THE SURFACE SALINITY.

TABLE 3.3-9. STATION IDENTIFICATION

1972 DATE:	1 cm OF RAIN ON 3 JUNE	5 JUNE	6 JUNE	11 JUNE / 0.64 cm OF RAIN	26 JUNE	13 JULY / 0.18 cm OF RAIN	18 August
DAYS AFTER RAIN:		+2	+3		+23(+15)		+76(+68)(+36)
REGION		STATION		TIME/IDENTIFICATION			
1		1310	1002		1040		0930
2		1204	1007		1110		0905
3		1345	0932		0930		1215
4		1225	0916		0907		1355
TRACE KEY:		———	— — —		-·-·-·-·		·········

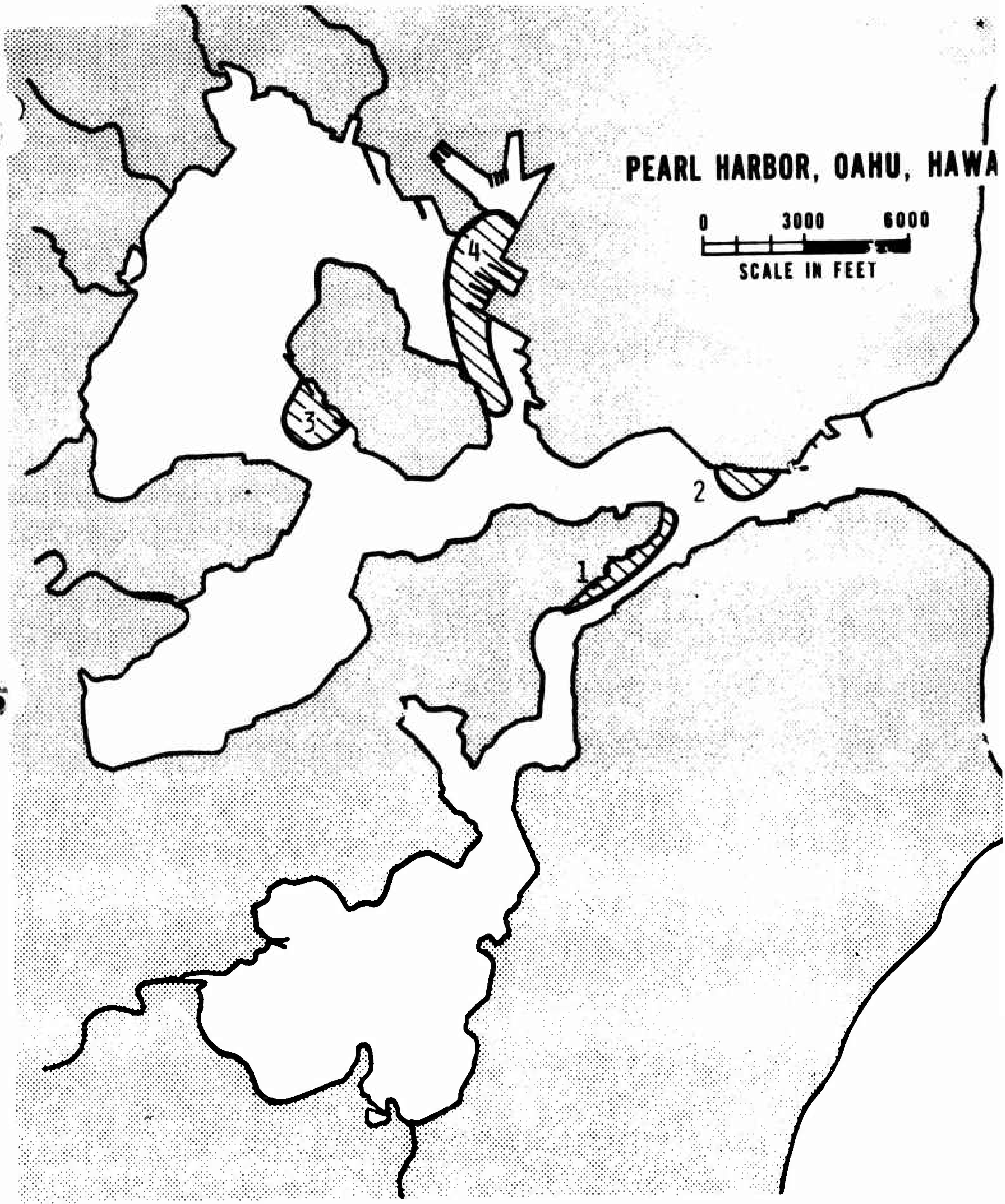


Figure 3.3-26. SELECTED "RAINFALL RESPONSE" REGIONS.

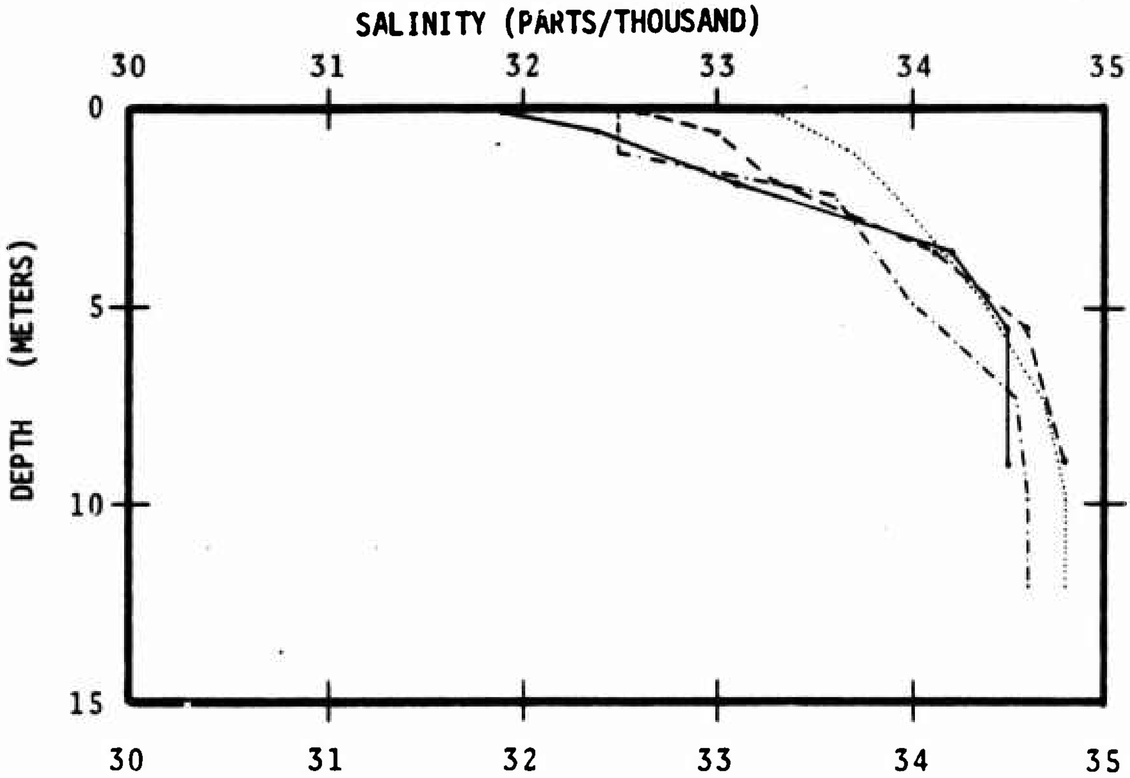


Figure 3.3-27. REGION 1 SALINITY PROFILES. TIMES OF PROFILES ARE IDENTIFIED IN TABLE 3.3-9.

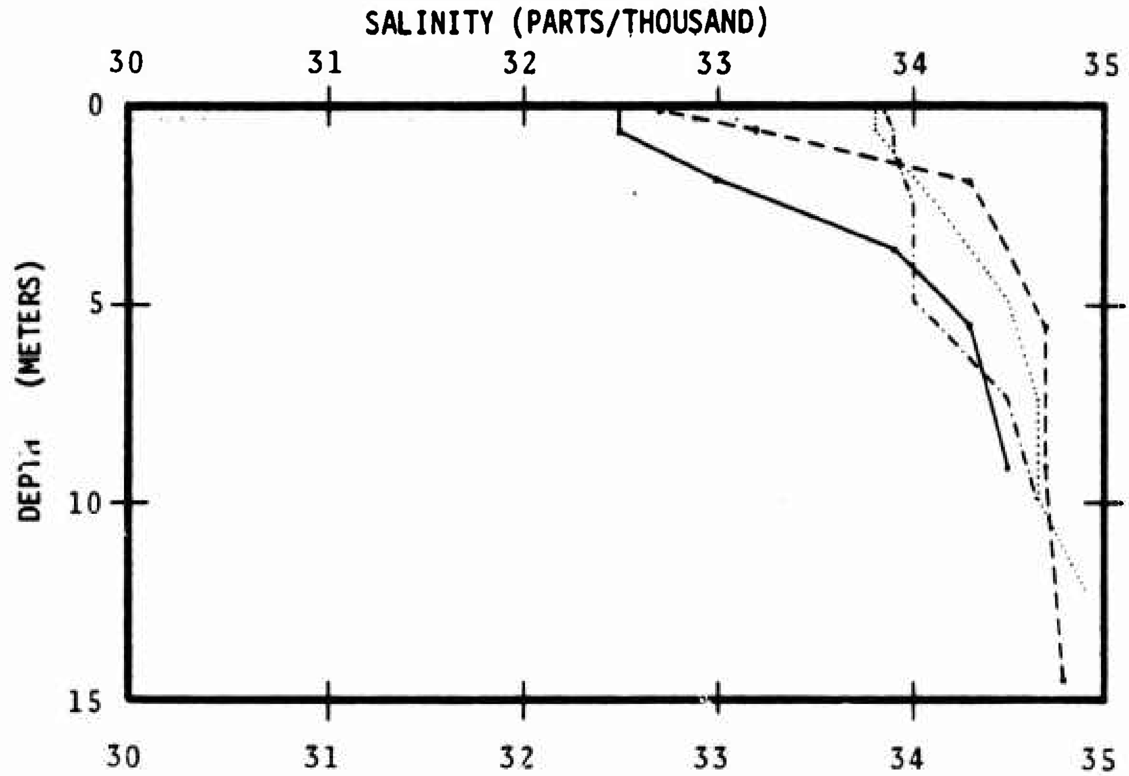


Figure 3.3-28. REGION 2 SALINITY PROFILES. TIMES OF PROFILES ARE IDENTIFIED IN TABLE 3.3-9.

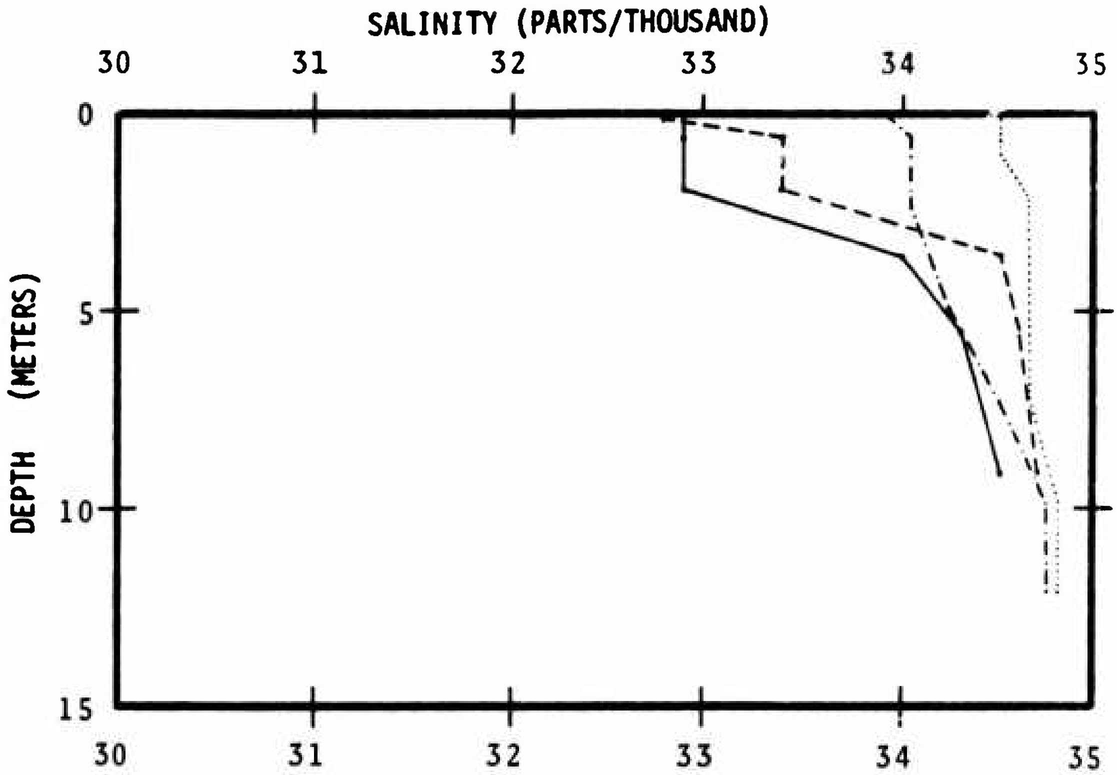


Figure 3.3-29. REGION 3 SALINITY PROFILES. TIMES OF PROFILES ARE IDENTIFIED IN TABLE 3.3-9.

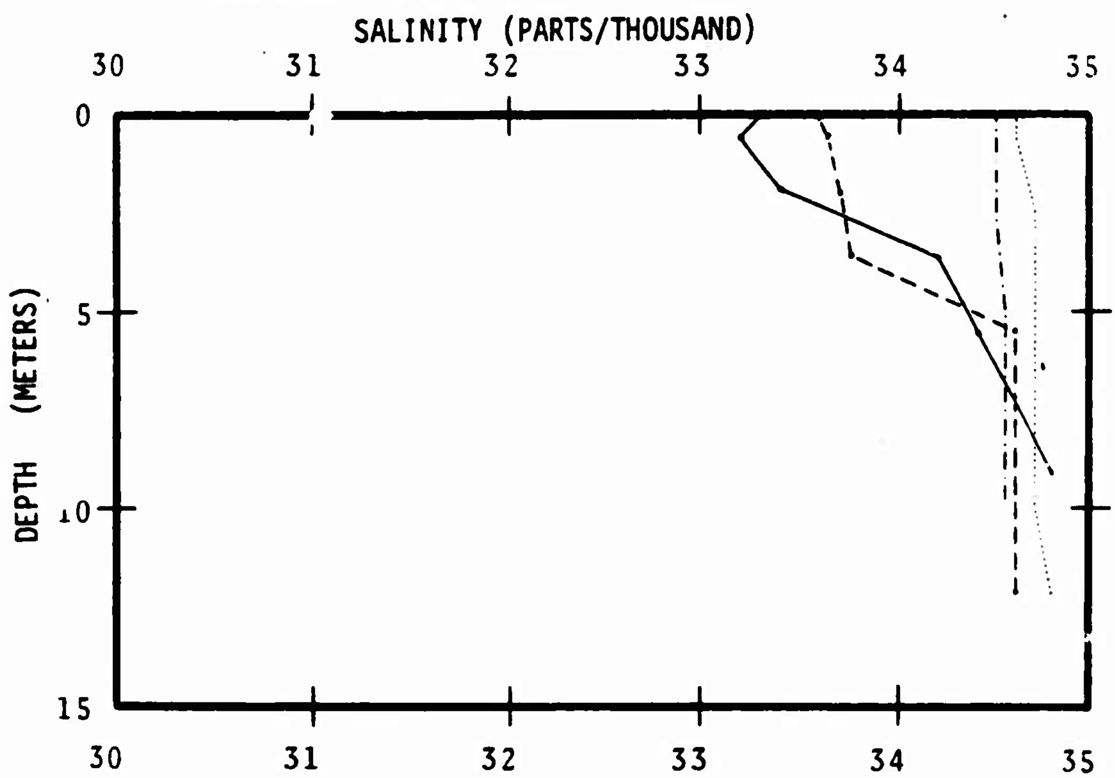


Figure 3.3-30. REGION 4 SALINITY PROFILES. TIMES OF PROFILES ARE IDENTIFIED IN TABLE 3.3-9.

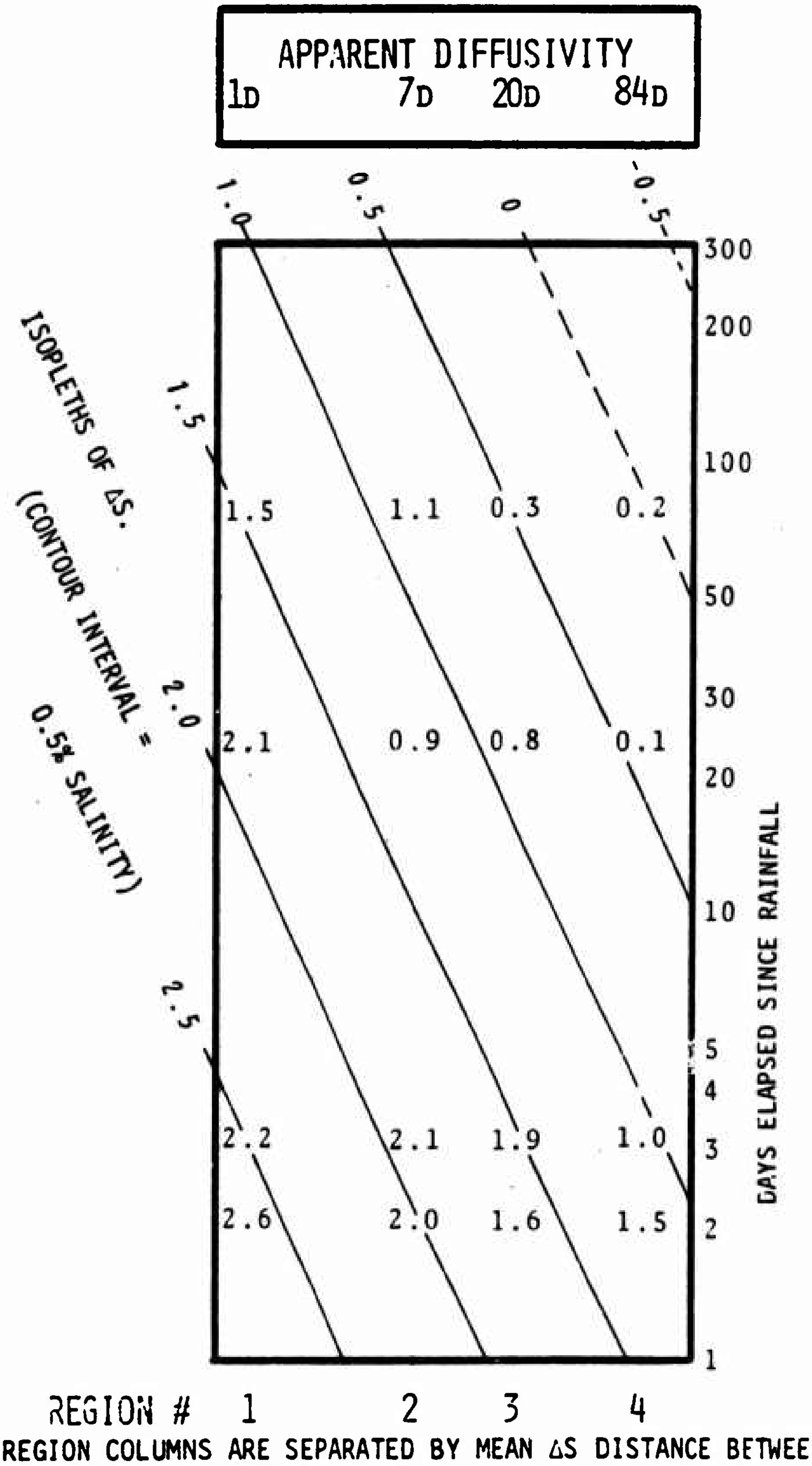


Figure 3.3-31. VALUES OF ΔS BY REGION AND TIME AFTER RAINFALL. SCALED, EQUIVALENT DIFFUSIVITIES FOR THE REGIONS APPEAR AT TOP.

ders of magnitude. While advection is also important in the reduction of ΔS, the activity of ships in Southeast Loch and around Ford Island (see Section 3.4) is very probably an important causative agent, see later discussion of ships' mixing.

While the waters of Pearl Harbor follow a fairly fixed response sequence upon the introduction of fresh water, the response rates vary dramatically around the harbor. The problem of determining mean fresh water influx rates suggests that it is impractical, without further knowledge, to use meteorological or hydrological data exclusively to estimate instantaneous fresh water influx. Yet such influx rates are required for determination of estuarine components of the circulation. Field observations show that ΔS increases as fresh water influx increases, as would be expected; thus, a linear ΔS term was included in the model. The data suggest that a higher order dependence may be appropriate. The fitting procedure may, then, place part of the estuarine circulation into the functional mean (δ). Since the study period was unusually dry, this procedure may result in underestimation of the strength of estuarine circulation under normal rainfall conditions.

DRIVING MECHANISMS - SALT WATER

In addition to fresh water, salt water and mixing processes are important driving forces in characteristic estuarine circulation. The salt water source for Pearl Harbor is the upper, mixed layer of the North Pacific Ocean. The properties of this water are modified somewhat near Oahu by runoff from the island and by upwelling.

The temperature and salinity of the salt water input to Pearl Harbor are conveniently measured at a depth of at least 10 meters at the harbor entrance. During the 1972-1973 survey, the maximum values of temperature and salinity of this seawater (associated with fall heating and evaporation) were about 26.6°C and 35.2 ‰ measured on 19 October. The corresponding minima were about 23.0°C and 34.0 ‰ measured on 17 February. Station profiles appear in a later discussion of water masses (see Figure 3.3-46). While the record is too short for accurate estimation of the mean values for salt water input, 24.5°C and 34.5 ‰ are indicated from the available data.

The volume rate of salt water inflow into Pearl Harbor is equal to the outflow of the surface layer minus the fresh water influx, according to the requirement of conservation of water mass for the harbor. From Equations 3.3-7 and 3.3-8, the mean salt water inflow is estimated to be as follows:

$$[illegible]_{72/73} = (0.115 \text{ m/sec})(300 \text{ m})(3 \text{ m}) = 103.5 \text{ m}^3/\text{sec} \qquad \text{Eq. 3.3-9}$$

salt water influx (1972/1973) = 103.5 - 4.5 = 99 m^3/sec.

For a normal year, the influx would be double or about 200 m^3/sec.

As the seawater progresses toward the heads of the lochs in the bottom layer, it is diluted with fresher waters from the surface layer by the mechanism of vertical mixing. At the same time, some of the (now diluted) seawater is mixed into the surface layer and then transported back to the ocean. The model residence times were estimated on the basis of this characteristic process.

DRIVING MECHANISMS - MIXING

The physical properties of an estuary are determined by the presence of fresh and salt water, by a set of driving forces, by mixing and by solid boundaries which contain the interactions. The mixing processes include both processes which act as driving forces (such as ship-induced mixing) and processes which stem from primary driving forces (such as tidal mixing).

Vertical and horizontal mixing in Pearl Harbor are produced by ship movements and by the effects of tide, wind, and waves. Although ship movements are not usually considered as a mixing process within estuaries, they are apparently important in Pearl Harbor. Ship-induced mixing is therefore considered in some detail. The tide produces classical mixing throughout the harbor. The typical northeast tradewinds blow parallel with the long (~4 km) expanses of water found in North and South Channels, producing a strong wind-driven circulation (see Figures 3.3-13 and 3.3-14) and some vertical mixing, particularly on the western side of the Main Channel to the west of Ford Island. Very little wave energy enters Pearl Harbor because of refractive losses near the harbor entrance. Locally generated wind-waves have heights of less than 0.3 meters and periods of less than 5 seconds. Additional wind-induced mixing results from these wind-generated waves.

Although the 1972-1973 study did not contain measurements of absolute mixing rates, relative mixing rates have been approximated from rates of fresh water dilution (see Figures 3.3-26 through 3.3-31). Another estimate of mixing rates is obtained from the residual water velocities $|\overline{R}|$ (see Figure 3.3-16). These residuals, in the main, most probably represent turbulent mixing velocities. Furthermore, regions in which turbulent mixing is the dominant physical process are also identifiable by a maximum in surface salinity (see References 3.3-29 and 3.3-30 for a theoretical analysis). Thus, surface salinities are plotted in Figure 3.3-32 as a third example of mixing distribution within Pearl Harbor. Again, the mixing rates appear to be maximum in South Channel and Southeast Loch, compare Figures 3.3-16 and 3.3-32. Since these surface maximums result from the vertical mixing of surface water with higher salinity bottom water, the mixing is also evident in salinity profiles. The profiles for points "A" and "B" in Figure 3.3-32 are given in Figure 3.3-33. Finally, diurnal changes in surface water temperature are also indicative of vertical mixing rates because vertical mixing distributes the effects of heat losses or additions to the surface of the water column. Thus, a small diurnal temperature range is indicative of a high rate of mixing. Temperature data for 27 April and 2 May are plotted in Figure 3.3-34. While all 4 of these demonstrations of vertical mixing are based on different physical principles, the results in each case are similar: mixing rates in Pearl Harbor are maximum in South Channel and Southeast Loch.

Possible causes of this observed mixing distribution are now considered. Tidal currents are the classic estuarine mixing force. From the model, the regions of major tidal influence are those with $\tau > 2 \times 10^3$ (see Table 3.3-3); these regions are indicated in Figure 3.3-35. The principal tidal effect is observed at the harbor entrance and in the entrances to South and North Channels. Similarly, the regions of major wind effects are those with $\mu > 0.02$ and are shown in Figure 3.3-36. Wind effects are important in the North Channel and in the Main Channel. Finally, the regions of major ship activity are sum-

(Text continued on page 3.3-60)

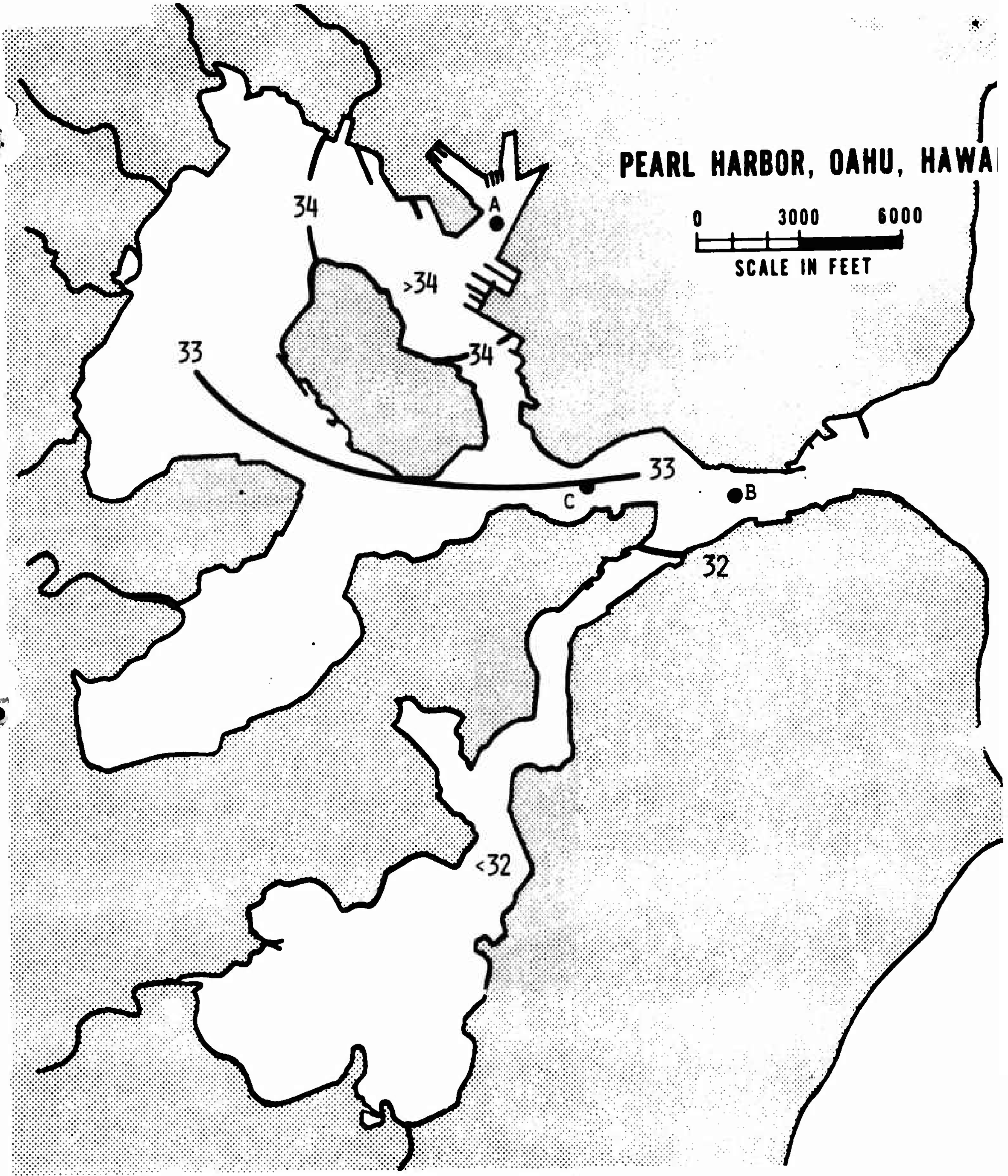


Figure 3.3-32. SALINITY AT 0.3 M on 23 NOVEMBER 1972. (PER MILLE) LOCATIONS OF STATIONS "A", "B" AND "C" ARE ALSO SHOWN.

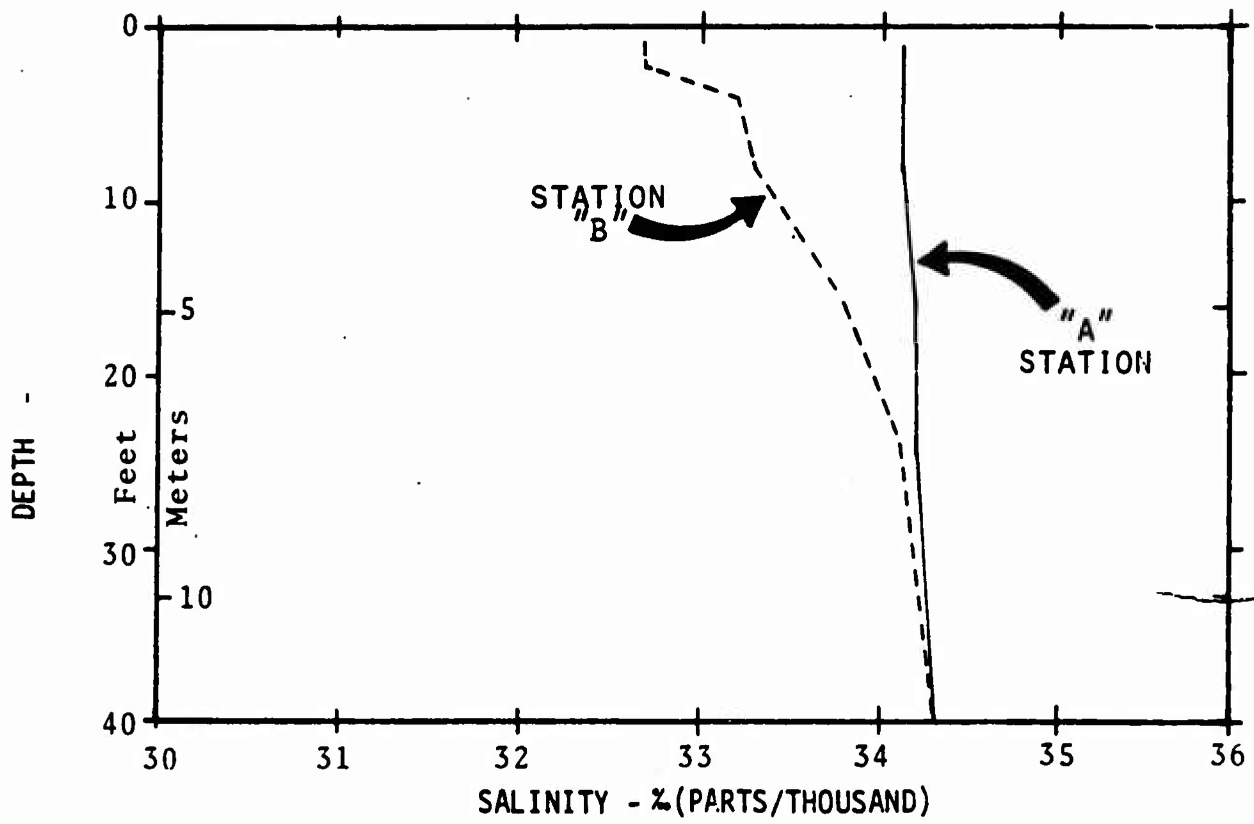


Figure 3.3-33. COMPARISON OF SALINITY PROFILES IN SOUTHEAST LOCH ("A" AT 11[illegible] ON 23 NOVEMBER 1972) AND THE MAIN CHANNEL ("B" AT 1025 on 23 NOVEMBER 1972). STATIONS WERE CONDUCTED UNDER TRADEWIND CONDITIONS AND EBB TIDE. (Reference 3.3-10). SEE Figure 3.3-32 FOR STATION LOCATIONS.

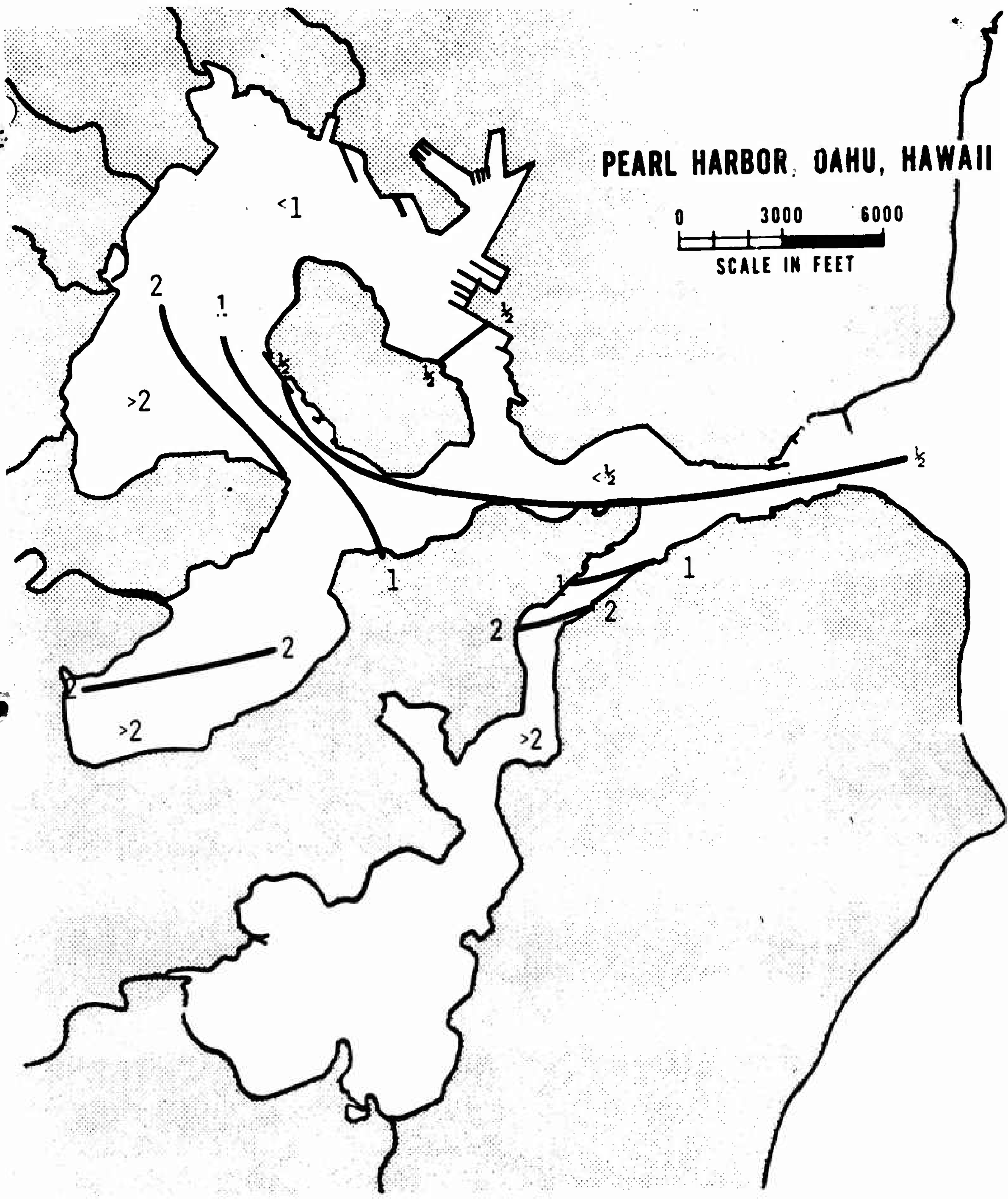


Figure 3.3-34. DIURNAL CHANGES IN TEMPERATURE (°C) AT 0.3 M. DATA FROM 27 APRIL AND 2 MAY 1973.

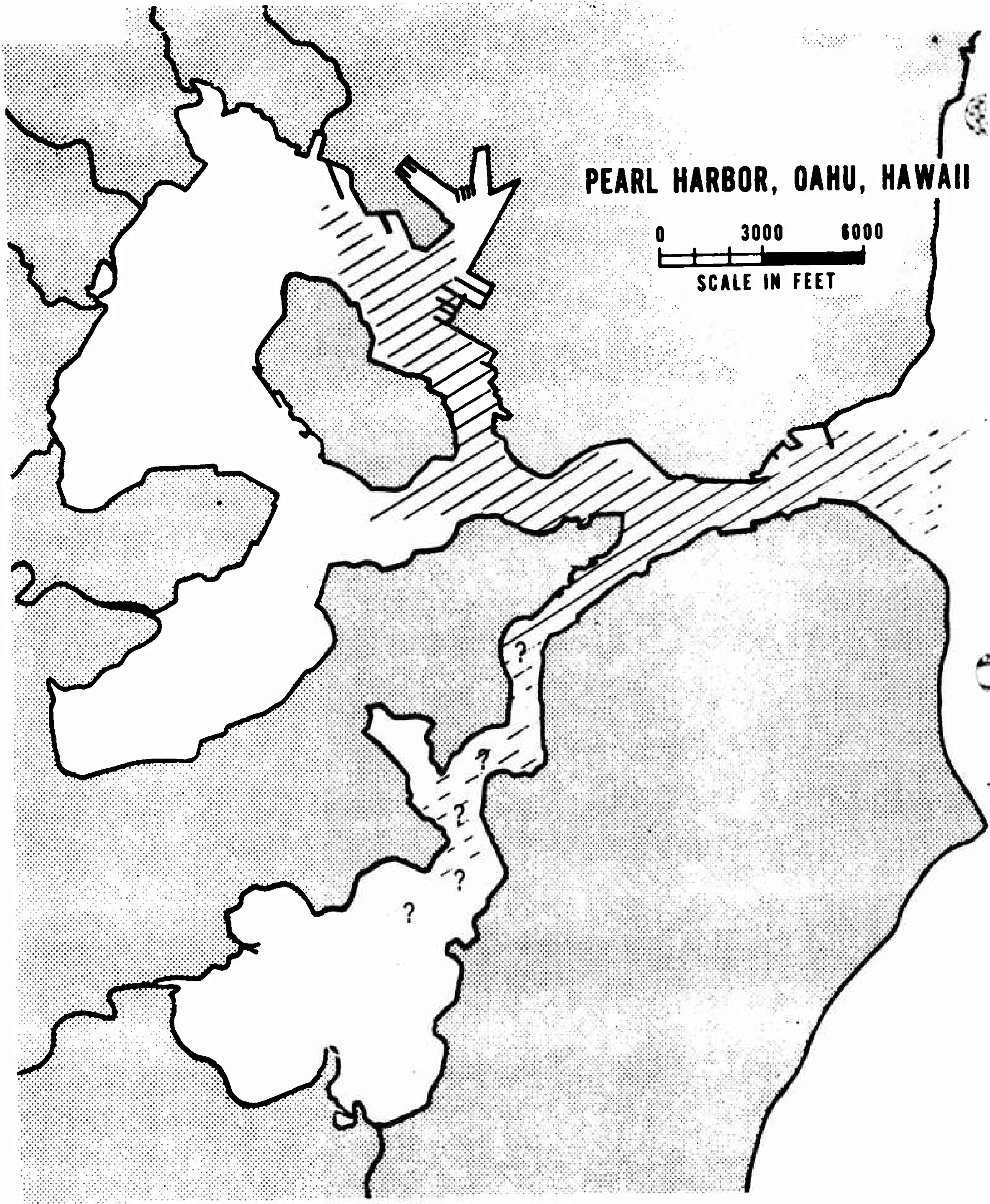


Figure 3.3-35. REGION OF MAJOR TIDAL CURRENTS.

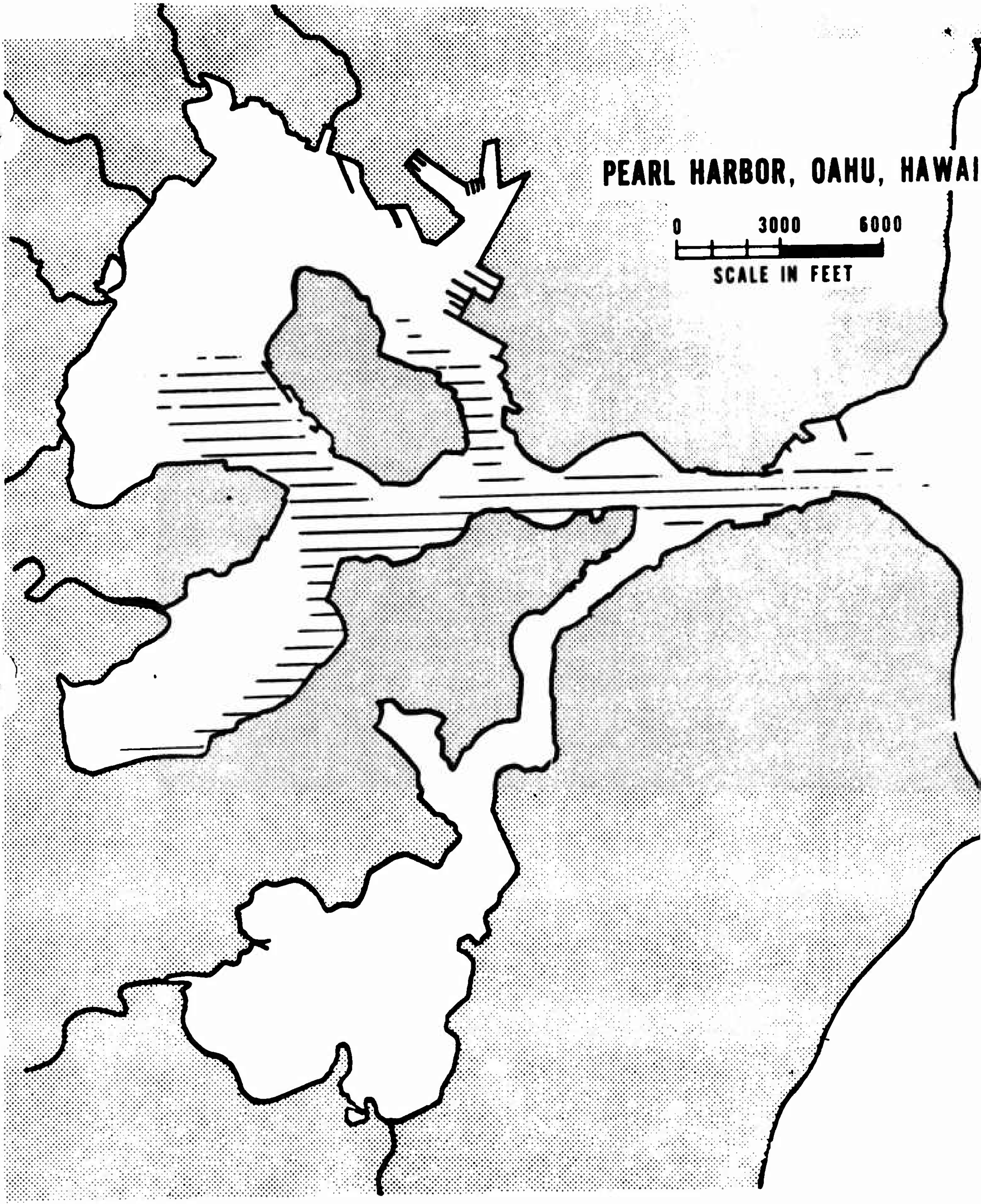


Figure 3.3-36. REGION OF MAJOR WIND-DRIVEN CURRENTS.

marized in Figure 3.3-37 (see also Figures 3.4-4 through 3.4-8). This distribution shows good general agreement with the distribution of maximum mixing just demonstrated in four different ways.

Ship activity, then, appears to be a very important driving force, especially in South Channel and Southeast Loch. The origins and destinations of ship movements within Pearl Harbor are described in detail in Section 3.4 and correspond to areas of the harbor that show mixing rates roughly 5 to 100 times greater than other parts of the harbor. Furthermore, no other known driving mechanism for estuarine circulation can satisfactorily account for the observed mixing rates. Thus, a correspondence between ship movements and enhanced mixing is established. In addition, the correspondence can be shown to be one of cause and effect by demonstrating that the magnitude of response resulting from a single ship movement is roughly proportional to the total effect observed. Several arguments can be advanced.

Figure 3.3-38 shows the replenishment oiler AOR-148, USS Ponchatoula, maneuvering in South Channel on 21 July 1972. The yellow-gray sediment which is being mixed up from the bottom at 14 meters is clearly visible as dark blotches near the ship's hull. The departure of the carrier CVA-63, USS Kitty Hawk, on 23 November 1972 was even more dramatic. Almost the entire Main Channel appeared turbid in her immediate wake. The reaction of the water column at the entrance to West Loch is shown in Figures 3.3-39, 3.3-42, and 3.3-43. The apparent recovery of the water column in about 30 minutes may be due to the stabilizing effect of fresh water outflows from West Loch. Similar vertical mixing was observed after the passage of smaller ships (see Figures 3.3-40 and 3.3-41). The modification of surface conditions is more pronounced than that of bottom conditions, as is shown in Figures 3.3-42 and 3.3-43. Although the expected reversals in behavior between surface waters and bottom waters often occur, the smaller magnitude of bottom effects suggests that horizontal mixing predominates in the bottom layers. Water buildup has also been observed along the sides of the channels after passage of a large ship. Mr. Dale reports (Reference 3.3-15) that a tidal gauge placed at the edge of the channel near well 226 (see Figure 3.3-37) rose 1½ cm about 5 minutes after passage and then slowly decayed to tidal level in about 5 to 10 minutes; this duration compares well with the recovery time of the salinity profile (see Figures 3.3-42 and 3.3-43). It should be noted that all material presented is representative of ships in passage and thus of situations in which the amount of total propulsive energy expended in mixing is reduced; in situations where large ships are being stopped, turned by tugs, or otherwise engaged in tight maneuvers, the amounts of energy going into stirring can be at least an order of magnitude greater.

The data presented in Section 3.4 indicate that about 30 important ship maneuvers occur in South Channel or Southeast Loch daily. The observations presented in Figures 3.3-39 through 3.3-43 indicate that the water column influenced by a major ship passage recovers in about 10 to 15 minutes. If such maneuvers as stopping and turning imply recovery times of 45 minutes (roughly 3 times that of a ship passage), the amount of ship activity reported in Section 3.4 would appear sufficient to account for the anomalous turbulent mixing observed in South Channel and Southeast Loch. Since mixing necessarily reduces the stability of the water column, the second ship passage or maneuver should be more efficient in producing mixing than the first; thus the total

(Text continued on page 3.3-68)

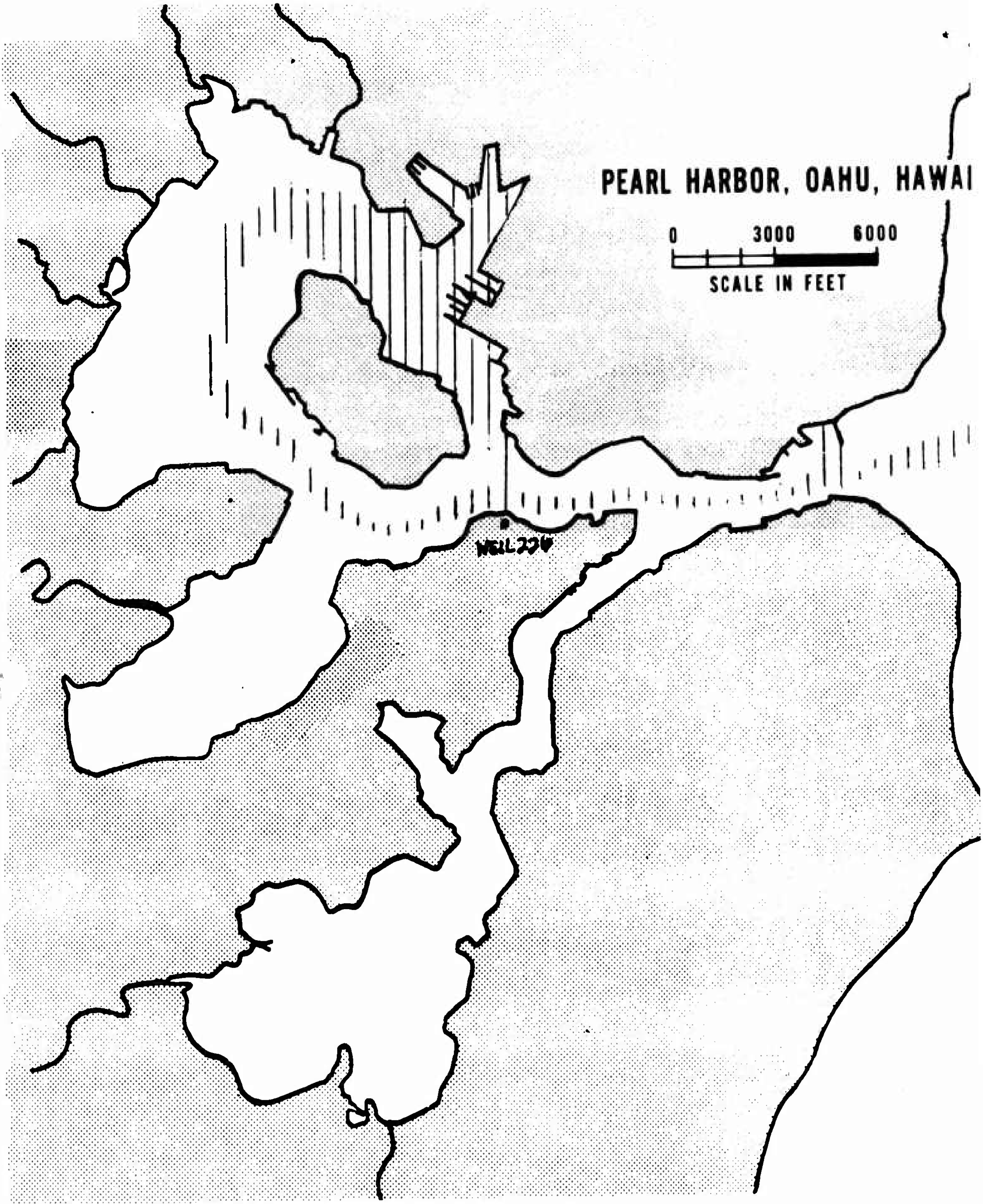


Figure 3.3-37. REGION OF 95% OF SHIP TRAFFIC.

Figure 3.3-38. USS PONCHATOULA (AO-148) AT THE ENTRANCE TO SOUTHEAST LOCH--PHOTO NEGATIVE. SHIP HAS 2 SHAFTS AND KEEL DEPTH IS 35 FEET. SEDIMENT STIRRED FROM THE BOTTOM APPEARS AS DARK BLOTCHES IN THIS PHOTO. THE OBSERVED COLOR WAS A LIGHT GRAY-TAN. TIME WAS ABOUT 1530 ON 21 JULY 1972. THE WATER COLUMN WAS WELL STRATIFIED (FOR SOUTH CHANNEL) BEFORE THIS EVENT: SURFACE TEMPERATURE WAS 27.1°C, WHILE IT WAS 25.3°C AT 12 METERS. SURFACE SALINITY WAS 33.7‰; SALINITY AT 12 METERS WAS 34.5‰.

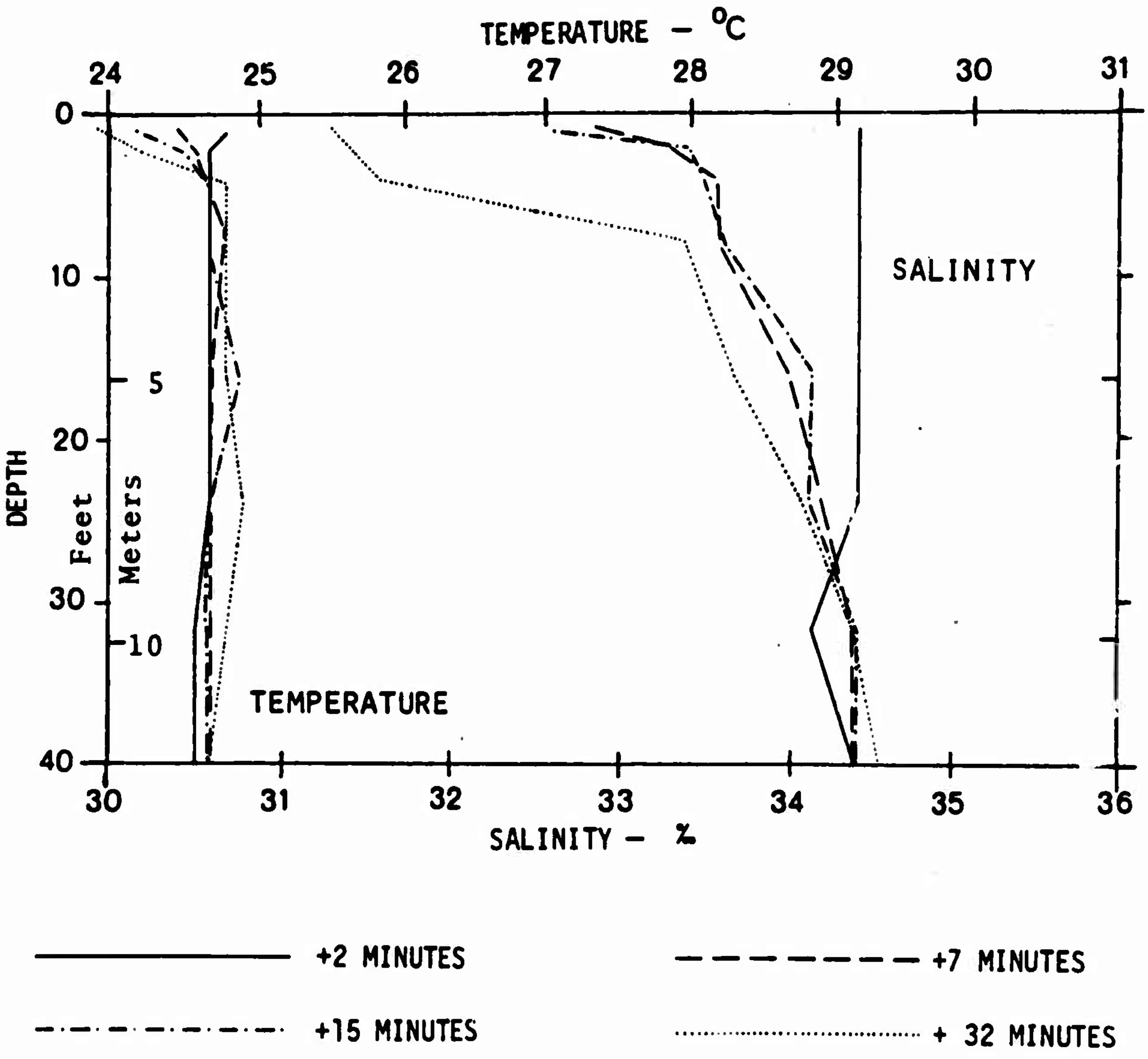


Figure 3.3-39. REACTION OF THE WATER COLUMN TO THE DEPARTURE OF THE AIRCRAFT CARRIER, USS KITTY HAWK (CVA-63), FROM PEARL HARBOR ON 23 NOVEMBER 1972. TIME OF PASSAGE IS 0748. SHIP SPEED WAS ESTIMATED TO BE 12 KNOTS: 4 SHAFTS, KEEL DEPTH IS 35.9 FEET. SEE Figure 3.3-32 FOR STATION LOCATION, STATION "B".

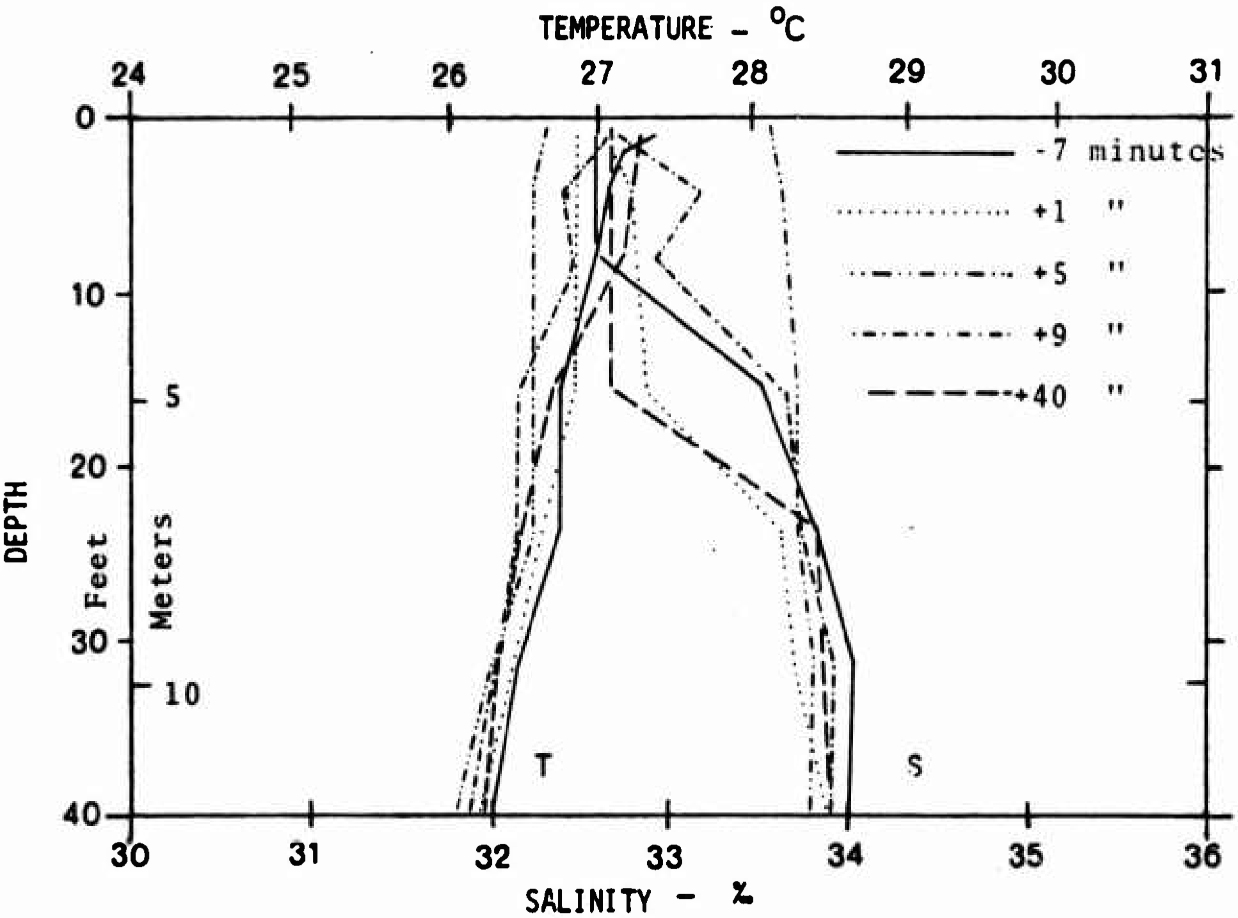


Figure 3.3-40. REACTION OF THE WATER COLUMN TO THE PASSAGE OF THE USS JASON (AR-8) SOUTH OF FORD ISLAND AT 1200 HOURS ON 17 FEBRUARY 1973. SHIP HAS 2 SHAFTS, KEEL DEPTH IS 23.3 FEET. STATION IS LOCATED AT "C" IN Figure 3.3-32.

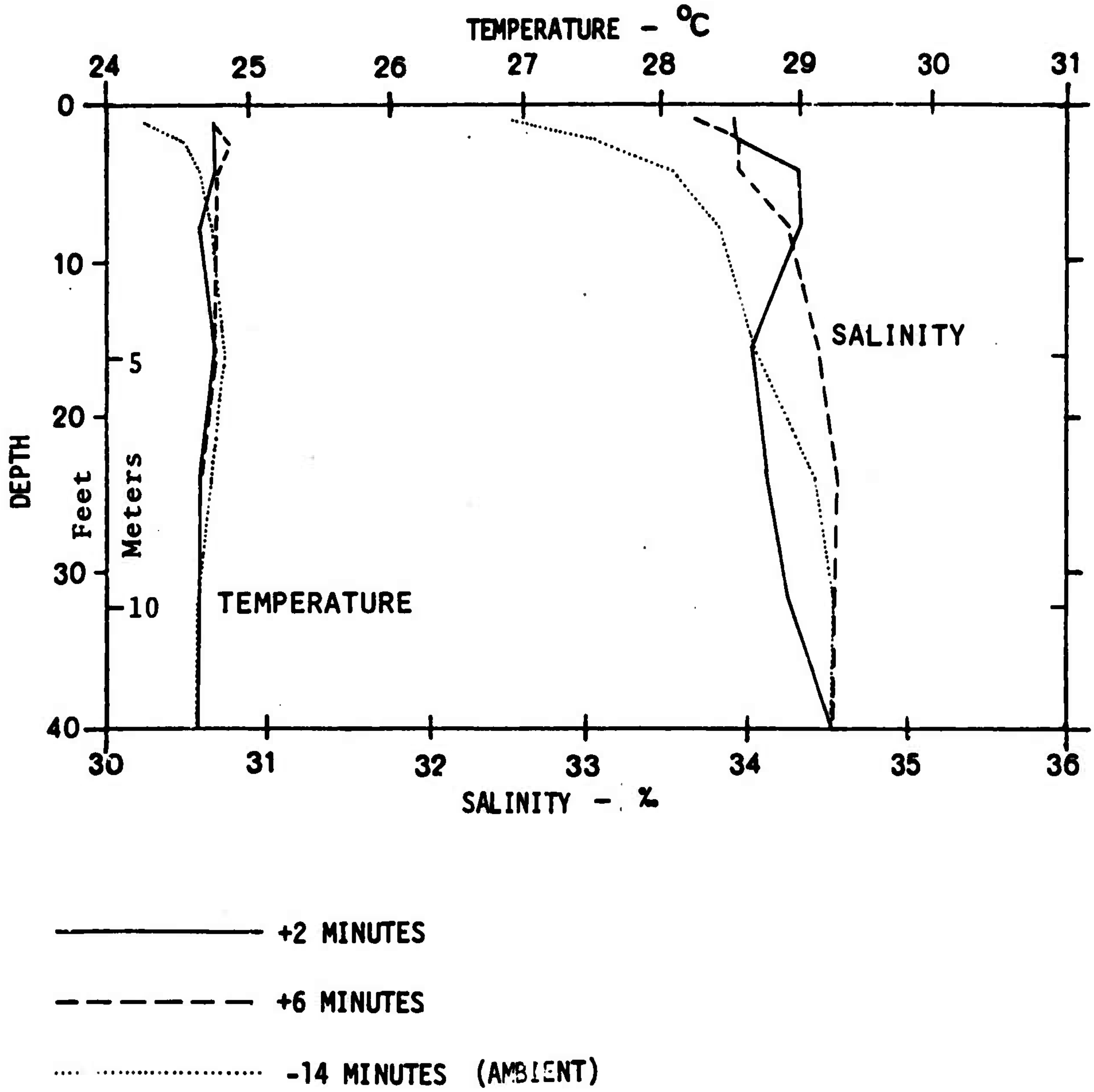


Figure 3.3-41. REACTION OF THE WATER COLUMN TO DEPARTURE OF REPLENISHMENT OILER USS SAVANNAH (AOR-4) FROM PEARL HARBOR ON 23 NOVEMBER 1972. TIME OF PASSAGE IS 0914. SHIP SPEED WAS ESTIMATED TO BE 12 KNOTS: 2 SHAFTS, KEEL DEPTH IS 35 FEET. SEE Figure 3.3-32 FOR STATION LOCATION, STATION "B".

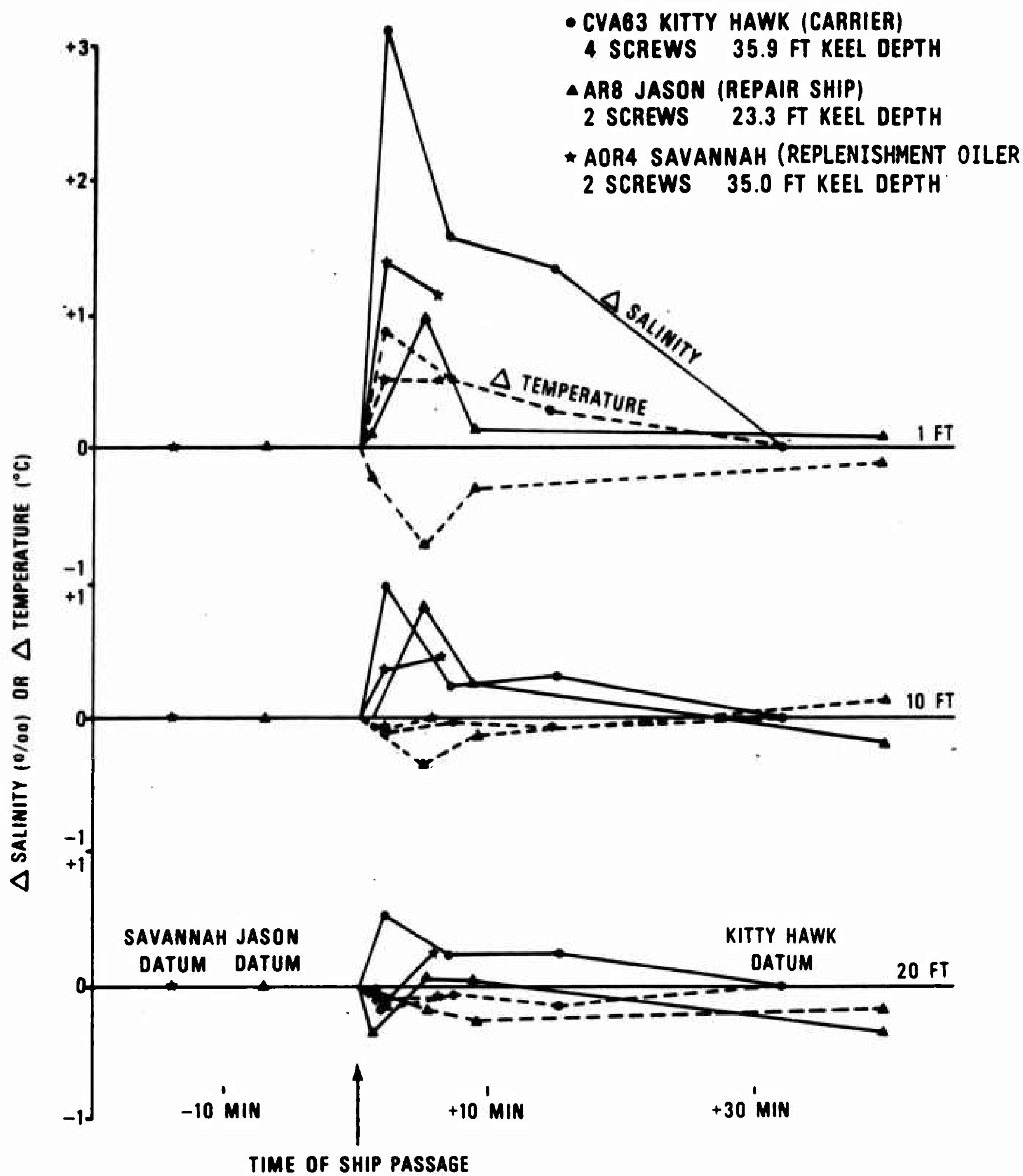


Figure 3.3-42. CHANGES IN SALINITY AND TEMPERATURE (FROM DATUM) DUE TO PASSAGE OF LARGE SHIPS.

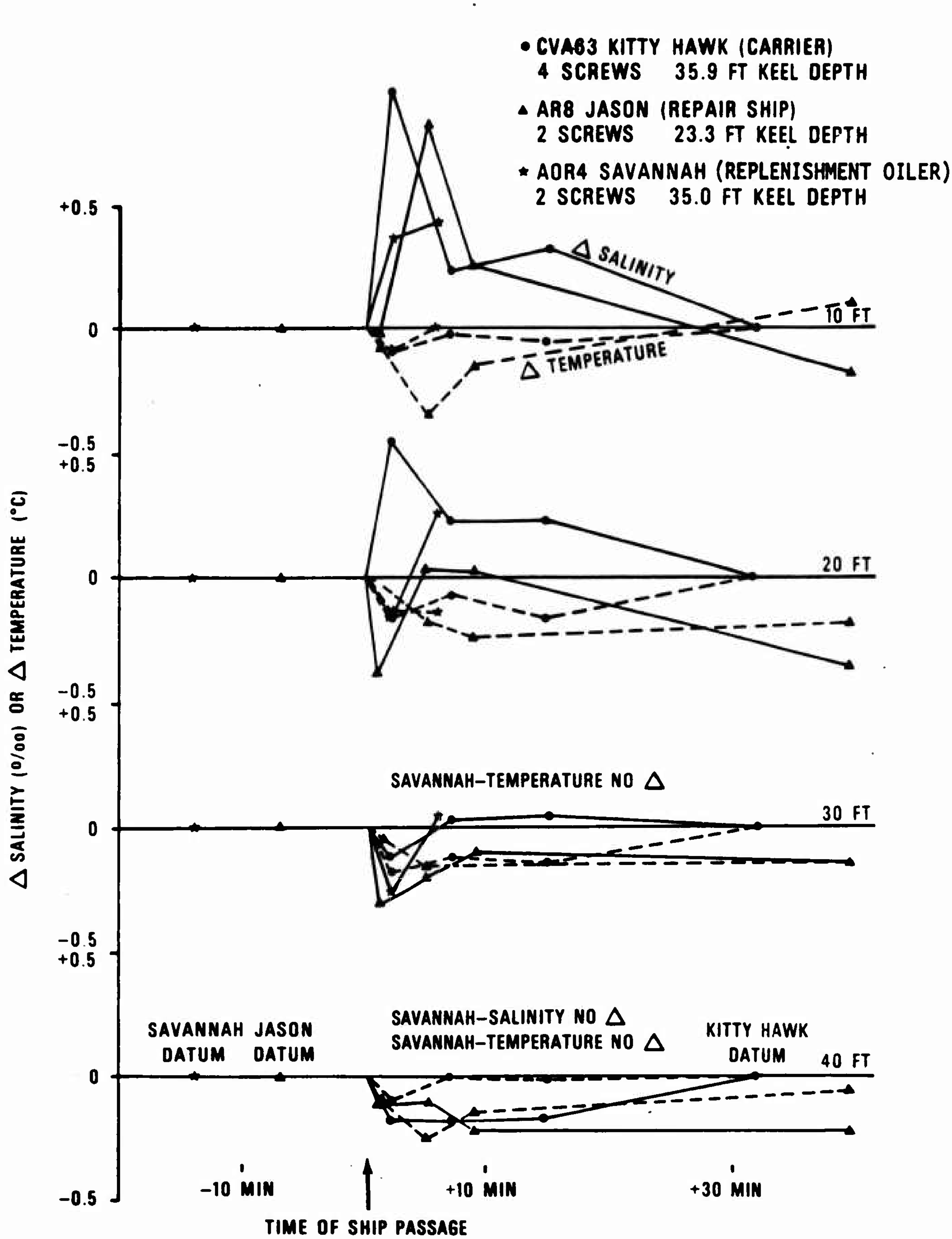


Figure 3.3-43. CHANGES IN SALINITY AND TEMPERATURE (FROM DATUM) DUE TO PASSAGE OF LARGE SHIPS.

effect of ships' activities during a day could well be cumulative. It appears then that there is ample evidence that mixing in much of Pearl Harbor, especially in South Channel and Southeast Loch, is predominantly driven by ships' activities.

DRIVING MECHANISMS - WIND

Wind stress and variations in wind stress are responsible for much of the circulation of Pearl Harbor. Simple, wind-induced currents are discussed here, while the effects of temporal and spatial variations are described in the following section. The region of major wind-driven currents, largely derived from the model, is shown in Figure 3.3-36. The currents produced in these regions by normal tradewinds (4.0 m/sec., 70° True) are shown in Figures 3.3-13 and 3.3-14. As may be seen from these figures, the wind-induced circulation is generally weaker in the lower layer, and in a different direction, than the wind-induced currents in the upper layer.

Unfortunately, the evaluation of the wind-induced circulation has several problems which reduce the accuracy of the results. Perhaps the most obvious difficulty is the problem of defining the relations between the local vertical and horizontal scales. The channels and lochs of Pearl Harbor are surrounded by rather abrupt shores with trees and buildings nearby. Consequently, winds which are measured near the water surface vary greatly within short distances. Similarly, the horizontal variations in the wind field (due to both topography and land and sea breeze effects) are again both important and troublesome. Anemometer readings at Pearl Harbor bear little resemblance to simultaneous measurements at Honolulu (Reference 3.3-9). The only good solution is measurement of the local wind field; however, this field is not easily measured in adequate detail. Two-minute average values of local wind measured about 2.3 m above the water surface were used to determine the model coefficient in Table 3.3-3 (columns 3, 4, and 5 or μ, $\Delta\mu$, and ν).

On occasion, temporal and spatial variations in wind patterns could not be distinguished. Thus, there existed conditions during the survey under which even the local wind fields could not be well defined. The mean Honolulu wind used in Figures 3.3-13 and 3.3-14 is assumed to approximate the whole general range of different local wind conditions over Pearl Harbor. And thus, the circulation shown in the figure cannot closely approximate local variants in the wind-driven current pattern.

A second problem concerns nonlinearities. A reversal of the general wind pattern, for example, does not exactly reverse the local wind field. This is particularly important for areas which are sheltered from certain wind conditions. Since tradewinds were dominant in Pearl Harbor during the 1972-1973 survey, circulation patterns associated with Kona (southerly or westerly) winds have not been included in the analysis resulting in the present model. The reliability of the model for such wind conditions is therefore unknown.

Thirdly, the wind-driven circulation is dependent on the stability--and even the detailed structure--of the water column. Cross-channel currents, upwelling and downwelling are all much less conspicuous when the water column is highly stratified. Also, as wind-induced currents enhance mixing, this process itself decreases vertical stability and thus increases the wind's current-inducing capability. In other words, varying wind stress curents tend to grow once they become important to harbor circulation. About twice the available data would be required to include such secondary effects in the analysis.

DRIVING MECHANISMS - DERIVATIVES OF THE WIND FIELD

Spatial and temporal variations in wind stress also strongly influence Pearl Harbor circulation within limited areas and for limited times. The effects of spatial and temporal changes are quite different; therefore, they are discussed separately.

The dominant spatial variation in wind is associated with the development of a sea breeze in the afternoon on sunny, warm days. Very light sea breezes only weaken the tradewinds near the harbor entrance. However, occasionally (e.g., 6 June 1972 [Reference 3.3-9] and 16 and 17 February 1973 [Reference 3.3-11]) the sea breezes develop sufficiently to overcome the tradewinds entirely near the harbor entrance. Under that condition, the tradewinds prevail in the upper reaches of the harbor and southerly winds are observed near the entrance. Where the winds meet, calm or easterly winds (directed toward the Waianae Range) are observed. This wind convergence is reflected in the surface water convergence shown in Figure 3.3-44 and is obvious from an accumulation of oil and flotsam as well. The convergence of the upper layer must be accompanied by deepening of the thermohalocline (the boundary between the upper and lower water layers) and divergence of the lower layer. However, sufficient observations are not available to verify these predicted effects.

The reactions of the harbor to spatial differences in wind stress must be transitory. That is, as the degree of thermohalocline depression increases, a compensating buoyant force, which opposes further convergence of the lighter, upper-layer water, is developed. When the sea breeze dies in the late afternoon, the potential energy which is stored in the density field must generate a reverse or divergent surface-layer flow.

A land breeze effect which is opposite to the observed sea breeze may be expected during the night. However, no data to verify this hypothesis are available.

While the currents which are associated with convergence and divergence of wind stress appear to be relatively unimportant determinants of Pearl Harbor circulation, temporal changes in wind stress are important in Middle Loch. The reason for this local importance is simply that the other driving mechanism (tide, fresh water influx, wind stress, and ship motions) are relatively ineffectual.

The term, dU/dt (where U is the axial component of the wind velocity and t is the time) was carried through the analysis used to generate the circulation model for Pearl Harbor. A small effect was observed at the harbor entrance although an appropriate lag time was not identified. A major effect, with approximately a 3-hour time lag was, however, observed in Middle Loch (column 4 or $\Delta\mu$ in Table 3.3-3).

This time lag may be explained by the theory of internal waves. If changes in wind stress are to produce relatively strong currents, the induced water

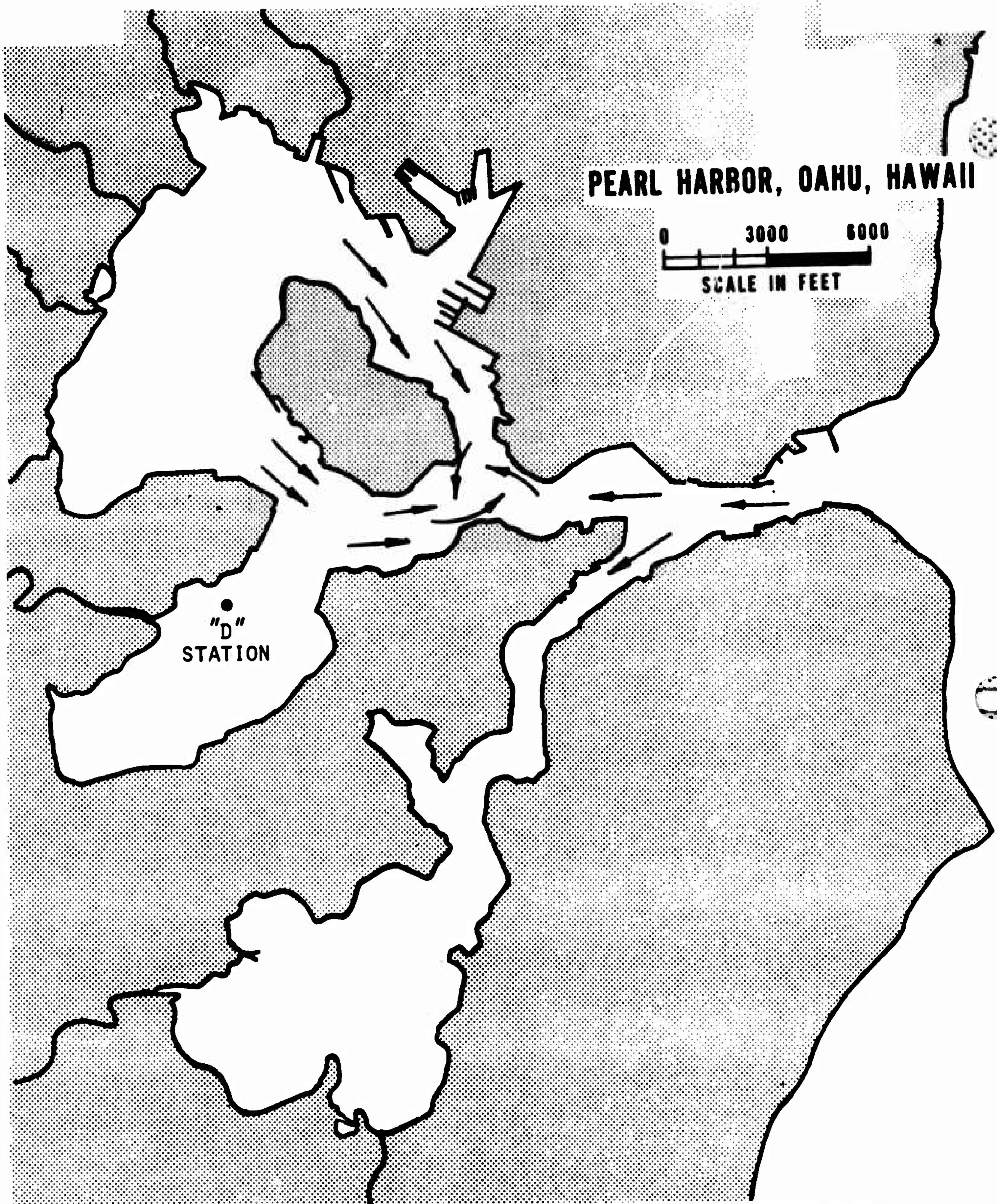


Figure 3.3-44. CONVERGENT FLOW PATTERN IN THE UPPER LAYER, OCCURRING DURING VERY WEAK WINDS OR CALMS.

motions must correspond to natural resonance frequencies of the water body. The situation in Middle Loch is represented by Class B internal waves which are described by Kinsman (Reference 3.3-29). For this class of waves, both upper and lower layer thicknesses must be much less than the horizontal length scale. Then the wave propagation velocity v is given by:

$$v^2 = \frac{gh'h''}{h}(1 - \rho'/\rho'') \qquad \text{Eq. 3.3-10}$$

where g is the acceleration of gravity, h' is the upper layer thickness, h" is the lower layer thickness, h=h'+h", ρ' is the density of the upper layer, and ρ" is the density of the lower layer. If L is the axial length of Middle Loch, then the (closed ended) fundamental period P is given by:

$$P = 2L/v \qquad \text{Eq. 3.3-11}$$

For resonance, the lag from onset of the change in driving force is:

$$\text{Lag} = P/4 \qquad \text{Eq. 3.3-12}$$

From these 3 equations, the resonant lag is found to be:

$$\text{Lag} = \left(\frac{\rho''h}{(gh'h'')(\rho''-\rho')}\right)^{1/2} \frac{L}{2} \qquad \text{Eq. 3.3-13}$$

The following data were typical for Middle Loch during the survey period: $h'=3m$, $h''=7m$, $h=10m$, $L=3x10^3 m$, $\frac{\rho''-\rho'}{\rho''}=1.3x10^{-3}$. From these approximate parameters, a fundamental resonance lag of 2.5 hours is calculated; this value is in reasonable agreement with the empirical lag of 3 hours.

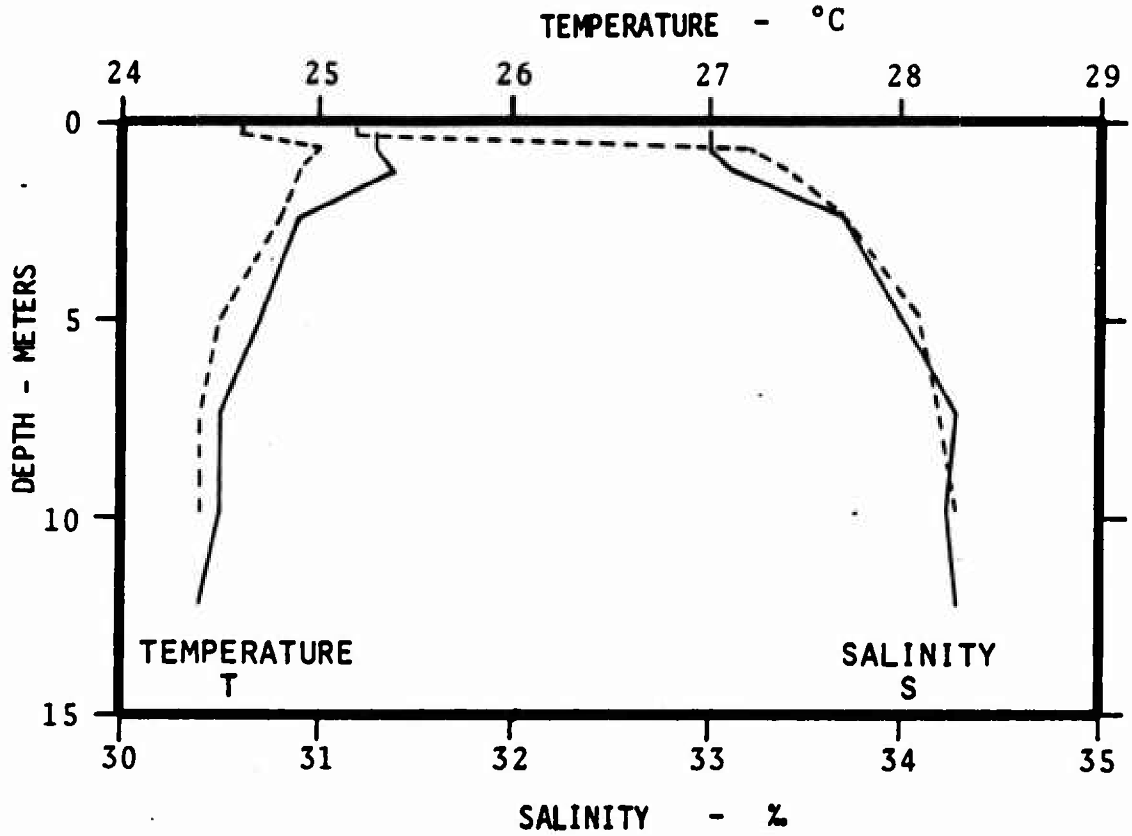
Current speeds ≤0.2 m/sec (16 February 1973, Reference 3.3-11) have been observed in Middle Loch. These currents are wind derivative currents resulting from changes in wind direction or speed, such as a change from tradewind to Kona conditions or a calming of the tradewinds. According to Table 3.3-3, wind derivative currents probably produce the dominant water motions in Middle Loch. However, their effect on flushing is not obvious because of their oscillatory nature.

Displacements of the upper and lower layers of the water column, which result from wind derivative currents, are reflected in temperature and salinity profiles. For example, Figure 3.3-45 shows a rapid return of a low-salinity upper layer with a calming of the tradewinds.

The upper layer is entirely displaced from the water column under strong wind conditions (e.g., 10 m/sec tradewind, Stations 1255 and 1450, 27 Jan 1973, Reference 3.3-11). Massive upwelling results near the upstream shores. This upwelled water in Middle Loch was observed to be a milky green color and odorous.

WATER MASSES

As stated earlier, the waters of Pearl Harbor are a mixture of fresh water from runoff and rainfall with seawater. Since the fresh water is lighter than



TRADEWINDS ———————— STATION 1300, 23 NOV 1972

WEAK KONA WINDS------------ STATION 1025, 24 NOV 1972

Figure 3.3-45. FORMATION OF AN UPPER LAYER UPON A CHANGE IN WIND STRESS. STATIONS ARE LOCATED NEAR THE ENTRANCE TO MIDDLE LOCH, AT POSITION "D" SHOWN IN Figure 3.3-44. TRADEWINDS (6 m/sec, 060°) DIED OUT BETWEEN THE TIMES OF THE TWO STATIONS WHICH ARE PLOTTED. THE FORMATION OF THE THIN, SURFACE, BRACKISH WATER LAYER IS ATTRIBUTED TO A FLOW WHICH WAS ASSOCIATED WITH AN INTERNAL WAVE PHENOMENON.

the seawater, the fresh water forms a surface layer and is gradually mixed downward. Within Pearl Harbor, then, two layers are generally observed: a mixed upper layer, and a lower layer with characteristics similar to those of near-shore ocean waters. Figure 3.3-46 indicates the range of temperature and salinity values observed at the harbor entrance in 1972-1973. However, the two stations which are shown do not reflect the range of values of surface salinity, which varied from about 31% to 34%. Since the survey period was relatively dry, even lower values in surface salinity would be expected during a more normal year. The temperature changes which are associated with the annual cycle of solar radiation are apparent in this figure.

Other typical temperature and salinity profiles in 4 regions of the harbor are shown in Figures 3.3-27 through 3.3-30. These profiles suggest a 2-layered water column with a typical upper layer depth of about 3 meters.

The volume of water in the upper layer in Pearl Harbor is:

$$V_u = \frac{h'}{h}(V_{ph}) \qquad \text{Eq. 3.3-14}$$

where h' is the depth of the upper layer, h is the mean water depth and V_{ph} is the mean volume of water in Pearl Harbor. Adjusting the data in Table 3.3-1 to Mean Water Level (Table 3.3-4), h is found to be 7.4 meters, and $V_{ph}=144 \times 10^6 m^3$. V_u is, then, $58 \times 10^6 m^3$. The lower layer volume is found to be about $90 \times 10^6 m^3$, by subtraction.

The volume of fresh water V_R in Pearl Harbor is:

$$V_R = \left(\frac{\Delta S}{S_b}\right)V_u \qquad \text{Eq. 3.3-15}$$

where ΔS and S_b are evaluated with Equation 3.8-8. V_R is then calculated to be $2.5 \times 10^6 m^3$, or about 1.8% of the volume of Pearl Harbor for 1972-1973. Again, the survey period was relatively dry, and the mean volume of fresh water in Pearl Harbor must be somewhat larger.

The mean, advective residence time T of fresh water in Pearl Harbor may be estimated from Equation 3.3-15:

$$T = \frac{V_R}{R} \qquad \text{Eq. 3.3-16}$$

where R is the mean fresh water influx. Equation 3.3-8 provides the estimate of $R=4.5 m^3/sec$ for 1972-1973. Then, for the survey period, $T=5.6 \times 10^5$ sec or 6½ days for the entire harbor, which agrees with that of Fisher (Reference 3.3-8). This estimated residence time is for dry-year flow; for a wet or normal year residence times of about 3 days would be calculated.

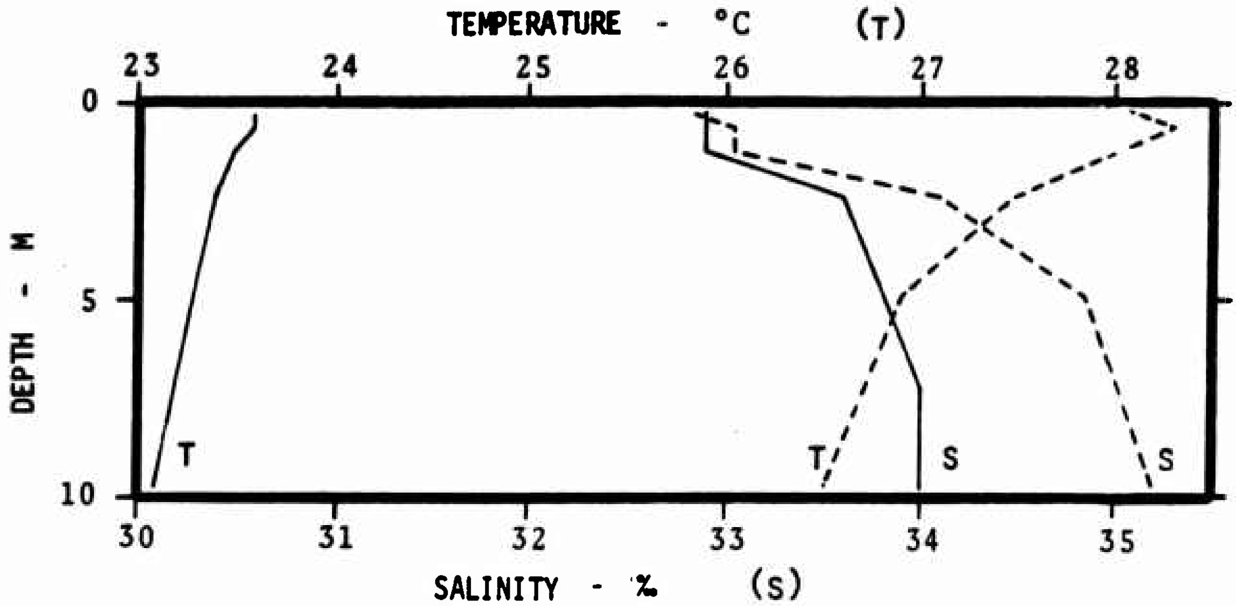


Figure 3.3-46. SEASONAL VARIATIONS IN TEMPERATURE AND SALINITY AT THE HARBOR ENTRANCE. - - - - STATION 1510 ON 19 OCTOBER 1972. ——— STATION 1015 ON 17 FEBRUARY 1973. STATIONS LOCATED AT "B" IN Figure 3.3-32.

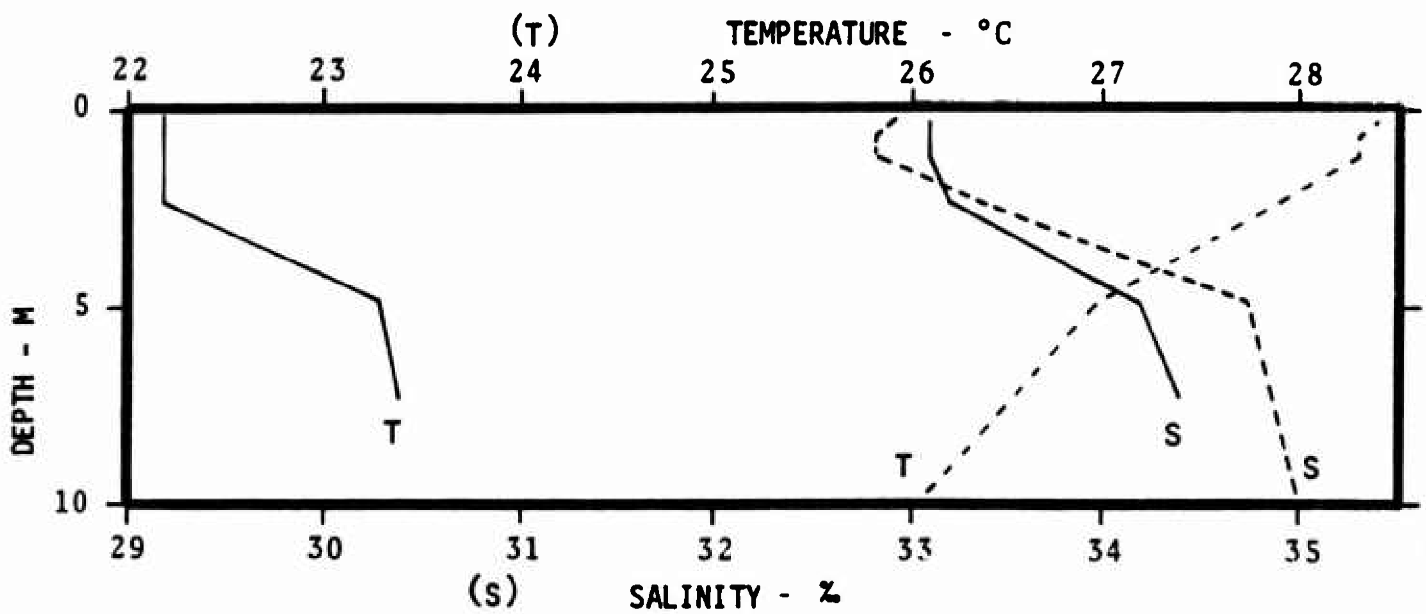


Figure 3.3-47. SEASONAL VARIATIONS IN TEMPERATURE AND SALINITY IN CENTRAL MIDDLE LOCH. - - - -STATION 1545 ON 19 OCTOBER 1972. ——— STATION 0835 ON 29 JANUARY 1973.

Since the mixture of fresh water with seawater forms the upper layer in the harbor, the residence time of fresh water should equal the upper layer residence times (suitably averaged) from the mouths of the streams entering Pearl Harbor. The estimates based on water velocities for typical residence times of upper layer waters appear in Figure 3.3-21. The major streams entering East and Middle Lochs are situated at residence times of about one day, according to this figure. Since the estimate according to Equation 3.3-16 is several times larger, residence times in West Loch must be quite long, if these estimates are consistent. It is also possible that the residence times of water at the head of Middle Loch could also have longer residence times. Fisher, for example, claims surface water residence times of 55 days, or 8 times his estimate for the harbor in general. A similar multiplication factor applied to the residence times shown in Figure 3.3-21 would produce times in essential agreement with these here calculated from fresh water volumes.

Toward the heads of the lochs, seasonal variations in temperature and salinity are greater than at the harbor entrance (Figure 3.3-46). Profiles for central Middle Loch appear in Figure 3.3-47 for comparison. Two features of temperature and salinity profiles in Figure 3.3-47 are of particular interest. First, in the winter, the temperature profile is inverted--with cooler water near the surface. Such an inversion in temperature reduces the stability of the water column and produces an unusual vertical mixing process, referred to as "salt fingering", which has been studied extensively in the last decade (Reference 3.3-31). Second, an apparent salinity inversion at the surface (higher salinity at the top of the water column) occurred at Station 1545 in Middle Loch (see Figure 3.3-44). Although this particular inversion was accompanied by a stabilizing temperature gradient, other observations suggested unstable profiles due to such surface salinity inversions. This suggests that local sources of dissolved solids may have affected the values of salinities which are computed from electrical conductivity and temperature by the sampling instrument.

GENERAL CONCLUSIONS

The 1972-1973 oceanographic survey was conducted to provide a basic preliminary understanding of the circulation of Pearl Harbor. This circulation has been summarized by developing a 3-dimensional model from the limited field observations and drogue tracks available. Several points, however, warrant special summary. They are:

1. The circulation of Pearl Harbor is driven by wind stress, temporal changes in wind stress, tide, ship-induced turbulence, and fresh water influx. These driving mechanisms have different relative importances in the various regions of Pearl Harbor, as indicated in Figure 3.3-6.

2. The currents in the upper layer of the harbor are generally directed oceanward (Figure 3.3-18). Speeds range up to about 0.3 meter/second (0.6 knot). The circulation of the lower layer is more variable and weaker, except for tidal currents which are similar in both layers (Figure 3.3-15). The tidal currents are strongest at the entrance to the harbor and in the entrance to East Loch. The tide enters East Loch primarily through South Channel. Mean tidal current speeds are less than 0.05 meter/second.

Flows in Pearl Harbor tend to be cyclonic (anticlockwise), except in Middle Loch where wind stress drives an anticyclonic circulation. There is a weak, mean cyclonic flow around Ford Island (Figure 3.3-17), predominantly in the lower water layer.

An empirical circulation model (Equation 3.3-1 and Table 3.3-3), which was developed in this study, may be used to estimate currents in Pearl Harbor, exclusive of West Loch, under a fairly wide variety of environmental conditions. Several conditions are modeled in Figures 3.3-11 through 3.3-18.

3. Typical residence times of water in the upper layer increase toward the heads of Middle and East Lochs. Except in Middle Loch, typical residence times of upper layer waters appear to be about one day of less (Figure 3.3-21). Typical residence times in the lower layer probably vary from about 1, for the head of East Loch, to more than 6 days for Middle Loch (See Figure 3.3-22).

These estimates suggest that contaminants which remain in the surface layer will be eliminated most rapidly from Pearl Harbor.

4. The general appearance of the water in Pearl Harbor is improved by moderate ship activity which enhances mixing processes and thus reduces the residence times for bottom waters. Although bottom material is stirred up by ships' activity, the material settles within 5 to 10 minutes and may be a cause of the generally improved water conditions in South Channel and Southeast Loch. It is definitely established that mixing is greatly enhanced by ship-induced water movements. Since mixing rates influence many physical and biological properties of Pearl Harbor, an understanding of the effect of ships' activity is an important factor in effective environmental management for the harbor.

REFERENCES

3.3-1. D. W. K. Au (1965), "Survey of the Distribution of the Eggs and Larvae of Nehu in Pearl Harbor", University of Hawaii Master Thesis No. 248.

3.3-2. Report on the Pollution of the Navigable Waters of Pearl Harbor, Interior Department, FWPCA, 1969, revised by EPA, 1971.

3.3-3. K. Bathen (September 1972), "Current Measurements in Pearl Harbor, Oahu, Hawaii", Look Laboratory of Ocean Engineering, Miscellaneous Report No. 6, University of Hawaii, Honolulu.

3.3-4. D. Cox and L. Gordon, Jr. (March 1970), Estuarine Pollution in the State of Hawaii, Vol. 1, Statewide Study, Water Resources Research Center, University of Hawaii, Honolulu, Hawaii.

3.3-5. T. Laevastu, et al (June 1964), Coastal Currents and Sewage Disposal in the Hawaiian Islands, HIG-64-1, Coastal Currents Project, Hawaii Institute of Geophysics, University of Hawaii, Honolulu, Hawaii, reissued: September 1969.

3.3-6. K. Wyrtki, et al (July 1969), Current Observations in the Hawaiian Archipelago, HIG-69-15, ONR Contract No. Nonr-3748(06), Hawaii Institute of Geophysics, University of Hawaii, Honolulu, Hawaii.

3.3-7. T. Chamberlain (February 1972), "Marine Environmental Impact Analysis, Waiau Power Plant", TR-3-170, prepared by B-K Dynamics, Inc., Rockville, Maryland, for Hawaiian Electric Company, Honolulu, Hawaii.

3.3-8. Leo J. Fisher (1961), "Field Report, Pearl Harbor Dye Dispersal Tests", NAVOCEANO Report 102-61.

3.3-9. N. Buske (September 1972), "Pearl Harbor Circulation", Data Report, Summer 1972, Sea-Test T.R. 3, prepared for Marine Environmental Management Office, NUC Hawaii Laboratory, Box 997, Kailua, Hawaii.

3.3-10. N. Buske (December 1972), "Pearl Harbor Circulation", Data Report, Fall 1972, Sea-Test T.R. 5, prepared for Marine Environmental Management Office, NUC Hawaii Laboratory, Box 997, Kailua, Hawaii.

3.3-11. N. Buske (March 1973), "Pearl Harbor Circulation", Data Report, Winter 1972-1973, Sea-Test T.R. 6, prepared for Marine Environmental Management Office, NUC Hawaii Laboratory, Box 997, Kailua, Hawaii.

3.3-12. N. Buske (June 1973), "Pearl Harbor Circulation", Data Report, Spring 1973, Sea-Test T.R. 8, prepared for Marine Environmental Management Office, NUC Hawaii Laboratory, Box 997, Kailua, Hawaii.

3.3-13. Pearl Harbor, Chart, N.O. 19084, U.S. Naval Oceanographic Office, Washington (For Official Use Only), 1969.

3.3-14. K. F. Bowden (1967), "Circulation and Diffusion", Estuaries, pp 15-36, NAAAS Publication No. 83, George H. Lauff (editor).

3.3-15. E. C. Evans III, et al (June 1972), "A Proximate Biological Survey of Pearl Harbor, Oahu", NUC TP 290, Naval Undersea Research and Development Center, San Diego, California.

3.3-16. Robert H. Dale (1974), USGS Honolulu, personal communication, 11 April 1974.

3.3-17. "Pearl Harbor Pollution Model Study", OICC MID-PAC and COMFOURTEEN Staffs, 1971.

3.3-18. V. Ekman (1963), "On the Influence of the Earth's Rotation on Ocean Currents", reprinted from Arkiv fur matematik, astronomi, och fysik, Band 2, No. 11, 1905, by Almqvist and Wiksells Boktryckeri ab Uppsalla.

3.3-19. Local Climatological Data, Annual Summary with Comparative Data, Honolulu, Hawaii, U.S. Department of Commerce, NOAA, Environmental Data Service, Asheville, N.C., 1971.

3.3-20. "Water Quality Program for Oahu with Special Emphasis on Waste Disposal", prepared by Engineering-Science Inc; Sunn, Low, Tom and Hara, Inc.; and Dillingham Corporation, Work Areas 8 and 9, pp 4-20.

3.3-21. Surface Winds, monthly, Honolulu, Oahu, Hawaii, 3-hourly, (224, 409 observations, 1939-1966), Data Processing Division, ETAC, USAF, Asheville, N.C., 1973.

3.3-22. Robert H. Dale (1974), USGS Honolulu, Personal communication 16 April 1974.

3.3-23. Tide Tables, West Coast of North and South America including Hawaiian Islands, NOAA, National Ocean Survey, Commerce Department, yearly (1972-1973).

3.3-24. Tide Calendar, Dillingham Corporation, Honolulu, Hawaii, 1973.

3.3-25. G. T. Hirashima (1971), "Availability of Streamflow for Recharge of the Basal Aquifer in the Pearl Harbor Area, Hawaii" USGS Water-Supply Paper 1999-B.

3.3-26. Ground-water Resources in Southern Oahu, Hawaii, Geological Water-Supply Paper 1774, U.S. Government Printing Office, Washington, 1971.

3.3-27. Surface Water Supply of the United States 1060-65, Part 16, Hawaii and other Pacific Areas, Geological Survey Water-Supply Paper 1937, U.S. Government Printing Office, Washington, 1971.

3.3-28. M. Rattray, Jr., and D. Hansen (1962), "A Similarity Solution for Circulation in an Estuary", Journal of Marine Research, 20(2).

3.3-29. D. Hansen and M. Rattray, Jr. (1972), "Estuarine Circulation Induced by Diffusion", Journal of Marine Research, 30(3).

3.3-30. B. Kinsman (1965), Wind Waves, Their Generation and Propagation on the Ocean Surface, Prentice-Hall, Englewood Cliffs, N.J.

3.3-31. T. G. L. Shirtcliffe and J. S. Turner (1970), "Observations of the Cell Structure of Salt Fingers", J. Fluid Mech. 41:4, pp 707-719.

EFFECTS OF SHIP ACTIVITY

Paul L. Jokiel
Evan C. Evans III

INTRODUCTION

Historically, the extensive physical modification of the Pearl Harbor marine environment is the direct result of the needs of U.S. Navy ships. The dredging of channels, filling of shallow regions and construction of wharves, docks and other structures resulted from shipping needs. Most of the present day environmental insult continues to revolve around ships, and thus it is useful to document the patterns of such activity in Pearl Harbor.

The environmentally significant effects of ship activity on the Pearl Harbor marine environment can be split into two main categories: a) the addition of materials to the ecosystem and b) the addition of energy into the ecosystem. The relative impact of the first category should be proportional to ship tonnage present at a given location and thus can be partially described by data on ship berthing (ship type and location). The second can be partially described from records of ship movement within the harbor.

MATERIALS ADDED TO ECOSYSTEM

Ships berthed in Pearl Harbor can potentially modify the water chemistry in many ways. Some materials (oil, heavy metals, fresh water, brine, etc.) are discharged as bilge water. Ship maintenance activities (welding, painting, scraping of old paint and rust from hulls, etc.) add yet other metals and toxins to the ecosystem. Lubricant and oil leakage occurs and occasionally large spills result from mistakes and accidents. All ships' hulls are coated with highly toxic materials to retard fouling. Such large surface areas exchange significant amounts of biocide with the water column. For example, according to Lindner (Reference 3.4-1), antifouling paints, to be effective, must release copper at the rate of $10 \mu g/cm^2/day$; for a $30,000\ ft^2$ hull area, this amounts to 250 grams-Cu/day. Although effects cannot be quantified, a general description of ship berthing distribution is a useful index since the magnitude of these effects should be proportional to the tonnage present.

Therefore, ship berthing distributions were quantified using ship berthing records made available by Pearl Harbor Port Services. A general description of all vessels using the harbor was compiled from records in Jane's Fighting Ships (Reference 3.4-2), and through conversations with personnel in charge of various units (Water Transportation, Patrol, Tug Command, etc.) and is presented as Table 3.4-1. Since all craft are restricted to speeds of five knots in the inner harbor, maximum available shaft horsepower is not a useful descriptive characteristic. For purposes of the ship movement discussion, draft and displacement are more useful. In some cases the characteristics of a given class are somewhat variable due to slightly differing designs and various levels of loading with fuel, ammunition, stores and cargo. Therefore, the values listed are intended to be approximate and exceptions are to be expected.

Table 3.4-1. CLASSES OF BOATS AND SHIPS ENCOUNTERED IN PEARL HARBOR RANKED IN ORDER OF INCREASING TONNAGE

I. Nonpropelled - moved by yard craft or tugs.
  A. Miscellaneous Harbor Service Craft
  (less than 100 tons displacement and 5 foot draft)
    1. PF (Paint Float)
    2. PF/WS (Paint Float With Scaffolding)
    3. Camal (Timber Ship Bumpers)
    4. Doughnuts (Waste Oil Containers)
  B. Barges (less than 1000 tons displacement and 10 foot draft)
    1. HCU (Harbor Clearance Unit, Personnel Barge)
    2. YOG, YOGN, YR, YG, YU (Various modifications of barge)

II. Propelled	Approx. Displacement (10^3 tons)	Draft (feet)
A. Small Boats (less than 40 tons)		
1. Water transportation small boats, yard craft, patrol boats	.01-.03	3-5
B. Large Boats (40-1000 tons)		
1. Commercial Fishing	.04-.05	5-7
2. Commercial Tour	.08-.10	7-10
3. Navy Tugs (YT)	.26-.40	9-11
4. Ford Island Car Ferries (YF)	.50-.70	10
C. Small Ships (1,000-14,000 tons)		
1. Mine Sweeper (MSO)	1	15
2. Fleet Tug (ATF)	1	15
3. Repair Salvage (ARS)	2	15
4. Submarine Rescue (ASR)	2	15
5. Escort (DE, DER)	2	15
6. Survey (AGS)	2	15
7. Cutter (WHEC)	3	15
8. Submarine (SS)	3	15
9. Nuclear Submarine (SSN)	3	15
10. Salvage Tug (ATS)	3	15
11. Floating Dry Dock (ARD)	3	15
12. Destroyer (DD)	4	20
13. Guided Missile Destroyer (DDG)	5	20
14. Gasoline Tanker (AOG)	5	20
15. Destroyer Leader (DLG)	6	25
16. Destroyer Leader (DL)	7	25
17. Ballistic Missile Submarine (SSBN)	7	20
18. Tank Landing Ship (LST)	8	15
19. Destroyer Leader, Nuclear (DLGN)	8	29
20. Cargo (AK)	9	24
21. Cargo (AG)	9	24
22. Landing Ship Dock (LSD)	9	24

Table 3.4-1. (Continued)

	Approx. Displacement (10^3 tons)	Draft (feet)
23. Survey Vessel (YAG)	10	24
24. Radar Ship (AGM)	10	24
25. Supply Ship (USNS)	10	24
26. Amphibious Command (LCC)	10	24
D. Medium Ships (14,000-20,000 tons)		
1. Amphibious Cargo (LKA)	14	26
2. Repair Ship (AR)	14	26
3. Amphibious Transport (LPA)	15	25
4. Cruiser (CLG)	15	25
5. Cruiser (CC)	17	27
6. Cruiser (CG)	17	27
7. Cruiser (CGN)	17	27
8. Cruiser (CA)	17	27
9. Aircraft Carrier (LPH)	18	26
10. Ammunition Ship (AE)	20	26
11. Destroyer Tender (AD)	20	26
12. Amphibious Cargo (LKA)	20	26
13. Submarine Tender (AS)	20	30
E. Large Ships (25,000-90,000 tons)		
1. Replenishment Oiler (AOR)	38	35
2. Oiler (AO)	25	30
3. Aircraft Carrier (CVS, Essex Class)	33	31
4. Aircraft Carrier (LHA)	39	28
5. Aircraft Carrier (CVA, Hancock Class)	44	31
6. Aircraft Carrier (CVS)	44	31
7. Aircraft Carrier (CVT)	44	31
8. Combat Support (AOE)	50	40
9. Aircraft Carrier (CVA, Midway Class)	64	36
10. Aircraft Carrier (CVA, Forrestal Class)	80	36
11. Aircraft Carrier (CVAN)	90	36

A summary of ship types at each berth in Pearl Harbor (for various dates from January 1971 through March 1973) is presented in Appendix C. These data consist of 37 sample days which were used to compute average tonnage per day as shown in Table 3.4-2 and graphically displayed in Figure 3.4-1. Berthing distribution correlates very well with total metal content of sediment (see Figure 4.1-2), suggesting that berthing data could be used as an index of metallic burdens of sediment.

Ship berths within various distances of the bio-stations are listed in Table 3.4-3 and average ship tonnage berthed within various distances in Table 3.4-4. Figure 3.4-2 shows tonnage berthed within various distances of each bio-station. Stations BE-03, BE-04 and BE-05 are in close proximity to heavily used berths. Stations BC-10, BC-11, BE-02 and BE-17 show a moderate influence by berthed ships while no tonnage was berthed close to stations BC-09, BM-07 and BW-13. Relative effect of ships' passage is also discussed in the following sections.

ENERGY ADDED TO THE SYSTEM BY SHIP ACTIVITY

Ship movement introduces energy into harbor waters, increasing mixing, disturbing sediments and creating surface waves. Such water and/or sediment movement can have a direct effect on the marine biota. For instance, fish farmers in the South commonly stir up the bottom of their ponds with an outboard in order to increase fish yields by making nutrients available, a practice which often also results in clarifying the water (References 3.4-3 and 3.4-4). It is helpful to discuss the effects of ships' movements in Pearl Harbor under three categories: a) surface or churning effects, b) water column or mixing effects, and c) bottom or scouring effects.

SURFACE EFFECTS

Ship movement disturbs the air-sea interface, mixing and dispersing the ever-present surface film of oil and creating surface waves. Ship activity tends to contaminate the water with a variety of petroleum products and residues ranging from small amounts of emulsified oil discharged from the exhausts and bilges of small boats through major oil spills. Land runoff of spilled oil or crankcase leakage frequently occurs in the dock area. Thus, surface oil is almost always present in the areas of major ship activity in Pearl Harbor. The constant churning of the surface waters by boats tends to disperse and mix the oil in the water column. It has been established (Reference 3.4-5) that the degree of oil emulsification largely governs the toxicity of oil-water mixtures to aquatic life. In addition to increasing toxicity, the breaking up of surface oil by physical forces spreads its effects throughout the water mass, thereby influencing a much greater number of organisms.

(Text continued on page 3.4-10)

Table 3.4-2. AVERAGE OF SHIP TONNAGE AT EACH BERTH FOR JANUARY 1971 - MARCH 1973 (37 SAMPLE DAYS)

Berth	Average Tonnage (tons/day)	Berth	Average Tonnage (tons/day)	Berth	Average Tonnage (tons/day)
A1	.60	DD3	0.27	V3	0.76
A2	1.27	DD4	7.02	V4	0.35
A3	1.70	F1	1.21	W1	0.30
A4	0	F2	0	W2	0.49
A5	1.16	F3	0	W4	1.35
A6	1.10	F4	0	W5	0.08
A7	0.21	F5	0.67		
B1	3.16	F12-13	1.49		
B2	5.46	GD2	.05		
B3	2.33	GD4	.11		
B4	1.73	H1-2	5.51		
B5-6	0	H3-4	21.30		
B7	3.24	K3+5	1.51		
B8	2.62	K6	.22		
B9	0	K7	12.51		
B10	6.08	K8	2.02		
B11	1.41	K9	.95		
B12	3.86	K10-11	1.02		
B13	4.19	M1-2	7.43		
B14	0.05	M3	2.18		
B15	2.24	M4	4.02		
B16	4.96	MRY2	.27		
B17	5.49	O2	.16		
B18	3.51	S1-9	1.37		
B19	0	S10	2.02		
B20	2.05	S11	1.95		
B21	2.19	S12	2.51		
B22	9.43	S13	0.83		
B23	15.37	S16	0.77		
B24	16.76	S17	1.38		
B25	12.97	S19	0.16		
B26	5.32	S20	2.94		
DD1	3.89	S21	2.70		
DD2	4.43	V2	0.65		

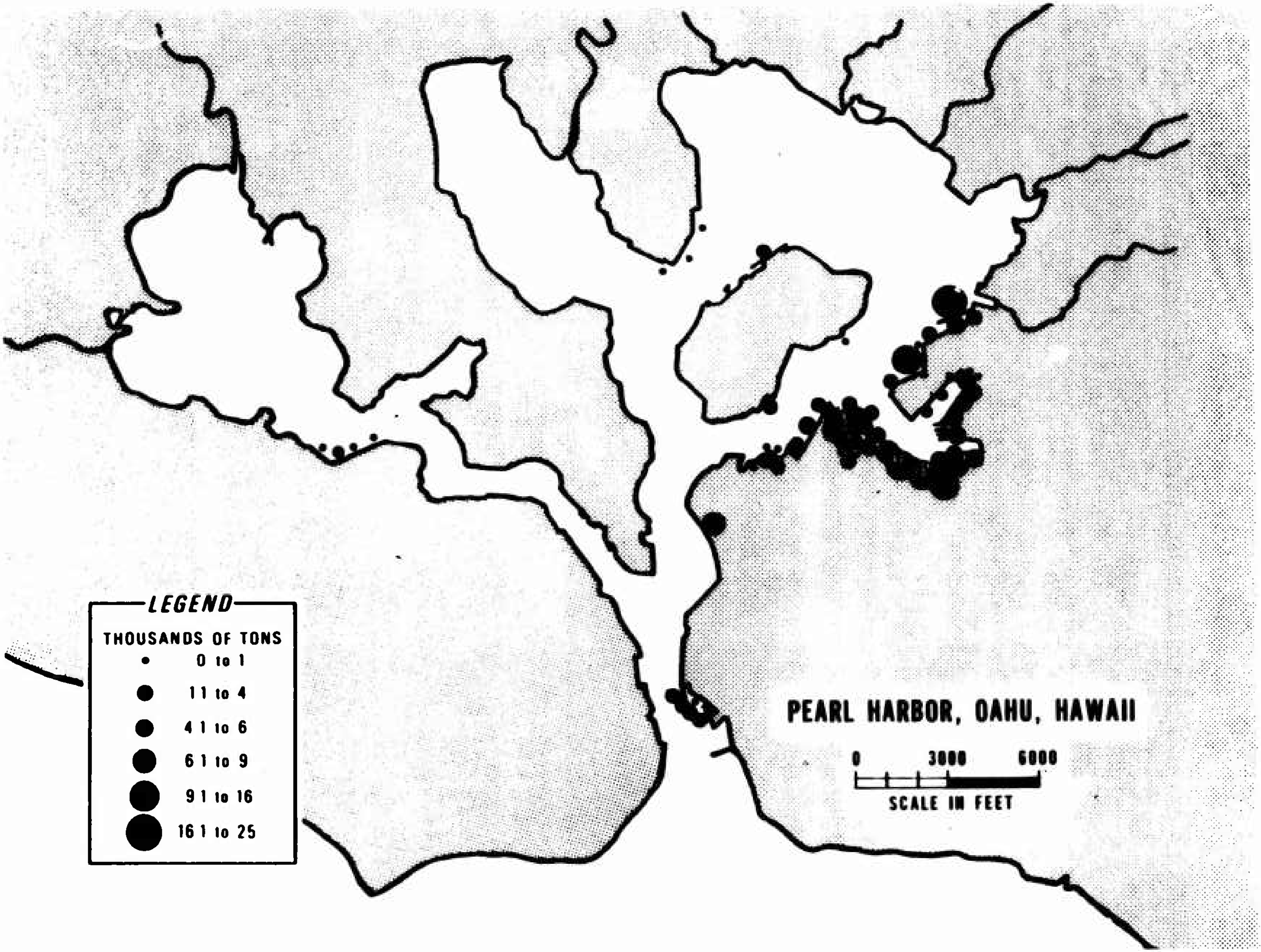


Figure 3.4-1. DISTRIBUTION OF SHIP TONNAGE IN PEARL HARBOR. MEAN OF 37 DAY SAMPLE

Table 3.4-3. SHIP BERTHS LOCATED WITHIN VARIOUS DISTANCES FROM STATIONS. (STATIONS IN ALPHABETICAL ORDER)

Station	Berths Within 800m	Berths Within 400m	Berths Within 200m	Berths Within 100m
BC-09	none	none	none	none
BC-10	DD4, W20-W25	DD4	none none	none
BC-11	A1-A7	none	none	none
BE-02	F1-F6, B3, B4 B6, B7	F4-F6	F4, F5	F5
BE-03	K6-K10, Y2, Y3 S3-S21, B1-B24	Y2, Y3	Y3	none
BE-04	B22-B28, M1-M4, S1-S21, Y2, Y3	B24-B28, M1-M4, S1-S9	B27, B28 M1-M3, S1 S3, S4	M2, M3
BE-05	H2, H3	none	none	none
BE-17	GD1-GD5, F1 F2, B1, B2	GD1-GD5, B1	GD2-GD5	GD3-GD5
BM-07	V1	none	none	none
BW-13	W6-W9, W17, W18	W6, W7, W17	none	none

Table 3.4-4. SHIP TONNAGE (THOUSANDS OF TONS DISPLACEMENT) BERTHED WITHIN VARIOUS DISTANCES OF BIO-STATIONS (STATIONS IN ALPHABETICAL ORDER)

Station	800 meters	400 meters	200 meters	100 meters
BC-09	0	0	0	0
BC-10	7.02	7.02	0	0
BC-11	6.04	0	0	0
BE-02	9.18	0.67	0.67	0.67
BE-03	129.42	0	0	0
BE-04	90.11	50.05	10.01	9.61
BE-05	26.81	0	0	0
BE-17	9.99	3.32	0.16	0.11
BM-07	0	0	0	0
BW-13	0	0	0	0

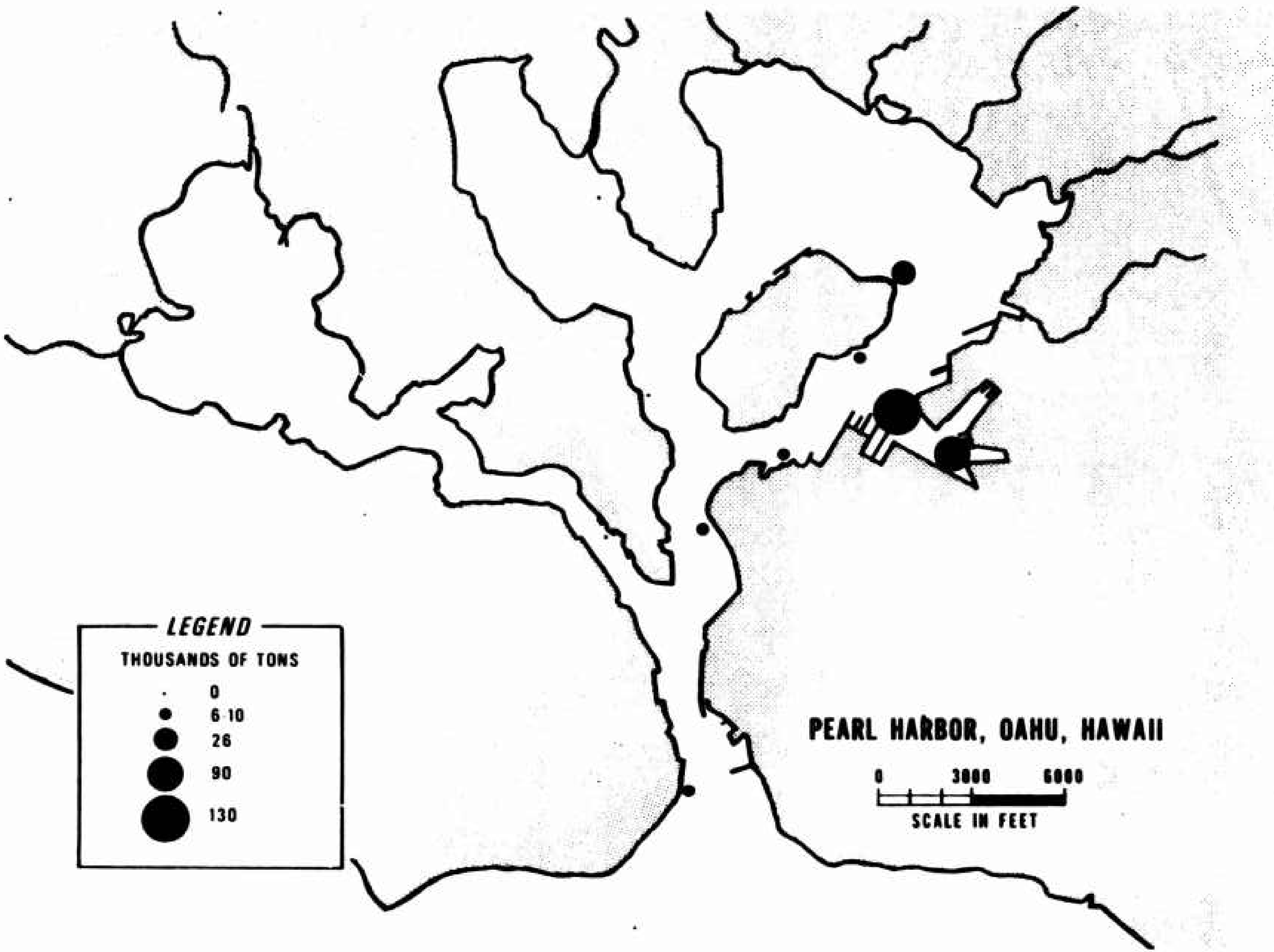


Figure 3.4-2. SHIP TONNAGE BERTHED WITHIN 800 METERS OF EACH BIO-STATION

The general impression of biologists studying the Pearl Harbor region is that oysters are rare in the region of ship activity but common in those areas not frequented by ships (see also Evans, Reference 3.4-6). Chipman and Galtsoff (Reference 3.4-7) found that water soluble fractions of crude oil greatly reduced normal functioning of oysters. Although control oysters maintained a pumping rate of 207-310 l/day, those exposed to the soluble oil fractions decreased their pumping rate to only 1-2.9 l/day after eight tc fourteen days of exposure. According to Galtsoff (Reference 3.4-8) the reduced pumping rate results from oil (or the soluble fraction of oil) coating the cilia of the oyster and reducing pumping efficiency. The oysters are then unable to feed. The deleterious effect of crude oil and lubricating oil on fish also has been shown to be due to a film formed over the gill filaments preventing gaseous exchange and resulting in death due to anoxia (Reference 3.4-9).

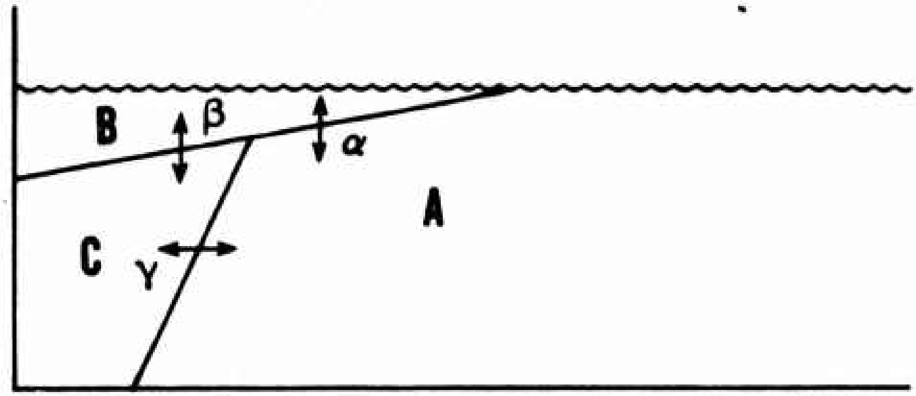
The occurrence of large waves produced by ship movement in the harbor is less frequent than wind generated waves; however, the former may be of at least equal significance because of their relatively large size. The continual occurrence of large ship-induced waves can damage or remove fragile benthic life forms from intertidal and subtidal regions. These waves break along the shoreline, suspending the finer sediments, eroding the shoreline and producing a higher degree of sorting in the beach material than might naturally occur. A sandy-silt shoreline beach can be reduced to gravel and rock if frequently subjected to ship wakes. Changes in type of substrate material can strongly influence the type of biota found at a given location.

WATER COLUMN EFFECTS

Energetic vortices introduced into the water column can break down vertical stratification (see Section 3.3) and increase horizontal mixing. By using the three-compartment model suggested for Pearl Harbor in Section 3.3, various possible mixing effects of ship traffic can be identified. This discussion follows the definitions established in Figure 3.4-3.

Ship movement and churning by screws through the compartment boundaries will modify exchange rates and influence the major water masses as follows:

1. Enhances mixing rate α which increases T_a and decreases T_b. Working material down into the rapidly-flushed tidal compartment, operates as a mechanism for removing surface water more rapidly.
2. Enhances mixing rate β which increases T_b and decreases T_c. Working material down into the deep harbor water should slow surface flushing and accelerate deep harbor flushing.
3. Enhances mixing rate γ which increases T_a and decreases T_c. Mixing the two deep water masses should increase the deep water flushing rate.



A is ocean water entering on an incoming tide.
B is relatively low salinity surface water in the harbor.
C is relatively high salinity deep water in the harbor, having maximum residence time in harbor.

α, β, and γ indicate the degree of mixing between A-B, B-C, and A-C, respectively.

Let T_X be the residence time of water in compartment X.

Figure 3.4-3. DEFINITIONS FOR 3 COMPARTMENT MIXING MODEL OF PEARL HARBOR

It is apparent that small boats enhance α and β, without effecting γ. Therefore, they should by one process increase the residence time of water in the surface layers and by another process decrease this residence time. The net effect on the residence time of deep harbor water should be to decrease it, and the net effect on the residence time of entering ocean water should be to increase it. However, large boats will increase α, β, and γ. The result will be to increase the residence time of incoming ocean water, decrease the residence time of old deep harbor water, with ambivalent effect on surface water. Therefore, it appears that small boat traffic might slightly increase flushing while large ship traffic should greatly enhance the flushing rate.

Further work is needed to quantify these relationships; however, it is clear that ship movement is an important factor in the Pearl Harbor marine environment.

BOTTOM EFFECTS

The larger ships actually drag their hulls along the silty bottom of the harbor. Their screws churn through this fine material, resuspending tons of it in the water column (see Section 3.3). The effect of this action on the water chemistry and biota have not been studied in detail. However, it is obvious that establishment of benthic communities can be physically prevented by such continual mechanical disturbance of the substrate. In some cases this disturbance is extreme. A large aircraft carrier could not clear the channel north of Ford Island in 1973 and became grounded on the bottom. The resulting attempts to free the ship by turning her screws through the silt and the activity of numerous assisting vessels created a great deal of water motion, disturbing large areas of harbor bottom and redepositing the silt in adjacent areas.

An apparent paradox is reported in Section 3.3 and in Evans (Reference 3.4-6). Regions of intense ship traffic appear to have clearer waters than do regions of little ship traffic in spite of the sediment which is stirred up by the ships, suggesting some complex relationships. Although this effect has not been studied in detail, it indicates another possibly important aspect of ships' mixing the waters of Pearl Harbor.

DESCRIPTION OF SHIP MOVEMENTS IN PEARL HARBOR

Monthly totals for all types of boat and ship movement were compiled from Pearl Harbor Port Services records for the period of the survey (see Table 3.4-5). Total ship movements for the 22-month period as well as monthly and daily means are presented in Table 3.4-6. Detailed data on daily ship movements are presented in Appendix C.

Table 3.4-5. MILITARY SHIP MOVEMENTS IN PEARL HARBOR
NOVEMBER 1971 TO AUGUST 1973 - MONTHLY TOTALS

Year	Month	Ships Entering Port	Ships Leaving Port	Inner Harbor Moves	Tug Moves	Tug Operating Hours	Pilot Moves	Ford Island Ferries Round Trips	Water Transportation Small Boat Runs	Harbor Patrol Boats Hours of Operation
1971	N	218	205	451	837	1002	236	896	5411	195
	D	108	88	252	536	557	165	896	5728	233
1972	J	112	133	406	613	464	235	890	5719	150
	F	132	122	441	653	879	181	893	5728	162
	M	120	122	518	672	711	195	894	5237	175
	A	106	129	471	595	708	233	897	5471	210
	M	122	123	451	676	516	172	896	5453	226
	J	169	155	425	658	662	173	894	5470	240
	J	210	206	406	710	802	215	893	5454	248
	A	137	127	353	420	457	153	878	5463	286
	S	144	140	435	733	633	171	698	5602	285
	O	118	121	339	403	461	100	894	5423	285
	N	120	116	413	531	651	147	867	5433	285
	D	102	99	287	363	612	147	882	5450	278
1973	J	116	121	387	495	781	116	896	5386	278
	F	109	101	352	441	556	124	853	4999	252
	M	112	108	429	539	781	200	896	5448	276
	A	114	113	432	400	560	152	862	5392	256
	M	100	98	398	410	473	150	886	5560	248
	J	104	96	471	340	456	128	763	5421	248
	J	94	109	373	383	525	123	879	5428	248
	A	90	102	388	514	648	157	884	5861	248

Table 3.4-6. MILITARY SHIP MOVEMENTS IN PEARL HARBOR NOVEMBER 1971 TO AUGUST 1973 - MONTHLY AND DAILY MEANS

Type of Ship Movement	Total Nov '71-Aug '73	Monthly Mean	Daily Mean
Ships Entering Port	2,757	125	4
Ships Leaving Port	2,734	124	4
Inner Harbor Moves	8,878	403	13
Ford Island Ferries (Round Trips)	19,187	872	29
Tug Moves	11,922	542	18
Tug Operating Hours	13,895	632	21
Hours/move	-	-	.86
Water Transportation			
Small Boat Runs	120,537	5,479	183
Pilot Moves	3,673	167	6
Harbor Patrol Boats (Hours)	5,312	241	8

Port Services estimates that 80% of activity occurs between 0600 and 1700 hours.

Operation of boats in the class measuring in the tens of tons are of significance because of the high level of activity within the harbor, (i.e. hundreds of runs per day). Their chief impact on the ecosystem probably is the continuous production of surface waves and the emulsification of oil films.

Boats in the class measuring in the hundreds of tons produce similar surface effects but also have sufficient draft to disrupt the pycnocline and increase mixing between surface and deeper layers.

The largest vessels have a draft that equals the depth of the harbor. Although visits by the large deep-draft vessels are less frequent than those of other classes of ships (example: large aircraft carriers are present in the harbor only for several days out of the month), their impact is significant because of the extreme disturbance of the harbor bottom.

Data on ship movement (location and intensity) are summarized in Figures 3.4-4 through 3.4-8 (also in Appendix C). Using these data and information on the general route taken by vessels moving between various locations, a relative ranking of bio-stations according to proximity to ship motion was established (see Table 3.4-7). Since data are not kept on the exact route taken by vessels between fixed points and since many small boat movements are unscheduled and not logged in detail, it was necessary in producing the table to use some judgement based on conversations with various shipyard personnel. Stations appear to fall into three clusters based on ship traffic in their area. They have been classified as those exposed to light, medium and heavy traffic (see Table 3.4-7 and also Figure 3.4-9). This relative ranking is in agreement with that established by the biologists on the basis of casual observation of resident marine organisms (see Section 1.0). Thus a competent biological observer can often rapidly and accurately describe many characteristics of an environment on the basis of "on site" experience and without lengthy and detailed data collection and analysis.

SHIP MOVEMENT AS A MECHANISM OF NEW SPECIES INTRODUCTION

Navy ships entering Pearl Harbor have played a role in the modification of the Hawaiian marine environment through the accidental introduction of species from other parts of the world. These "stowaways" journey in ballast tanks and on the fouled hulls of ships. Many introductions probably occurred in the years before the Hawaiian marine fauna was studied in detail by ecologists and therefore have not been documented. However, a number of recent occurrences have been reported in the scientific literature and demonstrate the drastic changes that have resulted.

The alga *Acanthophora spicifera* (Vahl) Boergesen is believed to have been accidentally introduced to Hawaii in 1950 on the heavily fouled barge YON 146 that had been towed to Pearl Harbor from Guam

(Text continued on page 3.4-23)

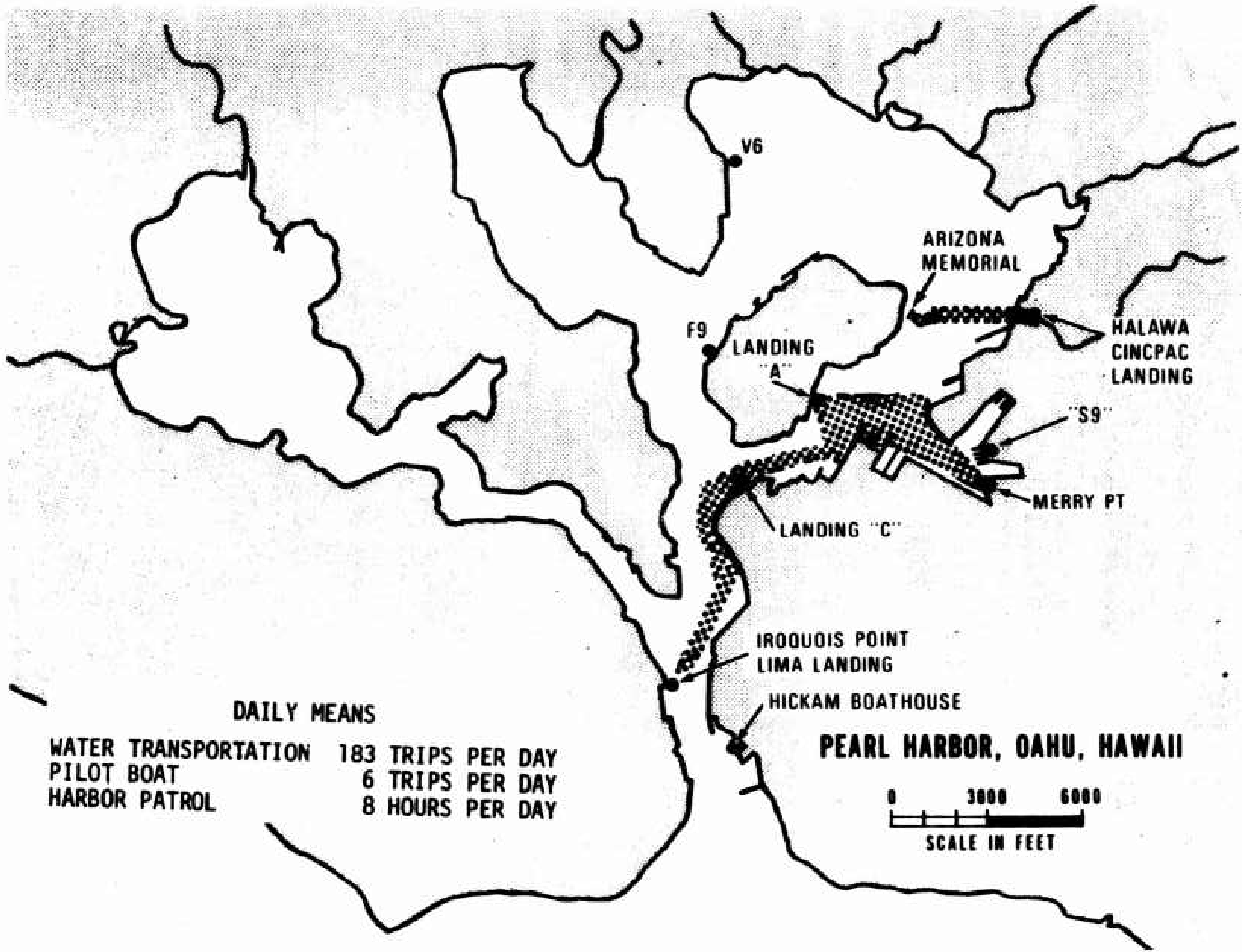


Figure 3.4-4. SMALL BOAT RUNS. ZONE ESTIMATED BY HARBOR SERVICES TO CONTAIN 95% OF ACTIVITY

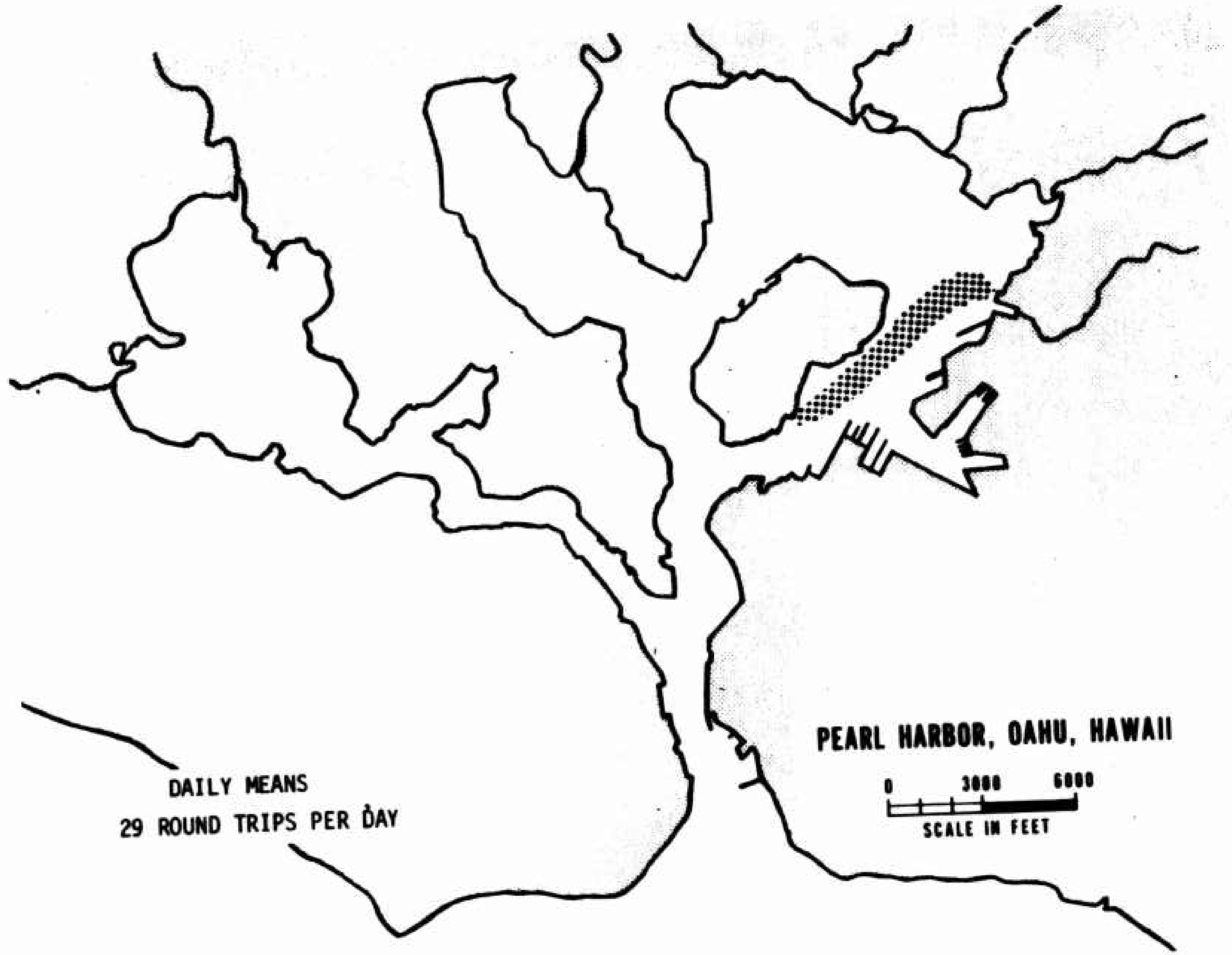


Figure 3.4-5. FORD ISLAND CAR FERRIES. ZONE ESTIMATED BY HARBOR SERVICES TO CONTAIN MORE THAN 95% OF ACTIVITY

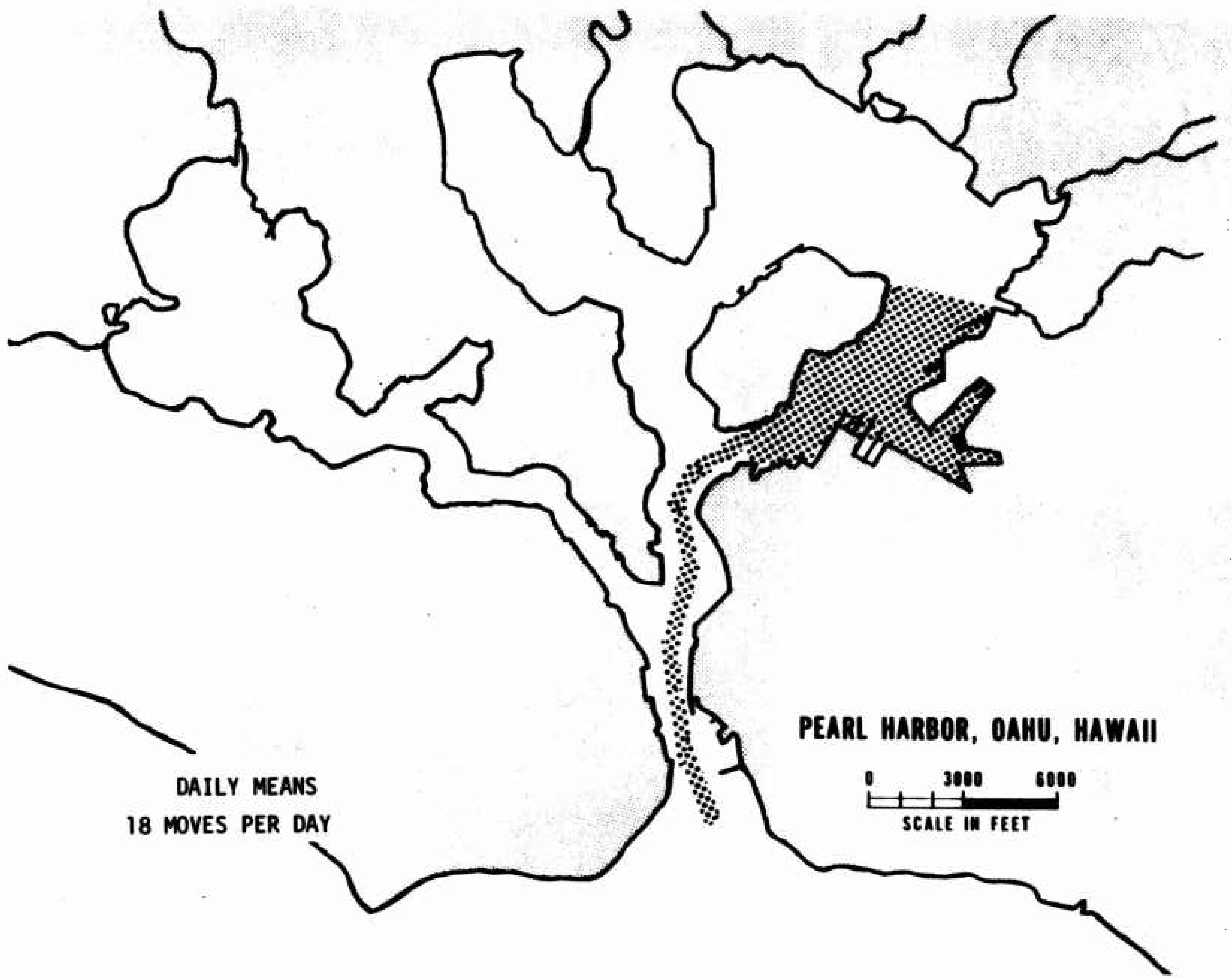


Figure 3.4-6. TUG MOVEMENTS. ZONE ESTIMATED BY HARBOR SERVICES TO CONTAIN MORE THAN 95% OF ACTIVITY

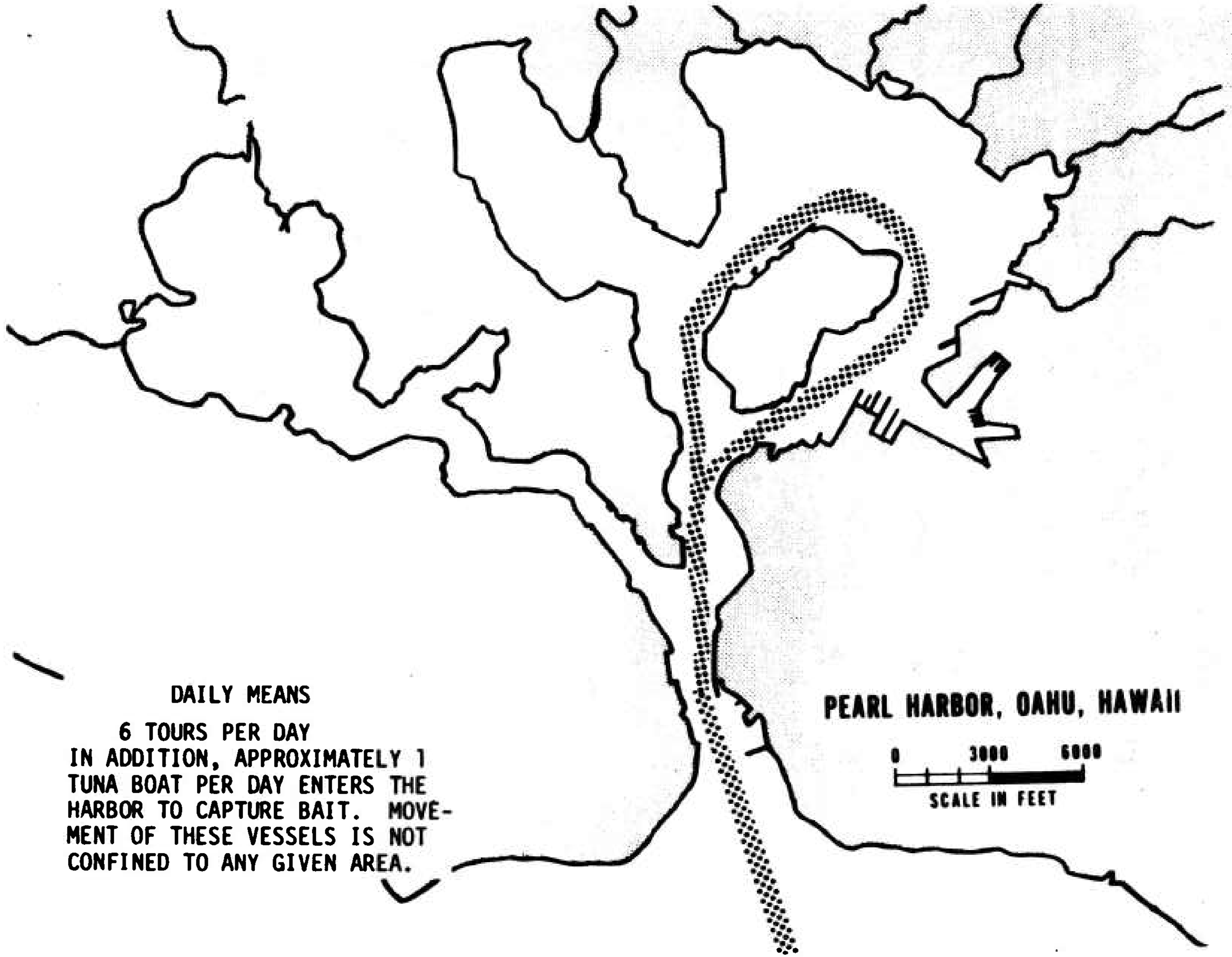


Figure 3.4-7. CIVILIAN TOUR BOAT TRAFFIC. ZONE ESTIMATED BY HARBOR SERVICES TO CONTAIN MORE THAN 95% OF TRAFFIC.

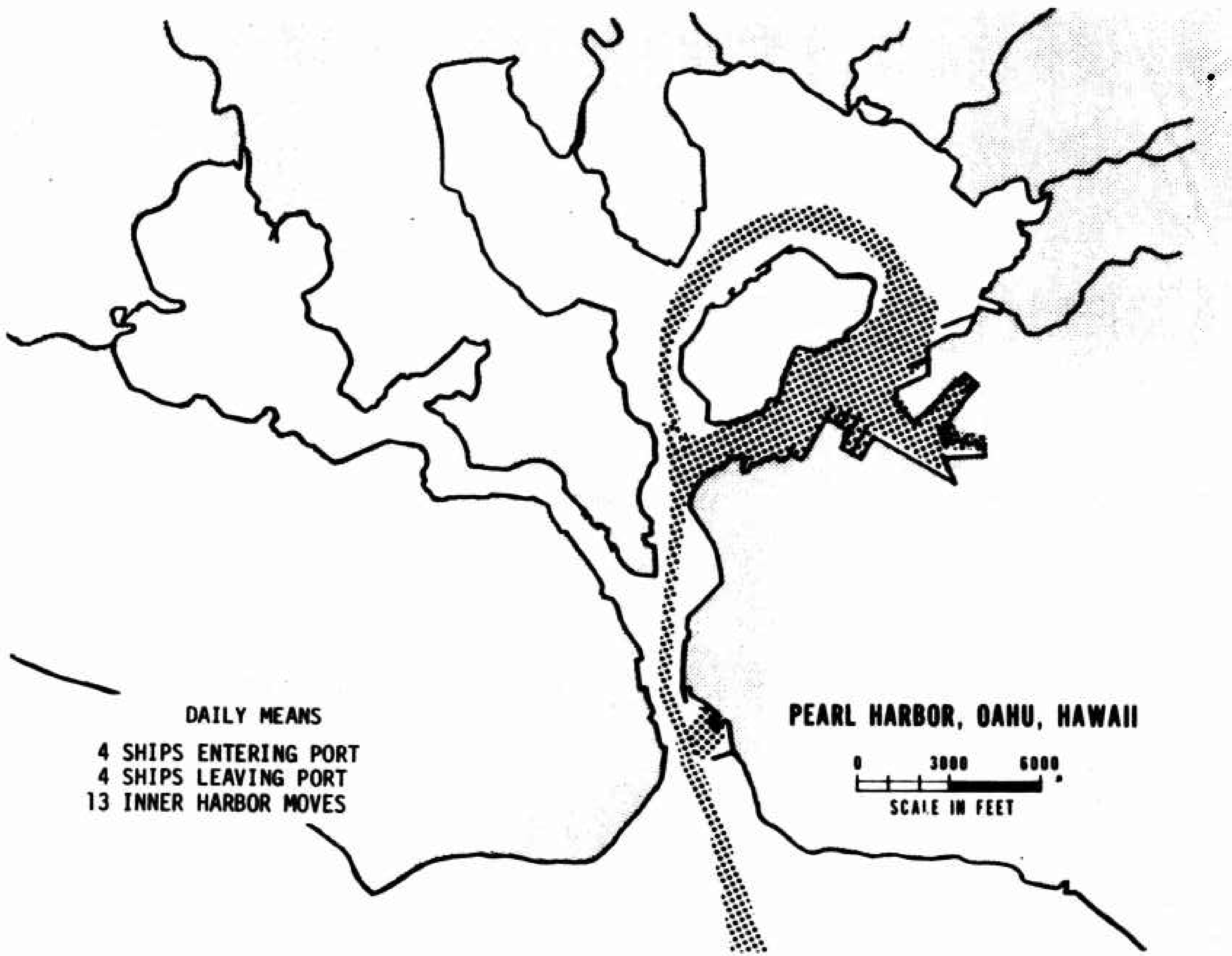


Figure 3.4-8. SHIP TRAFFIC (GREATER THAN 2000 TONS). ZONE ESTIMATED BY HARBOR SERVICE TO CONTAIN MORE THAN 95% OF ACTIVITY

Table 3.4-7. ESTIMATED SHIP AND BOAT ACTIVITY WITHIN 300 METERS OF THE VARIOUS BIO-STATIONS (RANKED IN ORDER OF DECREASING SHIP DISTURBANCE)

Station	Ship Movement	Ford Island Ferry	Civilian Tour	Tugs	Fishing	U.S.N. Tour	Arizona Shuttle	Small Boat Ferry	Iroquois Ferry	Pilot Boat	Summary: Ships Over 1000 tons	Summary: Boats	Classification
BE-03	14±4	0	6	16±2	0	5	0	40	0	6	14	73	"HEAVY"
BE-04	14±4	0	6	14±2	0	5	0	40	0	6	14	71	
BC-10	8±2	0	12	[illegible]±2	1-2	0	0	40	8	6	8	76	
BC-11	8±2	0	12	8±1	1-2	0	0	0	0	6	8	36	
BE-17	4±2	0	6	4±2	1-2	5	0	20	0	0	4	37	"MEDIUM"
BE-05	4±2	0	6	2±2	1-2	5	0	0	0	6	4	21	
BE-02	3±2	0	6	8±2	0	5	36	0	0	0	3	54	
BE-09	3±1	0	6	3±1	1	5	0	0	8	0	3	23	
BW-13	0.1±0.1	0	0	0	1-2	0	0	0	0	0	0.1	2	"LIGHT"
BM-07	0	0	0	0	1	0	0	0	0	0	0	1	

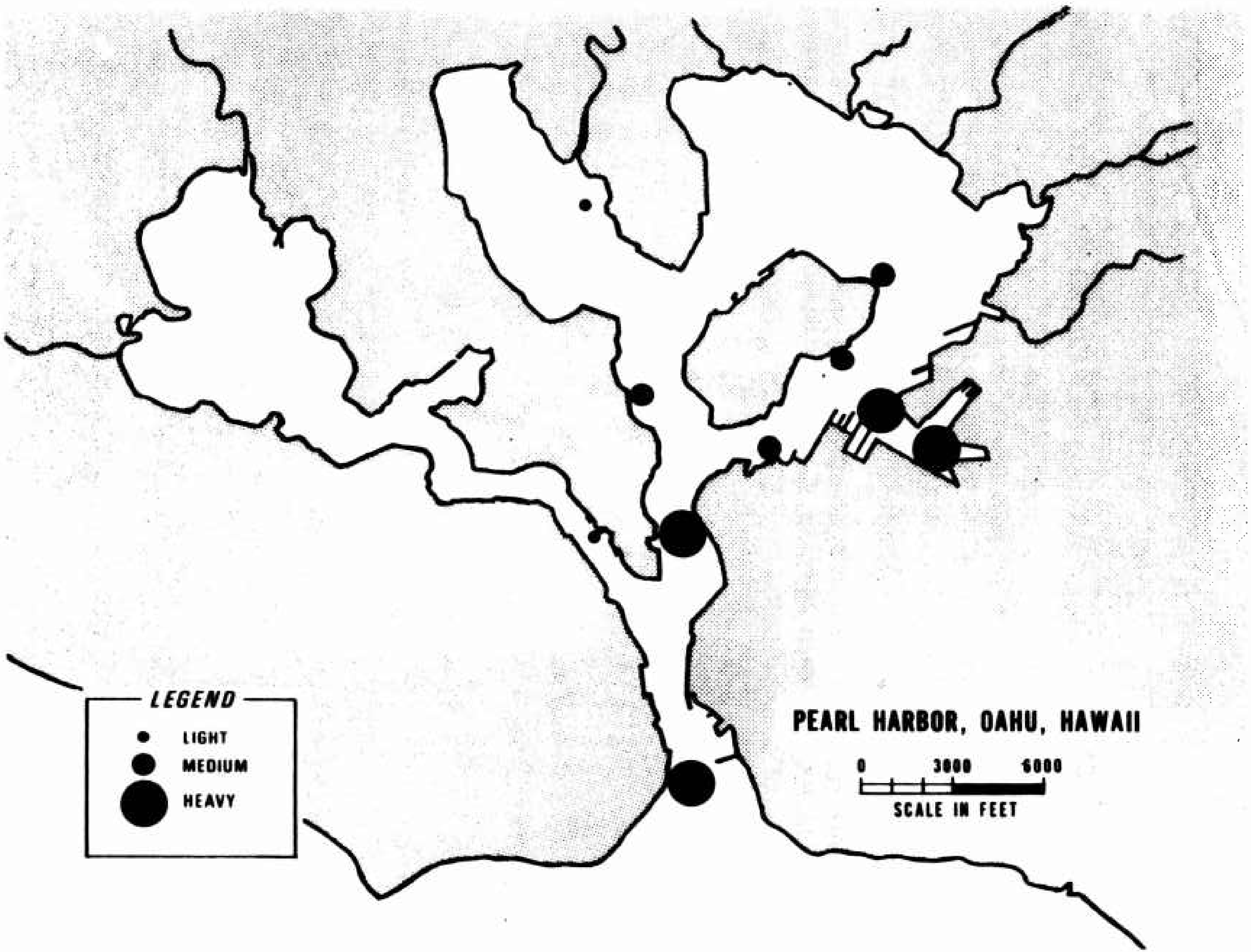


Figure 3.4-9. RELATIVE RANKING OF SHIP MOVEMENT NEAR BIO-STATIONS (SEE TEXT)

(Reference 3.4-10). Since its introduction, this alga has invaded much of the Oahu shoreline and has spread to other islands in the Hawaiian chain. It now is the dominant alga in many localities. Not all introduced alga become dominant, however. *Nemacystus decipiens*, another possible introduction, was first discovered in May 1963 at Kaaawa and slowly moved north and south along the coast, being found on Diamond Head in 1970 and at Waikiki in 1971; however, in 1972 the species was not found, and in 1973 only one piece was found at Waikiki (Reference 3.4-11). Likewise, the stomatopods *Gonodactylus falcatus* and *Gonodactylus hendersoni* are believed to have been introduced by slow moving, heavily fouled Navy barges towed to Pearl Harbor from the South and Western Pacific after World War II (Reference 3.4-12). *G. falcatus* has completely replaced the native species (*Pseudosquilla ciliata*) in some Hawaiian habitats. Edmondson (Reference 3.4-13) reported that Pearl Harbor ship traffic is probably responsible for the introduction of many species of invertebrates, including the crab *Schizophrys aspere* (H. Milne Edwards). The crab *Glabropilumnus seminudus* (Miers) has become common in Pearl Harbor since the first specimen was found by Edmondson (Reference 3.4-14) on the fouled hull of one of the barges that was towed from Guam. According to C. E. Cutress (Reference 3.4-15) the Rhizostomae *Cassiopea medusa* (Light) and *Cotylorhizoides pacificus* (Mayer) were almost certainly introduced to Hawaii from the Phillipines via Pearl Harbor during the 1941-45 period. Jones (Reference 3.4-16) reports on the possible introduction of the brackish water copepod *Pseudodiaptomus marianus* to Hawaii from Japan, probably in the ballast tanks of a ship. A similar introduction of a shrimp was made into San Francisco Bay via the same mechanism (Reference 3.4-17).

A rather unusual occurrence involving Pearl Harbor ship operations is reported by Gosline and Brock (Reference 3.4-18). Fourteen specimens of the blenny *Ecsenius hawaiiensis* (previously unknown to science) were taken from the fouling on the bottom of one of the barges brought from Guam and dry docked in Pearl Harbor. This fish has never been recorded from anywhere else in the world and has not been retaken in Hawaii since, despite intensive collecting. Apparently the fish had colonized the barge somewhere in the South Pacific but failed to become established in Hawaii.

REFERENCES

3.4-1. Elek Lindner, "Non-Polluting Anti-Fouling Coatings", Symposium on Naval Pollution Effect in the Environment, Naval Post Graduate School, September 1971.

3.4-2. Raymond B. Blackman (1973), Jane's Fighting Ships, 1972-1973.

3.4-3. H. S. Swingle and E. Z. Smith (1942), "Management of Farm Fish Ponds", Alabama Polytechnic Institute Bulletin No. 254.

3.4-4. R. M. Smith (1974), University of West Virginia, personal communication.

3.4-5. Clarence M. Tarzwell (1970), "Toxicity of Oil and Oil Dispersant Mixtures to Aquatic Life", Proc. Seminar on Water Pollution by Oil, Aviemore, Scotland, 4-8 May 1970, pp 263-272.

3.4-6. Evan C. Evans III, A. E. Murchison, T. J. Peeling, and Q. D. Stephen-Hazard (1972), "A Proximate Biological Survey of Pearl Harbor, Oahu", NUC TP-290.

3.4-7. W. Chipman, and P. S. Galtsoff (1949), "Effects of Oil Mixed with Carbonized Sand on Aquatic Animals", Special Sci. Report No. 1, U. S. Fish and Wildlife Service.

3.4-8. P. S. Galtsoff (1964), Environmental Factors Affecting Oyster Populations", U. S. Fish and Wildlife Service, Fish. Bulletin 64, pp 397-456.

3.4-9. A. H. Wiebe (1935), "The Effect of Crude Oil on Freshwater Fish", Trans. Am. Fish Soc. 65, pp 324-331.

3.4-10. Maxwell S. Doty (1961), "*Acanthophora*, A Possible Invader of the Marine Flora of Hawaii", Pacific Sci. 25, pp 547-552.

3.4-11. Costin and Groves (1973), Nature Conservation in the Pacific, Australian National University Press, p 185.

3.4-12. Robert A. Kinzie (1968), "The Ecology of the Replacement of *Pseudosquilla ciliata* (Fabricus) by *Gonodactylus falcatus* (Forsskål))Crustacea; Stomatopoda) Recently Introduced into the Hawaiian Islands", Pacific Sci. 22:4, pp 465-475.

3.4-13. Charles H. Edmondson (1951), "Some Central Pacific Crustaceans", Occ. Papers, Bishop Museum 20:13, pp 183-243.

3.4-14. Charles H. Edmondson (1962), "Xanthidae of Hawaii", Occ. Papers, Bishop Museum 22:13, pp 216-309.

3.4-15. in Doty, Reference 3.4-10.

3.4-16. E. C. Jones (1966), "A New Record of *Pseudodiaptomus marinus* Sato (Copepoda; Calanoida) from Brackish Waters of Hawaii", Crustaceana 10, pp 316-317.

3.4-17. W. A. Newman (1963), "On the Introduction of an Edible Oriental Shrimp (Caridea; Palemonidae) to San Francisco Bay", Crustaceana 5:2, pp 119-132.

3.4-18. William A. Gosline and Vernon E. Brock (1965), Handbook of Hawaiian Fishes, University of Hawaii Press.

STATISTICAL ANALYSIS
OF ENVIRONMENTAL DATA

Stephen V. Smith
Evan C. Evans III

INTRODUCTION

An ecosystem is a highly complex and interactive assemblage of both biotic and abiotic variables. Answering specific questions about the state of any ecosystem demands recognition of major patterns of variation within that system and subsequent interpretation of those patterns in terms of ecosystem dynamics. The large number of variables in all but the simplest ecosystems hampers efforts to recognize these overall patterns.

In any complex ecosystem it is obviously impossible to measure all aspects of the environment. In the present study of Pearl Harbor, data have been gathered for over 400 species of organisms at 10 locations in the harbor. Data for 10 sediment parameters at 92 locations and 15 water quality parameters at 37 locations have also been used. Each of these data arrays represents a simplified version of the field data actually gathered; furthermore,those field data are but a small part of the total information contained in the system. From this array of about 5000 pieces of information (small in comparison to its potential size) identifiable patterns of variation must be extracted. Tabulation without such extraction is insufficient for the meaningful interpretation of patterns within the ecosystem. The statistical techniques presented here are intended to provide tools for environmental analysis.

GENERAL PLAN OF DATA ANALYSIS

Both biotic and abiotic environmental data contain a great deal of redundancy; that is, there exist a great many similarities among the vast number of possible measurements which describe the ecosystem. It is convenient to view these relationships in terms of dimensions on a graph. For example, if one variable plotted against another on a graph shows a perfect linear relationship, then the total information on that graph can be reduced to a single axis oriented along that linear arrangement of points: this single axis, or dimension, contains the same information as the original two axes. If there is some scatter of points about the single substitute axis, then there is some information loss in using this axis. The analogy can be extended to many original axes, variables, or dimensions, and the information loss in going from many axes to few axes may be far overshadowed by the advantages of the resulting simplification of the data survey.

The redundancy in the ecosystem, however, presents the analyst with another advantage. If many parameters in the environment have been measured, they are likely to contain much of the information contained in the even greater number of unmeasured parameters. That is, a large, redundant data array is likely to capture much of the information contained in the still larger, and largely unanalyzed, natural system that has been sampled.

The general class of statistical techniques seeking relationships among variables is known as multivariate analysis. Of the many multivariate techniques available, the ones used here are particularly amenable to the definition of redundancies in a data array without prior identification of independent versus dependent variables. In this sense, the techniques presented here are closely related to correlation analysis - analysis of the degree to which variables are related to one another.

Figure 4.0-1 is a flow diagram which illustrates the major steps of multivariate analyses used here. The following brief discussion amplifies on that figure; the utility of the analyses should become apparent as the results are presented.

The original data used in the analyses consist of a table of m variables reported for each of n samples. The samples are locations throughout the harbor, and it is convenient to call them stations. In the analyses here, as in most statistical analyses, a useful initial step is the calculation of variable means and standard deviations.

Correlation analysis involves calculation of the familiar Pearson product-moment correlation coefficients between all pairs of variables. The result of that analysis is a square $m \times m$ correlation coefficient matrix. The squared correlation coefficients multiplied by 100 are termed coefficients of determination and define the degree of redundancy between the variables.

Complex tables of data frequently have missing elements which preclude presentation of a complete $m \times n$ data matrix. Yet such a complete data matrix is prerequisite to most forms of multivariate statistical analysis. Incomplete $m \times n$ data matrices are therefore patched by means of a technique recently developed by Wall (Reference 4.0-1) to estimate missing elements of the data matrix from the original data table and the correlation coefficient matrix. The technique generates two data matrices. One matrix has the best simple linear regression estimate of the missing data elements, while the other matrix has a random error superimposed upon each regression estimate. Wall presents the rationale for generating this second matrix and the separate use of each matrix in subsequent analyses. For the discussion here, it is sufficient to consider the two as a single data matrix.

The core of the statistical treatment of data in this section is factor analysis. Returning to the graphical analogy presented above, factor analysis is the search for axes which simplify the original data matrix to one with fewer variables. This analysis is a rigorous mathematical method of extracting statistically useful and reproducible results from a large collection of variously interdependent variables. The factors are themselves variables calculated from the original data, and these factors may be considered to be quantitative numerical indices which summarize a large fraction of the information contained in the original data matrix. Factors may be calculated in a variety of ways, but for given data and

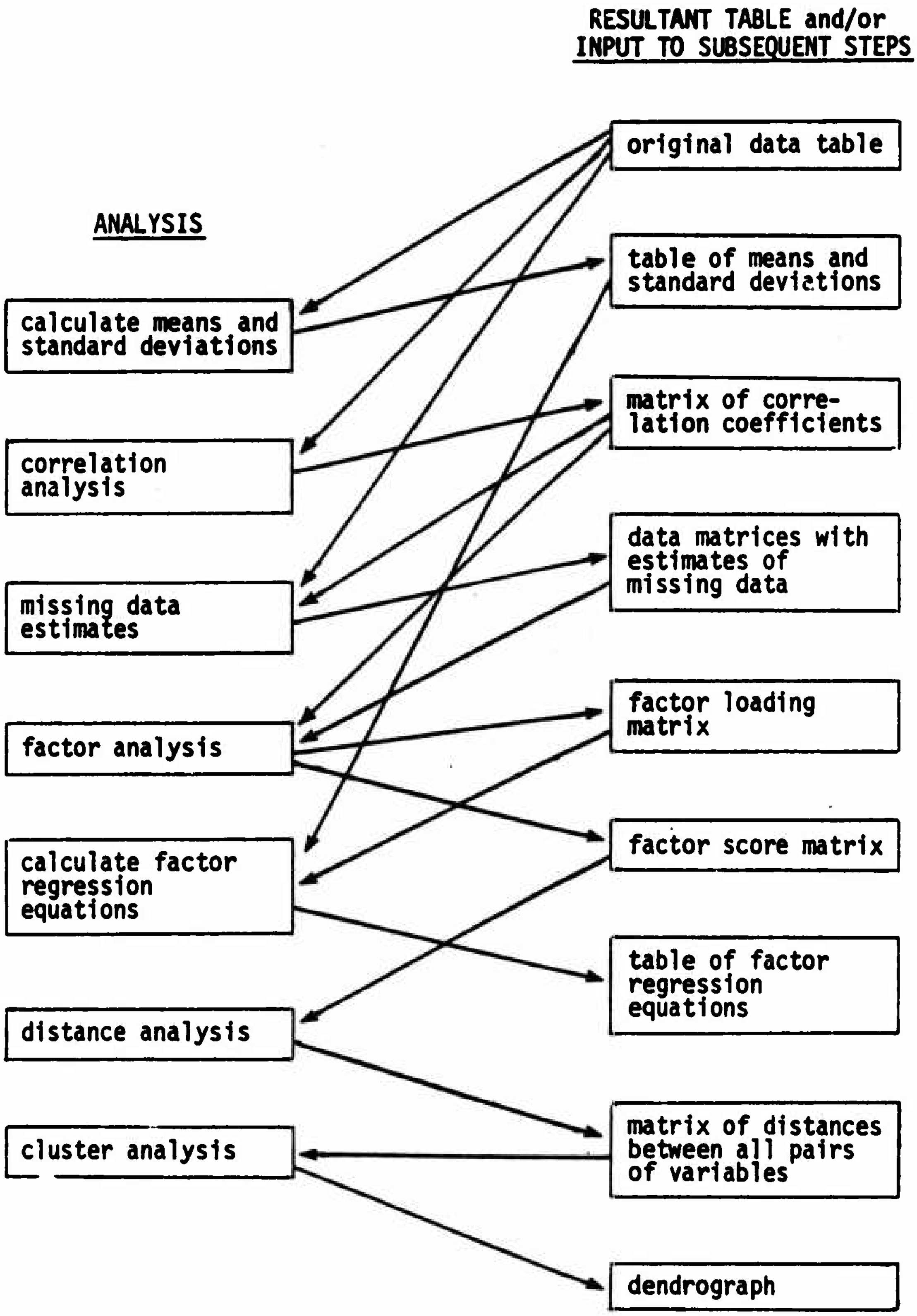


Figure 4.0-1. FLOW DIAGRAM OF MAJOR STEPS IN PEARL HARBOR SEDIMENT METAL MULTIVARIATE STATISTICAL ANALYSES.

specified criteria[1] the results of factor analysis are completely reproducible. The factors have a maximum correlation with the original data and no correlation with one another. The correlation coefficients between the factors and the original variables are called factor loadings, and the strengths[2] of the factors at the individual stations are termed factor scores.

The maximum number of factors which can be extracted from a $m \times n$ data matrix is either m or n, whichever is the smaller number. Usually the analyst stops short of this maximum, since simplification of the original data matrix is the major desired outcome of the analysis.

Matrices of both factor loadings and factor scores have several properties which are interesting and relevant to the presentation here. All scores for each factor are standardized to a mean of 0.0 and a standard deviation of 1.0. Unless the frequency distribution of the scores is strongly skewed, there will be a mode of scores near 0.0. Score values thus represent standard deviation units away from that mean value.

Squared factor loadings times 100 are coefficients of determination and represent the percent correspondence between a given factor and the associated variable. Since the factors are not correlated with one another, the factor loadings may be treated as partial correlation coefficients. Thus, for a given number of factors, the summed coefficients of determination between those factors and a particular variable represent the percent of the total variability in that variable explained by those factors. This sum is called the communality over those factors. Summing the coefficients of determination of a single factor over all the variables and dividing by the number of variables yields the percent of variation in the original data matrix explained by that factor.

---

[1]This investigation has used principal components analysis with orthogonal (varimax) rotation. The calculations were performed with a modular package of subroutines for each step of the analysis. That package was developed by Wall (Reference 4.0-2) and is available through the University of Hawaii Computer Center. The package is faster and more versatile than more widely available routines (e.g. BMD*, Reference 4.0-3), but results are identical. The cutoff criterion used here is to examine a plot of eigenvalues versus unrotated factor number. Only factors with eigenvalues above 1.0 are considered, and a major slope break in the plot is sought. Those factors above the slope break are used.

* BMD = a degenerate acronym, see Reference 4.0-3.

[2]This concept is difficult to explain to those unfamiliar with matrix algebra. Roughly, it is a measure of how well a given factor represents all the variables at a given station; however, the measure is weighted so that those variables which load most heavily on the given factor count the most. Exactly, it is: $\hat{S}_{nxp} = Z_{nxm} R^{-1}_{mxm} F_{mxp}$

where $\hat{S}$ is the score matrix (stations vs. factors), Z is the standardized data matrix (stations vs. variables), R is the correlation matrix (variables vs. variables), and F is the factor loading matrix (variables vs. factors). For further discussion see Reference 4.0-4.

Finally, the rigor of the statistical calculation requires that the factor loadings be standardized regression coefficients between the factor scores and the original variables. It is thus possible to turn the loadings of all the factors on a given variable into a multiple regression equation. Let X be the value of a variable at a station, Z be X's standardized value; over all stations let μ be its mean and α be its standard deviation. The loading of the ith factor on that variable is α_i, and the score of the ith factor at the station is S_i. The definition of a standardized variable is given by the following equation:

$$Z = \frac{X - \mu}{\sigma} \tag{1}$$

The standardized regression equation over the p factors is:

$$Z = \sum_{i=1}^{p} (\alpha_i) S_i \tag{2}$$

It follows from equations (1) and (2) that:

$$X = \mu + \sum_{i=1}^{p} (\sigma\alpha_i) S_i \tag{3}$$

where μ is the intercept of the regression line on X, and the $(\sigma\alpha_i)$ values are the regression slope coefficients.

All of the above properties of the factor matrices have practical application which should become apparent as this section continues.

Distance analysis is the next step in the statistical procedures considered here. This analysis involves locating each station in a p-dimensional Cartesian space defined by the factors and then calculating the distance in that space between the stations. Distances between any two stations a and b (D_{ab}) can be determined by an extension of the Pythagorean Theorem to p dimensions, where the factor scores are represented by S:

$$D_{ab} = \left[\sum_{i=1}^{p} (S_{ia} - S_{ib})^2 \right]^{\frac{1}{2}} \tag{4}$$

A matrix of distances between all station pairs may be scaled between 0 and 1 by dividing each distance by the maximum distance.

Any technique which defines groups of stations near one another in such a p-dimensional space is known as cluster analysis. Dendrographs (Reference 4.0-5) are inverted tree-like diagrams which graphically portray the results of cluster analysis. The clusters are displayed in a fashion which facilitates their recognition and also permits rigorous cluster definition on the basis of distance between members. In the dendrograph, the length of the inverted tree limbs (ordinate values) represents the "degree of cluster" or actually the mean distance between all members of the cluster. The ordinate scale is normalized from zero to 1.0 for maximum separation and is also expanded; tick marks are in tenths. Reading the abscissa is slightly more complex. Only specific distances have meaning, namely distances (abscissa values) between two immediately adjacent limbs. These distances represent the mean distance between the joining entity (singularity or each member of a second cluster) and each member of the already established cluster. It is an expression of the "separation" between the established cluster and the new member(s) being joined. The scale of the abscissa is also normalized from zero to 1.0 for maximum separation; tick marks along the abscissa represent units of 1.0.

Figure 4.0-1 is not a rigorous diagram followed without exception in all analyses. Some additional analyses were undertaken for specific purposes. Moreover, it is possible to use data or insight gathered at any stage in the analysis to loop back to any preceding stage. Finally, in some instances, certain steps in the general analytical scheme were skipped when they seemed unlikely to produce further useful information.

REFERENCES

4.0-1. Charles F. Wall (1971), Correlations with missing data. Unpublished manuscript and personal communication with S.V. Smith.

4.0-2. Charles F. Wall (1971), "Dimensionality of Nations (DON) Project", University of Hawaii Program Writeup, University of Hawaii Statistics and Computing Center.

4.0-3. W. J. Dixon (1973), BMD Biomedical Computer Programs, 3rd ed., University of California Press.

4.0-4. R. J. Rummel (1970), Applied Factor Analysis, Northwestern University Press, pp 436 ff.

4.0-5. Richard B. McCammon (1968), "The Dendrograph: A New Tool For Correlation", Geological Soc. Amer. Bull. 79, 1663-1670.

MULTIVARIATE STATISTICAL ANALYSES
OF PEARL HARBOR SEDIMENT HEAVY METALS

Stephen V. Smith
Evan C. Evans III

INTRODUCTION

Marine sediments effectively scavenge certain chemicals from seawater and release these materials slowly or not at all unless the water chemistry is drastically altered. As a consequence, marine sediments can be useful long-term cumulative samplers of those chemical parameters. If sediment samples can be interpreted adequately, they should provide considerable insight into present and past environmental quality.

The present analysis was undertaken in order to define the major sources of trace metal input into Pearl Harbor, Oahu. The analysis draws extensively on the sampling program undertaken by the NCEL Environmental Protection Data Base at Pearl Harbor and described by Youngberg (Reference 4.1-1). The data are of high quality analytically, and they contain much useful environmental information. Therefore, these data also prove useful for the detailed illustration of multivariate statistical techniques employed both here and elsewhere in this report.

DATA USED IN THIS ANALYSIS

Youngberg reports the composition of sediments at each of approximately 130 stations throughout Pearl Harbor and its watershed. Ninety-two of these stations were in the harbor itself (Figure 4.1-1); replicate samples from 7 stations were also used, bringing the total variables analyzed to 99. Youngberg's data is used for those harbor stations and for the following nine metals reported in the sediment: Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, and Zn. Also included as a tenth variable is his data for the sum of (Ag + Cu + Cd + Cr + Ni + Pb + Zn)*. Following Youngberg's convention, the somewhat inappropriate term of "total metals" is used for this summation. All of these variables used except Hg are reported for all 99 samples. Sixteen stations lacked data on Hg, so values for these stations were estimated from the variable most highly correlated with it (Cu).

Table 4.1-1 presents the summary statistics for the ten variables. All metals except Fe are present only at trace levels, below 0.1% by weight of Pearl Harbor sediments. For most variables, the standard deviation exceeds the mean, demonstrating a marked tendency for "tails" of high values on the frequency curves for the various metals. That is, there tend to be more very high values than would have been predicted for a normal (or Gaussian) frequency distribution (possible explanation given later). Cr and Fe have the lowest ratio of standard deviation to mean (0.6), demonstrating that they lack such high-value tails.

---

*Youngberg used this summation as inclusive of those heavy metals measured at most stations (thus excluding Hg) and also considered to be environmental hazards (excluding Fe and Mn). It is not clear why the missing data criterion excluded Hg but not Ag. The latter is reported less frequently than is Hg and is therefore excluded from our analyses. Despite this problem, Youngberg's summed metals appear to be a useful variable to include in this analysis.

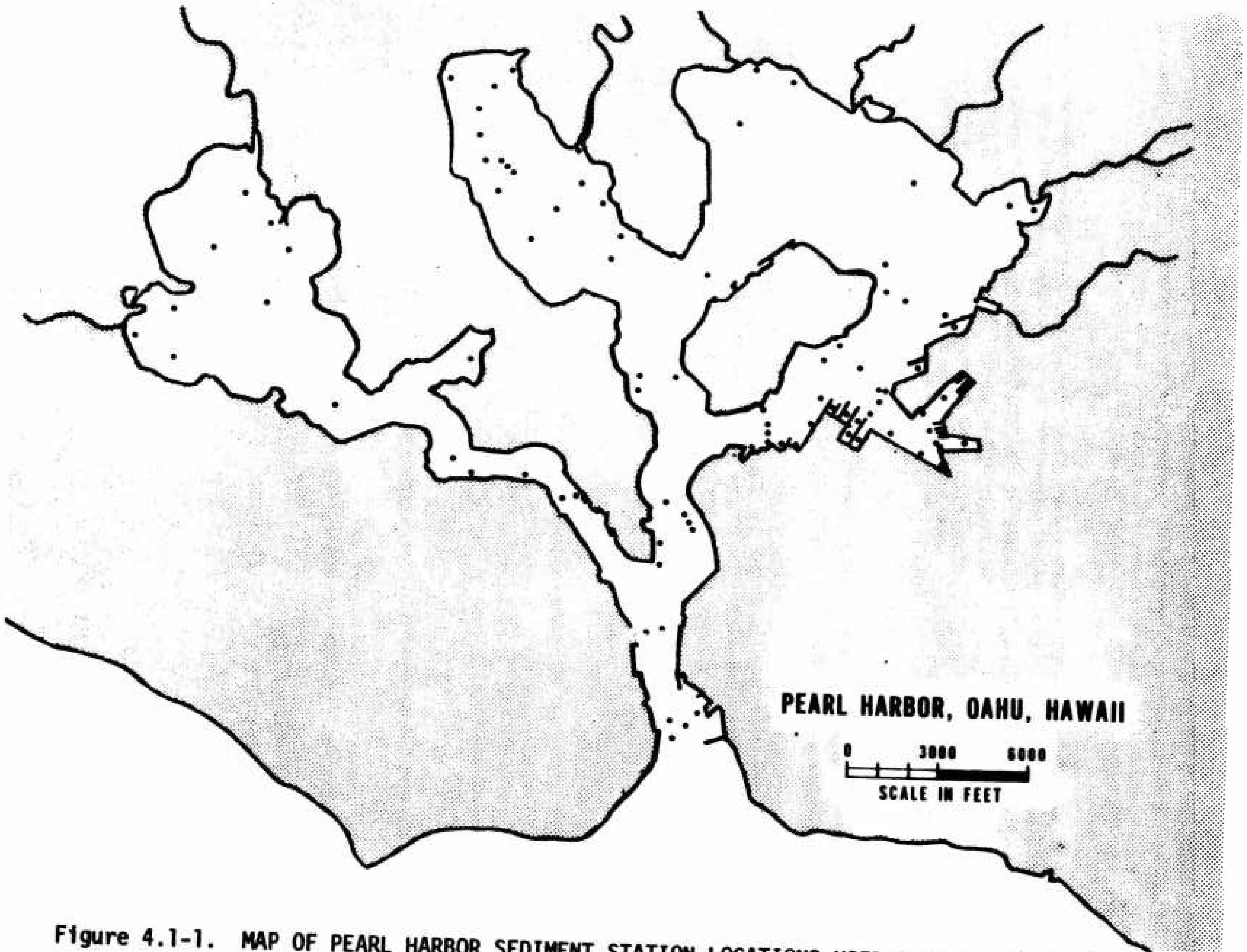


Figure 4.1-1. MAP OF PEARL HARBOR SEDIMENT STATION LOCATIONS USED IN THIS ANALYSIS.

Table 4.1-1. GENERAL STATISTICS ON 10 VARIABLES MEASURED AT 92 STATIONS[2] IN PEARL HARBOR.

UNITS mg/kg (dry weight)

VARIABLE	MEAN	STANDARD DEVIATION	STD. DEV/MEAN
Cd	0.88	1.83	2.1
Cr	101	59	0.6
Cu	156	192	1.2
Fe	33776	20771	0.6
Pb	114	213	1.9
Mn	573	577	1.0
Hg	1.10	1.29	1.2
Ni	125	148	1.2
Zn	250	293	1.2
Σmetals[1]	744	658	0.9

[1] Σmetals = Ag + Cu + Cd + Cr + Ni + Pb + Zn

[2] Hg was measured at 82 stations; values were estimated as discussed in the text at the remaining stations.

Skewed distributions violate a major assumption underlying the probability analysis of almost all multivariate statistics: that the variables have Gaussian frequency distributions. For several reasons the consequences of violating this assumption are not severe. First, probability statements are not a direct concern of the present analysis. Secondly, multivariate techniques such as factor analysis have proven to be robust techniques which are relatively insensitive to this assumption of a Gaussian frequency distribution.

FACTOR ANALYSIS

Factor analysis delineates patterns among the variables listed in Table 4.1-1. Two factors explain 65% (44% + 21%) of the variability in the original 10-variable data matrix. Table 4.1-2 lists the variable communalities and factor loadings. Mn and Cd have low communalities (19 and 39%, respectively); all other variables are 55 to 97% explained by the two factors.

Factor I explains 44% of the variability in the original data matrix. The factor correlates highly with total metals, Cu, Hg, Zn, Pb, and Cd in order of decreasing correlation. It is convenient to name the factor after the total metals. Factor II explains 21% of the variability in the original data matrix. The factor correlates highly with Cr, Fe, and Ni, and moderately with Mn. Both natural occurrence and human usage tend to make these metals occur together; the factor is named after Fe, the most common metallic constituent of Pearl Harbor sediments, and also the major metallic ion for which the other metals loading on Factor II often substitute in silicate minerals.

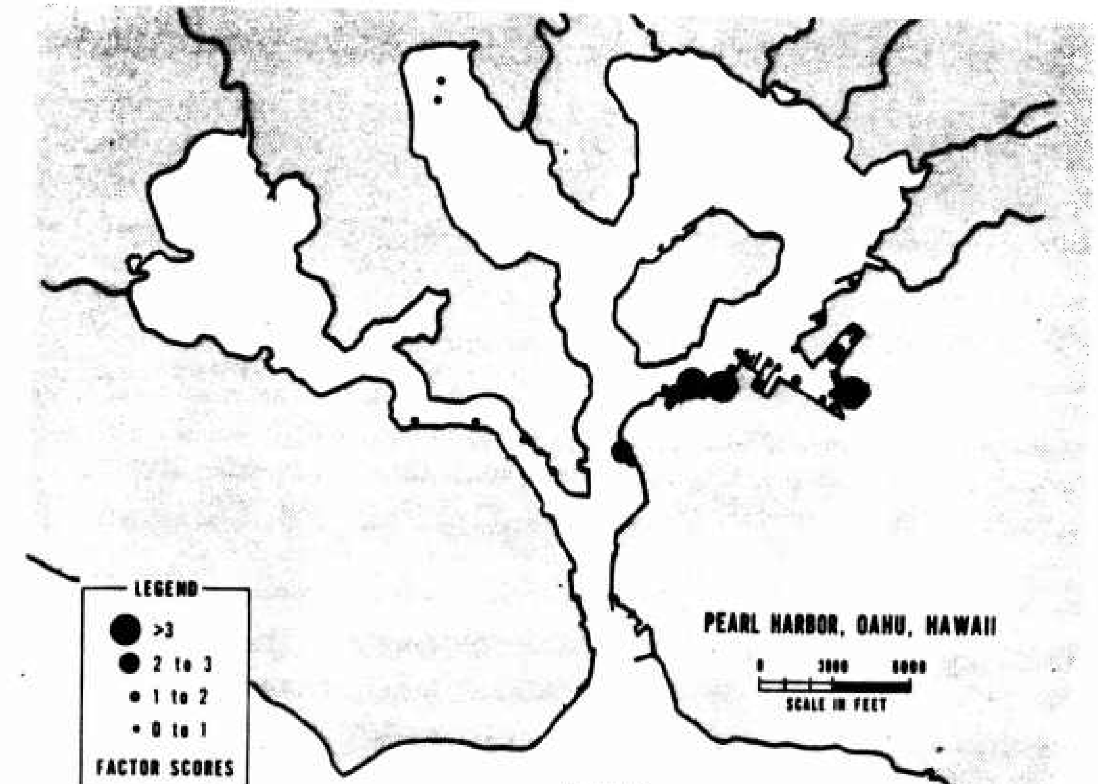
Maps of factor scores (Figure 4.1-2) reveal distinctive and relatively simple geographic distribution patterns for each of the two factors. The maps show those stations scoring above average on each factor, with the dot size being proportional to the score of the factor at each station. High scores on the total metals factor (factor I) occur almost exclusively in the South Channel-Southeast Loch portion of the harbor. These are the primary shipyard areas. Two high values occur together just around the bend from South Channel into the Main Channel, near a powerplant and additional shipyard area. Two slightly above average scores are together in the upper reaches of Middle Loch in the vicinity of the Inactive Ship Maintenance Facility; three low scores are near docks in the lower portion of West Loch.

Scattered above-average scores on the Fe factor (factor II) can be found along the shoreline throughout much of Pearl Harbor, but only three concentrations of high scores are to be found. The upper portion of Middle Loch has both the highest scores and the greatest number of high scores. West Loch also has several above-average scores, including one very high one. Both of these areas may be characterized as being influenced by relatively large stream outflows. Several high scores also occur in the shipyard area of Southeast Loch.

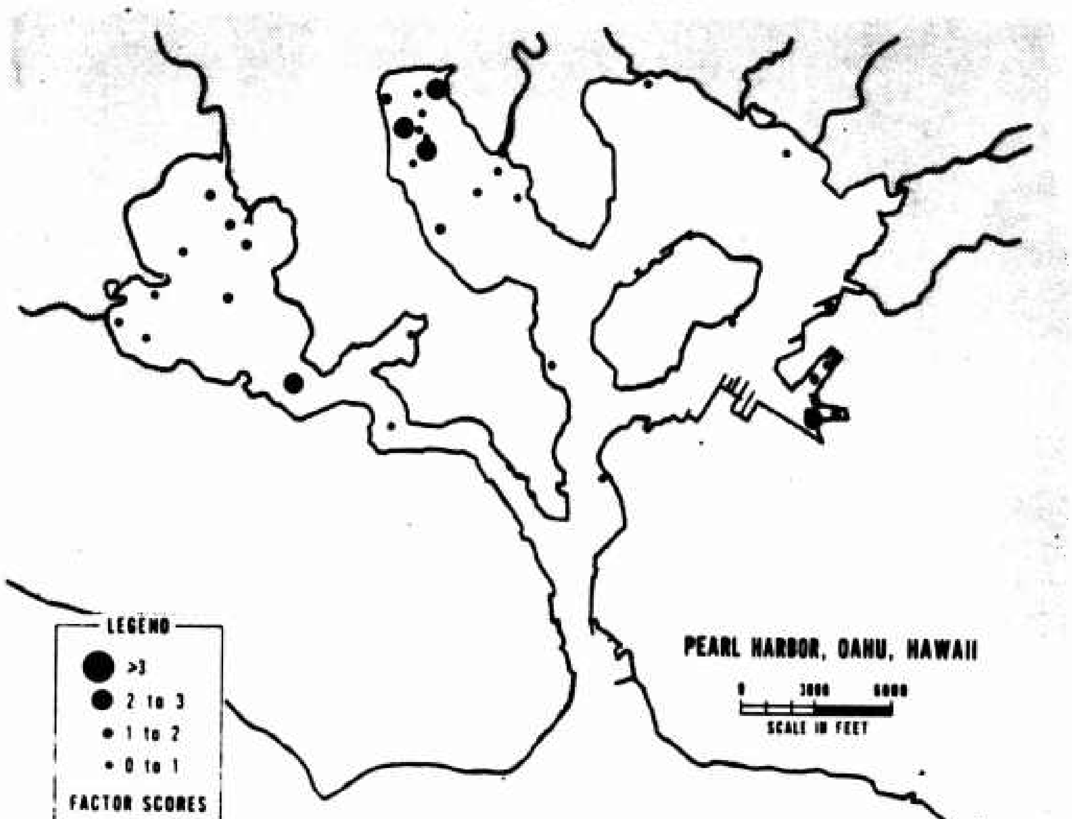
Figure 4.1-3 is a scatter diagram of factor I versus factor II scores. The scores show an interesting pattern relative to the four quadrants of the graph. Almost half of the stations score below average (that is, below 0) on both factors. Slightly less than a third of the stations are below average with respect to factor I and above average on factor II. About one

Table 4.1-2. MATRIX OF ROTATED FACTOR LOADINGS, PEARL HARBOR SEDIMENT METAL DATA.

		FACTOR I	FACTOR II
Percent of variation explained		44	21
VARIABLE	COMMUNALITY %		
Cd	39	0.62	-0.04
Cr	79	0.18	0.87
Cu	87	0.93	0.04
Fe	57	0.10	0.75
Pb	71	0.84	0.01
Mn	19	-0.10	0.42
Hg	78	0.88	-0.03
Ni	55	0.01	0.74
Zn	74	0.86	0.00
Σ metals	97	0.95	0.25



FACTOR I
Total Metals



FACTOR II
Fe Associates

Figure 4.1-2. MAPS OF PEARL HARBOR SEDIMENT METAL FACTOR SCORES. FACTOR I IS CALLED THE "TOTAL METALS" FACTOR AND FACTOR II, THE "Fe ASSOCIATES" FACTOR.

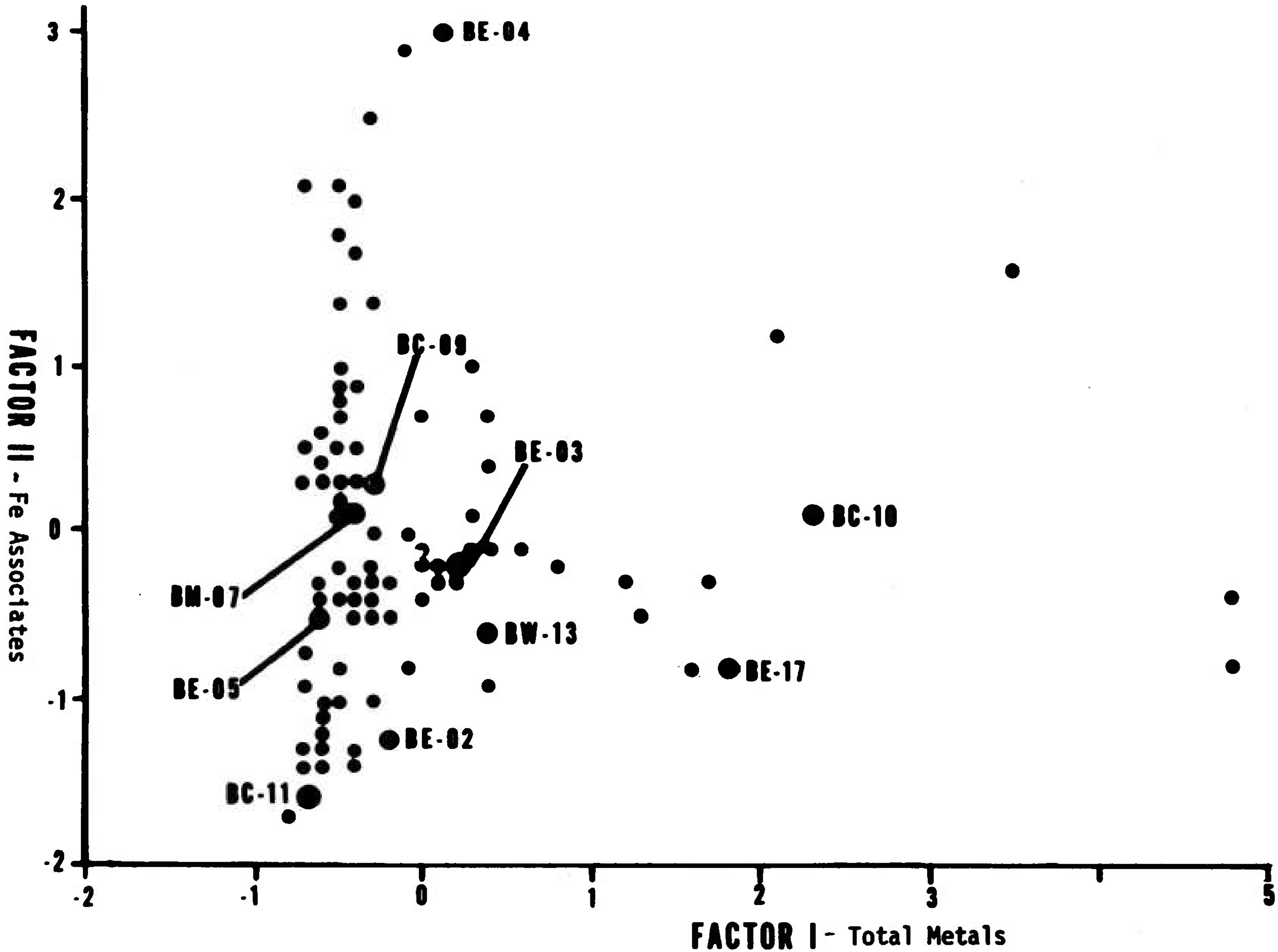


Figure 4.1-3. SCATTER DIAGRAM OF FACTOR I SCORES VERSUS FACTOR II SCORES. THE NUMBERED SYMBOLS REFER TO PEARL HARBOR BIO-STATIONS.

sixth of the stations are below average on factor II and above average on factor I. Very few stations are above average on both factors, but about half are above average on at least one of the two factors.

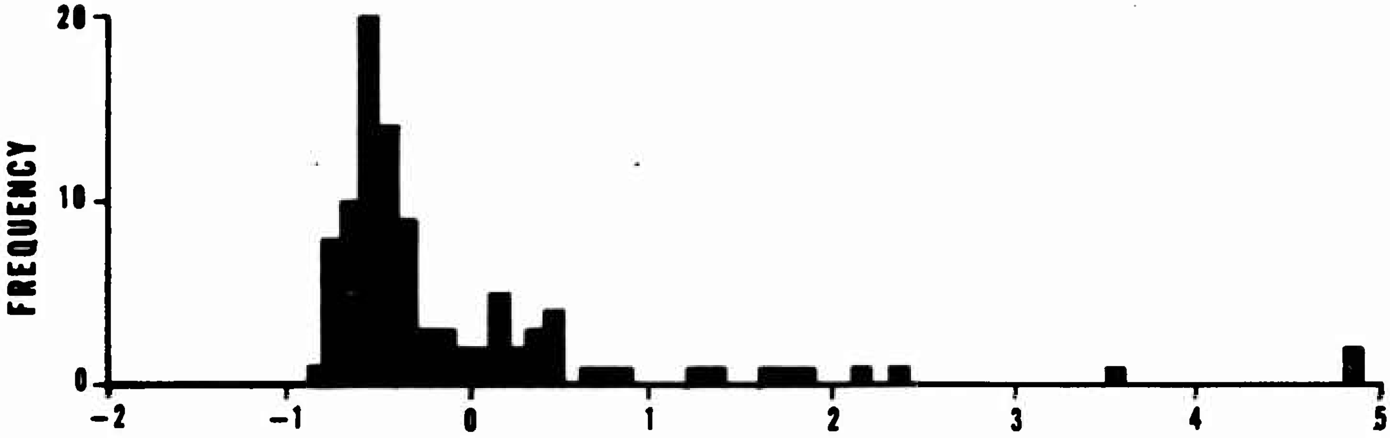
Frequency histograms for the two sets of factor scores are shown in Figure 4.1-4. The total metals scores are tightly clustered about a mode 0.6 standard deviation units below the mean. No scores fall more than 0.3 standard deviation units below this mode, but a positive "tail" of high scores stretches over 5 standard deviation units above the mode. By contrast, the Fe factor shows a much weaker mode (about 0.4 standard deviation units below the mean) and a somewhat more symmetrical distribution about that mode (possible explanation given later).

DISTANCE--CLUSTER ANALYSIS

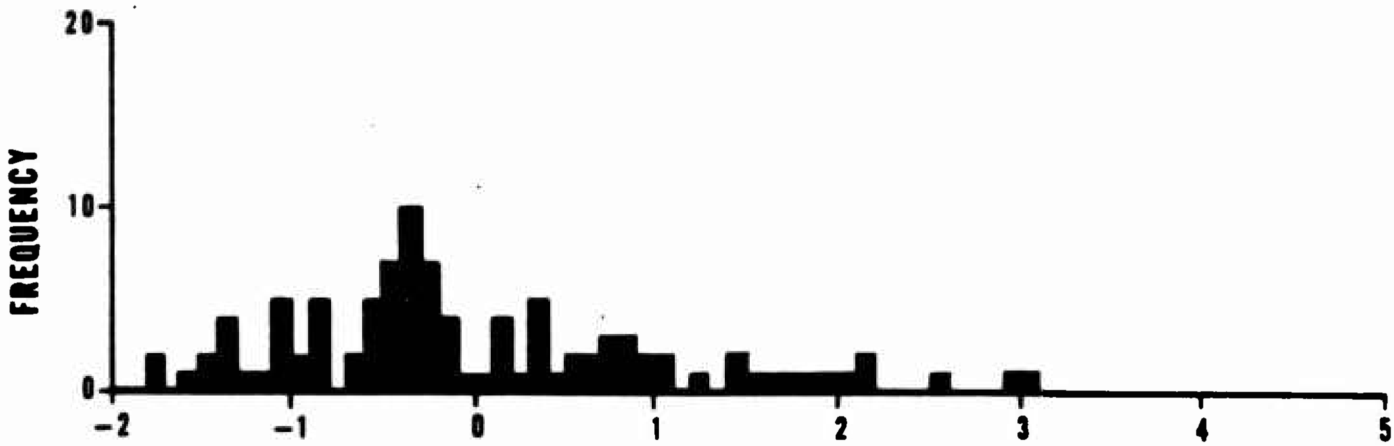
Distance analysis of the data may be approached in several ways. Each of the two approaches presented here makes use of the factor scores as objective summaries of the original data. Such summary data have at least three distinctive advantages over the original data. The factor scores represent the major overall characteristics of the original data while reducing the apparent complexity of the data matrix--in this study, from an unwieldy 10 variables to only 2 factors. The information retained represents 65% of the information present in the original data; the "lost" 35% may be regarded as the inevitable "noise" to be found in any complex environmental data matrix. Much of this so-called noise would undoubtedly be meaningful if only we knew enough about the system to interpret it. In the meantime, such noise serves primarily to obscure the quantitatively more important characteristics of the data matrix. Finally, the factor score summary eliminates redundancy. Separate interpretation of Cu, Hg, Zn, Pb, and Cd, all of which have very comparable patterns of variation, probably originating from comparable environmental controls, is not necessary.

First, consider a relatively simple form of distance analysis. Obviously, that station with the lowest score on both of the two factors has the lowest heavy metal burden. Station BC-11 falls very near that station with the lowest score on both of the two factors (see the labelled PHBS bio-stations plotted on Figure 4.1-3). The distance from that station to each other station can either be measured off the diagram or calculated from the station scores using the Pythagorean Theorem (see section 4.0, equation 4). Figure 4.1-5 is a map of Pearl Harbor showing the factor-score distance from BC-11 to each other station as proportional to dot size. Stations with factor scores near BC-11 (small dots) are prevalent near the mouth of the harbor. The three areas with factor scores most distant from the BC-11 scores (large dots) are in the South Channel-Southwest Loch region, in upper Middle Loch, and in upper West Loch.

Table 4.1-3 contains the results of eleven different techniques for rating the environmental quality of the Pearl Harbor bio-stations. For each technique, low numerical ratings represent good environmental quality while high numerical ratings indicate poor quality. Rating A represents the sediment metal factor score distance from bio-station BC-11 discussed earlier. Ratings B and C are both intuitive assessments based on the



FACTOR I - Total Metals



FACTOR II - Fe Associates

Figure 4.1-4. FREQUENCY HISTOGRAMS OF FACTOR I AND FACTOR II SCORES.

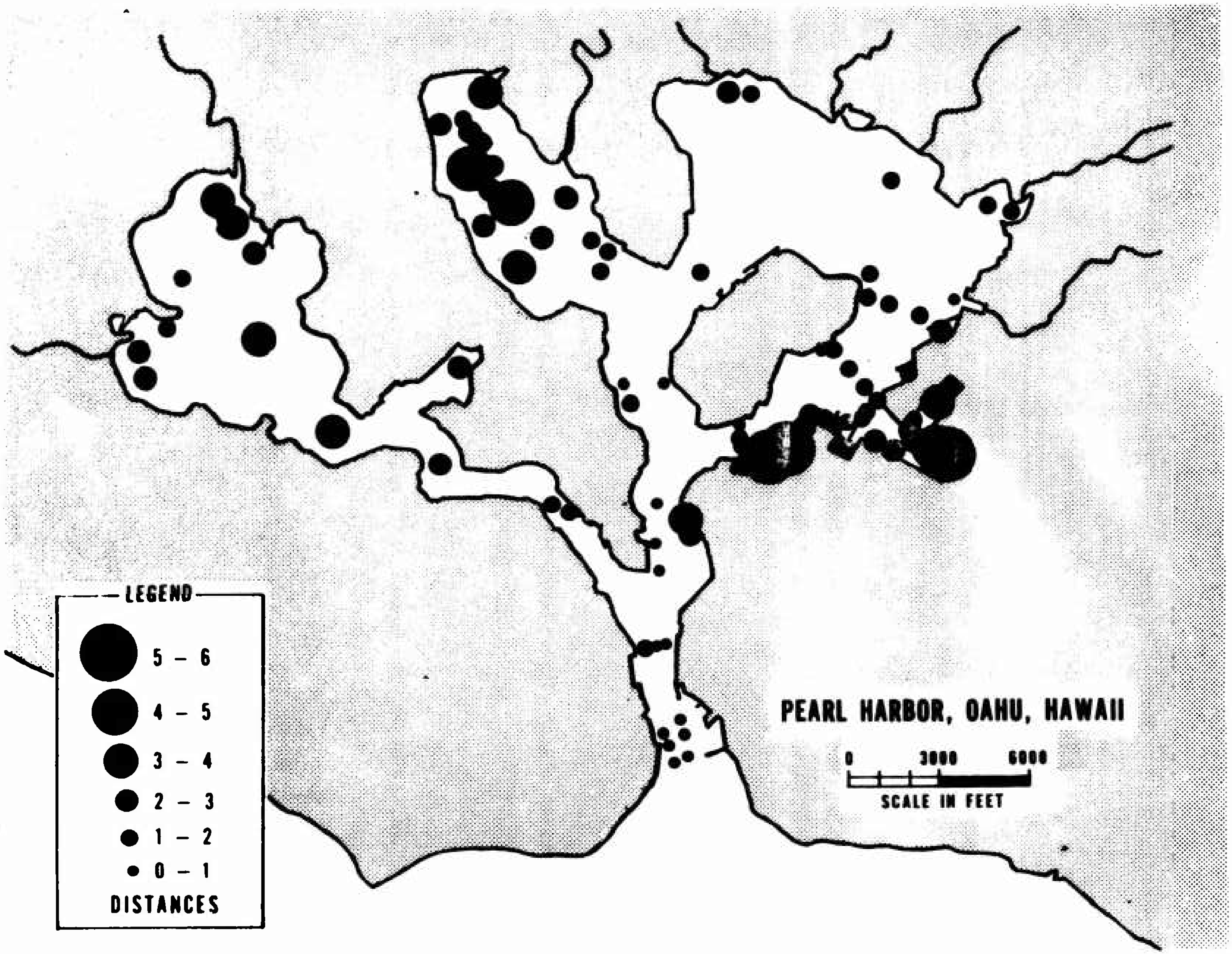


Figure 4.1-5. DISTANCES IN A TWO-DIMENSIONAL FACTOR SPACE BETWEEN BC-11 AND EACH OTHER STATION.

Table 4.1-3. VARIOUS ENVIRONMENTAL RATINGS ESTABLISHED FOR PHBS BIO-STATIONS, AS DISCUSSED IN TEXT.

	RATING TECHNIQUE										
	A	B	C	D	E	F	G	H	I	J	K
PHBS BIO-STATION	Sediment metals factor score distance from BC-11	Intuitive rank level on benthos	Intuitive rank level on fishes	$\frac{30}{\text{number of species}}$	$\frac{\text{weighted env. pref.}}{\text{number of species}}$	Domestic sewage	Industrial effluent	Oil	Silt	Oil-silt distance from BC-11	Oil-silt-industrial effluent dis. from BC-11
BE-02	0.6	7	4	1.6	2.2	1	1	2	2	1.4	1.7
BE-03	1.7	6	6	1.9	2.6	0	2	3	2	2.2	3.0
BE-04	4.7	10	10	5.0	9.3	2	2	4	3	3.6	4.1
BE-05	1.1	3	2	2.3	3.8	2	0	2	3	2.2	2.2
BM-07	1.7	5	7	1.8	3.2	3	0	1	2	1.0	1.0
BC-09	1.9	2	3	1.8	2.7	0	0	1	3	2.0	2.0
BC-10	3.4	8	8	1.6	1.9	0	2	4	1	3.0	3.6
BC-11	0.0	1	1	1.1	0.8	5	0	1	1	0.0	0.0
BW-13	1.0	4	5	1.4	2.0	0	1	1	3	2.0	2.2
BE-17	2.6	9	9	3.0	4.9	3	5	3	4	3.6	6.1
CORRELATION WITH RATING TECHNIQUE A		0.76	0.85	0.79	0.77	-0.22	0.50	0.79	0.25	0.83	0.71

observations of an experienced biologist in the field. Rating B is based primarily on the condition of the benthic community which is logically assumed to be most strongly influenced by sediment characteristics. Rating C is the overall bio-station rating previously given with the bio-station descriptions; this rating is strongly influenced by fish populations. Ratings D and E are both mathematically defined ratings based on fish observations; D is based on number of fish species present (formerly reported as Rating R in Reference 4.1-2), while E is based on species presence and on estimated species preference for particular environments (formerly reported as Rating B in Reference 4.1-3). Ratings F through I are proximate field estimates of degree of specific insult for: domestic sewage, industrial effluent, oil, and silt respectively. Ratings J and K are again distances from bio-station BC-11 calculated in the same manner as the factor score distances (Rating A). In 2-dimensional space, rating J is the oil-silt distance from BC-11. In 3-dimensional space, rating K is the oil-silt-industrial distance from BC-11.

Correlation coefficients between Rating A and each of the other ratings are given in the bottom row in Table 4.1-3. Figure 4.1-6 is a scatter diagram of these other ratings plotted against Rating A. Domestic sewage (Rating F) shows a low negative correlation with the heavy metal factor scores, while the remainder of the ratings correlate positively. Only industrial effluent (Rating G) and silt (Rating I) show correlation below +0.7. Thus, most of the environmental quality ratings in Pearl Harbor (based both on the biota and specific sources of insult) appear to be related to the heavy metal composition of the sediments.

The data also suggest that oil and the combination oil-and-silt appear to be most closely correlated with heavy metals in the sediment, and thus may be indicating some as yet unknown casual relationship. Oil (Rating H) correlates at +0.79 with heavy metals (Rating A). The oil-silt combination (Rating J) increases this correlation to +0.83, but the oil-silt-industrial combination (Rating K) decreases it to +0.71. Other possible 2-dimensional distances, such as oil-industrial or silt-industrial (not presented), show relatively low correlations with heavy metals, a fact that further bolsters the hypothesized relationship between oil and heavy metal content of the sediments.

The dendrograph presented in Figure 4.1-7 results from a more complex form of distance analysis. Rather than merely relating the distances of all stations to a single reference station, the dendrograph is designed to elucidate clusters of stations which are nearer to one another than they are to other clusters. Five station clusters on the dendrograph have been identified (labelled A through E), as well as three singular stations (numbered 1 through 3), and one station pair (numbered 4).

Figure 4.1-7 also shows a map of each cluster, and Figure 4.1-8 locates the clusters on a scatter diagram of factor scores. The ellipses of Figure 4.1-8 enclose each mean cluster position at a distance of two standard deviation units. Clusters D, A, B, and E lie along a gradient of increasing Factor II (Fe associates factor) scores with little variation in Factor I (total metals factor). All clusters except A are elongate

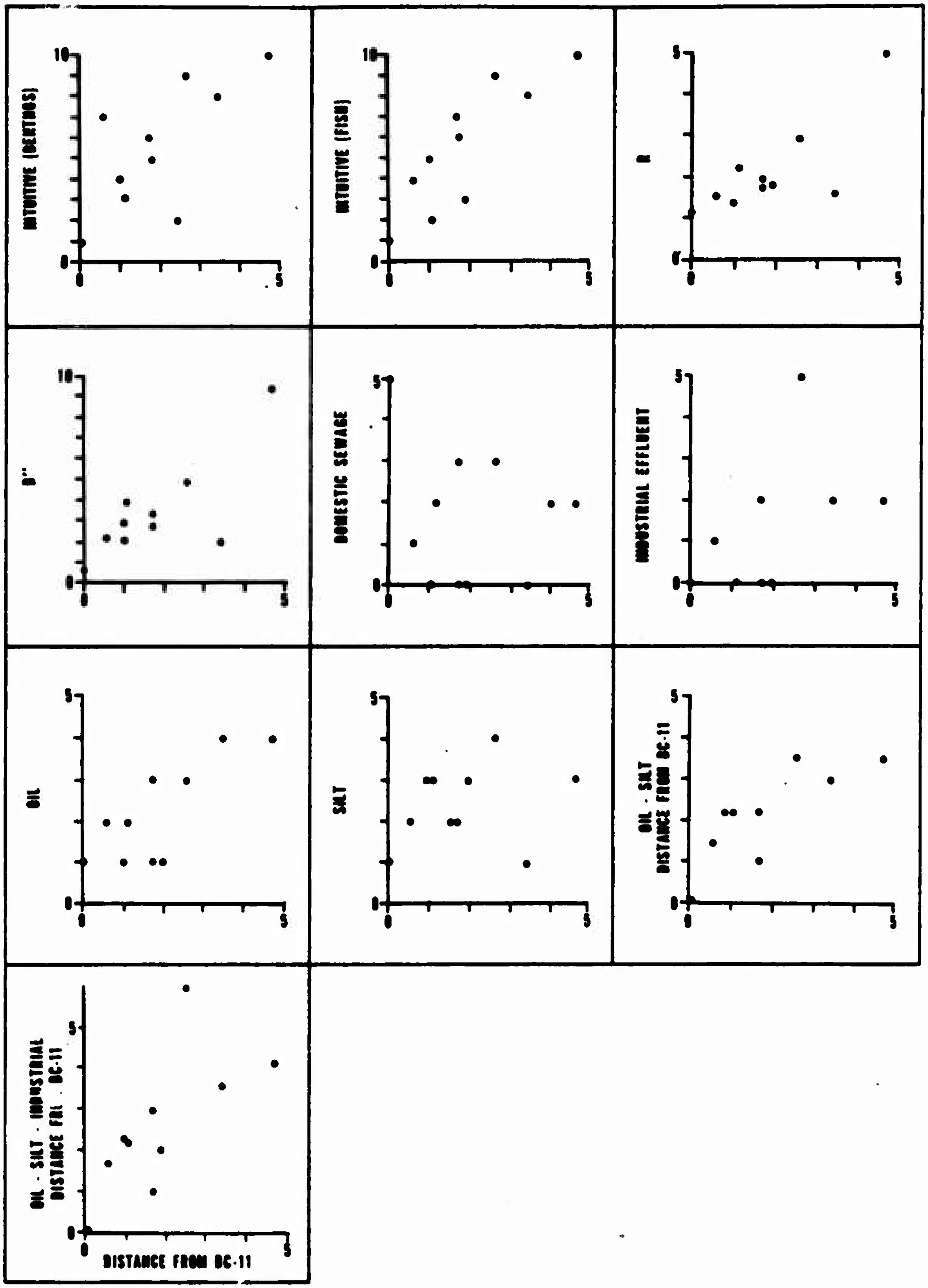


Figure 4.1-6. SCATTER DIAGRAMS OF TWO-DIMENSIONAL FACTOR SCORE DISTANCES OF EACH BIO-STATION FROM BC-11 VERSUS VARIOUS ENVIRONMENTAL RATINGS FOR THOSE STATIONS.

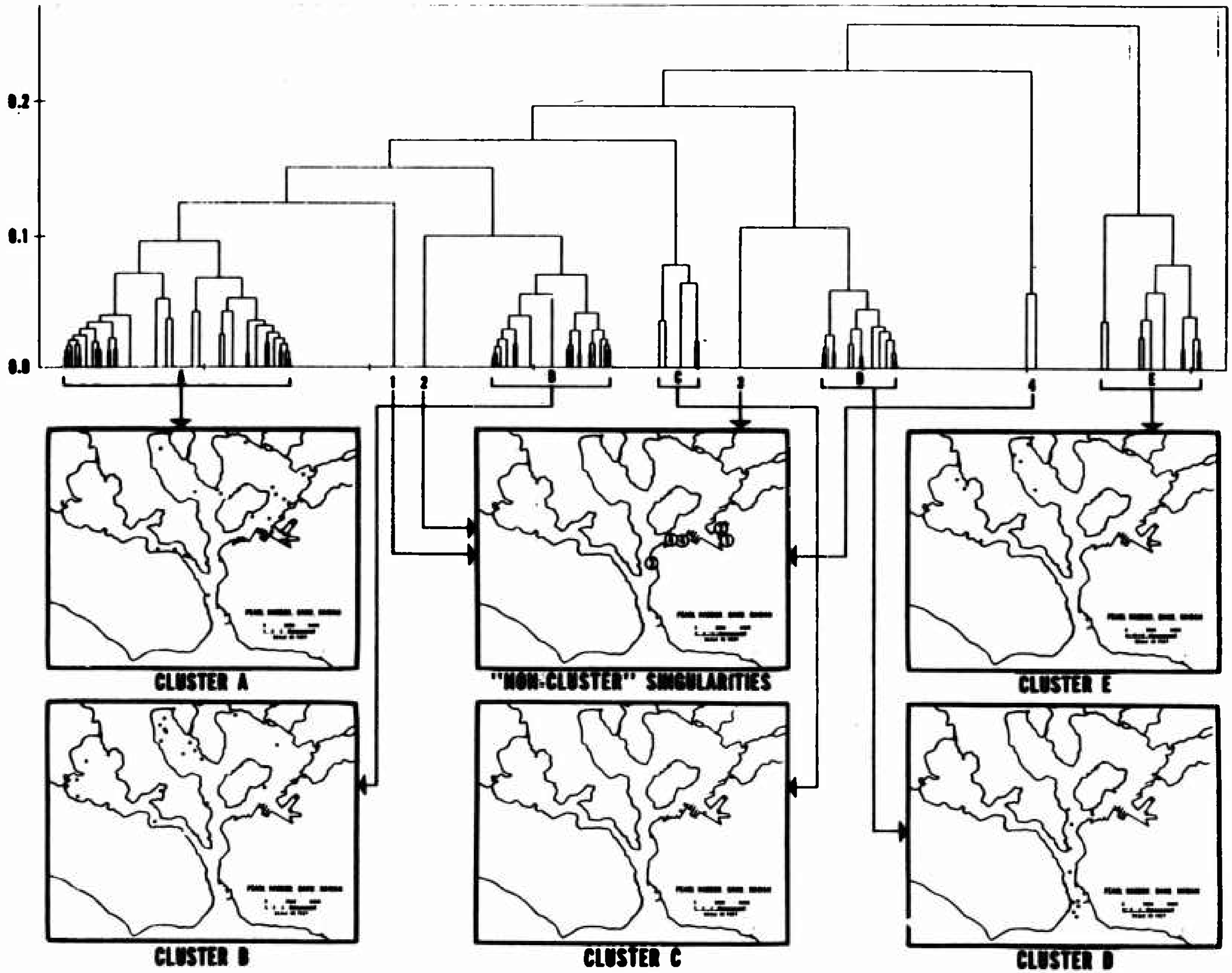


Figure 4.1-7. DENDROGRAPH OF DISTANCES BETWEEN TWO-DIMENSIONAL FACTOR SCORES. NOTE THE FIVE MULTI-STATION CLUSTERS (A-E), THREE SINGULAR STATIONS (1-3), AND ONE STATION-PAIR (4).

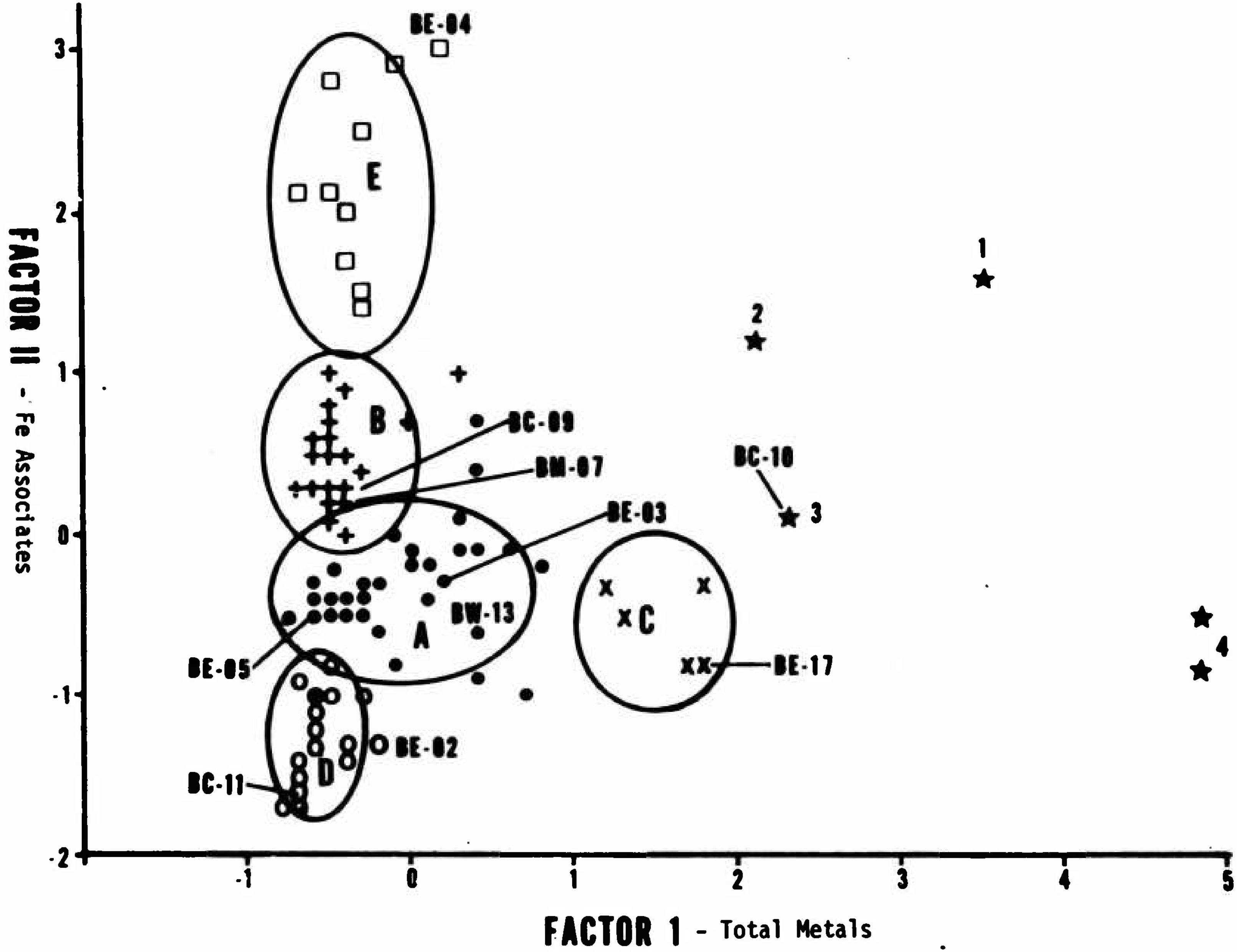


Figure 4.1-8. SCATTER DIAGRAM OF FACTOR SCORES, SHOWING MEAN CLUSTER POSITIONS ± 2 STANDARD DEVIATION UNITS.

along the Factor II axis. For the most part, the stations score slightly below average (0) on Factor II. From the maps in Figure 4.1-8, it can be seen that the cluster series D→A→B→E represents a geographic gradient from the outer portions of the harbor to the upper reaches of West and Middle Lochs. Cluster A, the only one which is elongate parallel to the Factor I axis, represents the intersection of this cluster series with a second series. This second series consists of clusters A and C, singularity number 3, and station pair number 4 (Figure 4.1-8). From Figure 4.1-7 it can be seen that this second series represents a progressive geographic restriction from the harbor in general to the South Channel region. Only two of the 99 stations remain outside these two cluster series. These two stations both score high on both factors, and both are in Southeast Loch.

ENVIRONMENTAL INTERPRETATION OF THE HEAVY METAL MULTIVARIATE ANALYSES

The analyses which have been presented are consistent with the following general interpretation of Pearl Harbor heavy metal burdens. Factor I represents the effect of industrial activity in the harbor, and Factor II is related to terrestrial inputs of materials. Figures 4.1-7 and 4.1-8 both demonstrate that the total metal factor becomes more dominant in samples progressively nearer to the shipyard, a site of heavy industrial activity. All of the metals loading heavily on Factor I (Table 4.1-2) have one or more common industrial uses. On the other hand, West and Middle Lochs are areas of high runoff, and Factor II becomes dominant in those areas (Figures 4.1-2 and 4.1-7). Since the metals loading heavily on that factor (Table 4.1-2) can be derived from soils in the Pearl Harbor watershed or from agricultural activity there, the factor is most easily interpreted as a terrestrial influence factor. Mn is a metal of obvious potential derivation from land, and this material loads only moderately on the factor (Table 4.1-4). This slight discrepancy suggests that there may actually be two distinct terrestrial influences which are not quite separated by the analyses. Note, however, that all metals found in the Pearl Harbor sediments which are significantly above world averages (cf. Tables 4.1-2 and 4.1-4) load heavily on Factor I, the "industrial factor". As observed earlier, these same metals also show a pronounced positive "tail" in the histogram of factor scores (Figure 4.1-4) while metals loading on Factor II, the "terrestrial factor", do not. This difference may be due to the fact that the industrial factor is composed of "ecologically strange" metals which are added randomly to an environment which normally contains trace amounts of these metals. Metals loading on Factor II are normally found in the environment, thus any random additions tend to be masked by natural variations.

The fact that the environmental ratings given in Table 4.1-3 identify oil and silt as important environmental insults which are further related to heavy-metal scores is consistent with the interpretation of a terrestrial factor (Factor II) and a shipyard factor (Factor I). Oil may be primarily an indicator of shipyard activity or, more interestingly, it may actually contribute to the heavy-metal content of the sediments. The data necessary to resolve such questions are not available at the time of writing.

Table 4.1-4. COMPARISON OF METALLIC COMPOSITION OF PEARL HARBOR SEDIMENTS AND WATERSHED SOILS (NCEL/YOUNGBERG) WITH WORLD SOIL COMPOSITION (BOWEN*). (ALL VALUES IN ppm (mg/kg) of OVEN-DRIED MATERIAL)

	Pearl Harbor (NCEL)						World Soils (Bowen)		
	Sediments			Watershed Soils					
	Average**	Low	High	Average	Low	High	Average	Low	High
Cadmium	1.2	ND	11	0.5	ND	0.46	0.06	0.01	0.7
Chromium	10.	9	360	63	4.4	170	100	5	3000
Copper	157	8	1200	55	4.2	140	20	2	100
Iron	33651	13	93000	41455	19000	71000	38000	7000	550000
Lead	115	ND	1700	12	ND	30	10	2	200
Manganese	575	ND	4800	1068	39	4000	850	100	4000
Mercury	1.1	0.07	9.5	0.74	ND	5.1	0.03	0.01	0.3
Nickel	126	4	930	144	7.9	860	40	10	1000
Silver	3.6	ND	21	1.3	ND	8.4	0.1	0.01	5
Zinc	251	16	1900	81	9.9	380	50	10	300
Σ Metals†	747	26	3777	350	67	1450	220	29	4600

* Bowen, Trace Metals in Biochemistry (1966), pp 39-40

** With one exception, the values given by Youngberg vary slightly from those given in Table 1 which were averaged from NCEL field data in the Univ. of Hawaii Computer Center. The NCEL value for chromium appears to be low by a factor of 10 on the basis of data given in Appendix B of their report.

† Σ Metals = sum of Ag, Cu, Cd, Cr, Ni, Pb, & Zn. In Bowen's table Ag & Cd contribute negligible amounts to this total.

The association of silt with elevated heavy-metal content in the sediments may represent an interaction of industrial effluents with terrigenous material only or it may result primarily from the scavenging of bottom sediments stirred up by ship activity or it may result from a combination of both.

For the most part, it appears that only one of these two factors comes strongly into play at a time (Figure 4.1-3). It is reasonable to suppose that industrial sites have been chosen away from areas with high risk of flooding. The few areas in Southeast Loch with high scores on both factors are probably not exceptions to this interpretation; rather, they probably mark areas where industrial activity has unduly altered the Factor II metals.

Shipyard areas may play two quite separate roles in imposing the heavy metal insult on sediments. Certainly, the supply of the metals themselves is an obvious and necessary role. As pointed out elsewhere in this report, the movement of large ships effectively stirs sediments up into the water column and thus makes surfaces abundantly available for reaction with the metals. Unfortunately the data are not sufficient to decide if this stirring makes the sediments more effective in their total scavenging of metals or if the same total load of metals is merely dispersed through a greater sediment mass as a result of this stirring.

The observed relationship between biological assessment of environmental insult and heavy metal burdens cannot be taken as more than circumstantial evidence that these metals are deleterious to the biota. Rather, the metals could be no more than indicators of environmental status actually caused by some other parameter(s) coincident with the heavy metal burden. It is instructive, however, to compare the metal content of Pearl Harbor sediments with EPA guidelines for acceptable metal levels in marine spoils (Reference 4.1-4). The factor loadings provide a useful way to present this comparison in a summary form.

Rearrangement of equation (3), Section 4.0, allows solution for the score (S) which coincides with the EPA upper acceptable levels (X). In solving the equation for the guideline scores, only the single factor which is most strongly related to the variable is considered; that is, equation (3) is reduced to the simple linear regression equation:

$$X = \mu + (\alpha\sigma)S \qquad (3a)$$

By rearrangement

$$S = \frac{X - \mu}{\alpha\ \sigma} \qquad (4)$$

The EPA guideline values for the X's in equation (4) are inserted and the maximum factor scores which are compatible with those guidelines are calculated. Table 4.1-5 summarizes the results of those calculations. Three of the variables in the list are not directly subject to EPA

Table 4.1-5. CALCULATED FACTOR SCORES COMPATIBLE WITH EPA GUIDELINES FOR THE OBSERVED HEAVY METAL LOADINGS.

VARIABLE	MEAN mg/kg	STD. DEV. mg/kg	MAJOR LOADING (factor)	STD. DEV. times LOADING	EPA GUIDE mg/kg	COMPATIBLE SCORE
Cd	0.88	1.83	.62(I)	1.13	2	1.0
Cr	101	59	.87(II)	51	100	0.0
Cu	156	192	.93(I)	179	100	-0.6
Fe	33776	20771	.75(II)	15778	---	---
Pb	114	213	.84(I)	179	50	-0.4
Mn	573	577	.42(II)	242	---	---
Hg	1.10	1.29	.88(I)	1.14	0.5	-0.5
Ni	125	148	.74(II)	110	50	-0.7
Zn	250	293	.86(I)	252	75	-0.7
metals	744	658	.95(I)	625	---	---

guidelines (Fe, Mn, Σ metals). The first two are not considered environmental hazards, while the third variable is subject to the guidelines in its constituent parts. These three variables are excluded from further consideration.

The compatible scores (last column in Table 4.1-5) may be compared with the appropriate factor-score histogram for Factors I or II (see Figure 4.1-4). Since these are histograms of standard scores, the average Pearl Harbor station scores zero. For Cd, the average station is one standard deviation unit below EPA's guideline level (compatible score = +1.0), so that metal is apparently a comparatively minor problem in the harbor. Cr is at the guideline level. The average Pearl Harbor station exceeds EPA guideline levels for Cu, Pb, Hg, Ni, and Zn by about half a standard deviation unit. In fact, comparison of Figure 4.1-4 with Table 4.1-5 suggests that the modal values for Pearl Harbor stations lie very near this guideline. All of these metals except Ni are Factor I metals; hence, shipyards and other industrial activities are apparently responsible for the major excesses of hazardous metals in the harbor.

It would appear that two major factors contribute most of the heavy metal burden to sediments of Pearl Harbor: (a) industrial activity and (b) terrestrial input. The industrial activity is apparently by far the more serious of the two. The sediment heavy metal data may not unequivocally implicate industrial activity in the deterioration of environmental conditions in the harbor, but these data strongly suggest that hypothesis to be true. Not only does the heavy metal insult correlate strongly with biological assessment of insult, but also the heavy metal content of the sediments significantly exceeds levels which have been judged elsewhere to be maximum tolerable levels. Few locations in the harbor completely escape this insult, but the most serious insult seems to remain near its points of origin--primarily the naval shipyard.

It is important to note that stream outflows, whether polluted or not, also represent an environmentally significant perturbation roughly equivalent in magnitude but different in kind to that of a shipyard. Not only do streams transport terrigenous material which modifies the physicochemical environment about their outfalls, but also to strictly marine organisms, the fresh water itself is an important environmental insult, possibly equivalent to that of a shipyard. Multivariate statistical analysis has resolved a stream factor and an industrial factor from the confusion of the raw field data. Furthermore the total metals factor, Factor I, suggests efficient ways of identifying environmental insults specifically associated with shipyard or industrial activities.

REFERENCES

4.1-1. Alv Dan Youngberg (1973), "A Study of Sediments & Soil Samples From Pearl Harbor Area, Navy Environmental Protection Data Base", NCEL publ., M.P.A. 6.2.1.2.

4.1-2. Evan C. Evans III (1972), "Surveillance, Sewage, & Surprises", pp 59-76 in Navy Action '72, Environmental Conference on Monitoring and Surveillance of Pollution, Naval Facilities Engineering Command, San Francisco.

4.1-3. Thomas J. Peeling, J. Geoffrey Grovhoug & Evan C. Evans III (1972), "Pearl Harbor Biological Survey - Summary Report for First Survey Cycle", NUC TN-801.

4.1-4. Environmental Protection Agency (1972), "Proposed Guidelines for Determining Acceptability of Dredged Spoils to Marine Waters", preliminary draft compiled by Region IX, San Francisco.

STATISTICAL ANALYSIS

OF WATER QUALITY

Stephen V. Smith
Evan C. Evans III

INTRODUCTION

Water quality in an estuary such as Pearl Harbor represents the complex interaction of numerous processes. There are at least three distinct biological reasons for concern with water quality. The biota may be directly responsive to particular aspects of water quality. Secondly, the biota may be responsive to those processes which control the water quality. Finally, the biota may themselves alter the water quality.

The primary processes which alter the water quality in an estuary include the introduction of materials from the land via any one of several means (stream runoff, domestic sewage inflow, surface runoff, introduction of industrial wastes, groundwater seepage, etc.); patterns of water movement in the estuary from tides, winds, and other forces; exchange of materials across the air-sea and sediment-sea interfaces; and biological activity. It is obvious that interpretation of water quality is best effected by adequate time-series and space-series information. Given such information, one may be able to quantify many of the processes which control water quality.

There is a spatially and temporally extensive set of water quality data for Pearl Harbor (Reference 4.2-1). The purpose of the presentation here is to extract, summarize, and interpret environmentally relevant information from that report.

DATA USED IN THIS ANALYSIS

It is useful to contrast the water quality data with the previously discussed sediment heavy metal data. The metallic content of sediments represents a cumulative record of silts and their exchange burden supplied to the harbor by rivers and runoff, and serially incorporated into the sedimentary column. There is little reason to suspect that repeated sampling of the sediments accumulating throughout much of the harbor would show significant patterns of fluctuating composition. By contrast, water quality does fluctuate in response to many temporally varying processes. Perhaps the most obvious such process is that of tidal ebb and flow.

Ideal data control at a station would involve some sampling design in phase with either time of day or tidal state, together with one or more detailed sampling series over a complete diel cycle. As discussed by Morris et al (Reference 4.2-2, page 26), the actual sampling schedule in Pearl Harbor differed dramatically from that ideal:

> "Early in the sampling program the cruises were conducted at the same tidal slack, but because of the movement of high and low tides to non-working hours, every four to five days, this method was abandoned. An attempt was then made to sample the same station at the same time of each sampling day but this also proved to be trying because of weather and the constraint it put on other sampling programs. Finally, a random-type sampling program was developed which appeared compatible with both scheduling and laboratory capability."

Such a sampling design has demanded the adoption of analytical strategies other than direct time-series analysis. Each measurement used in this report was made at each sampling station several times. It is assumed that the mean value as well as the extremes for each parameter at each station are adequately represented in the data which have been collected. The most obvious flaw in this assumption is the absence of nighttime data, but all stations are equally subject to that particular bias. Three separate sets of analyses have been attempted on the water quality data. The first is an analysis of mean values encountered at each sampling station. The second is an analysis of minima and maxima encountered at each station (termed minimax). Observed variations in water properties suggest a third analysis to be environmentally relevant, namely an analysis of functional extremes. For a particular water property, all stations may tend toward a similar mean value, which may lie near one of the two extremes for that property. The opposite extreme for the same property will tend to vary more among the stations. For example, the mean water temperature of all the stations reported here is about 25.7°C, close to the range of lower temperatures which varies between 22 and 24° for all stations. By contrast, the upper temperatures recorded at the various stations range from 28 to 40°C (see Figure 4.2-1). A second consideration is that variations towards one extreme frequently seem more likely to be damaging than variations towards the other extreme. Usually (including the temperature example just presented) each of the above considerations suggests the same "functional extreme" for the variable in question. Consequently, functional extremes for each of the variables employed have been picked, and those data have been analyzed.

There are some minor discrepancies between the data used in this report (Reference 4.2-1), and those reported by Morris et al (Reference 4.2-2). Although both data bases are built from the same field data, the water quality data used in this analysis was extracted directly from the original field data sheets prior to the publication of the Morris report, which was received after the present analysis had been completed. The differences between the two data bases probably represent only different editing decisions. The huge array of original data precludes item-by-item matching of the two data matrices; however, it may be assumed that the process of multivariate analysis itself will smooth most of the differences.

The original NCEL water quality survey of Pearl Harbor included approximately 35 variables, only a few of which were measured repeatedly at all of the approximately 120 sampling stations. The statistical analyses here used 15 variables at 37 stations including or adjacent to the NUC biostations. The sampling stations used are summarized in Figure 4.2-2, and the statistics of the variables used are given in Table 4.2-1 and Figure 4.2-1. The present analyses used matrices of means, minima, and maxima for 15 variables at 37 stations - a total of 1665 pieces of information. Over 10,000 entries went into the construction of those matrices. Data from the remaining 83 stations have not been used at all. Hence, the analyses reported here used approximately 10% of the total NCEL observations available for a description of the water quality of Pearl Harbor.

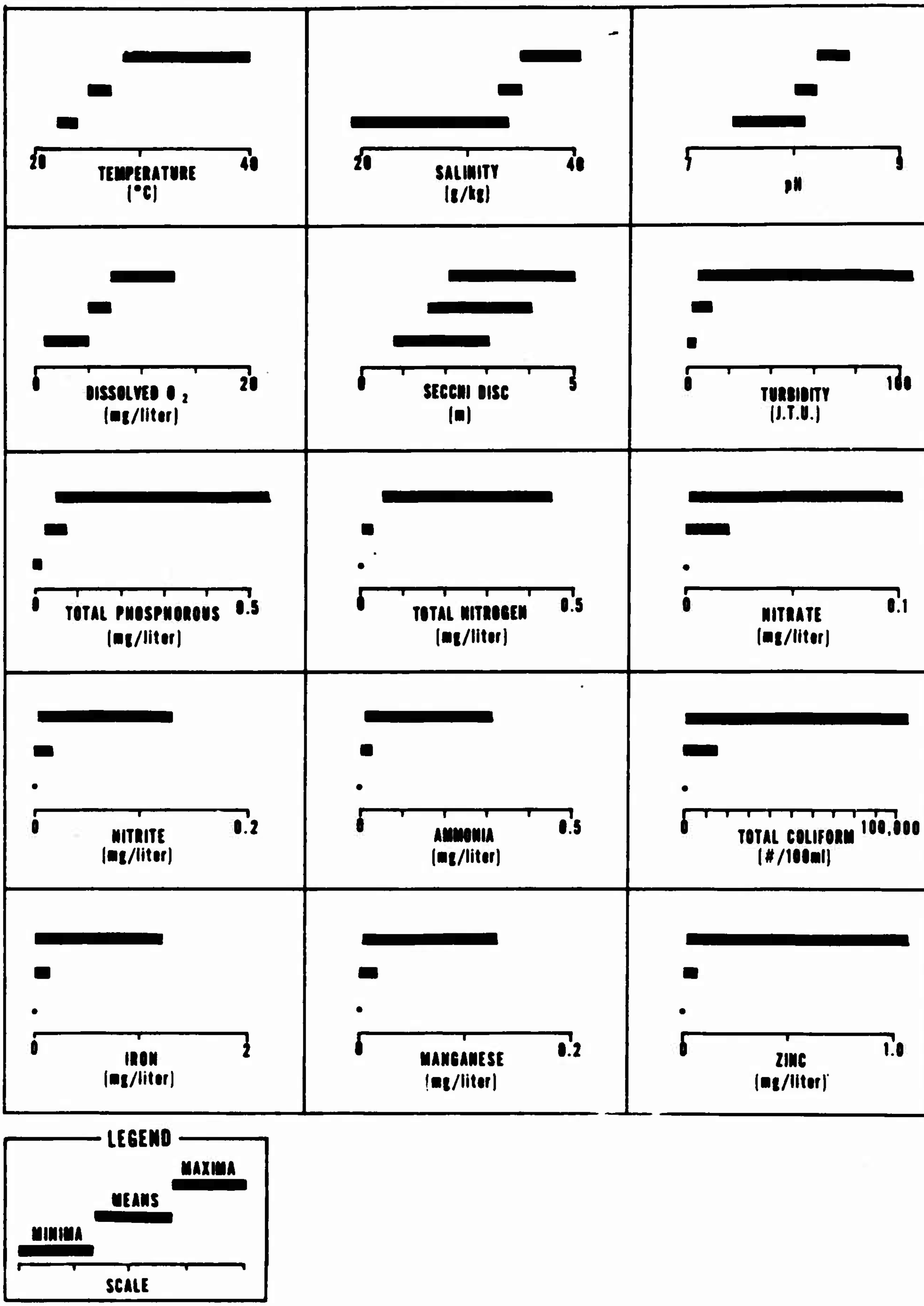


Figure 4.2-1. MEANS, MINIMA AND MAXIMA FOR 15 WATER PROPERTIES MEASURED IN PEARL HARBOR.

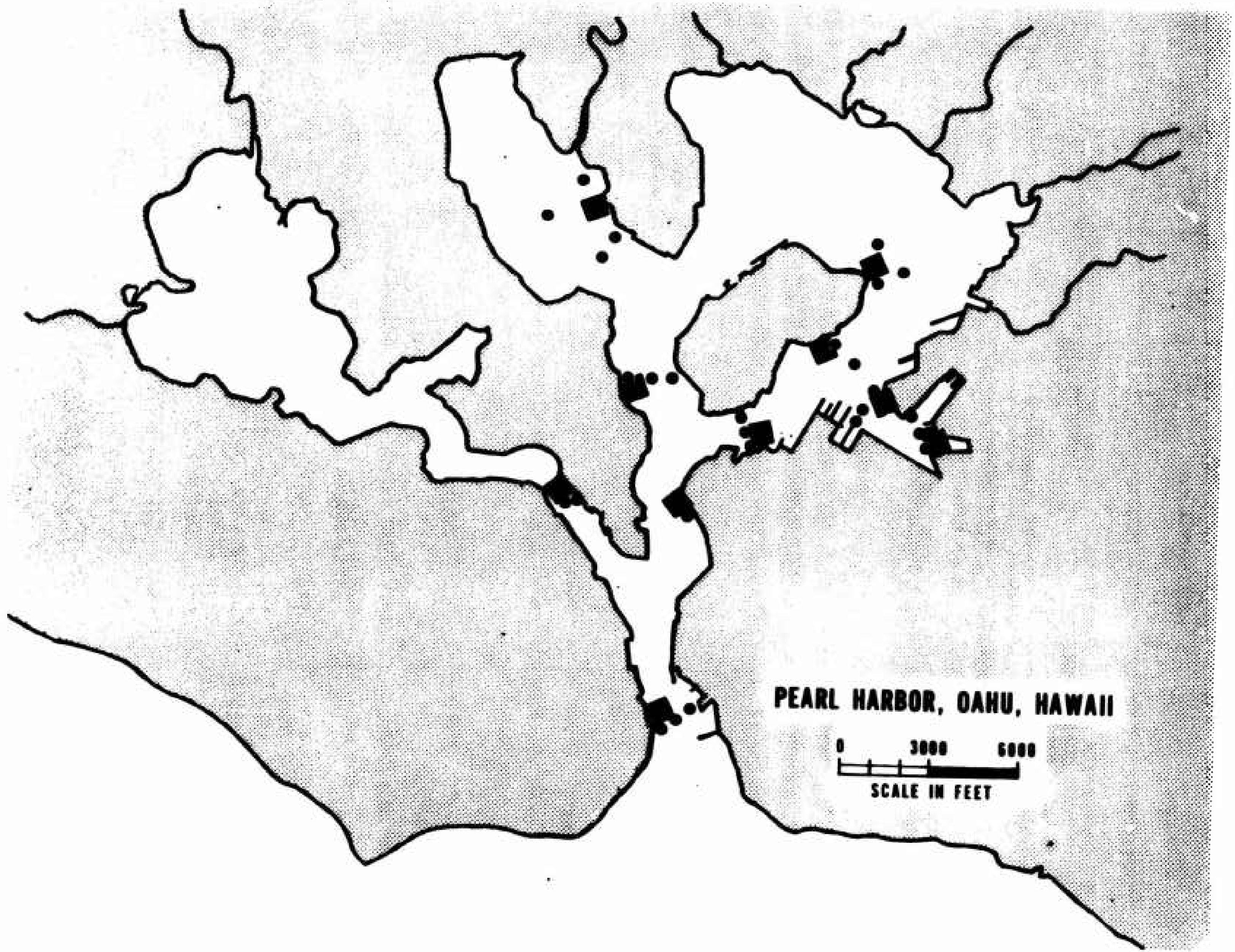


Figure 4.2-2. STATION LOCATIONS.
SQUARES INDICATE THE NUC BIO-STATIONS.

Table 4.2-1. SUMMARY STATISTICS, PEARL HARBOR WATER QUALITY, PLUS COMPARISON WITH OFFSHORE WATER QUALITY.

VARIABLE	MEAN	STD. DEV. MEAN	MIN.	STD. DEV. MIN.	MAX.	STD. DEV. MAX.	OCEANIC[1]
TEMPERATURE °C	25.7	0.9	22.9	0.7	29.4[2]	2.3	25
SALINITY g/kg	34.7	0.5	28.7[2]	5.5	36.7	1.0	35
pH pH units	8.11	0.04	7.88[2]	0.24	8.40	0.18	8.3
DIS. O_2 mg/liter	5.7	0.6	2.8[2]	1.0	9.4	1.7	6.5
SECCHI DISC meters	2.5	0.7	1.7[2]	0.7	3.4	1.0	20
TURBIDITY J.T.U.	5.5	4.4	1.3	0.4	25.0[2]	22.7	< 0.1
TOTAL P mg/liter	0.04	0.02	0.01	0.01	0.18[2]	0.13	< 0.01
TOTAL N mg/liter	0.03	0.01	0.00	0.00	0.12[2]	0.07	< 0.01
NITRATE-N mg/liter	0.005	0.004	0.000	0.000	0.03[2]	0.02	< 0.01
NITRITE-N mg/liter	0.004	0.003	0.000	0.000	0.02[2]	0.02	< 0.01
AMMONIA-N mg/liter	0.012	0.006	0.000	0.000	0.05[2]	0.06	< 0.01
TOT. COLI. #/100ml	2028	3543	11	16	8552[2]	17647	0
IRON mg/liter	0.03	0.04	0.00	0.00	0.14[2]	0.25	< 0.01
MANGANESE mg/liter	0.002	0.005	0.000	0.000	0.02[2]	0.03	< 0.01
ZINC mg/liter	0.01	0.01	0.00	0.00	0.13[2]	0.20	< 0.01

[1] For offshore Oahu, as compiled from various sources.

[2] Functional extreme, as defined and discussed in the text.

Unfortunately, this selection of stations for analysis eliminates any detailed consideration of water condition deep within West Loch because the only NUC bio-station there was discontinued due to lack of funds. This water body is of special interest because of the large oyster beds known to exist within it. The specific analysis of water quality in West Loch can, however, be undertaken at a later date since the measurements have been made and reported by NCEL (References 4.2-1 and 4.2-2). For greater convenience, average water conditions for the various lochs of Pearl Harbor are summarized from the NCEL report in Section 3.2.

Table 4.2-1 and Figure 4.2-1 list the mean, standard deviation of the mean, minimum, standard deviation of the minimum, maximum, and standard deviation of the maximum for the water properties measured at the 37 sites. Also included for comparison is the expected value for these water properties in the open ocean adjacent to Oahu. The actual data used in these analyses are reproduced in Section 3.2. Following is a brief discussion of each variable, including a consideration of the processes which might alter that parameter towards the "functional extreme".

Temperature. The mean water temperature in the harbor is near the offshore mean, and the variations largely follow the offshore seasonal variation. Heating by thermal effluents or possibly by local restriction and stagnation are the major probable causes of deviation from the mean; hence, maximum values are considered to be the functional extreme.

Salinity. Mean and maximum salinities in the harbor lie near the offshore mean. There may be a minor influence of salinity increase from evaporation, but the major cause of salinity variation in the harbor is from various terrestrial sources of runoff and seepage. Thus, minimum values are the functional extreme.

Hydrogen ion. Biochemical activity as well as various inputs of water from the land could either raise or lower hydrogen ion levels, conventionally expressed in terms of pH. The data suggests that lowered pH, probably below levels attributable to biological activity, is the appropriate functional extreme.

Dissolved oxygen. This property, like pH, is at least partly responsive to various biotic and abiotic chemical processes in the harbor. Again, introduction of external water sources may alter oxygen levels. Finally, the oxygen content of water actively and rapidly responds to deviations from saturation by gas exchange across the air-sea interface. The important functional extreme is the lower oxygen levels.

Secchi disc. This measurement is related to water transparency and is consistently lower in the harbor than in the adjacent ocean. Any particulate or dissolved materials in the water can lower the secchi disc reading, as can various spurious optical effects such as density stratification (index of refraction), low ambient light intensity, and surface choppiness. Low secchi disc readings are judged to be the functional extremes.

Turbidity. Also a measure of the passage of light through water, this parameter is not so subject to the spurious optical effects as is a secchi disc reading. However, laboratory turbidity readings are affected by aging of the water and by settling of particulate materials together with possible adsorption of materials to the sides of the sample containers. Largely because of particulate material in the water, readings are higher in the harbor than outside it. Turbidity maxima are considered the functional extremes.

Particulate and dissolved nutrients (including total phosphorous, total nitrogen, nitrate, nitrite, and ammonia). All of these nutrients are higher in the harbor than outside it. Nutrient sources in the harbor are sewage outfalls, stream runoff, runoff from agricultural areas, groundwater seepage, and so forth. It is unlikely that biological activity is sufficient to lower the concentration of these materials significantly. High values are the functional extremes.

Total coliform bacteria. These bacteria are added to the harbor from sewage and from soil-water runoff. These bacteria do not normally occur in seawater and survive in seawater for only short periods of time; thus high values are considered the functional extremes.

Trace metals (including iron, manganese, and zinc). These materials are ordinarily present in seawater at very low concentrations. Pearl Harbor values far exceed these trace concentrations. In common with the discussion of these materials in sediments, zinc is likely to have industrial wastes as a major source. Iron and manganese probably enter largely in various forms of terrestrial runoff. For all of these trace metals, the maximum values are assumed to be the functional extremes.

ANALYSIS OF VARIABLE MEANS

Factor analyzing the matrix of variable means yields five factors which explain 70% of the data variance. Table 4.2-2 shows the matrix of variable loadings. All of the variables have communalities between 51 and 85%. Figure 4.2-3 illustrates the distribution of factor scores at the stations throughout the harbor.

Factor I, explaining 18% of the variance in the data, shows strong positive correlation with total coliform bacteria and phosphorous and moderate negative correlation with both salinity and secchi disc readings. The factor is highest through Middle Loch and at BC-09, probably in response to the drainage of agricultural waters into much of that area.

Factor II explains 11% of the variance and shows strong positive correlation with zinc and moderate positive correlation with total nitrogen. The distribution of factor scores cannot be readily generalized, but the highest scores are found in the upper portion of Middle Loch. Although Peal Harbor sewage probably contains significant amounts of zinc, the origin of this factor is not readily apparent, either from the loadings or from the scores.

Factor III, which explains 13% of the variance, shows strong positive correlation with turbidity and strong negative correlation with pH. Both East Loch-Southeast Loch and the upper portions of Middle Loch have high scores.

Table 4.2-2. WATER QUALITY MEANS, FACTOR LOADING MATRIX.

FACTOR NUMBER		I	II	III	IV	V
PERCENT OF TOTAL VARIANCE		18	11	13	14	14
VARIABLE	COMMUNALITY %					
temperature	77	.28	.37	-.29	.55	-.41
salinity	57	-.64	-.07	.37	-.01	-.14
pH	74	.03	-.25	-.82	.05	-.02
dis. O_2	78	.01	-.36	-.44	-.54	.39
secchi disc	81	-.69	-.12	.21	.09	-.52
turbidity	67	-.06	-.10	.80	.04	.08
total P	83	.83	.04	.01	.01	.39
total N	55	-.04	.66	.07	-.23	.22
nitrate-N	60	.03	-.15	-.16	.71	.23
nitrite-N	76	-.14	-.10	.09	.85	-.01
ammonia-N	51	.36	.33	.20	.48	-.05
total coliform	85	.89	-.18	.13	.05	-.07
iron	74	.19	-.17	.16	.07	.80
manganese	69	.22	.21	-.05	.02	.77
zinc	65	.00	.79	.04	.11	-.12
		positive ω coliform and total P negative ω secchi and salinity	positive ω total N and Zn	positive ω turbidity negative ω pH	positive ω NO_2 and NO_3	positive ω Fe and Mn

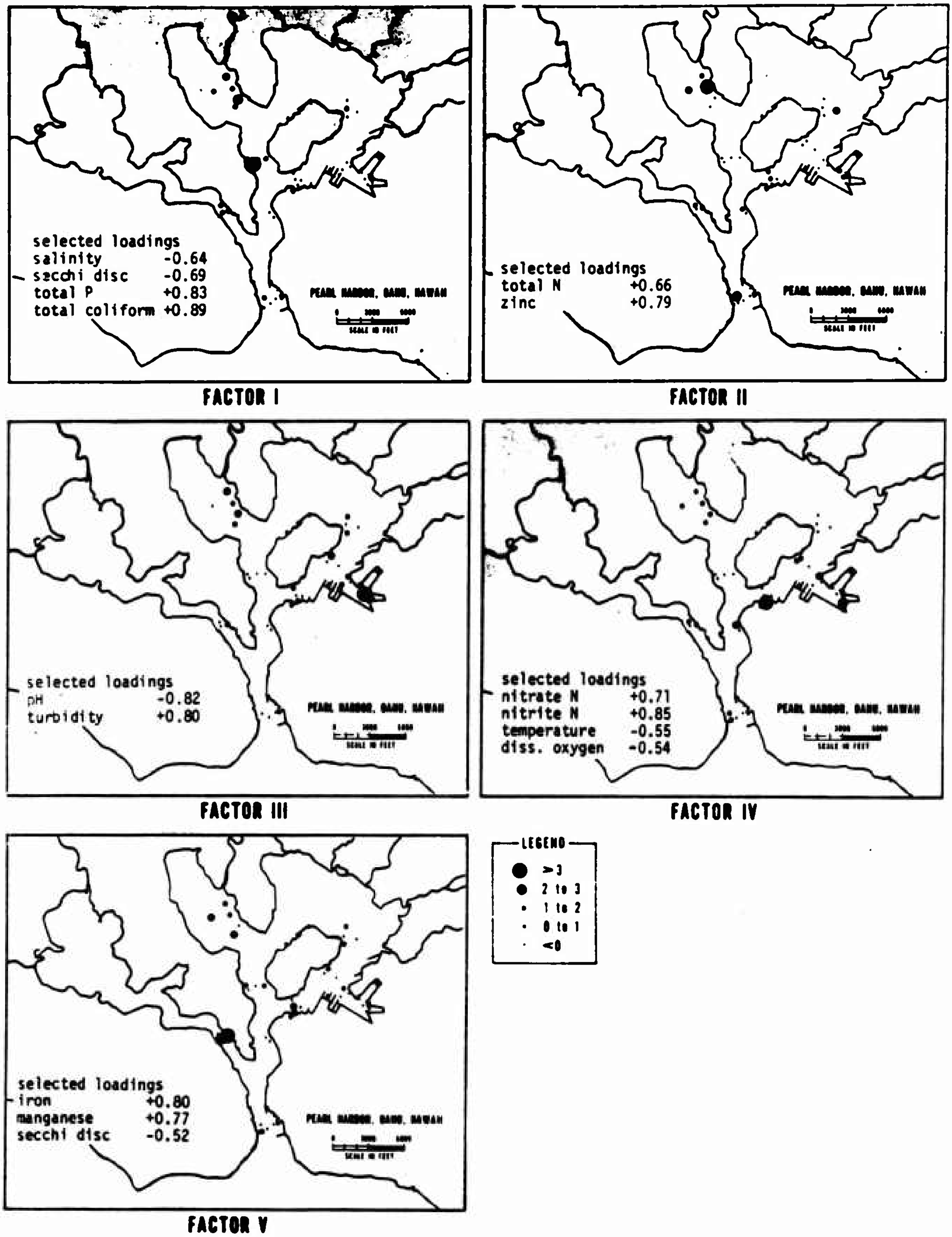


Figure 4.2-3. MAPPED FACTOR SCORES FOR WATER QUALITY MEANS

Factor IV explains 14% of the variance and shows strong positive correlation with both nitrate and nitrite, moderate positive correlation with temperature, and moderate negative correlation with dissolved oxygen. The high factor scores are scattered throughout the harbor.

Finally, Factor V explains 14% of the variance and shows strong positive correlation with both iron and manganese and moderate negative correlation with secchi disc readings. The loadings and scores are both consistent with suggesting that the factor is associated with the input and possibly the resuspension of terrigenous sedimentary materials. This suggestion is in general agreement with the pattern seen in the sediment heavy-metal data.

These five factors have not yielded particularly well to environmental interpretation. Nevertheless the factors are useful in summarizing the original, far more complex data matrix. It is possible to reduce these data still further--to an estimate of the degree to which the water quality at each station deviates from the composition of oceanic waters. For each of the five factors, the most negative score observed in the harbor is the score most nearly approaching oceanic composition. It is therefore possible to create an hypothetical station which is made up of the best score on each factor, and then to calculate the factor score distance in 5-dimensional space from that hypothetical station to each real station in the harbor. That hypothetical station has the following score on each factor: -0.9, -1.6, -1.5, -1.5, -1.8. The introduction section presented the means by which the value of each variable can be calculated from factor loadings (see Section 4.0, equation 3). Table 4.2-3 presents the results of reconstituting seawater by those calculations and shows that for most properties (factor-reconstituted seawater is more turbid), the hypothetical station indeed does approach the general ocean water composition listed in Table 4.2-1. Figure 4.2-4 maps the factor-score distances for water quality means from this hypothetical station to each real station. A few stations closely approaching the hypothetical station can be found in the Main Channel. Several of these stations are, however, near stations of relatively poor quality (see later discussion under environmental interpretation). The water surrounding Ford Island has relatively consistent moderate water quality, while most other areas show at least some stations with great deviations from the hypothetical station. Perhaps the major characteristic of the figure is the lack of geographically striking patterns of water quality variation.

Figure 4.2-5 is a dendrograph constructed from the distances between stations calculated with the five water quality factor scores. The overriding characteristic of the dendrograph is the lack of clusters. This characteristic reinforces the conclusions drawn from both the individual factor score maps and from the map of distances from the "best" (hypothetical) station; the mean water quality of Pearl Harbor does not lend itself readily to interpretation of geographic gradients. In terms of the mean water composition, the harbor must be considered relatively uniform.

Table 4.2-3. RECONSTITUTED SEAWATER AS CALCULATED FOR THE BEST WATER QUALITY MEAN FACTOR SCORES. THE HYPOTHETICAL STATION WITH THIS COMPOSITION HAS THE FOLLOWING SCORE ON EACH FACTOR: -.9, -1.6, -1.5, -1.5, -1.8.

VARIABLE	VALUE AT "BEST" STATION
TEMPERATURE °C	25
SALINITY g/kg	35
pH pH units	8.2
DISSOLVED OXYGEN mg/liter	6.5
SECCHI DISC meters	3.4
TURBIDITY J.T.U.	5
TOTAL PHOSPHOROUS mg/liter	.01
TOTAL NITROGEN mg/liter	.02
NITRATE-NITROGEN mg/liter	.001
NITRITE-NITROGEN mg/liter	.001
AMMONIA-NITROGEN mg/liter	.001
TOTAL COLIFORM BACTERIA #/100ml	-300
IRON mg/liter	-.04
MANGANESE mg/liter	-.007
ZINC mg/liter	.00

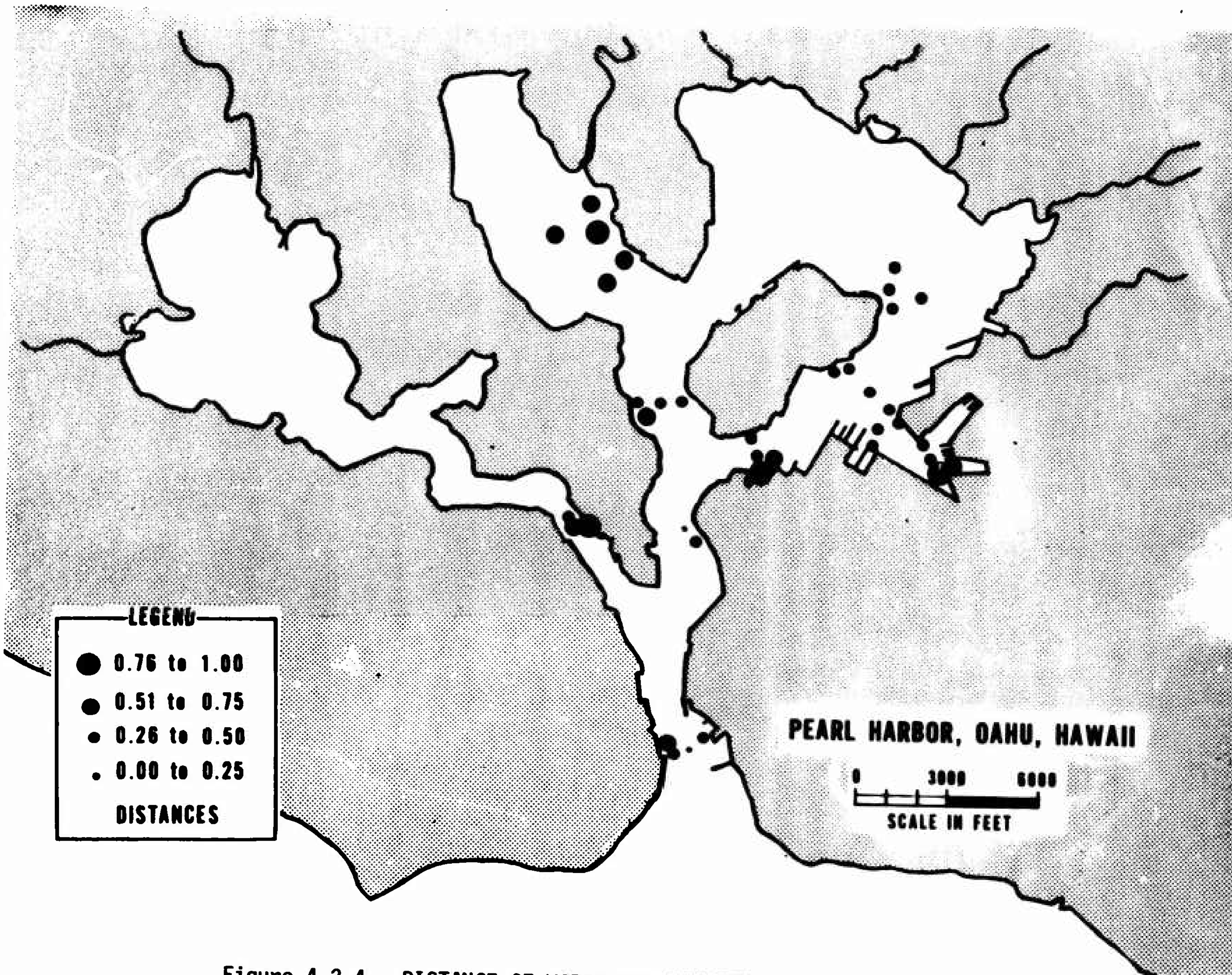


Figure 4.2-4. DISTANCE OF WATER QUALITY MEANS FROM "BEST" STATION.

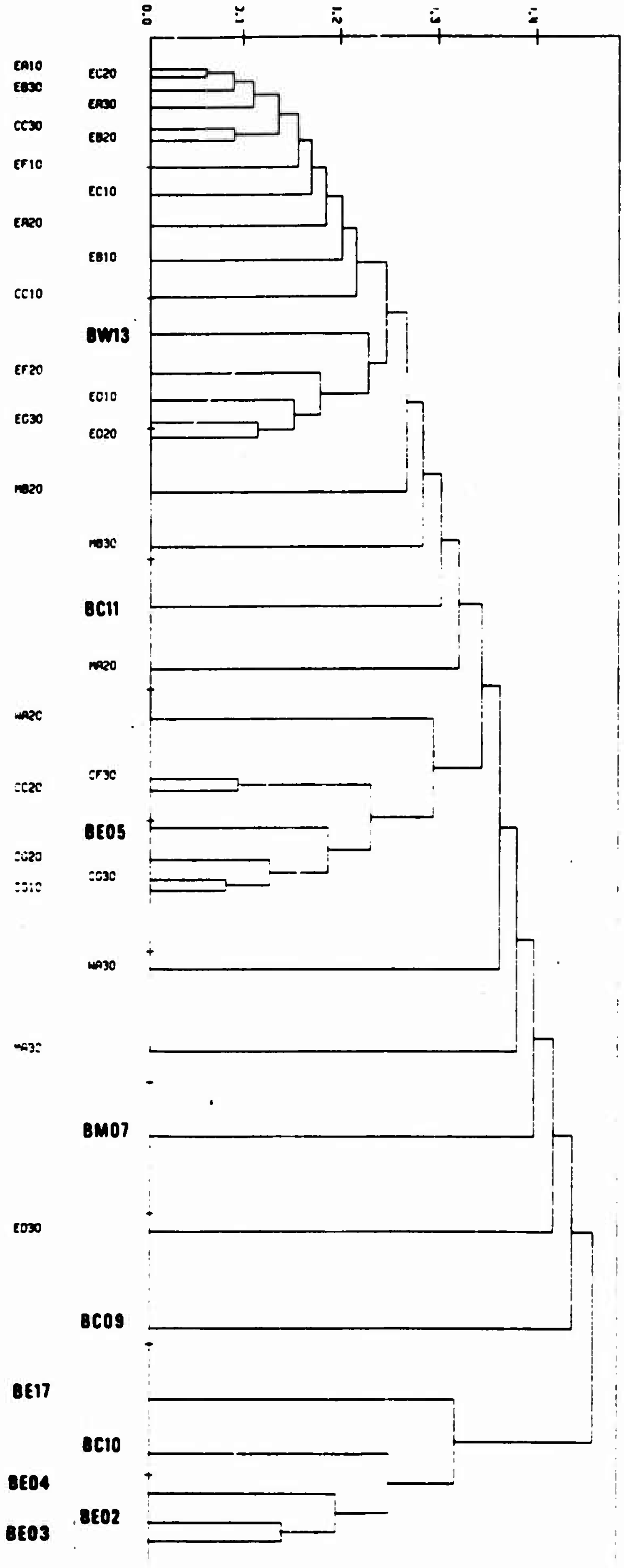


Figure 4.2-5. PEARL HARBOR WATER QUALITY MEANS.

MINIMAX ANALYSIS

Table 4.2-4 shows the minimax factor loading matrix with five factors. The minimum values for seven of the variables (all nitrogen and trace metal measurements) had to be excluded from the analyses, because those variables had minima of 0.0 at all stations.

As was the case with the factors calculated from water quality means, the minimax factors are difficult to interpret. In fact, only one characteristic of these minimax factors merits further attention here. Of the eight variables for which both minimum and maximum values were used in the analysis, only one shows both extremes loading heavily on the same factor. That single variable is the minimum and maximum secchi disc readings. If a given variable were to vary over its entire range in response to one major process (or a few closely interrelated processes), then both minima and maxima might be expected to load heavily on a single factor. The variation in secchi disc readings therefore seems to result simply from the presence or absence of suspended material in the water column from sources that are uniformly available to all stations in the harbor. That the loading of both minima and maxima on a single factor is not the case for the remaining variables can be interpreted in the following manners. Perhaps the controlling process for each variable is quite different for one extreme and for the other. In view of the general asymmetry of minimum and maximum deviations from the means (Figure 4.2-1), this explanation seems plausible. An equally plausible possibility is that the same processes are important over the entire range of variation but that the process-to-variable functions are markedly nonlinear. For either interpretation, it seems likely that the minimax treatment may mask environmentally relevant information to be found in the "functional extremes".

ANALYSIS OF FUNCTIONAL EXTREMES

Table 4.2-5 presents a factor loading matrix for 7 factors explaining 81% of the variance in the 15-variable matrix of functional extremes. The communality of the variables ranges from 66 to 93%. Figure 4.2-6 shows the maps of factor scores. The individual factors are no more easily interpretable than the previous water quality factors have been, so these functional extreme factors need not be discussed individually here.

When factor score distances are calculated from the "best" station (-1.3, -1.3, -1.4, -1.7, -1.4, -2.8, -0.9), an interesting fact emerges. Figure 4.2-7 is a map of these distances and Figure 4.2-8 is a histogram showing the frequency distribution of these distances. Clearly, the NUC bio-stations suffer far greater "functional extreme" insult than do most of the other stations in the harbor. There seems to be a straightforward but important explanation of this phenomenon. The bio-stations for the most part lie immediately adjacent to the shore (see Table 4.2-6), while most of the other sampling stations are somewhat farther offshore. Thus, the overall water quality functional extremes originate primarily from the shore (perhaps not surprising) and rapidly dissipate with distance away from shore to a general background level.

Table 4.2-4. WATER QUALITY MINIMAX, FACTOR LOADING MATRIX

FACTOR NUMBER		I	II	III	IV	V
PERCENT OF TOTAL VARIANCE		18	13	11	9	8
VARIABLE	COMMUNALITY (%)					
temperature						
min	83	-.38	.20	.68	-.39	-.16
max	57	-.17	-.28	-.04	-.14	.67
salinity						
min	64	-.32	-.54	-.27	-.14	-.39
max	74	.14	-.14	-.17	-.66	.49
pH						
min	78	-.02	.02	-.01	.88	.07
max	63	.37	.37	.28	-.18	.50
dis. O_2						
min	46	-.14	-.62	-.19	.02	.17
max	71	.64	.04	.26	.31	.36
secchi disc						
min	79	-.85	-.16	-.18	.12	-.02
max	81	-.88	.16	-.05	.10	.05
turbidity						
min	75	.83	-.02	.19	-.14	.01
max	63	.07	.70	-.31	.16	-.12
total P						
min	53	.08	-.24	.11	-.16	-.65
max	61	.46	.15	.14	-.60	-.06
total N						
max	58	.26	-.14	.67	.16	-.06
nitrate-N						
max	71	.07	.83	-.05	-.03	.14
nitrite-N						
max	40	-.06	.58	.19	-.12	.08
ammonia-N						
max	53	.07	.14	.70	13	-.06
total coliform						
min	36	.53	.17	-.13	-.08	-.15
max	20	.33	.16	.24	-.05	-.07
iron						
max	71	.49	.52	-.44	.08	.00
manganese						
max	31	.43	.22	-.25	.05	.09
zinc						
max	32	.14	.02	.46	-.19	.24

Table 4.2-5. WATER QUALITY FUNCTIONAL EXTREMES, FACTOR LOADING MATRIX.

FACTOR NUMBER PERCENT OF TOTAL VARIANCE		I 13	II 13	III 13	IV 13	V 10	VI 10	VII 9
VARIABLE	COMMUNALITY (%)							
max temperature	66	.06	-.09	-.17	.01	.10	.77	-.08
min salinity	83	-.43	-.28	.08	-.56	-.06	-.18	-.45
min pH	78	.16	.22	-.47	.03	-.68	.02	.17
min dis. O_2	71	-.47	-.17	.08	-.13	-.55	.38	.02
min secchi disc	82	-.06	-.30	-.62	-.42	.01	.14	-.38
max turbidity	83	.45	-.13	-.32	.25	.12	-.66	.03
max total P	93	.20	.03	.94	.06	.06	-.01	.08
max total N	88	-.10	.91	.18	.04	.02	.07	-.02
max nitrate-N	79	.76	-.06	.02	.45	-.01	-.03	.10
max nitrite-N	85	.81	.03	.36	-.22	-.07	-.08	-.04
max ammonia-N	79	.10	.86	-.07	-.05	.12	-.10	-.02
max total coliform	91	.00	-.06	.14	-.02	.04	-.10	.94
max iron	75	.25	-.08	-.03	.67	.00	-.48	.00
max manganese	76	-.06	-.03	.15	.86	.00	.00	-.04
max zinc	72	-.01	.22	-.06	-.01	.79	.15	.15
		positive w NO_2 and NO_3	positive w total N and NH_3	positive w total P negative w secchi disc	positive w Fe and Mn	positive w Zn negative w pH	positive w temperature negative w turbidity	positive w coliform

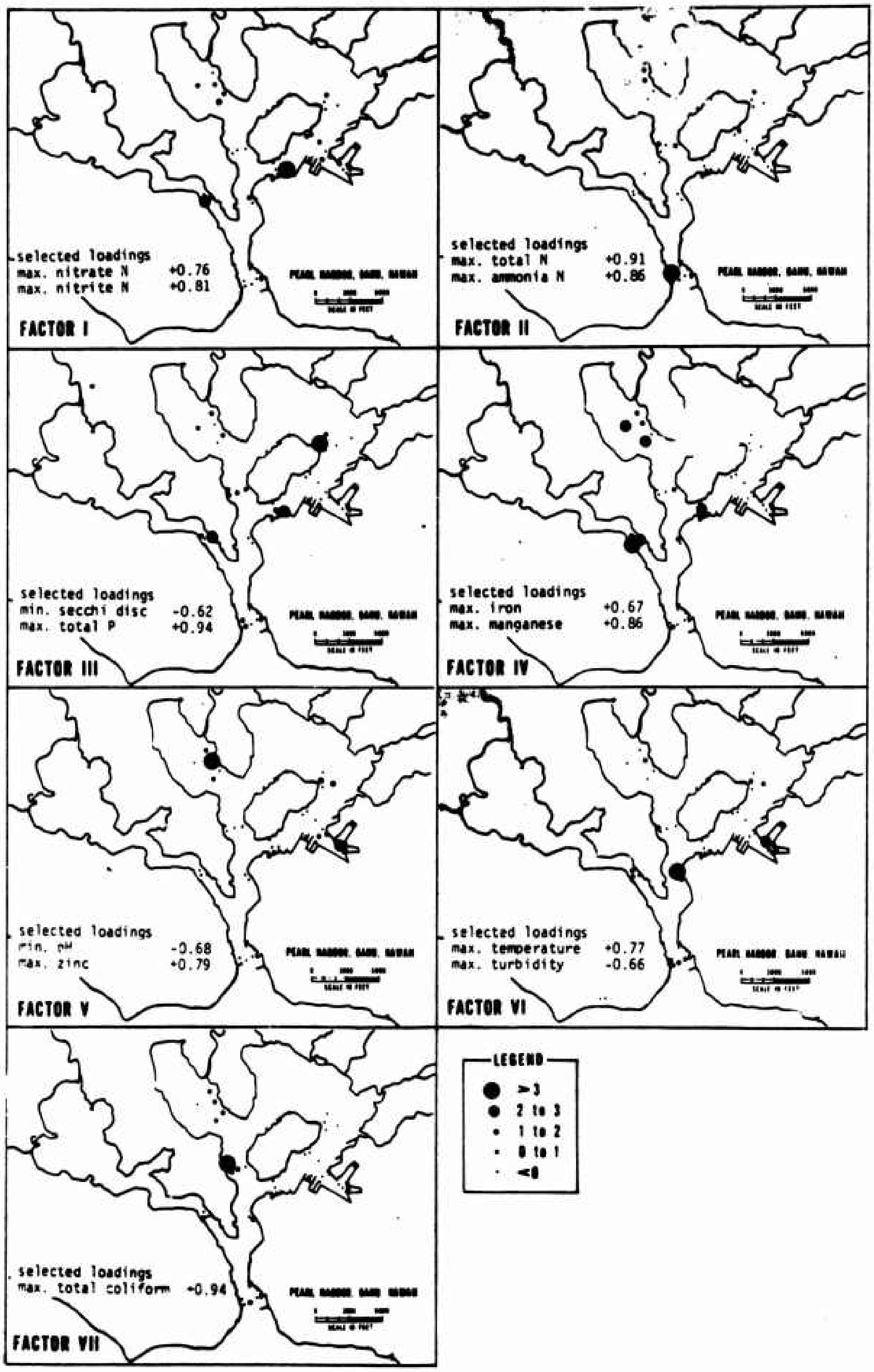


Figure 4.2-6. MAPPED FACTOR SCORES FOR WATER QUALITY FUNCTIONAL EXTREMES

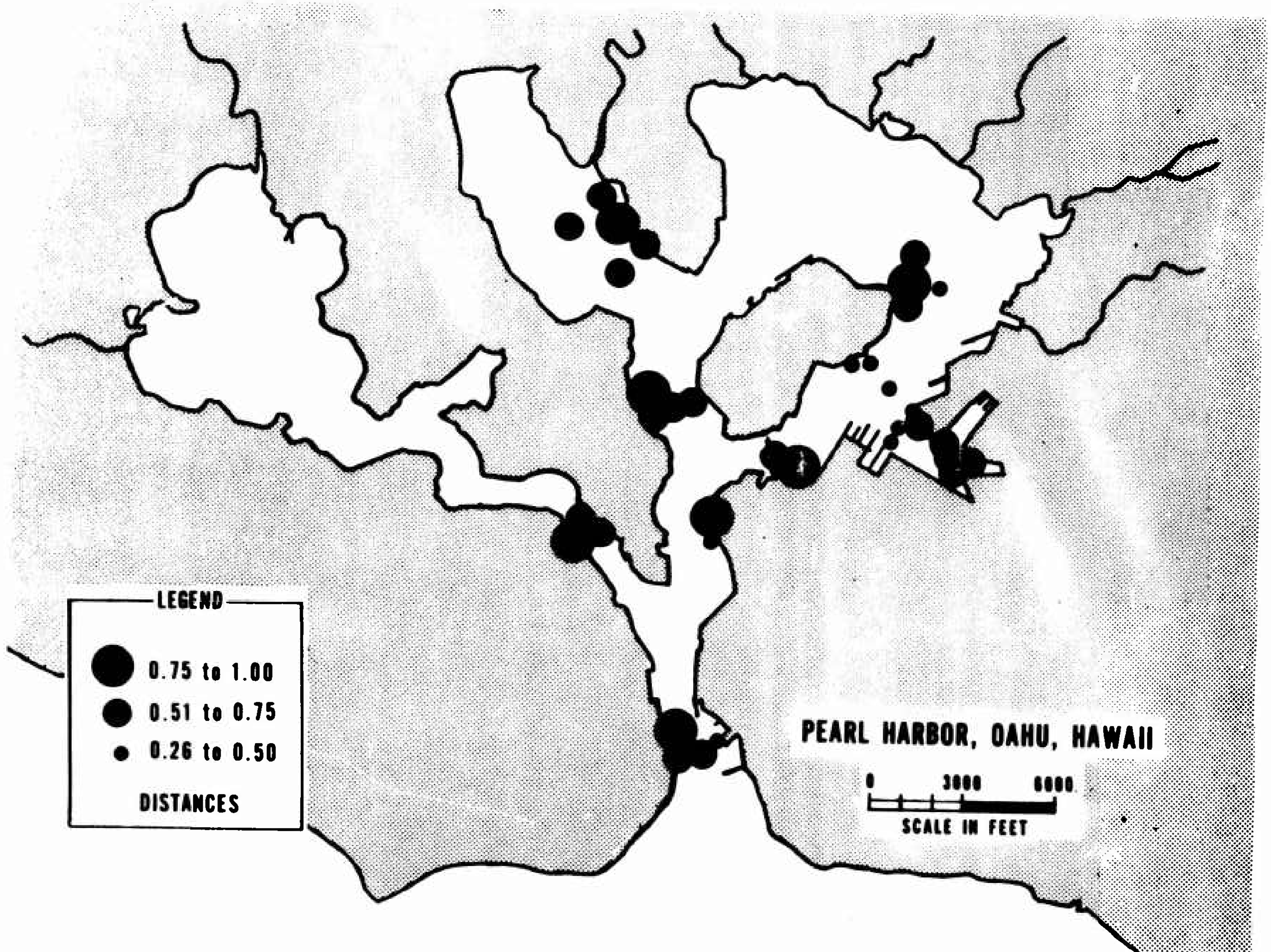


Figure 4.2-7. WATER QUALITY FUNCTIONAL EXTREMES DISTANCE FROM "BEST" STATION.

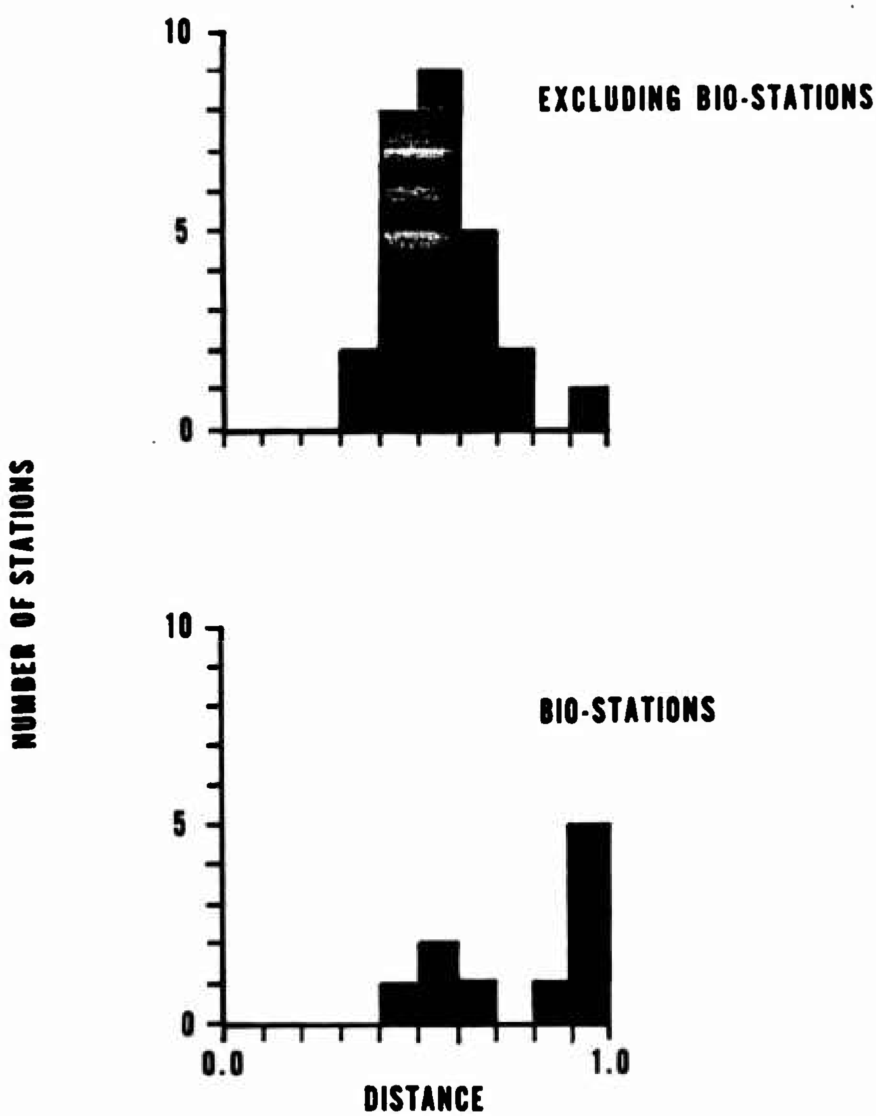


Figure 4.2-8. WATER QUALITY EXTREMES, SCALED FACTOR SCORE DISTANCES FROM "BEST" STATION.

Table 4.2-6 MAJOR INSULTS NEAR PHBS BIO-STATIONS.

STATION	DISTANCE TO INSULT				
	0 to 50 m	50 to 100 m	100 to 200 m	200 to 400 m	400 to 800 m
BE-02	shore				toilet--Arizona Memorial
BE-03	shore	4" sewer		oil under piers	
BE-04	shore, 4" sewer		oil and diesel leaks, gas spillage		oil under piers, 4" sewer, underground oil
BE-05			septic tank	shore	toilet--Arizona Memorial
BM-07				shore	4" sewer, stream, primary outfall, inactive ship maintenance
BC-09		shore, irrigation water			septic tank, secondary outfall, scrap
BC-10	shore	cooling water			septic tank, oil in ground, cooling water
BC-11	shore, primary outfall, sewage treatment				sewage treatment
BC-13	shore, irrigation water				septic tank
BE-17	shore, 8" sewer		cooling water		

ENVIRONMENTAL INTERPRETATION OF PEARL HARBOR WATER QUALITY

The water quality of Pearl Harbor deviates considerably from that of the adjacent ocean. From the standpoint of mean conditions in the harbor, there is little in terms of a consistent geographic pattern to describe the variations in the harbor. However, the functional extreme conditions in the harbor do show one consistent pattern. Extremes of bad water quality are found along the shoreline and generally improve to a pattern of little variation for "mid-stream" locations. Such a pattern suggests that localized point sources of insult to the harbor may have relatively confined direct impact on the immediate environment. At the same time, each of these local insults contributes to the general, overall poor quality of the harbor waters. It should be noted, however, that water quality data can be "fudged" toward compliance or non-compliance simply by obtaining water samples further from or closer to the shoreline.

These observations do not say a great deal about the specific nature of water quality insults in Pearl Harbor, but they point the way towards appropriate future monitoring of water quality there. Any sampling in the harbor should be conducted in a manner consistent with relating water quality to temporal variations over periods of well less than one day. This almost certainly speaks for means of remote sensing. If the monitoring is meant to characterize particular points of insult, sensing should be done as near that insult source as possible. To avoid cryptic insults in a general monitoring of harbor conditions, sensors or sampling sites should be taken away from the shoreline or from areas of potential midwater insults. Probably relatively few monitoring sites would be sufficient to characterize the general condition of harbor waters if the data were clearly linked with a few standard meteorological and oceanographic observations.

REFERENCES

4.2-1. NCEL, Navy Environmental Protection Data Base (1972), Field Collections Records of Water Quality Data Collected in Pearl Harbor during 1972.

4.2-2. D. E. Morris, S. W. Surface, and J. P. Murray (1973),"Completion Report For The Pearl Harbor, Hawaii Study Covering The Test Period Through Calendar Year 1972", Navy Environmental Protection Data Base, M.P.A. 6.2.1.4.

STATISTICAL ANALYSIS
OF PEARL HARBOR BIOTA

Gerald S. Key
Stephen V. Smith
Evan C. Evans III

FISHES

The mobility of marine fishes is perhaps the single most important attribute of general fish ecology which makes the data for this class of organisms both difficult to interpret and potentially extremely valuable in environmental assessment. The mobility of fishes, along with their variety of species, habits and habitats makes effective sampling of the entire fish fauna difficult. On the other hand, these same two attributes of mobility and diversity, coupled with the well developed sensory acuity of fishes, makes these organisms potentially sensitive indicators of even transient environmental perturbations occuring at nearly all levels of the food chain.

In following the analytical procedures outlined in Figure 4.0-1, certain conventions have had to be adopted for the biotic data. Most of these conventions are related to the nature of biologic sampling data, where the mere presence of a variable (i.e., a species) is itself useful information. Furthermore, biologic sampling data may frequently be gathered from a variety of sources, including historical records, species lists, visual sightings, collections, etc., and these data of information of potential value in defining and interpreting environmental patterns would be lost if these data were to be excluded from analysis.

Assuming that the probability of observing (by whatever sampling methods) the "presence" of a species in a given environment is directly proportional to that species' abundance, then the presence/absence (P/A) of a species can be used as a record of its environmental preferences. Obviously, reliable abundance data, which contain more information per variable than do P/A data, should more rigorously define these relationships, but abundance data are frequently unavailable or were gathered by methods which preclude their direct comparison. A policy of using both P/A and abundance data (where available) has therefore been adopted in the analyses presented in this report.

However, when P/A data are used in factor analysis, variables (species) are either present (scored as 1's) or absent (scored as 0's) at each sampling location; obviously, in situations where a given species is present (or absent) at all locations that variable will have zero variance. A prerequisite of factor analysis is that each variable must have some, non-zero variance. This condition is a special case of the general fact tha variables which are either exceedingly rare or exceedingly common tend to bias the correlation coefficients and to place undue weight on extremes which contain little information on general conditions. This situation is usually remedied by placing frequency cut-off limits on extreme values.

Limits used in this report are: for the P/A data, present at at least 10% of the stations but not more than 90% and for the absolute abundance data, abundance reported for 10% or more of all stations. Since only 10 bio-stations were sampled in Pearl Harbor, these limits are equivalent to one-to-nine and one or more bio-stations, respectively.

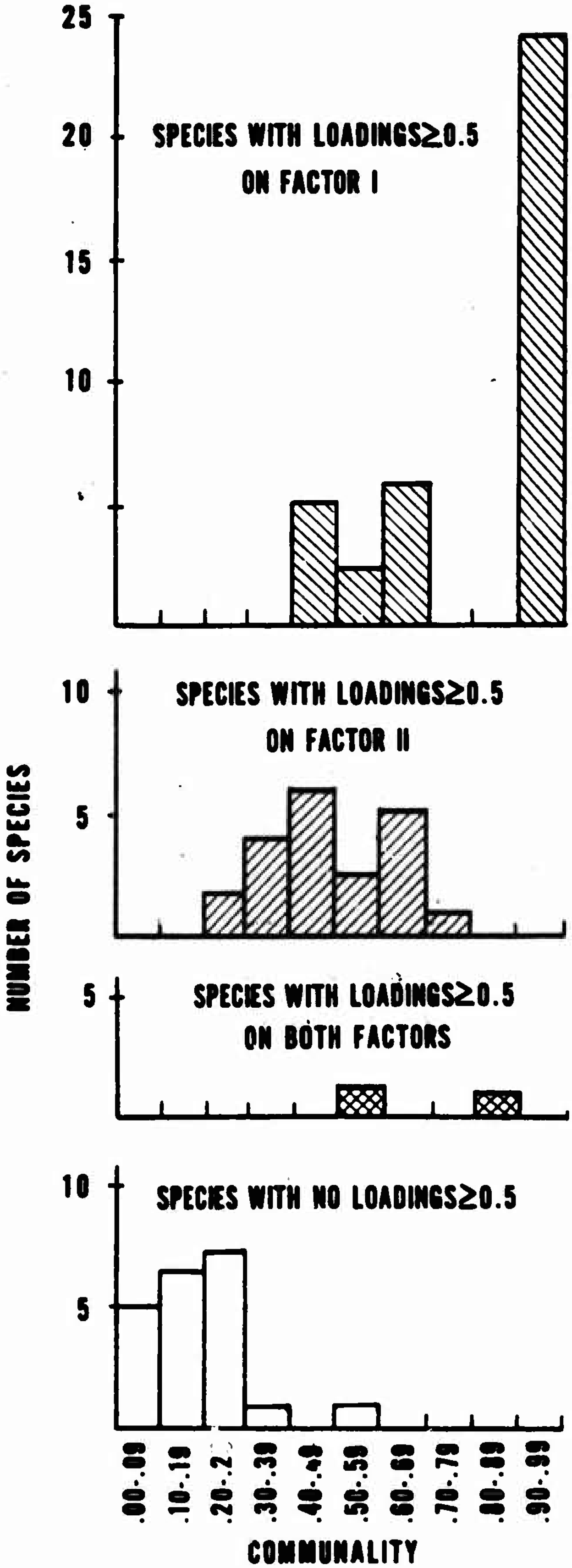


Figure 4.3-1. HISTOGRAM OF COMMUNALITIES ASSOCIATED WITH TWO FACTORS EXTRACTED FROM PRESENCE-ABSENCE DATA FOR 80 FISH SPECIES.

Data Used In This Section. As discussed in Section 2.1, a total of 90* species of fish is reported for Pearl Harbor. The following numbers of species are used in the analyses described in this section:

Species Group	Number of Species
Total number of species	87
Total number of species present at all 10 bio-stations	7
Total number of species present at nine or fewer bio-stations (P/A data)	80
Total number of species collected (i.e., counted) at one or more bio-stations (abundance data)	61
Total number of species reported from sightings only	26

The means and standard deviations for the 80 species present at nine or fewer bio-stations and for the 61 species collected (i.e., counted) at one or more bio-stations are presented in Table 4.3-1.

Data Analysis and Discussion. Two factors were extracted from the 80 P/A variables presented in Table 4.3-1, and the factor loadings and communalities for each of these variables are presented in Table 4.3-2. A plot (Figure 4.3-1) of the communalities for these 80 species reveals a bi-modal distribution, with one mode comprising species whose variances were well described by these two factors and a second mode which includes species moderately to poorly described by the extracted factors. Of the 24 species with communalities in the .90-.99 range, 22 species have loadings on Factor I in excess of 0.95, indicating that the variances of these 22 species are almost wholly described by this single factor. Furthermore, Table 4.3-1 shows that 21 of these 22 species are reported from a single bio-station (BC-11), further that the average frequency of the 40 species with factor loadings ≥ 0.50 on Factor I was 11% (i.e., one bio-station). In contrast, the average frequency of the 21 species with factor loadings ≥ 0.50 on Factor II is 40% or 4 bio-stations. Figure 4.3-2 reveals that only station BC-11 had a factor score > 1.0 for Factor I, and that this station (and BW-13) is far removed from the other stations. The same situation is shown by a dendrograph (Figure 4.3-3) generated from these factor scores, where again station BC-11 is most distant (0.85 units** from the remaining nine bio-stations (BW-13 is 0.68 units).

*Three fish species, *Canthigaster jactator*, *Ctenogobius tongerevae*, and *Oxyurichthys lonchotus* were reported from data unavailable at the time these analyses were performed, and thus only 87 of the 90 species reported in Section 2.1 were used in the analyses which follow. Note that all three are insignificant species.

**See Section 4.0 for explanation of dendrograph.

(Text continued on page 4.3-10)

Table 4.3-1. MEANS AND STANDARD DEVIATIONS FOR THE 90 FISH SPECIES REPORTED FROM PEARL HARBOR BY PHBS.

Species	Presence-Absence Mean*	Presence-Absence Std. Dev.	Absolute Abundance Mean	Absolute Abundance Std. Dev.
Abudefduf abdominalis	1.0	---	0.5	1.27
Abudefduf sordidus			0.1	0.32
Acanthurus dussumieri	0.2	0.42	0.4	0.97
Acanthurus mata	0.9	0.32	4.0	4.24
Acanthurus olivaceus	0.1	0.32	0.3	0.95
Acanthurus triostegus	0.6	0.52	1.3	3.77
Acanthurus xanthopterus	1.0	----	7.9	7.52
Aetobatus narinari	0.8	0.42	0.5	0.71
Albula vulpes	0.3	0.48	2.0	4.14
Antennarius chironectes	0.1	0.32	0.1	0.32
Apogon snyderi	0.3	0.48	0.2	0.63
Arothron hispidus	1.0	----	26.2	24.47
Asterropteryx semipunctatus	1.0	----	NC	
Aulostomus chinensis	0.1	0.32	NC	
Bathygobius fuscus	0.5	0.53	NC	
Bothus patherinus	0.2	0.42	0.1	0.32
Brachirus barberi	0.4	0.52	0.4	0.70
Calotomus spinidens	0.3	0.48	0.1	0.32
Canthigaster coronatus	0.1	0.32	NC	
*Canthigaster jactator***	0.1	0.32	NC	
Carangoides gymnostethoides	0.1	0.32	0.1	0.32
Caranx ignobilis	0.1	0.32	0.1	0.32
Caranx mate	0.5	0.53	1.3	2.54
Caranx melampygus	0.9	0.32	3.1	3.81
Caranx sexfasciatus	1.0	----	1.9	2.13
Carapus margaritiferae	0.1	0.32	0.1	0.32
Carcharhinus limbatus	0.2	0.42	0.3	0.95
Chaetodon auriga	0.8	0.42	5.2	9.99
Chaetodon lunula	0.3	0.48	2.2	4.73
Chaetodon miliaris	0.3	0.48	7.7	16.15
Chanos chanos	0.4	0.52	3.2	7.16
Cheilio inermis	0.1	0.32	0.1	0.32
Conger marginatus	0.3	0.48	1.3	2.67
Ctenochaetus strigosus	0.3	0.48	NC	
*Ctenogobius tongarevae***	0.1	0.32	0.3	0.95
Dascyllus albisella	0.5	0.53	NC	
Diodon holocanthus	0.2	0.42	NC	
Diodon hystrix	0.2	0.42	0.1	0.32
Elops hawaiiensis	1.0	----	10.8	10.41
Entomacrodus marmoratus	0.1	0.32	0.1	0.32
Exallias brevis	0.1	0.32	0.1	0.32
Flammeo sammara	0.3	0.48	0.1	0.32
Foa brachygrammus	1.0	----	NC	
Gnathanodon speciosus	0.4	0.52	NC	
Gnatholepis anjerensis	0.2	0.42	0.2	0.42

Table 4.3-1. CONTINUED.

Species	Presence-Absence *Mean	Presence-Absence Std. Dev.	Absolute Abundance Mean	Absolute Abundance Std. Dev.
Gymnothorax flavimarginatus	0.1	0.32	0.3	0.95
Gymnothorax petelli	0.1	0.32	NC	
Gymnothorax undulatus	0.7	0.48	0.7	0.95
Hemiramphus depauperatus	0.3	0.48	NC	
Heniochus acuminatus	0.1	0.32	NC	
Kuhlia sandvicensis	0.6	0.52	1.2	1.99
Kyphosus cinerascens	0.1	0.32	0.2	0.63
Labroides phthirophagus	0.1	0.32	NC	
Lutjanus fulvus	0.4	0.52	0.4	0.52
Microcanthus strigatus	0.2	0.42	0.1	0.32
Micrognathus edmondsoni?	0.1	0.32	NC	
Mollienesia latipinna	0.1	0.32	NC	
Mugil cephalus	0.5	0.53	7.4	13.19
Mulloidichthys auriflamma	0.1	0.32	0.1	0.32
Mulloidichthys samoensis	0.3	0.48	1.4	4.09
Myripristis murdjan	0.2	0.42	NC	
Naso brevirostris	0.4	0.52	1.4	2.99
Naso unicornis	0.1	0.32	0.3	0.95
Omobranchus elongatus	0.1	0.32	0.3	0.95
Opua nephodes	0.2	0.42	0.2	0.42
Ostracion meleagris camuram	0.2	0.42	NC	
Oxyurichthys lonchotus **	0.1	0.32	0.2	0.63
Parupeneus multifasciatus	0.1	0.32	NC	
Parupeneus pleurostigma	0.2	0.42	NC	
Pervagor spilosoma	0.1	0.32	NC	
Polydactylus sexfilis	0.2	0.42	1.4	3.50
Priacanthus cruentatus	0.1	0.32	0.1	0.32
Saurida gracilis	0.4	0.52	0.1	0.32
Scarus sordidus	0.1	0.32	0.1	0.32
Scarus sp. (juvenile)	0.3	0.48	NC	
Scomberoides sancti-petri	0.4	0.52	1.3	2.83
Scorpaena coniorta	0.1	0.32	0.1	0.32
Scorpaenopsis diabolus	0.1	0.32	0.1	0.32
Sphyraena barracuda	0.7	0.48	0.2	0.42
Sphyrna lewini	0.9	0.32	9.0	11.78
Stethojulis balteatus	0.4	0.52	0.1	0.32
Stolephorus purpureus	0.3	0.48	0.3	0.95
Synodus variegatus	0.1	0.32	NC	
Tilapia mossambica	0.2	0.42	NC	
Tylosurus crocodilus	0.2	0.42	NC	
Upeneus arge	0.6	0.52	1.9	4.01
Zanclus canescens	0.3	0.48	NC	
Zebrasoma flavescens	0.4	0.52	NC	
Zebrasoma veliferum	0.3	0.48	0.1	0.32

* - Mean presence is equivalent to frequency of occurence
** - These species were reported from data not used in these analyses.
NC = not counted

Table 4.3-2. FACTOR LOADINGS AND COMMUNALITIES FOR 80 FISH SPECIES. (PRESENCE-ABSENCE ONLY) USED FOR FACTOR ANALYSIS.

Rotate Factor Matrix

FACTOR NUMBER		I	II
PERCENT OF TOTAL VARIANCE		39.4	17.1
Species	**Communality(%)**		
Abudefduf sordidus	33	-0.32	-0.48
Acanthurus dussumieri	67	0.82*	0.05
Acanthurus mata	24	0.08	-0.48
Acanthurus olivaceus	96	0.95*	-0.23
Acanthurus triostegus	55	0.08	-0.74*
Aetobatus narinari	25	0.17	-0.47
Albula vulpes	48	0.35	-0.60*
Antennarius chironectes	96	0.95*	-0.23
Apogon snyderi	50	0.53*	-0.47
Aulostomus chinensis	96	0.95*	-0.23
Bathygobius fuscus	59	-0.50*	-0.58*
Bothus patherinus	19	-0.24	-0.36
Brachirus barberi	43	0.29	-0.59*
Calotomus spinidens	96	0.95*	-0.23
Canthigaster coronatus	96	0.95*	-0.23
Carangoides gymnostethoides	68	-0.28	-0.77*
Caranx ignobilis	1	-0.06	-0.05
Caranx mate	27	-0.38	-0.35
Caranx melampygus	24	0.07	-0.48
Carapus margaritiferae	96	0.95*	-0.23
Carcharhinus limbatus	8	0.01	0.29
Chaetodon auriga	21	0.15	-0.43
Chaetodon lunula	53	0.69*	0.23
Chaetodon miliaris	45	0.67*	0.01
Chanos chanos	15	-0.28	-0.27
Cheilo inermis	96	0.95*	-0.23
Conger marginatus	53	0.69*	0.23
Ctenochaetus strigosus	44	0.35	-0.57*
Dascyllus albisella	44	0.35	0.57*
Diodon holocanthus	67	0.82*	0.05
Diodon hystrix	67	0.82*	0.05
Entomacrodus marmoratus	95	0.95*	-0.23
Exallias brevis	96	0.95*	-0.23
Flammeo sammara	50	0.53*	-0.47
Gnathanodon speciosus	46	0.39	-0.55*
Gnatholepis anjerensis	14	-0.11	-0.35
Gymnothorax flavimarginatus	95	0.95*	-0.23
Gymnothorax petelli	96	0.95*	-0.23
Gymnothorax undulatus	39	0.17	-0.60*
Hemiramphus depauperatus	8	-0.12	0.25
Heniochus acuminatus	96	0.95*	-0.23
Kuhlia sandvicensis	31	0.26	-0.50
Kyphosus cinerascens	96	0.95*	-0.23
Labroides phthirophagus	96	0.95*	-0.23

Table 4.3-2. CONTINUED.

FACTOR NUMBER PERCENT OF TOTAL VARIANCE		I 39.4	II 17.1
Species	Communality(%)		
Lutjanus fulvus	13	0.34	-0.12
Microcanthus strigatus	82	0.50*	-0.76*
Micrognathus edmondsoni?	95	0.95*	-0.23
Mollienesia latipinna	68	-0.28	-0.78*
Mugil cephalus	28	0.19	-0.49
Mulloidichthys auriflamma	96	0.95*	-0.23
Mulloidichthys samoensis	45	0.67*	0.01
Myripristis murdjan	67	0.82*	0.05
Naso brevirostris	28	-0.30	-0.44
Naso unicornis	96	0.95*	-0.23
Omobranchus elongatus	68	-0.28	-0.77*
Opua nephodes	34	0.05	0.58*
Ostracion meagris camurum	67	0.82*	0.05
Parupeneus multifasciatus	96	0.95*	-0.23
Parupeneus pleurostigma	48	0.66*	-0.21
Parupeneus porphyreus	25	0.17	-0.47
Pervagor spilosoma	96	0.95*	-0.23
Polydactylus sexfilis	8	0.01	0.29
Priacanthus cruentatus	96	0.95*	-0.23
Saurida gracilis	40	0.60*	0.19
Scarus sordidus	96	0.95*	-0.23
Scarus sp. (juvenile)	72	0.33	0.78*
Scomberoides sancti-petri	27	-0.33	0.40
Scorpaena coniorta	96	0.95*	-0.23
Scorpaenopsis diabolus	96	0.95*	-0.23
Sphyraena barracuda	49	-0.02	-0.70*
Sphyrna lewini	8	0.04	-0.29
Stethojulis balteatus	66	0.26	-0.76*
Stolephorus purpureus	11	-0.33	-0.07
Synodus variegatus	95	0.95*	-0.23
Tilapia mossambica	33	-0.33	-0.46
Tylosurus crocodilus	11	-0.01	0.33
Upeneus arge	14	0.35	0.12
Zanclus canescens	45	0.07	0.01
Zebrasoma flavescens	62	0.19	-0.77*
Zebrasoma veliferum	58	0.32	-0.70*

* Denotes species with factor loadings ≥ 0.50 on that factor

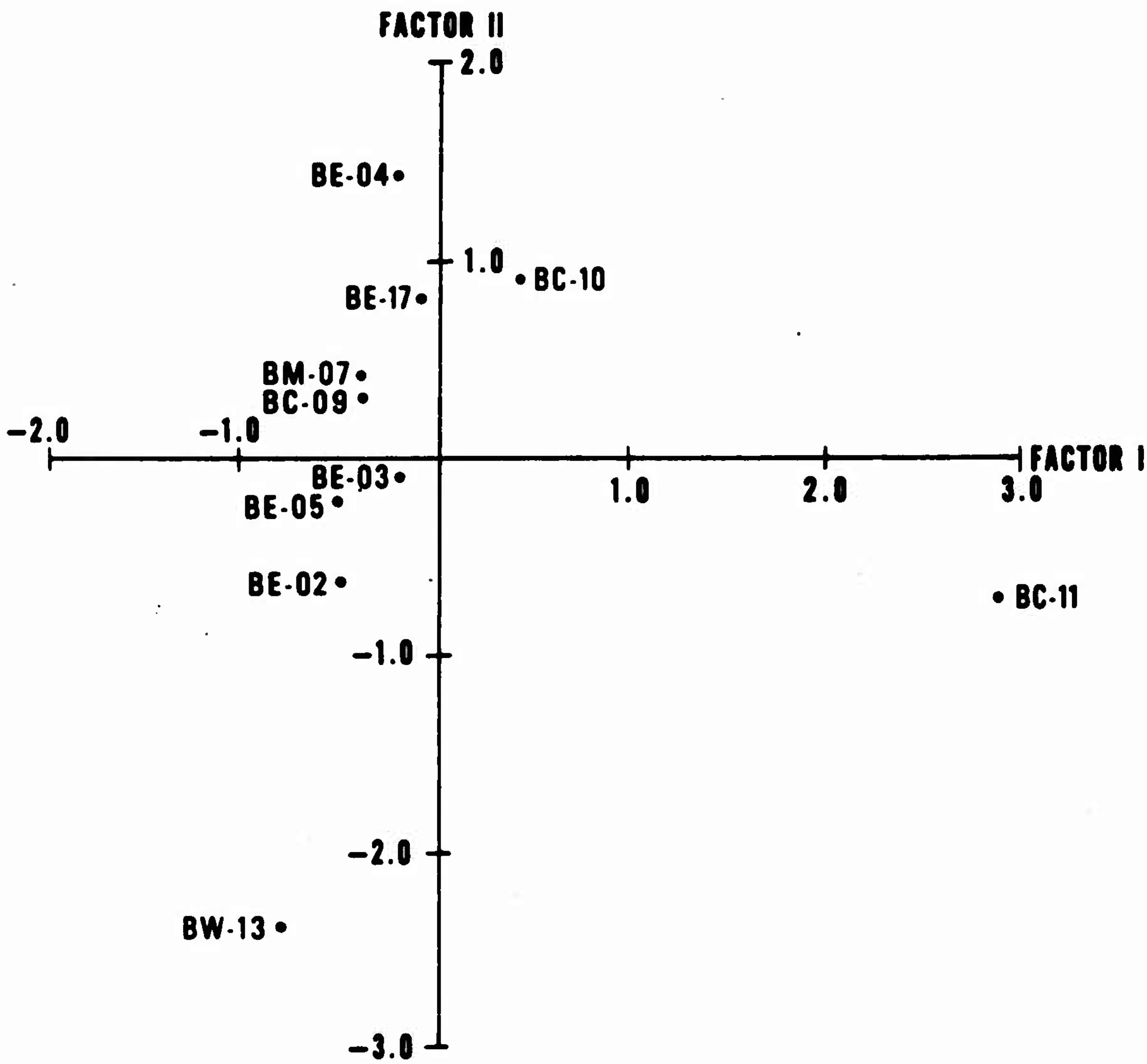


Figure 4.3-2. FACTOR SCORES FOR TEN PEARL HARBOR BIO-STATIONS. FACTORS WERE EXTRACTED FROM PRESENCE-ABSENCE DATA FOR 80 FISH SPECIES.

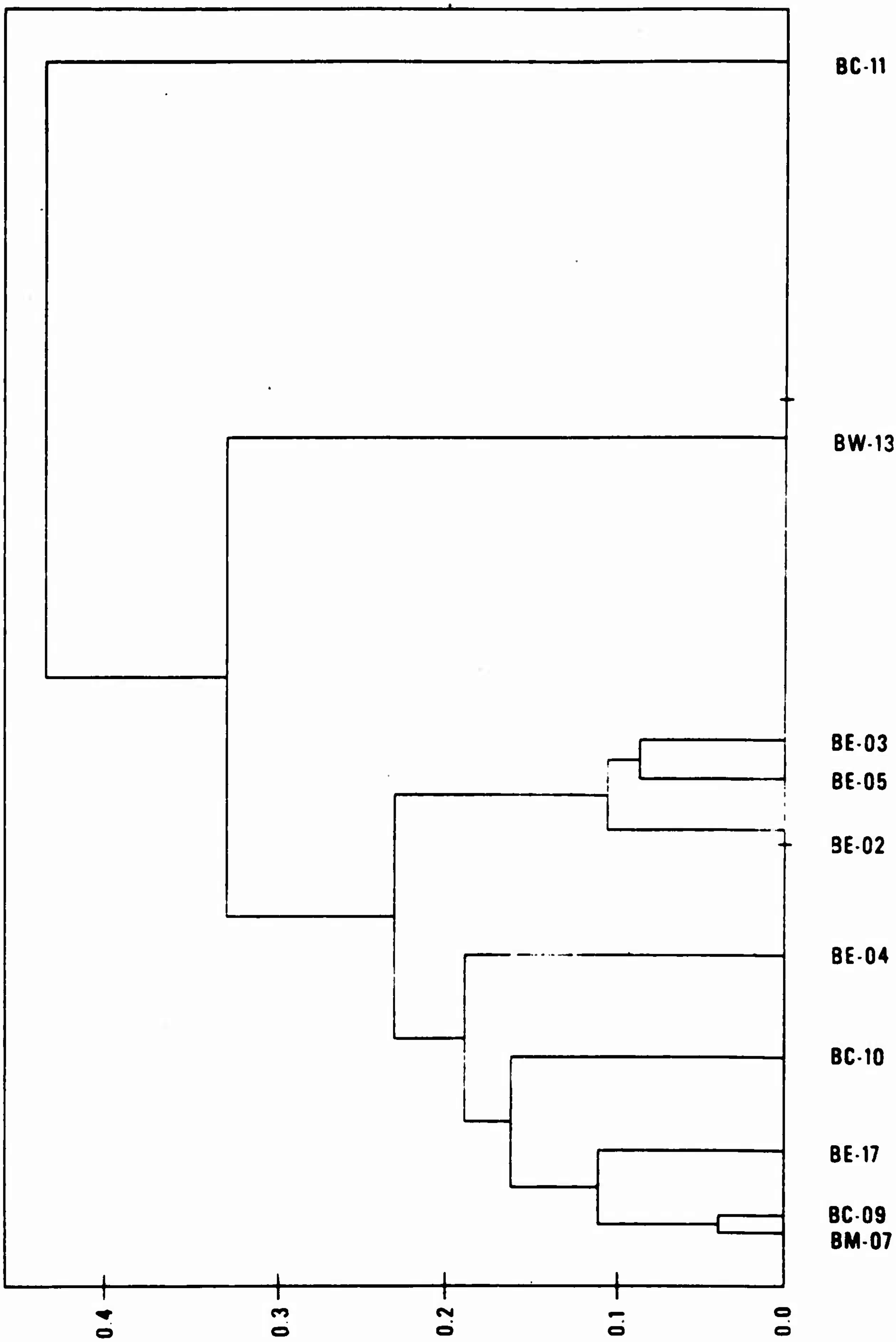


Figure 4.3-3. PEARL HARBOR FISHES P/A 2 FACTORS.

From the data presented in Section 2.1 and the preceding paragraphs, the following observations concerning fish fauna can be made: 62 of the 80 species are reported from bio-station BC-11; 40 species have factor loadings ≥ 0.50 on Factor I, and the variances of 22 of these species are almost wholly described by Factor I; and finally, the 40 species which are strongly correlated with Factor I are, on the average, present at only one bio-station, while the 21 species associated with Factor II are present at an average of four bio-stations.

These observations suggest that Factor I has delineated a group of species which are infrequently observed in Pearl Harbor, and which are largely restricted in their distribution to a single bio-station, BC-11. These results strongly suggest that the only objective separation of the 10 Pearl Harbor bio-stations is between station BC-11 and the remaining nine bio-stations.

No apparent attribute is shared by the 40 species correlated with Factor I nor the 21 species correlated with Factor II beyond the "uniqueness vs. commonness" separation just discussed. A variety of ordination techniques* with these data were employed in an attempt to sort out additional patterns. The results of all such analyses were the same: namely, that the only objective separation of the 10 bio-stations is between BC-11 and all other bio-stations, and that the pattern(s) among the remaining nine stations is solely a function of the type of analysis employed, as is demonstrated by Table 4.3-3, where from two to nine factors have been extracted from the P/A data for these 80 species of fish. It can be seen that Factor I consistently explains about 39% of the total variance, regardless of the number of factors extracted and that the remaining explained variance is more or less evenly divided among the additional factors. If additional patterns did indeed exist, a decrease in the percent variance explained by the first factor and a sequential decrease in the percent variance explained by each additional factor extracted would be expected.

The lack of consistent patterns among the nine bio-stations other than BC-11 could also indicate that the fish species found at those locations are ubiquitous in all of those environments, and that these stations cannot, therefore, be separated on basis of P/A data alone. If real differences do exist between the fish faunas of these bio-stations, then they can only be identified on the basis of the relative abundances of the fish species.

To examine the possibility that the remaining bio-stations can separate on this basis, five factors have been extracted from the abundance data for the 61 species collected at one or more bio-stations in Pearl Harbor. These five factors (Table 4.3-4) accounted for 88% of the total variance contained in the original data matrix. Once again Factor I accounts for over half of the total variance explained by the extracted factors.

The factor scores for each of these five fish abundance factors are presented graphically in Figures 4.3-4 through 4.3-8. Each factor appears

*several distance analysis strategems and frequency cutoff criteria

(Text continued on page 4.3-19)

Table 4.3-3. PERCENT OF TOTAL VARIANCE EXPLAINED BY EACH FACTOR FOR TWO TO NINE FACTORS EXTRACTED FROM P/A DATA ON 80 FISH SPECIES.

Factor Number	Number of Factors Extracted 2	3	4	5	6	7	8	9
1	39	38	39	39	39	39	39	39
2	17	16	13	13	12	12	12	11
3		15	12	12	10	10	10	9
4			12	12	10	9	8	8
5				8	10	9	8	8
6					8	8	7	7
7						7	7	7
8							6	6
9								4

Table. 4.3-4. FACTOR LOADINGS AND COMMUNALITIES FOR 61 FISH SPECIES (ABUNDANCE DATA).

Rotated Factor Matrix

FACTOR NUMBER		I	II	III	IV	V
PERCENT OF TOTAL VARIANCE		45.3	12.0	10.9	10.4	9.2
Species	Communality(%)					
Abudefduf abdominalis	91	-0.11	0.17	-0.16	-0.91*	-0.15
Abudefduf sordidus	41	-0.14	0.18	-0.26	0.38	-0.38
Acanthurus dussumieri	99	0.96*	-0.28	-0.02	0.05	-0.05
Acanthurus mata	48	0.30	0.16	-0.04	0.43	-0.42
Acanthurus olivaceus	99	0.99*	0.04	-0.03	0.04	-0.02
Acanthurus triostegus	99	0.99*	0.05	-0.05	0.08	-0.05
Acanthurus xanthopterus	41	-0.12	0.11	0.32	-0.49	-0.20
Aetobatus narinari	96	0.78*	-0.32	0.34	0.12	0.36
Albula vulpes	91	-0.06	0.13	0.37	0.13	0.86*
Antennarius chironectes	99	0.99*	0.04	-0.03	0.04	-0.02
Apogon snyderi	99	-0.03	0.04	0.03	-0.02	
Arothron hispidus	62	-0.38	0.10	-0.40	0.36	-0.43
Bothus patherinus	93	-0.09	0.13	0.95*	0.09	-0.02
Brachirus barberi	92	0.33	0.16	0.78*	0.14	0.40
Calotomus spinidens	99	0.99*	0.04	-0.03	0.04	-0.02
Carangoides gymnostethoides	93	-0.09	0.13	0.95*	0.09	-0.02
Caranx ignobilis	41	-0.14	0.18	-0.26	0.38	-0.38
Caranx mate	85	-0.17	0.08	0.90*	0.06	-0.05
Caranx melampygus	83	0.12	-0.88*	0.15	0.07	-0.11
Caranx sexfasciatus	93	-0.30	-0.87*	-0.25	-0.05	-0.14
Carapus margaritiferae	99	0.99*	0.04	-0.03	0.04	-0.02
Carcharhinus limbatus	95	-0.10	0.07	-0.15	0.08	0.95
Chaetodon auriga	99	0.76*	-0.64*	-0.04	-0.01	-0.09
Chaetodon lunula	98	0.54*	-0.83*	-0.01	0.04	-0.08
Chaetodon miliaris	99	0.79*	-0.60*	-0.02	0.05	-0.08
Chanos chanos	91	-0.13	0.07	-0.05	-0.11	0.93*
Cheilio inermis	99	0.99*	0.04	-0.03	0.04	-0.02
Conger marginatus	99	0.90*	-0.41	-0.04	0.06	-0.08
Diodon hystrix	99	0.99*	0.04	-0.03	0.04	-0.02
Elops hawaiiensis	96	-0.26	0.05	-0.16	-0.84*	0.40
Entomacrodus marmoratus	99	0.99*	0.04	-0.03	0.04	-0.02
Exallias brevis	99	0.99*	0.04	-0.03	0.04	-0.02
Flammeo sammara	97	-0.07	-0.98*	0.00	0.02	-0.08
Gnatholepis anjerensis	95	-0.12	-0.64*	0.71*	0.08	-0.08
Gymnothrax flavimarginatus	99	0.99*	0.04	-0.03	0.04	-0.02
Gymnothorax undulatus	96	0.89*	-0.18	0.21	-0.21	0.22
Kuhlia sandvicensis	92	-0.18	-0.45	0.81*	0.07	-0.09
Kyphosus cinerascens	99	0.99*	0.04	-0.03	0.04	-0.02
Lutjanus fulvus	58	0.41	0.31	-0.32	-0.39	-0.26
Microcanthus strigatus	99	0.99*	0.04	-0.03	0.04	-0.02
Mugil cephalus	51	0.01	0.18	-0.01	0.06	0.69*
Mulloidicthys auriflamma	99	0.99*	0.04	-0.03	0.04	-0.02
Mulloidicthys samoensis	99	0.99*	0.05	-0.05	0.07	-0.05
Naso brevirostris	94	-0.11	-0.53*	-0.08	-0.79*	-0.15
Naso unicornis	99	0.99*	0.04	-0.03	0.04	-0.02

Table 4.3-4. CONTINUED.

FACTOR NUMBER		I	II	III	IV	V
PERCENT OF TOTAL VARIANCE		45.3	12.0	10.9	10.4	9.2
Species	Communality(%)					
Omobranchus elongatus	93	-0.09	0.13	0.95*	0.09	-0.02
Opua nephodes	64	-0.16	-0.77*	-0.11	0.08	-0.06
Parupeneus porphyreus	72	-.28	0.25	-0.34	-0.57*	-0.38
Polydactylus sexfilis	95	-0.10	-0.95*	-0.04	0.04	0.18
Priacanthus cruentatus	99	0.99*	0.04	-0.03	0.04	-0.02
Saurida gracilis	99	0.99*	0.04	-0.03	0.04	-0.02
Scarus sordidus	99	0.99*	0.04	-0.03	0.04	-0.02
Scomberoides sancti-petri	91	-0.13	0.13	-0.17	-0.92*	0.09
Scorpaena coniorta	99	0.99*	0.04	-0.03	0.04	-0.02
Scorpaenopsis diabolus	99	0.99*	0.04	-0.03	0.04	-0.02
Sphyraena barracuda	57	-0.20	0.29	-0.36	0.41	-0.39
Sphyrna lewini	80	-0.24	-0.00	-0.06	-0.86*	0.06
Stethojulis balteatus	99	0.99	0.04	-0.03	0.04	-0.02
Stolephorus purpureus	15	-0.13	0.20	-0.22	0.16	-0.14
Upeneus arge	92	-0.15	0.06	-0.22	0.06	0.91*
Zebrasoma veliferum	94	-0.08	0.12	-0.10	-0.95*	-0.12

* Denotes species with factor loadings ≥ 0.50 on that factor

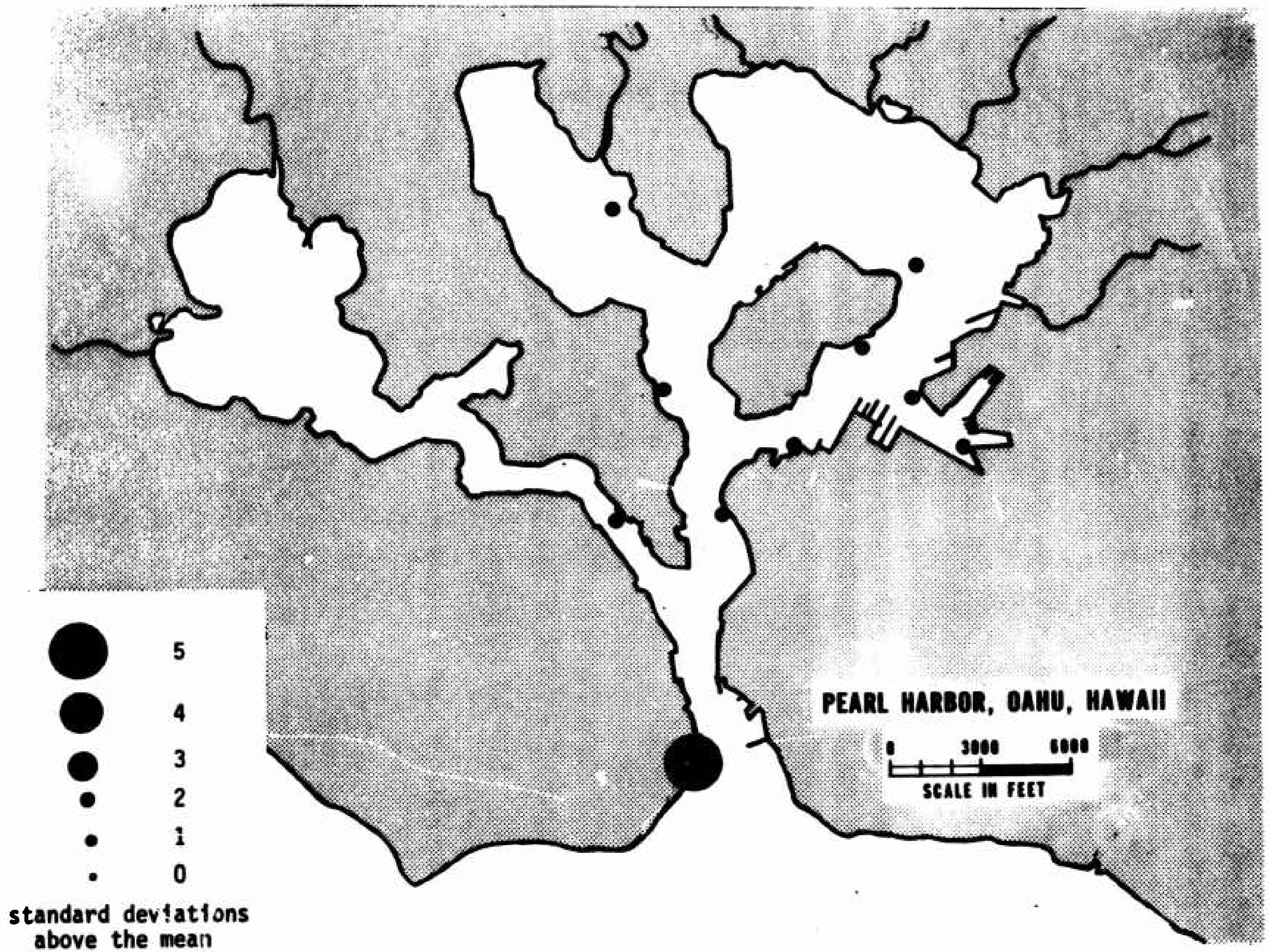


Figure 4.3-4. FACTOR SCORES FOR 10 BIO-STATIONS: FACTOR I.
SCORES WERE CLACULATED FROM ABUNDANCE DATA FOR 61 FISH SPECIES.

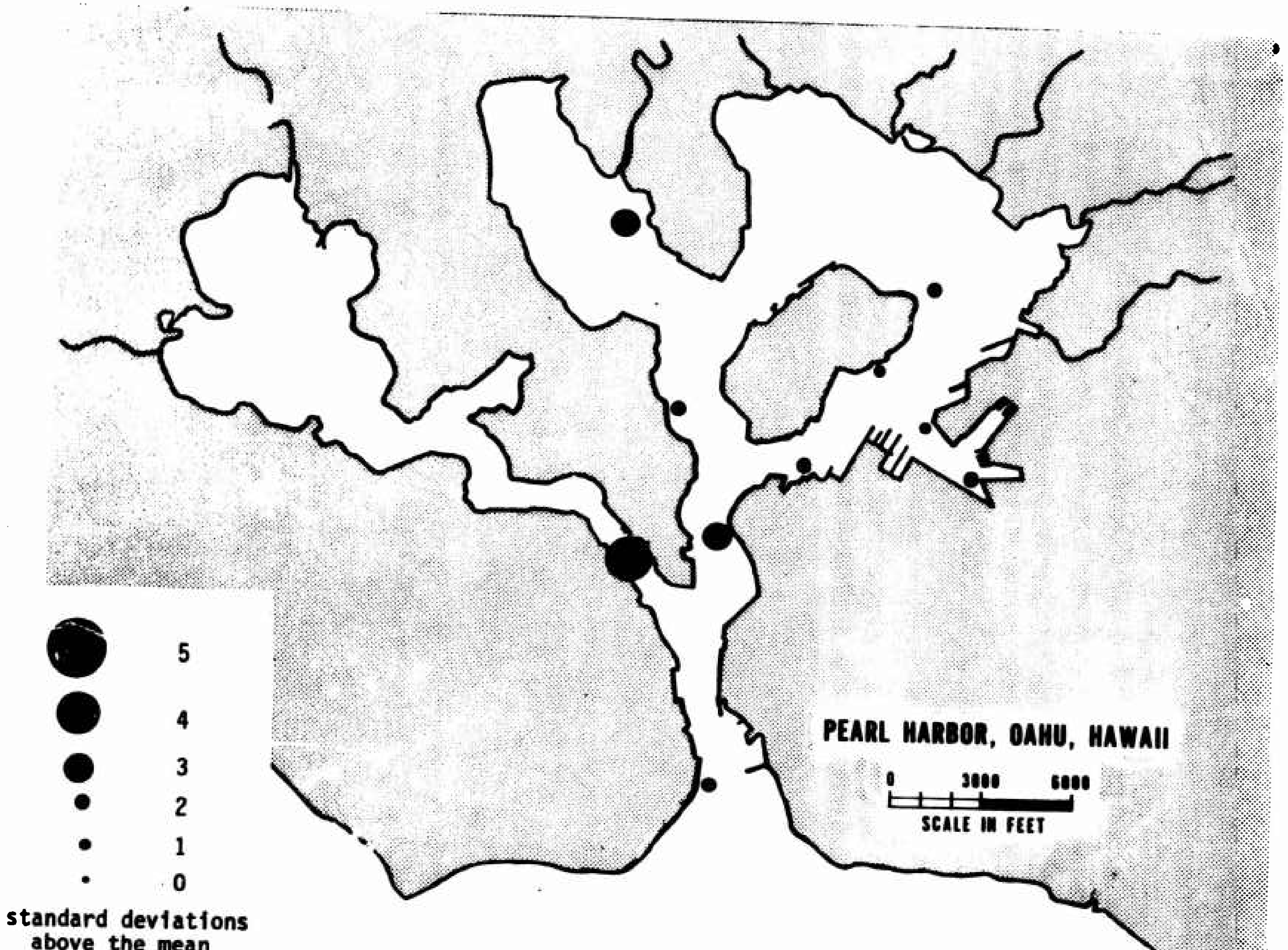


Figure 4.3-5. FACTOR SCORES FOR 10 BIO-STATIONS: FACTOR II.
SCORES WERE CALCULATED FROM ABUNDANCE DATA FOR 61 FISH SPECIES.

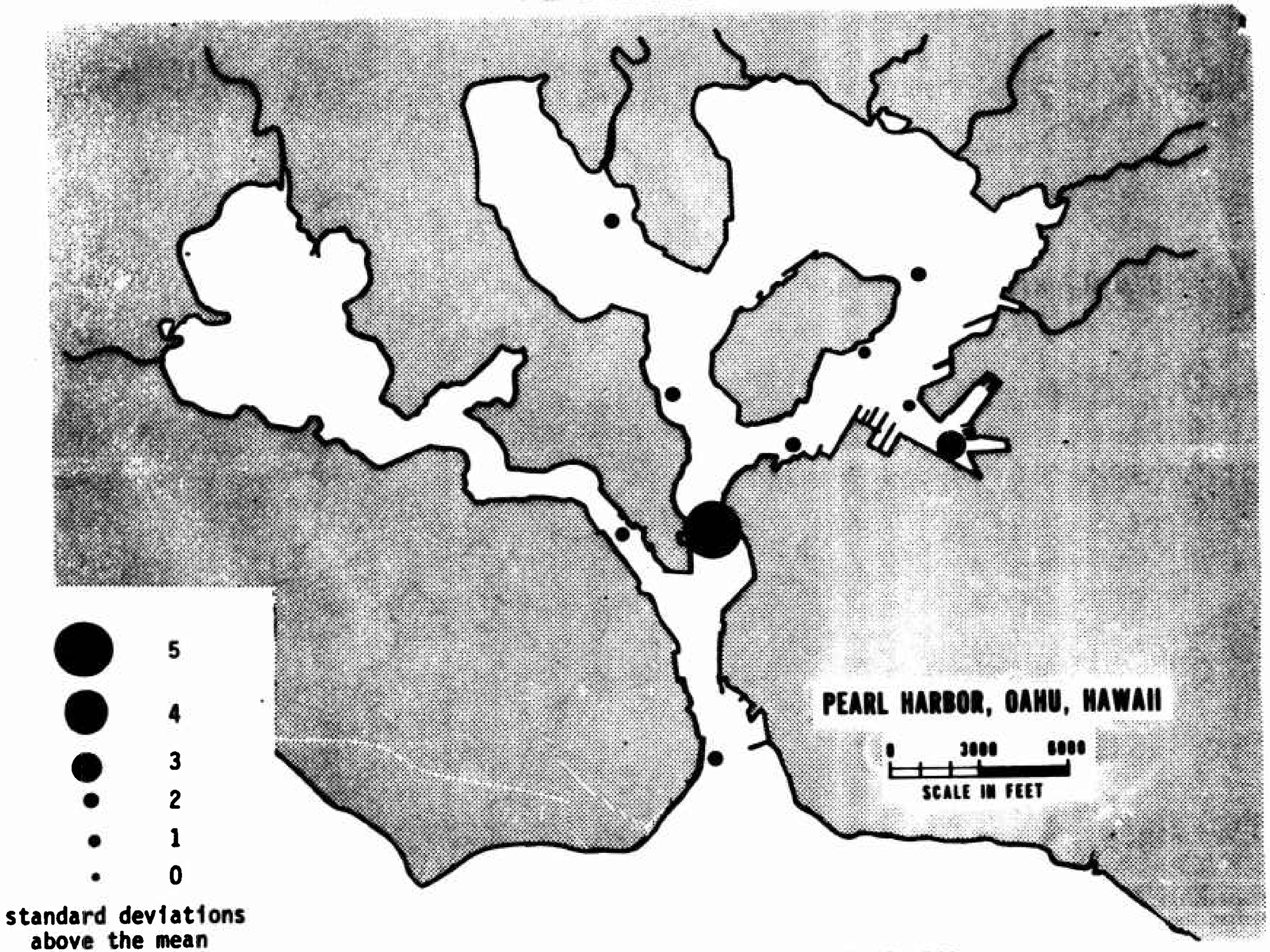


Figure 4.3-6. FACTOR SCORES FOR 10 BIO-STATIONS: FACTOR III. SCORES WERE CALCULATED FROM ABUNDANCE DATA FOR 61 FISH SPECIES.

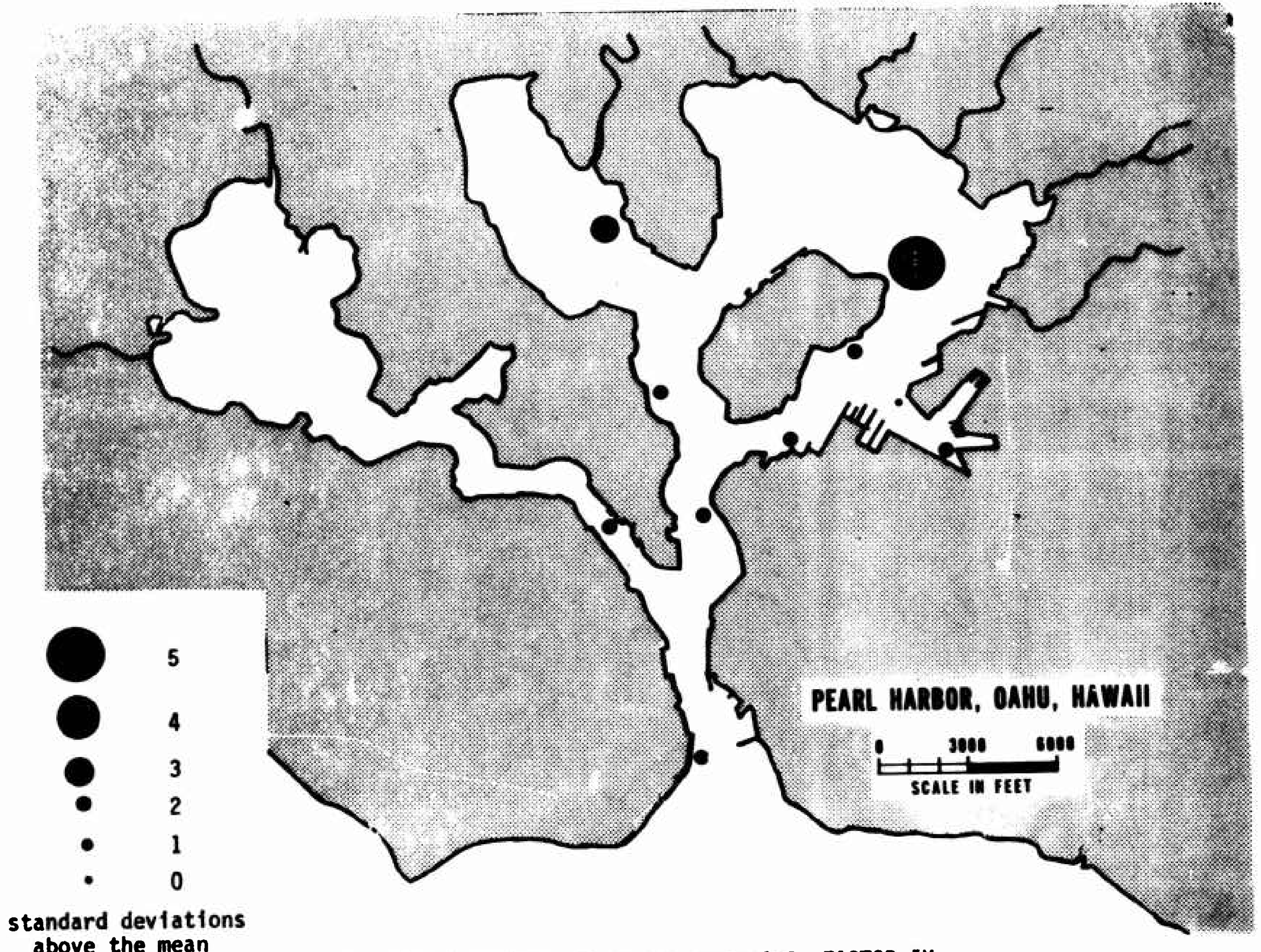


Figure 4.3-7. FACTOR SCORES FOR 10 BIO-STATIONS: FACTOR IV. SCORES WERE CALCULATED FROM ABUNDANCE DATA FOR 61 FISH SPECIES.

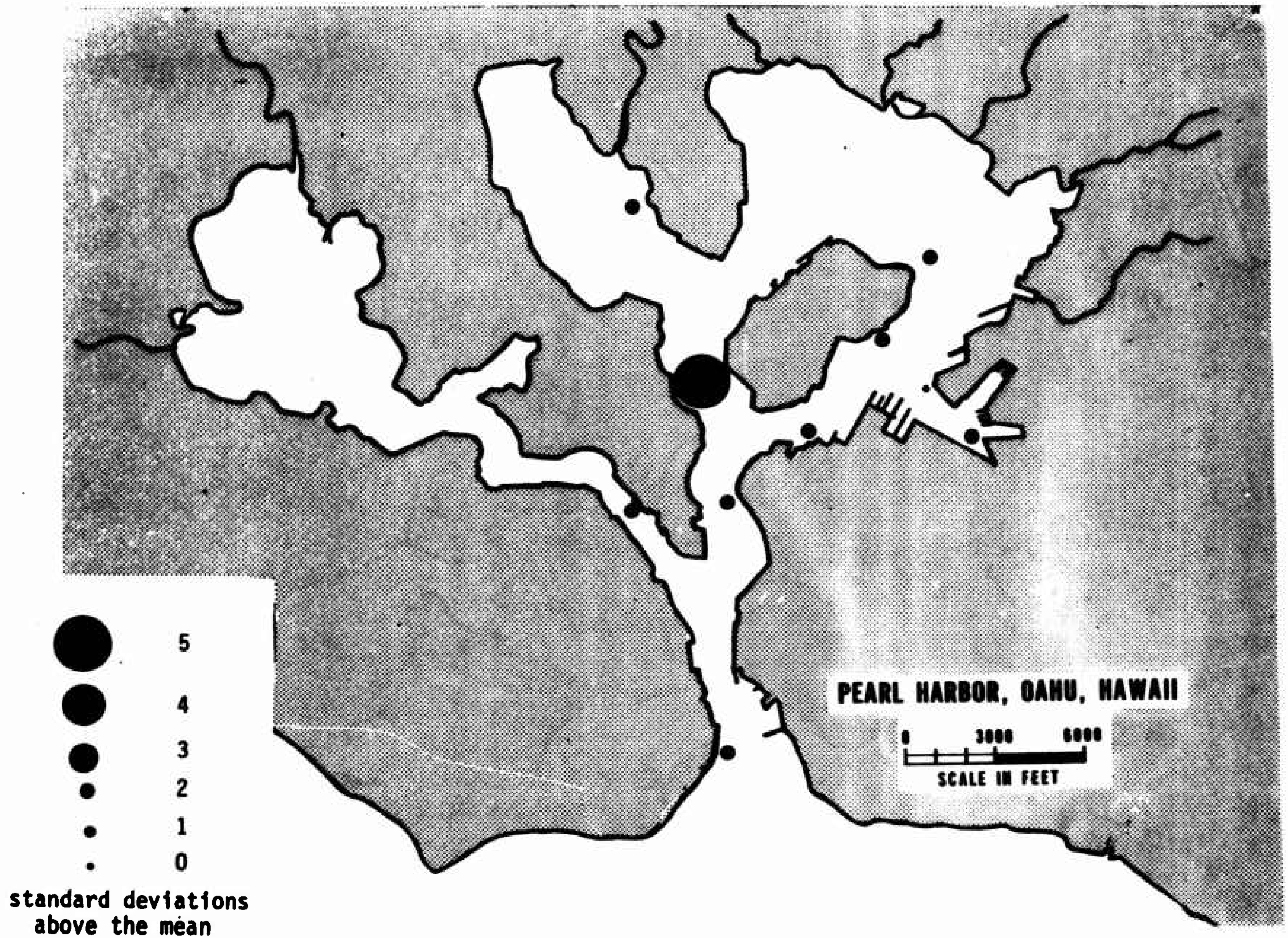


Figure 4.3-8. FACTOR SCORES FOR 10 BIO-STATIONS: FACTOR V.
SCORES WERE CALCULATED FROM ABUNDANCE DATA FOR 61 FISH SPECIES.

to be related to only one bio-station. Factor I, which accounts for 45% of the total explained variance, is again associated with station BC-11. Of the species having the highest correlations (factor loadings ≥ 0.50) on Factor I, 26 species were either collected only at BC-11 or are most abundant there. This number represents almost half of all the species collected at the 10 bio-stations in Pearl Harbor. In fact, if this same comparison is made for each of the five factors (Figure 4.3-9) the factors are seen to rank the five bio-stations having one or more species unique to or most abundant at one of these five locations. As was the case with the P/A fish data (Figures 4.3-1 through 4.3-3), the only definitive separation of the 10 bio-stations on the basis of the fish abundance data is between BC-11 and all other stations. Since none of the factors is bipolar and the highest factor score for each factor has the same sign as the species with the strongest correlations with that factor, these bio-stations can be assumed to be directly related to whatever attributes are shared in common by those species.

Most of the species with high correlations on Factor I are associated with hard substrates. For example, Factor I includes all of the eels (Muraenidae and Congridae), rockfishes (Scorpaenidae), wrasses (Labridae), parrotfishes (Scaridae) and butterflyfishes (Chaetodontidae) and none of the jacks (Carangidae) or damselfishes (Pomacentridae), both of which are mid-water carnivores. The apparent trend among the factors is one of a decrease in the number of species associated with hard substrates with increasing factor number, so that Factor V includes only one species of shark (*Carcharinus limbatus*) and four species which feed over soft substrates (sand or mud). A similar correlation with substrate has also been observed for the fishes of Kaneohe Bay (References 4.3-1 and 4.3-2). However, since the factors are orthogonal (uncorrelated) to one another, the trend is not simply one of the "degree of hard-bottomness". For example, three of the species (*Albula vulpes*, *Chanos chanos*, and *Mugil cephalus*) that are correlated with Factor V are also common to estuarine environments in the Hawaiian Islands. Other variables, such as salinity, not accommodated by the extracted factors may be involved. Moreover, while the trends among the five bio-stations associated with these factors are consistent, individually Factors II through V each account for only about 10% of the total variance explained. Collectively these four factors account for about the same total explained variance as does Factor I alone. Thus again it must be concluded that the most objective separation of the 10 bio-stations on the basis of fish abundance data is between BC-11 and the other nine stations. This separation might be termed "reef vs. harbor", recognizing that the preference of a given species for either of these macro-environments represents more than a simple uni-variate dichotomy.

The results of the latter analyses demonstrate how the use of abundance data can add to the interpretation of environmental pattern while still maintaining the same basic relationships defined on the basis of the P/A data. Each bit of P/A data is restricted to a simple binary "yes-no" choice, while no such limitation is placed on the abundance data. It is encouraging, therefore, that the same relationships can be extracted with either type of data, for abundance data are frequently unavailable or not strictly comparable.

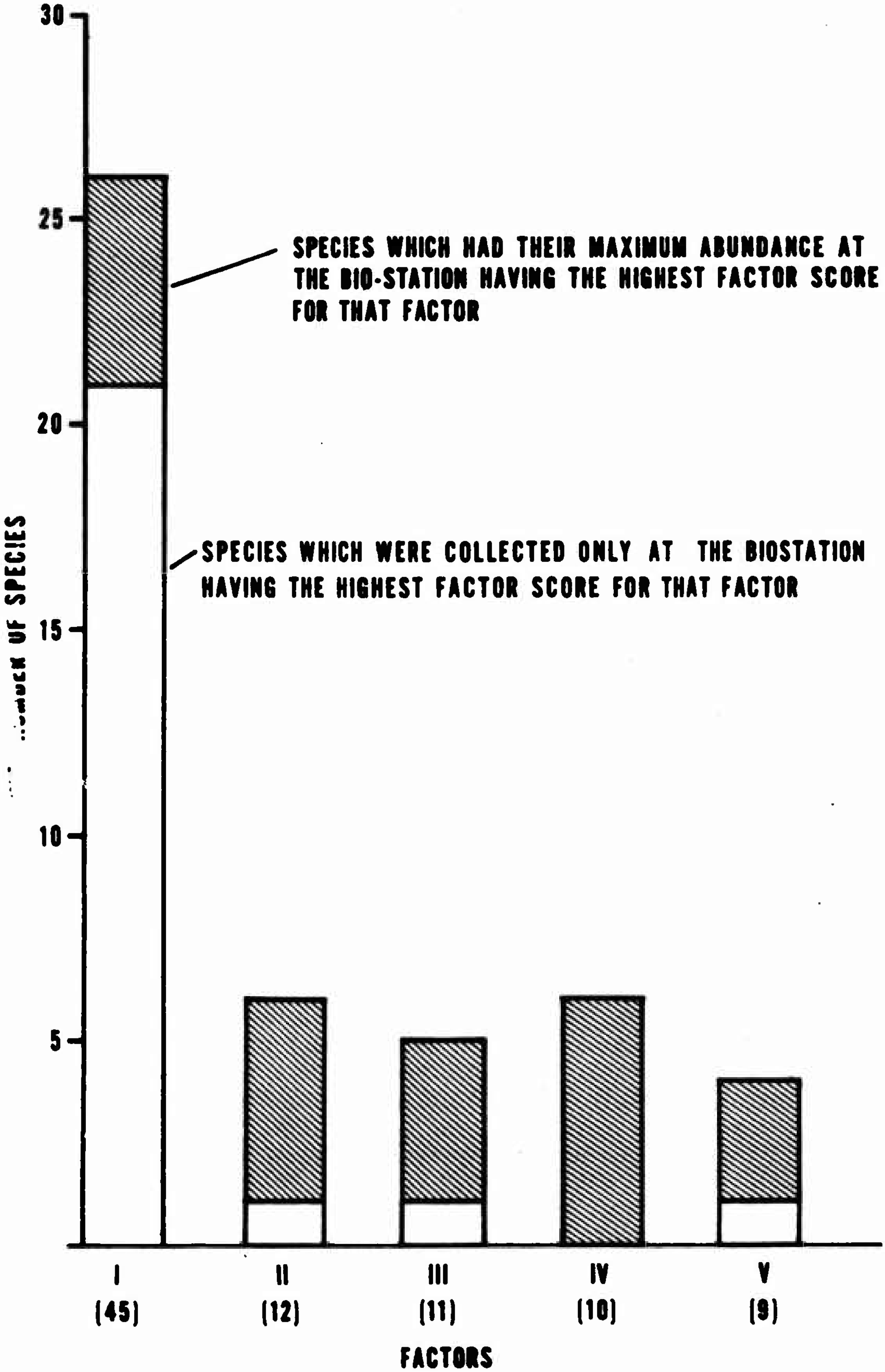


Figure 4.3-9. NUMBERS OF FISH SPECIES HAVING THEIR MAXIMUM ABUNDANCE AT THE BIO-STATION WITH THE HIGHEST SCORE FOR THAT FACTOR. FACTORS WERE EXTRACTED FROM ABUNDANCE DATA FOR 61 FISH SPECIES. NUMBERS IN PARENTHESES ARE THE TOTAL VARIANCE EXPLAINED BY EACH FACTOR.

The inability to identify additional patterns among the Pearl Harbor fish data could also be a consequence of the characteristics of the harbor's fish fauna and/or the methods of analysis. Three alternatives appear possible in this regard. First, there may not be any additional patterns characteristic of the Pearl Harbor fish fauna, and thus the analyses have identified the only consistent patterns to be found. This alternative would imply that the "harbor" faunal assemblage is more or less homogenous and does not reflect any variation in environmental conditions which might occur there. Second, characteristic differences in the abundance and distribution of fishes may actually exist between the nine "harbor" bio-stations, but the collected data are insufficient to detect them. The only recourse in this eventuality would be to gather more detailed information on the distribution and abundance of fishes in Pearl Harbor. And finally, additional patterns may exist in the data collected, but the analyses used have been unable to detect them.

Obviously, the first two alternatives cannot be tested without additional data from Pearl Harbor. The third alternative can, however, be examined by applying the analytical procedures used with the Pearl Harbor data to similar data from an area with apparent differences in the abundance and/or distribution of fishes between sampling sites. The data reported by Devaney and Whistler (Reference 4.3-3) for Kaalualu Bay, Hawaii have been used for this purpose. These particular data were selected because: 1) all observations were made using the same sampling technique (visual transects); 2) abundances are available for each species present at a given sampling site; 3) the number of species (43) and the number of cases (28 "transects") are roughly comparable to the Pearl Harbor data; and 4) Kaalualu Bay is a nearshore environment with obvious freshwater and terrigenous influences; thus, the biota to be found there may be responding to some of the same environmental conditions to be found in Pearl Harbor.

A total of 43 species of fish are present at 2 to 27 of sampling sites in Kaalualu Bay; no species is present at all 28 sites. The means and standard deviations for these 43 species are presented in Table 4.3-5. It should also be noted that 17 of these 43 species are also reported from Pearl Harbor. The analysis of the Kaalualu Bay fish fauna is restricted to the P/A data since both the P/A and the abundance analyses produce similar results.

Three factors were extracted from the P/A data for the 43 species listed in Table 4.3-5. These three factors explain 60% of the variation contained in the original data matrix, with Factor I accounting for only 26% of the explained variance. The factor loadings and communalities for each of the 43 species are presented in Table 4.3-6.

The distribution of communalities (Figure 4.3-10) for these 43 species shows no definition trend in the ranges associated with each factor. Nor are the factors simply ranking the number or average frequencies of these species (Table 4.3-6), as was the case with the Pearl Harbor fish data.

Table 4.3-5. MEANS AND STANDARD DEVIATIONS FOR THE 43 SPECIES OF FISH (PRESENCE-ABSENCE ONLY) REPORTED FROM KAALUALU BAY, HAWAII BE DEVANEY AND WHISTLER (1972).

Species	Mean*	Standard Deviation
Fistularia potimba	0.11	0.32
*Kuhlia sandivecensis***	0.11	0.32
*Apogon snyderi***	0.11	0.32
*Mulloidichthys samoensis***	0.11	0.32
*Parupeneus porphyreus***	0.57	0.50
*Parupeneus multifasciatus***	0.18	0.39
*Chaetodon lunula***	0.18	0.39
Chaetodon ornatissimus	0.11	0.32
Chaetodon multicinctus	0.14	0.36
*Abudefduf abdominalis***	0.50	0.51
Abudefduf imparipennis	0.07	0.26
Plectroglyphidodon johnstonianus	0.54	0.51
Pomacentrus jenkinsi	0.32	0.48
Chromis vanderbilti	0.18	0.39
Chromis leucurus	0.07	0.26
Paracirrhites arcatus	0.18	0.39
Cirrhitops fasciatus	0.25	0.44
Juvenile labrids	0.11	0.32
Pseudocheilinus octotaenia	0.07	0.26
*Labroides phthirophagus***	0.11	0.32
Pseudocheilinus tetrataenia	0.14	0.36
Thalassoma dupperreyi	0.64	0.49
Thalassoma purpureum	0.21	0.42
Thalassoma ballieui	0.14	0.36
Gomphosus varius	0.29	0.46
Coris venusta	0.07	0.26
*Stethojulis balteatus***	0.89	0.32
Macropharyngodon geoffroyi	0.11	0.32
*Scarus sordidus***	0.39	0.50
Cirripectus variolosus	0.46	0.51
Runula goslinei	0.21	0.42
*Bathygobius fuscus***	0.25	0.44
*Asterropteryx semipunctatus***	0.39	0.50
*Acanthurus triostegus***	0.82	0.39
Acanthurus leucopareius	0.07	0.26
Acanthurus nigrofuscus	0.14	0.36
Acanthurus nigroris	0.07	0.26
*Acanthurus olivaceus***	0.11	0.32
*Ctenochaetus strigosus**	0.11	0.32
*Zebrasoma flavescens***	0.11	0.32
Sufflamen bursa	0.07	0.26
*Canthigaster jactator***	0.18	0.39
Canthigaster amboinensis	0.18	0.39

*Mean presence is equivalent to frequency of occurrence.
**Denotes species also reported from Pearl Harbor by PHBS.

Table 4.3-6. FACTOR LOADING AND COMMUNALITIES FOR 43 FISH SPECIES (PRESENCE-ABSENCE ONLY) REPORTED FROM KAALUALU BAY, HAWAII BY DEVANEY AND WHISTLER (1972).

Rotated Factor Matrix

FACTOR NUMBER		I	II	III
PERCENT OF TOTAL VARIANCE		26.3	19.7	14.4
Species	**Communality(%)**			
Fistularia potimba	8	-0.09	-0.05	0.26
Kuhlia sandivecensis	38	-0.01	0.06	0.61*
Apogon snyderi	68	0.81*	0.01	0.17
Mulloidichthys samoensis	31	-0.10	0.53*	0.15
Parupeneus porphyreus	26	-0.39	-0.20	0.27
Parupeneus multifasciatus	63	0.19	0.61*	-0.47
Chaetodon lunula	48	-0.14	0.68*	0.04
Chaetodon ornatissimus	71	0.76*	0.29	-0.20
Chaetodon multicinctus	96	0.70*	0.64*	-0.25
Abudefduf abdominalis	18	-0.37	-0.19	0.10
Abudefduf imparipennis	90	-0.02	0.91*	-0.28
Plectroglyphidodon johnstonianus	67	0.23	0.04	-0.79*
Pomacentrus jenkinsi	67	0.41	0.26	-0.66*
Chromis vanderbilti	81	0.64*	0.51*	-0.38
Chromis leucurus	94	0.97*	-0.04	-0.06
Paracirrhites arcatus	77	0.66*	0.55*	-0.19
Cirrhitops fasciatus	61	0.53*	0.38	-0.43
Juvenile labrids	91	0.36	0.84*	-0.26
Pseudocheilinus octotaenia	94	0.97*	-0.04	-0.06
Labroides phthirophagus	72	0.80*	-0.12	-0.24
Pseudocheilinus tetrataenia	96	0.70*	0.64*	-0.25
Thalassoma dupperreyi	66	0.12	0.03	-0.80*
Thalassoma purpureum	7	-0.19	-0.17	-0.05
Thalassoma ballieui	96	0.70*	0.64*	-0.25
Gomphosus varius	51	0.45	0.34	-0.44
Coris venusta	3	-0.04	-0.14	-0.09
Stethojulis balteatus	30	-0.46	0.17	-0.23
Macropharyngodon geoffroyi	87	0.83*	0.40	-0.12
Scarus sordidus	58	0.01	0.28	-0.71*
Cirripectus variolosus	40	-0.06	-0.04	-0.45
Runula goslinei	38	-0.23	0.04	-0.57*
Bathygobius fuscus	57	-0.14	0.09	0.74*
Asterropteryx semipunctatus	68	-0.23	0.03	0.79*
Acanthurus triostegus	5	0.06	0.20	0.07
Acanthurus leucopareius	65	0.49	0.63*	-0.13
Acanthurus nigrofuscus	96	0.70*	0.64*	-0.25
Acanthurus nigroris	90	-0.02	0.91*	-0.28
Acanthurus olivaceus	91	0.36	0.84*	-0.26
Ctenochaetus strigosus	71	0.82*	-0.13	-0.15
Zebrasoma flavescens	87	0.83*	0.40	-0.12
Sufflamen bursa	65	0.49	0.63*	-0.13
Canthigaster jactator	54	0.65*	0.21	-0.26
Canthigaster amboinensis	16	0.22	0.17	-0.28

* Denotes species with factor loading ≥ 0.50.

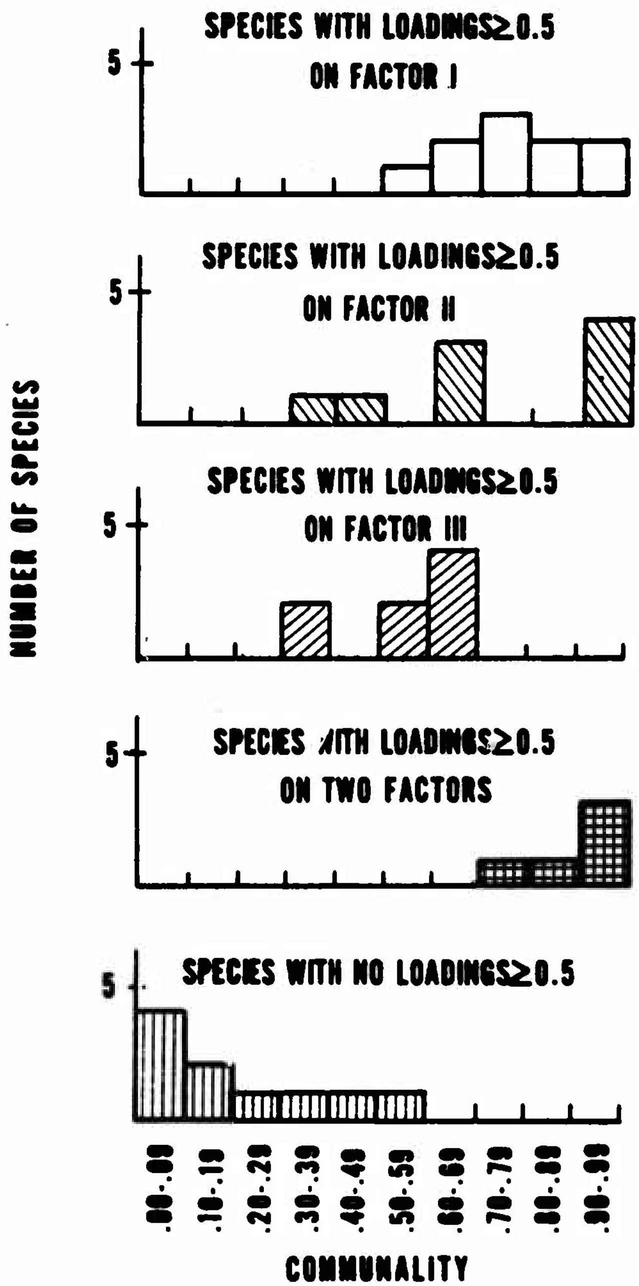
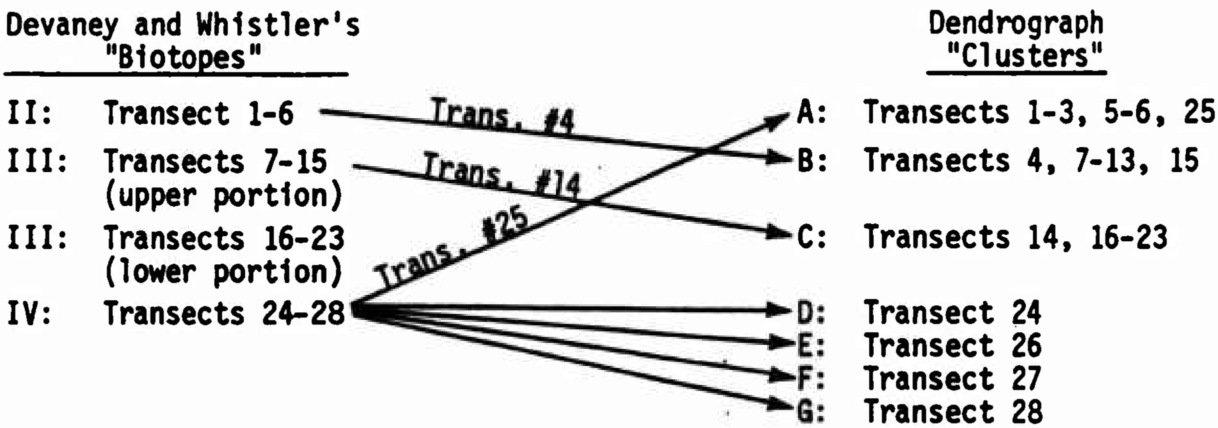


Figure 4.3-10. COMMUNALITIES FOR THE 43 SPECIES OF FISH REPORTED FROM KAALUALU BAY, HAWAII BY DEVANEY AND WHISTLER (1972). VALUES ARE BASED ON THREE FACTORS EXTRACTED FROM THE PRESENCE-ABSENCE DATA FOR THESE SPECIES.

The significance of the factors extracted from the Kaalualu Bay fish data can be illustrated by mapping the factor scores (Figure 4.3-11 to 4.3-13) and by examining a dendrograph generated from these scores (Figure 4.3-14). The dendrograph, in particular, shows three clusters and four singularities. If these seven entities or "clusters" are plotted on a map of Kaalualu Bay (Figure 4.3-15), each "cluster" is seen to delimit a group of transect sites in spatial proximity to one another.

Beyond the fact that the analyses have identified a half dozen or so patterns among the fish species reported from Kaalualu Bay, it is interesting to compare the results of these analyses with those of Devaney and Whistler. These authors recognized four "biotopes" within Kaalualu Bay, based on their evaluations of the physiography and faunal assemblages they observed. Data from three of these biotopes have been factor analyzed. When the "clusters" determined by such analyses are compared with Devaney and Whistler's "biotopes", a high degree of correlation between the two classification systems is apparent:



It is particularly satisfying that, without ever having visited Kaalualu Bay, essentially the same patterns have been extracted from the transect data as those determined by Devaney and Whistler, who had the additional advantage of direct observation. Furthermore, the discrepancies between the two classification systems are themselves quite informative. For example, Devaney and Whistler report for Transect 4 that "the first live coral was noted at the S end of [this] transect". Of the remaining five transects in Biotope II, only Transect 5 had any live coral. The water depth at Transect 4 was nearly twice that at Transect 5 and quite similar to the water depths for the transects within the upper portion of Biotope III (Cluster B). While Devaney and Whistler treated Transect 4 as an unexplained anomaly, multivariate analysis suggests that the transect is in fact an extension of Biotope III. Devaney and Whistler also report "...12 heads of *Pocillopora damicornis* [coral]..." from Transect 14 and that this was the only record of this coral species at any of the transects in the upper portion of Biotope III, although another coral species, *Porites lobata*, was reported from Transect 15. Again Transect 14 (and Transect 15) had water depths quite similar to those found in Cluster C, where

(Text continued on page 4.3-31)

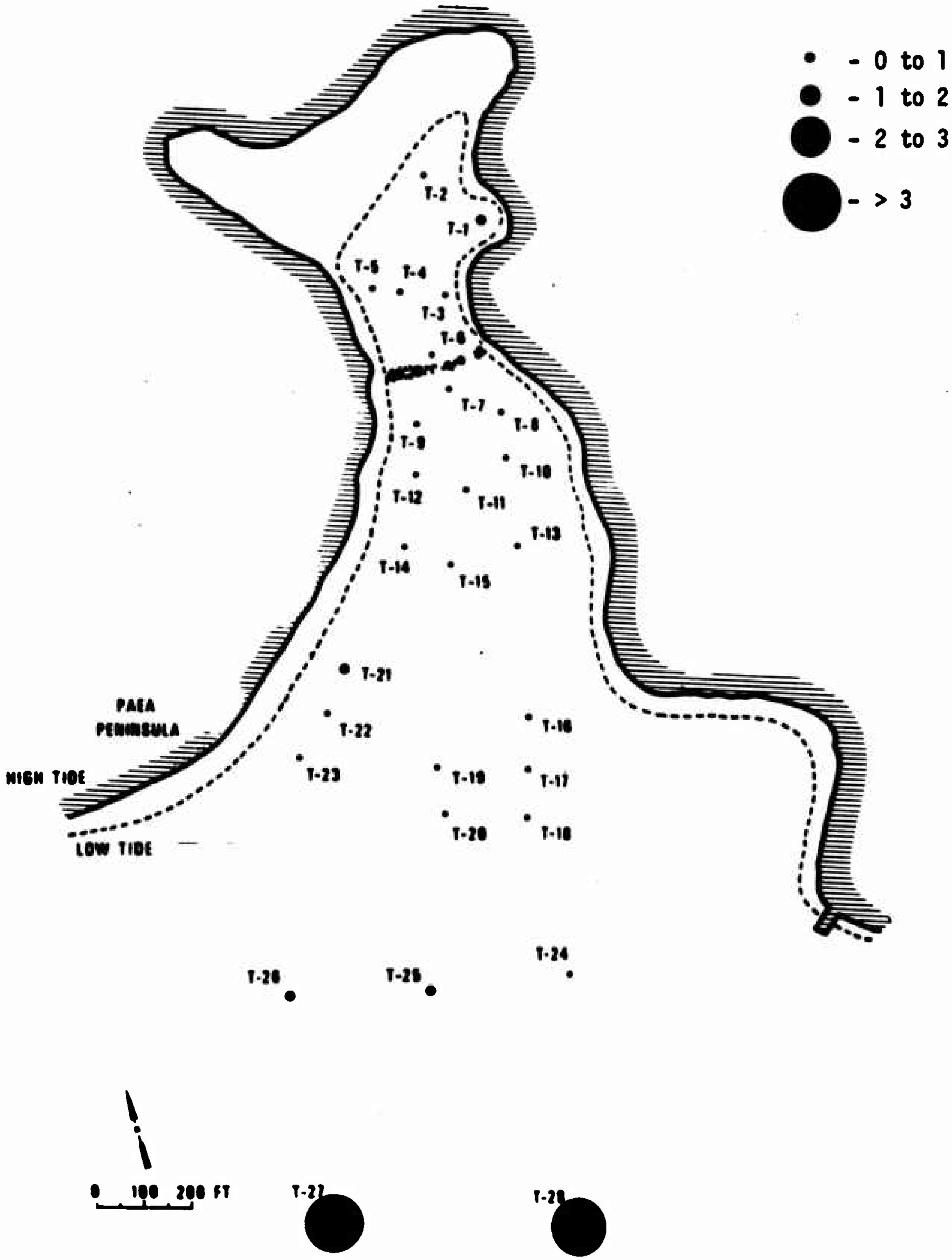


Figure 4.3-11. FACTOR SCORES FOR 28 TRANSECT SITES, KAALUALU BAY, HAWAII: FACTOR I. MAP REDRAWN FROM DEVANEY AND WHISTLER (1972).

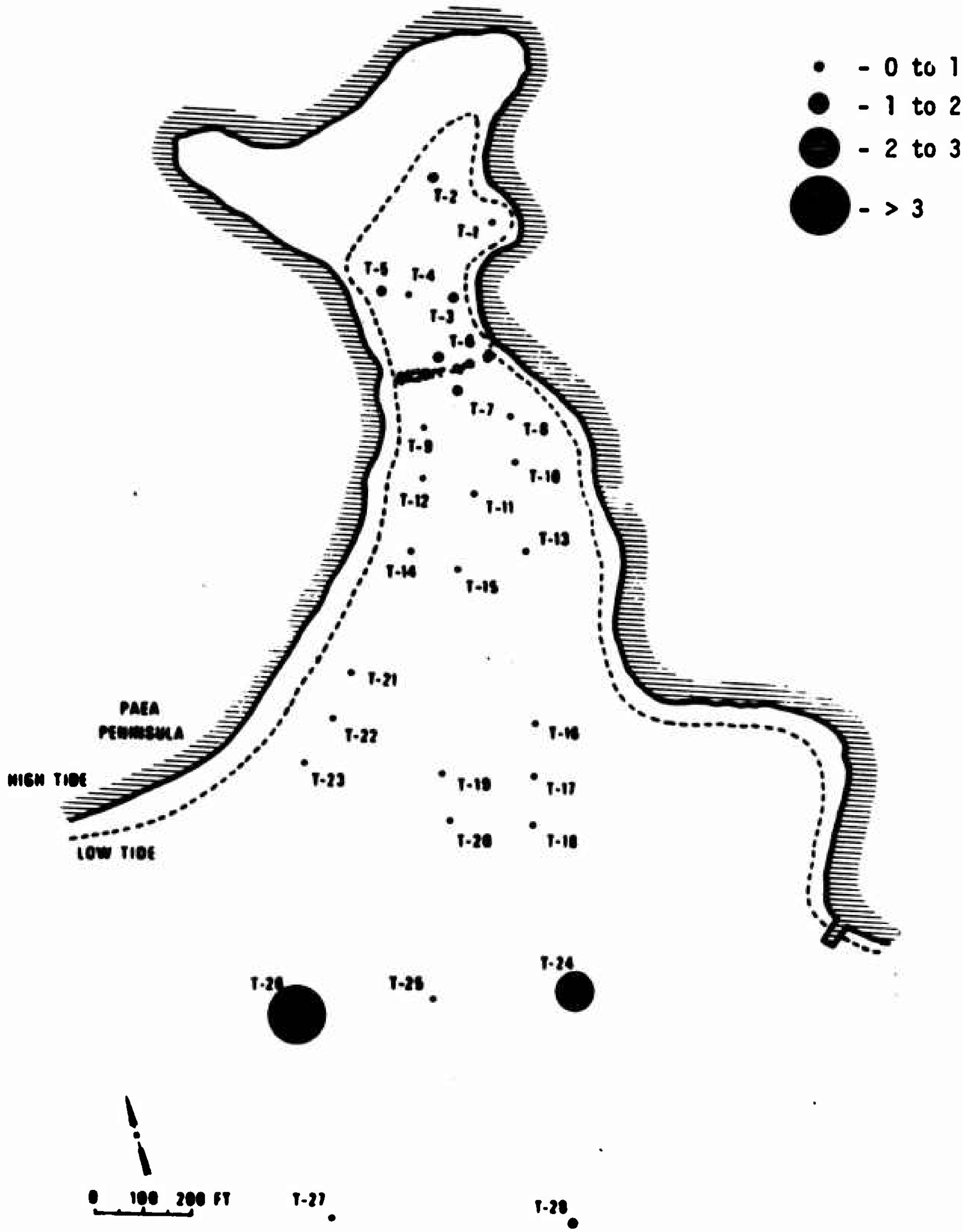


Figure 4.3-12. FACTOR SCORES FOR 28 TRANSECT SITES, KAALUALU BAY, HAWAII: FACTOR II. MAP REDRAWN FROM DEVANEY AND WHISTLER (1972).

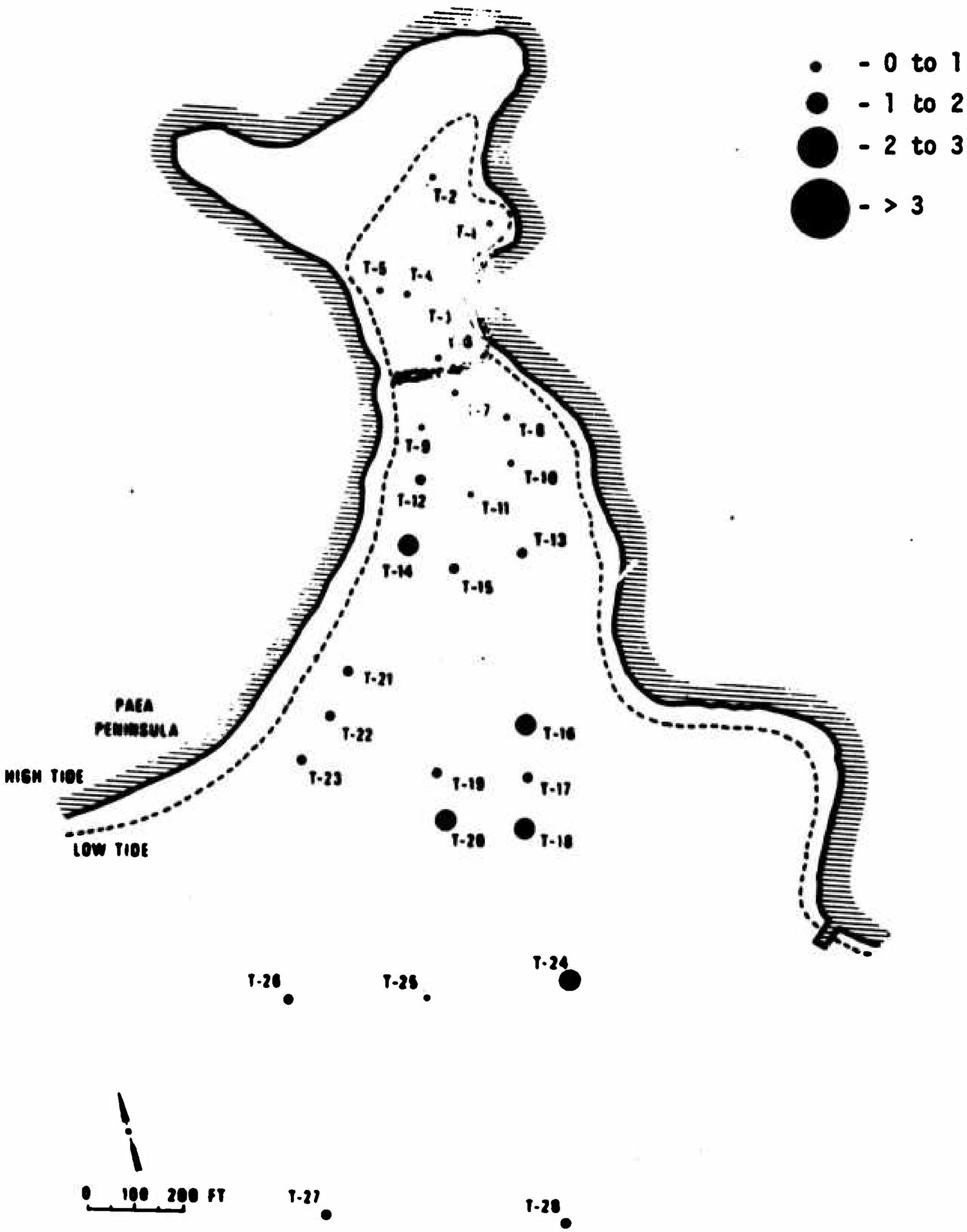


Figure 4.3-13. FACTOR SCORES FOR 28 TRANSECT SITES, KAALUALU BAY, HAWAII: FACTOR III. MAP REDRAWN FROM DEVANEY AND WHISTLER (1972).

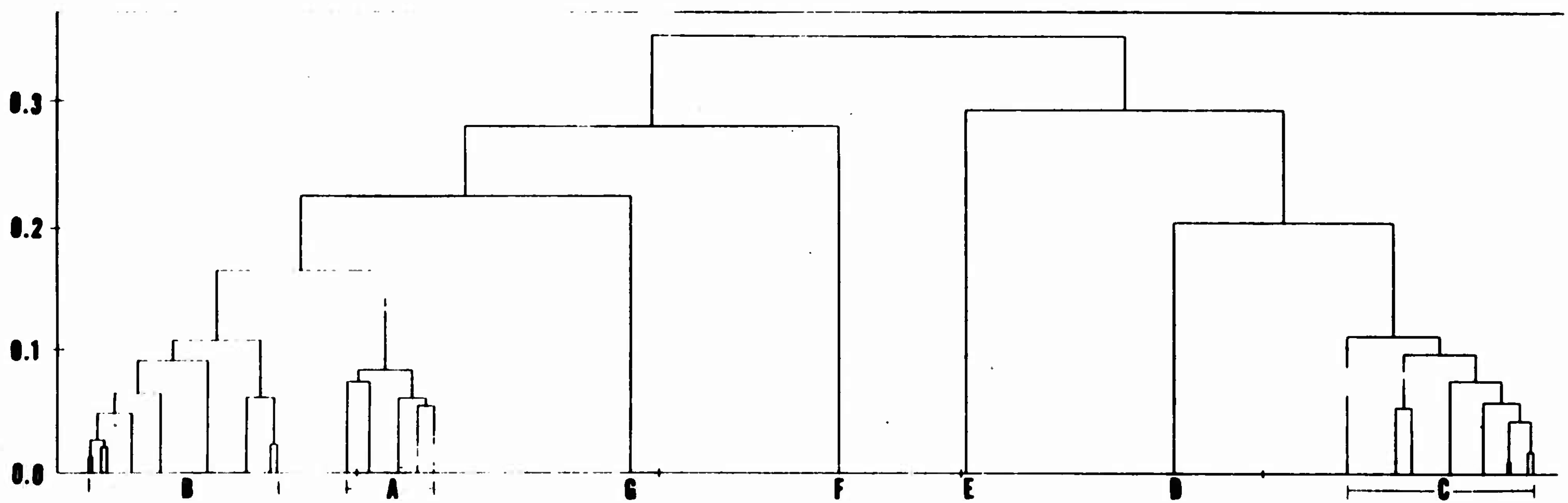


Figure 4.3-14. KAALUALU BAY, HAWAII FISH P/A 3 FACTORS.

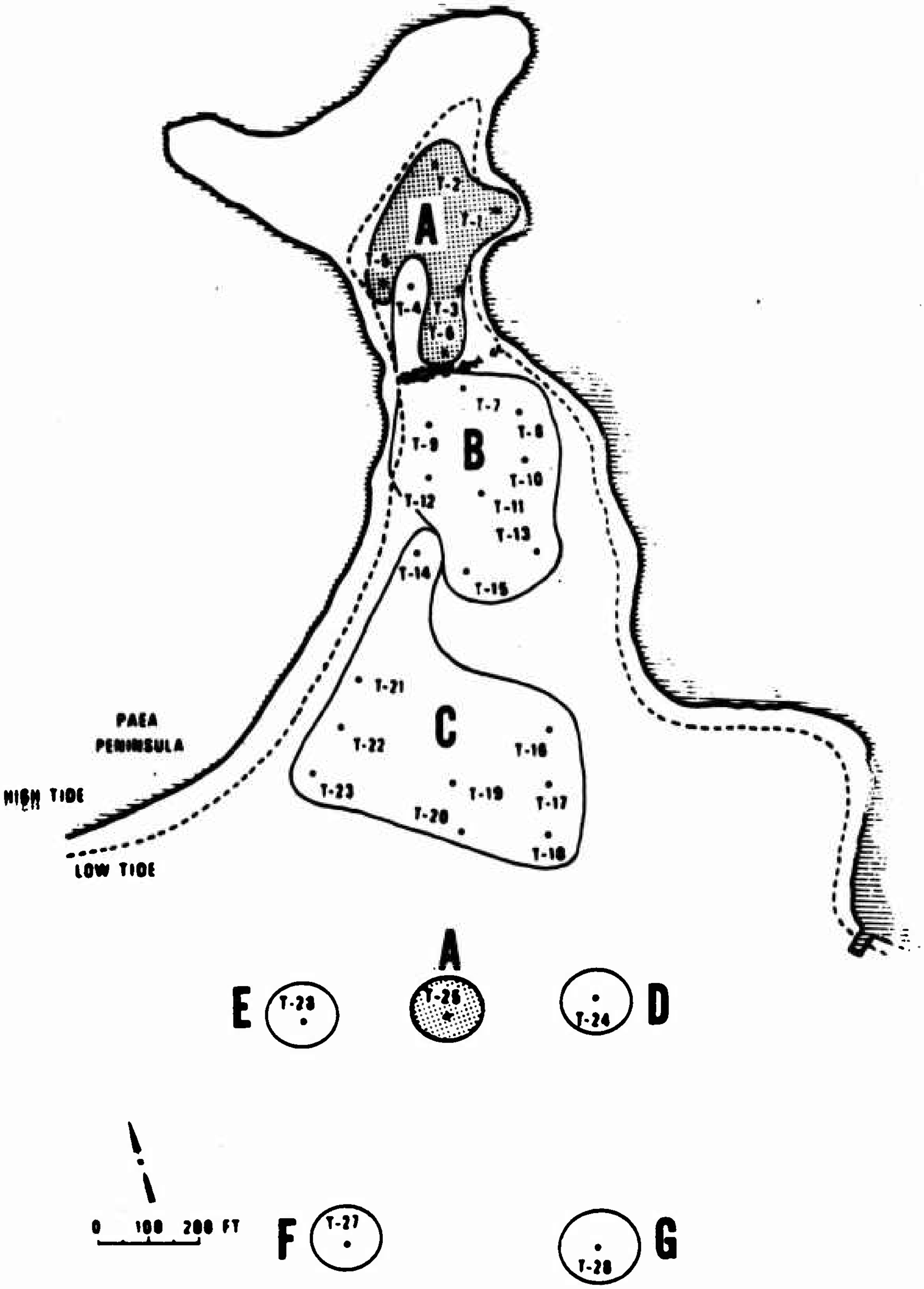


Figure 4.3-15. MAP OF KAALUALU BAY, HAWAII, SHOWING THE DISTRIBUTION OF THE CLUSTERS IDENTIFIED IN FIGURE 4.3-14. ORIGINAL DATA ARE FROM DEVANEY AND WHISTLER (1972).

Pocillopora damicornis (but not *Porites lobata*) was also common. Thus, a second anomaly unexplained by Devaney and Whistler is shown to be an extension of the deeper water Cluster C.

An even more intriguing descrepancy between the two classification systems occurs with respect to Transect 25, which in the factor analytic classification is associated with Cluster A. This association was at first perplexing, until it was noted from Devaney and Whistler's transect descriptions that Transect 25 is located over a sandy bottom, while the two closest transects (24 and 25) are located over hard bottoms with 5-15% live coral coverage. Devaney and Whistler also report that "silty, sandy" bottoms characterize some of the other transects grouped into Cluster A. However, the other transects in Cluster A are also characterized by low surface salinities, and thus this association involves more than just the presence of a sandy bottom.

From these attempts to understand the discrepancies between the "clusters" and Devaney and Whistler's "biotopes" three variables (i.e., substrate composition, water depth, and coral coverage), which were not included in our original data matrix but which are perhaps associated with the apparent composition of the extracted factors, have been identified. While most of their data are insufficient to perform the analyses, Devaney and Whistler also discuss a number of other variables (e.g., wave exposure, surface salinity, and invertebrate fauna composition) which might be used to explain the species composition of the extracted factors and the clusters they define.

The data for two separate nearshore marine environments in the Hawaiian Islands (Pearl Harbor and Kaalualu Bay) can also be combined and treated as samples from a single "Hawaiian nearshore marine environment". This combination resulted in 92 species which are present at 10% to 90% of the 38 combined sampling sites. From the P/A data for these 92 variables two factors were extracted which account for 27% and 19%, respectively, of the total variance contained in the original data matrix. The extracted factors are essentially separate groupings of the species reported from the two localities, with Factor I containing 40 species from Pearl Harbor and Factor II containing 25 species from Kaalualu. Of the 17 species present at both locations, 14 had factor loadings ≥ 0.50 on one of the two factors, with two species being correlated with Factor I, four species being correlated with Factor II, and eight species being uncorrelated with either factor.

The factor loadings, factor scores, or communalities are not presented for these 92 species, but rather these data are summarized in a dendrograph (Figure 4.3-16) generated from the factor scores. It is apparent from this dendrograph that basically the same integrity of the clusters recognized in the separate analyses has been maintained. All of the Pearl Harbor biostations appear as singularities or as small and isolated clusters, while Kaalualu Clusters A,B,C, and D,E,F,G are more closely associated than they were in the separate analysis.

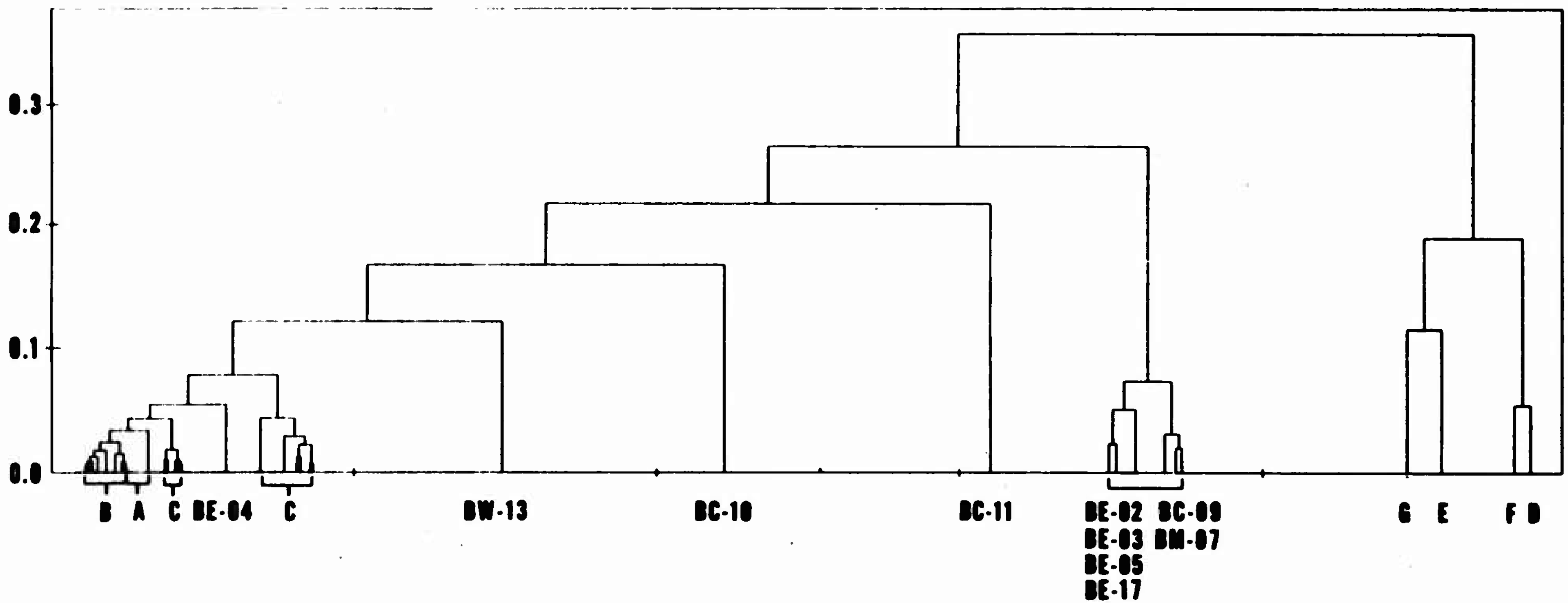


Figure 4.3-16. PEARL HARBOR-KAALUALU BAY FISHES P/A 2 FACTORS.

REFERENCES

4.3-1. S. V. Smith (1971), "Factor Analysis: A tool for Environmental Studies", Marine Technology Society Journal 5:6, 15-19.

4.3-2. Stephen V. Smith, Keith E. Chave & Dennis T. O. Kam (1973), "Atlas of Kaneohe Bay", UNIHI-SEAGRANT-TR-72-01.

4.3-3. Dennis M. Devaney & Arthur Whistler (1972), "Preliminary Biological Survey of Kaalualu, Hawaii", U.S. Army Corps of Engineers, contract no. DACW84-72-C0013.

STATISTICAL ANALYSIS
OF BENTHIC FAUNA

Gerald S. Key
Stephen V. Smith
Evan C. Evans III

INTRODUCTION

This section deals with a large number of marine organisms which are grouped on the basis of their common habitat rather than on the basis of taxonomic similarity, like fish (Section 4.3) or micromollusca (Section 4.5). The term "benthos" includes a great diversity of taxa, life histories, and modes of existence. Therefore, no *a priori* assumption(s) of probable response can be made for the benthic fauna as a whole. Most benthic organisms do, however, share at least one common trait, viz. a relative lack of motility. This lack varies in degree from forms such as sponges, bryozoans, and ascidian tunicates, which are wholly sessile as adults, to forms such as crabs, isopods, and gastropod mollusca, which may exhibit some, but generally restricted, range of movement. The principal means of dispersal and recruitment for all these forms involves a planktonic egg or larval stage. This combination of a sedentary adult stage following a planktonic existence tends to enhance the chances of benthic faunal exposure to a wide range of both transient and chronic insults. Consequently, forms resident in polluted harbors will tend to be resistent to the environmental stresses characteristic of that harbor. Furthermore, because these organisms live near the water-substratum boundary, they are likely to be affected by physicochemical processes occurring on either side of that interface.

DATA USED IN THIS ANALYSIS

The present analyses include benthos data from three of the five replicate samples collected at each of the 10 bio-stations (Section 2.2) and cover a range of water depths at most of these locations, see Table 2.2-1. Since the processing of the third replicate showed the cumulative benthic checklist to be plateauing (see Figure 4.4-1), the statistical analysis was performed on the truncated data set rather than wait for processing of the remaining two replicates. The data used in this analysis thus differ slightly from those reported in Section 2.2; for instance, of the 114 taxa identified to the generic or specific level appearing in Table 2.2-2, only 103 appear in Table 4.4-1. Three species (*Paramarphysa* sp., *Angulus nucella* and *Bugula californica*) are missing. Lack of these entries is considered entirely insignificant to the following analyses. Eight others are included in the analysis as members of higher taxonomic groups*. In Table 4.4-1, 33 such higher taxonomic groupings are considered, bringing the total number of variables to 136. In the basic field data (Section 2.2), each taxon was reported by wet weight and by number of individuals. For colonial organisms the number of individuals is difficult to assess accurately and in most instances only wet weights are reported. In a few cases (*Amathia distans* and *Bugula neritina*), the number of individuals was estimated, thus these taxa are included in the individual abundance analysis**. The 3 replicates at 10 bio-stations represented 87 separate samples which could be treated separately, combined by bio-station, or combined by bio-station and

---

* *Syllis spongicola* in *Syllis* sp.; *Dasybranchus lumbricoides* in Capitellidae; *Phascolosoma dentigerum* in Sipunculida; *Balanus amphitrite* in Ostracoda; *Colidotea edmondsoni* in Isopoda; *Bansenolana sphaeromiformis* in Cirolanidae; *Xanthias* sp. in Xanthidae; and *Polyclinum* sp. in Ascidiacea. Also in Table 4.4-1, the individuals reported as *Madaeus elegans* are now considered *M. simplex*.

** In future analyses, wet weight of colonial organisms (after some appropriate standardization) should probably be entered in lieu of individual counts. This mixture of two kinds of data is considered preferable to omitting the colonial taxa from consideration.

(Text continued on page 4.4-6)

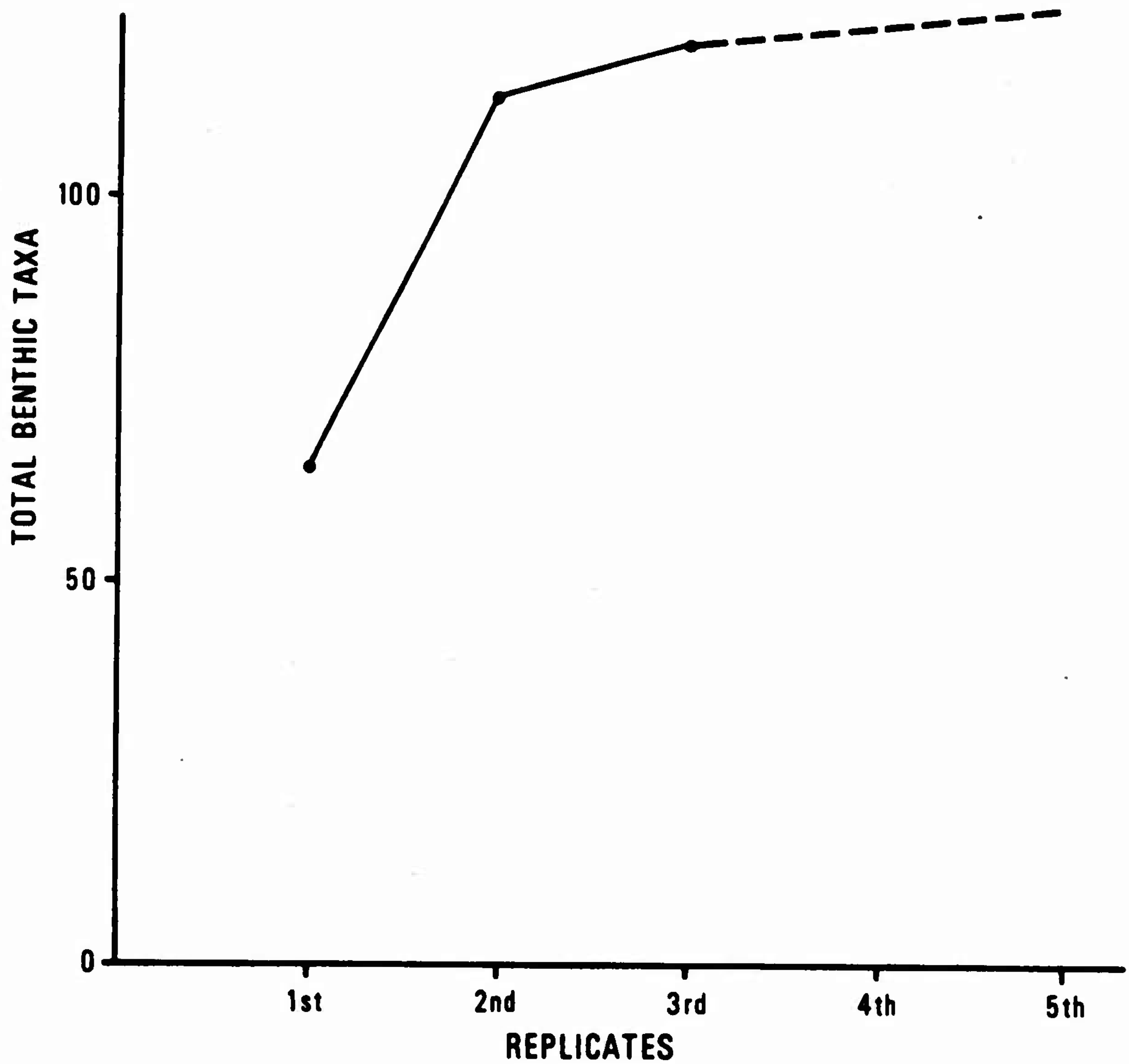


Figure 4.4-1. CUMULATIVE ADDITIONS TO BENTHIC CHECKLIST AS REPLICATES WERE PROCESSED

Table 4.4-1. MEANS AND STANDARD DEVIATIONS OF VARIABLES USED FOR ABUNDANCE ANALYSES

TAXON	MEAN	STD. DEV.
Phylum Cnidaria	0.034	0.322
Subclass Zoantharia	0.023	0.151
Radianthus cookei	0.011	0.107
Epiphellia humilis	2.069	11.510
* Phylum Nematoda	0.483	1.970
* Phylum Annelida	0.207	0.917
* *Paralepidonotus ampulliferus*	0.115	0.355
Iphione muricata	0.011	0.107
* *Eurythoe complanata*	3.851	14.685
Syllis sp.	1.241	6.115
Syllis cornuta	0.011	0.107
Trypanosyllis zebra	0.264	1.544
Opisthosyllis	0.011	0.107
Family Nereidae	0.046	0.338
Ceratonereis sp.	0.092	0.448
* *Nereis* sp.	5.540	15.899
Micronereis sp.	0.034	0.322
Platynereis sp.	0.322	2.517
Perinereis sp.	0.011	0.107
Perinereis cultrifera	0.011	0.107
Laeonereis sp.	0.034	0.239
* *Eunice antennata*	0.195	0.607
Eunice australis	0.034	0.239
Eunice filamentosa	0.184	1.136
* *Eunice vittata*	11.667	84.981
Eunice siciliensis	0.517	2.542
* *Eunice* sp.	3.172	14.766
Marphysa sanguinea	0.575	4.620
* *Nematonereis unicornis*	2.2C7	6.511
Diopatra sp.	0.276	1.523
Oenone fulgida	0.046	0.338
* Lumbrinerid sp.	2.379	8.840
Arabella sp.	0.126	0.478
Cirratulus sp.	0.011	0.107
Family Orbiniidae	0.103	0.863
Family Capitellidae	1.195	7.410
* Family Terebellidae	0.310	1.306
Family Sabellidae	0.195	1.337
* *Hydroides norvegica*	0.149	0.561
Hydroides lunulifera	0.195	1.237
* Phylum Sipunculida	2.356	9.698
Class Pycnogonida	0.218	1.115
Subclass Ostracoda	0.356	1.607
Order Tanaidacea	0.529	4.824

* Denotes variables which were also used for P/A analyses.

Table 4.4-1. (Continued)

TAXON	MEAN	STD. DEV.
* *Apseudes* sp. 1	11.862	41.853
* *Apseudes* sp. 2	7.471	26.635
Family Tanaidae	0.184	1.084
* *Leptochelia dubia*	12.023	61.381
Anatanais insularis	0.011	0.107
Order Isopoda	0.092	0.658
Family Anthuridae	0.034	0.322
Mesanthura hieroglyphica	1.563	14.045
* Family Cirolanidae	3.391	19.193
Limnoria sp.	0.011	0.107
Paracerceis sculpta	0.264	1.325
* Order Amphipoda	7.069	24.162
* *Lembos macromanus*	3.115	19.757
* *Corophium acherusicum*	32.080	144.196
* *Ericthonius brasiliensis*	1.368	8.934
Elasmopus rapax	26.057	116.753
Leucothoe hyhelia	0.358	3.431
Class Decapoda	0.023	0.214
* Section Caridea	0.195	0.567
* Family Alpheidae	0.092	0.421
Alpheus sp.	0.126	0.606
* *Alpheus lobidens polynesica*	1.540	5.200
Alpheus mackayi	0.149	0.561
Alpheus rapax	0.092	0.362
Alpheus rapacida	0.057	0.384
Alpheus platyunguiculatus	0.011	0.107
Alpheus paracrinitus	0.046	0.301
Alpheus lanceloti	0.034	0.239
Alpheus heeia	0.140	1.006
Leptalpheus pacificus	0.011	0.107
Synalpheus pachymeris	0.069	0.643
Synalpheus thai	0.103	0.458
Synalpheus streptodactylus	0.023	0.214
Synalpheus bituberculatus	0.678	3.512
Family Diogenidae	0.011	0.107
Calcinus latens	0.046	0.429
Parthenope whitei	0.011	0.107
Family Portunidae	0.011	0.107
Libystes nitidus	0.069	0.397
Portunus longispinosus	0.023	0.151
* *Thalamita integra*	0.655	1.620
Thalamita admete	0.264	1.094
Family Grapsidae	0.011	0.107
Family Xanthidae	0.172	0.781
Platypodia eydouxi	0.195	1.160
Lophozozymus dodone	0.046	0.338

* Denotes variables which were also used for P/A analyses.

Table 4.4-1. (Continued)

TAXON	MEAN	STD. DEV.
Madaeus simplex	0.172	0.930
Madaeus elegans	0.195	1.302
Leptodius sanguineus	0.011	0.107
Carpilodes bellus	0.011	0.107
Etisus electra	0.414	2.254
Etisus laevimanus	0.759	2.929
Panopeus pacificus	0.920	6.108
Phymodius nitidus	0.080	0.750
Chlorodiella laevissima	0.011	0.107
* *Pilumnus oahuensis*	1.862	5.916
Macrophthalmus telescopicus	0.161	0.588
Order Stomatopoda	0.023	0.214
Pseudosquilla ciliata	0.011	0.107
Gonodactylus falcatus	0.046	0.260
Subclass Streptoneura	0.023	0.151
Family Vermetidae	0.023	0.151
Dendropoma platypus	0.069	0.643
Bittium unilineatum (= B. zebrum)	0.391	2.625
Hipponix sp.	0.230	2.144
Hipponix pilosus	1.368	6.967
Crucibulum spinosum	0.046	0.338
* *Crepidula aculeata*	0.759	2.663
Natica gualteriana	0.023	0.151
Cymatium sp.	0.023	0.151
Class Bivalvia	0.034	0.184
Brachidontes crebristriatus	0.563	3.935
Family Ostreidae	0.011	0.107
Crassostrea sp. 1	0.195	1.429
Crassostrea sp. 2	0.057	0.536
Ostrea thaanumi	0.023	0.214
Spondylus sp.	0.011	0.107
Anomia nobilis	0.057	0.318
Ctena bella	0.207	0.823
* *Hiatella hawaiiensis*	14.138	35.571
* *Amathis distans*	0.011	0.107
* *Bugula neritina*	0.011	0.107
* *Ophiactis savignyi*	13.655	61.555
Amphiopholis squamata	0.471	2.749
Holothuria pervicax	0.011	0.107
Class Ascidiacea	0.046	0.260
* *Ascidia* sp.	0.184	0.639
Styela sp.	0.759	5.201
Class Osteichthyes	0.069	0.397
Oxyurichthys lonchotus	0.011	0.107
Bathygobius fuscus	0.011	0.107
Asterropteryx semipunctatus	0.103	0.483

* Denotes variables which were also used for P/A analyses.

depth*. Furthermore, analysis could proceed in three ways: abundance data on the basis of wet weight, abundance data on the basis of number of individuals, and presence/absence (P/A) data. Factor analysis of P/A data requires the application of some cutoff criterion to prevent variances near zero; here a 10%-to-90% cutoff criterion was used which considerably reduced the number of variables admitted. The nine possible combinations of variables and cases are summarized in Table 4.4-2. Factor analyses and cluster analyses were performed on all 9 possible combinations of data and treatment. All results have not, however, been included in this report. For the two modes of abundance analysis (by wet weight and by individual count), comparable factors with respect to both loadings and scores were obtained. Moreover, analyses by individual sample proved more informative than the analyses of samples combined by depth or by bio-station. Most of the variability encountered in the benthos data is depth-related, while much of the remainder occurs only at a single bio-station. Hence, combination by depth or bio-station merely supresses the major variability and enhances the less important interstation variability. Furthermore, patterns of interstation variability can be recognized in the analysis by individual sample and are similar to those obtained from either of the combined data sets. The redundant analytical results are therefore omitted. Only abundance analysis by individual count and P/A analysis are presented for the uncombined sample data.

ABUNDANCE ANALYSIS

Table 4.4-1 presents the mean number of individuals per sample and the standard deviation for the 136 taxa used in these analyses. Contrary to the presentation in other sections, phyletic rather than alphabetic listing is used for reasons intimated in the introduction. Benthic fauna represent a combination of organisms based on habitat, and many unrelated phyla are included. Alphabetization thus results in the loss of important information useful in the interpretation of results. All organisms which could not be identified to the generic or specific level were combined into higher taxonomic groupings. Thus, for example, "Family Xanthidae" includes all crabs identifiable as xanthids but which were lacking sufficient characteristics for assignment to a particular genus.

Factor analysis of the 136 variables from the 87 benthic samples yields five factors which explain 9, 9, 8, 8, and 7%, respectively, of the data in the original 87x136 matrix. Total variance explained is 41%; thus the 5 factors contain almost half of the information contained in the data matrix. Because of the large number of variables involved, the complete factor loading matrix has not been reproduced. Rather, the factor loading data are summarized in Figure 4.4-2 and in Tables 4.4-3 and 4.4-4. Figure 4.4-2 is a histogram of the number of taxa (variables) falling into quartiles based on communality, or the percent of total variability of that taxon explained by the 5 factors (see also Section 4.0). The histogram shows that 41% of the taxa represented fall into the first quartile (communalities of 25% or less), meaning that the distribution of these organisms does not relate well to the patterns represented by the 5 factors. On the other hand, 26% of the taxa fall into the last quartile (communalities of 75% or greater), meaning that these taxa bear strong relationships with the 5 factors.

---

* On the basis of field observations (Section 2.2), the following depth classifications have been adopted: shallow, 0 to 15 feet; intermediate, >15 to 25 feet; deep, >25 feet.

(Text continued on page 4.4-15)

Table 4.4-2. NUMBER OF CASES AND VARIABLES USED IN EACH FACTOR ANALYSIS OF PEARL HARBOR BENTHIC DATA

	SAMPLE COMBINATION (# cases)	DATA TREATMENT (# variables)		
		No. Individuals	Wet Weight	P/A
by Sample	87	136	143	34
by Station/Depth	23	136	143	68
by Station	10	136	143	145

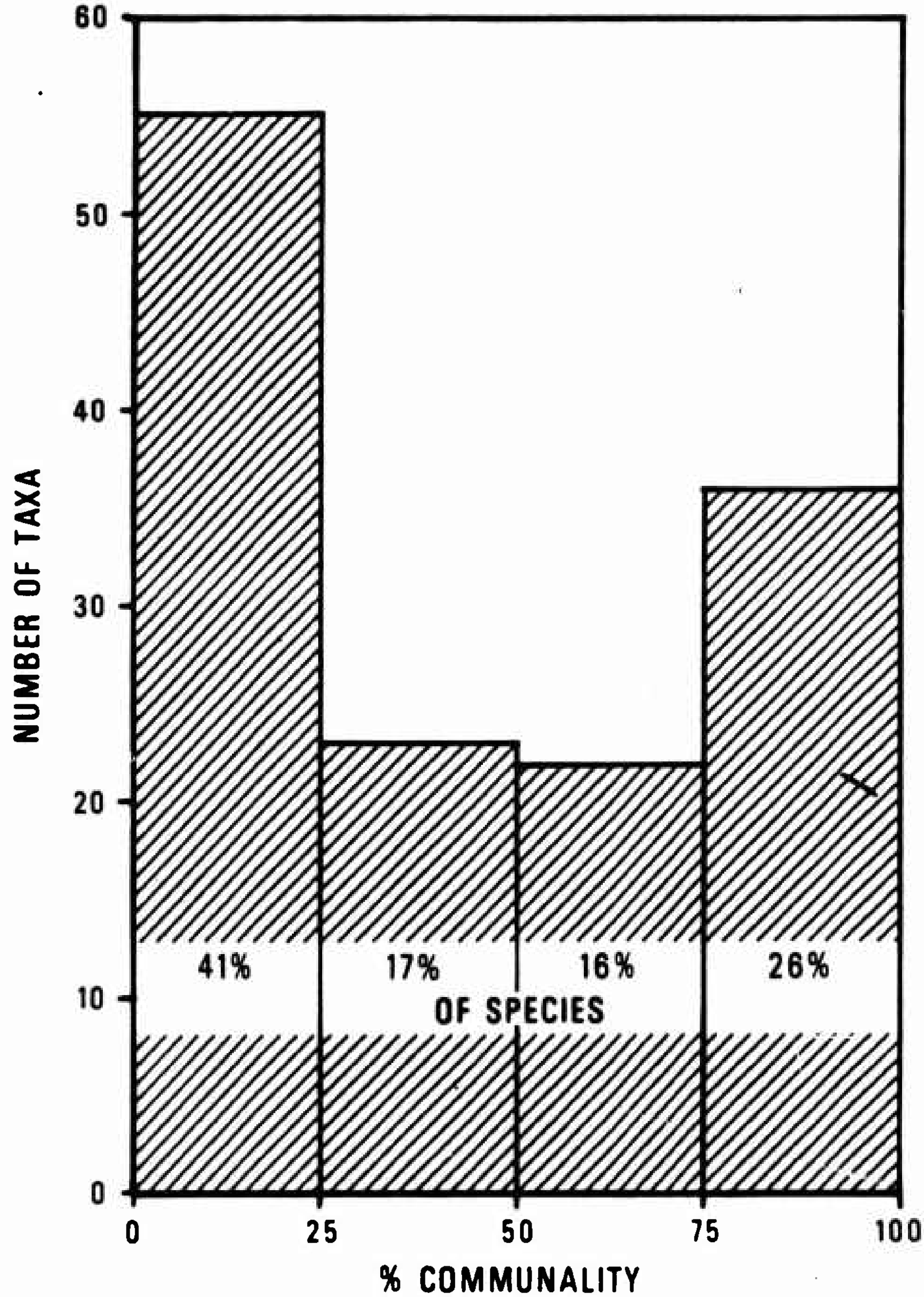


Figure 4.4-2. QUARTILE PLOT OF VARIABLE COMMUNALITY ABUNDANCE ANALYSIS OF BENTHIC ORGANISMS

Table 4.4-3. AFFINITY OF VARIABLES FOR THE FIVE FACTORS CALCULATED FROM INDIVIDUAL ABUNDANCE ANALYSIS (87 cases and 136 variables)

PERCENT VARIANCE EXPLAINED	FACTORS I	II	III	IV	V
	NUMBER OF VARIABLES LOADING				
0 - 25	114	118	121	125	121
25 - 50	13	4	3	1	9
50 - 75	7	5	5	2	6
75 - 100	2	8	7	8	0

Table 4.4-4. FACTOR LOADING MATRIX FOR INDIVIDUAL ABUNDANCE ANALYSIS (ONLY THOSE VARIABLES WITH AT LEAST ONE ABSOLUTE LOADING 0.5 OR GREATER ARE TABULATED).

FACTOR NUMBER		I	II	III	IV	V
PERCENT OF TOTAL VARIANCE		9.2	9.2	8.5	7.6	6.6
VARIABLE	COMMUNALITY %					
ANNELIDS "Segmented Worms"	*					
Errant Polychaetes	*					
Iphione muricata	67	.80	-	-	-	-
Eurythoe complanata	90	.86	-	-	-	-
Trypanosyllis zebra	48	.68	-	-	-	-
Family Nereidae	93	-	-	.96	-	-
Platynereis sp.	29	-	-	-	-	.53
Laeonereis sp.	43	.52	-	-	-	-
Eunice antennata	45	-	-	-	-	.63
Eunice filamentosa	82	-	.87	-	-	-
Eunice siciliensis	57	-	-	-	-	.74
Eunice sp.	83	-	-	-	.75	-
Nematonereis unicornis	50	.64	-	-	-	-
Oenone fulgida	88	-	-	.89	-	-
Lumbrinerid sp.	48	.63	-	-	-	-
Arabella sp.	51	.69	-	-	-	-
Sedentary Polychaetes	*					
Family Terebellidae	27	-	.51	-	-	-
Hydroides lunulifera	93	-	.96	-	-	-
SIPUNCULIDS "Peanut Worms"	77	.51	-	-	-	.56
ARTHROPODS	*					
Ostracods	*					
Subclass Ostracoda	31	.54	-	-	-	-
Tanaids	*					
Order Tanaidacea	96	-	-	-	.98	-
Anatanais insularis	82	-	.90	-	-	-
Isopods	*					
Order Isopoda	91	-	-	-	.96	-
Family Anthuridae	36	.57	-	-	-	-
Mesanthura hieroglyphica	36	.57	-	-	-	-
Family Cirolanidae	86	-	-	.91	-	-
Paracerceis sculpta	66	-	-	-	-	.80
AMPHIPODS	*					
Order Amphipoda	70	-	-	-	-	.81
Corophium acherusicum	41	-	-	-	-	.63
Ericthonius brasiliensis	46	.66	-	-	-	-
Elasmopus rapax	79	-	-	-	-	.74
Decapods - shrimp	*					
Section Caridea	37	-	-	-	-	.56

* These entries are not variables; they are presented only to show phyletic groupings.

Table 4.4-4. (Continued)

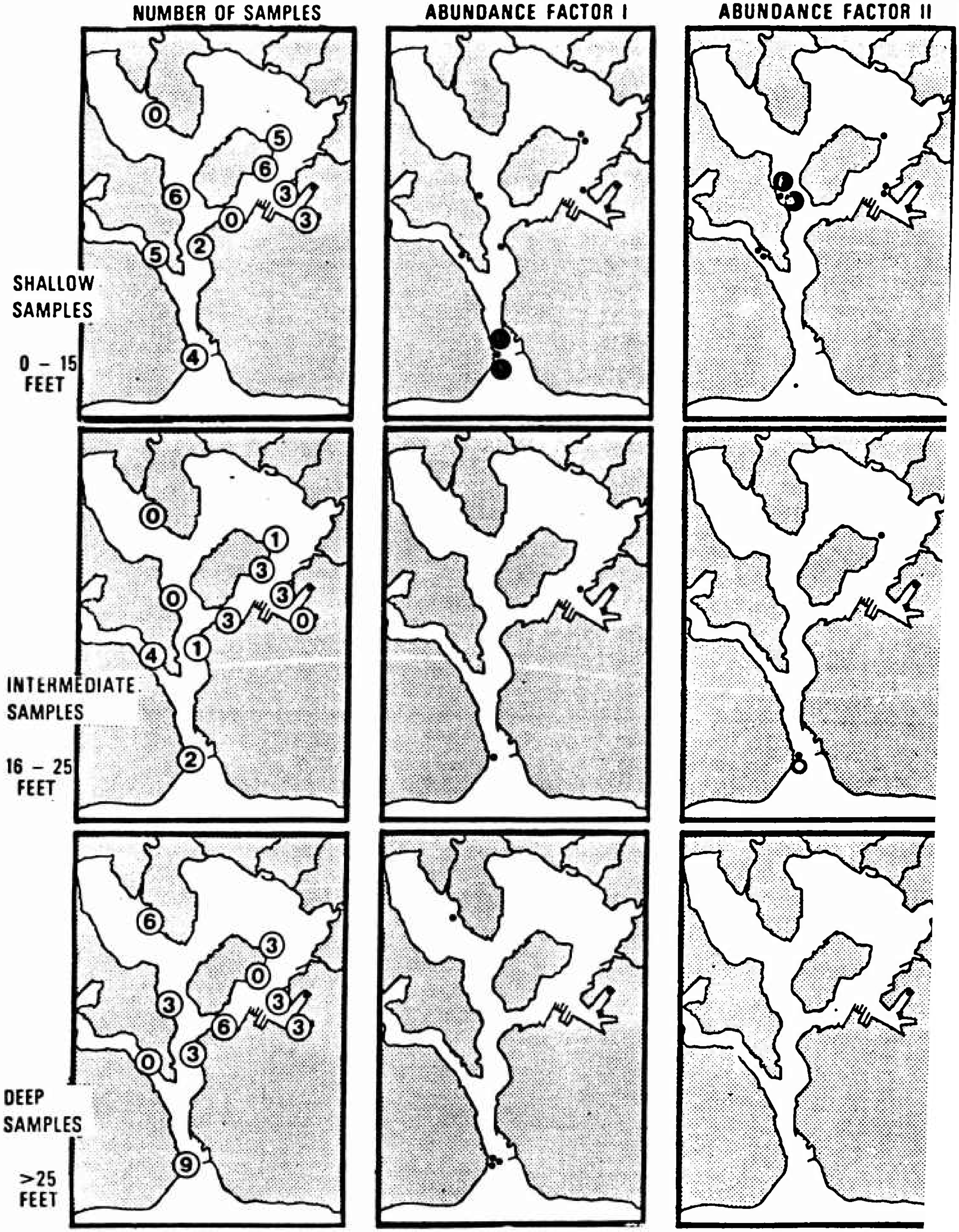
FACTOR NUMBER		I	II	III	IV	V
PERCENT OF TOTAL VARIANCE		9.2	9.2	8.5	7.6	6.6
VARIABLE	COMMUNALITY %					
Alpheus lobidens polynesica	89	-	.73	-	-	-
Alpheus paracrinitus	51	-	-	.71	-	-
Alpheus lanceloti	74	.74	-	-	-	-
Alpheus heeia	98	.99	-	-	-	-
Synalpheus pachymeris	96	-	-	-	.98	-
Synalpheus thai	54	-	.50	-	-	-
Synalpheus streptodactylus	88	-	-	.94	-	-
Synalpheus bituberculatus	73	-	-	.85	-	-
Decapods - crabs	*					
Calcinus latens	88	-	-	.94	-	-
Portunus longispinosus	65	-	-	.78	-	-
Thalamita integra	43	-	-	-	-	.63
Thalamita admete	93	.64	.71	-	-	-
Family Grapsidae	67	.80	-	-	-	-
Family Xanthidae	84	.82	-	-	-	-
Platypodia eydouxi	90	.95	-	-	-	-
Lophozozymus dodone	66	.80	-	-	-	-
Madaeus simplex	88	.72	-	.60	-	-
Madaeus elegans	49	-	-	-	.67	-
Leptodius sanguineus	96	-	-	-	.98	-
Carpilodes bellus	88	-	-	.94	-	-
Etisus electra	34	-	-	.51	-	-
Etisus laevimanus	72	-	-	.77	-	-
Panopeus pacificus	65	-	.74	-	-	-
Chlorodiella laevissima	82	-	.90	-	-	-
Pilumnus oahuensis	80	-	.53	-	-	.69
Stomatopods	*					
Order Stomatopoda	96	-	-	-	.98	-
Gonodactylus falcatus	89	-	-	.77	-	-
MOLLUSCA	*					
Gastropods	*					
Subclass Streptoneura	47	-	.68	-	-	-
Dendropoma platypus	96	-	-	-	.98	-
Bittium unilineatum	65	-	-	-	-	.80
Hipponix spp.	96	-	-	-	.98	-
Hipponix pilosus	64	-	.76	-	-	-
Crucibulum spinosum	87	-	-	.93	-	-
Crepidula aculeata	57	-	-	-	.71	-
Cymatium sp.	48	-	-	.69	-	-
Pelecypods	*					
Brachidontes crebristriatus	52	.67	-	-	-	-

* These entries are not variables; they are presented only to show phyletic groupings.

Table 4.4-4. (Continued)

FACTOR NUMBER		I	II	III	IV	V
PERCENT OF TOTAL VARIANCE		9.2	9.2	8.5	7.6	6.6
VARIABLE	COMMUNALITY %					
Family Ostreidae	36	.57	-	-	-	-
Crassostrea sp.	79	-	.88	-	-	-
Ostrea	96	-	-	-	.98	-
Anomia nobilis	36	-	-	-	-	.59
Hiatella hawaiiensis	68	-	-	-	-	.56
BRYOZOANS	*					
Amathis distans	82	-	.90	-	-	-
ECHINODERMS	*					
Ophiuroids	*					
Ophiactis savignyi	90	-	.92	-	-	-
Amphiopholis squamata	58	-	-	-	-	.74
TUNICATES	*					
Class Ascidiacea	62	-	.78	-	-	-
Styella sp.	96	-	.98	-	-	-
BONY FISHES	*					
Class Osteichtyes	29	-	.53	-	-	-

* These entries are not variables; they are presented only to show phyletic groupings.


NUMBER OF SAMPLES
ABUNDANCE FACTOR I
ABUNDANCE FACTOR II
SHALLOW SAMPLES
0 – 15 FEET
INTERMEDIATE SAMPLES
16 – 25 FEET
DEEP SAMPLES
>25 FEET

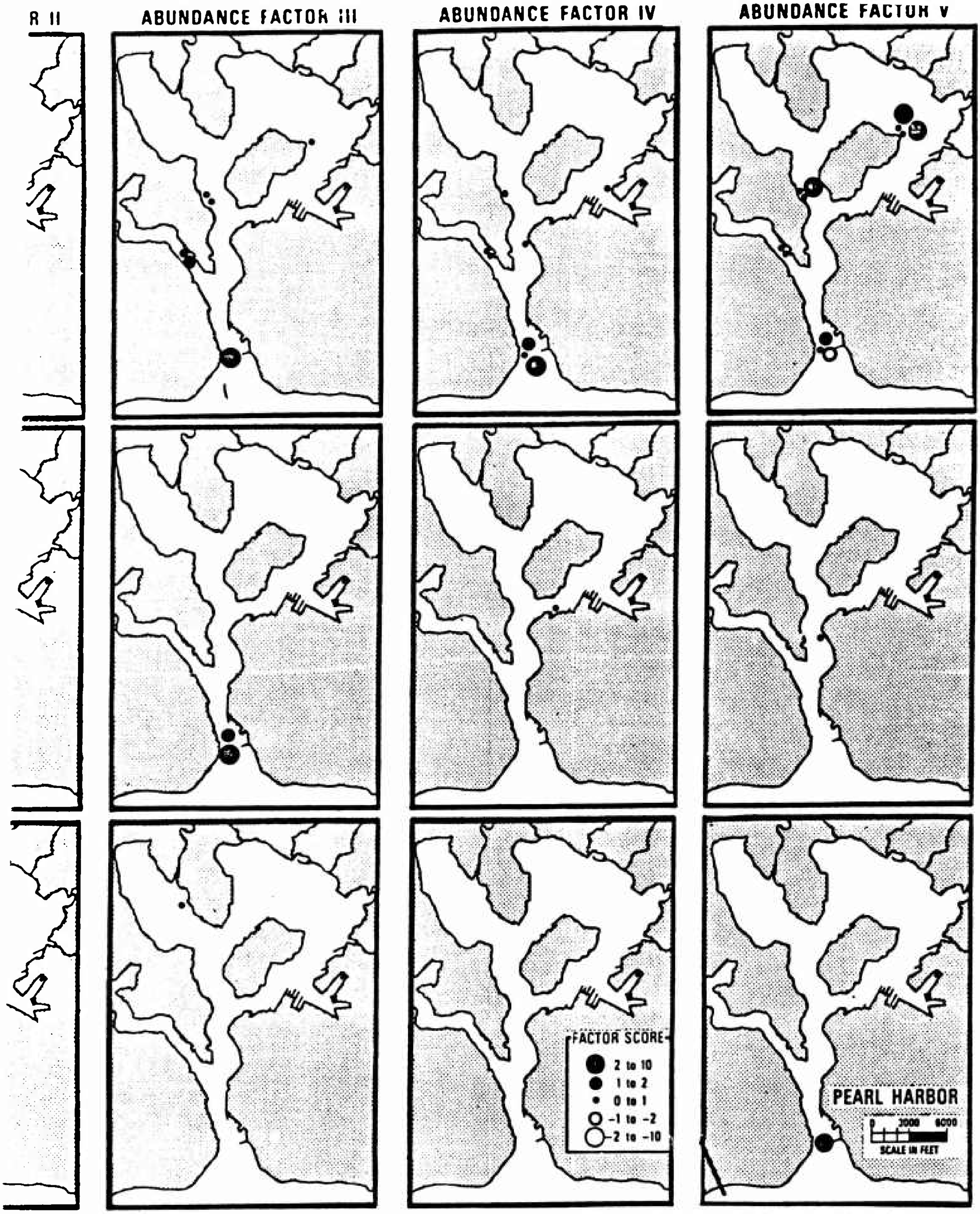


Figure 4.4-3. FACTOR SCORE MAP, ABUNDANCE ANALYSIS OF BENTHIC ORGANISMS

272

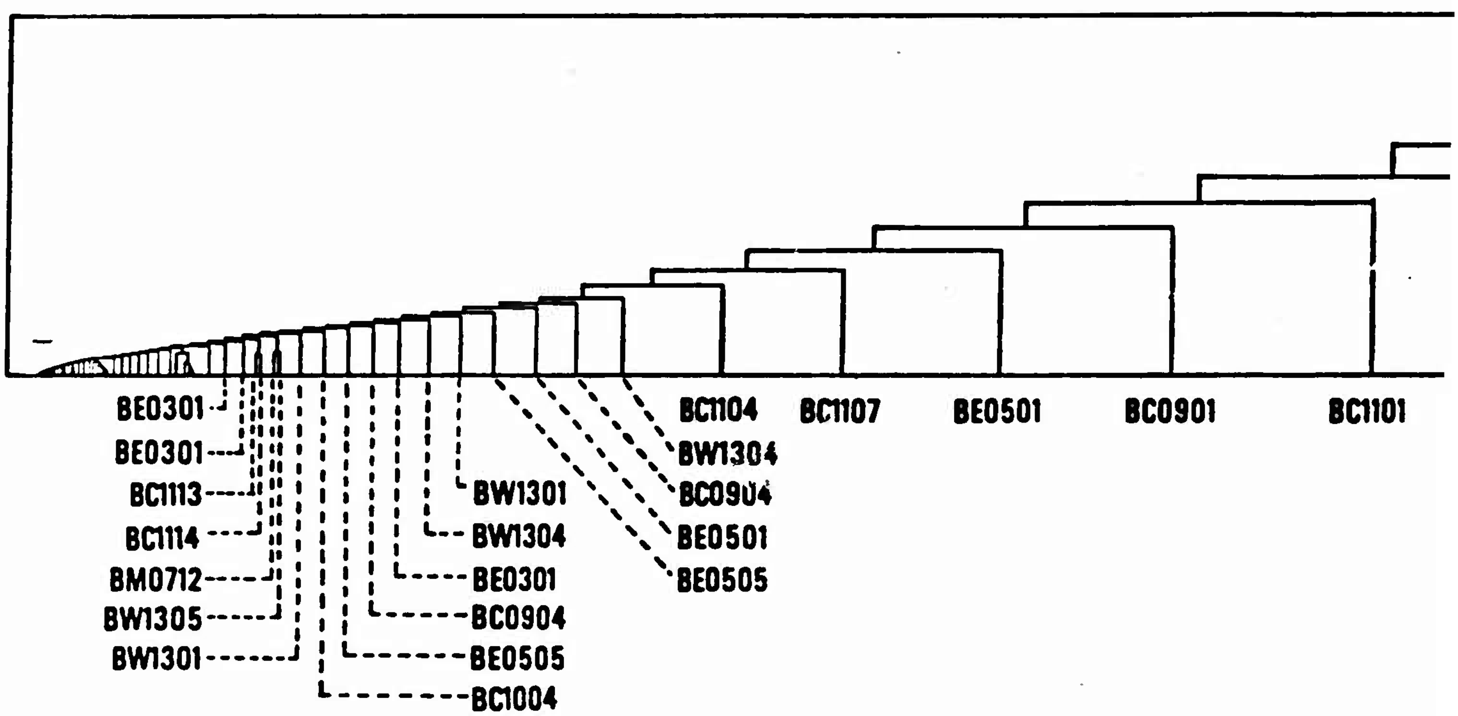
The data contained in the histogram (Figure 4.4-2) are further broken down in Table 4.4-3 where affinity among the taxa for particular factors is summarized on the basis of percent variance explained (100 times the squared factor loading). For 52 taxa, over 50% of the variance is explained by one of the 5 factors, as may be seen by summing the tabular entries in the upper two quartiles (such summation is permissible since taxa in these quartiles would load on only one factor). Table 4.4-4 presents the actual factor loadings for all taxa having at least one absolute loading of 0.5 or greater (i.e. greater than 25% of the variance explained), thus detailed loading is presented for all taxa in the upper three quartiles of Table 4.4-3. For reasons previously given, phyletic listing is used. Note there are only 4 double loading entries: sipunculids on Factors I and V, and the three crabs, *Thalamita admete*, *Madaeus simplex*, and *Pilumnus oahuensis*, loading on Factors I and II, I and III, and II and V, respectively.

Several patterns among the taxa associated with these factors emerge. Factor I includes a group of errant polychaete worms (7 taxa), isopods (2 taxa), shrimp (2 taxa), crabs (6 taxa) and attaching bivalves (2 taxa), suggesting a rubble substratum overlain by a veneer of soft sediment. Nine taxa out of 22 (41%) have loadings greater than 0.71 (50% of variance explained), but only two decapods (*Alpheus heeia* and *Platypodia eydouxi*) have loadings greater than 0.87 (75% of variance explained). This loading pattern possibly indicates a high degree of patchiness for this habitat type.

There is no apparent taxonomic grouping of organisms loading on Factor II, but there is a strong suggestion of an association based on feeding type. With the possible exception of *Eunice filamentosa* and *Anatanais insularis*, all of the species with loadings greater than 0.87 on Factor II are either filter feeders or detritus feeders. Thirteen out of 18 (13/18 or 72%) have loadings of 0.71 or greater, and 8/18 or 44% have loadings greater than 0.87. The preponderance of filter or detritus feeders suggests a relatively high load of suspended organic matter. The two species with the highest loadings on Factor II (*Hydroides lunulifera* and *Styela* sp.) are common components of the fouling community attached to docks and piers in southern Kaneohe Bay, an area greatly affected by the effluents from a municipal sewer outfall (Reference 4.4-1).

With the exception of a reduced number of polychaete worms, Factor III includes a group similar in phyletic composition to that loading on Factor I, namely polychaete worms (2 taxa), shrimp (3 taxa), crabs (6 taxa), and gastropods (2 taxa). Twelve taxa out of 15 (12/15 or 80%) have loadings of 0.71 or greater, and 7/15 or 47% have loadings greater than 0.87. Factor III, like Factor I suggests a rubble substratum overlain by a veneer of soft sediment; the greater proportion of higher loadings may also indicate a lower degree of patchiness.

The remaining two factors are more difficult to interpret biologically. Factor IV has a large preponderance of high loadings, 4 arthropods and 3 mollusca with loadings of 0.98 (96% of variance explained), with one additional arthropod loading at 0.96 (92% of variance explained). Of the 3 mollusca with high loadings, two (*Dendropoma platypus* and *Ostrea thaanumi*) are suspension feeders, and this pair is joined by a third suspension feeder (*Crepidula aculeata*) with a loading of 0.71. The loading of the arthropods again suggests rubble substratum; that of the mollusca, relatively high amounts of suspended organic matter in the water column. Ten taxa out of 11 (10/11 or 91%) have loadings of 0.71 or


BE0301
BE0301
BC1113
BC1114
BM0712
BW1305
BW1301
BC1004
BE0505
BC0904
BE0301
BW1304
BW1301
BE0505
BE0501
BC0904
BW1304
BC1104
BC1107
BE0501
BC0901
BC1101

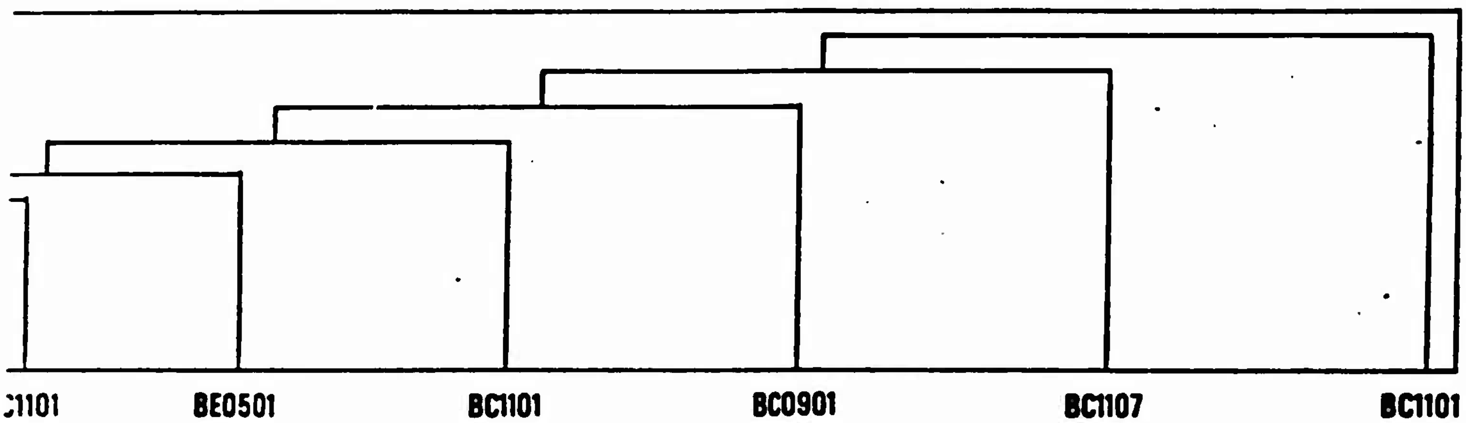


Figure 4.4-4. DENDROGRAPH BASED ON 5-FACTOR SCORE DISTANCES, ABUNDANCE ANALYSIS OF BENTHIC ORGANISMS

greater, and 8/11 or 72% have loadings greater than 0.87. Factor V shows a scattering of phyletic groups, none loading heavily. Six taxa out of 15 (6/15 or 40%) have loadings of 0.71 or greater, and none have loadings greater than 0.87.

In addition to these factor descriptors, two more generalizations may be inferred from Table 4.4-4. Factors I, III, and IV appear similar to one another in phyletic composition, and may thus represent variability associated with heterogeneous rubble substratum. Factors II and V show some overlap with the first group of factors, but both appear to be "catch-all" factors from a phyletic standpoint, this being especially true for Factor II. Both Factors II and V are also strongly dominated by filter feeding organisms. The second generalization to be inferred from Table 4.4-4 is not as pronounced as the one just described; however, the following taxa show affinities for particular factors: polychaetes strongly for Factor I, tanaids and isopods for II and IV, shrimps for III, crabs for I and III, gastropods strongly for IV, and bivalves for I and V. These taxa may therefore represent promising general indicator organisms for environments such as those encountered in Pearl Harbor. Better information on habitat needs and preferences are required for the development of that potential and to better relate these taxa to the factors here recognized.

Figure 4.4-3 presents a series of dot maps representing factor scores for the abundance analysis by individual sample. The maps are divided into shallow (0 to 15 feet), intermediate (>15 to 25 feet), and deep (>25 feet) depth classes to emphasize the depth-dependent character of the factor scores. As in other sections, modal scores between -1 and +1 have been omitted to reduce clutter. As before, the size of the dot indicates the degree of significant departure (positive or negative) from the average score which is, of course, zero. The first map in each series indicates the total number of samples in that depth class at each of the bio-stations. Inspection of the maps shows the high scores to be overwhelmingly dominated by the shallow-water samples. Of the 60 "nonmodal" scores on the 5 factors, 45 (75%) are in the shallow-depth class, 9 (15%) in the intermediate, and 6 (10%) in the deep. Moreover, most of the variability again occurs at bio-station BC-11. BC-11 shows nonmodal scores in all depth classifications: at shallow depths, Factors I, IV, and V show 3 nonmodal scores out of a possible 4 (3/4); at intermediate depths, Factor II and III show 2/2; at deep depths, Factor I shows 3/9. Bio-stations BE-03, BE-05, BC-09, and BC-10 dominate certain of the factors in the shallow depths only: BE-03 and BC-09, Factors II and V (the filter feeding factors); BE-05, Factor V; and BC-10, Factors I and IV. Certain bio-stations, BE-02 and BE-04, show no nonmodal scores, and in general the intermediate and deep depth classifications show very few nonmodal scores.

A dendrograph (Figure 4.4-4) constructed from the factor-score distances between bio-stations fails to distinguish any well-defined clusters. Rather, the pattern which emerges is one of progressive deviation of samples from a single ill-defined cluster. As might have been anticipated from the factor scores, the samples farthest from the center of that cluster are from bio-stations BE-05, BC-09, and BC-11, and the most deviant samples are from shallow water.

Several general conclusions can be drawn from these analyses. With respect to depth, a general gradient from a relatively variable shallow-water biota to a relatively invariant deep-water biota exists. With respect to bio-stations, three sample groups emerge. BC-11 is obviously distinctly different from the other bio-stations, all of which are more defintitely within the harbor proper. Bio-stations BE-03, BE-05, BC-09, and possibly BC-10 represent a second biotic unit. The remaining bio-stations are lumped together as an ill-defined association, BM-07, BW-13, and BE-17 being poorly represented by the 5 factors, and BE-02 and BE-04 being represented not at all.

PRESENCE/ABSENCE ANALYSIS

Table 4.4-5 presents the frequency of occurrence (i.e. the "mean presence") of the 34 taxa remaining after the 10-to-90% cutoff criterion is applied to the benthos samples. These species appear in more than 9 but less than 78 of the 87 benthic samples; 33 of them are also indicated in Table 4.4-1 by an asterisk. The 34th P/A entry is the Class Demospongia, inadmissable to the abundance analyses because it is a colonial organism reported only by wet weight. Table 4.4-6 summarizes the factor loading matrix which is again restricted to those taxa (variables) with at least one absolute loading of 0.5 or greater (i.e. greater than 25% of the variance explained). Only two factors, which explain 35% of the variance in the original 87x34 matrix, were used; additional factors did not significantly increase total variance explained. Most (28%) of the variance is explained by Factor I, while the remainder (7%) is explained by Factor II.

Neither the communalities nor the loadings in the P/A analysis are as high as in the abundance analysis. No taxa have a communality of 75% or greater, whereas many do in the abundance analysis; the highest P/A communality obtained is 59% (*Apseudes* sp. 1), and only 6 taxa have communalities of 50% or greater. Only 3 taxa (all loading on Factor I) have absolute loadings exceeding 0.71 (50% of variance explained).

On the basis of taxa loading on P/A Factor I (Table 4.4-6), Factor I appears to be similar to the Factor I-III-IV group noted in the abundance analysis. P/A Factor I is heavily dominated by polychaete worms, tanaids and isopods, amphipods, and crabs; the filter-feeding organisms which loaded on abundance Factors II and V also load weakly on P/A Factor I. The shrimp, which loaded heavily on abundance Factor III, were eliminated by the large reduction in variables resulting from the application of the P/A cutoff criterion. P/A Factor II appears as a catch-all factor showing only weak loadings which include two filter-detritus feeding organisms. In general, the P/A factor analysis appears to have preserved the biotic patterns seen in the more extensive abundance analysis, although the dominance of P/A Factor I has masked the feeding-type association (abundance Factors II and V) and several other possible taxonomic groupings seen in the abundance analysis.

Maps of P/A factor scores are presented in Figure 4.4-5; the same conventions as those described for Figure 4.4-3 have been used. As in the abundance maps, the high P/A scores are again most frequently seen in the shallow-water samples. The distribution of P/A scores is, however, somewhat more even; of the 85 nonmodal scores, 45 (53%) are in the shallow-depth class, 13 (15%) in the intermediate, and 27 (32%) in the deep. P/A Factor I is clearly depth-related; most shallow samples have relatively high positive scores, while most deep samples have low positive or even negative scores. P/A Factor II is less easily interpreted; the nonmodal scores seem to show an affinity for central Pearl Harbor samples complicated by both positive and negative values. P/A Factor II shows

Table 4.4-5. PERCENT FREQUENCY (BY SAMPLE) OF THE VARIABLES USED IN THE P/A ANALYSES

TAXON	% FREQUENCY
*Class Demospongia	40.2
Phylum Nematoda	11.5
Phylum Annelida	77.0
Paralepidonotus ampulliferus	11.5
Eurythoe complanata	28.7
Nereis sp.	35.6
Eunice antennata	12.6
Eunice vittata	19.5
Eunice sp.	20.7
Nematonereis unicornis	27.6
Lumbrinerid sp.	20.7
Family Terebellidae	12.6
Hydroides norvegica	13.8
Phylum Sipunculida	16.1
Apseudes sp. 1	24.1
Apseudes sp. 2	29.9
Leptochelia dubia	12.6
Family Cirolanidae	23.0
Order Amphipoda	46.0
Lembos macromanus	17.2
Corophium acherusicum	28.7
Ericthonium brasiliensis	11.5
Section Caridea	14.9
Family Alpheidae	12.6
Alpheus lobidens polynesica	16.1
Thalamita integra	24.1
Etisus laevimanus	13.8
Pilumnus oahuensis	26.4
Crepidula aculeata	13.8
Hiatella hawaiiensis	50.6
Amathia distans	12.6
Bulgula neritina	32.2
Ophiactis savignyi	23.0
Ascidia sp.	10.3

* This variable (sponges) is not included in the individual abundance analyses.

Table 4.4-6. FACTOR LOADING MATRIX FOR P/A ANALYSIS (ONLY VARIABLES WITH AT LEAST ONE ABSOLUTE LOADING 0.5 OR GREATER ARE TABULATED)

FACTOR NUMBER		I	II
PERCENT OF TOTAL VARIANCE		28	7
VARIABLE	COMMUNALITY %		
NEMATODES	35	-	.58
ANNELIDS "Segmented Worms"	21	-	-
Errant Polychaetes	*		
Eurthoe complanata	42	.64	-
Eunice antennata	37	.54	-
Eunice vittata	33	.58	-
Eunice sp.	53	.65	-
Nematonereis unicornis	25	.50	-
Lumbrinerid sp.	32	.56	-
SIPUNCULIDS "Peanut Worms"	58	.74	-
ARTHROPODS	*		
Tanaids	*		
Apseudes sp. 1	59	.77	-
Apseudes sp. 2	49	.70	-
Leptochelia dubia	49	.70	-
Family Cirolanidae	33	.56	-
Amphipods	*		
Order Amphipoda	50	.67	-
Corophium acherusicum	47	.64	-
Ericthonius brasiliensis	30	.55	-
Decapods - crabs	*		
Thalamita integra	28	.53	-
Etisus laevimanus	28	.52	-
Pilumnus oahuensis	47	.64	-
MOLLUSCA	*		
Gastropods	*		
Crepidula aculeata	50	.50	.50
Pelecypods	*		
Hiatella hawaiiensis	40	.60	-
BRYOZOANS	*		
Bulgula neritina	45	-	.60
ECHINODERMS	*		
Ophiuroids "brittle stars"	*		
Ophiactis savignyi	53	.73	-

* These entries are not variables; they are presented only to show phyletic groupings.

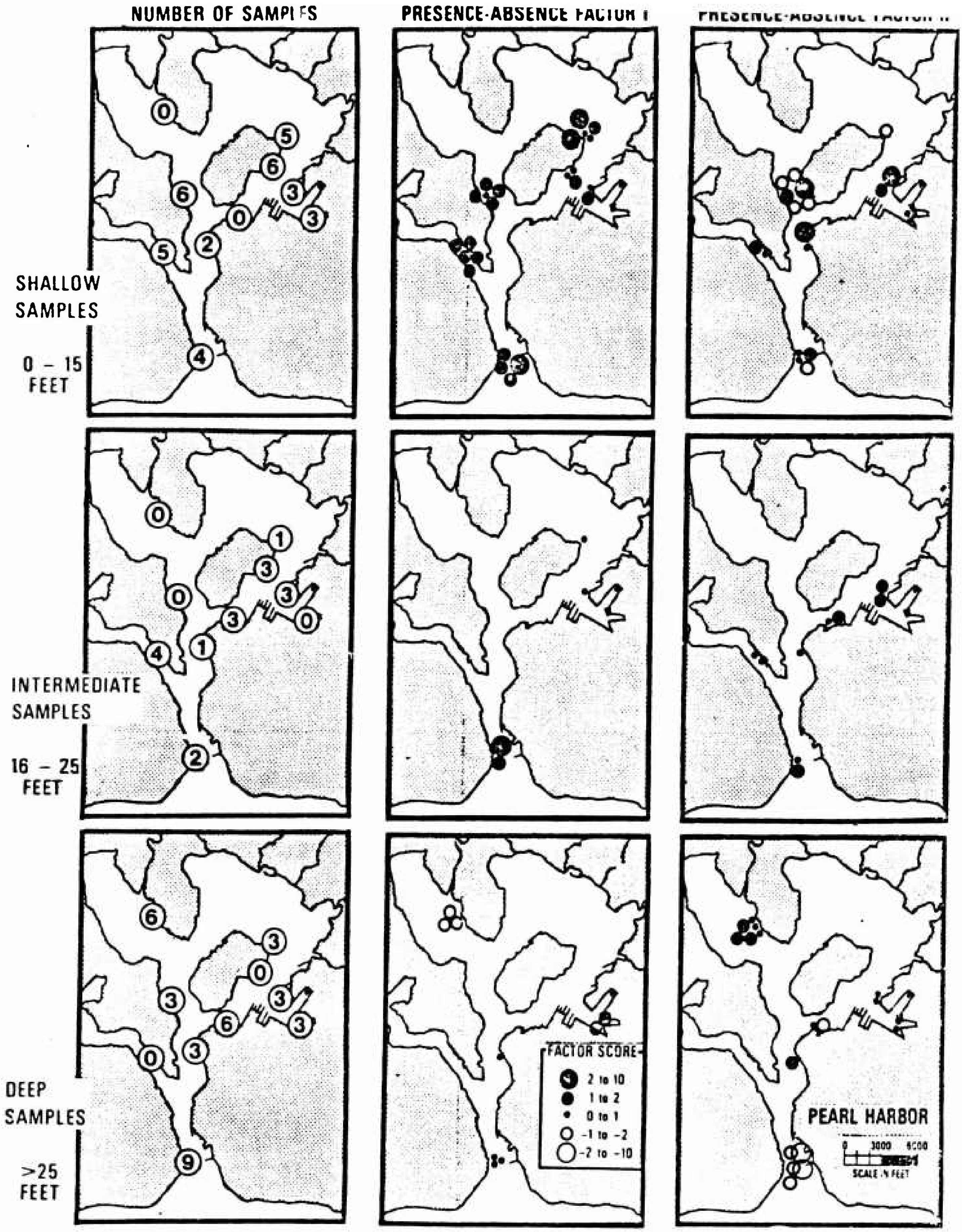


Figure 4.4-5. FACTOR SCORE MAP, P/A ANALYSIS OF BENTHIC ORGANISMS

292

almost as many nonmodal scores in the shallow depths as Factor I; 21 nonmodal scores out of a possible 34 (21/34) versus Factor I's 24/34. In the intermediate and deep depth classifications, Factor II does better than Factor I: 9/17 versus 4/17 in intermediate, and 18/36 versus 9/36 in deep. Bio-station BC-11 is again unique but not as clearly so in the P/A scores as in the abundance scores. BC-11 exhibits high scores on both P/A Factors I and II in the shallow and intermediate depth classifications and high negative scores on Factor II only, for the deep samples. In the shallow samples, BE-03, BC-09, and BC-11 score heavily on both Factors I and II (11/12 and 12/12 respectively), although on Factor II both BC-09 and BC-11 exhibit a positive-negative combination. BE-05 and BW-13 score heavily on Factor I only (10/10), and BE-04 and BC-10 score heavily on Factor II only (5/5). For the intermediate and deep classes, the generally reduced number of samples at all bio-stations tends to obscure the patterns. In the deep samples, however, the heavy scores on Factor II and BM-07 (6/6 all positive) and BC-11 (5/9 all negative) should be noted. Also in the deeper classifications, bio-stations BE-02, BE-05, and BC-09 are not represented at all by either of the two P/A factors.

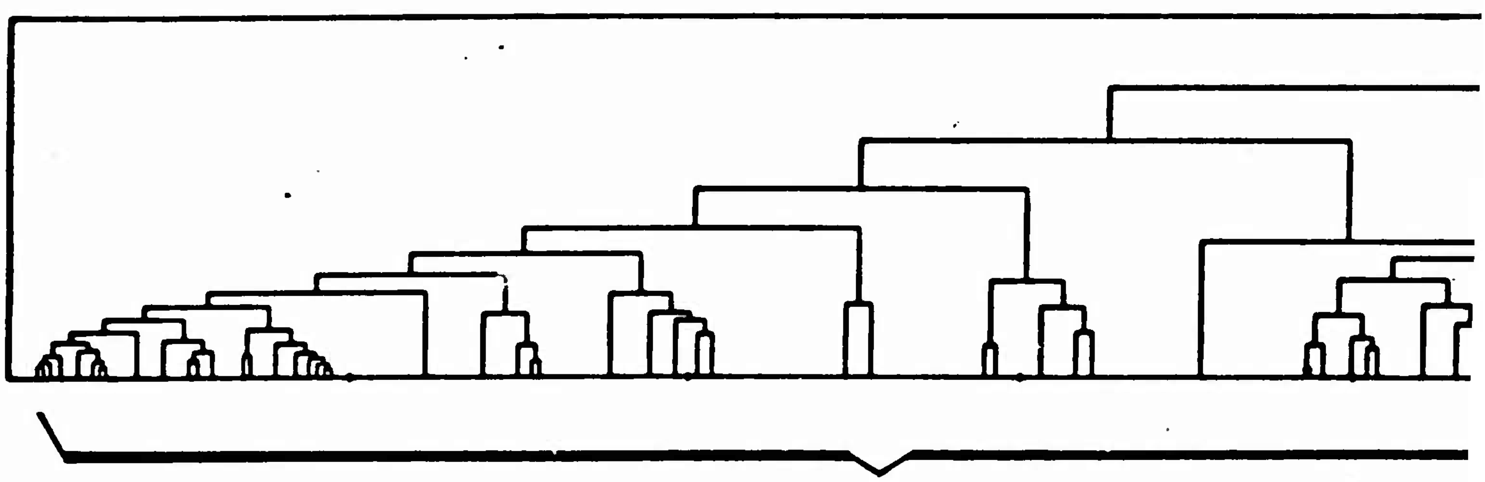
When the P/A factor scores are used to construct a dendrograph (Figure 4.4-6), three distinct clusters (A, B, and C) emerge. These clusters are also mapped in Figure 4.4-7; the depth classification and total possible samples format is the same as Figures 4.4-4 and 4.4-6. The dots, however, simply indicate presence in the given cluster. Cluster A contains 67 (77%) samples and is by far the largest of all the clusters, including all the deep samples, 15 out of a possible 17 (15/17 or 88%) of the intermediate samples (actually, with the exception of BC-11, Cluster A contains all intermediate samples too), and 16/34 or 47% of the shallow samples. Interestingly, none of the 9 possible shallow samples at BC-11 and BW-13 are contained in Cluster A. The mean depth (± standard error) of all 67 samples in Cluster A is 26±2 feet. Cluster B contains 8 (9%) samples, 7 shallow and 1 intermediate at BC-11; their mean depth (± standard error) is 10±3 feet. Cluster B contains samples from BE-03, BC-09, BC-11, and BW-13; if Cluster B is considered to be restricted to shallow samples, BM-07 and BE-17 could not be represented since no shallow samples were taken at these bio-stations. Cluster C is similar, containing 12 (14%) samples, 11 shallow and 1 intermediate at BC-11; their mean depth (± standard error) is 9±2 feet. Cluster C contains samples from BE-02, BE-05, BC-09, BC-11, and BW-15; again BM-07 and BE-17 could not be represented if the assumption made for Cluster B is applied. The primary difference between the latter two clusters (and perhaps among all three) is probably substrate type. Unfortunately, the available descriptive data on substrate type (see Table 2.2-1) are insufficient to resolve this point.

In any event, the P/A data primarily demonstrate a depth-related pattern in Pearl Harbor and weakly, if at all, indicate some pattern among the bio-stations. It therefore appears that P/A analysis is sufficient to recognize the same primary pattern obtained from the abundance analysis but is insufficient to resolve patterns of interstation variability.

SUMMARY

The benthic fauna of Pearl Harbor do reveal distinctive patterns of variability. The primary pattern is apparently related to water depth, although

(Text continued on page 4.4-26)



A

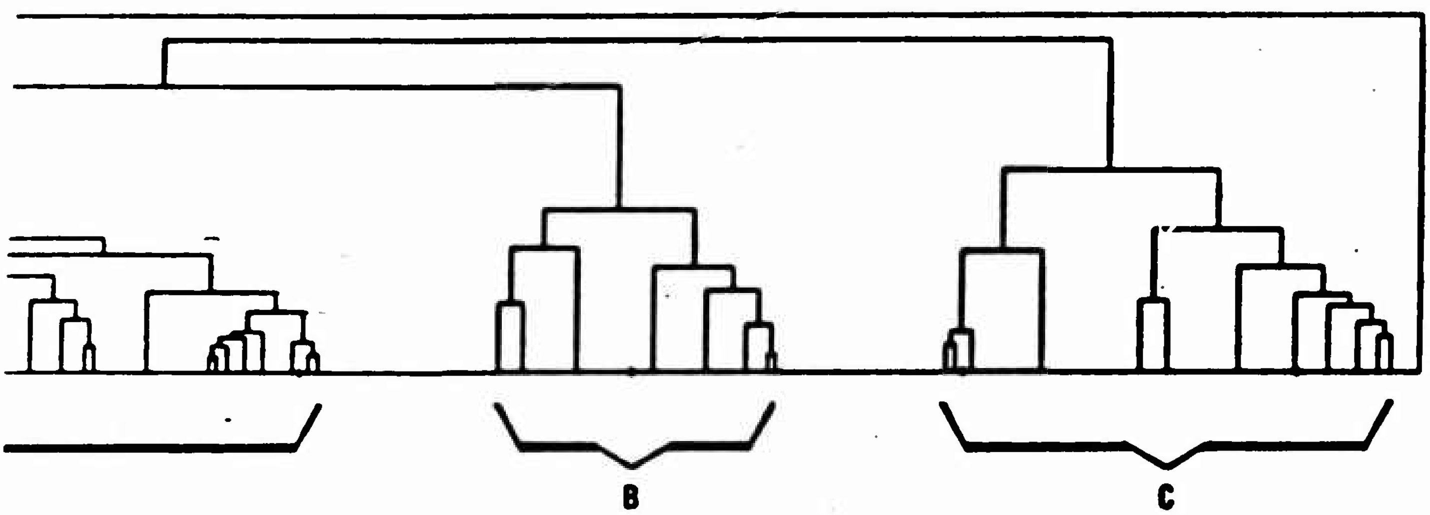


Figure 4.4-6. DENDROGRAPH BASED ON 2-FACTOR SCORE DISTANCES, P/A ANALYSIS OF BENTHIC ORGANISMS

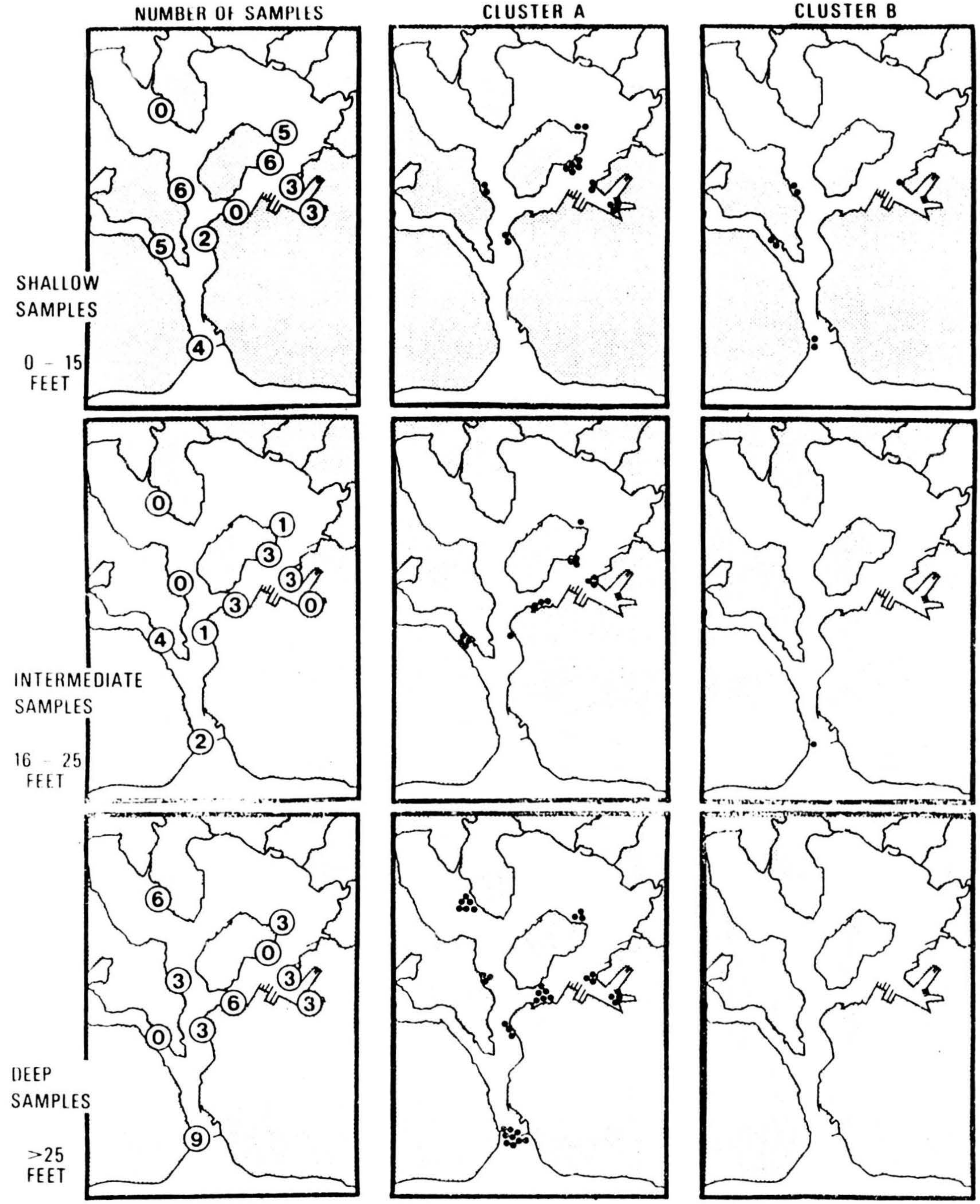


Figure 4.4-7

132

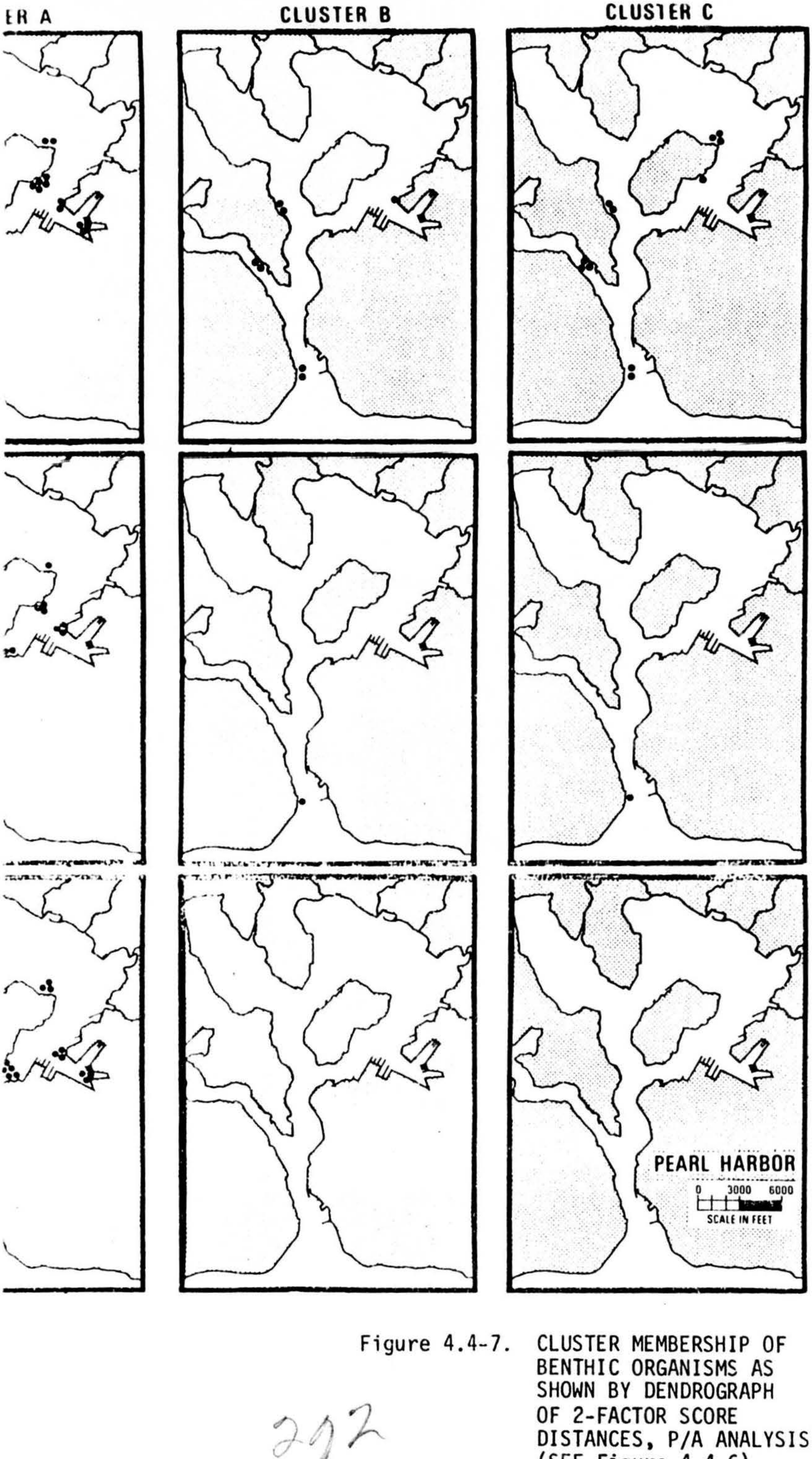


Figure 4.4-7. CLUSTER MEMBERSHIP OF BENTHIC ORGANISMS AS SHOWN BY DENDROGRAPH OF 2-FACTOR SCORE DISTANCES, P/A ANALYSIS (SEE Figure 4.4-6)

212

it also may contain an associated or independent relationship to substrate type. Another pattern may also be discerned among the bio-stations. BC-11 stands distinct from the rest. BE-05 and BC-09 are a second less distinctive group, while the remaining bio-stations (BE-02, BE-03, BE-04, BM-07, BC-10, BW-13 and BE-17) offer little quantitative justification for further division on the basis of benthic organisms. Comparison with the micromolluscan analysis (Section 4.5) shows essentially the same divisions among the bio-stations. Figure 4.5-4 shows BE-05, BC-09, and BC-11 as separate entities; only BE-02 is missed by the benthic analysis. Further discussion of the environmental interpretation of these patterns may be found in Sections 4.7 and 5.0.

REFERENCES

4.4-1. Eric B. Guinther, personal communication.

STATISTICAL ANALYSIS
OF MICROMOLLUSCA

Stephen V. Smith
Evan C. Evans III

INTRODUCTION

Micromollusca and some of their uses as indicators of water quality have been described in Section 2.3. Since living and dead members cannot be distinguished with certainty, micromolluscan techniques are best considered an analysis of death assemblages. This fact, however, does not detract from their utility as indicators. The preservation of their remains in sedimentary layers, however, permits the determination of past environmental condition. Furthermore, they may also be a potentially valuable analogue to the accumulation of heavy metals in bottom sediments. Indeed, the distribution of the *Hiatella/Odostomia indica* assemblage recognized by Kay in Section 2.3 closely resembles the distribution of Factor I metals in Section 4.1; compare Figures 2.3-3 and 4.1-2. Further discussion of these and other points may be found in Sections 4.7 and 5.0.

DATA USED IN THIS ANALYSIS

As described in Section 2.3, micromolluscan assemblages were extracted from sediment samples taken at 18 different locations in Pearl Harbor (see Figure 2.3-1 and Table 2.3-1). The basic input data are displayed in Table 2.3-5 which includes 72 species of micromollusc and one unidentified bivalve, collected at 16 bio-stations within Pearl Harbor and one bio-station outside the harbor. A 17th bio-station within the harbor, BM-16, which contained no living organisms, is ommitted from Table 2.3-5 but has been included in the multivariate analysis presented in this section. The treatment here includes both the multivariate analysis of species abundance and of species presence/absence (P/A) in a 25 cm^3 aliquot of sediment from each of the 18 bio-stations. In the P/A analysis, a 10%-to-90% cutoff criterion was used to prevent variances near zero; this means that only those species present at 2 or more, or at 16 or less bio-stations were used.

FACTOR ANALYSIS

Factor analyzing the micromolluscan species abundance matrix (18 stations x 73 variables) produced the 5-factor loading matrix presented in Table 4.5-1. These five factors account for 88% of the total variance in the 18x73 data matrix. Forty-five species load heavily (42 >0.8 and 3 >0.6) on Factor I, which explains 59% of the variance. The remaining four factors make only modest contributions to the percent of total variance explained, 10% for Factor II, and 6% each for the three remaining factors. Ten species load heavily (5 >0.8 and 5 >0.6) on Factor II, 5 species (3 >0.8 and 2 >0.6) on Factors III and IV, and 4 (3 >0.8 and 1 >0.6) on Factor V. Factor scores for the 18 bio-stations are presented in Table 4.5-2 and mapped into Pearl Harbor in Figure 4.5-1. Only BC-12 scores heavily on Factor I which is clearly representative of Kay's varied *Tricolia/Cithna* assemblage, compare Figures 4.5-1 and 2.3-3. Again a single bio-station scores highly on three of the remaining factors, viz. BE-05 on II, BE-02 on III, and BC-09 on V. Two bio-stations score highly on Factor IV, BE-04 positively and BW-14 negatively. Species loadings on Factors III through V do not correspond with Kay's assemblages in Section 2.3. Factor III is dominated by the mesogas-

Table 4.5-1. PEARL HARBOR MICROMOLLUSCA, ABSOLUTE ABUNDANCE ROTATED FACTOR LOADING MATRIX

Factor number		I	II	III	IV	V
Percent of total variance		59.1	10.4	6.6	5.7	5.8
Species	**Communality (%)**					
Acar plicata	100	1.00	-0.00	-0.02	-0.06	-0.01
Alaba goniochila	100	1.00	-0.00	-0.02	-0.06	-0.01
Anomia nobilis	92	-0.14	0.10	0.07	-0.94	-0.01
Arca sp.	99	-0.06	0.99	0.05	-0.01	0.06
Aspella producta	100	0.69	0.72	-.03	-0.05	0.03
Balcis sp.	91	0.30	-0.09	0.08	-0.86	-0.26
Barbatia nuttingi	100	1.00	-0.00	-0.02	-0.06	-0.01
Bittium hiloense	100	1.00	-0.00	-0.02	-0.06	-0.01
Bittium impendens	100	1.00	-0.00	-0.02	-0.06	-0.01
Bittium parcum	97	1.00	-0.02	-0.00	-0.07	0.02
Bittium zebrum	95	-0.14	0.69	-0.37	-0.08	-0.56
Brachidontes sp.	90	0.20	-0.12	0.04	-0.90	0.22
Cantharus farinosus	99	-0.06	0.99	0.05	-0.01	0.06
Carinapex sp.	100	1.00	-0.00	-0.02	-0.06	-0.01
Cerithiopsis sp. A	98	-0.12	0.18	-0.59	-0.05	-0.75
Cerithiopsis sp. B	100	1.00	-0.00	-0.02	-0.06	-0.01
Cerithium nesioticum	100	1.00	-0.00	-0.02	-0.06	-0.01
Chama sp.	99	-0.06	0.99	0.05	-0.01	0.06
Cithna sp.	100	1.00	-0.00	-0.02	-0.06	-0.01
Crepidula aculeata	7	-0.08	-0.11	0.10	-0.09	0.19
Crucibulum spinosum	54	-0.16	-0.12	0.10	-0.68	0.20
Ctena bella	99	-0.08	-0.02	0.17	-0.12	-0.97
Cyclostremiscus kennyi	100	1.00	-0.00	-0.02	-0.06	-0.01
Cyclostremiscus minutissimus	100	1.00	-0.00	-0.02	-0.06	-0.01
Cyclostremiscus sp. A	100	1.00	-0.00	-0.02	-0.06	-0.01
Cyclostremiscus sp. B	8	-0.04	-0.08	0.08	0.25	0.07
Cyclostremiscus sp. C	100	1.00	-0.00	-0.02	-0.06	-0.01
Cyclostremiscus sp. D	100	1.00	-0.00	-0.02	-0.06	-0.01
Cysticus sp.	100	1.00	-0.00	-0.02	-0.06	-0.01
Diala varia	100	0.97	-0.00	-0.23	-0.05	-0.03
Diodora granifera	100	1.00	-0.00	-0.02	-0.06	-0.01
Engina sp.	3	-0.07	-0.06	0.07	-0.08	0.10
Euchelus gemmatus	100	1.00	0.14	-0.01	-0.06	-0.00
Heliacus sp.	94	0.65	-0.07	0.00	-0.71	0.12
Hiatella hawaiensis	18	-0.23	0.13	0.14	0.20	0.22
Hipponix spp.	6	-0.08	-0.15	0.05	0.15	0.07
Julia exquisita	100	1.00	-0.00	-0.02	-0.06	-0.01
Kogomea sandwicensis	100	1.00	-0.00	-0.02	-0.06	-0.01
Leiostraca sp.	100	1.00	-0.00	-0.02	-0.06	-0.01
Leptothyra candida	100	1.00	-0.00	-0.02	-0.06	-0.01
Leptothyra rubricincta	99	1.00	-0.00	-0.01	-0.05	-0.01
Merelina sp.	100	1.00	-0.00	-0.02	-0.06	-0.01

Table 4.5-1. (Continued)

Species	Communality (%)	I	II	III	IV	V
Factor Number		I	II	III	IV	V
Percent of total variance		59.1	10.4	6.6	5.7	5.8
Natica sp.	7	-0.08	-0.11	0.08	0.19	0.09
Obtortio fulva	99	-0.11	-0.02	-0.30	-0.10	-0.94
Obtortio perparvulum	100	1.00	-0.00	-0.02	-0.06	-0.01
Odostomia eclecta	100	1.00	-0.00	-0.02	-0.06	-0.01
Odostomia indica	13	-0.19	0.21	0.01	0.21	0.08
Odostomia oodes	95	-0.20	0.63	-0.34	-0.40	-0.49
Odostomia patricia	100	1.00	-0.00	-0.02	-0.06	-0.01
Odostomia paulbartschi	74	0.85	-0.05	0.03	-0.08	0.08
Odostomia scopulorum	100	1.00	-0.00	-0.02	-0.06	-0.01
Odostomia stearnsiella	97	0.10	0.95	0.01	-0.21	-0.11
Odostomia sp.	12	-0.06	-0.12	0.11	0.28	0.11
Ostrea spp.	54	0.06	0.71	-0.06	0.10	-0.16
Parashiela beetsi	100	1.00	-0.00	-0.02	-0.06	-0.01
Peristernia chlorostoma	99	-0.06	0.99	0.05	-0.01	0.06
Phenacolepas sp.	100	1.00	-0.00	-0.02	-0.06	-0.01
Pillucina spaldingi	98	-0.07	-0.02	0.16	-0.10	-0.97
Risoella spp.	98	0.14	-0.04	-0.93	-0.30	-0.03
Rissoina ambigua	100	1.00	-0.00	-0.02	-0.06	-0.01
Rissoina gracilis	100	1.00	-0.00	-0.02	-0.06	-0.01
Rissoina miltozona	100	1.00	-0.00	-0.02	-0.06	-0.01
Rissoina turricula	100	1.00	-0.00	-0.02	-0.06	-0.01
Rocellaria sp.	98	-0.07	-0.01	-0.99	0.03	-0.10
Scissurella aequatoria	100	1.00	-0.00	-0.02	-0.06	-0.01
Tricolia variabilis	100	1.00	-0.00	-0.02	-0.06	-0.01
Triphora spp.	99	0.94	0.29	-0.14	-0.06	0.00
Trochus histrio	99	-0.09	0.72	-0.68	0.02	-0.03
Turbonilla sp.	100	0.67	-0.01	-0.73	-0.02	-0.08
Turrid sp.	100	-0.07	-0.01	-0.99	0.03	-0.10
Vermetus sp.	100	1.00	-0.00	-0.02	-0.06	-0.01
Zebina tridentata	100	1.00	-0.00	-0.02	-0.06	-0.01
Bivalve spp.	100	0.98	-0.01	-0.13	-0.11	-0.01

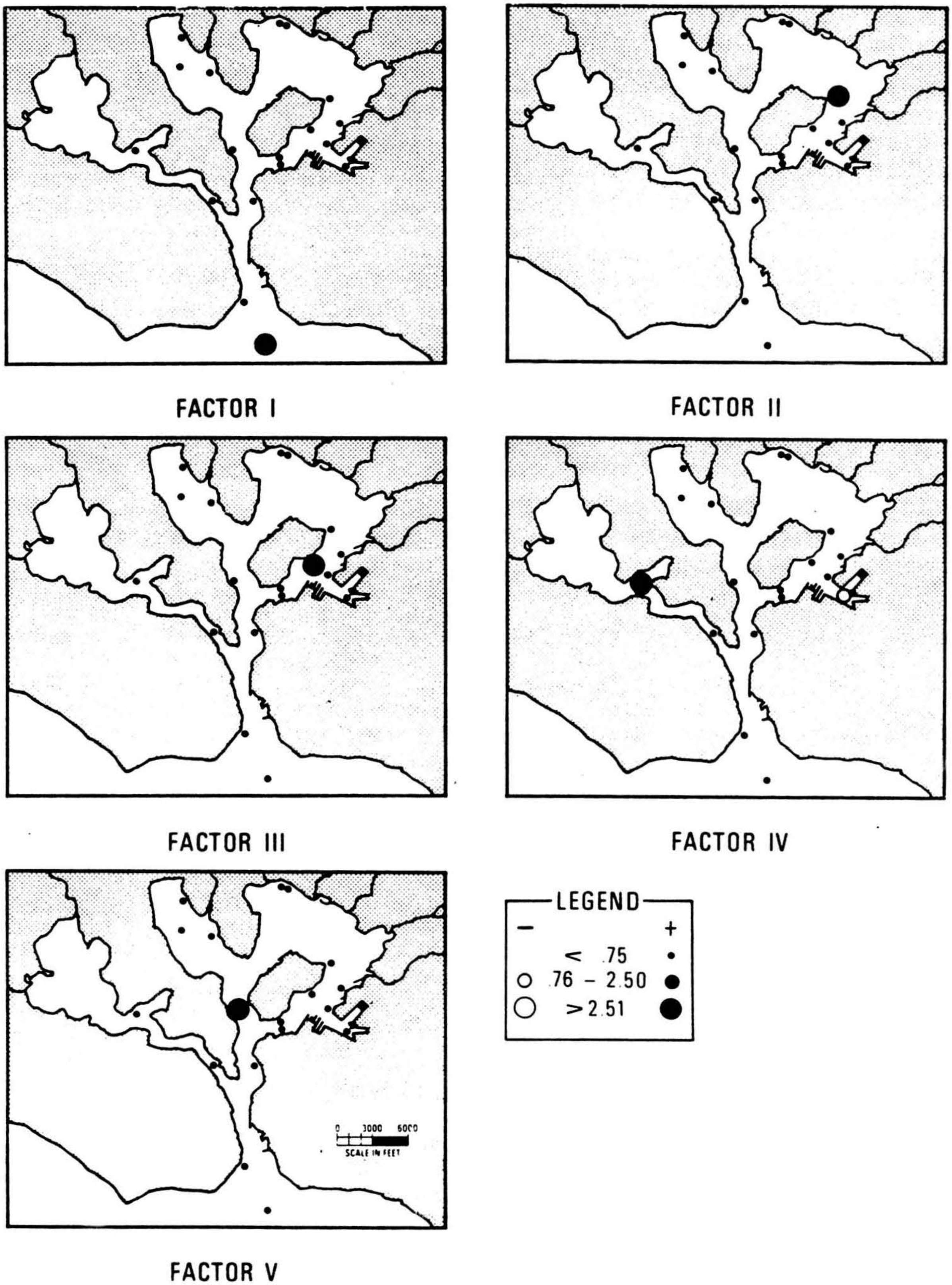


Figure 4.5-1. FACTOR SCORE MAP, ABUNDANCE ANALYSIS OF MICROMOLLUSCA

tropod genus *Risoella*, a neogastropod Turrid, and a free-living bivalve *Rocellaria* sp.; of these only *Risoella* appears in significant numbers at a number of bio-stations. Both Factors IV and V are dominated by two bivalve species each; the former by the cement forming *Anomia nobilis* and the byssal thread forming *Brachidontes* sp., and the latter by the two free-living benthic forms *Ctena bella* and *Pillucina spaldingi* (the mesogastropod *Obtortio fulva* also loads heavily on Factor V). Factor II, on which BE-05 scores highly, somewhat resembles Kay's assemblage dominated by *Odostomia oodes*; however, *O. stearnsiella*, a species which she does not single out, shows an even higher loading than *O. oodes*. Furthermore, three of the six species listed by Kay as characteristic of her four assemblages show very low commonalities on the five factors, viz. *Crepidula aculeata* 7%, *Hiatella hawaiensis* 18%, and *Odostomia indica* 13%). Thus, with the exception of the *Tricolia/Cithna* assemblage, there appears to be a relatively poor relationship between Kay's assemblages and these factors based on species abundance.

Factor analysis based on P/A data yields patterns similar to those just presented on absolute abundance data. The data matrix (reduced to 18x29 by the cutoff criterion) produced the 3-factor loading matrix presented in Table 4.5-3. These three factors account for 57% of the total variance. Species loadings on these three factors are more moderate than the abundance case, 12 species loading significantly on Factor I, 3 on II, and 10 on III. BC-12 cannot be well represented in this analysis since those species admitted by the cutoff criterion constitute only 20% of the total number of micromollusca found at that station; nevertheless, those species present at BC-12 again load significantly on Factor I. Species loading on Factor II are those absent from BC-12, and species loading on Factor III are a combination of species not found at BC-12 or there only in small numbers. The factors for the 18 bio-stations are presented in Table 4.5-4 and mapped into Pearl Harbor in Figure 4.5-2. Interesting combinations of negative-scoring and positive-scoring bio-stations appear in the maps. For Factor I, BC-09 and BE-06c are the reverse of BC-12; for Factor II, BE-02, BE-05, and BC-09 form a positive group with BC-12 and BW-14 forming a negative pair; for Factor III, BE-06w, BM-08, and BM-16 (all highly stressed bio-stations) form a positive group while BE-06c, BC-09, BC-12, and BW-14 form a negative group. The significance of these groupings, if indeed they are significant, remains to be interpreted. With the exception of the stressed group identified for Factor III, all bio-stations involved show up as singularities in the cluster analysis which follows.

CLUSTER ANALYSIS

Factor scores were used to calculate distances between bio-stations in 5-space for the abundance analysis and in 3-space for the P/A analysis. These distances were then used to construct two dendrographs, Figure 4.3-3 for abundance and Figure 4.5-4 for P/A. Inspection of these figures shows them to be quite similar. Bio-stations BE-02, BE-05, BC-09, BC-12, and BW-14 appear as singularities or as members of singular pairs in both figures. In the P/A dendrograph (Figure 4.5-4), these bio-stations are joined by BC-06c and BC-11 as second members of singular pairs. BC-12 remains a singularity in both dendrographs. Considering first the abundance dendrograph (Figure 4.5-3), two clusters

Table 4.5-3. PEARL HARBOR MICROMOLLUSCA, PRESENCE/ABSENCE ROTATED FACTOR LOADING MATRIX

Species	Communality (%)	I	II	III
Factor number		I	II	III
Percent of total variance		24.5	15.5	16.6
Anomia nobilis	51	-0.12	0.36	-0.61
Aspella producta	65	0.72	0.37	0.07
Balcis sp.	46	0.48	-0.05	-0.47
Bittium parvum	72	0.76	-0.34	-0.14
Bittium zebrum	76	-0.14	0.78	-0.36
Brachidontes sp.	86	0.71	-0.47	-0.36
Cerithiopsis sp. A	80	0.05	0.86	-0.23
Crepidula aculeata	46	0.16	0.14	-0.65
Crucibulum spinosum	56	-0.04	-0.40	-0.64
Ctena bella	53	-0.31	0.28	-0.60
Diala varia	73	0.77	0.30	-0.08
Euchelus gemmatus	65	0.72	0.37	0.07
Heliacus sp.	67	0.72	-0.26	-0.29
Hiatella hawaiensis	55	-0.64	0.08	-0.36
Hipponix spp.	58	0.16	-0.21	-0.72
Leptothyra rubricincta	40	0.62	-0.05	0.06
Natica sp.	8	-0.19	-0.19	0.09
Obtortio fulva	67	-0.15	0.57	-0.57
Odostomia indica	32	0.06	0.06	-0.56
Odostomia oodes	38	0.07	0.06	-0.61
Odostomia paulbartschi	72	0.76	-0.34	-0.14
Odostomia stearnsiella	52	0.33	0.21	-0.50
Odostomia sp.	17	-0.02	-0.39	-0.13
Ostrea spp.	38	0.14	0.49	-0.35
Risoella spp.	50	0.44	0.09	-0.55
Triphora spp.	68	0.73	0.36	-0.11
Trochus histrio	71	0.21	0.82	-0.00
Turbonilla sp.	73	0.77	0.35	-0.08
Bivalve spp.	63	0.72	0.12	-0.31

Table 4.5-4. PEARL HARBOR MICROMOLLUSCA, PRESENCE/ABSENCE ROTATED FACTOR SCORES FOR BIO-STATIONS

Factor number		I	II	III
Bio-Station	Communality* (%)			
BE-01	29	-0.54	-0.55	-0.27
BE-02	62	0.75	2.28	0.45
BE-03	29	-0.54	-0.55	-0.27
BE-04	26	-0.46	-0.48	-0.34
BE-05	56	0.42	2.35	-0.42
BE-06c	66	-0.93	0.42	1.86
BE-06w	60	-0.40	-0.20	-1.35
BM-07	40	-0.44	-0.05	-0.50
BM-08	41	-0.35	-0.16	-1.08
BC-09	60	-0.83	1.14	1.50
BC-10	6	-0.09	-0.05	-0.38
BC-11	43	0.68	-1.58	0.78
BC-12	95	3.62	-0.26	0.02
BW-13	28	-0.48	-0.48	0.49
BW-14	48	0.45	-1.23	1.62
BE-15	14	-0.33	-0.46	0.45
BM-16	60	-0.00	-0.17	-2.08
BE-17	33	-0.54	0.12	-0.48

* This value is an approximation of communality; it is in fact the sum square of scores divided by the sum square of varialies expressed as percent.

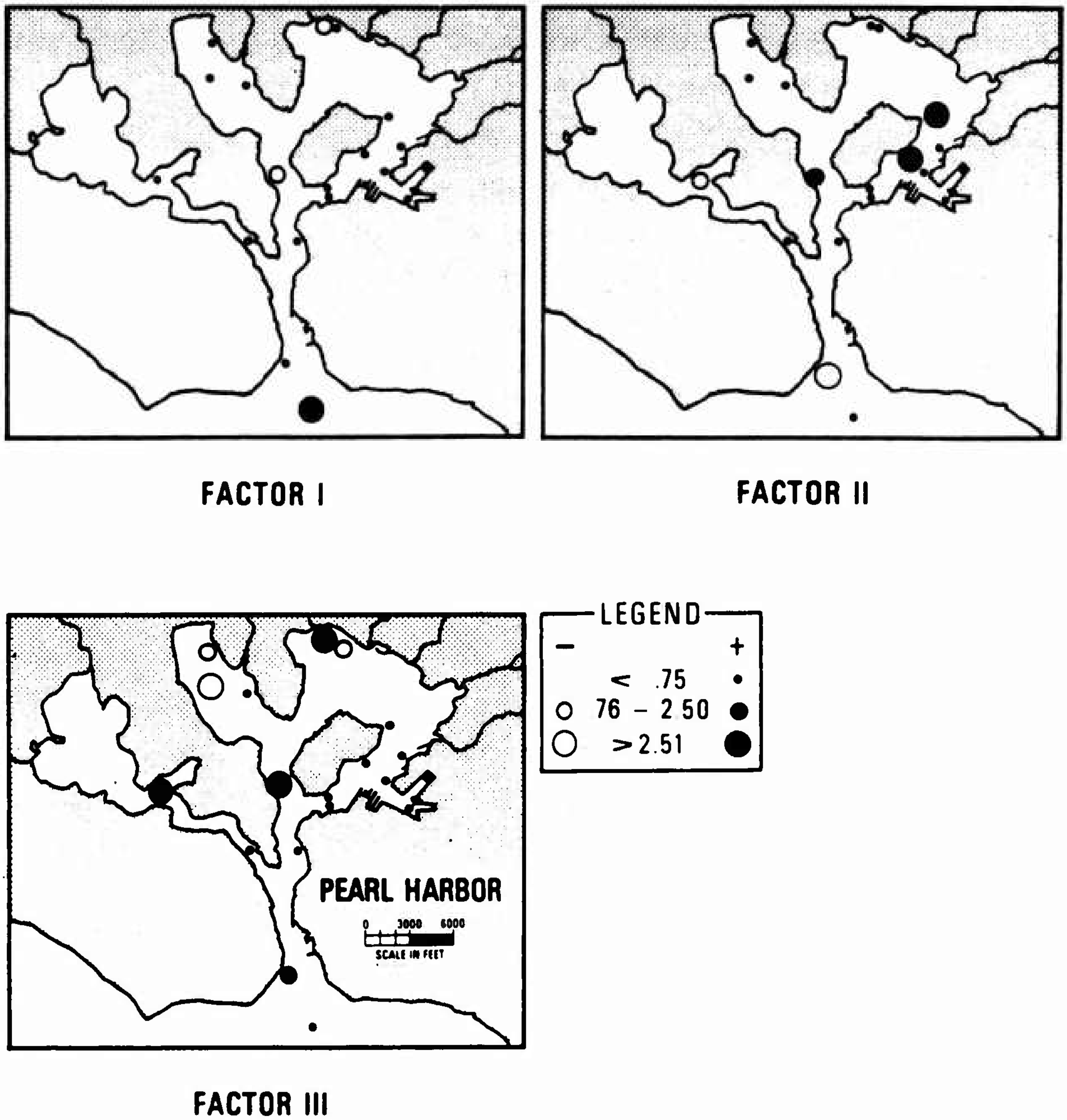


Figure 4.5-2. FACTOR SCORE MAP P/A ANALYSIS OF MICROMOLLUSCA

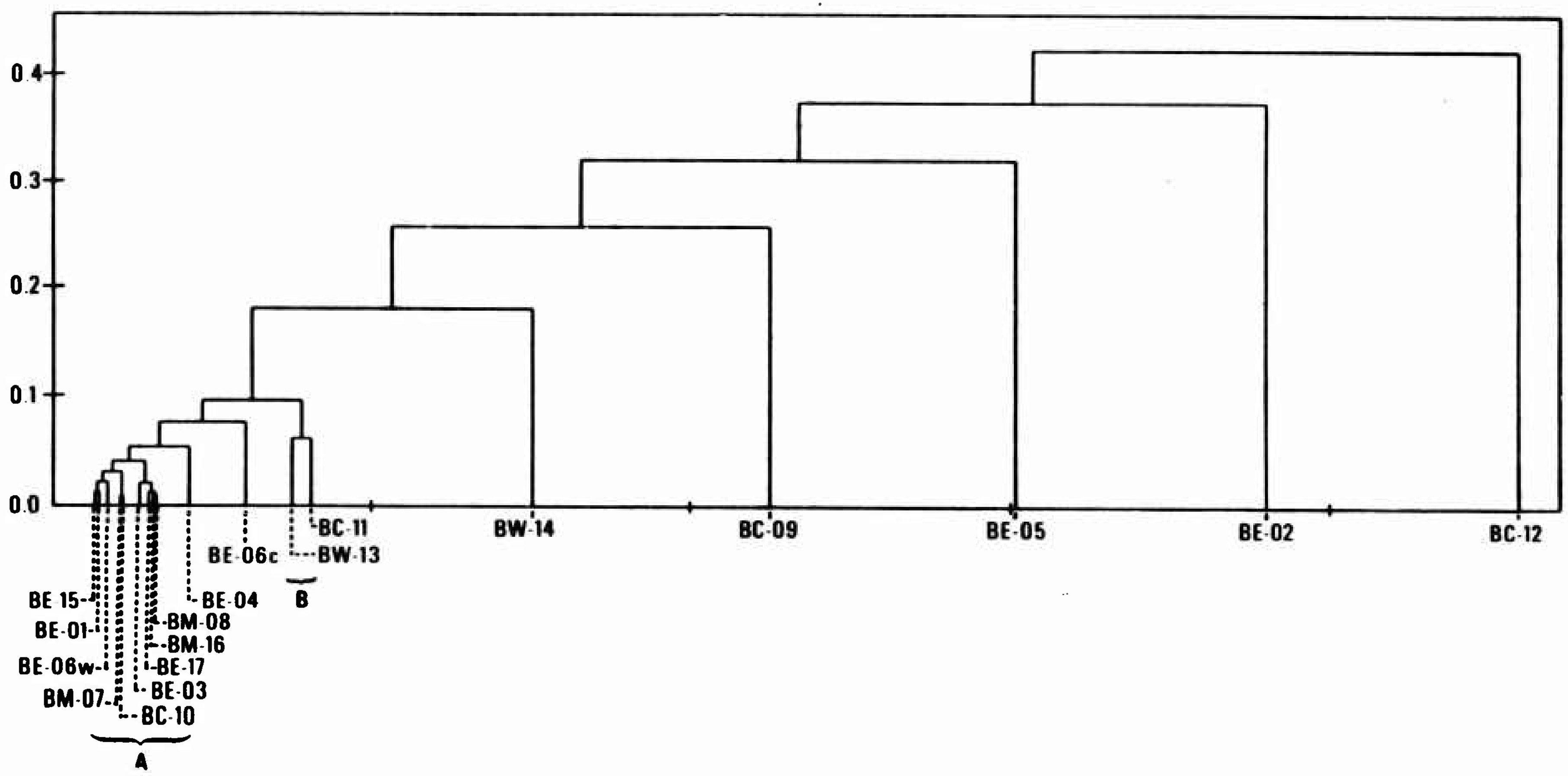


Figure 4.5-3. MICROMOLLUSCA, 5-FACTOR SCORE DENDROGRAPH (Absolute Abundance)

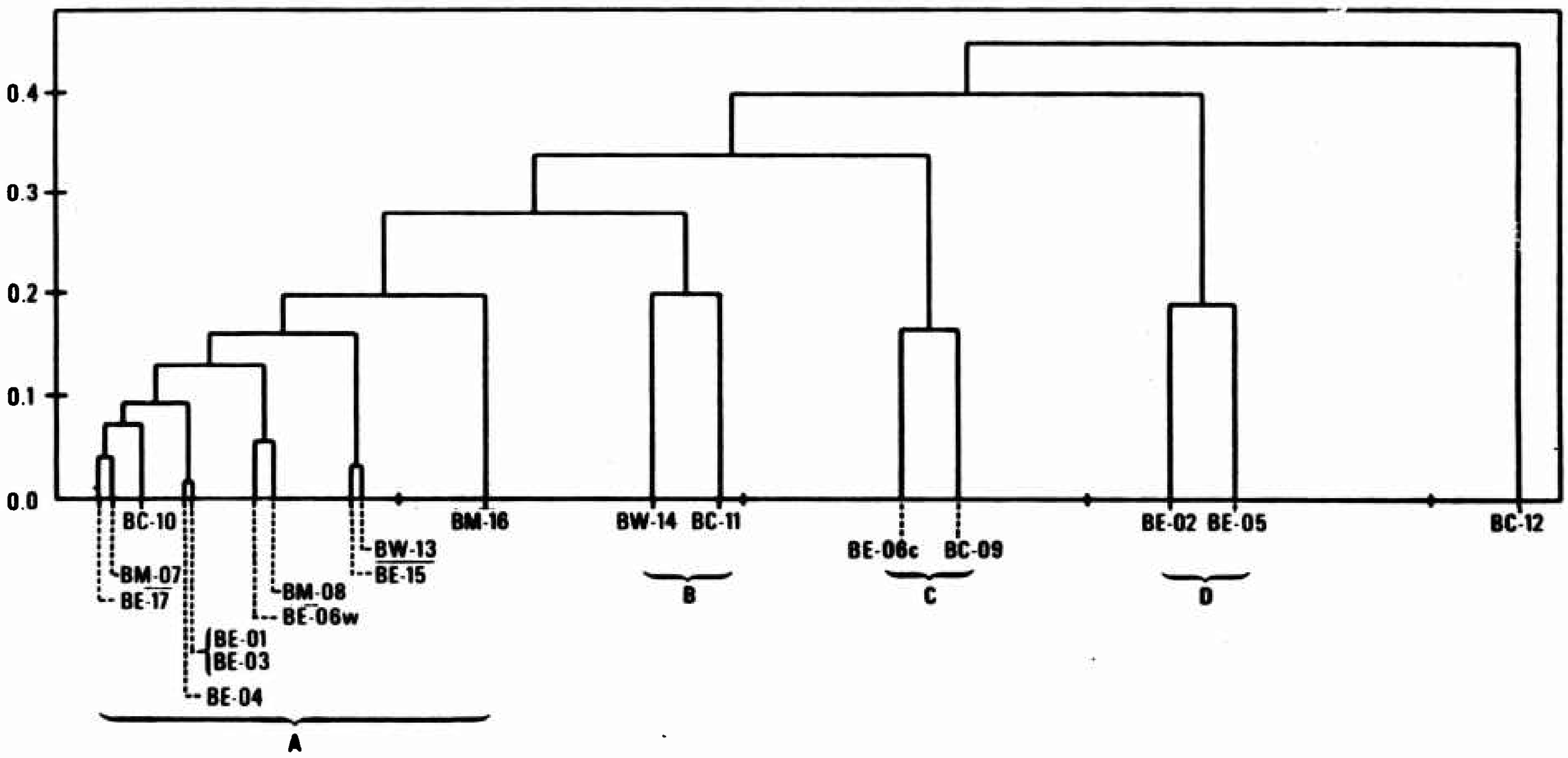


Figure 4.5-4. MICROMOLLUSCA, 3-FACTOR SCORE DENDROGRAPH (Presence/Absence)

A and B, may be defined. Cluster A contains bio-stations BE-01, BE-03, BE-04, BE-06w, BM-07, BM-08, BC-10, BE-15, BM-16, and BE-17 and very nearly coincides with Kay's *Hiatella/Odostomia indica* assemblage. The inclusion of BM-08, a member of Kay's *Odostomia oodes* assemblage is the only exception since BM-16 was not considered by Kay in her analysis. She describes the *Hiatella/O. indica* assemblage as one having the fewest number of species (see Section 2.3), thus the inclusion of BM-16, with no organisms, and of BM-08, which is also low in total number of species (see Table 2.3-5), would seem appropriate. The second cluster, B in Figure 4.5-3, contains BC-11 and BW-13, and may or may not contain BE-06c. BC-11 represents Kay's *Crepidula*-dominated assemblage. BW-13 and BE-06c are members of her *Odostomia oodes* assemblage. All three bio-stations might enjoy improved water quality. BC-11 and BW-13 because of their channel locations. BE-06c because normal surface currents would tend to push Southeast Loch waters away from that bio-station and also because the Waiau intake may stimulate local circulation, see Section 3.3. The low communality of *Crepidula aculeata* (7%, see Table 4.5-1) with the 5 factors effectively excludes that species from the statistical analysis, therefore it is not surprising that a bio-station dominated by it does not stand alone. The remaining bio-stations constituting Kay's *Odostomia oodes* assemblage are spread among the 5 (or 6 if BE-06c is included) singularities on the dendrograph, compare with Figure 2.3-3. This assemblage is described as containing relatively more species than the *Hiatella/O. indica* assemblage and thus may be considered more highly varied. BC-12 (with the most varied population) also stands among the singularities. A tabular comparison of Kay's assemblages and the 5-factor dendrograph is presented in Table 4.5-5 (here BE-06c is counted as a singularity).

Again the P/A dendrograph (Figure 4.5-4) is quite similar to that obtained from absolute abundance data. BC-11 and BW-14, BC-06c and BC-09, and BE-02 and BE-05 now show up as singular pairs. The reason for this appearance may be seen by inspecting a three-dimensional plot of the factor scores (Figure 4.5-6). Note the three vector pairs of roughly equivalent direction and length. Interestingly, BE-06c joins another member of the *Odostomia oodes* assemblage, BC-09. Again a tabular comparison of Kay's assemblages and P/A dendrograph clusters is presented in Table 4.5-6. Finally, a triangular plot of the important species composing Kay's micromolluscan assemblages (see Table 2.3-6) has been prepared on the basis of their loading or non-loading on the three P/A factors, see Figure 4.5-5. Species loading on Factor I are: *Bittium parcum*, *B. zebrum*, *Cithna* sp., *Cyclostremiscus minutissimus*, *Leptothyra rubricincta*, *Obtortio perparvulum*, *Tricolia variabilis*, and *Triphora* spp.; those on Factor II are: *Odostomia indica*, *O. oodes*, and *O. steamsiella*; and those not loading significantly on any of the three factors are: *Crepidula aculeata*, *Cyclostremiscus* sp. B, *Hiatella hawaiensis*, and *Hipponix* spp. Comparison of Figure 4.5-5 with 2.3-3 shows that three of Kay's assemblages, viz. the *Tricolia/Cithna*, the *Hiatella/O. indica*, and the *Odostomia oodes*, tend to occupy opposite corners of the plot, again indicating good agreement between this clustering technique and Kay's assemblages.

In summary, the cluster analysis reveals one cluster (A in both dendrographs) and one singularity (BC-12) that are nearly coincident with two of Kay's assemblages. Kay's *Odostomia oodes* assemblage is characterized by its heterogeneity on both dendrographs, while Kay's *Crepidula*-dominated assemblage at BC-11 is not recognized. The curious phenomenon emerges that the cluster

(Text continued on page 4.5-17)

Table 4.5-5. CLUSTER/ASSEMBLAGE COMPARISON, 5 FACTOR SCORE DISTANCES
(Absolute Abundances)

Kay's Assemblages	cluster A	cluster B	BE-02	BE-05	BE-06c	BC-09	BC-12	BW-14	TOTALS
Hiatella/O. indica	8								8
Odostomia oodes	1	1	1	1	1	1		1	7
Tricolia/Cithna							1		1
Crepidula		1							1
no organisms	1								1
TOTALS	10	2*	1	1	1*	1	1	1	18

* If BE-06c is included in cluster B, its total becomes 3 and the BE-06c column is struck.

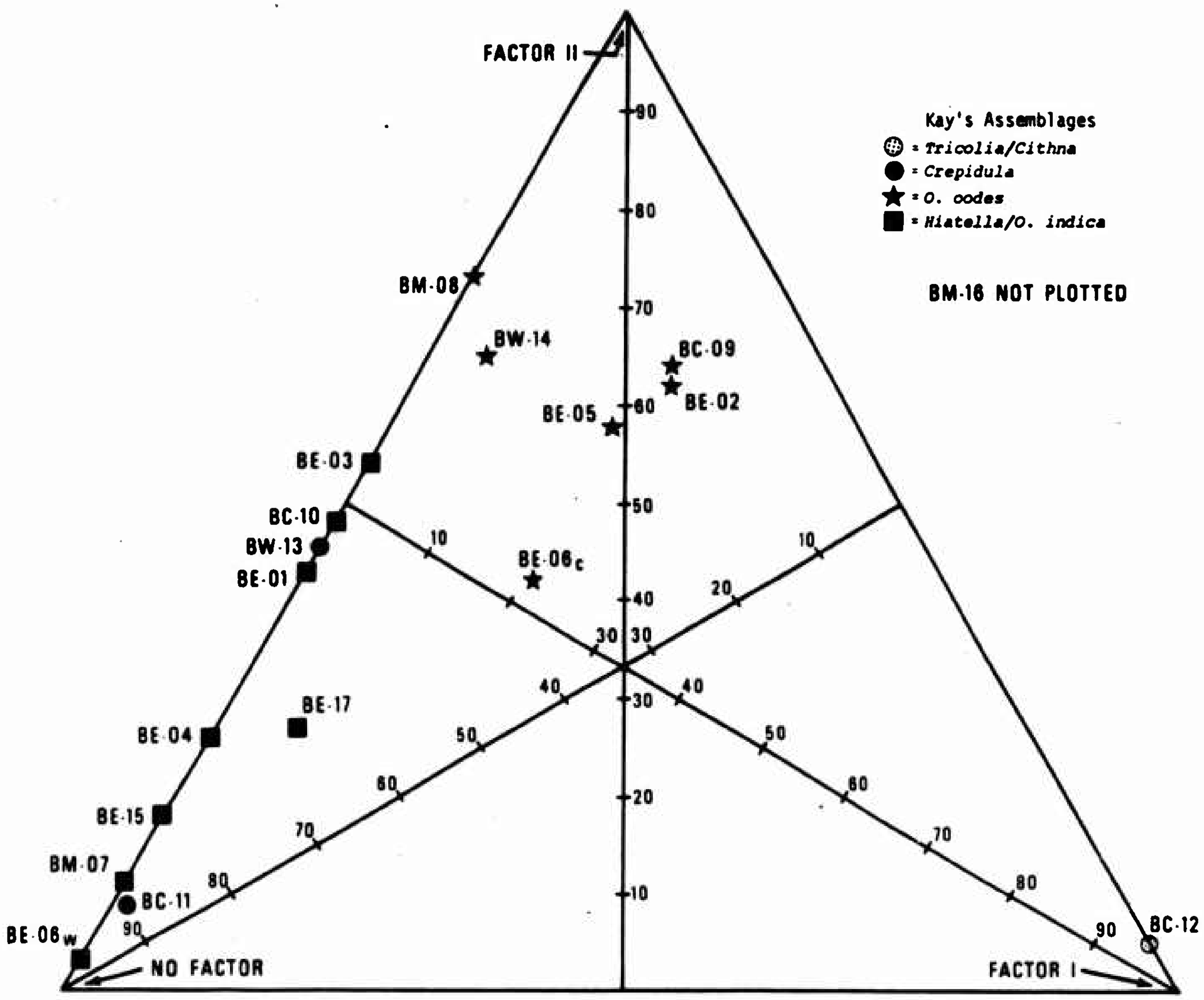


Figure 4.5-5. MICROMOLLUSCS TRIANGULAR PLOT OF DOMINANT SPECIES GROUPED BY P/A FACTOR LOADING

Table 4.5-6. CLUSTER/ASSEMBLAGE COMPARISON, 3 FACTOR SCORE DISTANCES (Presence/Absence)

Kay's Assemblages	cluster A	cluster B	cluster C	cluster D	BC-12	TOTALS
Hiatella/O. indica	8					8
Odostomia oodes	2	1	2	2		7
Tricolia/Cithna					1	1
Crepidula		1				1
no organisms	1					1
TOTALS	11	2	2	2	1	18

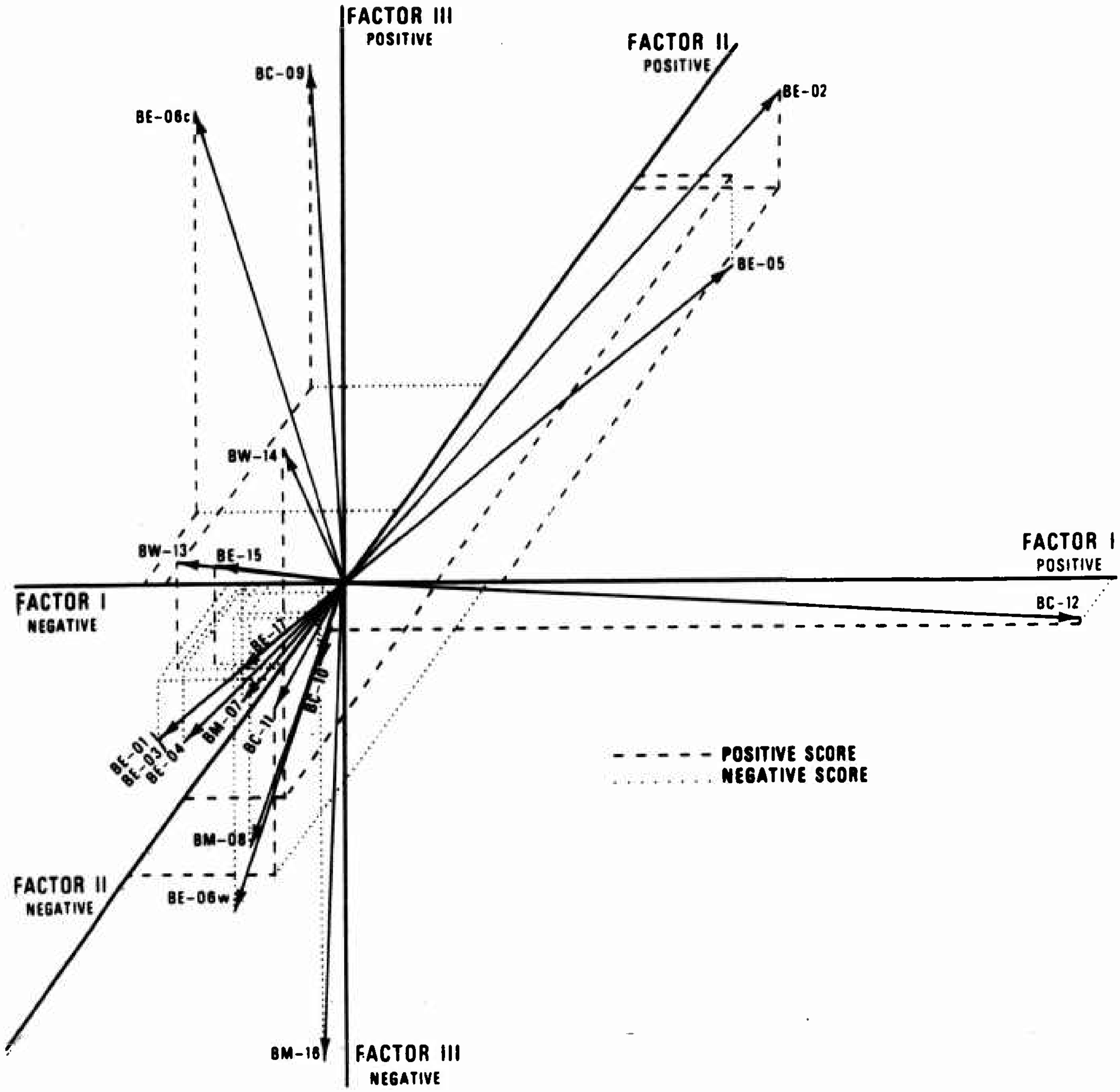


Figure 4.5-6. MICROMOLLUSCA, 3-DIMENSIONAL PLOT OF P/A FACTOR SCORES

analysis yields results quite similar to Kay's definition of assemblages while factor analysis does not. Two related considerations probably explain this discordance.

The first consideration is the "information content" of the absolute abundance data used for factor analysis and of the percentage or relative abundance data used to define Kay's assemblages. The two sets of information obviously differ; an abundant species in a particular sample may or may not dominate in terms of percentage. There is more information in absolute abundance data than in percentage data; percentages may be derived from absolute abundance but not *vice versa*. For this reason, absolute abundance was used in the factor analysis. In this sense, the similarities rather than the differences between the two analyses are, perhaps, surprising.

Differences in "information content" do not, however, explain why cluster analysis of the factor scores is needed in this instance to find similarities which do exist. Here, the argument is procedural. The orthogonal factor analysis used is designed to define groups of variables which are uncorrelated with one another. Thus, two distinct but correlated groups would not be defined as a single entity. Instead, two uncorrelated groups containing elements of the two correlated groups would be defined. For this reason, factor analysis might be described as "biologically sterile" (Reference 4.5-1). In contradistinction, the cluster analysis techniques employed are expressly designed to look for relationships among the bio-stations and are capable of recognizing similarities even among the orthogonal factor scores. Another aspect of Kay's assemblages is that they are necessarily negatively correlated, as may be seen by the following trivial consideration. A given bio-station is assigned to only one assemblage; thus, if two species characteristic of two different assemblages are present at that bio-station, the station assignment is given to that species having a slight plurality while the slightly less important species is not recognized. The combination of factor and cluster analysis is therefore a particularly powerful and objective analytical tool.

Another important fact is to be gained from a comparison of the analyses based on absolute abundance and on presence/absence (P/A) data. The same patterns emerge from both these different analytical procedures. This fact contrasts with the results of the several different analyses performed on the Pearl Harbor fish data, see Section 4.3 and especially Table 4.3-3. Except for the singularity of bio-station BC-11, any patterns emerging from the fish data were very dependent on the exact characteristics of the analysis employed. The fish data are therefore considered noncoherent. The patterns obtained from the micromolluscan data are, on the other hand, relatively coherent, in the sense that they are less dependent on the nature of the analysis performed. They are real characteristics of the data. Thus, another important benefit of multiple analytical approaches is the recognition of coherence or analysis-independent patterns. For further discussion of these matters, see Sections 4.7 and 5.0.

REFERENCES

4.5-1. Thomas A. Ebert, personal communication. Dr. Ebert has used the term "biologically sterile" in the general context of statistics which yield nonintuitive results. In the situation described above, he might have so used the term.

PILING BIOTA

Stephen V. Smith
Gerald S. Key
Evan C. Evans III

INTRODUCTION

The final group of organisms to be discussed in this section comprise the biotic assemblages which inhabit vertical hard surfaces, both artificial and natural. For convenience, these organisms are referred to as "piling biotas". To the extent that these biotic assemblages utilize a type of substratum (e.g., pier pilings, seawall, etc.) not naturally available in the harbor, this community of organisms is largely a product of human activity; its distribution is primarily a reflection of the introduction of required substrata by the Navy.

There are a variety of useful characteristics of these biotic assemblages and the substrata they inhabit, justifying the study of such fouling communities as potential bio-indicator systems. The artificial substrata do not vary greatly in composition or in physical characteristics, wood or concrete being the most commonly used materials. Metal surfaces are also commonly introduced by Naval activities and are broadly grouped into piling substrata. The surfaces of piling substrata are generally far less complex than either natural rock or sediment surfaces, thus the problems of objective, quantitative sampling are reduced. The variation which does exist in piling substrata is therefore relatively easily described.

The piling biota provide many useful comparisons and contrasts with the benthos (see Section 4.4). Included among the piling biota are a diverse assortment of taxa, life histories, modes of existence and relative mobilities. Dispersal is primarily via planktonic larvae, and the habitats of these organisms are at the physical boundary between the water and a hard substratum. All of these characteristics are reminiscent of those which have been described for the benthos. In fact, piling biota are a subsection of the more inclusive term "benthic biota" and are distinguished primarily by the form of the vertical substrata which they occupy. The considerable overlap between the taxa listed among the benthos and those found within the piling habitats is illustrated in Figure 4.6-1.

The benthos may live in (or on) a variety of sediment types, or on some hard surface. Unfortunately, those substratum types were not well defined during our sampling of the benthos. The piling biota are limited to a narrow variety of initial substrata--hard surfaces consisting of wood or concrete pilings, rock ledges, or metal. Usually certain members of the piling community can alter these substrata, providing habitats that were not present on the original bare surface.

Because of the reasonably well defined nature of the piling substrata, the piling biota can be used to answer, at least partially, a question raised by the benthos data: how much of the vertical and geographical variability in the benthos data can be traced to variability in the type of available substrata?

DATA ANALYSIS AND DISCUSSION

The analyses presented here include piling biota samples gathered during two sampling periods in the harbor from 0- and 10-foot water depths at nine of the ten bio-stations. The type of piling at each bio-station and the depth are given in Table 4.6-1. BC-09 did not have pilings or other hard vertical substrata nearby, so that station was excluded from the piling sampling program. As was

(Text continued on page 4.6-4)

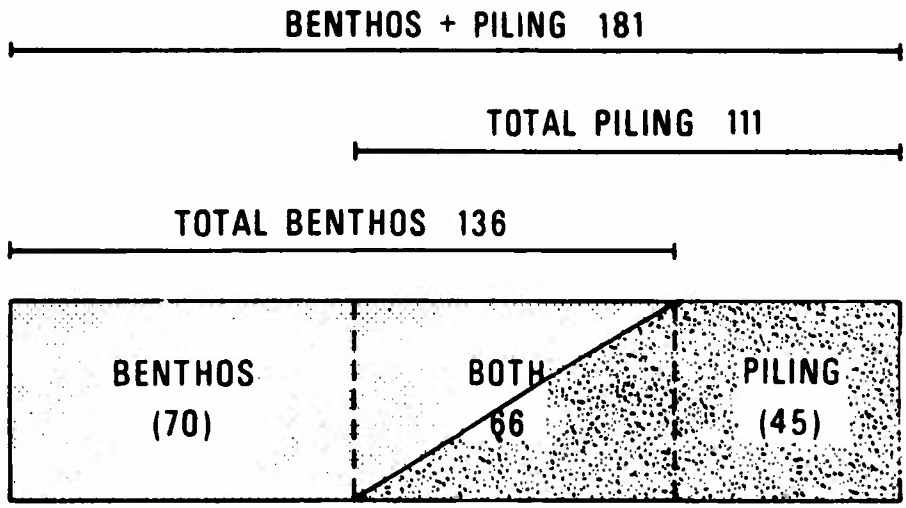


Figure 4.6-1. OVERLAP IN SPECIATION OF BENTHIC AND PILING COMMUNITIES.

Table 4.6-1. SUBSTRATUM TYPES AT THE NINE BIO-STATIONS USED IN THE PILING BIOTA SURVEY.

	BIO-STATION								
DEPTH (FT.)	BE-02	BE-03	BE-04	BE-05	BM-07	BC-10	BC-11	BW-13	BE-17
0	CP	CP	CP	CB	WP	CB	MPP	WP	WP
10	CP	CP	CP	MAC	WP	RL	MPP	WP	WP

CB = Concrete Block; CP = Concrete Piling; MAC = Metal Anchor Chain; MPP = Metal Pipe; RL = Rock Ledge; WP = Wooden Piling (creosote treated).

done with the benthos data, taxonomic identifications were made to the generic or specific level insofar as possible, and the taxa were enumerated both by wet weight and number of individuals. Since analysis of samples combined by depth or bio-station was shown (see Section 4.4) to yield no additional information, the piling taxa were analyzed only by sample (36 samples; 2 from each of the two depths at each of the nine bio-stations). In the multivariate analyses, the data were treated both as abundance data (number of individuals for those taxa with which that measurement is meaningful; wet weight for two taxa) and as presence/absence (P/A) data. As previously noted, factor analysis of P/A data requires the exclusion of those variables occurring at the extremes of the frequency distribution. Again, a 10%-to-90% frequency cutoff (4 to 33 samples) has been employed.

ABSOLUTE ABUNDANCE

Table 4.6-2 lists the mean and standard deviation of the 111 variables* used in the absolute abundance factor analysis. Phyletic rather than alphabetic listing is again used (see Section 4.4) since piling biota represent a combination of many very different groups of organisms. Factor analysis of these data resulted in two factors which explain 15% and 12%, respectively, of the variance in the original data matrix; total variance explained is thus 27%. Cutoff criteria as stated in Section 4.0 terminated the analysis at two factors. Thirty-five variables show loadings greater than 0.5 on at least one of the two factors; these variables are included only in the abbreviated factor loading matrix as Table 4.6-3. As shown by a histogram dividing the range of communalities into four quarters (Figure 4.6-2), 76 taxa (variables), fall into the first quarter (communalities of 25% or less), only 9 taxa (variables) fall into the next two quarters (communalities between 25% and 75%), and the remaining 26 taxa (variables) fall into the last quarter (communalities of 75% or greater). Neither factor shows a strong affinity for particular taxonomic groups.

Figure 4.6-3 shows maps of the factor scores for the 0-foot or "shallow" and the 10-foot or "deep" samples. As has been the case with the other biotic analyses, the highest scores are at bio-station BC-11. Unlike the benthos samples, the piling scores are highest for the deep samples. This difference may be more apparent than real. The "shallow" benthos samples were mostly subtidal and included samples to depths of 15 feet (as handled in the analyses of Section 4.4-4), whereas the "shallow" piling samples are all intertidal. The "deep" piling samples treated in the present analyses are still within the depth range covered by the "shallow" benthos.

Another notable characteristic of the piling factors is that while nine bio-stations were sampled with equal effort at each of the two depths, Figure 4.6-3

---

* This list differs slightly from that presented in Section 2.4. An insect (Family Chironomidae) was included in the factor analysis, but was omitted from Table 2.4-2 as it is probably contamination from surface runoff. The colonial species, *Amathia distans*, *Bugula californica*, and the ascidian, *Polyclinum* sp., were omitted from the factor analysis. None of these differences can have any significant effect on the results of the analysis.

(Text continued on page 4.6-12)

Table 4.6-2. MEANS, STANDARD DEVIATIONS AND FREQUENCIES FOR THE PILING BIOTA USED IN FACTOR ANALYSES.

TAXON	MEAN**	STANDARD DEVIATION	FREQUENCY (%)
*Class Demospongiae	32.908**	45.110	66.7
*Subclass Zoantharia	0.500	1.748	13.9
Polycladida	0.028	0.167	
Phylum Nematoda	0.639	2.642	
*Phylum Annelida	2.611	4.747	47.2
Paralepidonotus ampulliferus	0.056	0.333	
Eurythoe complanata	0.667	3.052	
Family Phyllodocidae	0.111	0.465	
*Family Syllidae	18.833	30.357	63.9
**Syllis (Typosyllis) variegata*	0.917	2.842	22.2
**Ceratonereis* sp.	0.528	1.055	25.0
Nereis spp.	0.028	0.167	
**Nereis (Neanthes) caudata*	2.000	10.340	11.1
Platynereis sp.	0.139	0.593	
**Perinereis cultrifera*	2.139	7.713	22.2
**Eunice antennata*	0.694	1.238	33.3
**E. filamentosa*	0.639	2.232	16.7
E. vittata	0.361	2.167	
E. (Palolo) siciliensis	0.028	0.167	
**E. (Nicidion)* sp.	3.000	8.724	33.3
Lysidice collaris	0.278	1.667	
**Nematonereis unicornis*	2.861	8.135	38.9
**Oenone fulgida*	0.722	2.433	11.1
*Lumbrinerid sp. 1	0.111	0.523	33.3
Lumbrinerid sp. 2	1.167	2.299	
Dorvillea sp.	0.111	0.398	
*Family Cirratulidae	18.028	29.758	61.1
*Family Terebellidae	1.111	3.169	19.4
*Family Sabellidae	3.722	10.547	30.6
**Hydroides norvegica*	13.278	60.487	16.7
H. crucigera	0.028	0.167	
H. lunulifera	0.556	2.372	
*Phylum Sipunculida	0.583	1.713	16.7
Phascolosoma dentigerum	1.083	5.562	
*Class Pycnogonida	0.833	2.274	16.7
Subclass Ostracoda	0.139	0.833	
**Balanus amphitrite amphitrite*	20.167	61.939	44.4
**B. eburneus*	4.583	18.339	19.4
B. trigonus	0.028	0.167	
Order Mysidacea	0.111	0.398	
**Apseudes* sp. 2	0.833	2.635	13.9
**Leptochelia dubia*	5.556	14.348	22.2
**Anatanais insularis*	2.472	7.504	25.0
**Mesanthura hieroglyphica*	0.361	1.291	11.1
Limnoria sp.	0.028	0.167	
L. tripunctata	0.083	0.500	
**Sphaeroma walkeri*	4.194	10.262	30.6

Table 4.6-2. (Continued)

TAXON	MEAN**	STANDARD DEVIATION	FREQUENCY (%)
Paracercoeis sculpta	0.111	0.398	
**Dynamenella* sp.	1.139	4.486	19.4
*Order Amphipoda	7.361	24.760	55.6
Lembos sp. A	1.028	6.167	
**Corophium baconi*	0.667	2.280	19.4
**C. acherusicum*	0.694	3.188	13.9
Ericthonius brasiliensis	0.444	2.335	
**Elasmopus rapax*	32.083	91.045	44.4
Photis hawaiensis	0.139	0.833	
Leucothoe sp.	0.333	1.287	
**L. hyhelia*	0.778	2.652	19.4
Podocerus brasiliensis	0.583	3.500	
*Section Caridea	0.667	1.512	22.2
Alpheopsis equalis	0.361	2.167	
Alpheus sp.	0.083	0.500	
A. gracilis simplex	0.028	0.167	
A. paralcyone	0.278	1.256	
A. paracrinitus	0.028	0.167	
A. gracilipes	0.056	0.232	
A. heeia	0.028	0.167	
Synalpheus thai	0.083	0.368	
**S. bituberculatus*	0.500	2.035	13.9
S. coutierei	0.028	0.167	
Section Brachyura	0.167	0.697	
Family Portunidae	0.028	0.167	
**Thalamita integra*	0.361	0.990	13.9
Metapograpsus thukuhar	0.083	0.280	
Family Xanthidae	0.361	1.268	
Platypodia eydouxi	0.139	0.543	
Madaeus simplex	0.028	0.167	
Carpilodes bellus	0.056	0.333	
**Panopeus pacificus*	1.889	4.990	33.3
Liocarpilodes integerrimus	0.028	0.167	
**Pilumnus oahuensis*	3.028	5.422	58.3
Glabropilumnus seminudus	0.083	0.280	
Gonodactylus falcatus	0.222	0.832	
Class Insecta (Family Chironomidae)	0.028	0.167	
Diodora granifera	0.028	0.167	
*Family Vermetidae	2.083	3.459	47.2
Dendropoma ?psarocephala	0.028	0.167	
Vermetus alii	0.472	2.091	
Hipponix pilosus	0.083	0.280	
**Crepidula aculeata*	4.000	6.866	58.3
Mitrella zebra	0.056	0.333	
Mitra sp.	0.056	0.333	
**Odostomia pupu*	0.722	2.636	16.7
Siphonaria normalis	0.250	1.025	
Order Nudibranchia	0.028	0.167	
Class Bivalvia	0.083	0.368	
Hormomya crebristriatus	0.194	0.889	

Table 4.6-2. (Continued)

TAXON	MEAN**	STANDARD DEVIATION	FREQUENCY (%)
Isognomon perna	0.250	1.500	
*Family Ostreidae	1.111	1.703	38.9
Crassostrea virginica	0.028	0.167	
Anomia nobilis	0.056	0.232	
**Hiatella hawaiiensis*	21.694	54.125	69.4
**Bugula neritina*	0.009**	0.051	
**Ophiactis savignyi*	49.417	152.379	27.8
Amphipholis squamata	0.167	0.697	
*Class Ascidiacea	0.028	0.167	
**Ascidia* sp.	0.250	0.692	13.9
**Styela* sp.	11.167	44.838	47.2
**Hermandia momus*	0.194	0.710	11.1
Omobranchus elongatus	0.028	0.167	
Asterropteryx semipunctatus	0.028	0.167	

* Frequency listed is only for those variables occurring in 10%-to-90% of the samples and used for P/A factor analysis.

** The abundance figures are number of individuals except for those taxa which are specifically flagged. For those variables, abundance is in wet weight.

Table 4.6-3. FACTOR LOADING MATRIX FOR ABSOLUTE ABUNDANCE ANALYSIS. (ONLY THOSE VARIABLES WITH AT LEAST ONE ABSOLUTE LOADING GREATER THAN 0.5 ARE TABULATED).

FACTOR NUMBER		I	II
PERCENT OF TOTAL VARIANCE		15	12
VARIABLE	% COMMUNALITY		
ANNELIDS "Segmented Worms"	*		
Errant Polychaetes	*		
Paralepidonotus ampulliferus	97	.97	-
Eurythoe complanata	96	-	.93
Eunice filamentosa	96	.70	.69
Eunice vittata	97	.97	-
Nematonereis unicornis	95	.70	.68
Oenone fulgida	56	.72	-
Lumbrinerid sp. 1	54	-	.71
Sedentary Polychaetes	*		
Family Terebellidae	51	.52	-
SIPUNCULIDS "Peanut Worms"	80	.89	-
Phascolosoma dentigerum	94	-	.96
ARTHROPODS	*		
Tanaids	*		
Apseudes sp. 2	74	.85	-
Amphipods	*		
Lembos sp. A	97	-	.97
Leucothoe sp.	83	.89	-
L. hyhelia	80	.87	-
Decapods - Shrimp	*		
Section Caridea	29	.53	-
Alpheopsis equalis	97	-	.97
Alpheus gracilis simplex	97	-	.97
A. paralcyone	97	.97	-
A. paracrinitus	97	-	.97
A. gracilipes	97	.80	.57
A. heeia	97	-	.97
Synalpheus thai	29	-	.54
S. bituberculatus	94	-	.92
Decapods - Crabs	*		
Family Xanthidae	38	.56	-
Madaeus simplex	97	.97	-
Carpilodes bellus	97	.97	-
Glabropilumnus seminudis	35	.57	-
Stomatopods	*		
Gonodactylus falcatus	94	.71	.67
MOLLUSCA	*		
Gastropods	*		
Mitra sp.	97	-	.97
Nudibranchia	97	-	.97

Table 4.6-3. (Continued)

FACTOR NUMBER		I	II
PERCENT OF TOTAL VARIANCE		15	12
VARIABLE	% COMMUNALITY		
Pelecypods	*		
Isognomon perna	97	.97	-
ECHINODERMS	*		
Ophiuroids	*		
Ophiactis savignyi	86	.90	-
TUNICATES	*		
Ascidia sp.	49	.57	-
Hermandia momus	90	.92	-
BONY FISHES	*		
Asterropteryx semipunctatus	97	.97	-

* These entries are not variables; they are presented only to show phyletic groupings.

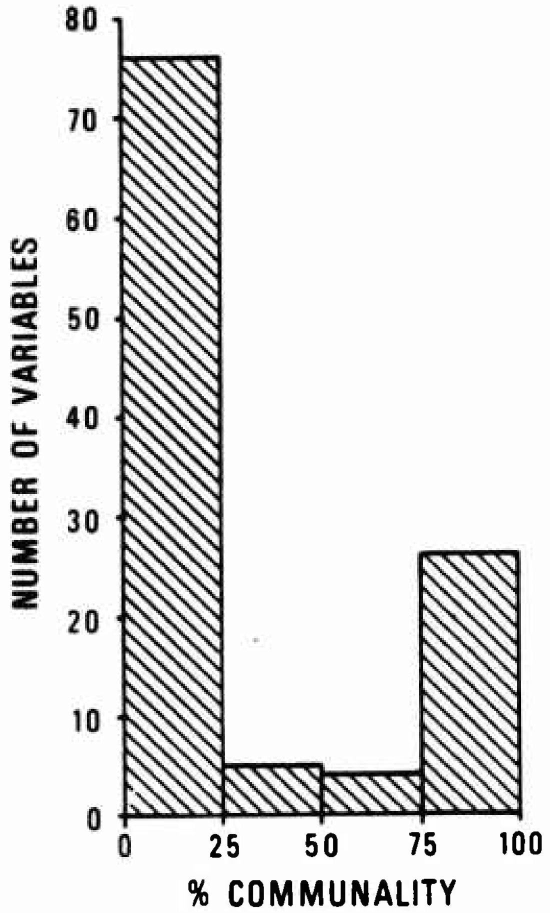


Figure 4.6-2. DISTRIBUTION OF COMMUNALITIES FOR ABSOLUTE ABUNDANCE ANALYSIS OF PILING ORGANISMS.

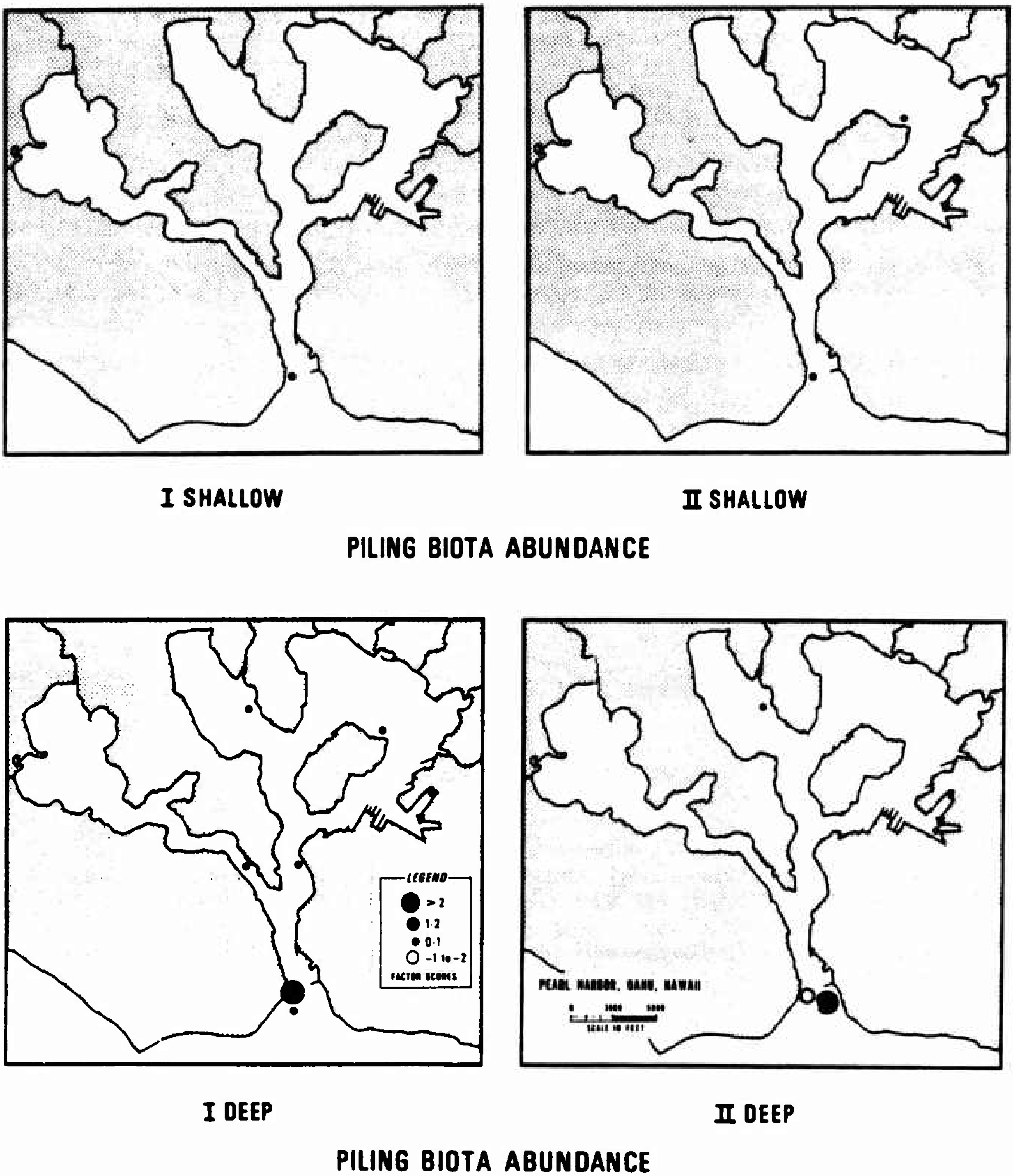


Figure 4.6-3. FACTOR SCORE MAP, ABSOLUTE ABUNDANCE ANALYSIS OF PILING ORGANISMS.

shows only one instance (BC-11) in which a particular station/depth has both its scores differing significantly from 0. There appear to be two alternative explanations for this situation. One possibility is that the two factors represent some time-dependent differences among the samples. This possibility can be tested by examination of the frequency distribution of the two factors at each sampling time. Figure 4.6-4 demonstrates that no temporal differences between the samples are apparent. The most probable alternative explanation is that the physical size of the individual samples was inadequate to characterize them; that is, the variation is simply one of sampling "noise". This noise is apparently sufficient to mask all but two characteristics of the analysis: that BC-11 stands apart from the other bio-stations and that most of the variation occurs at the 10-foot sample depth.

A dendrograph was constructed from the piling abundance factor scores, but is not presented since it fails to show any clustering tendency among the samples.

PRESENCE/ABSENCE

The mean and standard deviation of the 49 variables used for the P/A analyses are given in Table 4.6-2. Four factors explain 43% of the variance (14, 11, 9 and 9%, respectively) in the original data matrix. A histogram dividing communality range into quarters (Figure 4.6-5) shows most P/A variables to be in the intermediate range rather than in the extremes as found for the abundance data (Figure 4.6-2). Only 6 taxa (variables) fell into the first quarter (communalities of 25% or less) and none fell into the last quarter (communalities of 75% or greater). All of the remaining 43 taxa (variables) fell into the two middle quarters (communalities between 25% and 75%). Those variables with loadings greater than 0.5 on at least one factor are included in the abbreviated factor loading matrix of Table 4.6-4. As was the case with the abundance analyses, there is no strong affinity of any of the factors for particular taxonomic groups.

The factor score maps for the P/A data are shown in Figure 4.6-6. The maps are striking in their contrast to the abundance maps. In the first place, there is a strong and obvious tendency for a station/depth scoring heavily on a given factor to do so for both samples. Thus, there are a total of 22 examples of station/depths which have two scores on a factor, each different from the modal class. Only 6 examples of a sign reversal for a score at a station/depth occur. It would appear, therefore, that the samples taken are adequate representations of the presence or absence of taxa at a location, even though the previous analysis suggests that these same samples do not adequately sample the standing crop of the taxa involved.

The P/A factors appear to be strongly depth-related. Factors I and III are strongest in deep samples, while Factors II and IV are strongest in shallow samples. Moreover, there is an apparent geographic trend in the factor scores as well, particularly in the two deep-water factors. Factor I is best developed at bio-stations BC-11 and BE-05, while Factor III is strongest at BW-13 and BM-07. No such geographic trend is readily apparent in the two shallow-water factors.

The analysis suggests both depth-related variation and location-related variation in the harbor. No attention has yet been given to possible substratum-

(Text continued on page 4.6-18)

Table 4.6-4. FACTOR LOADING MATRIX FOR P/A ANALYSIS. (ONLY THOSE VARIABLES WITH AT LEAST ONE ABSOLUTE LOADING GREATER THAN 0.5 ARE TABULATED).

FACTOR NUMBER		I	II	III	IV
PERCENT OF TOTAL VARIANCE		14	11	9	9
VARIABLE	% COMMUNALITY				
PORIFERA "Sponges"	*				
Class Demospongiae	55	-	-.65	-	-
ANNELIDS "Segmented Worms"	64	-	-.64	-	-
Errant Polychaetes	*				
Perinereis cultrifera	59	-	-	-	.71
Eunice filamentosa	54	.58	-	-	-
Nematonereis unicornis	38	.52	-	-	-
Oenone fulgida	48	.66	-	-	-
Sedentary Polychaetes	*				
Hydroides norvegica	38	-	-	-	-.51
ARTHROPODS	*				
Subclass Cirripedia - Barnacles	*				
Balanus amphitrite amphitrite	43	-	-	-	.59
Tanaids	*				
Apseudes sp. 1	56	.72	-	-	-
Leptochelia dubia	62	.74	-	-	-
Anatanais insularis	33	-	.54	-	-
Isopods	*				
Sphaeroma walkeri	53	-	.66	-	-
Dynamenella sp.	34	-	.57	-	-
Amphipods	33	.52	-	-	-
Corophium baconi	40	-	-	.63	-
Elasmopus rapax	52	-	-	-	-.51
Decapods - Shrimp	*				
Synalpheus bituberculatus	43	.65	-	-	-
Decapods - Crabs	*				
Thalamita integra	51	-	-	.59	-
Panopeus pacificus	50	-	-	-	.53
Pilumnus oahuensis	48	-	-.62	-	-
MOLLUSCA	*				
Gastropods	*				
Family Vermitidae	39	-	-	-.55	-
Odostomia pupu	54	-	-	.52	-
Pelecypods	*				
Family Ostreidae	48	-	-	-	.61
ECTOPROCTA	*				
Bugula neritina	56	-	-	.71	-

Table 4.6-4. (Continued)

FACTOR NUMBER		I	II	III	IV
PERCENT OF TOTAL VARIANCE		14	11	9	9
VARIABLE	% COMMUNALITY				
ECHINODERMS	*				
Ophiuroids	*				
Ophiactis savignyi	42	.54	-	-	-
TUNICATES	*				
Class Ascidiacea	36	-	-.52	-	-
Ascidia sp.	53	.65	-	-	-
Styela sp.	62	-	-	-	.67

*These entries are not variables: they are presented only to show phyletic groupings.

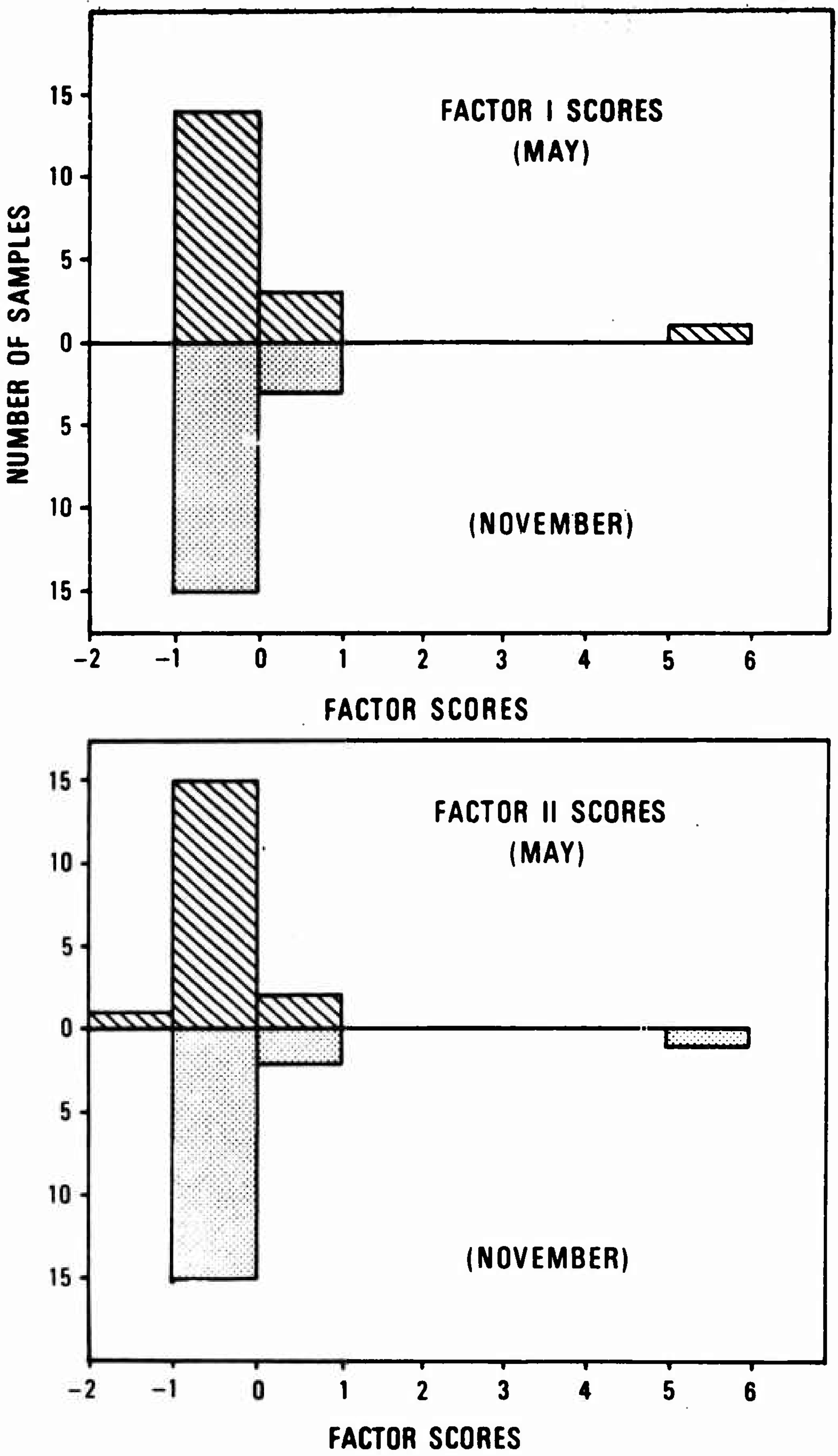


Figure 4.6-4. FREQUENCY DISTRIBUTION OF ABUNDANCE ANALYSIS FACTOR SCORES FOR THE MAY AND NOVEMBER SAMPLING PERIODS.

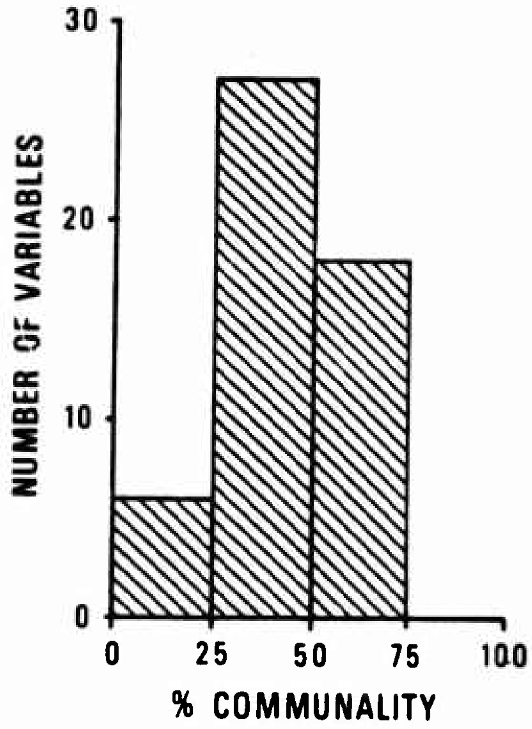
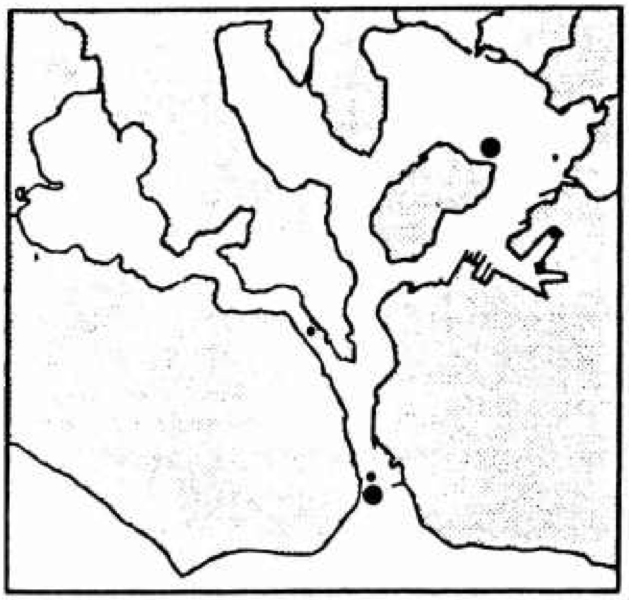
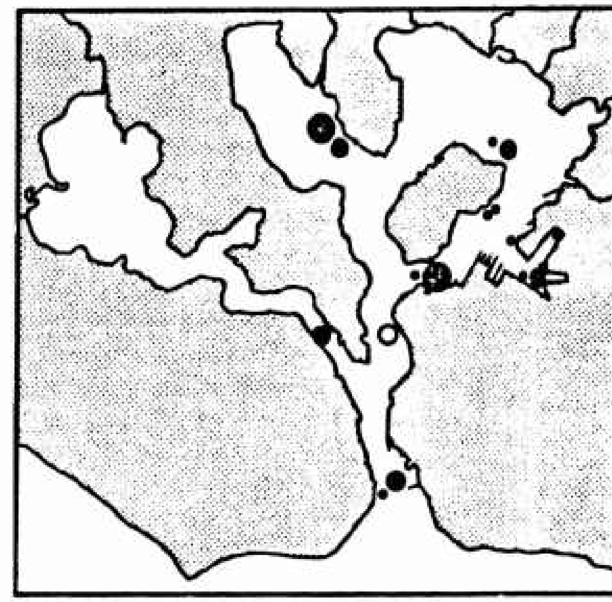


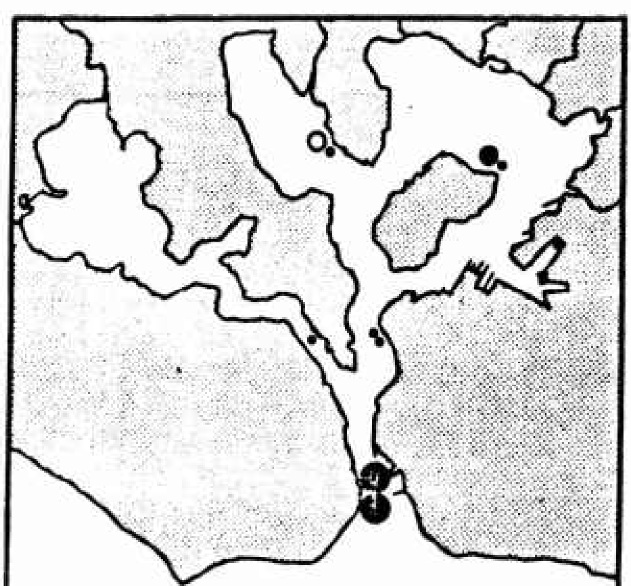
Figure 4.6-5. DISTRIBUTION OF COMMUNALITIES FOR P/A ANALYSIS OF PILING ORGANISMS.



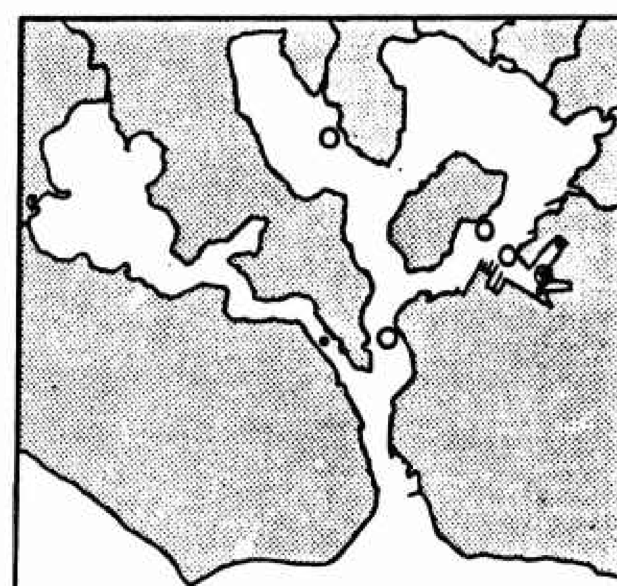
I SHALLOW



II SHALLOW



I DEEP



II DEEP

197

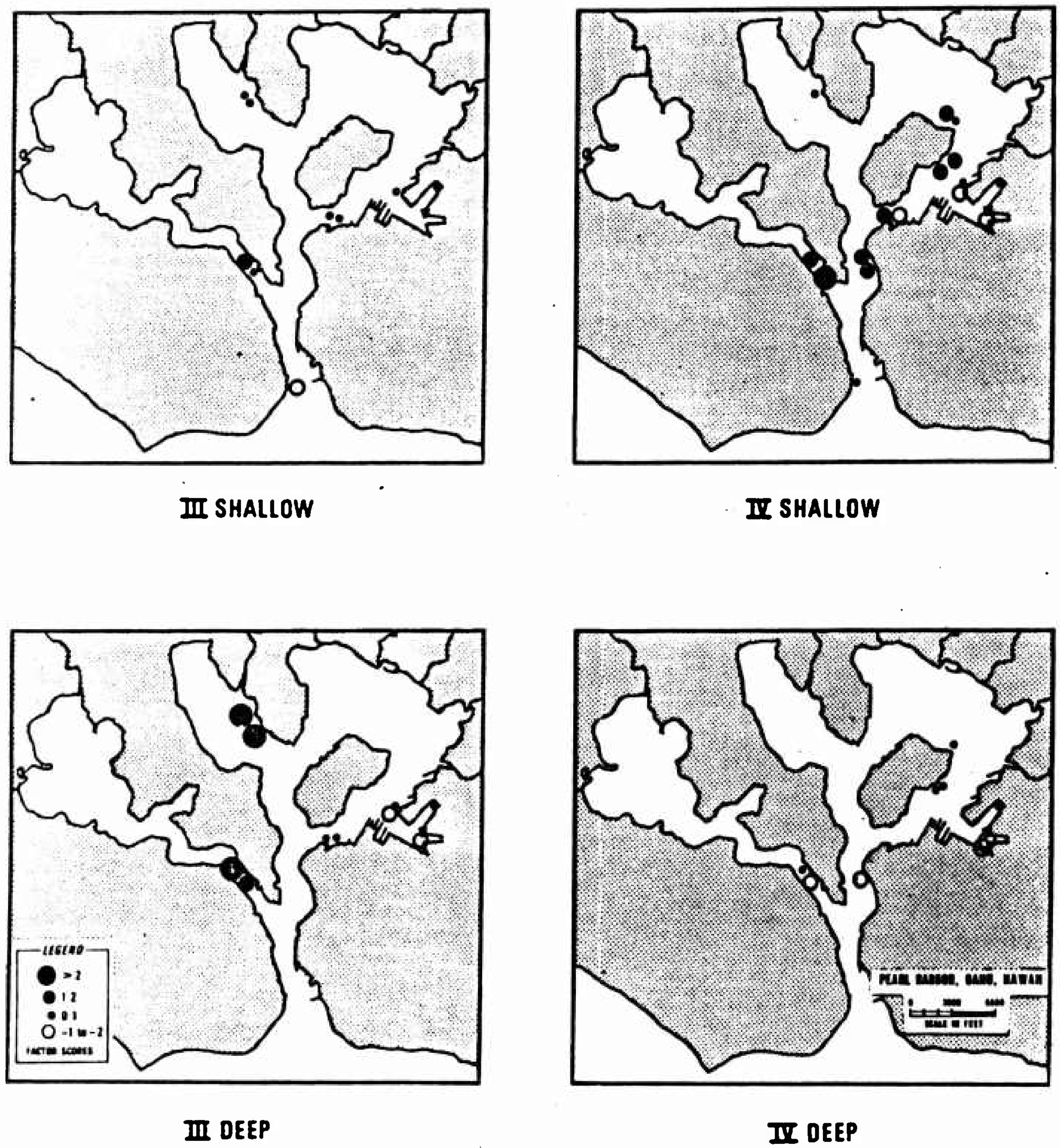


Figure 4.6-6. FACTOR SCORE MAP, P/A ANALYSIS OF PILING ORGANISMS.

related variation. Cluster analysis of the P/A factors is useful for the discussion of variations in the piling biota with respect to water depth, geographic location and type of substratum. A dendrograph of P/A factor score distances is shown in Figure 4.6-7. Four distinct clusters can be seen. Figure 4.6-8 presents the distribution of these clusters in two different manners: distribution maps and three-dimensional histograms. The substratum types reported in Section 2.4 are divided here into wood, concrete (plus one case of natural rock outcrop) and metal. Table 4.6-1 presents the substrate type for each piling station and depth.

Almost half (15) of the samples fall into Cluster A. It can be seen that the cluster does not include any samples with metal substrates, but the exclusion appears to be one of geographic location rather than substrate type. Most of the samples within this cluster lie in the South Channel and Southeast Loch area of the harbor, and none of the piling samples from that area are metal. Concrete is the most common substrate type in the cluster, yet concrete pilings outside of South Channel are not in the cluster. Wooden pilings in South Channel, however, are in the cluster. Hence, the cluster appears closely related to location.

Only 3 samples fall into Cluster B. All are deep and all are from wooden pilings. Not all of the wooden pilings show samples within this cluster (BE-17 lacks them); therefore, the cluster again does not appear to be substratum-dependent. Rather, the samples within this cluster are from the two lochs with the lowest ship activity, highest turbidity, etc.

Cluster C includes 7 samples. They are from areas to either side of the South Channel area (BC-11, BE-05 and one sample at BC-10). The cluster excludes wooden pilings, but again the exclusion appears to be one of location rather than substratum dependence.

Cluster D contains the remaining 11 samples. Of all the clusters, this one is the clearest in its characteristics. It is obviously primarily related to depth, being entirely restricted to the surface samples, including 61% of the surface samples and all three types of piling substrata.

The general conclusion to be drawn from this cluster analysis is that within the range of variation in types of piling substratum, there is very little piling community response to substratum. There is a clear and relatively simple relationship between the biotic patterns and sample depth. There is also a more complex separation of the biota into distinct groupings by location in the harbor.

SUMMARY

Analysis of the piling biota data suggests that the sample sizes used were not sufficiently large to determine the absolute abundance of organisms with any confidence. However, that problem does not appear to exist with the presence/absence data. These latter data suggest that within the relatively narrow (but well defined) range of substratum types, biotic composition is not particularly affected by that substratum variation. There is a strong depth-related variation in the biota between the 0- and 10-foot samples. Particularly

(Text continued on page 4.6-21)

PEARL HARBOR BIOLOGICAL SURVEY PILING FAUNA BY SAMPLE

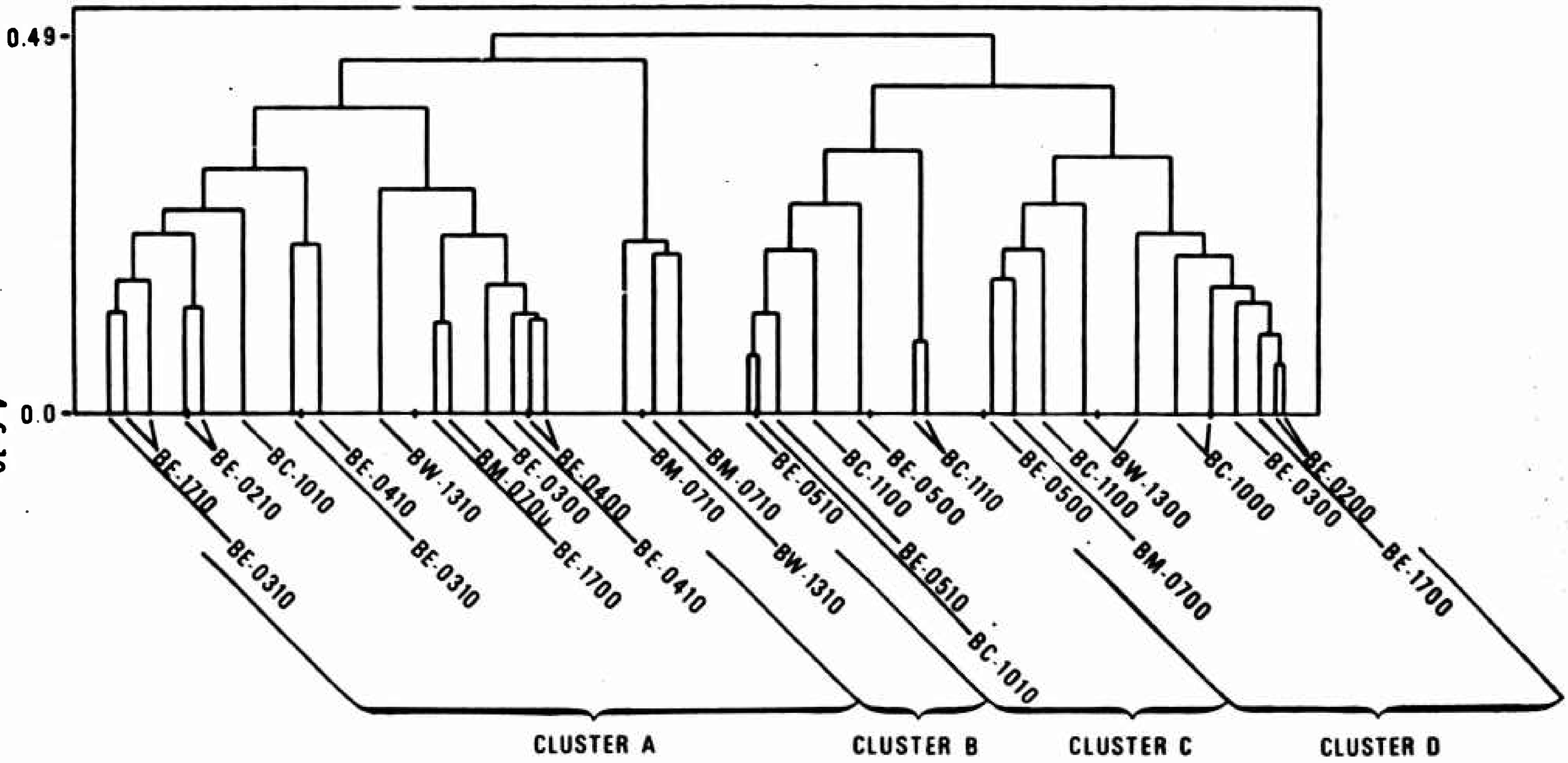


Figure 4.6-7. DENDROGRAPH BASED ON 4-FACTOR SCORE DISTANCES, P/A ANALYSIS OF PILING ORGANISMS.

NOTE: The final two digits on each sample label list the depth in feet.

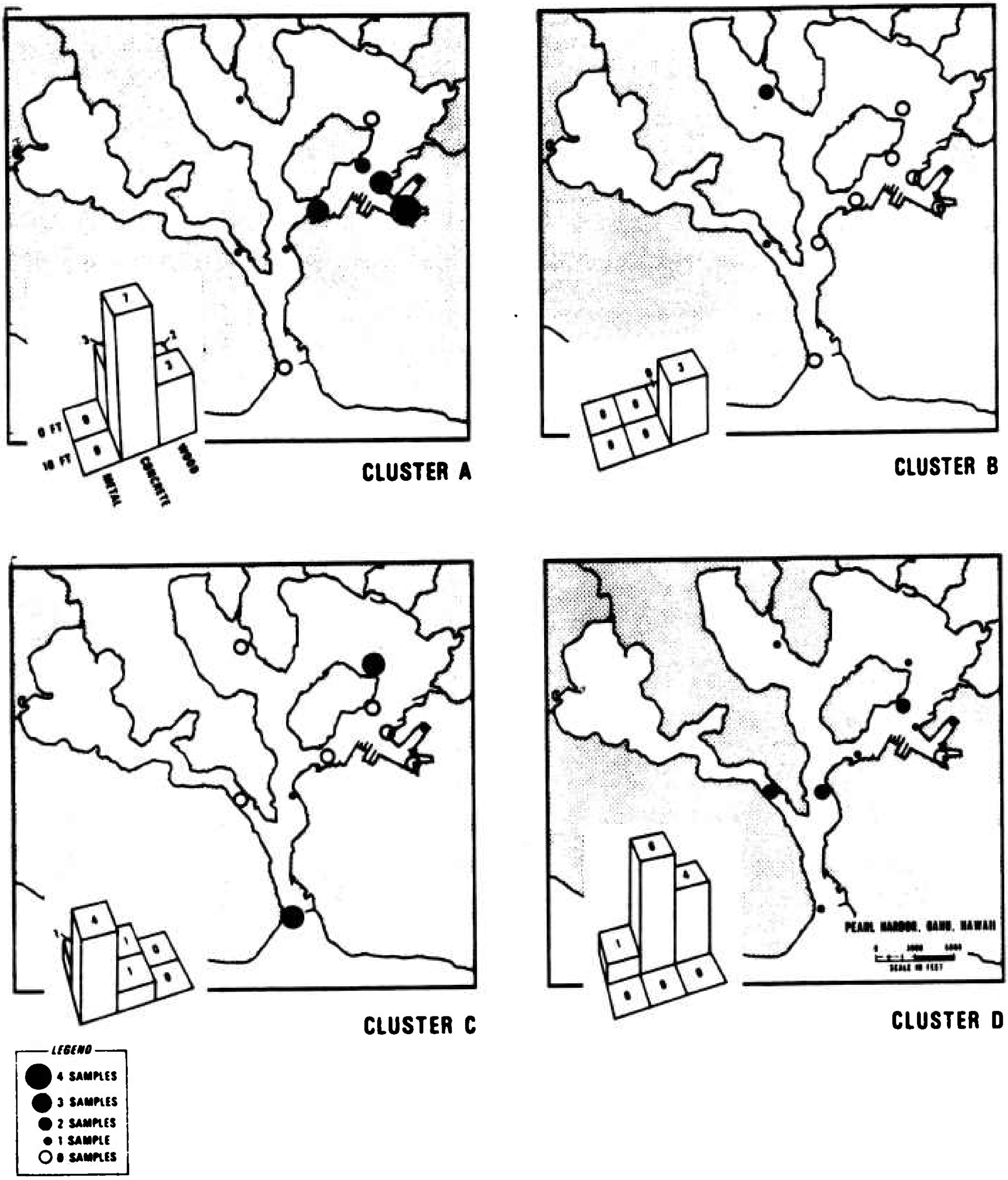


Figure 4.6-8. CLUSTER MEMBERSHIP OF PILING ORGANISMS AS SHOWN BY DENDROGRAPH OF 4-FACTOR SCORE DISTANCES, P/A ANALYSIS.

evident in the 10-foot samples is a grouping of samples according to location in the harbor. This grouping includes those samples in the South Channel and Southeast Loch area (BE-02, BE-03, BE-04 and BE-17), bio-stations immediately outside that grouping (BE-05 and BC-11) and the two bio-stations most removed from that area (BM-07 and BW-13). Only BC-10 is not covered by this division; it is intermediate between the first two groups.

INTERCOMPARISONS

Evan C. Evans III
Stephen V. Smith
Gerald S. Key

INTRODUCTION

The previous statistical sections have each presented an analysis of discrete components of Pearl Harbor, viz., sediment, water quality, fish, benthic community, micromollusca, and piling community. Each such analysis has sought and found patterns among the various samples collected. While the sampling arrays for both water quality and heavy metals in the sediment were large (100 or more stations), the biological sampling stations were restricted to 17 micromolluscan, 10 fish, 10 benthos, and 9 piling stations. This section summarizes what may be learned from these separate analyses when considered collectively and, additionally, considers possible effects due to circulation (see Section 3.3) and ship traffic (see Section 3.4).

INTERCOMPARISONS

The overriding conclusion of the statistical analysis is that Pearl Harbor (West Loch excepted*) is properly considered a single ecologic unit, at least from the standpoint of its environmental status. With the possible exception of the heavy-metal content of the sediment (see Section 4.1), none of the environmental groupings found in the data are particularly strong. The majority of the variation found is either depth-related or substratum-related. Unquestionably, other environmental variations do exist, including those due to differences in kind and degree of insult resulting from human activities. These variations, however, do not appear to be large enough to be distinguished from the inherent variability found in any ecosystem. Hence, the initial conclusion that Pearl Harbor*, to a first approximation, may be treated and interpreted as a single environmental/ecological unit.

It appears to be a matter of general accord that Pearl Harbor is a heavily stressed and, therefore, damaged ecosystem (Reference 4.7-1). On the basis of the statistical analyses herein reported, the norm for the harbor as a whole* is one of heavy stress. This situation may be contrasted with that in the second major estuary on Oahu, Kaneohe Bay (Reference 4.7-2). Kaneohe Bay is also recognized as stressed, but with a notable difference. In this bay, the damage due to stress is concentrated in the southeastern basin and decreases markedly with distance from that location. No such spatial pattern is evident in Pearl Harbor.

Homogeneity does not, however, imply uniformity. Any nontrivial statistical population must possess some variation from the norm. It is useful, therefore, to inspect the various analyses performed for "deviant bio-stations". Two considerations are of particular interest in this regard. First, is it possible to judge these deviant bio-stations as environmentally "better" or "worse" than the harbor norm? Second, do bio-stations which deviate with respect to one component of the system (e.g., heavy metals) also tend to deviate with respect to another component (e.g., the benthos)?

---

* This conclusion does not necessarily apply to West Loch. The single bio-station in West Loch (BW-13) does not provide sufficient biological data to arrive at any realistic conslusions about the arm of Pearl Harbor. The heavy-metal content of West Loch sediments, the micromolluscan assemblage at BW-14, and the ship traffic data all suggest that this loch may differ from the remainder of the harbor. These suggestions notwithstanding, any discussion of Pearl Harbor as a whole explicitly excludes West Loch.

(Text continued on page 4.7-3)

Table 4.7-1. BIO-STATIONS WITH AT LEAST ONE SCORE OUTSIDE THE RANGE ±1.

	BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17	Totals
Fish Abundance		X		X		X	X	X	X		6
Fish P/A			X					X	X		3
Benthos Abundance				X		X		X	X		4
Benthos P/A	X	X	X	X	X	X	X	X	X	X	10
Micromollusc Abundance	X		X	X							3
Micromollusc P/A	X			X		X		X			4
Piling Abundance						(1)		X			1(1)
Piling P/A	X	X	X	X	X	(1)	X	X	X	X	9(1)
TOTALS	4	3	4	6	2	4(1)	3	7	5	2	40
PERCENTAGE	50	38	50	75	25	67(1)	38	88	62	25	

(1) No piling data were available for BC-09.

The statistical analyses performed permit two approaches to these queries. The first approach, factor analysis, is a multivariate technique relying on the detection of redundant patterns in the data. The extracted factors replace the variables (or taxa) in determining which, if any, bio-stations differ from the norm. Although this approach is not capable of identifying specific bio-indicator organisms, it is valuable in that it provides an objective means of identifying potential indicator groupings. When used to determine individual patterns as it is here, the approach may be considered essentially univariate, or at least "pseudo-univariate". The second approach, cluster analysis, is more nearly multivariate since this approach permits simultaneous consideration of differences or similarities with respect to all dimensions (in this case, factors). Thus, the norm becomes the major cluster or clusters, while the deviants become either small clusters or singularities.

To consider deviations in the factor scores, the following operational procedures were adopted. For the factor analysis of each biotic group (8 such analyses in all), the stations differing by more than one standard deviation unit from the mean score (i.e., zero) on at least one factor are listed in Table 4.7-1. In the case of multiple samples per bio-station such as in the benthos or piling studies, only one sample need meet this criterion for the bio-station to be classified as a deviant. To highlight those bio-stations most frequently differing from the norm, the percentage of deviant cases is presented in the bottom row.

Of the ten bio-stations tabulated, BC-11 is by far the most consistently different (88% of all analyses). The mean percentage (± one σ) of deviant cases for all other bio-stations is 48±18% with a range from 25% to 75%. BC-11, therefore, emerges as the bio-station most unlike the remaining bio-stations which are closer to the heavily stressed norm for the harbor. Certain subjective and objective ratings for BC-11 (Tables 1.0-1 and 4.1-3 strongly suggest that BC-11's deviation is in the direction of improved environmental conditions. Thus BC-11 may be considered the least insulted bio-station in Pearl Harbor. Extending this interpretation to the other bio-stations, BE-05, BC-09 and BW-13 also appear to be under relatively low insult compared to the rest of the harbor since they show frequent deviations from the norm (75, 67 and 62%, respectively). All bio-stations show at least one deviation in the P/A analyses for benthos and for piling*. The factor scores suggest that detectable variability in Pearl Harbor shows a weak trend away from the stressed norm for the harbor as a whole toward somewhat better environmental conditions.

The criteria for identifying deviations from the clusters are necessarily more difficult and less objective than those used on the individual factor scores. In fact, the criteria are best presented on a case-by-case basis for each of the dendrographs prepared for biotic communities.

Figure 4.3-3 presents the fish P/A dendrograph for Pearl Harbor. Bio-stations BC-11 and BW-13 are considered to be clearly separate from the single cluster containing the remaining bio-stations. For the benthos abundance dendrograph (Figure 4.4-4), it is impossible to define objectively any single cluster that does not contain all of the samples. However, inspection of Figure 4.4-4 from right to left shows that many shallow and intermediate depth samples from bio-stations BE-05, BC-09 and BC-11 appear on the margin of the massive

* BC-09 does not have piling samples; therefore, it is excluded from this statement.

cluster. This assemblage includes all (6) of the shallow and intermediate samples from BC-11, and 2 out of 5 and 6, respectively, for shallow samples from BE-05 and BC-09. Beyond these bio-stations, there is no further suggestion of orderly deviation. The benthos P/A dendrograph (Figure 4.4-6) shows one "norm" cluster (A) and two smaller deviant clusters (B and C). From Figure 4.4-7, it is seen that these deviant clusters contain shallow and intermediate depth samples from bio-stations BE-05, BC-09, BC-11 and BW-13. The micromollusca present additional problems due to the discontinued bio-stations. These are simply omitted from the following discussion. In the absolute abundance dendrograph (Figure 4.5-3), Cluster A is taken to be the norm. Bio-stations not appearing in Cluster A are summarized in Table 4.5-5, viz., BE-02, BE-05, BC-09, BC-11 and BW-13. In the P/A dendrograph for micromollusca (Figure 4.5-4), Cluster A is again taken to be the norm. The small clusters, B, C and D, are considered to be outside the P/A norm and include bio-stations BE-02, BE-05, BC-09 and BC-11. The dendrograph generated on piling P/A data (Figure 4.5-7) is the most difficult to treat objectively. Four clusters may be defined but none can be distinguished as the norm (Figure 4.6-8). The cluster analysis for the piling data is therefore omitted from the remaining discussion. Several other dendrographs (discussed, but not presented in the text) are also omitted since they add no new data to the patterns described.

Bio-stations which appear outside the normal cluster at least 3 times in the 5 cases treated are BE-02, BE-05, BC-09, BC-11 and BW-13 (Table 4.7-2). As with the factor scores, these deviant bio-stations would appear to correspond to those least insulted on the basis of ratings presented in Tables 1.0-1 and 4.1-3; thus, again the deviations suggest a trend away from the stressed norm for Pearl Harbor toward moderately impaired environmental conditions.

The above intercomparisons of the various analyses of Pearl Harbor biota suggest the following general answers to the first of the two questions posed. All bio-stations show some degree of deviation from the normal or stressed biotic condition characteristic of the harbor as a whole. On the basis of information available, whatever variation that does occur can be interpreted as a moderate trend toward improved environmental condition. BC-11 shows this tendency most frequently; four other bio-stations, BE-02, BE-05, BC-09 and BW-13 also show this tendency to a lesser degree. The remaining five bio-stations exhibit conditions close to the stressed norm. It is possibly true that the present degree of environmental stress leaves little room for further deterioration in the harbor. The possibility is discouraging. However, the fact that half the bio-stations show some variation towards improved conditions suggests that the harbor may still have the capacity to respond positively under enlightened environmental management.

The second of the two questions posed above has been also been answered in part; that is, the same group of bio-stations show variation indicative of improved condition in more than one biotic component of the system. To answer the question fully, relationships between the biotic and the physicochemical parameters need to be inspected. One obvious result is the apparent lack of relationship between parameters defining water quality and those indicative of improved biological status. BE-02, BW-13, BE-05, BC-09 and BC-11, in that order, show increasingly poorer water quality (see Section 4.2), yet on the basis of their biological status, these are judged to be the "better" bio-stations with BC-11 the best. Water quality at the remaining bio-stations varies considerably, but in a manner which precludes further interpretation. Most certainly there

Table 4.7-2. BIO-STATION JUDGED TO FALL OUTSIDE OF THE "NORM" CLUSTER.

	BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17	Totals
Fish P/A								X	X		2
Benthos Abundance				X		X		X			3
Benthos P/A	X					X		X	X		4
Micromollusc Abundance	X			X		X		X	X		5
Micromollusc P/A	X			X		X		X			4
TOTALS	3	0	0	3	0	4	0	5	3	0	18

must be some relationship between biological status and water quality, suggesting that there is something wrong with the components (physicochemical or biological) under comparison. Analytic sensitivity, sampling density, sampling frequency, species resistance, etc., may be causes, but with the data available, no further speculation is possible.

On the other hand, there does appear to be a reasonable relationship between heavy-metal burdens in the sediment and biological status. Figure 4.3-1 shows BC-11, the least insulted bio-station, to have the lowest metallic burden in the sediment. Using factor score distances from BC-11 (Table 4.3-1), BE-02, BW-13 and BE-05, in that order, all show low metallic burdens. Thus, three out of four relatively "healthy" bio-stations show a relationship similar to BC-11.

The effects of circulation and mixing on biotic status is complex. Certainly BC-11, the "best" bio-station, is located in the most efficiently flushed region in the harbor (see Section 3.3). The other relatively good bio-stations vary considerably in the degree and nature of circulation at their locations. BW-13, due to tidal action, and BC-09, due to wind-driven currents, might also be expected to have reasonable circulation. The presence of BC-10, a relatively poor bio-station in a location which should receive good circulation due to tides and ship traffic, discourages further attempts to resolve patterns. It should be noted, however, that BC-10 is located in the thermal outfall of the Navy power plant and also has a high heavy-metal burden in the sediment.

In general, few of the relationships between physicochemical measurements and biological status are particularly good. Individual matchings can be found, but they are offset in any objective analytical scheme by the mismatches. The relatively homogeneous environmental status of Pearl Harbor as a whole would seem to be one of the reasons for this situation. That any objective and recurrent patterns at all can be resolved has been satisfying. The inability to resolve patterns on a scale fine enough to make objective multivariate matchings is unquestionably a result of confining the study to a single, heavily-impacted body of water. It should be noted that the multivariate technique was able to reproduce biotopes exactly when applied to Kaalualu Bay (see Section 4.3). Furthermore, on the basis of 2-factor score distances (fish P/A data), Pearl Harbor and Kaalualu locations form separate and distant clusters (Figure 4.3-16). These results indicate that the multivariate techniques used are capable of defining patterns and relationships when applied to a range of water bodies differing significantly in environmental condition.

REFERENCES

4.7-1. Pearl Harbor Pollution Model Study: The Identification and Compilation of all Significant Sources of Pollution Contributing to the Degradation of the Pearl Harbor Environment (April 1971), Prepared Jointly by the Commandant, 14th Naval District (District Civil Engineer) and OICC MIDPAC. Sponsored by Commander, Pacific Division, Naval Facilities Engineering Command, 91 pages.

4.7-2. Stephen V. Smith, et al. (February 1973), Atlas of Kaneohe Bay: A Reef Ecosystem Under Stress, UNIHI SEAGRANT TR-72-01, Honolulu, Hawaii.

SUMMARY AND CONCLUSIONS

Evan C. Evans III

GENERAL INFORMATION

This report on the biological composition and environmental condition of Pearl Harbor is the result of an almost compulsive effort to demonstrate the utility of an environmental data-gathering and data-processing system. The biological work was done as a subcontract under a larger program designed and managed by the Navy Civil Engineering Laboratory. This larger program was intended to gather complete environmental information including: water quality (both marine and stream), air quality, source emission data (both Navy, including ships, and non-Navy), land use and noise. Furthermore, program management wanted the test demonstration in Pearl Harbor to produce results within a year. Since the data-processing system was only in a conceptual stage of development, field survey work during the first year emphasized the broadcast gathering of information with analysis by NCEL's Data Base to follow later. Such a situation is hardly conducive to good experimental design, especially in a field as complex as marine biology. Nevertheless, the Pearl Harbor Biological Survey team was able to inventory the resident marine forms, map their general distribution and produce a report including their own initial analysis of the biological data within the required time (Reference 5.0-1). This report is the culmination of a continued effort to process and analyze data collected in Pearl Harbor from November 1971 to the termination of field work in December 1972. The work suffers from the constraints under which the initial field work was conducted. In spite of these constraints, the report represents the first thorough evaluation of the biological status of Pearl Harbor and has been the generative force behind several new concepts in environmental monitoring and assessment. These concepts, if applied by the Navy, can result in substantial reductions in the cost of future environmental surveys.

In addition to concepts, there are many concrete results. First, a checklist of 394 positively identified marine forms resident in Pearl Harbor now exists where none existed before. For the major divisions of sampling activity (fish, benthos, micromolluscan and piling communities), 343* organisms are listed both phyletically and alphabetically, in each case with its Hawaii Coastal Zone Data Bank (HCZDB) computer address or ORGID number.** This double listing combined with the NORGID number provides a simple and rapid means by which persons unfamiliar with the taxonomy of a particular group can locate a species in the phyletic listings usually employed by biologists. Furthermore, the NORGID number facilitates rapid and accurate computer processing which is essential to any analysis of environmental data. For fish, the checklist is equivalent in scope to that compiled by the University of Hawaii over many years for Kaneohe Bay. For benthos, it represents one of the most extensive local listings known, including four species newly reported in the Hawaiian Chain (*Alpheus rapacida*, *A. rapax*, *Synalpheus pachymeris* and *S. thai*) and one new species (*Leptalpheus pacificus*). Second, population size information and geographical distribution within the harbor (West Loch excluded) are provided for ten fish, twelve benthic animals and eleven piling animals, each selected for its importance to the general community structure of Pearl Harbor. These distributions will be useful in evaluating

---

* Only 343 organisms are treated in the text and in the factor analysis. Appendix E, however, contains 394 entries.

** ORGanism IDentification number.

biological response to the many Navy pollution abatement projects in the harbor. Third, certain of the many marine forms resident in Pearl Harbor have been selected on the basis of factor analysis as species having good potential as pollution rating indices. An index based on fish population and a second based on micromolluscan assemblages were devised and tested. The fish index shows promise but could not be fully evaluated due to the uniformly stressed condition of Pearl Harbor. The micromolluscan index showed good correlation with heavy-metal burdens in the sediment. Fourth, statistical procedure for analyzing environmental data, both biologic and physicochemical, was developed and tested with moderate success due to the field survey constraints mentioned above. Although the difficulty of applying such techniques is well known (Reference 5.0-2), further use of the procedures developed to a wider variety of field situations is expected to provide the Navy with an efficient and cost-effective means of analyzing environmental data. Lastly, the report itself serves as an instructive document in field survey techniques. Sampling devices and field techniques are described, identification and preservation procedures are given, and data processing routines are outlined in detail together with many different examples of final data display.

The analytical procedures are summarized first since they are basic to all subsequent discussion. This summation is followed by a brief summary discussion of the four major biological surveys: fish, benthos, micromolluscan and piling communities, in that order. Then the findings of the two special PHBS studies (harbor circulation and ship activity) are discussed principally from the standpoint of their possible environmental consequences to the harbor. Thereafter, the marine water quality determinations and the sediment analyses done by the Data Base team are briefly discussed. Next, the conceptual developments arising out of this study are summarized and their utility to the Navy is indicated. Finally, recommendations resulting from this entire effort are presented in brief form.

DATA ANALYSIS

Since the analytical support initially expected from the Data Base did not materialize, special procedures were developed by the PHBS team. Development of these procedures, therefore, came after the collection of field data had been terminated. Although the analytical situation was certainly not optimum from the standpoint of experimental design, it did represent a useful exercise since the ultimate application of the analytical system by the Navy would be to data reported by survey teams to a central processor who had little or no control over the field collection effort.

In brief, the general procedure for all data included principal component factor analysis followed by various forms of cluster analysis based on the factor scores. A detailed discussion of the procedure is given in Section 4.0. The highly generalized statistical techniques adopted in this study serve their major purpose when the general characteristics of the environment are poorly understood or the questions to be asked are poorly formulated. To some extent, these techniques serve as substitutes for adequate experimental design in the face of large amounts of data. Factor analysis has the advantages of reducing both the complexity of and the redundancy in environmental field data in a statistically rigorous manner. It also reduces "noise" or random variation which can mask certain important trends. The procedure summarizes the original data matrix with a smaller matrix of new variables (factors) which are orthogonal (i.e., there is no redundancy between them). Factor loadings are the correlation coefficients between the original data or variables and a given factor. Factor scores indicate the relative success with which a factor represents the original data at a given location or station. Since the factors are orthogonal or uncorrelated by design, they are not efficient at revealing natural associations or patterns. For this reason, cluster analysis is applied to the reduced matrix resulting from factor analysis. The cluster analysis techniques employed are expressly designed to detect relationships among the bio-stations and are capable of recognizing similarities even among the factor scores. They are simply ordination procedures which group nearest neighbors in factor-score space and present the results in some easily interpreted pattern. In this report a dendrograph is used, although many other display formats are possible. More detailed discussion of the dendrograph is again found in Section 4.0. The combination of factor and cluster analysis is a particularly powerful and objective analytical tool.

Another important aspect of the multivariate analysis techniques employed is that of pattern coherence. The multivariate techniques used are inherently robust, that is, they are relatively insensitive to deviations of the data from underlying assumptions that went into the development of the statistic. This property allows coherence to emerge. Multivariate analysis of any nontrivial data array will generate apparent patterns of variation; however, there are few rigorous methods of testing their statistical significance. The procedure used in the analysis of the Pearl Harbor data is such that a nonrigorous rule of thumb may be applied, that of pattern coherence. Four different biological groupings were analyzed, each in at least two different ways (absolute abundance analysis and presence/absence analysis). Thus, eight patterns based on differing data sets and analyses may be inspected for similarity or coherence. Such coherent patterns are reproducible characteristics of the environment, within a reasonable range of data distortion. They can be accepted as real, even in the absence of statistical rigor. Pattern coherence is discussed at greater length in Section 4.7 and is summarized in Table 5.0-1. It may be seen from this table that the biological data clearly distinguish an outer channel environment (BC-11 or BC-12) from the remainder of Pearl Harbor, that the analysis of micromolluscan data produced a consistent pattern within the harbor (although see discussion of fish analysis later), and that absolute abundance analysis (because of its greater information content) tended to produce sharper patterns. It should be stated that patterns which are not reproducible from one analysis to the next may nevertheless be real and that patterns seen by more intuitive treatments of the data may be missed by multivariate analysis. The approach of this report is, however, conservative and the criterion of coherence has been applied in accepting patterns describing environmental conditions in Pearl Harbor.

Two additional aspects of the analytical treatment are best presented prior to the summary of findings by biological group. The first is that the need for greater selectivity in collecting field data for statistical analysis is clearly apparent in the factor analysis. An inventory of resident forms, such as the one assembled by the PHBS team is always a requirement in any useful environmental study, but data collected for statistical analysis should be more restrictive. This fact is best demonstrated by ranking

Table 5.0-1. SINGULAR BIO-STATIONS BASED ON SCORES FROM FACTOR ANALYSIS.

Factor	Absolute Abundance Analysis: Fish	Benthos	μMoll.	Piling
I	BC-11	BC-11	BC-12	BC-11
II	BW-13 (BM-07 & BC-10)	BC-09	BE-05	BC-11
III	BC-10	BC-11 & BW-13	BE-02	no factor
IV	BE-05 (BM-07)	BC-11	BW-14 pos. (BE-04 neg.)	no factor
V	BC-09	BE-05 & BC-09	BC-09	no factor
Harbor Pattern	fairly sharp	complex, doubles and repeats	very sharp	no pattern

Factor	Presence/Absence Analysis: Fish	Benthos	μMoll.	Piling
I	BC-11	many	BC-11	BC-11 & BE-05
II	BW-13 pos. BE-04 neg.	many	BE-02 & BE-05 pos. BC-11 neg.	BM-07 & BE-17 (many)
III	no factor	no factor	BW-14, BC-09 & BE-06c	BW-13 & BM-07
IV	no factor	no factor	no factor	BW-13 (many)
Harbor Pattern	fairly sharp but complex	no pattern	sharp but complex	very fuzzy

Note: Bio-stations in parentheses score moderately on the factor. Sign of score is given only when there is a significant score of the opposite sign.

all analyses performed (including the nonbiological) on the basis of percent variance explained by the first two factors, thus;

Micromollusca, absolute abundance	70%
Sediment, metal burden, 10 metals	65%
Fish, absolute abundance	57%
Fish, presence/absence	56%
Micromollusca, presence/absence	40%
Benthos, presence/absence	35%
Water, minimax, 15 parameters	31%
Water, means, 15 parameters	29%
Piling, absolute abundance	27%
Water, extremes, 15 parameters	26%
Piling, presence/absence	25%
Benthos, absolute abundance	18%

The more conglomerate groups (including the water quality measurements) fall into the lower rankings. When the analysis concerns a single phylum or a single property like heavy metals, the extracted factors explain a far higher proportion of the variance in the original data. The reduction in variability explained is probably due to a problem which might be termed "conglomerate noise". Conglomerate noise is reduced by selectivity in the experimental design of environmental surveys.

The second aspect of the analytical treatment is a partial response to the conglomerate noise problem just discussed. Factor loadings may be used as an effective method of selecting those organisms having the best potential as bio-indicators. The Pearl Harbor study as a whole was intended to be and is a pilot assessment of a poorly understood environment. Of the 343 marine forms surveyed, those that load heavily on the extracted factors are those that respond to patterns accepted as real environmental characteristics. They may, therefore, be tentatively accepted as the best forms for intensive field study and statistical analysis. The number of species loading on the first factor and that loading on the remaining extracted factors are summarized in Table 5.0-2. The first factor has been tabulated separately to facilitate the discussion of lesser-factor importance appearing later under concepts. For absolute abundance factors, the number of species with loadings of 0.78 or greater (corresponding to 60% or better of variance explained by the factor) is tabulated. For presence/absence factors, loadings of 0.71 or greater (corresponding to 50% or better of variance explained) is used since the data matrix contains less information. The percent reduction of species that need be considered as potential bio-indicators is shown parenthetically after the appropriate entries in the table. If all species loading on a. factor are accepted, the reduction is 52%; if only those loading on lesser factors are accepted, the reduction is 78%. Application of these findings to the continued study of Pearl Harbor or to continued environmental monitoring of the harbor can result in considerable cost savings to the Navy.

FISH SURVEY

The utilization of fish or fish population structure as an indicator of general environmental condition has many pronounced advantages and many pronounced disadvantages. From a political standpoint, environmental status established on the basis of fish population is better "understood" by the general public. This is an advantage. From an operational standpoint, there

Table 5.0-2. REDUCTION OF BIO-INDICATORS BY FACTOR ANALYSIS.

Absolute Abundance loadings 0.78 or greater (coef. of determination = 60%)

Group	Total Spp.	Total Fctrs.	Loading on Factor I Only	Loading on Lesser Factors	Candidate Species All Factors (% red.)	Candidate Species Lesser Factors Only (% red.)
Fish	90	5	26	22	48(47%)	22(76%)
Benthos	136	5	7	29	36(74%)	29(79%)
μMoll.	73	5	42	14	56(23%)	14(81%)
Piling	111	2	14	10	24(78%)	10(91%)

Presence/Absence loadings 0.71 or greater (coef. of determination = 50%)

Group	Total Spp.	Total Fctrs.	Loading on Factor I Only	Loading on Lesser Factors	Candidate Species All Factors (% red.)	Candidate Species Lesser Factors Only (% red.)
Fish	80	2	29	8	37(54%)	8(90%)
Benthos	34	2	3	0	3(91%)	0(100%)
μMoll.	29	3	9	4	13(55%)	4(86%)
Piling	49	4	2	2	4(92%)	2(96%)

Note: Cutoff criteria for P/A analysis reduce the number of species admitted. The species are either rare or ubiquitous and therefore would be unlikely candidates as indicator species. Percent reductions tabulated, however, are only those determined by factor analysis.

are both advantages and disadvantages. Among the former is the fact that reasonably accurate fish inventorying can be performed by nontechnically trained personnel and that there are often local records of fishes for a given area. These records can be used at least as a pilot assessment of the environment to be studied. Among the operational disadvantages are the difficulty of obtaining representative samples of the entire fish fauna*. This disadvantage may be partially** overcome by visual transecting and completely overcome when there is sufficient information to select specific fish species for study. As potential indicators of environmental status, the mobility and diversity of fish populations together with their well developed sensory acuity make them potentially sensitive indicators of even transient environmental perturbations occurring at nearly all levels of the food web. These same traits cause them to avoid short-term insults and to exhibit stronger responses to habitat availability, food availability and seasonal changes than to general environmental quality. Fish tend to optimize any environmental situation by utilizing the habitat/food space within an acceptable range of ambient environmental conditions. If the integrated insult is sufficiently large, fish will leave the environment despite the availability of food and habitats. In this sense, fish populations are less likely to develop "adaptive noise" which is discussed under concepts below. In any event, fish response to general environmental status is likely to be a second order or third order effect. Thus, their use as indicators will require careful experimental design. Because of this fact, the extensive analysis of fish data in this report may be considered by some to be premature. This criticism is accepted. Nevertheless, the analysis was undertaken as part of the inventorying process for the political and operational advantages set forth above.

The phyletic and alphabetic checklist, in the case of fish, has been augmented by an illustrated listing presented in Appendix A. This appendix is provided as an exemplar of what can be done should fish populations be used as an indicator system. Similar treatment of other biological groups could be prepared if such an effort were warranted. Ninety fish species from 46 families were positively identified. Fish weights and lengths were measured and length-to-weight conversion factors were determined (Tables 2.1-4 and 2.1-8).

A large number of population assessment methods were used to obtain the broadest coverage of fishes resident in Pearl Harbor. Night-active fish are probably not well sampled, although overnight gill net sets got a reasonable sample of net-prone species. Estimations of day-active fish were made difficult by poor underwater visibility, especially at bio-stations BM-07 and BC-09. The fish population data obtained show the number of fish species declines with distance into the harbor from a high of 70 at BC-11 to a low of 10 at BE-04, deep within Southeast Loch (Figure 2.1-8). Bio-stations BC-10 and BW-13 to the east and west of the tip of Waipio Peninsula exhibit nearly equivalent diversity (42 and 43 species, respectively) which is higher than the remainder of the bio-stations deeper within the harbor. The greatest gill net catch-per-unit-effort (indicative of night-active fish) was re-

* Underwater explosive charges obtain total faunal collections from a defined water volume; however, such methods are not considered appropriate for most environmental investigations.
** Visual transecting is hampered by poor underwater visibility and is often difficult at night.

corded at BC-09, with bio-stations BE-05, BM-07 and BC-11 following in that order (Figure 2.1-5). BC-09 is located in and BE-05 is located near an area of downwelling (Figure 3.3-20), which suggests possible surface concentrations of food. BM-07 is located in a nutrient-rich area and the BC-11 catch is probably high due to fish movement in and out of the harbor. With the exception of BC-09, day-active fish biomass estimated by visual transect is also high at these same bio-stations (the estimate at BC-09 is probably low due to poor underwater visibility). Visual transect biomass is high at BW-13 too. The biomass at this bio-station together with BE-05 and BM-07 is high because of large populations of surgeonfish (Acanthuridae). The high biomass at BC-11 is due to a more varied fish population. Both species distribution and biomass indicate at least an environmental change from pelagic conditions to estuarine conditions and, when considered with other Pearl Harbor data, suggest a decline in marine environmental condition as the harbor is penetrated.

Geographic distributions for ten fish species selected for their feeding habits are presented in Figures 2.1-9 through 2.1-18. The goatfish (*Parupeneus porphyreus*) has a strong preference for South and Main Channels. It is also shown by tagging data to range widely from Pearl Harbor. Some fish tagged in the harbor were caught off Sand Island; others were returned from the Honolulu fish markets. The hammerhead shark (*Sphyrna lewini*) typically moves into enclosed shallow areas during the summer to deliver pups; its capture mainly at bio-stations BE-05 and BM-07 suggests a behavior similar to that observed in Kaneohe Bay. The algae feeders were found mainly at BE-05, BM-07 and BC-09, the surgeonfish (*Acanthurus xanthopterus*) at the first two bio-stations, the mullet (*Mugil cephalus*), an herbivore-detrivore, at the latter two, and the milkfish (*Chanos chanos*) only at BC-09. The threadfin butterflyfish (*Chaetodon auriga*), which is typically associated with coral reefs, was distributed as far into the harbor as BC-10. The tenpounder (*Elops hawaiiensis*), which is a voracious predator typical of tropical estuarine areas, was more generally distributed throughout the harbor, even appearing at BE-04, deep in Southeast Loch. The soft puffer (*Arothron hispidus*) tended to be distributed mainly in the more heavily stressed areas. Dr. Clarke (see Appendix B) also noted that the carangid (*Caranx sexfasciatus*) was often taken in Pearl Harbor whereas it is rarely taken in Kaneohe Bay, the reverse being true for *C. ignobilis*. He notes this as the single striking difference between the fish populations of the two estuaries.

An environmental preference rating (EPR) system was also developed for fish populations, but could not be thoroughly tested due, in part, to the apparently uniform condition of Pearl Harbor. Although the EPR system has been used by the Hawaiian Electric Company to rate the environmental impact of their Waiau power plant outfall (Reference 5.0-3), it (like Appendix A) is presented only as an exemplar of how such rating systems can be established. The EPR system is an organized way of recording fish population structure in response to known environmental conditions, combined with a simple arithmetic means of reducing the recorded fish responses to an environmental preference rating and a numerical indication of preference strength. When applied to Pearl Harbor, the system indicates BE-04 as the most stressed bio-station and BC-11 as the least. The remainder of the harbor is rated as midway between these two extremes and more or less uniform. To this extent the EPR system agrees with the factor analytic results. Although not done in this report, the EPR system could be applied to any biological group having potential as bio-indicators.

Factor analysis of both fish presence/absence and absolute abundance data indicate BC-11 to be a bio-station significantly different from all remaining bio-stations. Two factors were extracted in the P/A analysis. Only BC-11 exhibited a significantly high score on Factor I. On Factor II, BE-04 and BW-13 showed significant positive and negative scores respectively. Of the 26 species well described* by the two factors, 24 have loadings of 0.95 on Factor I meaning that their variance was almost wholly described by this factor. The bio-station scores on Factor II exhibit a suggestive gradient, ranging from high positive scores for bio-stations judged to be more environmentally stressed on the basis of all biological observations (see Section 4.7) to high negative scores for those judged to be least stressed on the same basis (Figure 4.3-2). Such a gradient would be expected if there was a lesser-factor detection of environmental condition (see later discussion of concepts); however, in this instance, tests using various ordination techniques do not demonstrate sufficient coherence for the gradient to be accepted as real. Both the factor analysis and the EPR system just described indicate that BC-11 is uniquely different from the remaining bio-stations. In fact, if fish species loading significantly on Factor I are inspected, the factor loadings are seen to correlate as might be expected with the mean EPR rating (Table 5.0-3). The Q-values** and f-values**, established on the basis of many field observations in waters about Hawaii, are consistent with species loadings on a factor strongly associated with the cleanest bio-station.

Table 5.0-3. COMPARISON OF EPR RATINGS WITH P/A FACTOR I LOADINGS.

factor loading	mean Q-value**	mean f-value**	species not rated**
0.95	6 (n = 17)	2.6 (n = 17)	7
0.80 to 0.94	10 (n = 5)	2.3 (n = 5)	0
0.60 to 0.79	14 (n = 10)	2.1 (n = 10)	0

Five factors were extracted in the absolute abundance analysis. Again, Factor I was strongly associated with BC-11 and explained 45% (cf. 39% for P/A analysis) of the variance. The remaining four factors explained a nearly equivalent amount of variance and each appeared to be associated with a particular bio-station: Factor II with BW-13, III with BC-10, IV with BE-05 and V with BC-09. With the possible exception of BC-10, these bio-stations are among the less stressed bio-stations (see Section 4.7). In spite of the difference in information content of the P/A and abundance data sets, the two analyses produce similar patterns. The isolation of BC-11 is real; furthermore, the fish species strongly associated with Factor I are predominantly associated with a hard substrata. An apparent trend among the four remaining factors is one of a decrease in number of species associated with hard substrata. A similar correlation with substratum has been observed through factor analysis of the fishes of Kaneohe Bay (References 5.0-4 and 5.0-5). However, since the factors are orthogonal (uncorrelated), the trend

* Communality of 80% or greater.

** Q-values indicate preferred environment and range from 0 for a clean environment to 50 for a polluted one; f-values indicate strength of preference and range from 3.0 for strong preference to 0 for no preference. Some species were not rated because of insufficient field observation. See page 2.1-38 for further discussion.

is not simply degree of "hard-bottomness". Other variables, such as salinity, not accommodated by the extracted factors may be involved. While the trends among the five bio-stations associated with the absolute abundance factors are consistent, the most objective separation, in the absence of other supportive biological evidence, is between BC-11 and the rest of Pearl Harbor. The conservative position is warranted by the P/A analysis which also makes the same real separation of BC-11, but lacks coherence for the remaining bio-stations (Table 4.3-3).

Several reasons can be advanced to explain the lack of additional patterns in the Pearl Harbor fish data. First, additional patterns characteristic of the harbor may not exist and the analysis identified the only real pattern that exists, that of reef versus harbor fishes. Second, characteristic differences may truly exist among the nine "harbor" bio-stations but the fish data collected are insufficient to detect them. Third, additional patterns may exist in the data but the analyses used are unable to detect them. The first two possibilities cannot be tested without additional data from Pearl Harbor. The third was tested by applying the analytical method to fish data gathered by Devaney and Whistler (Reference 5.0-6) from Kaalualu Bay, Hawaii. This application is, incidentally, an excellent example of the use of existing fish population records to estimate environmental condition. Although none of the PHBS survey team has ever visited Kaalualu Bay, factor analysis of Kaalualu fish data reproduced exactly the three biotopes established by Devaney and Whistler. Furthermore, three transects reported as anomalies by these authors were shown by the factor analysis to be modified extensions of the biotopes defined (Figure 4.3-15). The analysis revealed three variables (substrate composition, water depth and coral coverage) which were not included in the original data matrix but which are possibly associated with the extracted factors (see page 4.3-25 for further discussion).

If the fish data from Pearl Harbor and Kaalualu are combined and then factor analyzed, they are separated into two clusters associated with Kaalualu Bay, another cluster associated with Pearl Harbor and a series of singularities also associated with Pearl Harbor (Figure 4.3-16). Thus, the analytical technique is twice shown capable of making separations where real differences exist. Furthermore, the correlation of EPR ratings with loadings on Factor I suggests that fish transecting by competent field biologists can be used to estimate marine environmental status. For such application, however, the system would have to be "calibrated" in a number of marine environments differing from the more or less uniform conditions extant in Pearl Harbor.

BOTTOM SURVEY

The survey of bottom organisms was the most expensive and time-consuming effort of the entire survey. The results obtained are certainly the least cost-effective of the four biological surveys conducted. Data Base management required the emphasis on bottom survey with high statistical replication because of the success of sanitary engineers in detecting the influence of sewer outfalls by analysis of certain benthic forms. For this specific application, benthic surveys using proven bio-indicators are effective, but for the general survey of a little-known, multiply-insulted environment, they are not. The situation is a good illustration of the difficulty of assessing nonspecific environmental stresses by means of broadcast biological survey. Nevertheless, the PHBS effort was both useful and of value to the Navy for several reasons. First, the benthic community of Pearl Harbor was quite unknown prior to the survey. If bio-indicators are to be used to monitor the Navy's pollution abatement effort in Pearl Harbor, a fairly complete knowledge of naturally resident forms is required for their selection. The PHBS effort provided such an inventory and factor analysis has indicated 29 out of a total of 136 organisms have real potential as bio-indicators. Second, rapid and standardized means of collecting and processing bottom samples have been devised and are described in Section 2.2. Third, in conjunction with the analysis of other biologic groups, factor analysis of the bottom community has indicated some general trends in the environmental status of Pearl Harbor. Lastly, broadcast sampling and identification of benthic organisms are necessary if Pearl Harbor is to be used as part of an environmental range* for testing biological monitoring systems.

A total of 136 organisms were separated from the bottom material of Pearl Harbor, 114 of these were positively identified (87 to the specific level). Again, BC-11 was unlike the rest of the bio-stations in possessing the largest number of benthic species and a high count of individuals. BE-05, BC-09 and BW-13 also exhibited high numbers of both species and individuals with BE-05 having the highest individual count. The fact that BE-05 is near and BC-09 is in a region of downwelling (Figure 3.3-20) probably accounts for the high individual counts at these two locations. The 14 common benthic organisms (Table 2.2-7) showed no strong depth specificity. Total individuals in the bottom community was low at BE-04, BC-10 and BE-17; intermediate at BE-02, BE-03 and BM-07; and high at the remaining bio-stations. Three polychaete worms (*Nereis* sp., *Eurythoe complanata* and *Nematonereis unicornis*) were widely distributed throughout the harbor; the former showed by its high mean abundance at BE-17 considerable tolerance for sediments having high heavy-metal burdens, the latter two exhibited a gradient in mean abundance with high values at bio-stations judged to have better environments (see Section 4.7). Two crabs (*Etisus electra* and *E. laevimanus*) also exhibited an apparent preference for better environments, while a third (*Thalamita integra*) was more generally distributed throughout the harbor. Crabs are excellent organisms for the determination of copper in the general environment because of their ability to concentrate this metal, and copper is shown in the discussion of sediments below to correlate highly with other industrial metals. Thus, if crabs were used as indicators of heavy-metal status in the harbor, the third species mentioned above, not the others, should be used.

The sharpest division apparently caused by environmental differences is seen in the echinoderms, a situation which has been observed in other Navy harbors (Reference 5.0-7). With only a few exceptions, the phylum was

---

* An environmental range is a concept arising directly out of the Pearl Harbor study. It is a series of water bodies or regions which form a graduated scale, ranging from highly modified by human activity (such as a Navy harbor) to little modified by human activity (such as an infrequently visited bay). The range would be used as indicated above.

remarkably absent within the harbor. Those few that were present (*Ophiactis savignyi* and *Amphiopholis squamata*) were observed only at the bio-stations judged to be less environmentally stressed with the notable exception of the ubiquitous sea cucumber, *Opheodesoma spectabilis*. The class Echinoidea (sea urchins) was seen only at BC-11.

Ten species of algae were identified in the benthic samples (Table 2.2-8). The ulvoid algae are most widely distributed and the most abundant forms within the harbor. These algae have been used by Spencer as an indicator of pollution (Reference 5.0-8). The absence from Pearl Harbor of another green alga (*Dictyosphaeria cavernosa*) associated with pollution in Kaneohe Bay (Reference 5.0-9) is noteworthy. Its absence may be related to the absence of living stony coral in Pearl Harbor (an apparently introduced alcyonarian (soft) coral, *Telesto riisei*, was observed in the Main Channel and in Southeast Loch). Two species (*Dictyosphaeria cavernosa* and *D. versluyii*) are widely distributed throughout much of Kaneohe Bay, probably in response to an overabundance of nutrients due to treated sewage. The alga is known to exist along the southern coasts of Oahu and in Keehi Lagoon (Reference 5.0-10); however, it has not been observed in Pearl Harbor. The alga is very rare in the most insulted portion of Kaneohe Bay (the southeast basin). It appears likely that it may be an indicator of moderate pollution levels but is not tolerant of conditions found in Pearl Harbor.

The benthic survey consisted of 87 samples taken from various depths at ten bio-stations; each taxon was reported by wet weight and by number of individuals. Nine combinations of data and treatment were possible for the factor analysis (Table 4.4-2). All such combinations were, in fact, analyzed but only the two most useful analyses are reported on in detail, viz., absolute abundance by individual count and P/A analysis. In the absolute abundance analysis five factors accounting for 41% of the variance were extracted. Of the 136 taxa entering the analysis, 26 (19%) had communalities of 75% or greater, and 51 (38%) had communalities of 50% or greater. The former species bear a strong relationship to the extracted factors while the latter show moderate relationship. These relationships are summarized in Table 5.0-1. Several patterns emerge from an inspection of species loadings. Factors I, III and IV exhibit similar taxonomic associations, with the preponderance of polychaete worms and arthropods loading heavily. The association suggests a relationship to a rubble substratum overlain by a veneer of soft sediment. Maps of absolute abundance factor scores show the three factors to be associated with BC-11 and BW-13. It might be noted here that the fish factor analysis also suggested a substratum dependence. Factor II and, to a lesser extent, Factor IV suggest an association with filter-feeding or detritus-feeding organisms. Although Factors II and V show some overlap with the Factor I-III-IV group, they both appear to be "catchall" factors from a phyletic standpoint. Factor score maps for these factors show a strong association with BE-05 and BC-09 and some complex association with BC-11. No factor scores heavily in South Channel or Southeast Loch.

Inspection of the score maps shows the high scores to be overwhelmingly dominated by shallow water samples. Moreover, most of the variability again occurs at BC-11 which exhibits a complex pattern at all depths. A dendrograph constructed from factor-score distances fails to distinguish any well defined clusters. Rather, the pattern is one of progressive deviation of samples from a single ill defined cluster. The samples furthest from the center of that cluster are the bio-stations BE-05, BC-09 and BC-11, and the most deviant samples are from shallow water.

Although no cluster pattern emerges, the absolute abundance analysis does reduce the potential number of bio-indicators from 136 to 36 (Table 5.0-2). These may be identified by an inspection of factor loadings in Table 4.4-4. The species distributions relative to degree of environmental stress suggested by field observations are borne out in the factor loadings. The two polychaetes (*Eurythoe complanata* and *Nematonereis unicornis*), associated with relatively clean environments, have loadings of 0.86 and 0.64 respectively on Factor I. The two crabs (*Etisus electra* and *E. laevimanus*), similarly associated, have loadings of 0.51 and 0.77, respectively, on Factor III, which like Factor I has high scores at BC-11. The errant polychaete worm (*Nereis* sp.) was combined in the analysis with five other nereids, and the group has a loading of 0.96 on Factor III. An inspection of Table 2.2-4 shows that the large numbers of these worms at BC-11 masked its presence at the more stressed bio-stations. The ubiquitous crab (*Thalamita integra*) has a loading of 0.63 on Factor V, the "catch-all" factor. Two other crabs (*Thalamita admete* and *Pilumnus oahuensis*) broadly distributed in the harbor are among the few species with significant double loadings; the former loads 0.64 on Factor I and 0.71 on II; the latter, 0.53 on II and 0.69 on V. The echinoderms load on the two "catch-all" factors, *Ophiactis savignyi* loads 0.91 on Factor II, and *Amphipholis squamata* 0.74 on V. These factors score high on the better bio-stations within the harbor; Factor V also scores at BC-11.

Several general conclusions may be drawn from the abundance analysis. With respect to depth, there exists a gradient from a relatively variable shallow water to a relatively invariant deep-water community. It should be remembered that both seasonal change and pollution exposure are greatest in the surface and immediate subsurface waters, the latter being true because many pollutants are surfactant. With respect to the bio-stations, three sample groups emerge. BC-11 is distinctly different from the other bio-stations, all of which are more definitely within the harbor proper. Bio-stations BE-03, BE-05, BC-09 and possibly BC-10 represent a second biotic unit. The remaining bio-stations are lumped together as an ill-defined association, BM-07, BW-13 and BE-17 being poorly represented by the five factors, and BE-02 and BE-04 being represented not at all.

For the presence/absence analysis, the cutoff criterion causes a sharp reduction from 136 to 34 in the number of species considered. The factor analysis further reduces these 34 to only three as potentially promising bio-indicators (Sipunculids, the tanaid, *Apseudes* sp. 1, and the echinoderm, *Ophiactis savignyi*). Since the cutoff criterion removes species that are either rare or ubiquitous among the bio-stations, many of those eliminated would also be unlikely candidates as bio-indicators. P/A factor analysis produces two factors. Neither the communalities nor the loadings are as high as in the abundance analysis. On the basis of species with loadings of 0.5 or greater, P/A Factor I appears to be similar to the Factor I-III-IV group noted in the abundance analysis. P/A Factor II appears to be a "catch-all" factor showing only weak loadings which include two filter-detritus-feeding organisms. In general, the P/A factor analysis preserves the biotic patterns seen in the more extensive abundance analysis. Maps of P/A factor scores again show high scores most frequently in the shallow-water samples. BE-05, BC-09, BC-11 and BW-13 show high scores on Factor I, which is clearly depth-related. Most shallow samples have relatively high positive scores on Factor I, while most deep samples have low positive, or even negative, scores. P/A Factor II is less easily interpreted; the nonmodal scores seem to show an affinity for central Pearl Harbor with even a few moderate scores at BE-04 in Southeast Loch. The Factor II map is, however, complicated by both positive and negative scores, with BE-03, BC-09 and BC-10 showing high positive scores.

A dendrograph constructed from the P/A scores shows three distinct clusters (A, B and C, Figure 4.4-6). Cluster A, by far the largest, includes all deep samples and, with the exception of BC-11, all intermediate depth samples. Cluster A also contains nearly half (47%) of the shallow-water samples, but none of the nine possible shallow-water samples from BC-11 and BW-13. Both Cluster B and C are similar, each consisting mainly of shallow-water samples. Both contain samples from BC-09, BC-11 and BW-13; Cluster B also contains samples at BE-03, and Cluster C contains samples at BE-02 and BE-05. If these two clusters are considered to be restricted to shallow waters, then neither BM-07 or BE-17 could be represented,since no shallow-water samples existed at these locations. The P/A data primarily demonstrate a depth-related pattern in Pearl Harbor and weakly, if at all, indicate some complex pattern among the bio-stations. As with the abundance analysis, BC-11 stands distinct from the rest. BE-05 and BC-09 form a second less distinctive group, while the remaining bio-stations offer little quantitative justification for further division on the basis of benthic organisms.

The micromollusca are also members of the bottom community, but are here reported separately. Comparison of the benthic analysis with the micromolluscan analysis shows essentially the same division among the bio-stations. BE-05, BC-09 and BC-11 are distinguished as separate entities in both analyses, only BE-02 is missed by the benthic analysis. The correlation coefficient between benthic species and micromolluscan species is low (+0.41), but between number of individuals it is high (+0.85). Correlation coefficients between benthic species and either fish or piling species are also high, being +0.79 for the former and +0.81 for the latter. In most instances (Tables 3.1-1 and 3.2-2), all biological data show high internal consistency.

MICROMOLLUSCAN SURVEY

Eighteen samples of Pearl Harbor sediments were sent to Prof. E. Alison Kay for micromolluscan analysis. This analysis, therefore, represents a broader coverage of the harbor than that afforded by the other biological studies. The additional samples include one from deep inside West Loch (BW-14), two from Middle Loch (BM-08 and BM-16), a pair of samples taken on the cold or intake side (BE-06c) and on the warm or outfall side (BE-06w) of the Hawaiian Electric Company's Waiau Power, two more samples from South Channel (BE-01 and BE-15) and a sample from well outside Pearl Harbor (BC-12). Sample BM-16, taken within 50 feet of the Pearl City STP diffusers, contained no micromollusca. Locations of all bio-stations are shown in Figure 2.3-1.

This separate analysis of benthic forms was undertaken because Prof. Kay has reported a relationship between water quality and this group of marine organisms (Reference 5.0-11). Since micromolluscan shells are preserved in the sediment, an analysis of sediment cores permits the determination of past environmental conditions, a singular advantage over physicochemical means of determining water quality. Further advantages include: techniques are compatible with collection in unconsolidated sediments, large numbers of species can be sampled with a minimum of effort, and a large body of information is available on the habits and habitats of these organisms.

Seventy-three micromolluscan taxa were recovered from the sediment samples, of which 44 were identified to the specific level and 27 to the generic level. Only 37 species were found in samples from Pearl Harbor proper, while 54 were found at BC-12, a bio-station well outside the harbor. It is noteworthy that only 12 species were recovered from BC-11, indicating that while it appears to be the least environmentally stressed of the ten bio-stations used in the other three biological surveys, it is certainly not an unstressed bio-station. Conditions at BC-11 probably reflect the presence of the Iroquois Point STP diffusers at that location. Only 18 species are common to all bio-stations, five are widely distributed within Pearl Harbor and present only in small numbers at BC-12; the remainder are found only at the less environmentally stressed stations. This group (Table 2.3-4) would be expected to contain bio-indicator species having high potential.

Mean micromolluscan density for Pearl Harbor was 6.1 per cm^3, ranging from a low of zero to a high of 32.3 per cm^3 at BE-06w, located in the thermal outfall from the Waiau power plant. Four patterns are distinguishable among the bio-stations on the basis of species composition and number (Figure 2.3-3). A *Hiatella/Odostomia indica* assemblage was associated with the more stressed locations, and an *Odostomia oodes* assemblage was associated with those stations judged to be less environmentally stressed (see Section 4.7). BW-14 in West Loch and BE-06c and BM-08 located at the heads of Middle and East Lochs appear among the less stressed bio-stations. BW-14 has seven micromolluscan species in common with BC-12. BC-11 and BC-12 possess individually unique assemblages. The assemblage at BC-11 is dominated by *Crepidula aculeata*, which is prominent at the two other Main Channel bio-stations, BC-10 and BW-13 (Figure 2.3-2). If this species is ignored, the assemblage at BC-11 resembles the *Odostomia oodes* assemblage associated with the less environmentally stressed bio-stations. BC-12 is unique, with a varied *Tricolia/Cithna* assemblage containing more than 50 species. It should be noted that the geographic distribution of the *Hiatella/Odostomia indica* assemblage closely resembles that of the sediments having high burdens of metals associated with shipyard activity (cf. Figure 2.3-3 and Figure 4.1-2, score map for Factor I). Also the correlation coefficients between micromollusca and the sedimentary burdens of heavy metals are negative, being moderately high (-.68 and -.65, respectively) for copper and mercury (Table 3.1-1).

Gastropods dominate all micromolluscan assemblages except at BE-06w, BM-07 and BE-17; the first bio-station is located in a thermal outfall and the latter two are probably influenced by sewage discharges. At these three bio-stations filter-feeding bivalves are dominant. Although not dominant at the other bio-stations, the percentage of bivalves is three to six times greater* at the harbor bio-stations than at BC-12; bivalves are suspension feeders dependent on the primary productivity of the water column. Among the gastropods, a higher proportion of pyramidellids relative to mesogastropods occurs at most of the bio-stations within Pearl Harbor, while archaeogastropods and neogastropods are nearly absent. Pyramidellids are well known as ectoparasites on sedentary invertebrates and are frequently found in places of high environmental stress (Figure 2.3-4). In contrast to the Pearl Harbor bio-stations, BC-12 has a lower proportion of pyramidellids and a higher proportion of the three other molluscan orders. BC-12 also ranks highest in epifaunal species while the more stressed bio-stations rank highest in sessile species (Figure 2.3-5). The large proportion (82%) of sessile micromollusca at BC-11 again suggests high nutrient status due to the sewage outfall. The micromolluscan assemblages within Pearl Harbor represent an almost classical example of a situation where relatively few species occur in large numbers and where the organisms are largely subsisting on the primary productivity of the water column rather than the substrate. BC-12, on the other hand, exhibits an assemblage more typical of subtidal habitats characteristic of Oahu's leeward shore. Again, as in the fish and benthos study above, bio-stations outside the harbor are shown to be distinct from those within. Pearl Harbor itself is shown to be relatively uniformly stressed; however, factor analysis of the micromolluscan data is able to extract another meaningful pattern from these harbor bio-stations.

Factor analysis of the absolute abundance data yields five factors, explaining 88% of the variance in the original data matrix. Factor I alone explains 59% of the variance, while the remaining four factors make only modest contributions. Forty-five species load heavily on Factor I, which is clearly representative of Kay's *Tricolia/Cithna* assemblage and scores heavily at BC-12. Factor II, on which BE-05 scores highly, somewhat resembles Kay's assemblage dominated by *Odostomia oodes*. However, three of the six species characteristic of Kay's four assemblages show very low communalities on all five factors (*Crepidula aculeata*, 7%; *Hiatella hawaiiensis*, 18%; and *Odostomia indica* 13%). Like the benthos abundance analysis, the factors exhibit high scores usually at single bio-stations, viz., Factor I on BC-12, II on BE-05, III on BE-02 and V on BC-09. Factor IV shows high scores at two bio-stations, positively at BW-14 and negatively at BE-04. The pattern is sharper than that obtained from the benthos data. It is important to note that bio-stations BC-11 and BW-13, which in the other biological studies score heavily on Factor I (the low-stress factor), do not show significant scores in the abundance maps. This fact again emphasizes that BC-11 is not a totally unstressed bio-station since it can be suppressed by one considered more natural, BC-12. The appearance of BW-14 in the abundance score maps also suggests that this bio-station is among the less-stressed group (cf. above discussion of micromollusca in common with BC-12).

---

* Depending on whether individual count or number of species is considered (Table 2.3-7).

The P/A factor analysis results in three factors explaining 57% of the total variance. As with the benthos analysis, the species loadings are more moderate than the abundance case, 12 species loading significantly on Factor I, 3 on II and 10 on III. BC-12 cannot be well represented in the P/A analysis since the P/A cutoff criterion reduces the species to only 20% of the total found at that bio-station. Those species present at BC-12 again load significantly on Factor I. The pattern shown by the P/A-factor-score maps is similar to that produced by the abundance analysis, with most of the low-stress bio-stations showing high positive scores. Unlike the abundance analysis, BC-11 now exhibits some significant scores, negatively on Factor II on which species not present at BC-12 load significantly, and positively on Factor III, which also shows high positive scores at other less-stressed bio-stations. With most species uniquely characteristic of an unstressed environment removed by the P/A cutoff criterion, BC-12 no longer suppresses BC-11.

Although neither the abundance nor the P/A factor analyses relate well to Kay's micromolluscan assemblages, cluster analysis based on factor scores does. The two dendrographs produced indicate a large cluster containing the environmentally stressed bio-stations associated with the *Hiatella/Odostomia indica* assemblage. As already pointed out, this assemblage corresponds with the distribution of sediments having high burdens of metals probably resulting from shipyard activity. Bio-stations exhibiting Kay's *Odostomia oodes* assemblage show up in the two dendrographs as small clusters separated from the large stressed cluster or as singularities (Figures 4.5-3 and 4.5-4). Kay's *Crepidula*-dominated assemblage at BC-11 is not recognized.

The apparent discordance between factor analysis and cluster analysis in reproducing Kay's assemblages may probably be explained by two related considerations. First, the information content of absolute abundance data used in the factor analysis is greater than the percentage dominance data used by Kay; percentages may be derived from absolute abundance data but not the reverse. In this sense, the <u>similarities</u> rather than the differences between the two analyses are, perhaps, surprising. Second, as pointed out earlier, orthogonal factor analysis is designed to define groups of variables which are uncorrelated; thus, two distinct but correlated groups would not be defined by the same factor. Cluster analysis is, however, expressly designed to detect relationships among the bio-stations and is capable of recognizing similarities among the orthogonal scores. Furthermore, Kay's assemblages are necessarily negatively correlated with one another, that is, a given bio-station may be assigned only to one assemblage. If two species characteristic of two different assemblages are present, the bio-station is assigned to that characteristic of the species having plurality, however slight.

The important facts are that Kay's assemblages are reasonably reproduced by the analysis and that both abundance and P/A analyses produce the same pattern. The micromolluscan data are therefore coherent and the patterns produced are sharp (Table 5.0-1). Since the technique is relatively rapid and inexpensive, it is considerably more cost-effective than benthic survey. Moreover, despite the predominance of bio-stations outside the harbor, certain relationships correlating with the heavy-metal burdens of sediments inside Pearl Harbor were detected. The same general differences in environmental stress indicated by the fish data are also apparent in the micromolluscan data, but in the latter the differences are coherent. While continued fish surveys may be warranted, broadcast benthic surveys are not, unless such survey is limited to specific bio-indicators for specific environmental insults. The shallow water variability shown in the benthic data suggests a possible response to surfactant pollutants. This variation is not reflected in the micromolluscan data since a series of samples from different depths was not taken. Shallow water forms would, however, be expected on the basis of probability of exposure to provide the better bio-indicator system.

PILING SURVEY

Those marine organisms which inhabit vertical hard surfaces, either artificial or natural, were the object of the fourth biological survey and are referred to as the piling community. Marine borers, normally considered part of the piling community, were not included. Piling organisms, especially those near the water surface, are often maximally exposed to pollutants, many of which tend to concentrate in the surface layer. In addition to maximal exposure, there are other characteristics justifying the inclusion of piling assemblages in the Pearl Harbor survey. They occupy artificial surfaces which do not vary greatly in composition or physical characteristics, wood, metal and concrete being the most common materials. These surfaces are generally far less complex than either natural rock or bottom sediments, thus the problems of objective and quantitative sampling are reduced and the variation that does exist is more easily described. Furthermore, wood, metal and concrete surfaces are frequently introduced by the Navy in the course of its normal operations; thus, in effect, "standard" experimental surfaces are being automatically placed in marine environments which may at some time need study.

Samples of the piling communites at nine* bio-stations were collected at the surface and at 10-foot depth in June 1972 and again in November 1972. Thus, it is possible to look for seasonal changes in this set of data. The collection devices and sample processing techniques are fully described in Section 2.4. Absolute abundance data were obtained for 111 piling species, of which 66 are common with species collected in the bottom survey. Seventy-two organisms were positively identified to the specific level and 16 to the generic level. Again, BC-11 showed the greatest species diversity with 21 taxa unique to that bio-station. The largest species counts and individual counts were obtained from BE-03, BC-10, BC-11 and BW-13. A few seasonal differences may be seen in the field data, but they are not obvious.

Sponges were most abundant at bio-stations BE-02, BE-05, BM-07 and BC-11 and showed no particular dependence on substrata or depth. The number of epifaunal organisms living in or on piling sponges was less than that

* BC-09 was omitted from the piling survey since there were no appropriate vertical surfaces at that location.

observed on benthic sponges and did not appear to be related to the mass of sponge present. The geographic distribution of piling species and individual counts are presented by bio-station and by depth in Figures 2.4-2 through 2.4-6. The distributions of eleven species selected to illustrate various patterns in the harbor are shown in Figures 2.4-7 through 2.4-17. The bivalve (*Hiatella hawaiensis*) was collected in more piling samples (75%) than any other single organism. Although it was not collected in the piling samples at BE-04, it is present in the micromolluscan assemblage from that bio-station. The gastropod (*Crepidula aculeata*) was present in the 10-foot samples from all nine bio-stations and exhibited a preference for vertical surfaces. Its wide distribution throughout the harbor indicates its tolerance for existing environmental conditions; however, its distribution indicates a weak preference for channel areas. The barnacle (*Balanus amphitrite*) exhibited a strong tendency to occur only in the surface sample at all bio-stations except BE-04, possibly because of oil exposure at that location. The barnacle was five times more numerous at BW-13 than at the other bio-stations, possibly because of the high flushing rates (see Section 3.3) or because of the elevated nutrient status of surface water entering the Main Channel from West Loch (Figures 3.2-19 and 3.2-21), or both. The amphipod (*Elasmopus rapax*) was found throughout the harbor, principally in the 10-foot samples and is the only piling organism to show a moderate seasonal change, being more numerous in June. The vermetid mollusca show a definite preference for concrete, rock or other hard substrata, being most abundant in South Channel and Southeast Loch (Figure 2.4-12). Their distribution indicates a tolerance, and possibly a preference, for the more environmentally stressed locations. Vermetid growth at BE-02 completely cements together concrete piling spaced over six feet apart. Again the echinoderm (*Ophiactis savignyi*) was present only at bio-stations nearest the channel entrance, BC-10, BC-11 and BW-13.

Since the extended multivariate analysis of the benthic data had shown no increase in information through various possible combinations by depth or by bio-station, such combinations were not used in the piling analysis. Two analyses were performed, viz., absolute abundance by sample and P/A by sample. Factor analysis of the absolute abundance data yields two factors explaining 27% of the total variance. Cutoff criteria as stated in Section 4.0 terminated the analysis at two factors. Neither factor shows any strong affinity for any particular taxonomic group. Thirty-five taxa exhibit loadings of 0.5 or greater on at least one of the two factors, and only 26 taxa have communalities of 75% or greater. Factor score maps show high scores only at BC-11 for both the surface and 10-foot samples, although all nine bio-stations were sampled with equal effort. The possibility that some seasonal factor masked differences between bio-stations was investigated and found not to be the case. It appears that the lack of differences is due to "sampling noise". The size of the piling sample (6" by 6" by the thickness of the community sampled) was insufficient to determine any patterns other than that BC-11 is distinct from the other bio-stations and that most of the variation at BC-11 occurs in the 10-foot samples. A dendrograph constructed on the absolute abundance scores failed to show any clustering tendency among the samples.

The cutoff criteria for P/A analysis reduced the 111 taxa used in the abundance analysis to 49 (56% reduction). The analysis yields four factors explaining 43% of the total variance. Species loadings are less pronounced than in the abundance analysis and again no particular taxonomic affinities are apparent. No taxa have communalities of 75% or greater. The P/A-factor-score maps are, however, in striking contrast to those of abundance analysis. Samples scoring significantly on a given factor exhibit a strong tendency to do so for both seasons. Among the 22 cases of such double scorings there are six cases of sign reversal, suggesting seasonality. This indication is more apparent in the P/A-factor-score maps than in the original field data. It would appear, therefore, that the piling sample size was adequate for good representation of the presence or absence of a taxa at a bio-station, even though the abundance-score maps suggest that the standing crop was not adequately sampled. The multivariate analysis may thus indicate sample-size insufficiency for particular analyses.

The P/A factors appear to be strongly depth-related. Factors I and III are strongest in deep samples, while Factors II and IV are strongest in shallow samples. There is also a bio-station pattern apparent in the 10-foot samples; Factor I scores heavily at BE-05 and BC-11, Factor III at BM-07 and BW-13. No such geographic distribution is readily apparent in the surface water factors. A dendrograph constructed from the P/A-score distances shows four distinct clusters, which are mapped together with their substrata association in Figure 4.6-8. The largest cluster (A) is principally located in South Channel and Southeast Loch, and is not substratum related. Cluster B is small, containing three samples, all 10-foot, all on wood, and located in areas having low ship traffic. Cluster C is again location-dependent, not substratum-dependent; samples are located mostly at BE-05 and BC-11. Cluster D is entirely composed of surface samples on various substrata. This last cluster is clearly depth-related.

Although the piling samples contain a wide diversity of taxa, like the benthic samples, P/A analysis has shown seasonality, substratum dependence and geographic patterns. Thus, the continued use of this conglomerate group would, unlike the benthos, appear to warrant continued use as a bio-indicator system. Factor analysis has reduced the number of potential bio-indicators from 111 to 10 or 20. Further, the piling biota have the advantage of occupying more uniform substrata often introduced into the marine environment by the Navy. Lastly, piling biota form a vertical assemblage which experiences a pollution-exposure regime ranging from high probability of exposure at the surface to considerably lower probability at depth.

CIRCULATION AND SHIP ACTIVITY

Two special studies, supported by the PHBS, were conducted. The first, a survey of harbor circulation and characteristic water masses, was considered necessary for the proper interpretation of the biological data. The second, a survey of ship activity in Pearl Harbor, grew directly out of the findings of the PHBS effort itself. The preliminary survey of Pearl Harbor (Reference 5.0-12) and a subsequent survey of Apra Harbor, Guam (Reference 5.0-7) suggested some possible environmental effects of ship movements.

Since no quantitative data of the kind needed were known to exist for any harbor, the second study was initiated. Both efforts are unique, the former because it is the first detailed investigation of Pearl Harbor circulation, and the latter because it is the first of its kind.

In general physical dimensions, Pearl Harbor is not atypical of coastal plain estuaries. However, few such estuaries are as dendritic and, due to extensive dredging of ship routes, the bathymetric profiles of Pearl Harbor channels and lochs are exceptionally rectangular. Furthermore, the presence of Ford Island in East Loch permits tide-driven or wind-driven gyral circulation around it, flood tides being most often associated with weak cyclonic movement.

Insufficient funds were available to extend the circulation study into West Loch; therefore, this general discussion cannot be reliably extended to that region. Pearl Harbor circulation most closely resembles that of an estuary with two-layer flow in which vertical mixing is driven by both fresh water influx and tides. In addition to these mechanisms, circulation is also driven by the mixing processes themselves, by wind stress and by both spatial and temporal derivatives of wind stress. Currents are generally almost parallel to the shoreline. Surface outflow is influenced by fresh water influx and is concentrated on the west sides of North and South Channels. Tidal current reversals occur at peak tidal amplitudes. Flood currents tend to be more intense and to occur on the eastern sides of the channels, while ebb currents occur on the western sides. For instance, about two-thirds of the tidal exchange in East Loch occurs through South Channel. Also tidal currents at the harbor entrance are slightly more intense in the bottom layer, while at the entrances to Middle and East Lochs they are concentrated at the surface. This phenomenon suggests a vertical tidal-velocity shear with resultant vertical mixing in the upper reaches of the lochs.

Wind stress and variations in wind stress are responsible for much of the circulation in Pearl Harbor. The winds tend to follow the channels, reaching their greatest velocity where there is maximum fetch aligned with the wind aloft. Under tradewind conditions, wind-induced currents in North and South Channel are normally strongest and are set toward the harbor entrance. The high shoreline relief often causes marked cross-channel differences in both wind velocity and induced surface-current velocity. In fact, currents on the upwind sides of the channels are often opposite those on the downwind sides. With a sustained cross-channel wind, surface water moves cross-channel as well as axially along the channel. Cross-channel flows are generally less than 20% of axial flows. Sustained cross-channel wind stress tilts the thermocline and the halocline such that both boundaries contact the water surface. Surface flows are compensated by upwelling and downwelling on the upwind and downwind sides of the channels, respectively (Figures 3.3-4 and 3.3-20). Although wind-driven circulation is damped by the normally stratified or stable condition of Pearl Harbor, overturn due to wind stress increases vertical mixing which decreases stability. Thus, wind-stress currents tend to grow in intensity once they become established. Vertical mixing due to ships or other driving mechanisms also enhances wind-driven overturn for this same reason. Induced currents in the bottom layer are usually weaker and sometimes in a different direction. Wind-stress currents are, however, an important factor in the general circulation of Pearl Harbor;

mean maximum currents are about 0.2 m/sec in the surface layer and about 0.05 m/sec in the bottom layer.

Wind derivative currents* can be stronger than tidal or normal wind-stress currents. The dominant spatial variation in wind is associated with the development of a sea breeze in the afternoon on warm days. Occasionally, the sea breezes develop sufficiently to overcome the tradewinds entirely near the harbor entrance. Under these conditions, the tradewinds prevail in the upper reaches of the harbor with southerly winds near the harbor entrance. Where the two wind systems meet, calm or easterly winds occur. This wind convergence is reflected in a surface water convergence (Figure 3.3-44) which can be obvious from an accumulation of oil and flotsam southeast of Ford Island. While the currents associated with convergence and divergence of wind stress appear to be relatively unimportant determinants in Pearl Harbor circulation, temporal changes in wind stress are important in Middle Loch, where wind-driven cross-loch flows are often dominant. Under tradewind conditions, Middle Loch exhibits a three-layered circulation** with surface (0 to 0.3 m depth) and bottom (5 to 10 m depth) flows toward the head of the loch and a return flow at mid-depth. Middle Loch normally has a sluggish anticyclonic surface circulation; however, under changing wind conditions, surface velocities of 0.1 m/sec are often observed. When the tradewinds diminish, surface outflow from Middle Loch often occurs, particularly on ebb tides. A three hour time lag was observed between temporal changes in the wind field and the resultant currents in Middle Loch. The reason for this local importance of wind derivatives is simply that the other driving mechanisms (tide, fresh water influx, wind stress and ship activity) are relatively ineffectual.

Influx of fresh water into Pearl Harbor causes seaward flows in the surface layer and landward flows in the bottom layer, a type of circulation often called estuarine. The total drainage basin has an area of about 290 km^2. Rainfall in this basin is reported as 212 cm/year (Reference 5.0-13). Five major streams and three large springs provide a fresh water influx reported as 4.4 m^3/sec, 30% of which enters the head of West Loch and the remainder is divided equally between Middle and East Lochs. Two separate estimations, one based on rainfall and the second on oceanographic parameters, suggest that total freshwater influx may be twice this amount. The main thermocline and main halocline are normally at 1½ and 5½ meters depth. Pronounced estuarine profiles were observed along the western side of the Main Channel due to the fresh water influx from West Loch. Exceptionally dry weather conditions prevailed during the entire PHBS current survey; thus, the full extent of fresh water influences on the harbor may not have been observed. In addition to water, the streams transport large amounts of sediment into Pearl Harbor; in some locations sedimentation rates are in excess of 10 cm/yr.

The results of the current survey were organized into a quasi-3-D model of Pearl Harbor circulation; actually, the construct is a partially linked pair of 2-D models, one for the surface layer and the second for the bottom

---

* Currents caused by changes in wind speed or by wind velocity differences between two locations.

** A mid-depth layer of water with dissolved oxygen levels lower than surface or bottom waters observed near the Whiskey Docks may be evidence for similar three-layered circulation in West Loch (see Section 3.2).

layer. While the model is not elegant, it is sufficient to determine areas where particular driving mechanisms are dominant in Pearl Harbor (Figures 3.3-35 and 3.3-36) and also to estimate mean residence times for various water masses in the harbor. For further details of the model, see Section 3.3. Bottom water masses in Middle Loch are estimated to have mean residence times in excess of six days, for East Loch as a whole three to four days, but for South Channel, Southeast Loch, and the northeastern section of East Loch one to two days. Considering the residence times of the rest of East Loch longer times might be expected, but for South Channel and Southeast Loch, vertical mixing due to ship activity appears to be an important contributory factor reducing residence times. Wind-driven upwelling is probably the dominant factor in producing the shorter residence times at the head of East Loch and is certainly contributory at the other two locations. Surface water residence times are estimated to have a gradient ranging from a maximum of 30 hours at the heads of the lochs to 10 hours or less in the Main Channel. These times are, of course, influenced by wind and fresh water runoff.

The importance of ship-driven vertical mixing was demonstrated in four different ways by the PHBS circulation study. First, the distribution of the residual turbulence term in the circulation model corresponds to that of large ship* traffic (Figure 3.4-8) rather than that of tidal or wind-stress driving mechanisms (Figures 3.3-35 and 3.3-36). In Southeast Loch and South Channel, tight ship maneuvers could increase the amount of ship energy dissipated as turbulence by factors of 5 to 100 times that of a ship in transit. Also once vertical stability has been reduced by ship mixing, mixing processes driven by wind become more efficient. Second, in most estuaries an increase in apparent diffusivity due to tidally-driven mixing is normally expected as the harbor entrance is approached; instead, apparent diffusivity increases by two orders of magnitude as South Channel and Southeast Loch are approached. Again this impressive increase is most probably due to ship movements. Third, high surface salinities in an estuary are an indication of efficient vertical mixing. A map of surface salinity shows maximums in regions of high ship activity. Fourth, low diurnal changes in surface temperatures are also an indication of efficient vertical mixing and a map of their distribution is the same as that for salinity. Ship activity, then, appears to be a very important mixing "force" in South Channel, Southeast Loch and possibly in other regions of Pearl Harbor.

The reaction of the salinity and thermal profiles to the passage of large ships was also studied (Figures 3.3-42 and 3.3-43). Large disturbances, lasting 10 to 15 minutes after passage, are seen in the surface waters. A survey of ship movements (see Section 3.4) indicates that there are about 30 important ship maneuvers in South Channel and Southeast Loch daily. If such maneuvers as stopping and turning imply recovery times of 45 minutes (roughly three times the passage of a ship), the amount of ship activity would appear sufficient to account for the region of anomalous turbulent mixing observed. Furthermore, since mixing necessarily reduces the stability of the water column, the second ship passage or maneuver should be more efficient at producing mixing than the first. Thus, there appears to be ample evidence that ship mixing is an important oceanographic parameter in Pearl Harbor.

* Ships 2000 tons and over.

This demonstration of ship-activity effects is an important discovery in the understanding of Pearl Harbor as a whole. Beside the reduction of bottom water residence times, other environmental consequences may result. The larger ships with propellers near the bottom are seen to raise large amounts of silt (Figure 3.3-38). This material has a very large exchange capacity which can operate to sequester heavy metals from the water column. Ship stirring would, in effect, greatly increase the active exchange surface and hence the efficiency of the exchange process. That this effect might be beneficial to marine inhabitants of the upper water layers has already been suggested (References 5.0-7 and 5.0-12). For smaller ships with propellers near the surface, churning of the surface with the resultant emulsification of surface oil films can increase the toxicity of oil to marine life (Reference 5.0-14). An analysis of the heavy-metal burdens in the harbor sediments (see Section 4.1) suggests, however, that there may be some interaction between oil and bottom material (Table 4.1-3 and Figure 4.1-6). It is also noteworthy that singularities 1 and 2 in Figure 4.1-8, representing high sediment burdens in metals characteristic of shipyard activity, are from locations SE-04 and SE-05, chosen by the Data Base for the chronic appearance of oil slicks at those locations (Table II-1 of Reference 5.0-15). The singular pair, labeled 4, is from stations ES-06 and ES-08, again where there exists an increased probability of surface oil films resulting from ships or from runoff possibly bearing crankcase oils containing heavy metals. All four stations are in South Channel and Southeast Loch where maximum ship activity occurs. High sediment burdens could represent not only their addition to local waters, but also their efficient transfer to the sediments, a process possibly mediated by oil and by ship activity. A thorough investigation of these interesting possibilities is obviously beyond the scope of the PHBS effort.

In addition to mapping the principal regions of ship traffic in Pearl Harbor (Figures 3.4-4 through 3.4-8), the distribution of ships' berthing by tonnage was also mapped (Figure 3.4-1). The more stressed bio-stations are located in or near areas showing high ship density. In view of the discussion immediately above, general environmental health and the density of ships cannot be considered a simple inverse relationship. More complex interactions, both positive and negative, seem certainly to be involved. Increased vertical mixing due to ships would certainly be expected to improve dissolved oxygen levels in the bottom waters. Metals, especially from antifouling coatings, are entering the water column from the ships' hulls. Ship movements, possibly interacting with surface oil and bottom material, may operate to reduce the biological availability of those metals to organisms dwelling in the upper portion of the water column. As suggested previously (Reference 5.0-12), ship-oil interactions may somehow result in the greater water clarity observed in areas of Navy activity. Surface oil may also interfere with oxygen transport across the air-sea interface (Reference 5.0-16) and may influence net radiation balance and heat budgets locally (Reference 5.0-17). Lastly, ships are known to introduce new species into the biotic community of the harbor (see Section 3.4). The environmental importance of such introductions is at least equivocal.

SEDIMENT AND WATER QUALITY SURVEY

Both the sediment survey and the water quality survey were performed by the NCEL Data Base survey team. The results were factor analyzed by the PHBS team with especial emphasis on possible responses among the marine biota. In general, the more environmentally stressed bio-stations (BE-03, BE-04, BC-10 and BE-17) were among those stations having significant elevated metallic burdens in the sediments (Table 3.1-2). The benthic infauna in general and the micromollusca in particular showed moderate negative correlation with all metals in the sediments except manganese. The strongest negative correlations were shown for copper and mercury (mean coefficients were -0.57 and -0.59, respectively). Of the 35 water quality variables surveyed, only a few showed any correlation whatsoever with the biological community. As reported before (Reference 5.0-1), dissolved oxygen showed high positive correlation with the fish population (+0.50 to +0.80) and little to no correlation with the piling biota. The piling biota, however, showed very high positive correlations (+0.90 to +0.99) with Kjeldahl nitrogen and ammonia nitrogen in the bottom waters.

The heavy-metal content of drainage basin soils, stream-bed sediments and harbor bottom sediments is summarized in Section 3.1. Metal concentrations in the soils of the Pearl Harbor drainage basin were about the same as world averages for five metals (Cr, Fe, Ni, Pb and Zn; cf. Tables 3.1-3 and 4.1-4). For the stream-bed and harbor sediments, the metallic content for only two of these metals (Cr and Fe) remained about the same as the world average; the other three metals were higher. The additional metals for which an analysis was performed (Ag, Cd, Cu, Hg and Mn) averaged higher than world average in all three sets of samples. The heavy-metal data were very "noisy", making positive conclusions difficult. Generally elevated sedimentary content for the metals Ag, Cd, Cu, Hg, Pb and Zn are evident in Southeast Loch and South Channel, also to a lesser extent, near the Whiskey Docks in West Loch. High Cu and Zn concentrations seem to be associated with the Navy thermal outfall into the Main Channel, and the high Ni concentrations in central Middle Loch sediments may be associated with the Pearl City STP diffusers. It is noteworthy that the metallic concentrations in the sediments decrease as the entrance to Pearl Harbor is approached, although many show increases in areas of shipyard or industrial operations. It is particularly interesting that three harbors used by the Navy show very similar sedimentary burdens in three metals (Cu, Pb and Zn; Table 3.1-4).

From the standpoint of cost savings in the analysis of harbor sediments, it should be noted that many of the metals found in the Pearl Harbor sediments correlate well with one another. The highest is Cu with Hg (+0.84); other important correlations in decreasing order are: Cu/Pb +0.76, Pb/Hg +0.74, Cu/Zn +0.71, Hg/Zn +0.68, Cd/Fe +0.62, Cd/Zn +0.61 and Cr/Ni +0.58. This correlation indicates that, for Pearl Harbor at least, only a few of the more easily analyzed metals need be monitored and the rest can be inferred with reasonable certainty. The fact that three harbors used by the Navy (Table 3.1-4) have similar metallic burdens suggests that the same savings in heavy-metal monitoring may be realized in harbors other than Pearl. Furthermore, limited analysis of sedimentary cores could give a good indication of heavy-metal exposures in the past. These measures could be correlated with the degree of Navy utilization of that particular harbor to obtain a better estimate of heavy-metal exposures truly associated with Navy operations. As shown by Professor Turekian (Reference 5.0-18), harbors and estuaries tend to act as natural traps for heavy metals transported seaward by runoff from the land. This metal-trapping ability of estuaries may actually magnify the influence of all metallic inputs into the system, Navy and non-Navy.

Factor analysis of the heavy-metal data yields two factors which explain 65% of the total variance. Metals loading heavily on Factor I are Cu, Hg, Zn, Pb and Cd in that order. Those loading on Factor II are, again in order of decreasing loading, Cr, Fe, Ni and Mn, with Mn loading only moderately. An analysis of a scatter plot of factor scores (Figures 4.1-7 and 4.1-8) shows conclusively that Factor I is associated with shipyard activities and Factor II is associated with terrestrial runoff. These associations were not particularly apparent in the maps of stations with high metal content provided by the Data Base (Reference 5.0-19). With the exception of BW-13, all bio-stations judged to be stressed on the basis of their biological condition (see Section 4.7) score positively on Factor I; the better bio-stations score negatively on this same factor. The best bio-stations score negatively on both factors. Tabulations of factor-score distance from the "best" station (BC-11) show high positive correlations with various biological parameters (Table 4.1-3). Furthermore, these same distances exhibit high correlation (+0.79) with estimated oil exposure at a given bio-station and even higher correlation (+0.83) with a combination of estimated silt and oil exposures. These facts were the basis of the special studies of ship movements and the importance of ships' stirring as an oceanographic parameter reported earlier. The singularities appearing in the scatter diagram (Figure 4.1-3) were also discussed earlier, but the frequent appearance of these stations (ES-06, ES-08, SE-04 and SE-05) in the first ten stations ranked by specific metal in decreasing order of metallic burden should again be noted (Table 3.1-2). Unfortunately, the Data Base report on water quality (Reference 5.0-15) gives phenols and oil-&-grease measurements for only two of these stations (SE-04 and SE-05); these are: SE-04 phenols 9.4 ppb, oil-&-grease 1.5 ppm; for SE-05 phenols 5.6 ppb, oil-&-grease 0.4 ppm. Perhaps a better representation of oil exposures in South Channel and Southeast Loch is seen in the means for this region, which are (including entering source waters) 29.7 ppb (n = 82) for phenols and 8.4 ppm (n = 28) for oil-&-grease.

In addition to detecting clearly a shipyard and a terrestrial "signature" in the metallic content of the sediments, a histogram of score frequency on Factors I and II (Figure 4.1-4) is useful. Score frequencies on Factor I, the shipyard signature, are tightly clustered about a mode 0.6 standard deviation units below the mean. No scores fall more than 0.3 standard deviation units below this mode; however, a positive "tail" of high scores stretches over 5 units to the right. By contrast, score frequencies on Factor II, the terrestrial signature, exhibit a weaker mode about 0.4 standard deviations units below the mean together with a more symmetrical distribution about that mode. The presence of the long positive tail in the Factor I distribution probably reflects the fact that metals loading on this factor are "ecologically strange" metals which are added randomly by the industrial processes to an environment which normally contains only trace amounts. Metals loading on Factor II are normally found in the environment; thus any random additions tend to be masked by natural variations. The tight cluster about the mode in Factor I may also reflect the relatively uniformly insulted condition of Pearl Harbor as a whole.

These histograms may be used in a second way to display exactly what the status of Pearl Harbor is relative to acceptable metallic levels in sediments established by the Environmental Protection Agency. As indicated in Section 4.0, EPA levels may be converted to compatible scores (Table 4.1-5). These compatible scores may then be compared with the factor-score histograms, bearing in mind that all scores are standardized; thus an average Pearl Harbor station scores zero. Such a comparison shows that the average Pearl Harbor station is well below EPA guideline levels for Cd, at guideline levels for Cr, and above guideline levels for the metals Cu, Pb, Hg, Ni and Zn by about half a standard deviation unit.

Very few of the approximately 35 water quality parameters monitored by the Data Base bore any correlation with biological condition in Pearl Harbor. To this extent, this expensive series of measurements were useless. Conditions in the water column are transient and fluctuate greatly with tides, wind conditions and time of day. Thus, time-series analysis of the data is required; however, the Data Base sampling schedule was such as to preclude any such analysis. For the metals Cr, Cu, Fe, Mn, Pb and Zn, concentrations in bottom waters* correlated fairly well with sediment burdens of these same metals. However, for the reasons just stated, the water data were even more "noisy" than the sediment data. Cu and Zn were more frequently detected in bottom waters than in surface waters, while Fe and Mn appeared more uniformly distributed throughout the water column. Cr was detected mainly in surface waters. These same tendencies were seen at the bio-stations (Table 3.2-4), but the coverage was so limited that no positive statements can be made on the basis of metallic content of the water. Only the weak double inference can be made that bio-stations correlate with heavy metals in the sediments and that the metallic content of bottom waters also correlates fairly well with that in the sediment.

The few good positive correlations between biotic communities and water quality parameters have already been mentioned, viz., fish populations with high dissolved oxygen and piling biota with Kjeldahl nitrogen and ammonia nitrogen in bottom waters. Three different factor analyses were performed, viz., an analysis of variable means, of minimax and of functional extremes. Fifteen variables were selected from the 35 reported by the Data Base as being most likely to show biological response and as having been sampled sufficiently often to merit analysis. The variables selected were: temperature, salinity, pH, dissolved oxygen, Secchi disc, turbidity, nutrients (including total phosphorus, total nitrogen, nitrate, nitrite and ammonia), coliform bacteria and three trace metals (Fe, Mn and Zn). Factor analysis of the means yielded five factors explaining 70% of the total variance, but neither factor score maps nor dendrographs could be reliably interpreted beyond

---

* Bottom samples were collected one foot above the bottom or at 40-foot depth in deeper water.

the fact that water quality in Pearl Harbor was quite uniform (Figures 4.2-3 and 4.2-5). The factors summarized a large data matrix effectively (70% total variance explained), but perhaps "conglomerate noise" precluded any further interpretation. A hypothetical "best" station was constructed using the factor loadings of the five stations having the most negative scores on each of the five factors. Water parameters of this "best" station very closely resembled slightly turbid open ocean waters near Hawaii (cf. Tables 4.2-1 and 4.2-3), showing that all necessary data were represented by the factors. The hypothetical station was constructed to determine its factor-score distance to the other stations, the treatment that proved so illuminating for the sediment data. A map of such factor-score distances (Figure 4.2-4) shows large distances for stations in South Channel and Southeast Loch and for stations near the Pearl City STP diffusers; however, other stations near BC-09 and BW-13 (judged to be among the better bio-stations in Section 4.7) are also shown to be distant. The map thus detects large deviations from open ocean water quality but not specifically waters associated with a stressed marine environment.

Factor analysis of water quality minimax values yielded five factors explaining 59% of the total variance, but again the factors cannot be reliably interpreted. Cutoff criteria required the minimums for seven variables to be excluded. Of the eight variables for which both minima and maxima were analyzed, only one, Secchi disc, shows both extremes loading on the same factor. If a given variable were to vary over its entire range in response to one major process or a few closely related processes, such loading of both extremes on one factor would be expected. The Secchi disc loadings, therefore, simply reflect the fact that readings are simply controlled by the presence or absence of suspended silt in the water column. The loadings of the seven other variables suggest that their extremes are controlled by different processes or that if both extremes are controlled by the same process, the process-to-variable function is markedly nonlinear.

Factor analysis of functional extremes yielded seven factors explaining 81% of the total variance, again effective summarization of the original data matrix, but with factors which are difficult to interpret. Factor-score distances for a second hypothetical station again created from the loadings of lowest-scoring stations do not assist in factor interpretation. However, when a histogram of factor-score distance is made (Figure 4.2-8), the bio-stations are shown to exhibit a skewed distribution containing many large distances from the hypothetical best station. This distribution results from the fact that many of the bio-stations are located near shorelines, while the majority of the nonbiological stations are located in mid-channel. The histogram thus shows that the functional extremes in water quality originate primarily from the shore and rapidly dissipate with distance into a general background level. This consistent pattern shown by the functional extremes seems plausible since wave action which can suspend particulates and since most source water additions to the harbor are located at or near the shore. It should be noted that water quality data can be "forced" toward compliance or noncompliance with regulations simply by obtaining water samples farther from or closer to the shore.

The water quality results are particularly disappointing. A few relatively minor relationships can be derived from this large and expensive collection of data. Only three of the 35 measured parameters correlate at all with the biological condition of Pearl Harbor. The water quality data taken are definitely of little utility in assuring the basic intent of the Federal Water Pollution Control Act of 1972 as amended by PL 93-207 (1973) and PL 93-243 (1974). This Act states as its goals and policy for research and research-related programs (Section 101 (a)) that: "The objective of this Act is to restore and maintain the ... biological integrity of the Nation's waters", and states later as an interim goal that: "... the protection and propagation of fish, shellfish, and wildlife ... be achieved by July 1, 1983." It would appear from this analysis that the Navy could realize considerable financial savings and, in addition, develop a more effective system of environmental monitoring more consistent with this Act by developing a program based on the biological findings of this survey. Physicochemical parameters should still be monitored, but the number and kind of such parameters should be determined on the basis of known biological response. These measures should be augmented and internally checked by means of a reliable system of bio-indicators.

CONCEPTS

In addition to the biological survey of Pearl Harbor and the subsequent analyses of the data, a number of important concepts have resulted from this work. Some of these concepts are new, so far as is known, and some are not, but are well illustrated by the analysis of the data. The concept of ships as an important oceanographic and perhaps environmental parameter in shallow harbors arose out of the biological survey and was investigated as part of that survey. Since this has already been discussed, it need only be mentioned here. Perhaps the most important concept arising out of this work is that of an environmental range—that is, a series of water bodies roughly similar in general oceanographic properties but differing in the degree to which they are influenced by human activities. Such a range, or better a system of "intercalibrated" ranges located in different oceanic provinces, is needed to develop and test a limited number of reliable bio-indicator systems. Pearl Harbor could and does constitute part of an Hawaiian environmental range as a water body heavily influenced by human activity, both Navy and non-Navy. This biological survey was hampered by the fact that the remaining parts of an Hawaiian environmental range had not yet been developed, with the result that the potential bio-indicator systems identified by the survey could not be tested. The use of fish data from Kaalualu Bay, presented earlier, is an excellent example of how testing would proceed on a completed range. Here, the Bay was used to test the ability of the analytical system developed by the PHBS team to separate patterns in fish populations if they truly existed. The test showed emphatically that the analytical system could indeed make such separations; in fact, the test also showed that other environmental variables, not detected by the field survey team, could be identified by the multivariate analysis and that correct constructs of the field conditions could be made by persons who had never visited the site in question.

The full concept of a system of "intercalibrated" environmental ranges has been developed in another report (Reference 5.0-20), but the PHBS experience in Pearl Harbor has made very real contributions to the development of that concept, especially in the matter of how marine ecosystems in various quite different oceanic provinces might be interrelated. From the inter-comparison of bio-stations within Pearl Harbor and from the comparison of Pearl Harbor biological data with other embayments and estuaries about the Hawaiian Islands, it has become apparent that the intercalibration of different ranges will have to be done through statistical analysis of the more stressed elements of those ranges rather than through an analysis of pristine or unstressed elements. This concept is the reverse of the biological concept of a control and is indicative of the real differences in emphasis between classical ecology and research directed toward the quantitative assessment of stress or environmental insult. The concept of comparing moderately to highly insulted environments as a means of establishing relationships between unmodified natural environments in widely different geographic locations is either new or, if known, is little discussed in the literature. But once stated, the concept is obvious. Initially, quite different natural communities become increasingly similar as environmental stress is increased, since stress favors the more resistant organisms which persist and increase in numbers as habitat vacated by the less tolerant organisms becomes available. This statement is certainly true if the stresses applied to dissimilar environments are the same and may also be true if somewhat different stresses are applied. It may be visualized as an extension of the notion that high diversity implies low stress. A corollary of this concept would state that an unstressed environment is more likely to have greater similarity in biological composition to any stressed environment than to any unstressed and unrelated environment. The combination of the range concept with that of the increased probability of similarity among stressed environments results in a third concept, that of the recovery hyperspace. As environmental stresses are removed through some pollution abatement program, the relieved biological population can respond in a number of significantly different ways depending on a complex association of rate and kind of stress relief, recruitment potential in the area, composition of the relict population prior to abatement, and many other factors. Assuming eventual complete pollution abatement is possible, a number of significantly different but environmentally healthy natural communities are possible, some of which may be far more desirable from a human standpoint than others. With carefully considered environmental ranges, various stages in the hypothetical recovery process may be duplicated and, through appropriate tests, effective management strategems can be developed to direct environmental recovery to a specific natural condition considered optimum. Experience from the Pearl Harbor survey, then, has resulted in the development of a theory of environmental management and, also, a practical means of testing and developing that theory.

Factor analysis has been suggested as a good objective method of selecting potential bio-indicator species (see earlier discussion and Table 5.0-2). Once selected, a system of environmental ranges, just described, is needed to test potential bio-indicators under different conditions so that they can be perfected for wide Navy application in geographically distant and biologically dissimilar marine environments. Further selection and perfection of bio-indicator systems introduce two related concepts, viz., the lesser factor and adaptive noise. Both concepts were mentioned but not developed in the summary discussion of the fish data. For highly mobile forms, such as fish, it is suggested that the first factor or first few factors in multivariate analysis detect major trends in behavior such as availability of habitat or food, not responses to a gradient in environmental quality. Second-order or third-order trends might, however, be seen in factors extracted after major variants have been accommodated, hence the lesser-factor concept. The interesting gradient, already mentioned, in the scatter plot of the fish scores on Factors I and II (Figure 4.3-2) well illustrates what might be expected. Factor I has indicated an overriding habitat "force", possibly associated with hard substrata at BC-11. The lesser factor, Factor II, could be reflecting fish tendency to maximize the habitat/food space within an acceptable range of integrated or steady-state environmental insult. Unfortunately, the lack of coherence in the fish data, probably also a result of fish motility, does not permit the acceptance of Figure 4.3-2 as a proven example of the lesser factor concept. The concept itself, however, remains valid. The fact that fish can and do outrun short-term environmental insults enhances their use as bio-indicators since they are less likely to develop "adaptive noise". This concept relates directly to the earlier discussion of environmental ranges and the recovery hyperspace. Sessile forms or forms with low motility must respond to an increasingly polluted environment by adapting to the new conditions. Their distribution patterns are confounded by this adaptation as indicators of environmental condition; in short, they have developed "adaptive noise". Consequently, sessile forms may be less desirable as bio-indicators than mobile forms, which are more difficult to sample properly because of their very mobility. Any balanced investigation of bio-indicators should, therefore, include sufficient evaluation of both mobile and nonmobile forms so that objective tradeoffs can be made between potential bio-indicator systems.

The concepts of conglomerate noise and coherence have already been fully discussed. They are important not only in the design of meaningful environmental surveys and subsequent analysis, but also in the design and utilization of an environmental range system. The similarity, or coherence, between sedimentary burdens in specific heavy metals in San Diego Bay, Pearl Harbor and Apra Harbor, Guam, suggests the real possibility that geographically separated environmental ranges can be meaningfully linked. The combination of factor and cluster analysis has been shown to be a powerful yet objective method of handling the complexities of environmental data, both biological and nonbiological. Its ability to handle environmental data taken by others has been demonstrated, an important feature for any widespread environmental monitoring system. Furthermore, the analytical procedure can indicate inadequacies in data collection, as it did for the piling analysis.

Finally, the important concept that a trained field biologist can record real trends in environmental condition has been developed and partially proven during this survey. This is an important capability to the Navy since reliable environmental data are often required on short-term notice. The field biologists' ability to record and interpret point stress, and to see gradients in stress about those points, can be greatly enhanced with the development of bio-indicator systems on environmental ranges. The ranges can also be used as training grounds for Navy personnel wishing to acquire field survey capability, and as a means of cross-checking environmental ratings determined by different field teams. Use of nonbiological techniques should, of course, be included wherever practical in any environmental monitoring system; however, it should be remembered that the biota of Middle Loch served as a warning of severely stressed conditions which were neither suspected nor detected by teams using solely physicochemical methods (see Appendix G).

CONCLUSIONS AND RECOMMENDATIONS

In addition to performing the basic task of inventorying the biological communities resident in Pearl Harbor, the PHBS has demonstrated the need for biological survey as a necessary adjunct to any environmental study. Generalized physicochemical surveys alone cannot correctly describe marine living conditions in the true spirit of the Federal Water Pollution Control Act of 1972, as was demonstrated by an analysis of water quality data. However, a series of four different biological analyses was able to detect internally consistent biological patterns even though Pearl Harbor as a whole is fairly uniformly stressed by a complex of environmental insults. The distribution of heavy-metal burdens in harbor sediments produced results which correlated well with the biological patterns, but most of the water quality parameters examined did not. Future environmental surveys or continued monitoring efforts can be performed at considerable savings to the Navy by reducing the kinds of water quality parameters measured and by coordinating both water and sediment measurements more closely with biological surveys based on a system of bio-indicators. Such an approach would not only cost less, it would also better respond to the true intent of the Federal Water Pollution Control Act. There are increasing signs that the Environmental Protection Agency is moving away from the simple gathering of unanalyzed physicochemical data toward a full interpretation of biological condition and response as stated in that Act.

A powerful combination of factor and cluster analysis was developed by the PHBS team for the treatment of Pearl Harbor data. The system was shown to be capable of detecting real patterns in environmental data which is typically "noisy" and voluminous. Such capability was demonstrated not only for data collected by the PHBS team but also for data collected by others in areas never seen by PHBS personnel. This feature is important if the analytical procedures are to be used by the Navy to process environmental data from many geographically separated regions. Factor analysis was also used to identify potential bio-indicator species, objectively reducing 343 candidate species to 75 or less (approximately 80% reduction). These species were tested to the fullest extent possible in the uniformly stressed environment of Pearl Harbor. Although certain species show promise, further testing is necessary. To be used as bio-indicator systems, various combinations of these and possibly other species must be developed to full potential by testing on an environmental range. The new and valuable concept of environmental ranges grew directly out of the Pearl Harbor survey experience. A precise program for their development (Reference 5.0-20) has been written and promulgated.

A quantitative analysis of field survey reports has shown that trained field biologists can "read" environmental condition from short-term observations of the resident marine community. Demonstration of this capability is of particular importance to the Navy because of its frequent requirement for short-term, low-cost environmental surveys. The accuracy and sensitivity of these field procedures can be improved through continued testing and development on environmental ranges, which can additionally be used as training facilities for Navy personnel.

Four different biological analyses have shown consistently that the less environmentally stressed communities in Pearl Harbor are located in the Main Channel and on the shores of Ford Island. The most stressed locations surveyed were found in Middle Loch, on the shipyard side of South Channel and in Southeast Loch. Although Navy activities are probably responsible for many of the stressed areas, there are other important environmental stresses of definitely non-Navy origin. Furthermore, a detail study of harbor circulation has shown that the activity of Navy ships is an important oceanographic factor which appears to have some environmentally beneficial effects. This discovery plus the demonstration that wind-generated currents are a prominent feature of harbor circulation are essential to any complete understanding of Pearl Harbor. An investigation of the full role of ship activity in modifying the harbor environment is obviously beyond the scope of the biological survey; however, the discovery of the importance of ships to harbor circulation has generated sufficient interest to assure continued investigation.

A number of recommendations can be made on the basis of this study. First, at least one, and preferably two, full environmental ranges should be established for the continued testing and development of the bio-indicator systems identified. Second, data on the metallic burdens of sediments from a number of Navy harbors should be collected and analyzed using the techniques described in this report. Data on only certain heavy metals (Cr, Cu, Pb and Zn) are needed, but good spatial coverage in regions where the Navy is and is not active is required. Sediment cores should also be taken, but their number should be limited to only those regions showing significantly different metallic burdens in the surface layer. Third, the sediment survey should be accompanied by micromolluscan analyses of both surface samples and cores; however, generalized surveys of bottom infauna or epifauna should not be performed. Fourth, water column measurements should be greatly reduced over those performed in Pearl Harbor. Water quality parameters measured should include only those showing useful correlations with the marine biological community, such as dissolved oxygen, Kjeldahl nitrogen and perhaps phytopigments, although the utility of this last measure is not demonstrated in this report. A careful experimental design to evaluate the significance of various water parameters in a particular situation must, however, be developed before any water sampling program is undertaken. Diel measures of important parameters at several depths are required. Heavy metals in the water column should in most cases not be measured. Fifth, fish population structure should continue to be investigated as a potential bio-indicator system. Inventories of resident species should be made in harbors where they are not known; however, collection of fish data for statistical analysis should be limited to standardized procedures, such as the permanent emplacement of standard habitats. Fish should be monitored for gill and skin condition, and for heavy-metal burdens in both liver and flesh. The same metals as those specified above for sediments should be used. Sixth, piling or fouling communities should continue to be developed as a potential bio-indicator system. Again, only those species identified by factor analysis in this report should be followed in detail, not the entire community. Standardized fish habitats might also be used as standard substrates for this effort. Seventh, additional environmental monitoring and data handling procedures, both biological and physicochemical, should be sought in order to develop the Navy's environmental protection capability to the full extent intended in the Federal Water Pollution Control Act of 1972.

REFERENCES

5.0-1. Thomas J. Peeling, J. Geoffrey Grovhoug and Evan C. Evans III (1972), "Pearl Harbor Biological Survey - Summary Report for First Survey Cycle", NUC TN-801, LIMDIST.

5.0-2. Frederic H. Nichols (1973), "A Review of Benthic Faunal Surveys in San Francisco Bay", U.S. Geological Survey Circular 677.

5.0-3. John C. McCain and James M. Peck, Jr. (1972), "The Marine Environmental Impact of the Honolulu Power Plant - A Summary of the 1972 Investigations", Environmental Department, Hawaiian Electric Company Report, LIMDIST.

5.0-4. Stephen V. Smith (1971), "Factor Analysis: A Tool for Environmental Studies", Marine Technology Society Journal 5:6, 15-19.

5.0-5. Stephen V. Smith, Keith E. Chave and Dennis T. O. Kam (1973), "Atlas of Kaneohe Bay: A Reef Ecosystem under Stress", University of Hawaii SEAGRANT TR-72-01

5.0-6. Dennis M. Devaney and Arthur Whistler (1972), "Preliminary Biological Survey of Kaalualu, Hawaii", U.S. Army Corps of Engineers, contract no. DACW84-72-C0013, LIMDIST.

5.0-7. E. C. Evans III, J. G. Grovhoug and T. J. Peeling (197-), "Site Survey, Inner Apra Harbor, Guam", NUC letter report in preparation, LIMDIST.

5.0-8. Roger D. Spencer (1972), "Algal Pollution and Marine Fouling in Port Phillip Bay", PhD Thesis, University of Melbourne, Australia.

5.0-9. A. H. Banner and J. H. Bailey (1970), "The Effects of Urban Pollution upon a Coral Reef System - A Preliminary Report", Hawaiian Institute of Marine Biology Technical Report No. 25.

5.0-10. F. Raymond Fosberg (1972), personal communication.

5.0-11. E. Alison Kay and Marilyn F. Switzer (1973), "Molluscan Distribution Patterns at Fanning Island", pp 111-134 in K. E. Chave and E. Alison Kay, "Fanning Island Expedition, July and August, 1972", Hawaii Institute of Geophysics Report HIG-73-13.

5.0-12. Evan C. Evans III, A. Earl Murchison, Thomas J. Peeling and Q. Dick Stephen-Hassard (1972), "A Proximate Biological Survey of Pearl Harbor", NUC TP-290.

5.0-13. G. T. Hirashima (1971), "Availability of Streamflow for Recharge of the Basal Aquifer in the Pearl Harbor Area, Hawaii", U.S. Geological Survey Water-Supply Paper 1999-B.

5.0-14. Clarence M. Tarzwell (1970), "Toxicity of Oil and Oil Dispersant Mixtures to Aquatic Life", Proceedings, Seminar on Water Pollution by Oil, Aviemore, Scotland, pp 263-272.

5.0-15. D. E. Morris, S. W. Surface and J. P. Murray (1973), "Completion Report for the Pearl Harbor, Hawaii Study Covering the Test Period Through Calendar Year 1972", NCEL Report EPDB 73-005, LIMDIST.

5.0-16. W. D. Garrett (1972), "Impact of Petroleum Spills on the Chemical and Physical Properties of the Air/Sea Interface", NRL Report No. 7372.

5.0-17. J. C. Aukland and D. T. Trexler (1970), "Oil Pollution Detection and Discrimination by Remote Sensing Techniques", U.S. Coast Guard Project No. 714104/A/006, Final Report.

5.0-18. Karl K. Turekian (1971), "Rivers, Tributaries, and Estuaries", pp 9-73 in Donald Hood (ed.) Impingement of Man on the Oceans, Wiley-Interscience.

5.0-19. Alv Dan Youngberg (1973), "A Study of Sediments and Soil Samples from Pearl Harbor Area", NCEL Report EPDB 72-062, LIMDIST.

5.0-20. Evan C. Evans III (1974), "Marine Environmental Biology Program - Five Year Plan", NUC Program Proposal, LIMDIST.

GLOSSARY

GLOSSARY

abiotic - not living; not involving living processes

abscissa - the horizontal scale or coordinate in a Cartesian coordinate system (see ordinate)

archaeogastropod - a primative order of gastropods in which reduction of the right gill, auricle and kidney has not taken place; largely marine with a few fresh water species

adaptive noise - random variation in environmental survey data caused by differences in degree and kind of bio-indicator adaptation to polluted conditions; such variation can cause problems in analyses designed to determine general environmental condition (a coinage of this report, see page 5.0-7 for further discussion)

Aku boat - a commercial fishing boat largely engaged in the taking of tuna (Aku) subsequent to purse seining for baitfish (Nehu) in Pearl Harbor

algae - a group of lower photosynthetic plants varying greatly in color and habitat; may live in a variety of environments and range in size from microscopic, planktonic species to macroscopic, obvious forms

amphipod - a relatively small, shrimp-like crustacean of the order Amphipoda which includes the beach flea; usually marine organisms which lack shells and are prominent members of the plankton

anticyclonic - in the Northern hemisphere, moving in a clockwise direction; said of spiral circulation in fluids (see cyclonic)

arbolete gun - a type of speargun in which a metal shaft is propelled forward by rubber tubing; usually fired by a pistol-grip triggering mechanism

assemblage - here, a naturally occurring association of living forms or, in micromollusca, a collection of shells from such an association

baseline study - current parlance for any generalized collection of environmental information, usually without any experimental or analytical design

beach seine - a sampling net with float line and lead line, usually with a pocket of smaller mesh; fished laterally from a gently sloping shore in a U-shaped drag pattern

benthic - (also called benthonic) referring to that portion of the marine environment inhabited by organisms which live permanently on or in the bottom environment

benthos - bottom dwelling forms of marine life binary - any system of numbering or decision making involving a choice between two possibilities. Commonly denoted by 1 or 0; + or -, "yes" or "no", etc.

biocide - an agent (usually chemical) which kills living organisms

biological oxygen demand (or biochemical oxygen demand) - (BOD) a measure of the relative uptake of oxygen by wastewaters, effluents, or sediments under standardized laboratory conditions. The biological oxygen demand is commonly expressed in mg O_2 uptake per liter of water or gram of sediment over a five day period (for further discussion, see Standard Methods, 13th ed., pp 495ff)

biologically sterile - in this report, a term applied to statistical procedures which may be analytically valid but which do not yield intuitively satisfying results (coinage by Dr. Thomas A. Ebert, see page 4.5-17 for further discussion)

biomass - the mass of living material; frequently expressed on a per unit area or volume basis for a given environment

bio-station - in this report, a station delineated for the collection of biological samples

biota - the animal (faunal) and plant (floral) forms of a given region

biotope - an area in which the main environmental conditions together with the flora and fauna adapted to these conditions are uniform

bipolar factors - in factor analysis, any factor loading which has variables with both high positive and high negative correlation coefficients

BMD - a degenerate acronym probably once standing for Bio-Med Division; however, only the letters, not the term, are currently used

BOD - biological oxygen demand (q.v.)

botryoidal - grape-like

bryozoan - member of a small invertebrate phylum (Bryozoa); these sedentary "moss animals" are usually colonial, either branching or encrusting in form; the individual bryozoan has a tube-like body wall that surrounds its internal organs; noticeable fouling organism

carangid - any fish species belonging to the family Carangidae; a primarily tropical group which includes jacks and pilotfish; in Hawaii juveniles called "Papio", adults called "Ulua" carnivore - eating or living off the flesh of another animal

catch-per-unit-effort - in this report, a measurement in weight/time (usually lbs/hr. used in evaluating efficiency of various fish sampling methods)

cation exchange capacity - a measure of the number of negatively charged exchange sites on a surface (usually of a clay or mineral) where cations (or positively charged ions) can be held by ionic bonding; usually measured in milliequivalents per 100 grams (dry weight) of the material (for further discussion, see Lyon et al., Nature and Properties of Soils, 5th ed., pp 97ff)

caudal peduncle - the narrow portion of a fish's body just anterior (toward the head) from the tail fin

cheliped - in certain crustaceans, one of the pair of legs which carry the animal's pincers or claws (chela)

chemical oxygen demand - (COD) a routine laboratory procedure for determining the oxygen equivalent of that portion of the organic matter in a sample of wastewaters or sediments which is susceptible to oxidation by a strong chemical oxidant; usually expressed in mg. O_2 per liter of sample (for further discussion, see Standard Methods, XIII Ed., pp 495ff)

chronic insults - more or less continuous pollution exposure; frequently used to describe low-level pollution which often goes unnoticed

churning - in this report, the vigorous agitation of the sea surface by ships' propellers or other agents which cause the mixing or emulsification of oil or surfactant fluids

cluster - a group or association of either samples or variables in this report; often said of a group of points in factor-score spaces

cluster analysis - an ordination procedure (or routine searching technique) for finding and displaying clusters

COD - chemical oxygen demand (q.v.)

coefficient of determination - an expression in percent of the correspondence between two variables; in this report, often between a factor and an associated variable, in which case it is the squared factor loading times 100 (for further discussion, see page 4.0-4)

coelomic cavity - the abdominal cavity which contains major organs in higher animals; formed by any embryonic introverted pouch

coherence - the degree to which environmental patterns can be recognized from one multivariate analysis to another (a coinage of this report, for further discussion, see page 5.0-3) colonial organisms - organisms which are not solitary, i.e., many individuals live in a continuous structure such as Bryozoans, Corals, some Ascidians

communality - the percent of total variability in a given variable that is explained by a group of factors; it is the summed coefficients of variation (q.v.) between those factors and the given variable (see page 4.0-4 for further discussion)

conglomerate noise - uninterpretable variation caused by the analysis of a body of environmental data which is large and varied in composition (a coinage of this report, see page 5.0-5 for further discussion)

Coriolis force - an apparent force on moving particles resulting from the earth's rotation; it causes the moving particles to be deflected to the right in the Northern hemisphere, to the left in the Southern hemisphere; the force is proportional to the speed and latitude of the moving particle and cannot change the speed of the particle

correlation coefficient - the degree to which two variables vary in proportion to one another. The squared correlation coefficient times 100 equals the coefficient of determination

CPUE - catch-per-unit-effort (q.v.)

cryptic insults - pollution exposure which is not recognized as such; often a second-or third-order effect or a low-level chronic insult

cryptic species - an organism which is secretive in its habits, small or so colored as to make it difficult to observe

cyclonic - in the Northern hemisphere, moving in a counter-clockwise direction; said of spiral circulation in fluids (see anticyclonic)

death assemblage - in this report, an assemblage (q.v.) of remains (such as shells or bones) from a naturally occurring association of living forms

dendrogram - a type of graphical display resembling the limbs of a tree, used to present the results of cluster analysis; in this display only the ordinate has mathematical significance: the height of a limb indicates the degree of "clusteredness" of members arising from that limb (for further discussion, see page 4.5-5ff)

dendrograph - a type of graphical display superficially resembling and used for the same purposes as the dendrogram; in this display the abscissa also has mathematical significance: the distance between two immediately adjacent limbs indicates the mean separation between the entity being joined to the cluster and all members of the cluster joined (for further discussion see page 4.0-6) density stratification - the vertical separation of water masses resulting from differences in their densities (mass/volume)-see halocline, pycnocline and thermocline

detritus - particles produced by breakdown of animal and plant bodies, or by erosion of rocks and soil

detrivore - eating or living on detritus

diel cycle - a cycle involving a 24-hour period, usually a day and the adjoining night

dinoflagellate - a member of the class Dinophyceae; single-celled minute organisms which are often responsible for "red tide" phenomena; some species are toxic and may cause mass mortality to marine life

distance analysis - in this report, any analytical technique by which the relative separation between two cases in an n-dimensional Cartesian coordinate system is evaluated (for further discussion, see page 4.0-5ff)

dorsal - referring to the back or upper surface of an animal

ecosystem - a functional ecological unit composed of a complex of living organisms and the nonliving environment with which they interact; generally four components are recognized: abiotic elements, producers, consumers and decomposers

ectoparasite - a parasite that lives on the exterior of its host

eigenvalue - in factor analysis, a scalar value which indicates the degree to which an entire variable matrix loads on a given factor (for a more rigorous discussion, see Reference 4.0-4 pp 72ff)

environmental preference rating - in this report, a numerical expression of the degree of environmental pollution a given organism will normally tolerate (see page 2.1-38ff for further discussion)

EPA - Environmental Protection Agency

EPDB - Environmental Protection Data Base; an abbreviation for Navy Environmental Protection Data Base, a Navy-wide data base managed and operated by the Naval Civil Engineering Laboratory

epifauna - animals living on various surfaces; for instance, on the surface of, rather than in, the bottom sediments (see Figure 2.2-1)

EPR - environmental preference rating (q.v.)

estuarine circulation - the type of circulation that results from the influx of fresh water into a semi-enclosed body of salt water; four patterns are usually recognized depending on the degree of tidal or fresh water dominance and on the degree of mixing; circulation is two-layered with brackish water flowing seaward on the surface and tidally driven salt water moving landward on the bottom

estuary - an area where a river, stream (or system of streams) meet the ocean (e.g., Pearl Harbor); it is characterized by water whose salt content is between that of fresh water and marine environments and by a distinct population of animals and plants

eutrophication - a general process in aquatic ecosystems characterized by an accumulation of organic matter resulting from an excess of plant growth above and beyond that which can be consumed by the resident animal populations. Eutrophication is a natural process in many bodies of water (e.g., certain lakes) but may be artificially stimulated by human activities such as the discharge of sewage or thermal effluents

factor analysis - one of a class of multivariate techniques for reducing an original data matrix to a smaller matrix of variables (factors) which contain the original data; in this report, principal components analysis with orthogonal (varimax) rotation is used (see page 4.0-1ff for further discussion)

factor loading - the correlation coefficient between a given factor and a given variable (see page 4.0-4 for further discussion)

factor score - the relative success with which a factor represents the original data at a given location or station (see page 4.0-4 for further discussion)

factor-score space - a Cartesian space whose dimensions are equivalent to the number of factors being considered in which factor scores can be assigned specific coordinate locations

faunal assemblage - an assemblage (q.v.) of animals

filter feeder - an animal that obtains food by straining organisms from water passed through one portion of its body

fork length - a length measurement for fish with bilobed tail fins; measured from the most anterior point on the lower jaw to the deepest notched area on the caudal fin

fouling organism - a plant or animal that attaches to the surface of submerged, manmade or introduced objects such as ship hulls, piers, pilings, etc.

functional mean current - in this report, a current vector in the model of Pearl Harbor circulation which remains after currents associated with all driving mechanisms were removed (see page 3.3-18ff for further discussion, see also Figure 3.3-11)

gastropod component - that part of micromolluscan assemblages made up of gastropods

Gaussian distribution - a theoretical frequency distribution used in statistics that is bell-shaped, symmetrical and of infinite extent

halocline - a well-defined vertical gradient of salinity which is usually positive

Hawaii Coastal Zone Data Bank - a data bank and computer address system operated by the University of Hawaii; the system is designed to accommodate all marine life forms occurring in the Hawaii Archipelago and at selected localities within the Pacific Basin

Hawaii Institute of Marine Biology - a research institute of the University of Hawaii located on Coconut Island in Kaneohe Bay, Oahu

HCZDB - Hawaii Coastal Zone Data Bank (q.v.)

herbivore - eating or living on plants

HIMB - Hawaii Institute of Marine Biology (q.v.)

histogram - a graphical representation of frequency distribution by means of rectangles whose widths represent class intervals and whose heights represent the corresponding frequencies

holothurian - a member of the echinoderm class Holothuroidea (sea cucumbers)

identifiable visibility - the maximum distance at which fish can be positively identified during fish transecting (a coinage of this report)

illites - a complex hydrous aluminum silicate mineral which is high in potassium and in Hawaii is formed by weathering alteration of basalt in high-acidity/poor-drainage areas. Generally regarded as being intermediate between a clay mineral and mica

indicator organisms - organisms whose distribution, behavior, physiology, etc. is predictable for a specified environmental condition

infauna - bottom-dwelling organisms that live within the bottom substratum such as clams, gastropods, burrowing shrimp, etc. (see Figure 2.2-2) internal waves - a wave that occurs within a fluid whose density changes with depth, either abruptly at a sharp surface of discontinuity (interface) or gradually; wave heights, periods and lengths are usually large as compared to surface waves

isopods - crustaceans of the order Isopoda that are dorsal-ventrally flattened like pill bugs

Jackson Turbidity Unit - an arbitrary unit expressing the turbidity of fluids when measured by nephelometric methods; 40 Jackson units = the turbidity resulting from a 50 mg/ml suspension of formazin polymer (for further discussion, see Standard Methods, 13th ed., pp 349ff)

JTU - Jackson Turbidity Unit (q.v.)

kaolinite - a hydrous aluminum silicate clay mineral formed most commonly by weathering alteration of aluminum-bearing basalt minerals

loading - see factor loading

loch - in this report, an arm of the harbor which is constricted at its entrance

macroalgae - algal plants which are large enough to be seen and identified without magnification such as *Ulva*, *Caulerpa*, etc.

mean - (or average) of a variable is the sum of the values for that variable divided by the number of observations; symbol: $\bar{X}$

mean presence - the frequency of occurrence of a given species at a given location during a number of observations separated in time

megalops - a later larval form of certain decapod crustaceans

membrane filter count - the number of coliform colonies found using the membrane filter technique (for further discussion, see Standard Methods, 13th ed., pp 678ff)

MEMO - Marine Environmental Management Office, code 406 of the Naval Undersea Center

mesogastropod - an order of gastropod having only one gill, one auricle and one kidney; the largest order of gastropods including many common species

MFC - membrane filter count (q.v.)

microalgae - algal plants which are too small to be observed and identified without magnification such as Dinoflagellates, diatoms, etc.

micromollusc - mollusca whose shells measure 10 mm or less in greatest dimension; the group includes juveniles of species which will eventually attain dimensions greater than 10 mm and adults which mature at sizes as small as 0.5 mm in diameter

minimax - in this report, values which are extreme, i.e., minimum and maximum, providing the full range over a given set of data

mixed tide - a type of tide in which a diurnal wave produces large inequalities in heights and/or durations of successive high and/or low waters

mode - that measurement in a set of measurements having the greatest frequency

montmorillonite - a soft clay mineral that consists of a hydrous aluminum silicate containing iron and magnesium which has considerable capacity for exchanging part of the aluminum for magnesium, alkalies and other bases

motile - moving, or capable of motion

MS-222 - an anesthetizing compound used in tagging fish; ethyl-m-amino-benzoate methanosulfonate

multivariate analysis - any statistical analysis technique involving the comparison of more than two variables (for further discussion, see page 4.0-1ff)

NAVOCEANO - Naval Oceanographic Office

NCEL - Naval Civil Engineering Laboratory

neogastropod - an order of gastropods differing from mesogastropods (q.v.) in that members have a bipectinate osphradium, a concentrated nervous system and a shell usually with a siphonal canal; all are marine

net prone - having a tendency to be caught by gill nets

"noise" - in this report, a term used to describe random variation which cannot be interpreted in the data analysis

NORGID - numerical organism identification

NSRDC - Naval Ship Research and Development Center

NUC - Naval Undersea Center

observational noise - random variation in field survey data due to differences among observers, observational techniques or conditions under which observations are made (coinage of this report, see text for further discussion) omnivore - an animal that eats both other animals and plants

ONR - Office of Naval Research

ophiuroid - a member of the echinoderm class Ophiuroidea (brittle stars); these organisms have 5-8 elongate, slender arms radiating from a flat central disc

ordinate - the vertical scale or coordinate in a Cartesian coordinate system (see abscissa)

ordination techniques - formal methods by which entities are ordered or separated into categories

P/A - presence/absence; an analytical procedure in which only the presence or absence of an entity at a given location is considered (see binary)

pectoral girdle - a skeletal structure in fishes that provides support for the lateral, or pectoral, fins

pelagic - free swimming throughout the water column without depth preference; residing in open water

PHBS - Pearl Harbor Biological Survey

piling biota - the assemblage of organisms that tends to inhabit vertical wooden, concrete, metal or rock ledge substrata; almost entirely epifaunal

piscivore - eating or living on fish

plankton - drifting or slowly swimming animal or plant life that is a vital primary source of food for large organisms; usually microscopic organisms including eggs, larvae and adult forms; also includes jellyfish of all sizes

planktonivore - eating or living on plankton (q.v.)

population - statistically: that set of all similar entities from which a sample is drawn; ecologically: the total number of a given species resident or inhabiting a given area

porifera - a phylum which includes all sponges

protanderous hermaphrodite - a developmental condition present in some fishes whose male elements mature initially; then the organism undergoes a hermaphrodite transformation to a mature female status

purse seine - a large seine net set by two boats around a school of fish; when the school is enclosed, the bottom of the net is closed pycnocline - vertical density gradient in the water column

pyramidellid - a group in the gastropod order Tectibranchia having a shell covered by a mantle and one true gill; many are parasitic

pyrite - iron sulfite (FeS_2); a mineral having cubic crystal structure

recruitment - the addition of organisms to a statistical population either by movement (e.g., migration), growth, or other life history characteristics; implies replacement of individuals in a given population

residual velocity - in this report, turbulence or random errors in velocity determinations that could not be fit by the Pearl Harbor circulation model (for further discussion see page 3.3-30ff and Figure 3.3-16)

sabellid - a member of the polychaete family Sabellidae (feather duster or plume worms)

salt fingering - increased vertical mixing in apparent violation of the linear mixing laws caused by the greater diffusivity of heat than of salt (for further discussion, see Shirtcliffe and Turner, J. Fluid Mech. 41:4, 707-719 (1970))

sample - in this report, collection of data at a station at a single day and time

scarid - a fish belonging to the family Scaridae (parrotfishes); mostly tropical in geographic distribution; often feed on corals

scatter diagram - a plot in which the scatter of points is shown with no attempt to put a line through them

score - see factor score

scouring - in this report, the downward and sideward erosion of hard or consolidated substrata by current, waves or ship-induced turbulent action

sea urchin - see urchin

Secchi disc - a weighted disc (usually white) used in measuring vertical transparancy (clarity) through the water column; distance measurements in feet or meters are obtained

seiche mode - a standing wave phenomena caused by resonating characteristics of a given water basin under particular conditions of wind or tide serpulid - a member of the polychaete family Serpulidae (fan worms), a group that lives in calcareous tubes and are dominant tropical fouling organisms

sessile - permanently attached to a substratum; not free to move about

shape factor - a scalar term in the tidal current equation which depends on the form of the upstream channel (see equation 3.3-4 on page 3.3-40)

skewed distribution - any frequency distribution which lacks the bilateral symmetry of a Gaussian (or normal) frequency curve

snapping shrimp - species belonging to the family Alpheidae which are capable of producing sharp cracking sounds by the rapid closure of an enlarged claw

standard deviation - a measure of the dispersion of any variable about its mean value. Let $\bar{X}$ be the mean value, X_i be any single variable, and n be the number of observations. Then the standard deviation equals

$$\sqrt{\frac{\Sigma(\bar{X}-X_i)^2}{n-1}}$$

standard length - the distance from the most anterior part of a fish's head backward to the end of the vertebral column (structural base of the caudal rays)

standardized data - a convention in which the mean of a data set is taken as zero and all members of the set are expressed in terms of standard deviation units away from that mean value of zero

station - in this report, a geographic and depth location in Pearl Harbor (also see bio-station)

STP - sewage treatment plant

substratum - in this report, a material within or upon which an organism resides (e.g., pier piling, bottom sediments, water column)

switching effect - in this report, turbulence or residual velocity (q.v.) resulting from the switching from one current-driving mechanism to another at a point where two channels or lochs join

synodontid - any species belonging to the fish family Synodontidae (lizardfishes)

synonomy - a list of technical names which have been applied to a certain species tail - in this report, that portion of a frequency distribution which is far from the mean

terebellid - a member of the polychaete family Terebellidae which are tube-dwelling (sedentary) marine worms

thermocline - a layer of water marked by an abrupt temperature change with depth

tidal excursion - diurnal range of tidal height

TNTC - too numerous to count

TOC - total organic carbon

total length - the greatest dimension between the most anteriorly projecting part of the head and the farthest tip of the caudal fin when the caudal rays are squeezed together; the measurement is a straight line and is not taken over the curvature of the body

transmissometer - an instrument for measuring % light transmission through water

trap prone - having a tendency to be caught by traps

trophic structure - the hierarchy of the food web, consisting of a number of levels or stages in the transfer of food energy from the basic producers (plants) to herbivores, then carnivores, then secondary or tertiary carnivores

tsunami - a long-period sea wave produced by a submarine earthquake or volcanic eruption

tunicate - a member of the subphylum Urochordata; globular or cylindrical, often sac-like animals, many of which are covered by a tough, flexible tunic; many are sessile, some are pelagic

turbidimeter - an instrument for measuring water clarity; utilizes pressure of suspended matter; readout in Jackson Turbidity Units

turbidity - reduced water clarity resulting from presence of suspended matter

umbrella (or bell) - the gelatinous body of a jellyfish, usually bearing tentacles

upwelling - the process by which water rises from a lower to a higher depth, usually as a result of divergence and offshore currents

urchin - a member of the echinoderm class Echnoidea (sea urchins); possessing sucker-like tube feet and usually a spiny thin shell variable - the property measured by an individual observation

variability - the way in which an observed parameter changes with time or with repeated observation

ventral - pertaining to or situated on the lower (or abdominal) surface

visual transecting - a sampling method used to enumerate various organisms (fishes, corals) while swimming underwater (usually using SCUBA) along a specified survey line

wind derivative currents - currents caused by temporal changes in the wind speed or by differences in wind velocities at two different locations

zoea - an early larval form of certain decapod crustaceans

zooplankton - mostly microscopic animal (faunal) components of plankton

APPENDIX A

J. Geoffrey Grovhoug

INTRODUCTION

- three species are not pictured in Appendix A:

  1) *Scarus* sp. (juvenile) - parrotfish

  2) *Oxyurichthys lonchotus* - goby

  3) *Ctenogobius tongarevae* - goby

- the two digit prefix "85" indicating fish has been omitted from all HCZDB numbers included with the drawings in this appendix.

- associated with each figure is a reference scale, thus the length of the line shown is equivalent to 1 inch or 2.5 cm

- reference numbers listed in Table 2.1-3 refer to the page number and location of the drawing being described on that page.

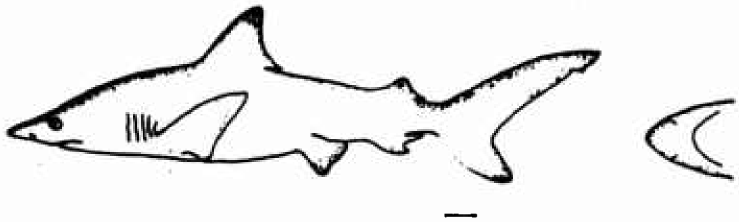
a	b
c	d
e	f
g	h

- sources for drawings in this appendix are listed on the following page.

SOURCES FOR PHBS FISH DRAWINGS

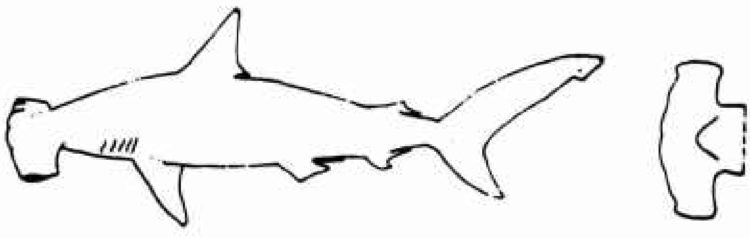
Abbreviation	
"G & B"	William A. Gosline and Vernon E. Brock (1960), Handbook of Hawaiian Fishes, University of Hawaii Press, 372 pages.
"Greenwood et al"	Humphrey P. Greenwood, et al (1966), "Phyletic Studies of Teleostean Fishes, With a Provisional Classification of Living Forms". Bulletin of the American Museum of Natural History, New York. 131:4, pp. 339-456; figures, plates and charts.
"Jones"	Robert S. Jones (1968), "Ecological Relationships in Hawaiian and Johnston Island Acanthuridae (Surgeonfishes)", HIMB Contribution #332.
"J & L"	Robert S. Jones and Helen K. Larson (1972), "A Key to the Families of Fishes as Recorded from Guam", University of Guam Marine Lab Tech. Report, 52 pages.
"J & E"	David Starr Jordan and Barton Warren Everman (1896), "The Fishes of North and Middle America: A Descriptive Catalogue...", Bulletin of the U.S. National Museum, Washington; part 4, index and plates.
"K, S & W"	Susumu Kato, Stewart Springer and Mary H. Wagner (1967), Field Guide to Eastern Pacific and Hawaiian Sharks. U.S. Dept. of Interior, Bureau of Comm. Fisheries Circular No. 271, Washington, 47 pages.
"Morita"	Clyde M. Morita (1963), Freshwater Fishing in Hawaii, Hawaii Div. of Fish and Game Publication, 20 pages.
"Sakuda"	Henry M. Sakuda (1973), Hawaiian Fishes, Div. of Fish and Game; drawings and brief descriptions, 20 pages.
"Schultz"	Leonard P. Schultz (1953), Fishes of the Marshall and Marianas Islands, U.S. National Museum Bulletin No. 202, Washington; 3 volumes, 1399 pages.
"Tinker"	Spencer W. Tinker (1944), Hawaiian Fishes, Tongg Publishing Co., Hawaii, 404 pages.
"PHBS"	"Pearl Harbor Biological Survey" - specimens and photographs.
"Randall photo"	Photograph taken by Dr. John E. Randall, B.P. Bishop Museum, Honolulu, Hawaii.

CARCHARHINIDAE



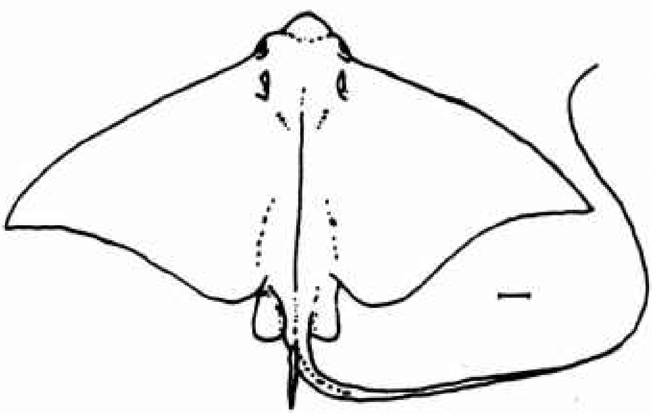
Black-tip shark, Mano
Carcharinus limbatus
after K, S & W
(16120503)

SPHYRNIDAE



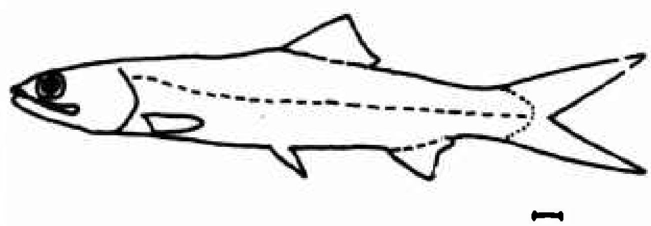
Scalloped hammerhead shark; Mano kihikihi
Sphyrna lewini
after K, S & W
(16130101)

MYLIOBATIDAE



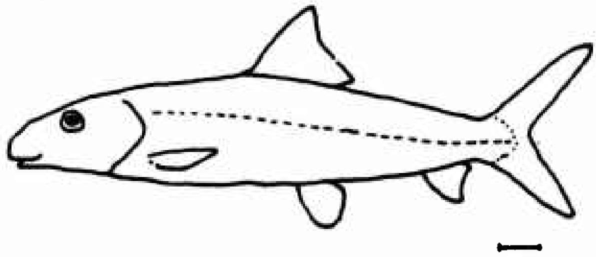
Spotted eagle ray; Hihimanu
Aetobatus narinari
after G&B
(17100101)

ELOPIDAE



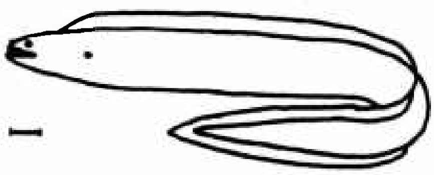
Tenpounder, Awaawa
Elops hawaiiensis
after G&B and PHBS photo
(21010101)

ALBULIDAE

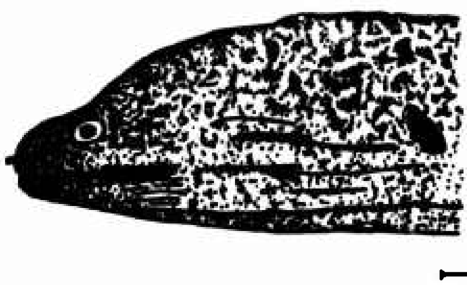


Bonefish; 'O'io
Albula vulpes
after G&B (21060101)

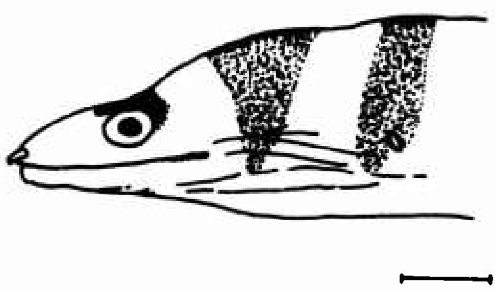
MURAENIDAE



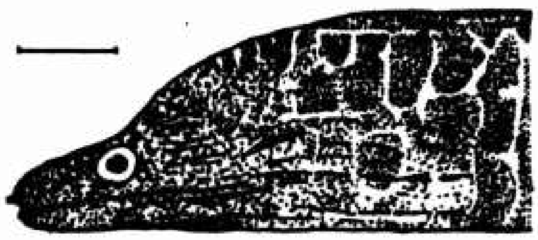
Gymnothorax sp. - general aspect
after Greenwood et al



Moray eel; Puhi paka
Gymnothorax flavimarginatus
after G&B (22050605)

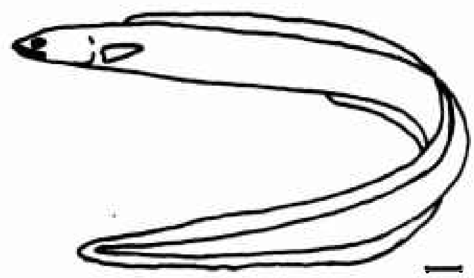


Moray eel; Puhi
Gymnothorax petelli
after G&B
(22050611)



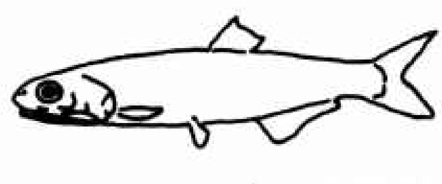
Moray eel; Puhi laumilo
Gymnothorax undulatus
after G&B (22050613)

CONGRIDAE



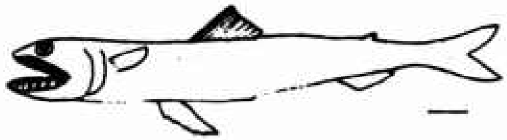
Conger eel; Puhi uha
Conger cinreus marginatus
after Greenwood et al
(22120501)

ENGRAULIDAE

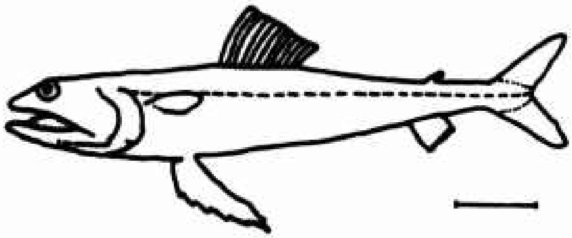


Anchovy; Nehu
Stolephorus purpureus
after Greenwood et al
(25070101)

SYNODONTIDAE

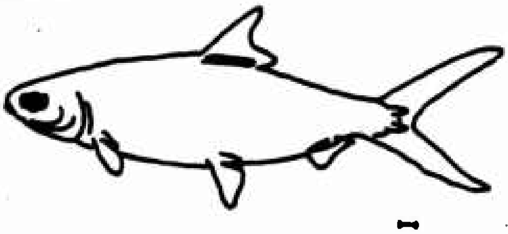


Lizardfish; Ulae
Saurida gracilis
after Schultz and PHBS specimen
(31470201)



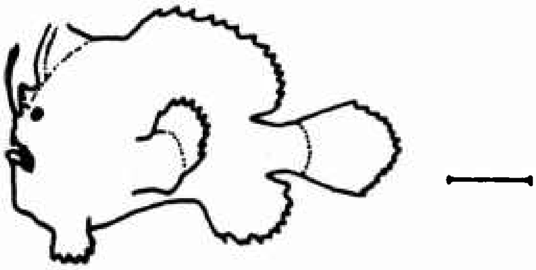
Lizardfish
Synodus variegatus
after G&B (31470304)

CHANIDAE



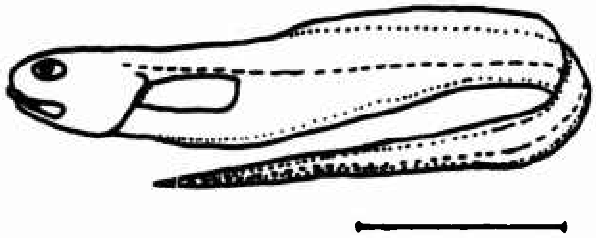
Milkfish; Awa
Chanos chanos
after Greenwood et al
(33060101)

ANTENNARIIDAE



Anglerfish, frogfish
Antennarius chironectes
after G&B (41070302)

CARAPIDAE

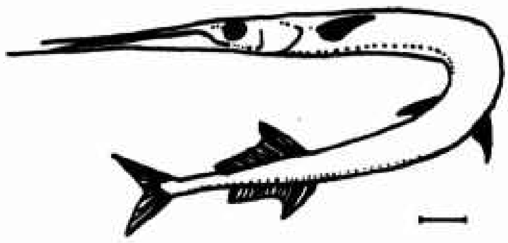


Pearlfish
Carapus margaritiferae
after Schultz & PHBS specimen
(42120301)

HEMIRAMPHIDAE

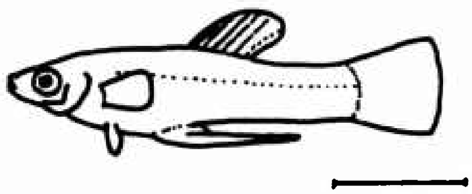
Halfbeak; Iheihe
Hemiramphus depauperatus
after Greenwood et al
(44015301)

BELONIDAE



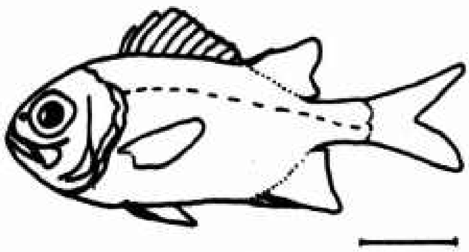
Needlefish; Ahaaha
Tylosurus crocodilus
after J&L (44020301)

POECILIIDAE

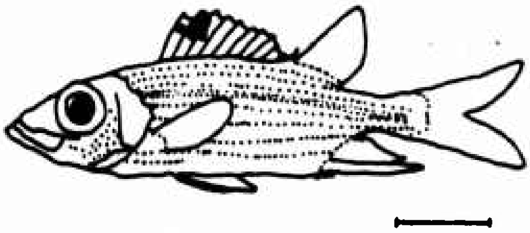


Molly
Mollienisia latipinna
after Greenwood et al
(44130101)

HOLOCENTRIDAE

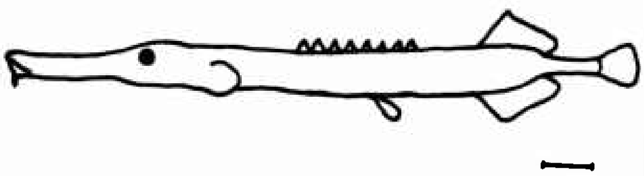


Soldierfish; Menpachi
Myripristis murdjan
after G&B (46180403)



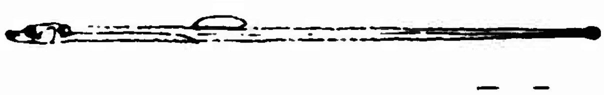
Squirrelfish; Ala-'ihi
Flammeo sammara
after G&B (46180501)

AULOSTOMIDAE



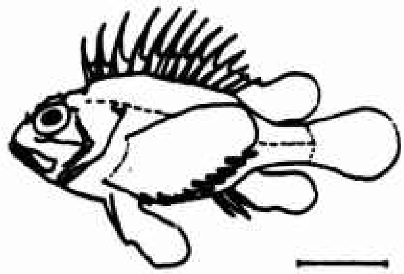
Trumpetfish; Nunu
Aulostomus chinensis
after J&L
(49060101)

SYNGNATHIDAE

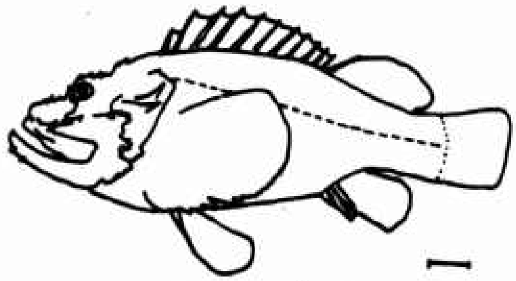


Banded pipefish
Micrognathus edmondsoni
after Schultz (49120502)

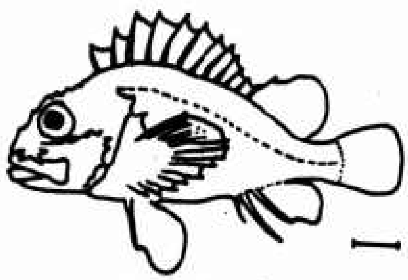
SCORPAENIDAE



Poisonous scorpionfish
Brachirus barberi
after G&B (52010301)

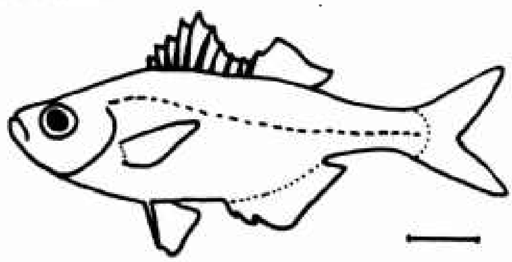


Common scorpionfish; Nohu
Scorpaenopsis diabolus
after G&B (52010701)



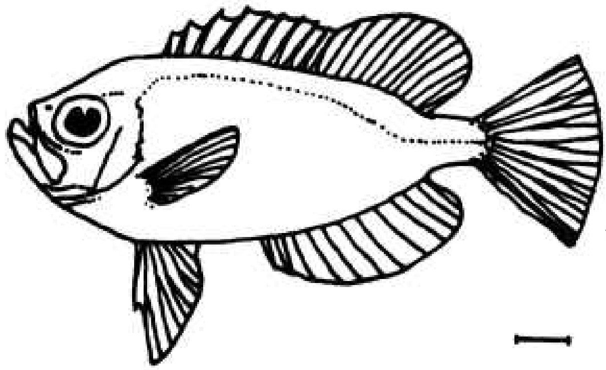
Scorpionfish
Scorpaena coniorta
after G&B (52011101)

KUHLIIDAE



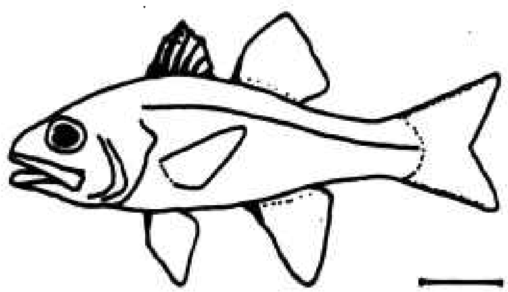
Mountain bass; Aholehole
Kuhlia sandvicensis
after G&B (54140101)

PRIACANTHIDAE

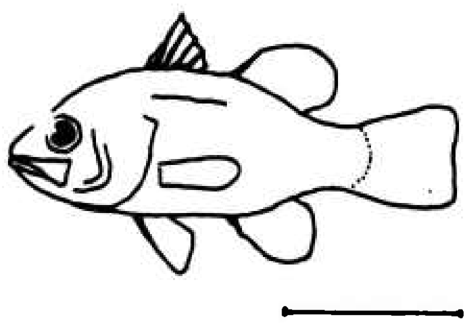


Red bigeye; Aweoweo
Priacanthus cruentatus
after J&L
(54170101)

APOGONIDAE

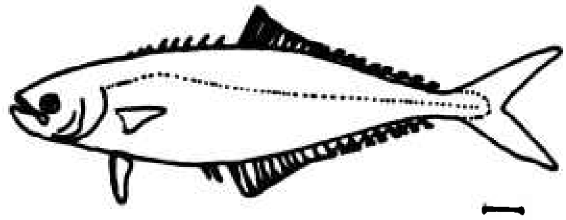


Cardinalfish; 'Upapalu
Apogon snyderi
after G&B
(54180404)

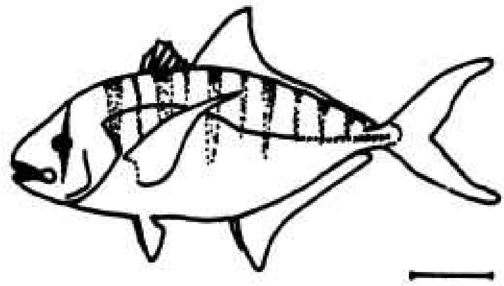


Cardinalfish; 'Upapalu
Foa brachygrammus
after G&B
(54180701)

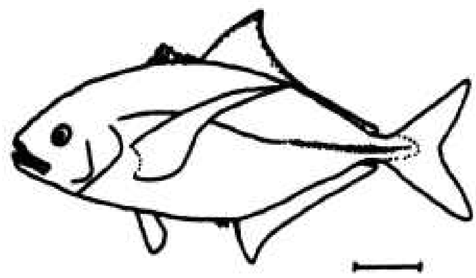
CARANGIDAE



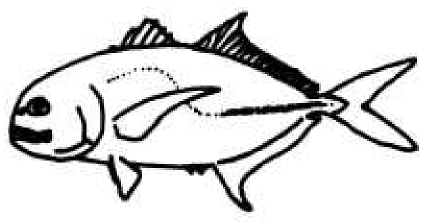
Leatherback; Lae
Scomberoides sancti-petri
after G&B (54290101)



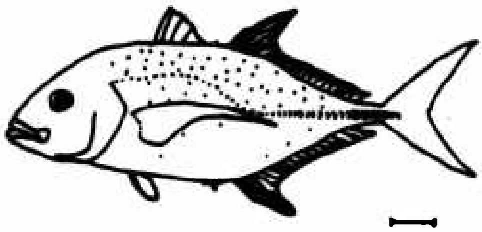
Yellow jack; Pa'opa'o ulua
Gnathanodon speciosus
after G&B (54290801)



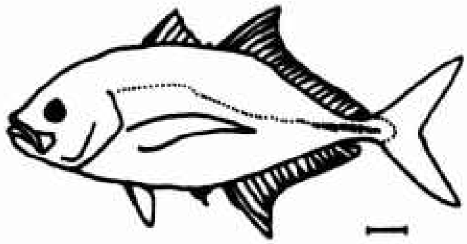
Jack; Ulua
Carangoides gymnostethoides
after G&B (54291001)



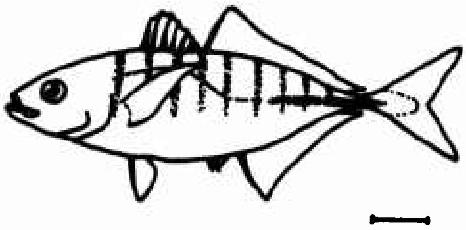
Jack; Ulua,
Caranx ignobilis
after G&B (54291202)



Blue jack; Ulua omilu
Caranx melampygus
after G&B (54291204)

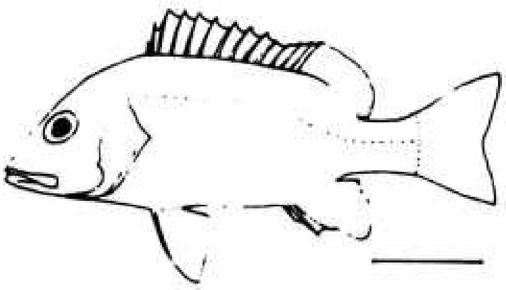


White jack; Pake ulua
Caranx sexfasciatus
after G&B (54291206)



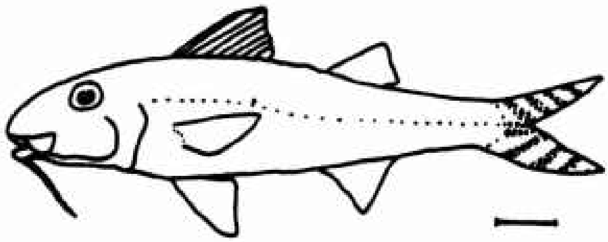
Jack; 'Omaka
Caranx mate
after G&B (54291207)

LUTJANIDAE

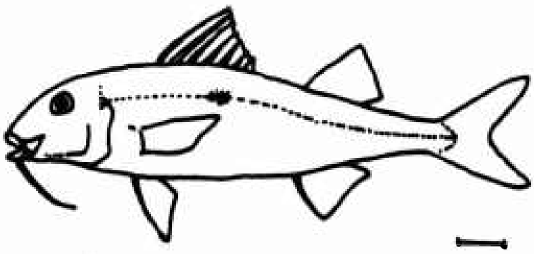


Black-tailed snapper; Toau
Lutjanus fulvus
from Randall photo & PHBS specimen
(54380704)

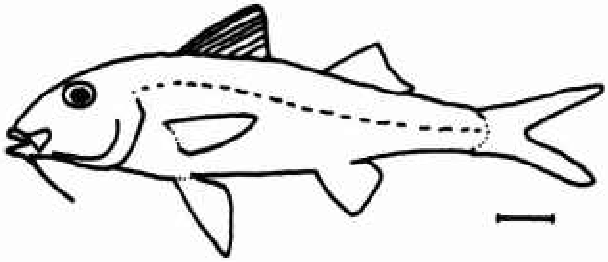
MULLIDAE



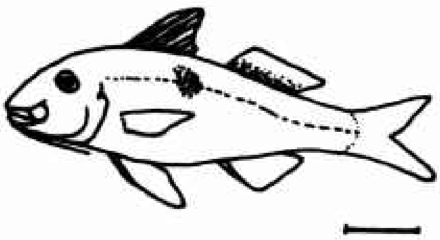
Striped-tailed goatfish; Weke pueo
Upeneus arge
after Sakuda & PHBS photo
(54470101)



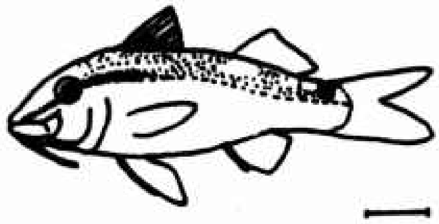
Sand goatfish; Weke a'a
Mulloidicthys samoensis
after G&B (54470201)



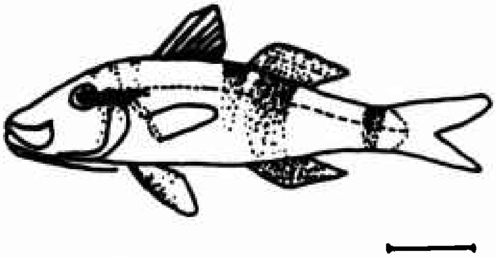
Goatfish; Weke 'ula
Mulloidichthys auriflamma
after Sakuda (54470202)



Goatfish; Malu
Parupeneus pleurostigma
after G&B (54470301)

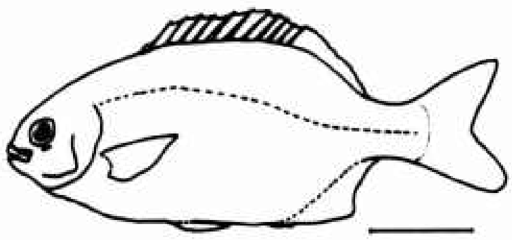


Goatfish; Kumu
Parupeneus porphyreus
after G&B (54470303)



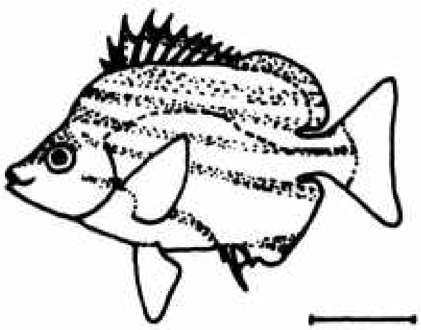
Goatfish; Moano
Parupeneus multifasciatus
after G&B (54470305)

KYPHOSIDAE



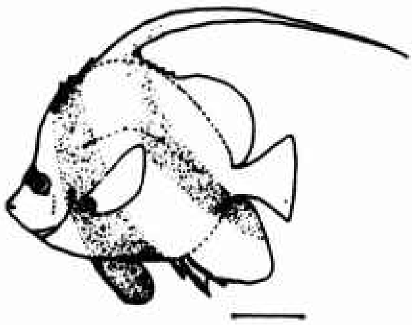
Rudderfish; Nenue
Kyphosus cinerascens
from PHBS photo (54530101)

SCORPIDIDAE

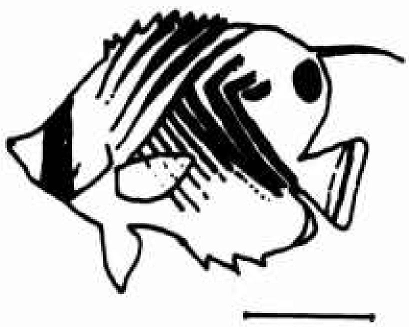


Convictfish
Microcanthus strigatus
after G&B (54530301)

CHAETODONTIDAE

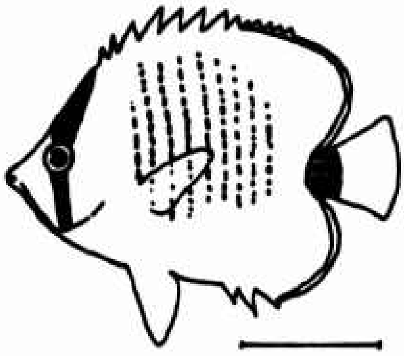


Poor man's moorish idol
Heniochus acuminatus
from Schultz photo
(54570502)



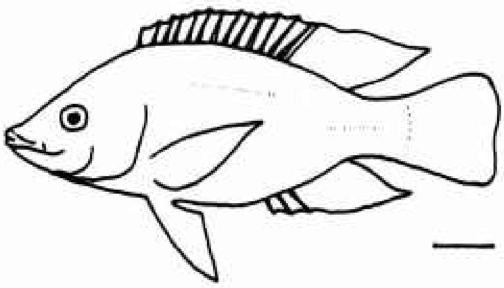
Threadfin butterflyfish
Chaetodon auriga
after G&B (54570706)

Raccoon butterflyfish
Chaetodon lunula
after G&B (54570708)



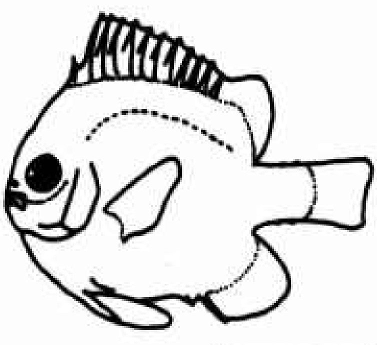
Lemon butterflyfish
Chaetodon miliaris
after G&B (54570715)

CICHLIDAE

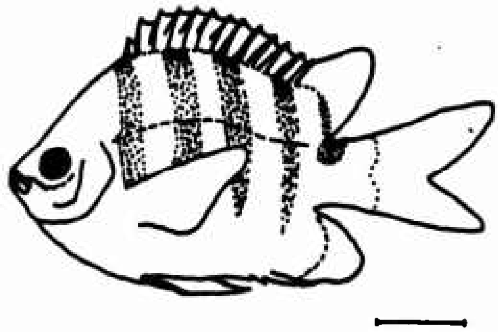


Mozambique mouthbreeder
Tilapia mossambica
after Morita (54630101)

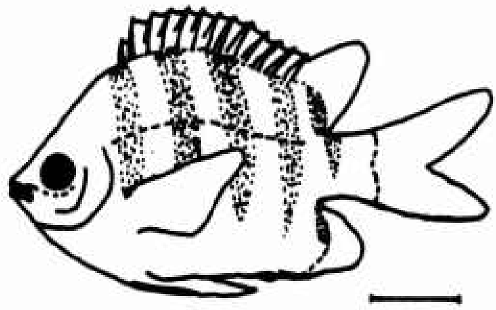
POMACENTRIDAE



Damselfish; Aloiloi
Dascyllus albisella
after G&B (54640101)

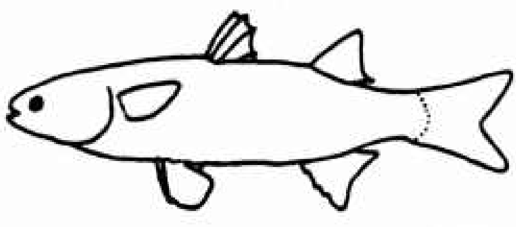


Damselfish; Kupipi
Abudefduf sordidus
after G&B (54640201)



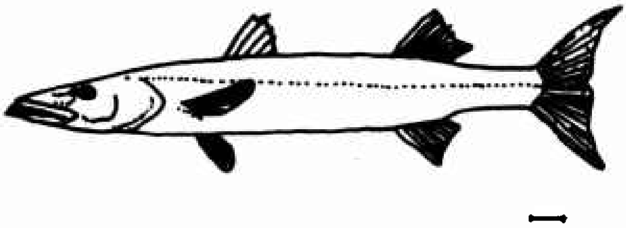
Sergeant major; Maomao
Abudefduf abdominalis
after G&B (54640202)

MUGILIDAE



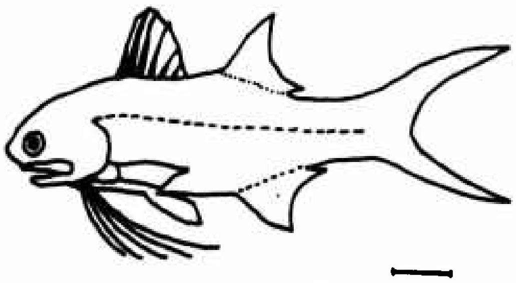
Mullet; Amaama
Mugil cephalus
after G&B (55010201)

SPHYRAENIDAE



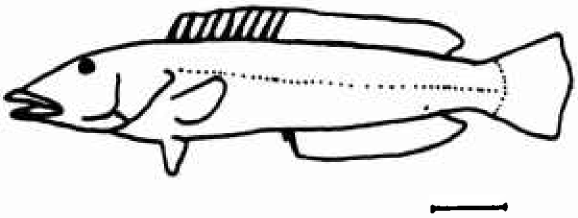
Great barracuda; Kaku
Sphyraena barracuda
after J&L (55030101)

POLYNEMIDAE

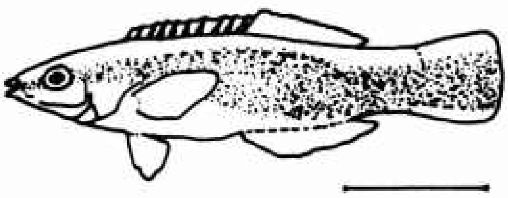


Threadfin; Moi
Polydactylus sexfilis
after G&B (55050101)

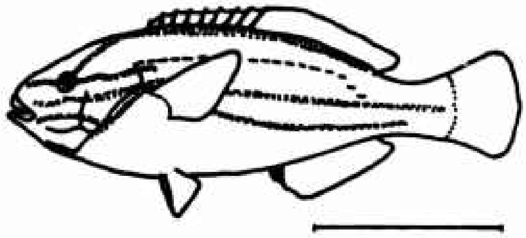
LABRIDAE



Mongoosefish; Kupoupou
Cheilio inermis
after G&B (55070101)

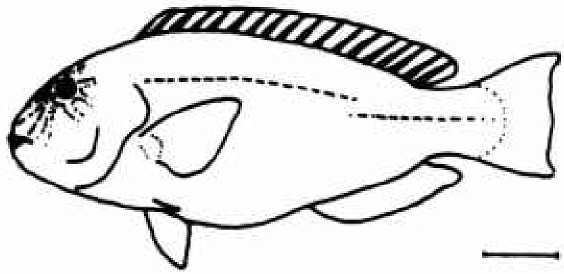


Cleaner wrasse
Labroides phthirophagus
from Schultz photo (55070401)

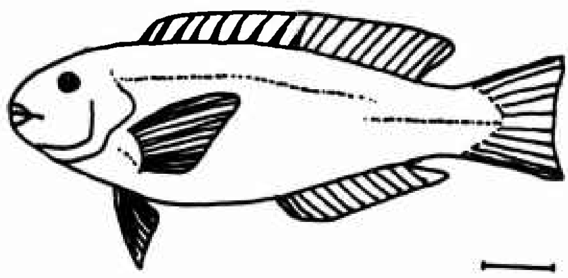


Tahitian wrasse; Hinalea
Stethojulis balteatus
after G&B (55071801)

SCARIDAE

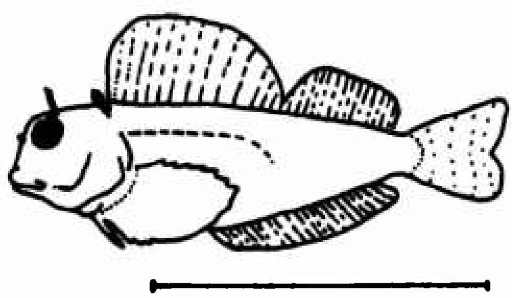


Parrotfish; Uhu
Calotomus spinidens
from Schultz photo (55090102)

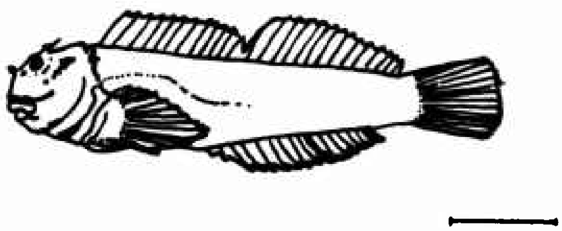


Parrotfish; Uhu
Scarus sordidus
after J&L (55090304)

BLENNIIDAE



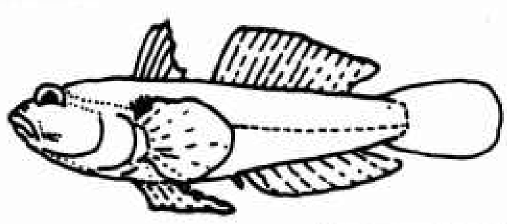
Blenny; Pao'o kau'ila
Exallias brevis
from PHBS specimen (55340101)



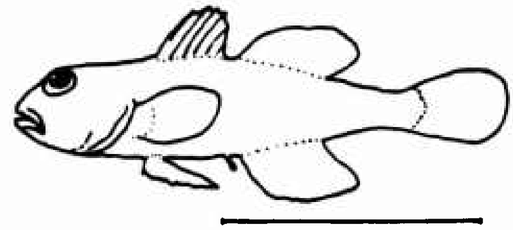
Blenny; Pao'o
Entomacrodus marmoratus
after G&B (55340301)

Blenny; Pao'o
Omobranchus elongatus
from PHBS specimen
(55340701)

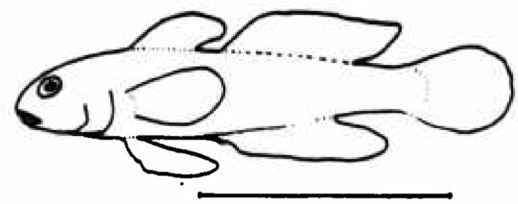
GOBIIDAE



Goby; O'opu kai, 'ohune
Bathygobius fuscus
after J&L (55600802)

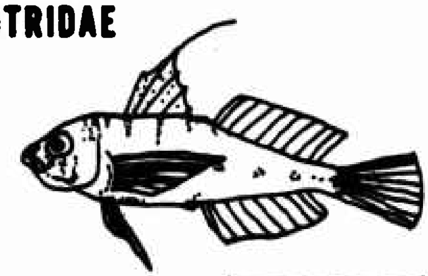


Goby; O'opu kai
Opua nephodes
after Tinker (55601201)



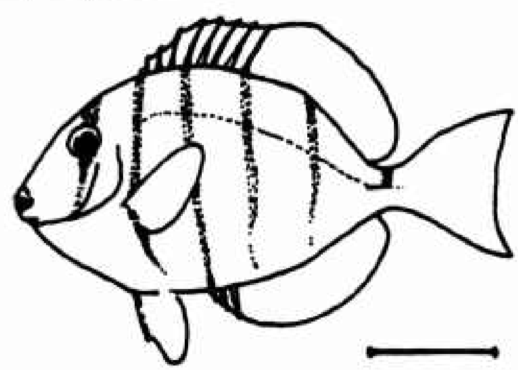
Goby. O'opu kai
Gnatholepis anjerensis
after Tinker (55601301)

ELEOTRIDAE

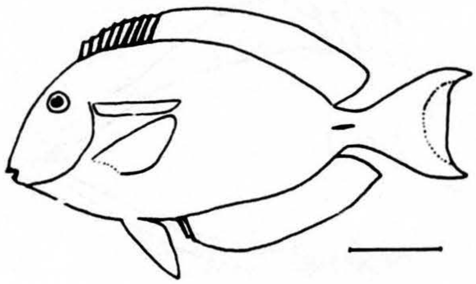


Sleeper goby
Asterropteryx semipunctatus
after J&L (55605301)

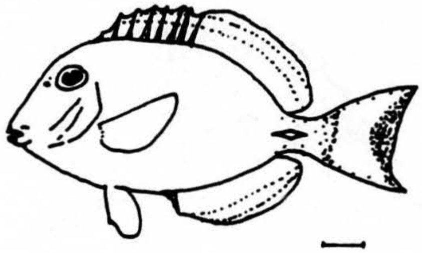
ACANTHURIDAE



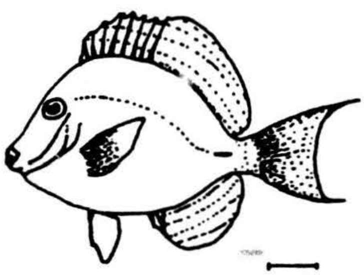
Convict tang; Manini
Acanthurus triostegus
after G&B (55690101)



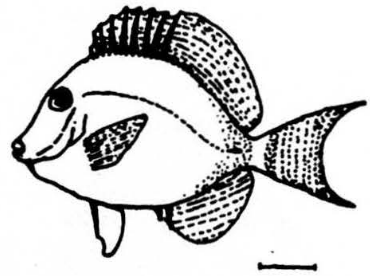
Orange-spot tang; Naenae
Acanthurus olivaceus
after Jones (55690109)



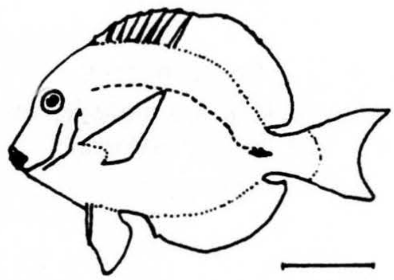
Surgeonfish; Palani
Acanthurus dussumieri
after G&B and PHBS photo
(55690110)



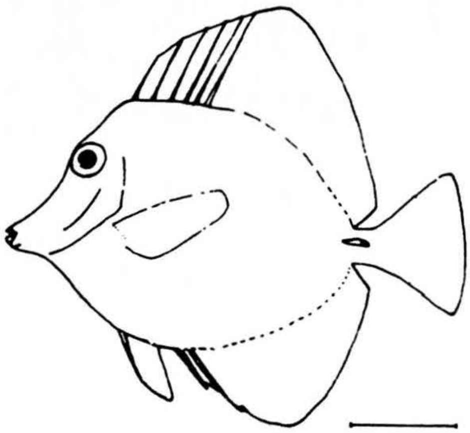
Surgeonfish; Pualu
Acanthurus xanthopterus
after G&B and PHBS specimen
(55690111)



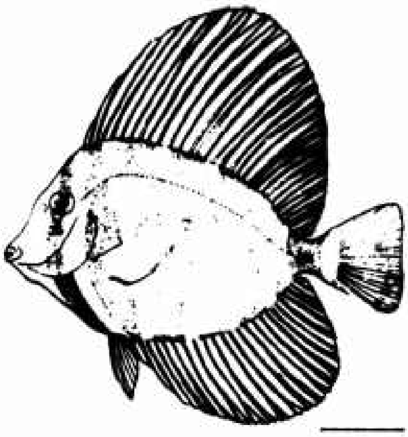
Surgeonfish; Pualu
Acanthurus mata
after G&B and PHBS specimen
(55690112)



Surgeonfish; Kole
Ctenochaetus strigosus
after G&B and Randall photo
(55690201)

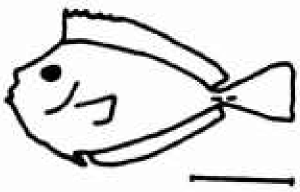


Yellow tang; Lau'i-pala
Zebrasoma flavescens
from Schultz photo
(55690301)

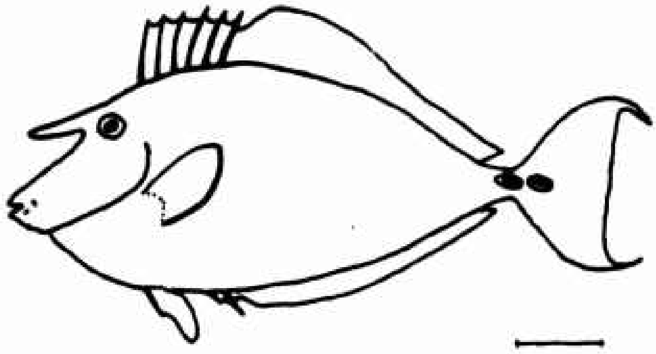


Sailfin tang
Zebrasoma veliferum
after Sakuda
(55690302)

Bumphead tang
Naso brevirostris (adult)
after Jones (55690403)

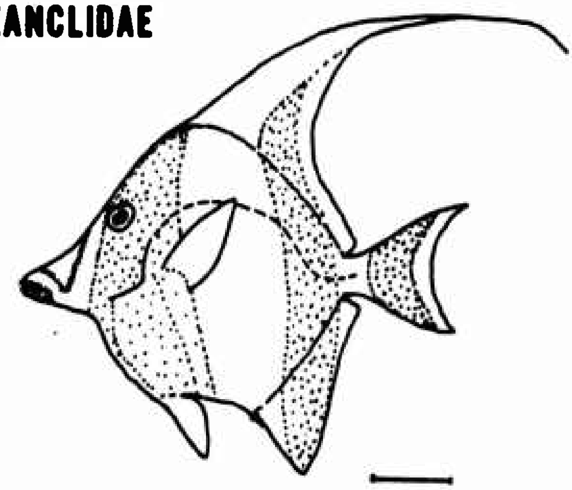


Naso brevirostris (juvenile)



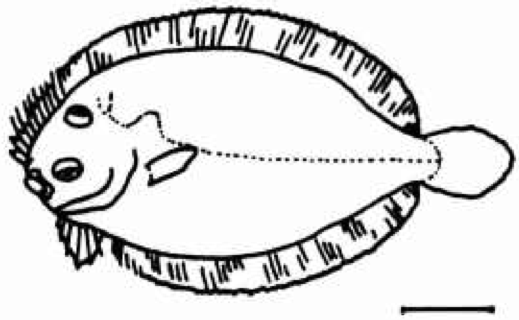
Unicorn tang; Kala
Naso unicornis
from PHBS specimen & photo
(55690404)

ZANCLIDAE



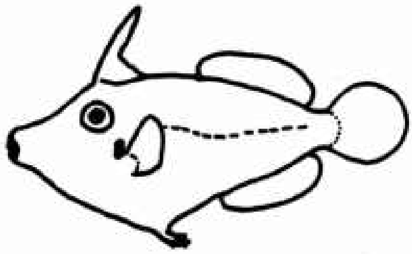
Moorish Idol; Kihikihiki
Zanclus canescens
from Randall photo
(55695101)

BOTHIDAE



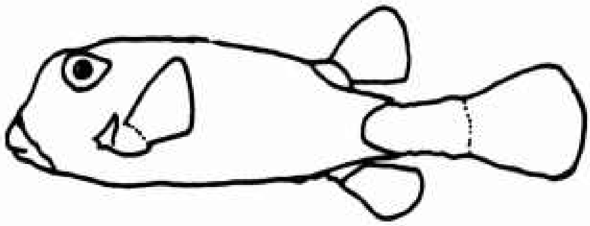
Flatfish; Paki'i
Bothus pantherinus
after G&B (57080402)

MONOCANTHIDAE



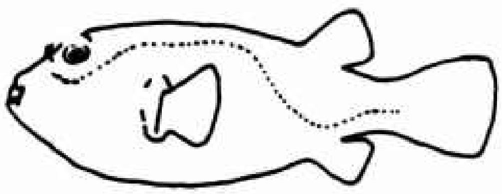
Fantail filefish; 'O'ili uwi'uwi
Pervagor spilosoma
after G&B (58025201)

OSTRACIONTIDAE



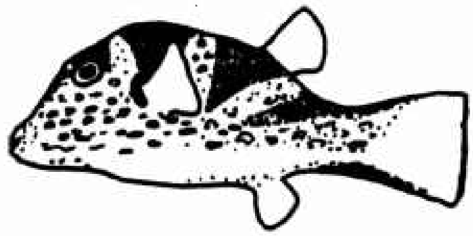
Boxfish; Pahu(adult),
Oopakahu(juvenile)
Ostracion meleagris camurum
after G&B (58030201)

TETRAODONTIDAE

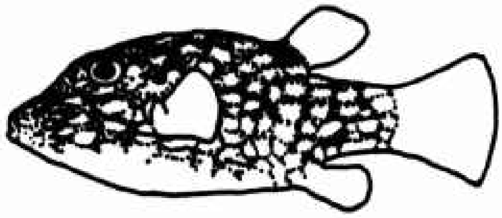


Soft puffer; Makimaki
Arothron hispidus
after G&B (58060302)

CANTHIGASTERIDAE

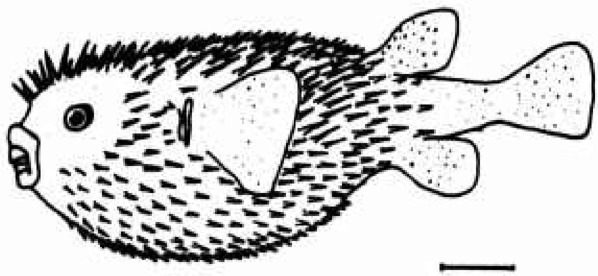


Sharp-backed puffer
Canthigaster coronatus
after G&B (58065101)

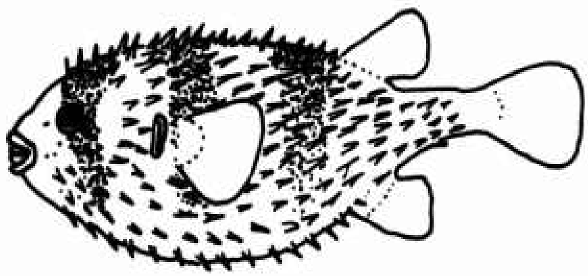


Hawaiian sharpnosed puffer
Canthigaster jactator
after G&B (58065102)

DIODONTIDAE



Porcupinefish; 'O'opu-kawa
Diodon hystrix
after J&E (58080201)



Porcupinefish; 'O'opu-kawa
Diodon holocanthus
after J&E (58080202)

APPENDIX B

Thomas A. Clarke

INTRODUCTION

Dr. Thomas A. Clarke, University of Hawaii, compiled this appendix on the basis of the stomach content of Pearl Harbor fish specimens provided by the NUC survey team. All fishes were collected from Pearl Harbor by gill net, frozen and delivered to Dr. Clarke. No information on the geographic location of the collections was provided with the specimens. Dr. Clarke's statements concerning probable habitat preference of species are based on his observations in Kaneohe Bay and in areas of Hawaii other than Pearl Harbor. It should be noted that the material provided Dr. Clarke includes gill-net collections for March and May, 1973, a period extending 2 months beyond that reported in Section 2.1.

Six series of gill net samples were analyzed. These samples were taken in September, October, November, and December of 1972 and in March and May of 1973. For each series, all ten Pearl Harbor bio-stations were sampled.

METHODS

Total and standard lengths of the specimens were measured to the nearest millimeter. For elasmobranchs and carangids, the precaudal and fork lengths, respectively, were taken instead of standard length. All specimens were examined externally for abnormalities, parasites, wounds (other than obvious net damage), and tags. The specimens were dissected, and sex and reproductive condition were noted. No histological examinations of gonads were made. Consequently, the sex of juveniles could not always be determined, and the degree of maturity was only roughly estimated.

The foregut of each specimen was examined. Any food remains therein were identified as clearly as possible. The lower intestinal tract was not examined. Fish remains in the stomachs were identified from scales where possible. Most of these identifications are good only to genus or family. Invertebrates, most of which were crustaceans, were identified only to major groups. Size of prey items was estimated if possible. Stomach contents of herbivorous fishes were classified simply as filamentous algae, microalgae, or macroalgae. "Microalgae" frequently included amorphous lumps of material that were probably both microscopic algae and detritus. "Macroalgae" frequently included small sessile invertebrates which were attached to the algae and which were probably eaten incidentally.

In the following sections, sizes of organisms are expressed as follows: fishes -- standard length (except as indicated otherwise); crabs -- carapace width; shrimps -- carapace length; all other invertebrates -- total length.

RESULTS

Thirty-one species of fishes were taken in the gill nets. One additional species, taken by dip-net, was included in the samples. The catch for each month, total catch, and the means and ranges of standard length for each species are given in Table B-1. Table B-2 lists catch by station for the 17 most abundant species. The data for each species are discussed individually

Table B-1. LIST OF FISHES TAKEN IN PEARL HARBOR SURVEY GIVING THE NUMBER COLLECTED IN EACH SERIES OF SAMPLES, TOTAL NUMBER COLLECTED, AND THE AVERAGE AND RANGE OF STANDARD LENGTHS FOR EACH SPECIES. (THE LENGTHS FOR SHARKS AND RAYS ARE EXPRESSED AS PRECAUDAL LENGTHS; THOSE FOR CARANGIDS, AS FORK LENGTHS).

Species	Sep	Oct	Nov	Dec	Mar	May	Total	Mean (Range) SL in mm.
Acanthurus dussumieri	1	2	1	-	3	-	7	183(121-257)
Acanthurus mata	1	14	8	5	3	-	31	166(114-230)
Acanthurus triostegus	1	6	-	1	-	-	8	121(97-150)
Acanthurus xanthopterus	4	13	1	1	1	3	23	172(130-234)
Aetobatus narinari	3	1	-	-	-	-	4	116(110-125)
Albula vulpes	3	1	4	2	2	7	19	345(261-425)
*Arothron hispidus**	-	-	1	-	-	-	1	197
Calotomus spinidens	-	-	1	-	-	1	2	215(186-243)
Carangoides gymnostethoides	-	-	-	1	-	-	1	168
Caranx ignobilis	-	-	-	-	-	1	1	397
Caranx mate	2	1	1	2	-	-	6	215(158-243)
Caranx melampygus	12	5	1	4	9	2	33	217(139-296)
Caranx sexfasciatus	8	3	1	4	3	4	23	260(165-406)
Carcharhinus limbatus	2	-	-	-	-	-	2	589(575-603)
Chaetodon auriga	-	1	-	-	-	-	1	125
Chaetodon lunula	1	-	-	-	-	-	1	112
Chanos chanos	9	10	-	1	1	2	23	453(315-620)
Elops hawaiiensis	23	19	13	15	14	15	99	440(302-714)
Kuhlia sandvicensis	1	8	-	-	1	-	10	195(172-213)
Kyphosus cinerascens	-	1	1	-	-	-	2	155(150-160)
Mugil cephalus	8	25	9	28	6	-	76	296(260-327)
Mulloidichthys auriflamma	1	-	-	-	-	-	1	170
Mulloidichthys samoensis	1	-	3	-	-	-	4	229(179-262)
Naso brevirostris	-	2	-	-	-	-	2	163(162-165)
Naso unicornis	-	1	-	-	-	-	1	257
Parupeneus porphyreus	6	12	5	4	4	1	32	224(189-271)
Polydactylus sexfilis	1	5	-	8	3	4	21	243(191-340)
Scarus sordidus	1	-	-	-	-	-	1	196
Scomberoides sancti-petri	1	10	1	-	4	1	17	343(285-550)
Sphyraena barracuda	-	-	-	1	-	1	2	449(413-485)
*Sphyrna lewini***	33	18	9	14	17	9	100	400(330-605)
Upeneus arge	-	-	-	2	3	8	13	244(226-262)

* dip netted

** excludes one large male taken at BC-09 in May

Table B-2. CATCHES BY STATION FOR THE 17 MOST ABUNDANT SPECIES OF FISHES COLLECTED. SPECIES ARE LISTED IN ORDER OF ABUNDANCE. FOR EACH STATION THE TOTAL NUMBER CAUGHT IS GIVEN, AND, IF THE SPECIES WAS TAKEN MORE THAN ONCE IN THE SIX SAMPLING PERIODS (SEP, OCT, NOV, DEC, MAR AND MAY), THE NUMBER OF TIMES IT WAS TAKEN APPEARS IN PARENTHESIS AFTER THE CATCH TOTAL.

SPECIES	STATION NUMBER									
	BE-02	BE-03	BE-04	BE-05	BM-07	BC-09	BC-10	BC-11	BW-13	BE-17
Sphyrna lewini	3	2	2	41(6)	25(4)	9(5)	16(4)	-	2(2)	-
Elops hawaiiensis	1	2	10(3)	33(6)	15(4)	18(6)	8(4)	1	8(5)	3(2)
Mugil cephalus	-	1	-	5(1)	32(4)	30(5)	-	7(3)	1	-
Caranx melampygus	1	4(3)	-	1	-	1	14(4)	7(2)	4(3)	1
Parupeneus porphyreus	4(3)	9(4)	-	10(4)	-	1	-	7(5)	-	1
Acanthurus mata	3(2)	13(3)	-	-	1	1	2	7(4)	4(2)	-
Acanthurus xanthopterus	2	-	-	-	1	-	2	5(3)	11(4)	2
Chanos chanos	-	-	-	3	-	13(3)	2(2)	-	5(2)	-
Caranx sexfasciatus	2(2)	1	4(2)	2	2(2)	2(2)	8(3)	1	-	1
Polydactylus sexfilis	-	-	-	-	-	3(2)	18(5)	-	-	-
Albula vulpes	-	-	-	-	-	10(4)	1(1)	1	7(3)	-
Scomberoides sancti-petri	-	-	2(2)	11(2)	-	3(3)	1	-	-	-
Upeneus arge	-	-	-	5(3)	-	2(2)	5	-	-	1
Kuhlia sandvicensis	-	-	-	-	-	-	4(2)	-	6(2)	-
Acanthurus triostegus	-	-	-	-	-	-	-	8(3)	-	-
Acanthurus dussumieri	-	-	-	-	-	-	1	6(4)	-	-
Caranx mate	-	-	-	-	5(4)	-	1	-	-	-

below. Attempts at generalizations are made for some species, but due to lack of published data on most, conclusions must be regarded as tentative. Further analysis of food items ingested by each species is presented in Table B-3.

Sphyrna lewini (hammerhead shark) was the most frequently taken species. It was caught most frequently at BE-05 and also consistently at BM-07, BC-09, and BC-10. Catches at other stations were sporadic. With the exception of an adult male taken at BC-09 in May, all specimens were recently born and immature. There were 56 males and 44 females. The catch was highest in September; differences between the catches of other months are probably insignificant.

The stomachs of the large male and of 39 of the pups were empty. Of the remaining pups, 39 contained fish remains. The most frequently identified prey were small gobioid fishes: *Asterropteryx, Bathygobius, Opua*; and one other fish, tentatively identified from scales as a synodontid (lizardfish). *Mugil, Upeneus, Gymnothorax, Scarus, Albula,* apogonid, and carangid remains were also found. Crustaceans were found in the stomachs of 23 specimens. These crustaceans were mostly alpheid shrimps (20-30mm) and small portunid crabs (20-40mm) but also included other small shrimps and stomatopods. Other items included one-half of an oyster shell, pieces of wood, a fish hook, and a leaf. Two specimens had small parasitic worms in their stomachs, but these may have come from prey.

The data on *Sphyrna lewini* in Pearl Harbor are in general agreement with results reported by Clarke (Reference B-1) for the same species in Kaneohe Bay, Oahu. The adults move into shallow, enclosed areas to mate and deliver pups. Although summer catch data are not available for Pearl Harbor, the high catch of pups in September and the capture of an adult in May indicate that the seasonal pattern is similar to that observed in Kaneohe Bay. The abundance of pups is highest during the summer with adults present almost exclusively then. In general, the stomach content data from Pearl Harbor agree well with data from *Sphyrna lewini* collected over mud or rubble bottom in Kaneohe Bay.

Caracharhinus limbatus (black-tip shark or volador) was taken only at BC-09 in September. The two specimens were recently born, both of them males. One had an empty stomach, and the other contained unidentifiable fish remains. Unpublished data (by Clarke) suggest that this species, like *Sphyrna lewini*, tends to deliver pups in shallow areas such as Pearl Harbor and Kaneohe Bay. It is likely that adults of this species occur in Pearl Harbor as well.

Aetobatus narinari (spotted eagle ray) was represented by only four specimens: two males and two females, all immature. Two had empty stomachs and two had bivalve (probably clam) remains. This species feeds primarily on infauna of sand or sand rubble bottoms. It occurs over a wide range of conditions, but appears to favor clear water.

Elops hawaiiensis (awa awa) was taken almost as frequently as *Sphyrna lewini*. It was taken most frequently at BE-05. It was also taken regularly at five other stations and at least once at all stations. There was no obvious trend in either abundance or size with season. All specimens were immature, and sex could not be accurately determined, even for the larger specimens.

Table B-3. FOOD ITEMS OF 32 SPECIES OF FISHES COLLECTED IN GILl
FROM PEARL HARBOR, HAWAII, FROM SEPTEMBER 1972 TO MA

SPECIES	No. of Individuals Examined	Sex Ratio M:F (Imm. = Immature)	% Stomach Contents Empty (MT)	FOOD ITEMS																							
				Fish (misc.)	*Albula*	*Arothron*	*Asterropteryx*	*Bathygobius*	*Gnatholepis*	*Gymnothorax*	*Mugil*	*Opua*	*Scarus*	*Stolephorus*	*Upeneus*	Apogonidae	Carangidae	Synodontidae	Crustacea (misc.)	Shrimp (misc.)	Alpheidae	Stomatopods (+ larvae)	Crabs (misc.)	Portunidae	Xanthidae	Barnacles	Isopods
Acanthurus dussumieri	7	1:1	0																								
Acanthurus mata	31	1:1	40																							●	
Acanthurus triostegus	8	Imm	0																								
Acanthurus xanthopterus	23	2:1	50																								
Aetobatus narinari	4	1:1	50																								
Albula vulpes	19	M	30																				●				
Arothron hispidus	1	F	0																								
Calotomus spinidens	2	1:1	50																								
Carangoides gymnostethoides (juv.)	1	Imm	MT																								
Caranx ignobilis	1	M	MT																								
Caranx mate	6	5:1	60	●										●													
Caranx melampygus	33	Imm	60	●			●		●				●	●					●				●				
Caranx sexfasciatus	23	5:4	25	●									●					●		●		●	●	●			
Carcharhinus limbatus	2	M	50	●																							
Chaetodon auriga	1	M	MT																								
Chaeton lunula	1	M	MT																								
Chanos chanos	23	Imm	50																								
Elops hawaiiensis	99	Imm	60	●				●	●					●		●	●			●		●	●	●	●	●	
Kuhlia sandvicensis	10	3:7	10																	●		●	●				
Kyphosus cinerascens	2	Imm	0																								
Mugil cephalus	76	2:1	0																								
Mulloidichthys auriflamma	1	F	0																		●						
Mulloidichthys samoensis	4	1:3	25																	●							●
Naso brevirostris	2	F	MT																								
Naso unicornis	1	M	0																								
Parupeneus porphyreus	32	12:17	30				●													●			●				
Polydactylus sexfilis	21	9:(9):2*	30	●		●	●	●	●			●							●								
Scarus sordidus	1	Decomposing																									
Scomberoides sancti-petri	17	1:2	90	●																							
Sphyraena barracuda	2	M	MT																								
Sphyrna lewini	100	14:11	40	●	●		●	●		●	●	●	●		●	●	●	●		●	●	●		●			
Upeneus arge	13	1:5	70																●		●	●	●				

Polydactylus sexfilis (moi) is a protandrous hermaphroditic species, i.e., with age, an individual undergoes the transformation male → intermediate → female (see text).

)F FISHES COLLECTED IN GILL NETS
, FROM SEPTEMBER 1972 TO MAY 1973.

FOOD ITEMS

Carangidae	Synodontidae	Crustacea(misc.)	Shrimp(misc.)	Alpheidae	Stomatopods(+ larvae)	Crabs(misc.)	Portunidae	Xanthidae	Barnacles	Isopods	Amphipods	Ostracods	Tanaids	Crustacean larvae (misc.-plankton)	Mollusca (misc.)	Bivalves	Gastropods	Nudibranchs	Polychaetes(misc.)	Echinoderms	Ophiuroids	Holothurians	Tunicates	Bryozoans	Coral Polyps(living)	Macroalgae	Microalgae	Filamentous algae	Detritus	Miscellaneous
																	●				●					●	●			●
									●																	●	●	●		●
																										●	●			
																							●			●	●	●		●
															●	●														
						●					●	●	●						●		●									
																														●
																									●		●			
														●																
		●				●																								
	●		●		●	●	●																							
																											●			
●			●		●	●	●	●	●						●				●					●						●
			●		●	●								●																
																										●				
																											●	●	●	●
				●							●							●	●		●	●								
			●							●	●											●								●
																										●				
			●			●					●																			
		●																												
●	●		●	●	●		●																							●
		●		●	●	●																								

292

The stomachs of 62 specimens were empty. Ten contained fish remains. One had eaten at least 13 *Bathygobius fuscus* (40-80mm); other identifiable prey species were *Stolephorus, Gnatholepis,* apogonids, and carangids. Twenty-five specimens contained crustacean remains. Two specimens had eaten *Podophthalmus vigil* (40mm), and nine others had eaten smaller (20-30mm) portunid or xanthid crabs. Shrimps (20-30mm) were found in 8 specimens. Stomatopods (50-80mm) were found in 4 specimens. Two specimens had eaten polychaetes. A large variety of other items was apparently taken incidentally, such as: barnacles, shells, bryozoans, pieces of wood, and in one specimen, two chicken bones and a piece of carrot! One specimen had a fish hook caught in the intestine with about 10 cm of monofilament leader hanging out the anus. The specimen was otherwise in good condition and had recently eaten two large stomatopods.

Elops is a voracious predator typical of tropical estuarine areas. As the above data indicate, it occurs over all types of bottom and takes its prey from both mid-water and the benthic areas. I have seen only one mature individual of this species from Hawaii, a female about 1m long. The larger individuals apparently either occur in areas other than those frequented by juveniles, or the habits of large individuals do not make them susceptible to bottom gill nets.

Albula vulpes (bonefish or o'io) was taken almost exclusively at BC-09 and BW-13. All specimens that could be sexed were mature or nearly mature males. Six specimens had empty stomachs. The other specimens had eaten small benthic invertebrates. Crabs (5-20mm) were most frequent; other food items included amphipods, tanaids, ostracods, ophiuroids, and polychaetes. This species feeds over sand or sand rubble bottom and generally prefers shallow, relatively clear areas.

Chanos chanos (milkfish or awa) was taken most frequently at BC-09 and was most abundant in September and October. All specimens were immature and could not be reliably sexed. The stomachs were either empty or contained various amounts of microalgae. Unpublished data (Clarke) from Kaneohe Bay indicate that immature *Chanos* are either more abundant or more susceptible to gill netting in the fall and early winter. Neither adults nor small (less than ca. 350 mm) individuals are taken frequently at any time.

Sphyraena barracuda (barracuda) was taken once in December (BE-03) and once in May (BE-05). Both specimens were males, and both had empty stomachs. *Sphyraena* apparently does not roam over wide areas as do many other predators such as *Elops*. This species may, therefore, be under-represented in gill net collections.

Mugil cephalus (striped mullet) was taken in three large catches at BM-07 and BC-09 and sporadically at several other stations. The large catches (18 at BM-07 in October, 11 at BM-07 in December, and 15 at BC-09 in December) were undoubtedly due to the passage of a school near the gill nets, and tend to obscure any seasonal or station trends. *Mugil* was absent from the May series. It is unlikely that this absence was due to movement out of the study area, but rather was due either to chance or perhaps to a change in behavior.

All specimens were mature, or nearly so. About two-thirds were males, primarily due to the large proportion of males in the three large catches mentioned above. The proportion of ripe individuals appeared to increase from September to December. The numbers were 0/8 (none out of eight), 3/25, 2/9, and 15/28 for the four months. In March, 3/6 individuals were ripe and two appeared spent, suggesting late winter to early spring spawning. There was no seasonal trend in size composition.

Almost all specimens contained some microalgae or filamentous algae. Specimens from BE-09 had frequently ingested sand grains as well. One specimen had a slightly deformed caudal fin.

Mugil is a herbivore-detritivore which feeds on the bottom or at the surface layer. This species, like *Elops*, is a typical component of shallow estuarine areas in the tropics and subtropics.

Polydactylus sexfilis (moi) was taken primarily at BC-10 and otherwise only at BC-09. This species is a protanderous hermaphrodite. The sexes of the different sized fish showed the same pattern as that noted by Lowell (Reference B-2). Nine specimens (191-255mm) were males; nine (243-272mm) were intermediate; and two (265 and 328 mm) were mature females. Another 340mm specimen was probably a female, but the internal organs were missing. There was no seasonal trend in either numbers or size.

Six specimens had empty stomachs. Fish remains were found in eight stomachs. All of the latter which could be identified were, with one exception, small gobies: *Opua, Bathygobius, Gnatholepis*. One specimen had eaten five small pufferfish and three *Asterropteryx*. Fourteen specimens contained crustacean remains. Small shrimp were most frequent and included a wide variety, of which only alpheids could be identified. These alpheids were unfortunately the least common among the variety of shrimp. Some stomachs contained as many as 25-40 shrimp (20-40mm). Other crustaceans included a stomatopod, a *Podophthalmus vigil* (40mm), and small xanthid crabs.

Two of the specimens examined had large isopods (*Nerocila* sp.) attached in the oral covity. Although these parasites were about 50 mm long, they apparently did not completely inhibit feeding; one of the specimens with an isopod in its mouth still had several recently ingested shrimp in the stomach.

Polydactylus normally occurs in exposed areas. However, the males and intermediate individuals particularly tend to occur sporadically in sheltered areas (Reference B-2). *Polydactylus* is nocturnal and apparently feeds mostly on small benthic crustaceans and fishes.

Kuhlia sandvicensis (aholehole) was taken only at BC-10 and BW-13; half the specimens were taken in October at BW-13. There were 3 males and seven females. All but the smallest individual were ripe or nearly so. The stomach of one specimen was empty. The remaining specimens had eaten mostly zooplankton. One specimen had eaten about 60 stomatopod larvae (15-20mm). Another had eaten a small crab. Otherwise, the most frequent items in the stomachs were crab zoeae and megalops. Shrimp larvae were the only other items noted.

Kuhlia is a nocturnal, planktonivorous species. The data above indicate that it feeds selectively and prefers larger planktonic organisms.

Scomberoides sancti-petri (lae) was taken mostly in October and at BE-05, due to a single catch of nine individuals (over half the total catch). Two specimens were too damaged for sex to be determined; five were males; and ten were females. Those over 275mm appeared mature, but only two females (375 and 550mm) were ripe. Only two stomachs contained food; in both cases these were unidentifiable fish remains.

Limited data on *Scomberoides* (Clarke, unpublished) indicate that the species is a wide-ranging predator which feeds primarily in mid-water rather than on the bottom. Thus, the low abundance indicated by the present data, may be an artifact of the sampling method employed.

Carangoides gymnostethoides (jack) was represented by a single juvenile taken at BW-13 in December. The identification must be regarded as dubious. The specimen was immature and the stomach empty.

Caranx melampygus (blackjack) was taken mostly at BC-10 but sporadically at most other stations. All specimens were immature and could not be reliably sexed. Nineteen specimens had empty stomachs. Thirteen contained fish remains; one contained six *Stolephorus* (ca. 50mm); three contained *Asterropteryx*; and one each contained *Gnatholepis* and *Scarus* sp. Five had eaten crustaceans; in two cases these were small crabs, but the rest of the crustaceans were unidentifiable.

Only the juveniles of *C. melampygus* appear to occur in shallow, enclosed areas; the adults are found in exposed and generally deeper areas. The juveniles tend to occur as small schools during the day and disperse at night. They feed primarily on benthic organisms.

Caranx sexfasciatus (white jack) was taken at all stations except BW-13 but never in high numbers. Among the 18 fish large enough to be sexed, 10 were males and 8 were females. Those over about 275mm were mature. Six specimens had empty stomachs. Ten contained fish remains, including scarids (three times) and a synodontid (once). Nine had eaten crustaceans: (*Thalamita* sp. in one specimen), shrimp, and one stomatopod.

Caranx mate (omaka) was taken mostly at BM-07. There were five males and one female, all but the smallest being mature or nearly so. Four had empty stomachs, and two contained fish remains. One was probably *Steolphorus*.

C. mate is apparently more of a pelagic species than other nearshore carangids. The little information on its diet from Kaneohe Bay indicates that it preys primarily on small, mid-water fishes such as *Stolephorus* and on larger zooplankton.

Caranx ignobilis (jack) was represented by a single immature male taken at BW-13 in May. The stomach was empty.

Upeneus arge (stripe-tail goatfish or weke) was taken only in December, March, and May, with the May catch accounting for most of the specimens. It was taken only at four stations (BE-05, BC-09, BC-10, and DE-17). Of the 12 undamaged specimens, there were 2 males and 10 females. Most of the females were mature and all six taken in May were ripe. Nine specimens had empty stomachs; the remainder had crustacean remains, including small crabs (5-20mm), alpheid shrimp, and one small stomatopod.

This species seems to prefer more turbid, muddy areas than other goatfishes. The seasonal trend in catches suggests that there is a change in either the distribution or behavior.

Mulloidichthys samoensis (sand weke or goatfish) was taken only at BC-11 in September and November. Three of the four specimens were females, and the largest two (249 and 262mm) appeared mature but were not ripe. The stomach of one specimen was empty; that of another contained only sand. One specimen had eaten a holothurian (30mm); the other had eaten six small shrimp and numerous isopods and amphipods. One specimen had a parasitic isopod (ca. 20mm) attached near the tail.

Mulloidichthys auriflamma (goatfish) was taken only once (BC-11). The specimen was an immature female, and the stomach contained 12 ophiuroids, 2 holothurians, about 6 polychaetes, 2 nudibranchs, an alpheid shrimp, and numerous amphipods. This species is unlikely to occur in Pearl Harbor regularly.

Parupeneus porphyreus (kumu or goatfish) was taken in low but fairly consistent numbers at all seasons and mostly at BE-05, BE-03, and BC-11. Of the undamaged specimens, there were 12 males and 17 females. Specimens under 200mm appeared immature. Two ripe females were taken in November and one in March.

Eleven specimens had empty stomachs; the remaining specimens had eaten small crustaceans: crabs, shrimp, and amphipods in roughly that order. One specimen had eaten an *Asterropteryx*. Two specimens had deformed caudal fins, and two others had infected, ulcerated wounds--probably from tagging. One of these, from BE-05 in December (222mm), contained the internal anchor tag #D-69. A complete tag, #D-00014, was recovered from a 263mm specimen taken at BE-05 in October. This specimen had been feeding recently and showed no other effects from tagging.

Kyphosus cinerascens (nenue or rudderfish) was taken only twice--both times at BC-11. The specimens were too young to be sexed reliably. The stomachs of both specimens contained macroalgae.

Chaet ion auriga (threadfin butterflyfish) and *Chaetodon lunula* (raccoon butterflyfish) were each taken once at BC-11 in October. Both specimens were males; the stomachs of both were empty. These species are normally associated with living coral and should not be considered a normal component of the fish fauna of Pearl Harbor.

Scarus sordidus (parrotfish) was taken once, and *Calotomus spinidens* (parrotfish) was taken twice. The *Scarus sordidus*, taken at BC-11 in September, was rotten, so sex and stomach contents could not be determined. The *Calotomus spinidens*, taken at BC-11 in November, was a ripe female whose stomach was filled with coral and microalgae; the *Calotomus spinidens*, taken at BC-10 in May, was an immature male (?), stomach empty. Both these species are completely inactive at night and thus unlikely to be caught in gill nets even if they were abundant. Whether the specimens caught were simply strays from outside the study area cannot be determined.

Acanthurus mata (pualu or surgeonfish) was taken most frequently at BE-03 and BC-11. The high numbers for October and November were due to multiple captures at these stations. Otherwise, this species appeared to occur singly or in pairs at all but three stations. None of the specimens were mature, and only a few larger and undamaged specimens could be reliably sexed. The sex ratio was probably about 50:50. Thirteen specimens had empty stomachs. The majority of the rest contained filamentous algae or macroalgae. Microalgae, sand, shells, and coral debris were also found. One specimen had eaten the filtering appendages of several barnacles.

Acanthurus xanthopterus (pualu or surgeonfish) was taken mostly at BC-11 and BW-13. Except for a catch of eight at BW-13 in October, the species was taken sporadically. Specimens over 150mm could be sexed fairly reliably (11 males, 5 females), but only one 200mm female appeared mature. The stomachs of 11 specimens were empty. Most of the rest contained macroalgae or filamentous algae, but there were traces of microalgae, sand, and debris in several. One specimen had eaten several tunicates.

Acanthurus dussumieri (palani) was, with one exception, taken only at BC-11. Only the two largest (a 200mm female and a 257mm male) could be sexed. Four specimens had eaten mostly macroalgae, and three a mixture of sand and microalgae. Three small gastropods were found mixed with macroalgae in one specimen, and ophiuroid arms were in another stomach, along with sand and microalgae.

Acanthurus triostegus (manini) was taken on only three occasions and only at BC-11. The specimens were too immature to sex reliably. Stomachs contained both microalgae and macroalgae.

Naso brevirostris (bumphead tang) was represented by two specimens taken at BC-10 in October. Both were immature females(?); stomachs were empty.

Naso unicornis (unicorn tang) was represented by a single immature male(?) taken at BC-11 in October. The stomach contained macroalgae.

Arothron hispidus (soft puffer) was not taken by gill net. A single immature female was collected by dip-net at BC-10 in November. The stomach contents were unidentifiable.

DISCUSSION

Despite biases from sampling with gill nets, the results of the survey allow a rough characterization of the fish fauna of Pearl Harbor in terms of trophic structure and dominant species, especially when the data are considered relative to more extensive work with a variety of gear in Kaneohe Bay.

Two species, *Mugil cephalus* and *Chanos chanos*, feed on microscopic algae and detritus. These species are typical of eutrophic, tropical and subtropical estuaries. *Mugil* is clearly one of the more abundant fishes in Pearl Harbor.

It is possible that *Chanos* may be equally important, but was somewhat under-represented in the collections because it tends to spend less time near the bottom.

The other herbivorous species taken were the surgeonfishes which, in contrast to the above species, graze algae from hard substrates and are more typically considered "reef" species. They tended to be much less widespread than either *Mugil* or *Chanos* and are undoubtedly associated with a few particular areas of Pearl Harbor. Whether they are important overall in the biological economy of the area is not certain since they are active mostly during the day and thus are not sampled well by the gill nets.

Sphyrna lewini and *Elops hawaiiensis*, in spite of the probability that they are somewhat over-represented in the collections, are obviously the dominant predatory species. *Elops* is the more widespread, less seasonal, and more catholic in its diet. *Elops* is typical of similar areas in the tropics. Whether the same is true for *Sphyrna lewini* is not certain, but appears true for most enclosed areas in Hawaii. *Sphyraene barracuda* may also be important as a predator but may be under-represented in the collections.

The other common predators were the carangids. *Caranx melampygus* and *C. sexfasciatus*, the more frequently collected carangids, are bottom feeders and are widespread. *C. mate* and *Scomberoides sancti-petri* tend to feed in mid-water and consequently may not have been adequately sampled. It is of interest to note that *C. ignobilis*, which was taken only once, is relatively common in Kaneohe Bay while *C. sexfasciatus* is rarely taken there. This is the single striking difference between the Pearl Harbor data and those from Kaneohe Bay.

With the exception of *Kuhlia sandvicensis*, which feeds on zooplankton, the remaining carnivores were species that remain close to the bottom at all times and feed on smaller benthic animals. The most frequently taken species were *Albula, Polydactylus*, and the goatfishes. Most are more typical of other habitats, but also occur in areas similar to Pearl Harbor. Some may be under-represented in the samples, but too little is known of their habits to be certain. For example, *Parupeneus porphyreus* has a rather restricted home range and may be unlikely to encounter set nets.

Most of the remaining species are typical "reef" species whose primary centers of abundance are in or near areas of live coral substrate. Some, e.g., the *Chaetodon* spp, are almost certainly wandering individuals and unimportant in the fauna, but others may be important locally where acceptable substrate is available. Because most of these species are diurnal, and thus not well-sampled by gill net, not even conjecture is possible.

REFERENCES

B-1. Clarke, T. A. (1971), "The Ecology of the Scalloped Hammerhead Shark, *Sphyrna lewini*, in Hawaii". Pacific Science, 25(2):133-144.

B-2. Lowell, N. E. (1971), "Some Aspects of the Life History and Spawning of the Moi, *Polydactylus sexfilis*". M.S. Thesis, University of Hawaii.

Appendix C

Paul L. Jokiel

SHIP BERTHING AND MOVEMENT DATA

A sample of ship berthing on 37 days randomly selected over a 26 month period (January 1971 to March 1973) is presented in this appendix (Table C-1). This random sample is considered typical of ship activity in Pearl Harbor during the sampling years. Small boat schedules and ferry movements are also provided (Tables C-2 through C-4).

DATE	SAMPLE	A1	A2	A3	A5	A6	A7	B1	B2	B3	B4	B7-B8	B10-11	B12	B13	B14	B15	B16	B17	B18	B20	B21	B22	B23	B24	B25	B26	D01	D02	D03	D04
29 Dec 72	1		ARS	2MSO				SS	3MSO	SS							ARS	DE	DE	DOG	ARS	DE	2DE	AO		DD,2DE DOG	2DE	ARD	ATS SSN		A
22 Dec 72	2		ARS	2MSO				SS	3MSO	SS							ARS	DE	DE	DOG	ARS	DE	2DE	AO		DD,2DE DOG	2DE	ARD	ATS SSN		A
15 Dec 72	3		ARS	2MSO		ATF		SS	3MSO	SS	DDG						ARS	DE	DE		ARS	DE	2DE	AO		DD,2DE	DE	ARD	ATS SSN		A
6 Dec 72	4		ARS	2MSO	ARS	WHEC				SS	DDG							DE	DE	DDG	ARS	DE	2DE			2DD,DE	DE	ARD	ATS SSN		A
1 Dec 72	5		2ARS	2MSO	ARS	WHEC		SS	SSN	SS	DDG								DE	DDG			2DE	DE	DD	DD,2DE	DE	ARD	ATS SSN		A
22 Nov 72	6		ARS	2MSO		ARS		SS	SSN	SS	DDG	DE					ATF DE		DE	DDG		DE	DE	DE	DD	DD,3DE	DE	ARD	ATS SSN		A
17 Nov 72	7			2MSO		ARS		SS	SSN	SS	DDG	DE	AD		DE		ATF DE		DE	DDG	DE	DE			ATF,DD	DD,DE		ARD	SSN		
10 Nov 72	8	HCU	ARS	2MSO		ARS		SS	SSN	SS	DDG	DE	AD		DE		ATF DE	ATF	DE	DDG	DE	DE	DD		DD	DD,DE		ARD	SSN		
3 Nov 72	9	HCU	ARS	2MSO		ARS		SS	SSN	SS		DE	AD		DE		ATF DE	ATF	DE	DDG	DE	DE	DD	DDG	DD	DDG,DD	DE	ARD	SSN		
17 Oct 72	10	HCU		ARS 2MSO				SS	SSN	SS		DE	AD	AG	DE		DE	ATF	ATF	DDG		DE	DD	DDG	AD	DD,2DE	2DE	ARD	SSN		S
2 Oct 72	11	HCU	ARS	MSO	ATS	ATF		SS	SSN	SS		DDG		AG	DE		DE	ARS	ATF	DDG		DE	2DD	DE	AD	DD,2DE	2DE	ARD	DE SSN		S
15 Sept 72	12	HCU	ARS	DD	ATS	ATF		SS	SSN	SS		DDG	ATF			DE	ATF	DD	DEG				AG,DD	2DD,DE	2DLG	3DDE 4DD	2DE	ARD	DE SSN		
5 Sept 72	13	HCU	ARS	DD	ARS ATF	ATF		SS	SSN			AD	DE					DD					DD,AG DLG	DDG,DD DE	2DD,DDE 2DLG	DDG,3DE DDE	DE	ARD	DE SSN		
18 Aug 72	14	HCU	ARS	ARS		ATF		SS	SSN			AD			ATF			DD		ATF		DD	AG,DD	DDG,DD DE	DLG	2DD	DE	ARD	DE SSN		
1 Aug 72	15	HCU	ATF	ARS	ATF			SS	SSN			AD	DD		AG		ATF				ARS	DLG	3DD	DDG,DD	AD	2DD,2DE	2DE,DD	ARD	DE SSN		
17 July 72	16	HUC		ARS	ARS		ATS	SS	SSN			AD	3D	AD	AG				ARS				ADG, DD	DDG 4DD	AD,DDG DD	3DE,DD DLG	2DE,DD	ARD	DE SSN		
3 July 72	17	HCU			ARS	ARS	ATS	3DD	SS	SS			3D		AG		ATF	DLG	ARS	ARD	2DE 2DD	2DD	2ADG	DDG 2DD	AD,DDG DD	3DLG,DE DD,DDG	DD,DE	SS	DE SSN		
16 June 72	18	HCU			ARS	ARS	ATS	AD	SSN		SS		DD		AG		ATF	DLG	ARS	ARD	DE		3ADG	DDG DD	ATF,AD	DLG	DD	SS	DD		
5 June 72	19	HCU	ARS		2ARS		ATS	AD	SSN		SS				AG			DLG		ARD	DE		3ADG	2DE	AD	DLG,DDG	2DD	SS	SSN		
24 May 72	20	HCU	ARS	ARS	2ARS	ATF			SSN		SS	SS	AD		AG		ATF	DLG		ARD	DE	DE	3ADG	DDG,DD DE	AD,DD DE	2DLG, DDG	ATS,DE	SS	DD SSN		
1 May 72	21	HCU		ARS	ATF	ARS			SSN		SS	SS	AD	AG	ARS		ARS	DLG	DD	ATF	DDG	DE	3ADG	DDG, 2DD	AD,DE	DLG,DE ATA,AG	2DE	SS	DD SSN		
14 Apr 72	22	HCU	ARS		ATF	2ARS		DD	SSN		SS	SS	AD	USNS			ARS	AD LST	DE	ATF	DDG	DE	3ADG	ARS,ATA 2DD	AD,DE	2DLG	DD,2DE	SS	SSN		
7 Apr 72	23	HCU	ARS	ARS	ATF	ARS		DD	SS SSN		DE	SS	AD	DLG	DE.		ARS	AD	ARD		DDG	DE	3ADG	2DD	ARS,ATA 2DD	2DE,DDG	DLG	SS			
20 Mar 72	24		ARS	ARS	ATF			HCU	SSN	AD		SS	AD	DDG	DE.		ARS	AD		ATF	DDG	ATF	3ADG DE	DD,AG	ARS,DD DE	2DE,DD DDG	2DLG	SS	ARD		
11 Feb 72	25		ARS	ARS					SS	SS	ATF				DD HCU		ATF	ATF				ATF	3ADG DE	AD,DD DDG	2AD,AG	2DE,DLG DDG	DD,DE DLG	SS 2SSN	SSN		
7 Feb 72	26	ARS	ATF		ARS	ARS			DD SS				ATF	DE AG	HCU		ARS ATF			AD	DD	ATF	3ADG	DE,DD DLG	2AD,DDG	DE,DLG DE,DLG	DD	SS 2SSN	SSN		
24 Jan 72	27		ATF	ATF	ATF	ARS		SSN	SSN SS		ARS	AD		AG	ARS HCU		ARS	ATF DE		AD			3ADG DE	DE	DD,DE DDG	DE,DLG	DD,2DE	SS 2SSN	SSN		
14 Jan 72	28	HCU	ATF	ATF	ATF	ARS			SS		ARS	DLG	DE	AG	ARS		ARS	ATF DE	DE	DE			3ADG	AD,AGM	AD,3DG 2DD,2DE	DD, DE DD,DDG	DLG	SS 2SSN	SSN		
28 Mar 73	29	HCU		ARS	ARS			SS	AD	ARS		LPH			ATS		ARS	AD					3DE	AD,2DE	AD,2DDG	DE,2DLG	DDG,2DE	SSN	2SSN		
14 Mar 73	30	HCU		ARS				SSN	AD	ARS		DE LST		ARS	ATS				DE DLG		ATF	DE	2DE	AD,DD	DE	3DE,DLG 2DDG		SSN	2SSN	ARS	
26 Feb 73	31							SS	AD		DE			ARS	ATS.		ARS	AD	DD		ATF		2DE	AD,DE	DE,DDG	DLG,DE DEG	DDG,2DE	SSN	2SSN	ARS	
26 Nov 71	32	HCU	ARS	ATF	ATF	ARS		DDG	DDG SS	ASR	DD	DDG	DE		AD		AD 2ARS		AD	ATF	DE	ADG DE	ADG,DDG WHEC	DE,DD AG	AD,4DE	DD	DLG,2DD	SS SSN	SSN		
11 Aug 71	33		ARS	ATF	ARS					DE	ARS DOG	SS	2MSO	ATF			DE	DD	AD			AD	ADG,DD DE	AD,DE LDG	DDG,2DE	LPH	2DD	SSN	SS SSN		
22 July 71	34				ARS	ATF		LPH	DLG	DE	ARS	DD, AOG	MSO		AG		DE	DD	AD	ATF	ARS DDG		2DD 2DE	AD,2DD	2DDG, 3DD	2DLG, 2DD	2DD,DE	SSN	2SSN		
19 Feb 71	35							SS	SSN	SSN		DLG	TAG	DE	ATF		DDG	2ADG	AD DD	ARS	ATF	2MSO	DE	AG	DE,DD AD	DE,LPH DD	DD,2DE DDG	SS	SSN		
29 Feb 71	36		ATF	ARS					SSN	SSN		DLG	TAG	DE			DDG	2ARS	AD DE	2ADG	ARS		2DD,2DE	DD,DE	2DE,AD	CVS	DE,DDG, DER	DLG	SSN	SS	
18 Jan 71	37								SSN	SSN	ATF	DE	TAG	ADG	AD.		DDG	ARS ATF	AD		2ARS	ATF	2DD,DE	DD,2DE	DLG,AD	LPH	2DE,MSO DER	DLG	SSN	SS	

393

B24	B25	B26	D01	D02	D03	D04	F1	F5	F12-1	GD2	GD4	H1-2	H3-4	K3-5	K6	K7	K8	K9	K10-1	M1-2	M3	M4	MRY	O2	S1-5	S10	S11	S12	S13	S16	S17	S19	S20	S
	DD,2DE DDG	2DE	ARD	ATS SSN		AO										USNS				USNS					ASR	SSN	SSN	SSN	SSN		ARS, ATF			2S
	DD,2DE DDG	2DE	ARD	ATS SSN		AO										USNS		USNS							ASR	SSN	SSN	SSN	SSN		ARS ATF			2S
	DD,2DE DDG	DE	ARD	ATS SSN		AO							USNS	USNS		USNS				USNS					ASR	SSN	SSN	SSN	SSN		ARS			2S
	2DD,DE	DE	ARD	ATS SSN		AO										USNS				AS	WHEC				ASR		SSN	SSN		ATF	ARS			2S
DD	DD,2DE	DE	ARD	ATS SSN		AO	AS						CVS			USNS	USNS			AO	USNS				ASR		SSN	SSN		ATF	ARS			2S
DD	DD,3DE	DE	ARD	ATS SSN		AO						ADR				USNS	DLG			USNS		AS	ATF	ATS	ASR		SSN	SSN		ARS	ARS ATF			2S
ATF,DD	DD,DE		ARD	SSN					DE							USNS						USNS	ATF	ATS	ASR		SSN	SSN		ARS	ARS ATF			
DD	DD,DE		ARD	SSN					DE				ATS			USNS	SS			USNS		USNS	ATF		ASR	SS	SSN	SSN						
DD	DDG,DD	DE	ARD	SSN					DE			2DD 2DDG	SS DDG	USNS						USNS			ATF		ASR DD	SSN	SSN	SSN						
AO	DD,2DE	2DE	ARD	SSN		SSN																	ATF		ASR	SS	SSN	SSN	ATS					
AO	DD,2DE	2DE	ARD	DE SSN		SSN	WHEC	WHEC					AO USNS			USNS							ATF		ASR		SSN	SSN			ARS			
2DLG	3DDE 4DD	2DE	ARD	DE SSN			WHEC					USNS	CVS	USNS		AO				CVS		AOR	ATF			SS	SSN	SSN	ARS		ARS			
2DD,DDE 2DLG	DDG,3DE DDE	DE	ARD	DE SSN		SS						AO	CVS			AO				CVS			ATF				SSN	SSN		DDE	ARS		DE,2	
DLG	2DD	DE	ARD	DE SSN		SS								SS	2DD	USNS											SSN	SSN			2ATF			
AO	2DD,2DE	2DE,DD	ARD	DE SSN		SS						USNS	DLG			USNS	USNS			DLGN						SSN		SSN		ARS				
AO,DDG DD	3DE,DD DLG	2DE,DD	ARD	DE SSN		SS		WHEC				DD	LPH					ADG										SSN	2ATF	ATF				
AO,DDG DD	3DLG,DE DD,DDG	DD,DE	SS	DE SSN		SS	WHEC					SS USNS	SS							USNS	USNS	DLGN					SSN SS		ATF	ATF	ATF		DD	
ATF,AO	DLG	DD	SS	DD		SS	WHEC	WHEC																			SSN SS			ATF	ATF			
AO	DLG,DDG	2DD	SS	SSN		SS	WHEC						DDG								USNS					SSN	2SSN			ATF	2ATF		ARS	
AO,DD DE	2DLG, DDG	ATS,DE	SS	DD SSN		SS							DDG CVS	USNS		USNS				DE	USNS					SSN	2SSN	AGS		ATF			DE	
AO,DE	DLG,DE ATA,AG	2DE	SS	DD SSN		SS							CVS									USNS			ATF	SSN		AGS	SSN	2ATF	ARS		ARD	
AO,DE	2DLG	DD,2DE	SS	SSN		AO						LST										USNS				SSN	SSN		SSN	ATF	ARS 2ATF		ARD	
ARS,ATA 2DD	2DE,DDG	DLG	SS			SS						LSD	CVS			LKA	LPH	USNS	LPH	LST	LSD	2LST			ATF	SSN	SSN	SSN	SSN	ATF	ATF		ARD	
ARS,DD DE	2DE,DD DDG	2DLG	SS	ARD		AO SS			SSN													DE				SSN	SSN	SSN			ATF		ARD	
2AO,AG	2DE,DLG DDG	DD,DE DLG	SS 2SSN	SSN		SS						AO										DE			ASR	SSN	SSN		ARD	ATF		ARS		
2AO,DDG	DE,DLG DE,DLG	DD	SS 2SSN	SSN		SS						DLG	CVA						USNS	DE					ASR	SSN		ARS		ATF		ARD		
DD,DE DDG	DE,DLG	DD,2DE	SS 2SSN	SSN		SS						AO	CVA			LST					DDG DE	AO			ASR	SSN		2MSO	2MSO	ATF	ATF		ARD	
AO,DDG 2DD,2DE	DD, DE DD,DDG	DLG	SS 2SSN	SSN		SS						2AO	CVA			USNS		USNS		LCC	DE	DDG DE			ASR DLG	SSN				ATF	ATF		ARD	
AO,2DDG	DE,2DLG	DDG,2DE	SSN	2SSN		DE								SS						USNS		USNS						ARD		ATF	ATF		AS SSN	
DE	3DE,DLG 2DDG		SSN	2SSN	ARS	DE						DE AOE	CVA	USNS		AO	LPH										SSN	ARD SSN		ATF	ATF		AS SSN	
DE,DDG	DLG,DE DEG	DDG,2DE	SSN	2SSN	ARS	SS	WHEC	DE					CVA			USNS	USNS					USNS				SS	SSN	ARD SSN			ATF		AS,SS SSN	
AO,4DE	DD	DLG,2DD	SS SSN	SSN		SS		USNS CVS				USNS	CVA			USNS									DD	SSN	SSN	SSN		ATF	ARS		ARD	
DDG,2DE	LPH	2DD	SSN	SS SSN		SS				ARS	ARS	AO ACG													2MSO	SSN	SS	SSN					ARD	
2DDG, 3DD	2DLG, 2DD	2DD,DE	SSN	2SSN			DDG					2AO	DD USNS			USNS				CG	SS				2MSO ATF	SSN	SSN				ARS MSO		ARD	
DE,DD AD	DE,LPH DD	DD,2DE DDG	SS	SSN		DLG					ARS	AO	SS			USNS				USNS					2ATF	SSN	SSN	SSN			ARS			
2DE,AO	CVS	DE,DDG, DER	DLG	SSN	SS		DD	DD				AO									DDG DE	ATF	ATF		ATF	SSN	SSN	SSN			ATF MSO			
DLG,AO	LPH	2DE,MSO DER	DLG	SSN	SS		DE					AO				USNS				USNS	DDG	ATF	ATF		ATF	SSN	SSN	SSN			ATF			

Table C-1. 37 RAND
BERTHIN
FROM JA
1973.
unoccup
blanks
empty o

	K9	K10-1	M1-2	M3	M4	MBY	O2	S1-5	S10	S11	S12	S13	S16	S17	S19	S20	S21	V2	V3	V4	W1	W2	W4	W5
			USNS					ASR	SSN	SSN	SSN	SSN		ARS ATF			2SSN							
	USNS							ASR	SSN	SSN	SSN	SSN		ARS ATF			2SSN							
			USNS					ASR	SSN	SSN	SSN	SSN		ARS			2SSN							SSN
			AS	WHEC				ASR		SSN	SSN		ATF	ARS			2SSN				2SSN	DE SSN		
			AD	USNS				ASR		SSN	SSN		ATF	ARS			2SSN				DE			
			USNS		AS	ATF	ATS	ASR		SSN	SSN		ARS	ARS ATF			2SSN							
					USNS	ATF	ATS	ASR		SSN	SSN		ARS	ARS ATF								DD		
S			USNS		USNS	ATF		ASR	SS	SSN	SSN												USNS	
			USNS			ATF		ASR DD	SSN	SSN	SSN						SSN			SS			USNS	
						ATF		ASR	SS	SSN	SSN	ATS											SS	
						ATF		ASR		SSN	SSN			ARS									SS	
			CVS		AOR	ATF			SS	SSN	SSN	ARS		ARS			SSN		AO			SS		
			CVS			ATF				SSN	SSN		DDE	ARS		DE	2SSN							
										SSN	SSN			2ATF			SSN				DD	ARS	SS	
ST			DLGN						SSN		SSN		ARS				SSN							
	AOG										SSN	2ATF	ATF				SSN					ATF SS		
			USNS	USNS	DLGN					SSN SS		ATF	ATF	ATF		DD	SSN							
										SSN SS			ATF	ATF			ATF							
				USNS					SSN	2SSN			ATF	2ATF		ARS	ATF	LST						
			DE	USNS					SSN	2SSN	AGS		ATF			DE								
					USNS			ATF	SSN		AGS	SSN	2ATF	ARS		ARD	ARD						SSN	
					USNS				SSN	SSN		SSN	ATF	ARS 2ATF		ARD	AGS				DDG			
PH	USNS	LPH	LST	LSD	2LST			ATF	SSN	SSN	SSN	SSN	ATF	ATF		ARD		USNS		USNS				
					DE				SSN	SSN	SSN			ATF		ARD	2SSN				DD			
					DE			ASR	SSN	SSN		ARD	ATF	ARD										
		USNS	DE					ASR	SSN		ARS		ATF	ARD			SSN SS							
				DDG DE	AD			ASR	SSN		2MSO	2MSO	ATF	ATF		ARD	SSN						SSN	
	USNS		LCC	DE	DDG DE			ASR DLG	SSN				ATF	ATF		ARD	SSN						SS	
			USNS		USNS						ARD		ATF	ATF		AS SSN	SSN							
FH										SSN	ARD SSN		ATF	ATF		AS SSN	2SSN	SS						
NS					USNS				SS	SSN	ARD SSN			ATF		AS,SS SSN						ARS		
								DD	SSN	SSN	SSN		ATF	ARS		ARD							SS	
								2MSO	SSN	SS	SSN					ARD	SSN							
			CG	SS				2MSO ATF	SSN	SSN				ARS MSO		ARD	SSN	SS						
			USNS					2ATF	SSN	SSN	SSN			ARS										
				DDG DE	ATF	ATF		ATF	SSN	SSN	SSN			ATF MSO										
			USNS	DDG	ATF	ATF		ATF	SSN	SSN	SSN			ATF									SS	

Table C-1. 37 RANDOM SAMPLES OF SHIP BERTHING TAKEN OVER A PER[illegible] FROM JANUARY 1971 TO MARCH 1973. (Berths completely unoccupied not listed; blanks indicate berth was empty on the date sampled)

393

Table C-2. SHIP MOVEMENT - WATER TRANSPORTATION SMALL BOATS

SMALL BOAT SCHEDULE FOR IROQUOIS POINT AND PEARL CITY

The below schedule will be maintained Monday through Friday only. No runs will be scheduled on Saturdays, Sundays or holidays.

Iroquois Point

(MORN) Leave Iroquois Landing at 0615 with continuous runs to Lima Landing and Hickam Boathouse, leaves Iroquois Landing at 0715 and 0810 for Boathouse, Ford Island via Lima Landing and Landing "C".

(EVE) Leave Landing "A" at 1505 and 1650 for Iroquois Landing via Landing "C" and Lima Landing. Leave Iroquois Landing at 1802 for Boathouse, Ford Island via Lima Landing and Landing "A".

Pearl City

(MORN) Leave V-6 at 0630, 0645, 0715 and 0730 for F-9 (Ford Island).

(EVE) Leave F-9 at 1600, 1615 and 1630 for V-6.

From 14ND-NAVSTA-11250/6 (Rev. 3-73)

Table C-3 SHIP MOVEMENT - SCHEDULED FORD ISLAND CAR FERRY RUNS

HALAWA - FORD ISLAND,
VEHICULAR AND PEDESTRIAN

Ferry Schedule

Depart Ford Island	Depart Halawa Terminal
0035	0015
0120	0100
0205	0145
0505	0230
0550	0530
0645	0620
0725	0705
0810	0740
0855	0835
0945	0920
1030	1010
1115	1055
1230	1140
1315	1255
1400	1340
1445	1425
1535	1510
1620	1600
1705	1645
1750	1730
1835	1815
1920	1900
2005	1945
2050	2030
2135	2115
2220	2200
2305	2245
2350	2330

Table C-4. SHIP MOVEMENT - WATER TRANSPORTATION SMALL BOATS

NAVAL STATION FORD ISLAND SMALL BOAT FERRY

Depart Lndg "A"	Depart Lndg "C"	Depart Sierra 9	Depart Merry Pt.
0520	0530		
0540	0550		
0555(0600+)		0600(0605+)	0610(0615+)
*0600	0610		
*0620	0630		
0620		0625	0635
0640(0630+)	0650(0645+)		
0645		0650	0700
*0700	0710		
0710		0715	0725
0720(0730+)	0730(0745+)		
*0735		0740	0750
*0740	0750		
0800		0805	0815
0830	0845		
0900		0905	0915
0930	0945		
1000		1005	1015
1030	1045		

Depart Lndg "A"	Depart Lndg "C"	Depart Sierra 9	Depart Merry Pt.
1100		1105	1115
1130	1145		
1200		1205	1215
1230	1245		
1300		1305	1315
1330	1345		
1400		1405	1415
1430	1445		
1500		1505	1515
1530	1540(1545+)		
*1530		1535	1545
*1550	1600		
1600		1605	1615
*1610	1620		
*1630		1635	1645
1630	1645		
*1650	1655		
1700		1705	1715
1730	1745		

*Does not run on Saturday, Sunday or holiday.
+Sunday schedule

0555 until 2200 daily Landing "A" to Merry Pt. will stop at Sierra 9, Sub base

0800-0215 Daily

"A" to Merry Pt: on the hour
Merry Pt to "A": quarter past the hour
"A" to "C": on the half hour
"C" to "A": quarter till the hour

ARIZONA MONUMENT SHUTTLE

Tuesday through Sunday continuous - 0900-1530
Halawa Landing to Arizona Monument.

NAVY PEARL HARBOR TOUR

Tuesday through Saturday - 0830, 0930, 1030, 1330, 1430
From Halawa Landing - One hour trip around inner harbor.

Table C-5. OCEANOGRAPHIC SURVEY DATES (SEE SECTION 3.3)

(* Indicates random berthing, is included in Table C-1 for date indicated)

1972	Jun	4, 5*, 6, 25, 26, 27
	Jul	19, 20, 21
	Aug	17, 18*
	Sep	5, 6, 25, 26
	Oct	9, 10, 18, 19, 22, 23
	Nov	22*, 23, 24
	Dec	20, 21
1973	Jan	26, 27, 28*, 29
	Feb	5, 6, 15, 16, 17
	Mar	5, 6, 7
	Apr	26, 27, 28, 29, 30
	May	1, 2

(Same as sampling dates on which physical oceanographic data were taken)

Ship berthing and ship movement data on all 1972-1973 survey dates (see Section 3.3) are available in the MEMO office. Because of their great bulk they have not been included in this appendix. The survey dates are summarized in Table C-5.

Appendix D

Norman L. Buske

MISCELLANEOUS OBSERVATIONS

The drogue survey and current analysis was performed under contract by Mr. Norman L. Buske, Sea-Test, Kingston, Rhode Island. Section 3.3 is a revised version of the final report filed by Mr. Buske. All original data for the survey is contained in four large data reports (References 3.3-9 through 3.3-12) which are on file in the Marine Environmental Management Office. The following sample calculation was supplied by Mr. Buske to illustrate how the coefficients in Table 3.3-3 were obtained from the raw drogue track data. The example is for the surface coefficients at Location 5, see Figure 3.3-10. The axial direction of this location was 50° True; all wind and current components are with respect to this heading. A list of the drogue tracks used in the analysis follows the sample calculation.

CURRENT ANALYSIS: STATION # 5U

The observed water velocities for the selected drogue paths appear in columns 1 and 2. The components according to Figure 3-1 appear in columns 3 and 4.

Similarly, wind velocities from the data reports appear in polar form in columns 5 and 6 and in rectangular components in columns 7 and 8.

The wind-derivative terms are estimated from the observed changes in wind velocity, column 9.

The values of ΔS (column 10) come from the salinity profiles for each day for the various regions. Interpolated where required.

ΔH is the change in tidal height between successive tidal extrema from Tide Tables.

t/ΔT is the fractional time elapsed over the half tidal cycle, column 13. t indicates flood, - ebb. Column 13 is column 11 multiplied by the size of the local phase. This is the tidal term in Equation 3-1 divided by T and multiplied by ΔT. The effect of variable ΔT is, thus, not included in this analysis.

Now, the constituents of u are sought. It is apparent that the wind term U is important. So, pairs of items are selected which are relatively invariant, except in u and U:

Items: (i,j)	(9,8)	(20,-)	(21,-)	(29,-)	(7,-)
U_i-U_j	1.1	1.2	1.8	1.1	1.3
u_i-u_j	2.4	1.3	3.	1.0	3.
u_i-u_{j}/U_i-U_j	2.2	1.1	1.7	.9	2.3

The mean value of u_i-u_{j}/U_i-U_j is 1.64 for these selected pairs. (Because of the apparent strong relation, 4 of the pairs used are single items. That is, the effect is assumed to be primarily due to the wind.)

After a look at the tidal constituent, the wind effect appeared to be slightly underestimated. Thus, the final wind estimate was increased to 2.0, which is subtracted from the velocity, column 14. 40% of the water velocity (u component) is accounted for.

Now the remaining velocity is considered for the tidal effect. As above:

Items: (i,j)	(7,17)	(28,29)	(23,22)	(3,9)	(3 or 4,-)
T_i-T_j	2.2	.7	2.9	2.4	2.4
u_i-u_j	1.0	.4	.4	1.4	1.0
u_i-u_{j}/T_i-T_j	.45	.57	.14	.58	.42

The mean ratio is 0.43, which does not have much effect on the residuals. This is rounded to 0.4, which is subtracted in column 15.

Next the estuarine term is evaluated (the item numbers have been lost) on the velocity components of column 15:

Items: (i,j)	(1,-)	(2,-)	(13,21)	(15,-)
$\Delta S_i - \Delta S_j$	2.3	2.3	1.1	1.2
$u_i - u_j$	-1.7	-1.8	- .2	0
$u_i - u_{j/\Delta S_i - \Delta S_j}$	- .7	- .8	- .2	0

The mean effect (ratio) is -0.425, which is rounded to -0.4 and subtracted in column 16, with a small reduction in the residuals.

The other driving terms were considered in a similar manner, with no effects apparent. Then the mean (0.44) of column 16 is removed. The result is column 17, from which the residual is calculated.

The same procedure was repeated for the v component of velocity.

Table 3-1 is obtained by converting to meter/sec. This is simple except for the tide. There, T must be multiplied by the mean half-tidal period ($\overline{\Delta T}$), about 2.2×10^4 sec, for Pearl Harbor before the conversion is made. The total, multiplicative conversion factor is:

$$\left(\frac{3.281 \text{ ft/sec} \times 2.5 \times 10^4 \text{ sec}}{19.44 \text{ kts}}\right) = 4.2 \times 10^3 \ \frac{\text{ft}}{\text{kts}}$$

For example, T for Station 5U (u component) is 0.4 kt/ft x 4.2×10^3 ft/kt = $1.68 \times 10^3 \sim 2 \times 10^3$, which appears under T in Table 3-1.

			WATER VELOCITY			PONENT		∿ v COMPONENT	
DATA POINT DROGUE NO.	DATE	NO. ITEM	[1] SPEED	[2] DIRECTION	W	ΔS REMOVED [16] +0.4 ΔS	MEAN REMOVED [17] -.4	PARALLEL WIND REMOVED [18] v-1V	MEAN REMOVED [19] + [illegible]
1128-1257	6/6	1	.298	239		-.8	-1.2	-.6	-.3
1246-1416	6/6	2	.279	227		-.9	-1.3	-.1	.2
1157-1305	26/6	3	.1757	259		.1	-.3	-.2	.1
1300-1403	27/6	4	.1962	220		.2	-.2	.0	.3
0911-1040	20/7	5	.1229	352		.5	.1	-1.1	-.8
1017-1106	18/8	6	.1033	241		1.8	1.4	-.2	.1
1106-1237	18/8	7	.3005	238		.5	.1	-.6	[illegible]
1243-1338	18/8	8	.2873	228		.4	.0	-.4	[illegible]
0837-0934	6/9	9	.0781	280		-.3	-.7	-.7	-.4
1244-1420	6/9	10	.2616	220		-3.5	-3.9	.0	.6
0926-1031	10/10	11	.0934	210		.0	-.4	.4	.7
1133-1335	10/10	12	.0863	350		-.1	-.5	.1	[illegible]
0921-1011	19/10	13	.1377	230		.7	.3	.0	.3
1121-1345	19/10	14	.2616	230		-1.1	-1.5	.0	.3
1052-1130	23/10	15	.0639	250		1.7	1.3	.3	.6
0909-1009	23/10	16	.0708	270		2.9	2.5	-.7	-.4
1120-1201	25/10	17	.3952	240		-.4	-.8	-.9	-.6
1055-1211	24/11	18	.0586	330		1.5	1.1	-.5	[illegible]
1216-1345	24/11	19	.0978	030		1.4	1.0	-.6	-.3
0815-0829	27/1	20	.1736	270		1.3	.9	.0	.3
1106-1235	27/1	21	.3391	230		.5	.1	-1.4	-1.1
0923-1044	6/2	22	.1050	220		.0	-.4	.2	.5
1421-1623	6/2	23	.2474	240		.4	.0	-.5	-.2
1049-1154	16/2	24	.2399	230		.5	.1	.0	.3
1616-1717	16/2	25	.0266	040		1.5	1.1	.1	[illegible]
0932-1029	17/2	26	.3518	250		.1	-.3	-.9	-.6
0958-1104	6/3	27	.2363	240		1.0	.6	-.7	-.4
0819-1027	26/4	28	.0760	280		1.4	1.0	-.5	-.2
0816-0847	1/5	29	.1120	250		1.3	.9	-.2	.1
TOTAL |R|						26.8	24.0	9.7	10.[illegible]
UNITS:	1972-73		SPEED IN KNOTS	DEGREES TRUE			$\overline{\|R\|}$=.827 KNOTS		$\overline{\|R\|}$= [illegible] KNOTS

Table D-1. PEARL HARBOR: STATIO[illegible]

Table D-2. DROGUE DATA

Drogue tracks are identified by initial and terminal times and dates. Original data may be found in References 3.3-9 through 3.3-12. The data used in the analytical development of the preliminary circulation model are as follows:

STATION NUMBER	TIME	DAY	MO.	TIME	DAY	MO.	TIME	DAY	MO.
1S	1119-1212	26	06	0840-1011	20	07	1147-1321	20	07
	1007-1051	18	08	1000-1137	06	09	0954-1104	26	09
	0956-1104	10	10	1107-1244	10	10	0939-1055	19	10
	1101-1304	19	10	0847-0937	19	10	0740-0850	29	01
	1408-1555	06	02	1252-1413	26	04			
1B	1119-1215	26	06	1215-1336	26	06	0840-1005	20	07
	1005-1151	20	07	1151-1336	20	07	1336-1516	20	07
	0830-0947	18	08	0954-1109	26	09	1107-1239	10	10
	0845-0937	19	10	1046-1257	19	10	0849-0950	29	01
	0855-1120	26	04	1255-1422	26	04			
2S	1204-1252	05	06	1035-1155	06	06	1156-1315	06	06
	1116-1208	26	06	1208-1339	26	06	0848-1015	20	07
	1019-1139	20	07	0832-0954	18	08	1141-1318	06	09
	0948-1106	26	09	0905-0950	10	10	0844-0905	10	10
	0850-0944	19	10	1100-1308	19	10	0915-0934	23	11
	0959-1043	27	01	1229-1345	27	01	1125-1252	26	04
2B	1204-1250	05	06	1250-1429	05	05	1429-1528	05	05
	1035-1158	06	06	1158-1324	06	06	1116-1205	26	06
	1205-1343	26	06	0848-1007	20	07	1145-1344	20	07
	1344-1524	20	07	0832-0958	18	08	0958-1055	18	08
	1055-1251	18	08	0854-0957	06	09	0957-1147	06	09
	0948-1059	26	09	0846-0908	10	10	0946-1058	10	10
	0850-0939	19	10	0915-0932	23	11	0959-1040	27	01
	1222-1340	27	01						
3S	1132-1250	06	06	1252-1427	06	06	1427-1629	06	06
	1241-1350	18	08	0844-0950	06	09	0950-1058	06	09
	1058-1250	06	09	0919-1014	23	10	0937-1037	06	02
	1145-1254	06	02	1429-1606	06	02	1100-1157	16	02
	1336-1428	16	02	1428-1610	16	02	0939-1038	17	02
	1123-1231	17	02	1231-1358	17	02	1406-1541	06	03
	1241-1400	26	04						
3B	1132-1248	06	06	1248-1423	06	06	1241-1346	18	08
	0844-0948	06	09	0948-1055	06	09	0937-1039	06	02
	1039-1150	06	02	1252-1427	06	02	1429-1608	06	02
	1100-1159	16	02	1430-1604	16	02	0939-1036	17	02
	1229-1354	17	02	0829-1036	26	04	1241-1356	26	04

4S	1308-1400 27 06	1400-1507 27 06	0755-0928 20 07
	0930-1233 20 07	1019-1113 18 08	1118-1231 18 08
	1231-1332 18 08	0839-0945 06 09	0936-1231 26 09
	0928-1029 10 10	1135-1323 10 10	0919-1006 19 10
	1129-1347 19 10	0913-1011 23 10	1253-1432 23 10
	1127-1154 25 10	1057-1216 24 11	1357-1540 24 11
	0819-0901 27 01	1114-1237 27 01	0934-1041 06 02
	1158-1246 06 02	1051-1152 16 02	1329-1434 16 02
	0936-1041 17 02	1004-1058 06 03	0825-1030 26 04
	1236-1350 26 04		
4B	1308-1356 27 06	1356-1503 27 06	0755-0916 20 07
	1019-1111 18 08	1343-1423 18 08	0839-0943 06 09
	1246-1428 06 09	0936-1223 26 09	0928-1027 10 10
	1136-1325 10 10	0919-1013 19 10	0913-1011 23 10
	1130-1247 23 10	1247-1440 23 10	1046-1113 25 10
	1057-1214 24 11	1214-1348 24 11	0819-0902 27 01
	1245-1406 27 01	0934-1043 06 02	1257-1433 06 02
	1051-1151 16 02	1316-1425 16 02	1557-1712 16 02
	0936-1034 17 02	1119-1227 17 02	1004-1101 06 03
	1358-1537 06 03	1032-1231 26 04	1228-1346 26 04
5S	1128-1257 06 06	1246-1416 06 06	1157-1305 26 06
	1300-1403 27 06	0911-1040 20 07	1017-1106 18 08
	1106-1237 18 08	1243-1338 18 08	0837-0934 06 09
	1244-1420 06 09	0926-1031 10 10	1133-1335 10 10
	0921-1011 19 10	1121-1345 19 10	1052-1130 23 11
	0909-1009 23 10	1120-1201 25 10	1055-1211 24 11
	1216-1345 24 11	0815-0829 27 01	1106-1235 27 01
	0923-1044 06 02	1421-1623 06 02	1049-1154 16 02
	1616-1717 16 02	0932-1029 17 02	0958-1104 06 03
	0819-1027 26 04	0816-0847 01 05	
5B	1128-1242 06 06	1242-1413 06 06	1413-1637 06 06
	1157-1304 26 06	1304-1640 26 06	1300-1352 27 06
	1352-1458 27 06	0911-1037 20 07	1017-1109 18 08
	1109-1228 18 08	0940-1044 06 09	1243-1413 06 09
	1025-1138 10 10	1009-1127 19 10	1052-1128 23 11
	0909-1008 23 10	1117-1148 25 10	1055-1210 24 11
	1210-1343 24 11	0918-1004 27 01	1109-1247 27 01
	0923-1046 06 02	1049-1148 16 02	1619-1720 16 02
	0932-1031 17 02	1224-1346 17 02	0958-1056 06 03
	1226-1358 06 03	0819-1032 26 04	1004-1104 01 05
6S	1152-1256 26 06	1025-1129 18 08	1129-1325 18 08
	0808-0920 06 09	0920-1025 06 09	1036-1208 26 09
	1037-1227 10 10	1017-1136 19 10	0935-1026 23 10
	1225-1248 25 10	1041-1155 24 11	1022-1207 27 01
	1002-1101 29 01	1003-1100 06 02	1343-1529 06 02
	1122-1240 16 02	1414-1529 16 02	1657-1817 16 02
	1010-1113 06 03	0940-1137 26 04	1443-1508 01 05

Table D-12. (Continued)

6B	1201-1233	27	06	1233-1315	27	06	1315-1409	27	06
	1025-1127	18	08	0808-0923	06	09	1219-1403	06	09
	1036-1201	26	09	1037-1207	10	10	1207-1342	10	10
	1019-1134	19	10	1145-1327	23	10	1305-1336	25	10
	1041-1152	24	11	1320-1516	24	11	1002-1059	29	01
	1003-1056	06	02	1343-1456	06	02	1237-1414	16	02
	1656-1820	16	02	1010-1115	06	03	1422-1630	06	03
	0940-1136	26	04	1443-1506	01	05			
7S	1348-1518	05	06	1112-1229	06	06	1234-1359	06	06
	1149-1254	26	06	0944-1113	20	07	1113-1253	20	07
	1247-1449	20	07	1032-1140	18	08	1022-1215	06	09
	0915-1018	06	09	1033-1141	26	09	1023-1140	19	10
	0928-1029	23	10	1233-1302	25	10	1037-1145	24	11
	1145-1332	24	11	1332-1531	24	11	0901-1010	29	01
	1005-1104	06	02	1102-1220	06	02	1127-1242	16	02
	1120-1252	06	03	0947-1132	26	04	1450-1513	01	05
7B	1348-1505	05	06	1112-1232	06	06	1232-1356	06	06
	1149-1246	26	06	1221-1247	27	06	0944-1110	20	07
	1110-1250	20	07	1032-1132	18	08	0815-0913	06	09
	1213-1347	06	09	1033-1212	26	09	1023-1137	19	10
	0928-1027	23	10	1233-1309	25	10	1037-1144	24	11
	1317-1505	24	11	0901-1008	29	01	1005-1103	06	02
	1127-1233	16	02	1412-1524	16	02	1652-1813	16	02
	0947-1140	26	04	1450-1515	01	05			
8S	1142-1242	26	06	0830-0957	20	07	0957-1127	20	07
	1043-1143	18	08	1024-1151	26	09	0945-1032	23	10
	1227-1339	23	10	1017-1127	24	11	1136-1257	24	11
	1257-1445	24	11	1310-1423	27	01	0928-1026	29	01
	1223-1350	06	02	1134-1230	16	02	1507-1646	16	02
	1646-1808	16	02	1031-1130	06	03	1456-1556	06	03
	1155-1231	07	03	0957-1144	26	04			
8B	1142-1240	26	06	1240-1758	26	06	0830-0955	20	07
	0955-1124	20	07	1043-1145	18	08	1229-1354	06	09
	1024-1147	26	09	1030-1142	19	10	0945-1036	23	10
	1017-1130	24	11	1130-1302	24	11	1302-1428	24	11
	1310-1427	27	01	0928-1027	29	01	1130-1307	29	01
	1134-1227	16	02	1641-1752	16	02	1031-1125	06	03
	1226-1332	07	03	0957-1149	26	04			
9S	1106-1225	06	06	1138-1236	26	06	0826-0950	20	07
	0950-1121	20	07	1020-1154	26	09	1140-1432	19	10
	0949-1046	23	10	1046-1223	23	10	1020-1136	24	11
	1320-1432	27	01	0759-0840	29	01	1123-1312	29	01
	1347-1515	06	02	1409-1504	16	02	1130-1200	06	03
	1233-1308	07	03	1325-1449	26	04			
9M	1138-1236	26	06	1020-1137	24	11	1305-1456	24	11
	0759-0839	29	01	1134-1226	16	02	1454-1637	16	02
	1601-1658	06	03	1229-1340	07	03	1151-1229	07	03
	1325-1441	26	04						

Table D-2. (Continued)

9B	1106-1224	06	06	1224-1350	06	06	1138-1232	26	06
	0826-0952	20	07	0952-1119	20	07	1020-1142	26	09
	1143-1422	19	10	0949-1039	23	10	1039-1211	23	10
	1020-1139	24	11	1306-1453	24	11	1320-1435	27	01
	0759-0838	29	01	1008-1108	06	02	1347-1505	06	02
	1436-1620	06	03	1325-1444	26	04			
0S	1055-1217	06	06	1217-1342	06	06	1415-1520	27	07
	1427-1536	20	07	0823-0906	06	09	1013-1206	06	09
	1208-1328	06	09	0939-1046	10	10	1046-1212	10	10
	0932-1040	19	10	0758-0923	21	12	1023-1117	06	02
	1358-1537	06	02	1235-1412	06	03	1303-1429	26	04
	1029-1057	29	04						
0B	1055-1219	06	06	1219-1345	06	06	1330-1422	27	06
	1413-1515	27	06	0823-0908	06	09	0908-1010	06	09
	1010-1203	06	09	0939-1045	10	10	1045-1218	10	10
	1218-1402	10	10	0932-1037	19	10	0758-0925	21	12
	1023-1113	06	02	1402-1532	06	02	1624-1731	16	02
	1446-1624	16	02	1029-1100	29	04			

APPENDIX E

J. Geoffrey Grovhoug
Eric B. Guinther
Dennis T. O. Kam

GENERAL INFORMATION

The cumulative checklist of marine organisms collected from Pearl Harbor during the period May 1971 through May 1973 represents biota identified from the following sampling activities:

- Fish Survey (collections by gill nets, traps, dipnets, spears & hand capture; sightings by visual transects & general underwater observations. See Section 2.1 for details)
- Fish Stomach Analysis (See Appendix B)
- Benthic Faunal & Floral Survey (See Section 2.2 for details)
- Piling Faunal Survey (See Section 2.4 for details)
- Micromolluscan Survey (See Section 2.3 for details)
- Plankton sampling (collections conducted in November 1971 at eighteen locations throughout the harbor)
- Incidental field collections
- SCUBA and snorkel diving collections, observations & photos

Organisms contained in the cumulative checklist were examined and identified/verified by the following individuals:

Dr. Albert H. & Dora M. Banner (HIMB)	Alpheid shrimp (all)
Dr. Julie Brock (U of H)	Polychaetes (in part)
Dr. Allen Cattell (HIMB)	Dinoflagellates (all)
Dr. Thomas A. Clarke (HIMB)	Fish stomach analyses (all)
Dr. Dennis M. Devaney (B.P. Bishop Museum)	Ophiuroids(in part)
Dr. Maxwell S. Doty (U of H)	Marine algae (all)
Dr. Evan C. Evans III (NUC, MEMO)	Mollusca (in part)
J. Geoffrey Grovhoug (NUC, MEMO)	Invertebrates & Fishes (all)
Eric B. Guinther (HIMB)	Invertebrates (all)
Dr. E. Alison Kay (U of H)	Micromollusca (all)
Gerald S. Key (HIMB)	Fishes (in part)
Dr. John C. McCain (HECO)	Invertebrates (in part)
Dr. John M. Miller (HIMB)	Larval fishes & plankton (in part)
A. Earl Murchison (NUC, code 4030)	Fishes (in part)
Thomas J. Peeling (NUC, MEMO)	Fishes & Invertebrates (all)
Dr. John E. Randall (B.P. Bishop Museum)	Fishes (in part)
Q. Dick Stephen-Hassard (C. Brewer & Co.,Ltd.)	Invertebrates (in part)

Legend for organizations: HIMB = Hawaii Institute of Marine Biology, Coconut Island; U of H = University of Hawaii (Manoa campus); NUC, MEMO = Naval Undersea Center, Marine Environmental Management Office, code 406; HECO = Hawaiian Electric Company, Environmental Department

Organisms marked by an asterisk (*) in the cumulative checklist were collected only outside of bio-station BC-11 during the survey period.

Entries in the HCZDB # column: "X's" indicate that numbers have not yet been assigned; final "0's" indicate the level to which taxonomic identification has been performed

APPENDIX E. CUMULATIVE CHECKLIST OF MARINE ORGANISMS COLLECTED FROM PEARL HARBOR, OAHU (MAY 1971 - MAY 1973).

Plant Kingdom	HCZDB #
Chlorophyta (Green algae)	
Chlorophyceae	
Ulotricales	
Ulvaceae	
Ulva fasciata Delile	0413160201
Ulva lactuca Linnaeus	0413160202
Ulva reticulata Forsskål	0413160203
Ulva sp.	0413160200
Cladophorales	
Cladophoraceae	
Cladophora sp.	0418010100
Siphonales	
Caulerpaceae	
Caulerpa sertularioides (Gmelin)	0421030106
Caulerpa verticillata J. Agardh	0421030108
Chrysophyta (Golden-brown algae)	
Bacillariophyceae	
Centrales	
Coscinodiscaceae	
Coscinodiscus sp.	0741060100
Pyrrophyta (Fire algae)	
Dinophyceae	
Thecatales	
Prorocentridae	
Prorocentrum gracile Schütt	0912010101
Gymnodiniales	
Gymnodiniidae	
Cochlodinium catenatum Okamura	0921020101
Polykrikidae	
Polykrikos schwartzi (Bütschli)	0921030101
Noctiluca minuta (McCartney & Kofoid)	0921030201
Peridiniales	
Dinophysidae	
Dinophysis caudatum (Kent)	0924010301
Peridiniidae	
Gonyaulax minutum Wichener	0924030101
Peridinium crassipes (Kofoid)	0924030201
Ceratium ferka (Ehrenberg)	0924030301
Rhodophyta (Red algae)	
Rhodophyceae	
Gigartinales	
Hypneaceae	
Hypnea cervicornis J. Agardh	1324100102
Gracilariaceae	
Gracilaria lichenoides Linnaeus	1324150106
Ceramiales	
Ceramiaceae	
Griffithsia sp.	1326010400

Rhodophyta (continued)	
Ceramiaceae	
Spyridia filamentosa (Wulfen)	1326010602
Centroceras clavulatum (C. Agardh)	1326010901
Rhodomelaceae	
Acanthophora spicifera (Vahl)	1326040101
Polysiphonia subtilissima Montagne	1326040724

Animal Kingdom

Porifera (Sponges)	
Demospongiae	
Poecilosclerida	
Amphilectidae	
Mycale sp.	3524180100
Halichondrida	
Hymeniacidonidae	
Hymeniacidon sp.	3525220100
Axinellida	
Raspailiidae	
Phycopsis aculeata (Wilson)	3526260201
Cnidaria (Coelenterates)	
Hydrozoa	
Hydroida	
Pennariidae	
Pennaria tiarella McCrady	3711050101
Scyphozoa	
Rhizostomatida	
Cassiopeidae	
Phyllorhiza punctata von Ledenfeld	3724030101
Aurelia cf. *labiata* Chamisto & Eysenhardt	3723010101
Anthozoa	
Telestacea	
Telestidae	
Telesto ?riisei (Duchassaing & Michelotti)	3734010101
Actinaria	
Actiniidae	
Cladactella sp.	3742120100
Stoichactinidae	
Radianthus cookei (Verrill)	3742200101
Isophelliidae	
Epiphellia humilis (Verrill)	3742290201
Hormathiidae	
Calliactis ?polypus (Forsskål)	3742300101
Madreporaria	
Seriatoporidae	
* *Pocillopora meandrina* Dana	3746020110
Acroporidae	
* *Montipora* sp.	3746030100
Ctenophora (Comb jellies)	
Tentacula	
Cydippida	
Pleurobrachiidae	
Pleurobrachia sp.	3911010100

- Platyhelminthes (Flatworms)
  - Turbellaria
    - Polycladida
      - Planoceridae
        - *Planocera* sp. 4131070100

- Nemertea (Rubberworms) 4400000000

- Nematoda (Roundworms) 5100000000

- Annelida (Segmented worms)
  - Polychaeta
    - Errantia
      - Aphroditidae
        - *Paralepidonotus ampulliferus* (Grube) 5511012201
        - *Iphione muricata* (Savigny) 5511012401
      - Amphinomidae
        - *Eurythoe complanata* (Pallas) 5511040201
      - Phyllodocidae 5511060000
      - Syllidae
        - *Syllis* sp. 5511140100
        - *Syllis (Typosyllis) variegata* (Grube) 5511140107
        - *Syllis (Haplosyllis) spongicola* (Grube) 5511140108
        - *Syllis (Langerhansia) cornuta* (Rathke) 5511140109
        - *Trypanosyllis zebra* (Grube) 5511140301
        - *Opisthosyllis* sp. 5511140400
      - Nereidae
        - *Ceratonereis* sp. 5511160100
        - *Nereis* sp. 5511160400
        - *Nereis (Neanthes) caudata* (Delle Chiaje) 5511160410
        - *Micronereis* sp. 5511160500
        - *Platynereis* sp. 5511160600
        - *Perinereis* sp. 5511160800
        - *Perinereis cultrifera* 5511160804
        - *Laeonereis* sp. 5511160900
      - Eunicidae
        - *Eunice antennata* (Savigny) 5511200102
        - *Eunice australis* Quatrefages 5511200103
        - *Eunice filamentosa* Grube 5511200105
        - *Eunice vittata* (Delle Chiaje) 5511200108
        - *Eunice (Palolo) siciliensis* Grube 5511200109
        - *Eunice (Nicidion)* sp. 5511200111
        - *Lysidice collaris* Grube 5511200201
        - *Marphysa sanguinea* (Montagu) 5511200303
        - *Nematonereis unicornis* (Grube) 5511200401
        - *Paramarphysa* sp. 5511200500
        - *Diopatra* sp. 5511202200
        - *Oenone fulgida* (Savigny) 5511204201
        - Lumbrinerid sp. 5511206201
        - *Arabella* sp. 5511208100
        - *Arabella iridescens* Treadwell 5511208102
        - *Dorvillea* sp. 5511209100

Annelida (continued)	
Polychaeta	
Sedentaria	
Cirratulidae	
Cirratulus sp.	5521040100
Cirriformia sp.	5521040200
Cirriformia hawaiensis Hartman	5521040203
Chaetopteridae	
Phyllochaetopterus verrilli Treadwell	5521070102
Orbiniidae	5521080000
Capitellidae	
Dasybranchus lumbricoides Grube	5521130101
Terebellidae	
Thelepus setosus (Quatrefages)	5521225002
Sabellidae	
Sabella sp.	5521230100
Serpulidae	
Hydroides norvegica Gunnerus	5521244201
Hydroides crucigera (Morch)	5521244203
Hydroides lunulifera Claparede	5521244204
Mercierella sp.	5521244300
Spirorbis sp.	5521244800
Hirudinea	
Rhynchobdellida	
Piscicolidae	5552020000
Sipunculida (Peanut worms)	
Phascolosoma dentigerum (Selenka&deMan)	5611010103
Arthropoda (Arthropods)	
Chelicerata	
Pycnogonida	
Phoxichilidiidae	
Anoplodactylus portus Calman	6391010203
Endeidae	
Endeis nodosa Hilton	6391010301
Crustacea	
Ostracoda	6430000000
Copepoda	
Cyclopoida	
Copilia sp.	6443010300
Cirripedia	
Thoracica	
Balanus sp.	6451090100
Balanus amphitrite amphitrite Darwin	6451090101
Balanus amphitrite hawaiiensis Broch	6451090102
Balanus eburneus Gould	6451090103
Balanus trigonus Darwin	6451090106
Chelonobia sp.	6451070200
Malacostraca	
Mysidacea	6466000000
Tanaidacea	
Apseudes sp. 1	6468010102
Apseudes sp. 2	6468010103
Leptochelia dubia (Kroyer)	6468130101
Anatanais insularis Miller	6468140201

Arthropoda (continued)
Crustacea
Malacostraca
Isopoda

Mesanthura hieroglyphica Miller&Menzies	6471060201
Cirolana sp.	6471160100
Hansenolana sphaeromiformis (Hansen)	6471160201
Limnoria sp.	6471210100
Limnoria tripunctata Menzies	6471210103
Sphaeroma walkeri Stebbing	6471220101
Paracerceis sculpta (Holmes)	6471220201
Dynamenella sp.	6471220300
Colidotea edmondsoni Miller	6471270101
Amphipoda	
Lembos sp.	6473080400
Lembos macromanus (Shoemaker)	6473080405
Corophium baconi Shoemaker	6473180101
Corophium acherusicum Costa	6473180103
Ericthonius brasiliensis (Dana)	6473180201
Elasmopus ecuadorensis hawaiensis Schellenberg	6473250203
Elasmopus rapax Costa	6473250209
Photis hawaiensis Banard	6473320302
Leucothoe sp.	6473380100
Leucothoe hyhelia Banard	6473380101
Podocerus brasiliensis (Dana)	6473510201
Caprellidae	
Caprella scaura Templeton	6475XXXXXX
Decapoda/Natantia	
Leucifer sp.	6482020100
* *Conchodytes tridacnae* Peters	6483320401
Leander sp.	6483324200
Palaemonella sp.	6483324300
* *Gnathophylloides mammillatus* (Edmondson)	6483330101
Alpheopsis equalis Coutiere	6483410601
Alpheus sp.	6483411000
Alpheus lobidens polynesica Banner & Banner	6483411001
Alpheus mackayi Banner & Banner	6483411002
Alpheus rapax Fabricius	6483411003
Alpheus rapacida deMan	6483411004
Alpheus platyunguiculatus (Banner)	6483411005
Alpheus gracilis simplex (Banner)	6483411016
Alpheus diadema Dana	6483411022
Alpheus paralcyone Coutiere	6483411023
Alpheus paracrinitus Miers	6483411024
Alpheus lanceloti Coutiere	6483411027
Alpheus gracilipes Stimpson	6483411028
Alpheus heeia Banner & Banner	6483411036
Leptalpheus pacificus Banner & Banner	6483411101
Synalpheus pachymeris Coutiere	6483411201
Synalpheus thai Banner & Banner	6483411202
Synalpheus streptodactylus Coutiere	6483411204
Synalpheus bituberculatus deMan	6483411212

Arthropoda (continued)
Crustacea
Malacostraca
Decapoda/Natantia

Lysmata acicula (Rathbun)	6483430502
Enoplometopus occidentalis (Randall)	6485010101
Stenopus hispidus (Olivier)	6485110101

Decapoda/Reptantia

* *Panulirus marginatus* (Quoy & Gaimard)	6486060101
Panulirus penicillatus (Oliver)	6486060102
Scyllarides squammosus (Milne Edwards)	6486070201
* *Parribacus antarcticus* (Lund)	6486070301
Calcinus latens Randall	6487130302
Calappa hepatica (Linnaeus)	6488180102
Parthenope whitei (Adams & White)	6488260104
Libystes nitidus A. Milne Edwards	6488311201
Portunus sanguinolentus (Herbst)	6488312101
Portunus longispinosus Rathbun	6488312106
Scylla serrata de Man	6488312201
Thalamita integra Dana	6488313301
Thalamita admete (Herbst)	6488313303
Thalamita crenata Latreille	6488313313
Podophthalmus vigil (Fabricus)	6488315101
Metopograpsus thukuhar (Owen)	6488320301
* *Plagusia depressa tuberculata* (Lameroux)	6488323001
Platypodia eydouxi (A. Milne Edwards)	6488330504
Lophozozymus dodone (Herbst)	6488330602
Madeus simplex A. Milne Edwards	6488330801
Leptodius sanguineus (Milne Edwards)	6488331001
Xanthias sp.	6488331100
Carpilodes bellus (Dana)	6488331404
Etisus electra (Herbst)	6488331901
Etisus laevimanus Randall	6488331905
Panopeus pacificus Edmondson	6488332201
Phymodius nitidus (Dana)	6488332303
Chlorodiella laevissima (Dana)	6488332402
Liocarpilodes integerrimus (Dana)	6488332501
Pilumnus oahuensis Edmondson	6488335806
Glabropilumnus seminudus (Miers)	6488335901
* *Trapezia guttata* Ruppel	6488336004
Macrophthalmus telescopicus (Owen)	6488371301

Stomatopoda

Pseudosquilla ciliata Miers	6489010101
Gonodactylus falcatus (Forsskål)	6489010201

Mollusca (Mollusks)
Gastropoda
Archaeogastropoda
Scissurellidae

* *Scissurella* sp.	7021020100

Fissurellidae

Diodora granifera (Pease)	7021050302

Patellidae

Cellana sp.	7021070100

Mollusca (continued)	
Gastropoda	
Archaeogastropoda	
Trochidae	
Trochus histrio Reeve	7021120101
Euchelus gemmatus Gould	7021120403
Turbinidae	
Leptothyra rubricincta Mighels	7021140201
* *Leptothyra candida* Pease	7021140203
Phasianellidae	
* *Tricolia variabilis* (Pease)	7021160101
Phenacolepadidae	
* *Phenacolepas* sp.	7021230100
Mesogastropoda	
Littorinidae	
Littorina scabra (Linnaeus)	7022140101
Rissoidae	
* *Rissoina gracilis* Pease	7022260103
* *Rissoina ambigua* Gould	7022260104
* *Rissoina turricula* Pease	7022260105
* *Rissoina miltozona* Tomlin	7022260108
* *Merelina* sp.	7022260400
* *Zebina tridentata* Michaud	7022260501
* *Cithna* sp.	7022260600
* *Parashiela beetsi* Ladd	7022260701
Vitrinellidae	
* *Cyclostremiscus minutissimus* (Pilsbry)	7022290101
* *Cyclostremiscus emeryi* Ladd	7022290102
* *Cyclostremiscus* sp. A	70222901XX
Cyclostremiscus sp. B	70222901XX
* *Cyclostremiscus* sp. C	70222901XX
* *Cyclostremiscus* sp. D	70222901XX
Rissoellidae	
Risoella spp.	7022330100
Architectonicidae	
Heliacus sp.	7022380300
Vermetidae	
Dendropoma platypus (Morch)	7022430101
Dendropoma ?psarocephala Hadfield & Kay	7022430104
Vermetus sp.	7022430100
Vermetus alii Hadfield & Kay	7022430401
Diastomidae	
Diala varia A. Adams	7022530101
* *Alaba goniochila* A. Adams	7022530201
Obtortio fulva Watson	7022530301
* *Obtortio perparvulum* (Watson)	7022530302
Cerithiidae	
* *Cerithium nesioticum* Pilsbry & Vanatta	7022540103
* *Bittium hiloense* Pilsbry & Vanatta	7022540201
Bittium zebrum Kiener	7022540202
* *Bittium impendens* Hedley	7022540204
Bittium parcum (Gould)	7022540205

Mollusca (continued)	
Gastropoda	
Mesogastropoda	
Cerithiopsidae	
Cerithiopsis sp. A	70225501XX
* *Cerithiopsis* sp. B	70225501XX
Triphoridae	
Triphora spp.	7022560100
Eulimidae	
Balcis sp.	7022620600
* *Leiostraca* sp.	7022620700
Hipponicidae	
Hipponix spp.	7022720100
Hipponix pilosus (Deshayes)	7022720101
Calyptraeidae	
Crucibulum spinosum (Sowerby)	7022750101
Crepidula aculeata (Gmelin)	7022750201
Naticidae	
Natica sp.	7022910100
Natica gualteriana Recluz	7022910101
Cymatiidae	
Cymatium sp.	7022940100
Cymatium rubeculum Linnaeus	7022940101
Neogastropoda	
Muricidae	
Aspella producta Pease	7023010901
Pyrenidae	
Anachis zebra (Wood)	7023060101
Buccinidae	
Cantharus farinosus (Gould)	7023070401
Engina sp.	7023070500
Fasciolariidae	
Peristernia chlorostoma (Sowerby)	7023120201
Marginellidae	
Kogomea sandwicensis (Pease)	7023210301
Cysticus sp.	7023210400
Mitridae	
Mitra sp.	7023260100
Turridae	
Carinapex sp.	702331XXXX
Turrid sp	702331XXXX
Entomotaeniata (Pyramidellacea)	
Pyramidellidae	
Odostomia sp.	7031010200
* *Odostomia patricia* Pilsbry	7031010201
* *Odostomia eclecta* Pilsbry	7031010202
Odostomia indica Melvill	7031010203
Odostomia oodes Watson	7031010204
Odostomia paulbartschi Pilsbry	7031010205
* *Odostomia scopulorum* Watson	7031010206
Odostomia stearnsiella Pilsbry	7031010207
Turbonilla sp.	7031010300
Basommatophora	
Siphonariidae	
Siphonaria normalis Gould	7037100101

Mollusca (continued)
Gastropoda
Sacoglossa
Juliidae

* *Julia exquisita* Gould	7039160101
Nudibranchia	7044000000

Bivalvia
Arcoida
Arcidae

* *Acar plicata* Dillwyn	7053010101
* *Barbatia nuttingi* Dall, Bartsch & Rehder	7053010201
Arca sp.	7053010600
Mytiloida	
Mytilidae	
Hormomya crebristriatus (Conrad)	7054010301
Pinnidae	
Pinna sp.	7054050100
Pteroida	
Pteriidae	
Pinctada margaritifera (Linnaeus)	7055010101
Isognomidae	
Isognomon sp.	7055020100
Isognomon perna (Linnaeus)	7055020103
Ostreidae	
Crassostrea virginica Gmelin	7055060102
Ostrea spp.	7055060200
Ostrea sandvichensis Sowerby	7055060201
Ostrea hanleyana Sowerby	7055060203
Spondylidae	
Spondylus sp.	7055130100
Spondylus hawaiensis Dall,Bartsch & Rehder	7055130101
Anomiidae	
Anomia nobilis Reeve	7055200101
Veneroida	
Lucinidae	
Ctena bella Conrad	7056290101
Pillucina spaldingi Pilsbry	7056290301
Chamidae	
Chama sp.	7056470100
Tellinidae	
Angulus nucella Dall, Bartsch & Rehder	7056620302
Myoida	
Gastrochaenidae	
Rocellaria spp.	7057060100
Hiatellidae	
Hiatella hawaiensis Dall,Bartsch & Rehder	7057100101
Teredinidae	
Teredo sp.	7057190100
Cephalopoda	
Octopoda	
* *Polypus* sp.	707102XXXX

- Ectoprocta
  - Gymnolaemata
    - Ctenostomata
      - Vesiculariidae
        - *Amathia distans* Busk — 7511010101
    - Cheilostomata
      - Bicellariellidae
        - *Bugula neritina* (Linnaeus) — 7513060101
        - *Bugula californica* Robertson — 7513060102

- Echinodermata
  - Asteroidea
    - Gnathophiurida
      - Ophiactidae
        - *Ophiactis savignyi* (Muller & Troschel) — 7841010102
      - Amphiuridae
        - *Amphiopholis squamata* (Delle Chaije) — 7841030301
    - Chilophiurida
      - Ophicomidae
        - *Ophiocoma sexradia* (Duncan) — 7842030106
  - Echinoidea
    - Diadematoida
      - Diadematidae
        - *Diadema paucispinum* Agassiz — 7852010201
      - Cidaridae
        - *Eucidaris metularia* (Lamarck) — 7852210101
      - Echinidae
        - *Tripneustes gratilla* (Linnaeus) — 7852230201
      - Echinometridae
        - *Heterocentrotus mammillatus* (Linnaeus) — 7852240301
  - Holothuroidea
    - Aspidochirota
      - Holothuridae
        - *Holothuria pervicax* (Selenka) — 7871030306
    - Apoda
      - Synaptidae
        - *Opheodesoma spectabilis* Fisher — 7878010201

- Chaetognatha
  - *Sagitta* sp. — 8211010100
  - *Pterosagitta* sp. — 8211010200

- Chordata
  - Urochordata (Ascidiacea)
    - Enterogona
      - Phallusidae
        - *Ascidia* sp. — 8311040100
      - Clavelinidae
        - *Clavelina* sp. — 8311110100
      - Polyclinidae
    - Pleurogona
      - Styelidae
        - *Styela* sp. — 8311130200

Chordata (continued)
Urochordata (Ascidiacea)
Pleurogona
Tethyidae
Hermandia momus (Savigny) 8312030201
Urochordata (Thalacea)
Doliolida
Doliolidae
Doliolum sp. 8321020100
Urochordata (Larvacea)
Endostylophora
Oikopleuridae
Oikopleura sp. 8332010100

Chordata/Vertebrata
Chondrichthyes
Lamnida
Carcharhinidae
Carcharhinus limbatus (Valenciennes) 8516120503
Sphyrnidae
Sphyrna lewini (Griffith & Smith) 8516130101
Hypotremata
Myliobatidae
Aetobatus narinari (Euphrasen) 8517100101
Osteichthyes
Elopiformes
Elopidae
Elops hawaiiensis Regan 8521010101
Albulidae
Albula vulpes (Linnaeus) 8521060101
Anguilliformes
Muraenidae
Gymnothorax flavimarginatus (Rüppell) 8522050605
Gymnothorax petelli (Bleeker) 8522050611
Gymnothorax undulatus (Lacépède) 8522050613
Congridae
Conger cinreus marginatus Valenciennes 8522120501
Clupeiformes
Engraulidae
Stolephorus purpureus Fowler 8525070101
Salmoniformes
Synodontidae
Saurida gracilis (Quoy & Gaimard) 8531470201
Synodus variegatus (Lacépède) 8531470304
Gonorynchiformes
Chanidae
Chanos chanos (Forsskål) 8533060101
Lophiiformes
Antennariidae
Antennarius chironectes Lacépède 8541070302
Gadiformes
Carapidae
Carapus margaritiferae (Rendahl) 8542120301

Chordata (continued)
  Osteichthyes
    Atheriniformes
      Hemiramphidae
        Hemiramphus depauperatus Lay & Bennett 8544015301
      Belonidae
        Tylosurus crocodilus (Peron & LeSueur) 8544020301
      Poeciliidae
        Mollienesia latipinna LeSueur 8544130101
    Beryciformes
      Holocentridae
        Myripristis murdjan (Forsskål) 8546180403
        Flammeo sammara (Forsskål) 8546180501
    Gasterosteiformes
      Aulostomidae
        Aulostomus chinensis (Linnaeus) 8549060101
      Syngnathidae
        Micrognathus ?edmondsoni (Pietschmann) 8549120502
    Scorpaeniformes
      Scorpaenidae
        Brachirus barberi (Eschmeyer & Randall) 8552010301
        Scorpaenopsis diabolus(Eschmeyer&Anderson)8552010701
        Scorpaena coniorta (Jenkins) 8552011101
    Perciformes
      Kuhliidae
        Kuhlia sandvicensis (Steindachner) 8554140101
      Priacanthidae
        Priacanthus cruentatus (Lacépède) 8554170101
      Apogonidae
        Apogon snyderi Jordan & Evermann 8554180404
        Foa brachygrammus (Jenkins) 8554180701
      Carangidae
        Scomberoides sancti-petri (Cuvier) 8554290101
        Gnathanodon speciosus (Forsskål) 8554290801
        Carangoides gymnostethoides Bleeker 8554291001
        Caranx ignobilis (Forsskål) 8554291202
        Caranx melampygus Cuvier & Valenciennes 8554291204
        Caranx sexfasciatus Quoy & Gaimard 8554291206
        Caranx mate Cuvier & Valenciennes 8554291207
      Lutjanidae
        Lutjanus fulvus (Bloch & Schneider) 8554380704
      Mullidae
        Upeneus arge Jordan & Evermann 8554470101
        Mulloidichthys samoensis (Günther) 8554470201
        Mulloidichthys auriflamma (Forsskål) 8554470202
        Parupeneus pleurostigma (Bennett) 8554470301
        Parupeneus porphyreus (Jenkins) 8554470303
        Parupeneus multifasciatus (Quoy & Gaimard)8554470305
      Kyphosidae
        Kyphosus cinerascens (Forsskål) 8554530101
      Scorpididae
        Microcanthus strigatus (Cuvier&Valen.) 8554530301

Chordata (continued)

Osteichthyes

Perciformes

Chaetodontidae

Heniochus acuminatus (Linnaeus) 8554570502
Chaetodon auriga Forsskål 8554570706
Chaetodon lunula (Lacépède) 8554570708
Chaetodon miliaris Quoy & Gaimard 8554570715

Cichlidae

Tilapia mossambica (Peters) 8554630101

Pomacentridae

Dascyllus albisella Gill 8554640101
Abudefduf sordidus (Forsskål) 8554640201
Abudefduf abdominalis (Quoy & Gaimard) 8554640202

Mugilidae

Mugil cephalus Linnaeus 8555010201

Sphyraenidae

Sphyraena barracuda (Walbaum) 8555030101

Polynemidae

Polydactylus sexfilis(Cuvier&Valenciennes) 8555050101

Labridae

Cheilio inermis(Forsskål) 8555070101
Labroides phthirophagus Randall 8555070401
Stethojulis balteatus (Quoy & Gaimard) 8555071801

Scaridae

Calotomus spinidens (Quoy & Gaimard) 8555090102
Scarus sordidus Forsskål 8555090304
Scarus sp. (juvenile) 8555090320

Blenniidae

Exallias brevis (Kner) 8555340101
Entomacrodus marmoratus (Bennett) 8555340301
Omobranchus elongatus (Peters) 8555340701

Gobiidae

Oxyurichthys lonchotus (Jenkins) 8555600201
Ctenogobius tongarevae (Fowler) 8555600701
Bathygobius fuscus (Rüppell) 8555600802
Opua nephodes Jordan 8555601201
Gnatholepis anjerensis (Bleeker) 8555601301

Eleotridae

Asterropteryx semipunctatus Rüppell 8555605301

Acanthuridae

Acanthurus triostegus (Linnaeus) 8555690101
Acanthurus olivaceus (Bloch & Schneider) 8555690109
Acanthurus dussumieri(Cuvier&Valenciennes) 8555690110
Acanthurus xanthopterus (Cuvier & Val.) 8555690111
Acanthurus mata (Cuvier) 8555690112
Ctenochaetus strigosus (Bennett) 8555690201
Zebrasoma flavescens (Bennett) 8555690301
Zebrasoma veliferum (Bloch) 8555690302
Naso brevirostris (Cuvier & Valenciennes) 8555690403
Naso unicornis (Forsskål) 8555690404

Zanclidae

Zanclus canescens (Linnaeus) 8555695101

Chordata (continued)
Osteichthyes
Pleuronectiformes
Bothidae

Bothus pantherinus (Rüppell)	8557080402

Tetraodontiformes
Monocanthidae

Pervagor spilosoma (Lay & Bennett)	8558025201

Ostraciontidae

Ostracion meleagris camurum (Jenkins)	8558030201

Tetraodontidae

Arothron hispidus (Linnaeus)	8558060302

Canthigasteridae

Canthigaster coronatus (Randall,P.C.)	8558065101
Canthigaster jactator (Jenkins)	8558065102

Diodontidae

Diodon hystrix (Linnaeus)	8558080201
Diodon holocanthus (Linnaeus)	8558080202

APPENDIX F

J. Geoffrey Grovhoug

INTRODUCTION

During the course of the survey, numerous field observations were made which were incidental to major sampling activities. Some of these peripheral observations provide significant additional information regarding the status of the Pearl Harbor marine environment. Therefore, these observations are presented collectively in this appendix.

DISCUSSION

It was noticed early in the study that living stony corals were conspicuously absent from all bio-stations inside Pearl Harbor (including BC-11, located at the harbor's mouth in the entrance channel). Stony corals were observed several hundred yards outside of BC-11 along the ledge formed by the entrance channel. The occurrence of broken pieces of dead coral (mostly *Pocillopora meadrina* Dana) in benthic samples from all ten bio-stations indicates the past existence of live stony coral inside the harbor. It is also significant that no coralline algae were observed within Pearl Harbor.

One species of alcyonarian (soft) coral was collected at several locations in the entrance channel and in Southeast Loch (BE-03) from the 12-18 ft. depth range. A specimen of this soft coral sent to Mr. John Rees at Bodega Bay Marine Laboratory in California was identified as belonging to the genus *Telesto* (see Figure F-1). The densest populations of *Telesto* were observed along channel ledges between discontinued bio-station BC-12 and Hospital Point (BC-20). According to Mr. Rees, the specimens agree in all respects with the species *Telesto riisei* (Duchassaing & Mechelotti), a shallow-water Atlantic octocoral which thrives in murky water and is a fouling species on ship hulls; thus, shipborne introduction into Pearl Harbor for this species seems quite plausible. As discussed earlier in the report (see Section 3.4), the introduction of certain organisms from widespread geographic areas via fouling on ship hulls has been well documented in Hawaiian marine environments.

Two species of schyphozoan jellyfish, *Phyllorhiza punctata* von Ledenfeld and *Aurelia* cf. *labiata* Chamisto & Eysenhardt, were observed during the winter months. Both species were most numerous in West Loch, but were seen throughout the harbor. *Phyllorhiza* attains a diameter of 14 inches and provides protective shelter for juvenile "omaka", fish belonging to the species *Caranx mate* Cuvier & Valenciennes (Figure F-2). Several (5-8 individuals) juvenile carangids were observed residing under and/or inside the umbrella or bell for more than 80% of all specimens (*Phyllorhiza*) examined.

Several groups of crustaceans were also observed during field activities, but have not been documented elsewhere in the report (except in the Cumulative Checklist, Appendix E). Two species of spiny lobsters, two species of slipper lobsters and one species of true lobster (Family Homaridae) were observed along the ledge of the Pearl Harbor entrance channel. The spiny lobster, *Panulirus penicillatus* (Olivier); the slipper lobster, *Scyllarides squamosus* (Milne Edwards); and the western (true) lobster, *Enoplometopus occidentalis* (Randall), were seen at bio-station BC-11, but not farther inside the harbor. The remaining two species, *Panulirus marginatus* (Quoy & Gaimard) and *Parribacus antarcticus* (Lund), were observed only outside (seaward) of BC-11. The banded coral shrimp.

(Text continued on page F-3)

Figure F-1.

COLONY OF *Telesto ?riisei* GROWING ON CONCRETE PILING AT BIO-STATION BE-03; DEPTH: 16 FEET.

Figure F-2.

Phyllorhiza punctata FREE SWIMMING AT BIO-STATION BW-13 (NOTE JUVENILE *Caranx mate* UNDER BELL)

Stenopus hispidus (Olivier), inhabits most rock ledge environments within the harbor. This species was seen most often in male/female pairs and was collected or photographed at bio-stations BC-11, BE-03, BE-02, BE-05, BW-13 and BC-10. Another crustacean, the Samoan crab, *Scylla serrata* deMan, was observed at several locations in East Loch. This species is commercially important due to its large size and palatability; a single PHBS specimen weighing four pounds was collected in a gill net at bio-station BC-09 (on 15 Nov 1972). The tuberculate rock crab, *Plagusia depressa tuberculata* (Lameroux), inhabits intertidal environments at the entrance to Pearl Harbor and was observed only seaward of bio-station BC-11. This fast-moving, relatively large (0.5 lb.) grapsid crab is collected for both food and bait in Hawaii. Several other crabs and shrimp were collected in association with living stony corals outside bio-station BC-11 (see entries marked by asterisks in the Cumulative Checklist, Appendix E).

Certain members of two groups of echinoderms, sea urchins (Echinoids) and sea cucumbers (Holothurians) merit discussion concerning general distributional patterns. The sea urchins, *Diadema paucispinum* Agassiz and *Tripneustes gratilla* (Linnaeus), were observed at bio-station BC-11 and seaward only. No sea urchins were seen further inside the harbor on any occasion during the study. The holothurian, *Opheodesoma spectabilis* Fisher, was observed throughout the harbor at all ten bio-stations. The most dense aggregations of *Opheodesoma spectabilis* were seen at bio-stations BE-02, BE-05, BC-09 and BW-13; often more than five individuals were collected during gill net retrievals at these stations.

Another noteworthy field observation was the occurrence of deformities observed in two common Pearl Harbor species, the portunid crab, *Thalamita crenata* Latreille and the surgeonfish (or "Pualu"), *Acanthurus xanthopterus* (Cuvier & Valenciennes). As can be seen in Figure F-3, the male swimming crab, *Thalamita crenata* (collected in a gill net at BE-02 on 25 Apr 72), has an additional chela, or claw, originating from the ventral side of the right cheliped. This extra chela was completely formed including teeth and pigmentation; however, it was immovable and thus, non-functional. The actual cause for this morphological aberration is unknown. The surgeonfish, *Acanthurus xanthopterus* (shown in Figure F-4), completely lacks a caudal peduncle and caudal fin. The specimen was collected in a fish trap suspended in 18 feet of water at bio-station BM-07 on 6 Oct 72 and was alive and apparently healthy at that time. A normal individual of *Acanthurus xanthopterus* is shown in Figure F-5. Another similar (i.e., tailless) individual of *A. xanthopterus* was observed swimming in a school of normal surgeonfish along wooden pilings adjacent to BW-13 during late summer of 1972 by PHBS field team members; still another similar individual of the same species was sighted and reported by Dr. John C. McCain (personal communication) at the intake area of the Waiau Hawaiian Electric Power Plant during the summer of 1972. Thus, it seems possible that an aberrant strain of this species may be established within the harbor. The possiblity that only one individual was so motile as to be sighted in West Loch, Middle Loch and northern East Loch during this relatively short period of time is, indeed, remote.

Several other miscellaneous field observations were made by Mr. Norman L. Buske during his 1972-1973 current survey activities. These observations are presented in the following text.

(Text continued on page F-7)

Figure F-3. PHOTO OF RIGHT CHELIPED OF THE CRAB, *Thalamita crenata* COLLECTED AT BIO-STATION BE-02.

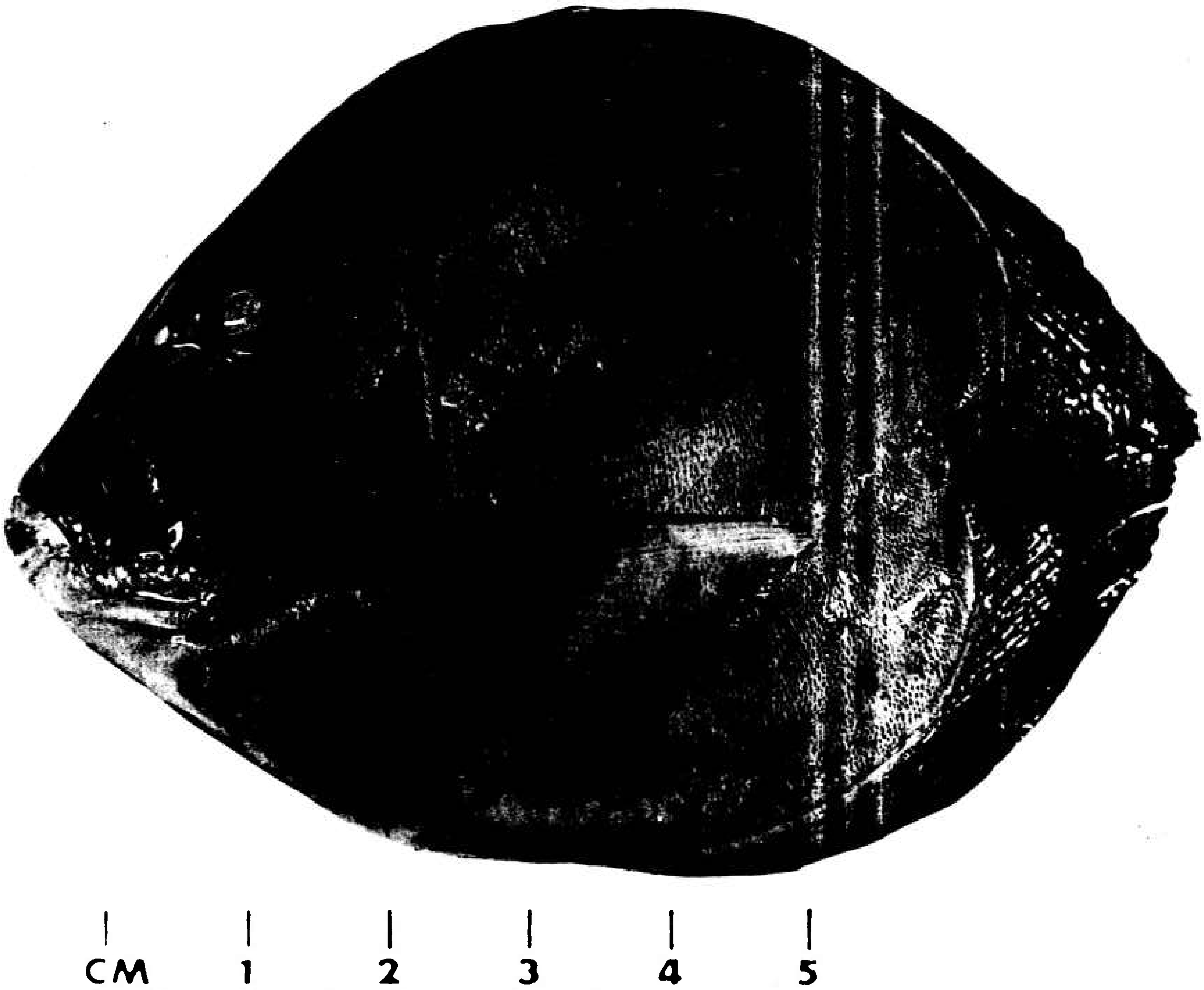


Figure F-4. PHOTO OF "TAILLESS" SPECIMEN OF *Acanthurus xanthopterus* COLLECTED AT BIO-STATION BM-07.

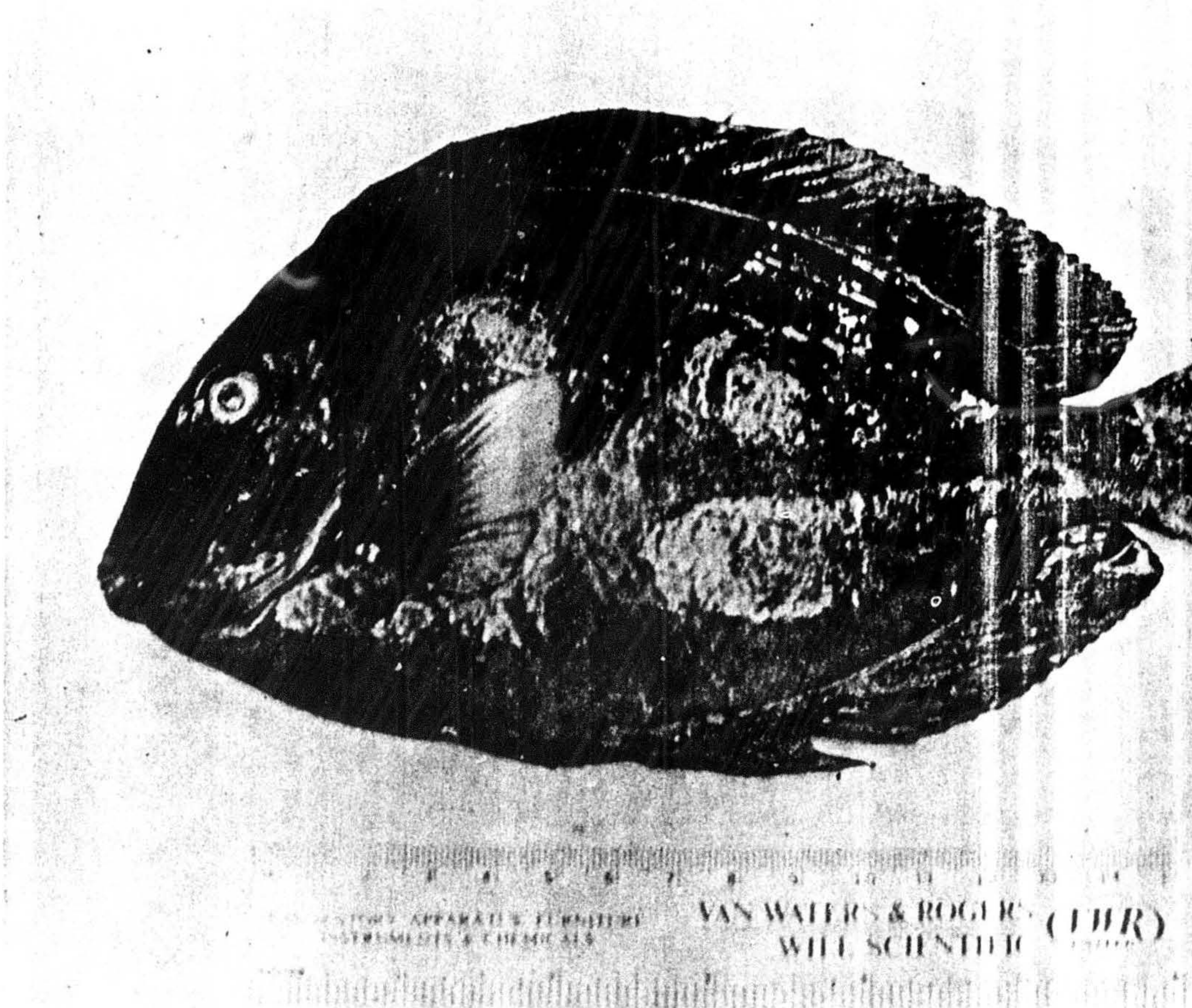


Figure F-5. PHOTO OF A "NORMAL" SPECIMEN OF *Acanthurus xanthopterus*.

1. Acoustic Source

On 23 and 24 November 1972, a sonar unit was being tested on a Naval destroyer which was berthed at the entrance to Southeast Loch. Although sound levels are decreased by three orders of magnitude (29.5 db) in passing from water to air, acoustic pulses could be both heard in air and detected on an inductive conductivity meter in water throughout the region. Near to the destroyer the acoustic signal in air was audible over a 60 horsepower Mercury outboard motor operating at full throttle (three meters from the observer). Biological effects of such sonar testing might be anticipated.

2. Oil and Flotsam

Scattered patches of oil were usually observed on the surface of the water in Southeast Loch, except under strong tradewind conditions. Surface oil and flotsam (logs, coconuts, beverage cans, etc.) also marked regions of wind convergence, particularly in the main channel south of Ford Island.

Upon a change in wind direction, large quantities of flotsam appeared on the waters of Pearl Harbor. The flotsam was observed for several hours, until it either left the harbor or accumulated on shore.

3. Turbidity

The region of intense ship traffic generally appeared to have clearer waters than did regions of little traffic in spite of the sediment which is occasionally stirred up from the bottom by ships. This suggests that moderate amounts of ship-induced mixing tend to mix suspended sediment downward while intense mixing brings silt up from the bottom. Thus, the general appearance of Pearl Harbor may be affected by ship activities. Sediment in the upper layer appears to originate from runoff from the Pearl Harbor drainage basin.

4. Dredging

The major channels of the harbor have "project depths" listed on NAVOCEANO Chart #19084. These depths are approximately maintained by dredging. The charted bathymetry of the harbor suggests to this author that the form of the harbor has been altered considerably by dredging and other improvements.

Since the circulation of an estuary may be considered to result from the interaction of certain driving forces with the estuarine boundaries, extensive dredging may have a profound effect on the physical properties of the estuary, such as circulation patterns. Thus, it is doubtful that the properties of the present Pearl Harbor system closely resemble those of the harbor before dredging was begun.

Since dredging operations introduce great quantities of sediment into the water column, transitory effects on the marine biota of the harbor might be expected.

The increased development of the Pearl Harbor watershed and the resulting erosion will probably increase future requirements for dredging of the harbor in order to maintain channel depths; however, no dredging was observed during the 1972-1973 survey period.

APPENDIX G

Thomas J. Peeling
J. Geoffrey Grovhoug

Report of An Invertebrate Kill in Middle Loch Pearl Harbor, Oahu.

INTRODUCTION

An integral part of the Pearl Harbor Biological Survey was the sampling of resident fish populations through the use of traps. On the 15th of June 1972 one such trap, which contained seven dead fish and two lethargic swimming crabs was recovered from bio-station BM-07 (Middle Loch). No cause for the condition of these marine animals was immediately discernable. Therefore, visual underwater inspections were conducted on the wooden pilings available at BM-07. These inspections showed that a massive kill had occurred or perhaps was still occurring among the sessile and free-moving invertebrates that populated the pilings below a depth of approximately 7-10 feet. Chemical analysis of samples from the water column was conducted for a number of sites on the afternoon of the 15th and again on the morning of the 16th, underwater inspections were conducted throughout Middle Loch, and offices in control of major sources of effluent into the loch were contacted for reports of any unusual occurrences. The purpose of this report is to present the available data, both from the immediate past and at the time of the mishap, in order to document the extent of the kill and to record the phenomenon for future study or comparisons.

Figure G-1 is an illustration of Middle Loch indicating areas of major interest in this report. Pier V-2 and the area around the degaussing station were checked but didn't at any time exhibit signs of stress. Sand blasting and painting of a large floating dry dock were being accomplished at the area marked "6" in the figure, but no evidence has pointed to this as a source of major importance. The canal marked "4" exhibited signs of septic stress on 16, 17, 18 and 19 June, but this seemed to be contained within the canal for the most part and is not believed to be connected to the mortality reported here. Water samples were taken at the mouth of Waiawa Stream but nothing unusual was indicated.

PRESENTATION OF DATA

A. Biological

The Pearl Harbor Biological Survey Field Team had conducted underwater observations of areas within Middle Loch on approximately a weekly basis since the 1st of November 1971. Until the 15th of June 1972, no unusual occurrences were evident and bio-station BM-07 had been comparing favorably with other Pearl Harbor bio-stations.

A fish trap had been suspended at BM-07 at a depth of approximately 11 feet on the 12th of June. On the 15th of June, hours later, when the trap was recovered, it contained three *Acanthurus xanthopterus* and four *Arothron hispidus*, all dead, and two crabs, *Thalamita crenata*, which were sluggish and jerky of movement. No cause for this condition was apparent and SCUBA dives were made in an attempt to obtain further information. Bio-station BM-07 under normal conditions has a large community of fishes of many families which swim around and feed on and among pilings. It was therefore surprising to the divers when not one fish was seen, not even near the surface. What was seen, however, was as equally surprising; dead and dying crabs hanging to growth on the pilings and settling to the bottom, and numerous dead and dying mollusca--the pelecypods with their valves gaping and the gastropods, mainly *Crepidula* sp.,

Table G-1. DISSOLVED OXYGEN VALUES FOR FIVE SITES IN MIDDLE LOCH. LOCATIONS ARE SHOWN IN FIGURE G-1.

Station	Month	Dissolved Oxygen (ppm) Surface	Bottom
MA-20	January	7.2	3.8
	February	8.5	7.0
	March	7.7	4.6
	June (16th)	7.8	3.5
MB-20	January	6.7	5.4
	February	8.8	5.8
	March	7.9	4.3
	June (16th)	4.2	2.3
BM-07	March	4.9	3.7
	June (15th)	7.5	2.2
	June (16th)	7.6	2.1
SM-05	February	4.5	NA
	March	2.4	2.7
	May	3.8	2.9
	June (13th)	0.4	0.4
	June (15th)	3.1	1.6
MC-20	June (15th)	6.7	0.8
	June (16th)	4.7	0.6

Note: NA = not available.

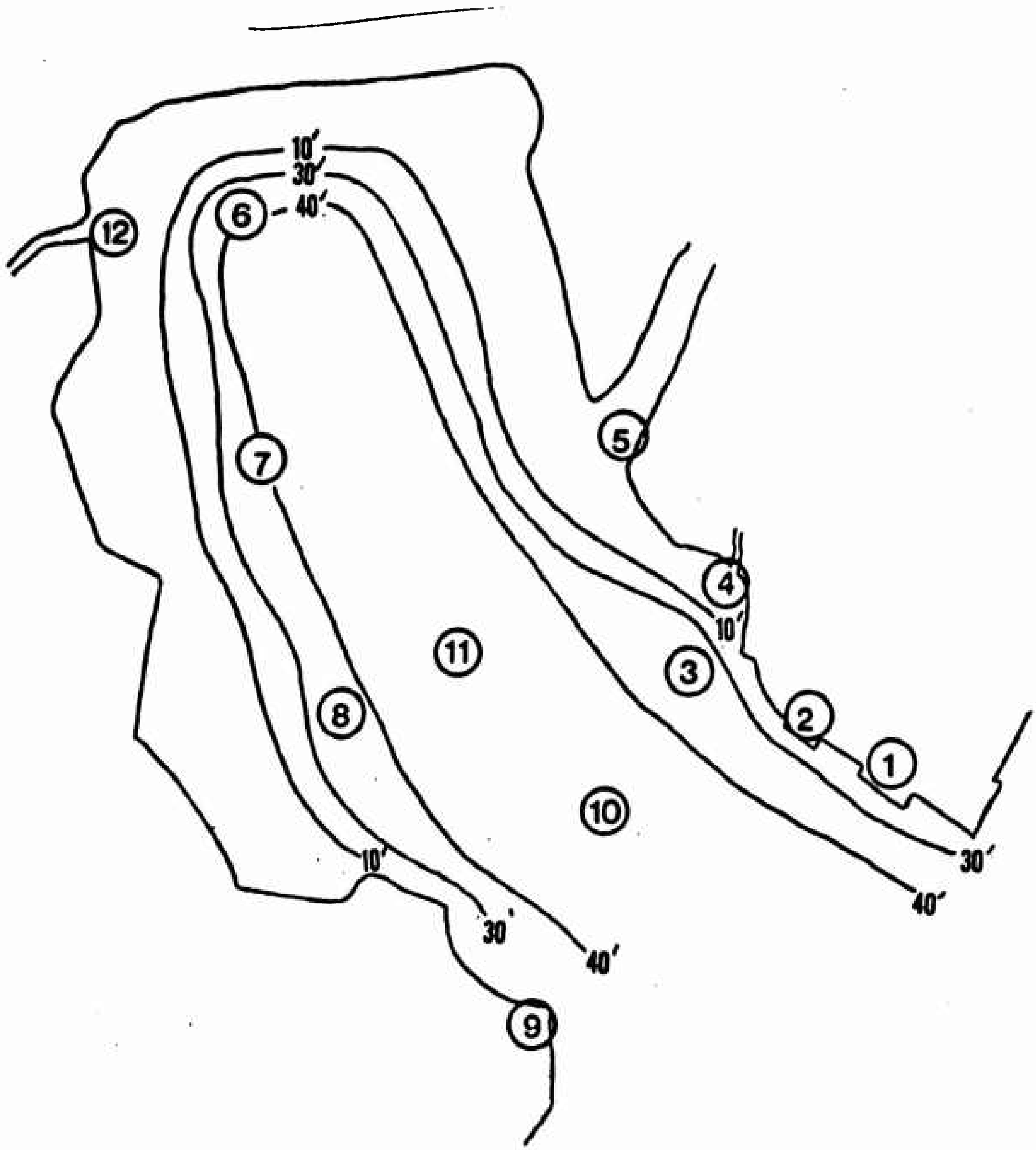


Figure G-1. POINTS OF INTEREST IN MIDDLE LOCH, PEARL HARBOR INCLUDING ESTIMATED DEPTH CONTOURS.

Legend: (1) V-2 Pier; (2) V-1 Pier; (3) Bio Station BM-07; (4) Canal from Pearl City Fuel Farm; (5) Waiawa Stream; (6) Floating Dry Docks (MC-20); (7) Pearl City Sewage Treatment Plant Diffusers (SM-05); (8) Area where first signs of mortality were encountered for the west side of the loch; (9) Degaussing Station; (10) MA-20; (11) effluent from the Waipio oxidation ponds (~4.2 mgd). Depths indicated are in feet.

breaking loose and tumbling down the pilings. The most numerous organisms, and seemingly the most affected, were the polychaetes; Terebellid, Serpulid and Sabellid worms were hanging from their tubes in great numbers. The errant worms, Syllids, Nereids, Eunicids, etc., were also seen lying on sponge mats and worm tubes and were frequently seen floating in the water column. These conditions extended from approximately 10 feet below the surface down to the bottom at 38 feet, but seemed to be intensified at the 15-17 foot level.

On the morning of the 16th of June, dives were made throughout Middle Loch to map the extent of the kill and to obtain further information relevant to its cause. Figure G-2 illustrates the results of these dives. A definite limit to the kill extending westward from the north side of pier V-1 was noted. Dives along pier V-1 showed that within a distance of 35 feet the mortality decreased rapidly and disappeared sharply. All dives made further into southern Middle Loch than this line witnessed normal conditions. The most notable observation on the 16th was that the fishes had returned to the area but were obviously restricting themselves to the upper 15 feet of the water column throughout the affected area (lined section of Figure G-2). The smaller carnivorous fishes had increased in number and their restriction to the upper 15 feet gave that water layer the appearance of being heavily populated. On the 19th, divers observed that the fishes were no longer limited to the upper 15 feet of water and that feeding had almost obliterated signs of the mortality except in areas proximal to the Pearl City STP diffusers.

Figure G-3 is an estimate of the percentage of mortality among the three major groups of affected organisms: polychaetes, mollusca and crustaceans. These estimates are based only upon visual observations conducted on the 15th and 16th of June 72, no detailed counts of dead or moribund organisms were made, thus the values given are approximate and may contain subjective error. The percent mortality increased going into Middle Loch, with the values around the Pearl City STP diffusers being the highest. As stated earlier, the polychaetes seemed to have been hit the hardest in all cases, mollusca and crustaceans being affected slightly less.

B. Chemical

Monthly water-column chemical analyses were available for various sites in Middle Loch from January 1972 through July 1972. These records have been reviewed and data believed pertinent to the invertebrate kill has been extracted for presentation here. Middle Loch is a distinctly stratified, modified three-layered body of water in which temperatures and salinities are predictable by seasonal changes and wind conditions (see Section 3.3, page 3.3-7). These parameters remained fairly stable in Middle Loch for the months February to June with a gradual increase in temperature apparent in June. The only parameter that seems to have fluctuated markedly is dissolved oxygen (DO). Available data indicate that the DO fluctuation occurred for a very short time period mainly at depths greater than 10 feet. Fortunately, water samples were routinely taken in the area of the diffusers from the Pearl City STP on the 13th of June. These samples seem to indicate that area as the source of a series of events that may be hypothetically traced through a period ending on the 19th of June.

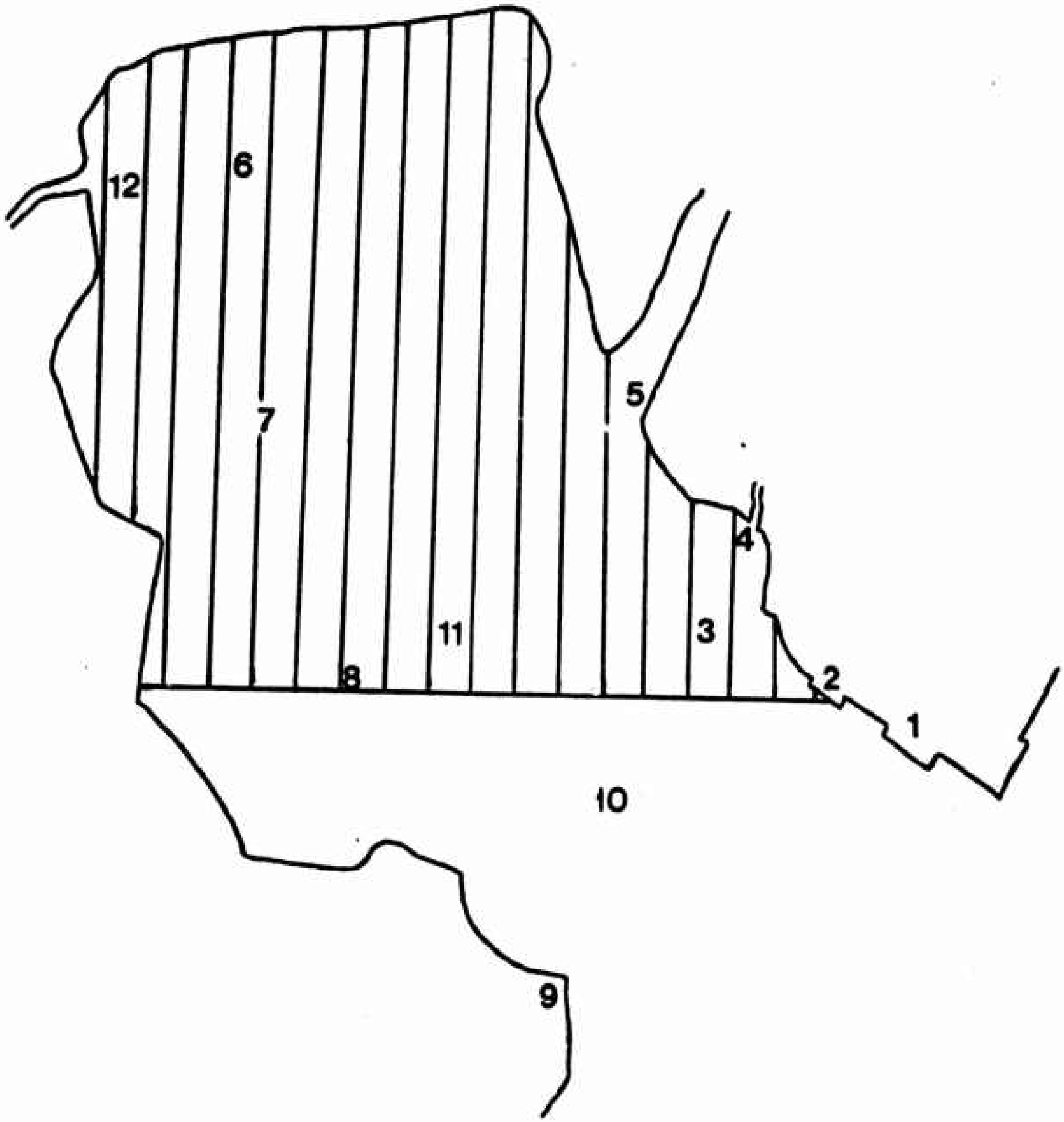


Figure G-2. EXTENT OF THE INVERTEBRATE KILL IN MIDDLE LOCH, PEARL HARBOR. LINED AREA INDICATES REGION OF KILL ON 15 JUNE 1972.

Legend: Same as Figure G-1.

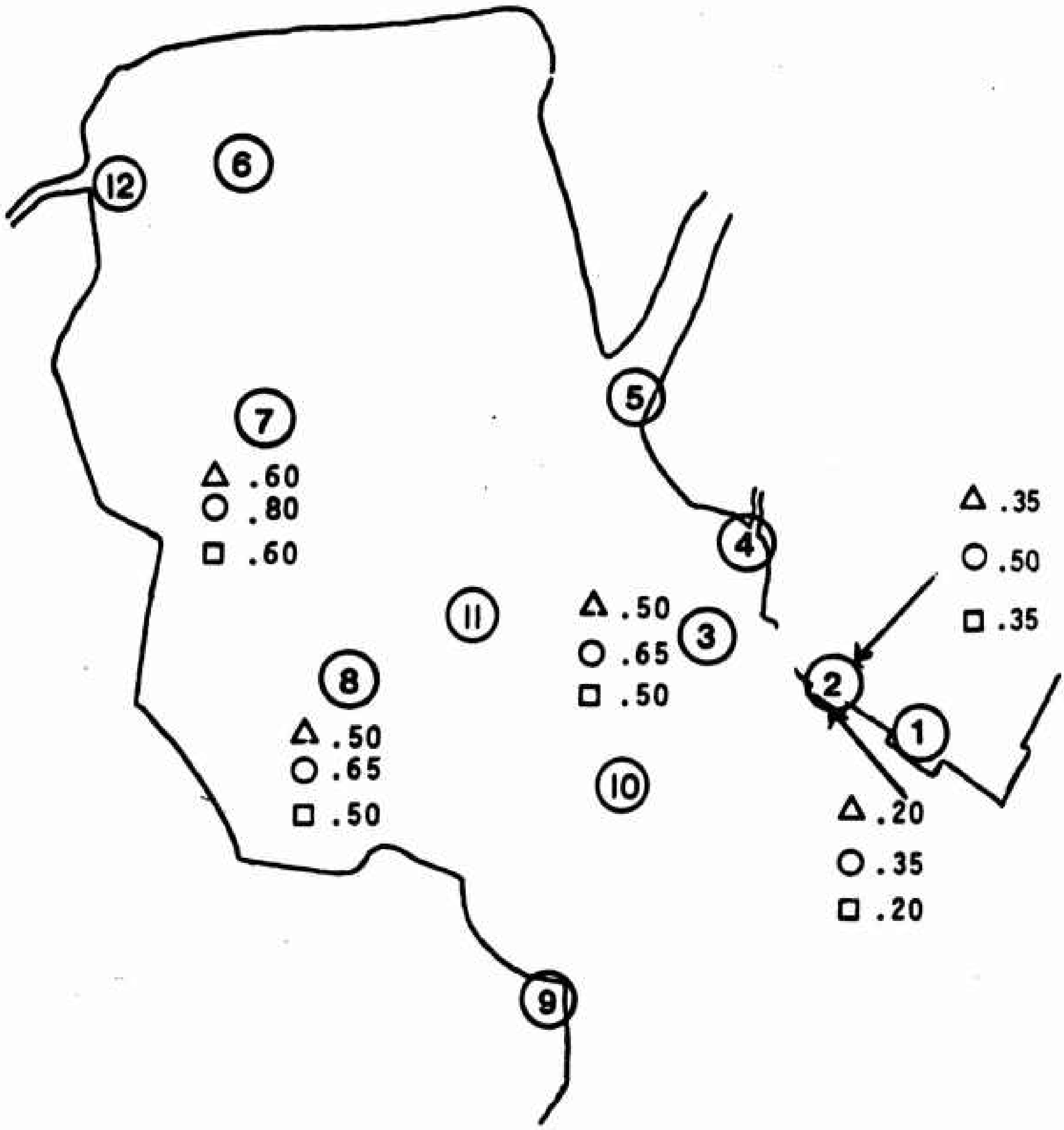


Figure G-3. ESTIMATED MORTALITY PERCENTAGE FOR THREE MAJOR GROUPS - MOLLUSCA, POLYCHAETES AND CRUSTACEANS.

Legend: △ = Mollusca
○ = Polychaetes
□ = Crustaceans

Table G-1 and Figure G-4 illustrate the trends for DO values at various sites in Middle Loch. Even though the information is scanty, it is obvious that DO values obtained during the period 12-16 June are abnormally low (in some cases, drastically low). DO values at SM-05, which is at the STP diffuser site, had averaged 2.8 ppm on the bottom until the 13th of June when both surface and bottom values dropped to 0.4 ppm. By the 16th of June the DO value for the bottom in this area was still low at 1.6 ppm.

C. Physical

A current survey for Pearl Harbor has been completed (see Section 3.3) and circulation patterns/water-mass movements within Middle Loch have been described. This data plus general information on estuarine bodies of water permit the following assumptions (see Figure G-5):

a. Middle Loch is stratified into three layers (surface and bottom, with a thin mid-layer wedge (Figures G-4 and G-5).

b. The upper, lighter layer has a net movement shoreward toward the head of Middle Loch.

c. The mid-depth wedge has a net movement seaward.

d. The lower, more saline layer has a net movement toward the head of Middle Loch.

e. Oscillation corresponding with tidal movement and wind stress does occur in the upper and lower layers.

f. An anticyclonic surface gyre exists in Middle Loch due to wind effects (see page 3.3-35).

CONCLUSIONS

All statements made here are based on short-term information and are intended to indicate possibilities rather than confirmed findings. Tentative conclusions are as follows:

1. On the 12th or 13th of June 1972, a large quantity of an oxygen scavenging substance entered Middle Loch in the vicinity of the Pearl City STP diffusers.

2. This substance quickly lowered the dissolved oxygen content in that area to an average of 0.3 ppm.

3. This substance and water of low DO values spread toward the mouth of Middle Loch in the upper layer and toward the head of the loch in the lower layer.

4. The lethal effects of these conditions were decreased in surface waters where atmospheric and photosynthetic oxygen was more available and increased in the lower water layer which had no rapid oxygen income.

5. The depressed DO values were lower and persisted longer in the area extending from the point of initial insult toward the head of Middle Loch.

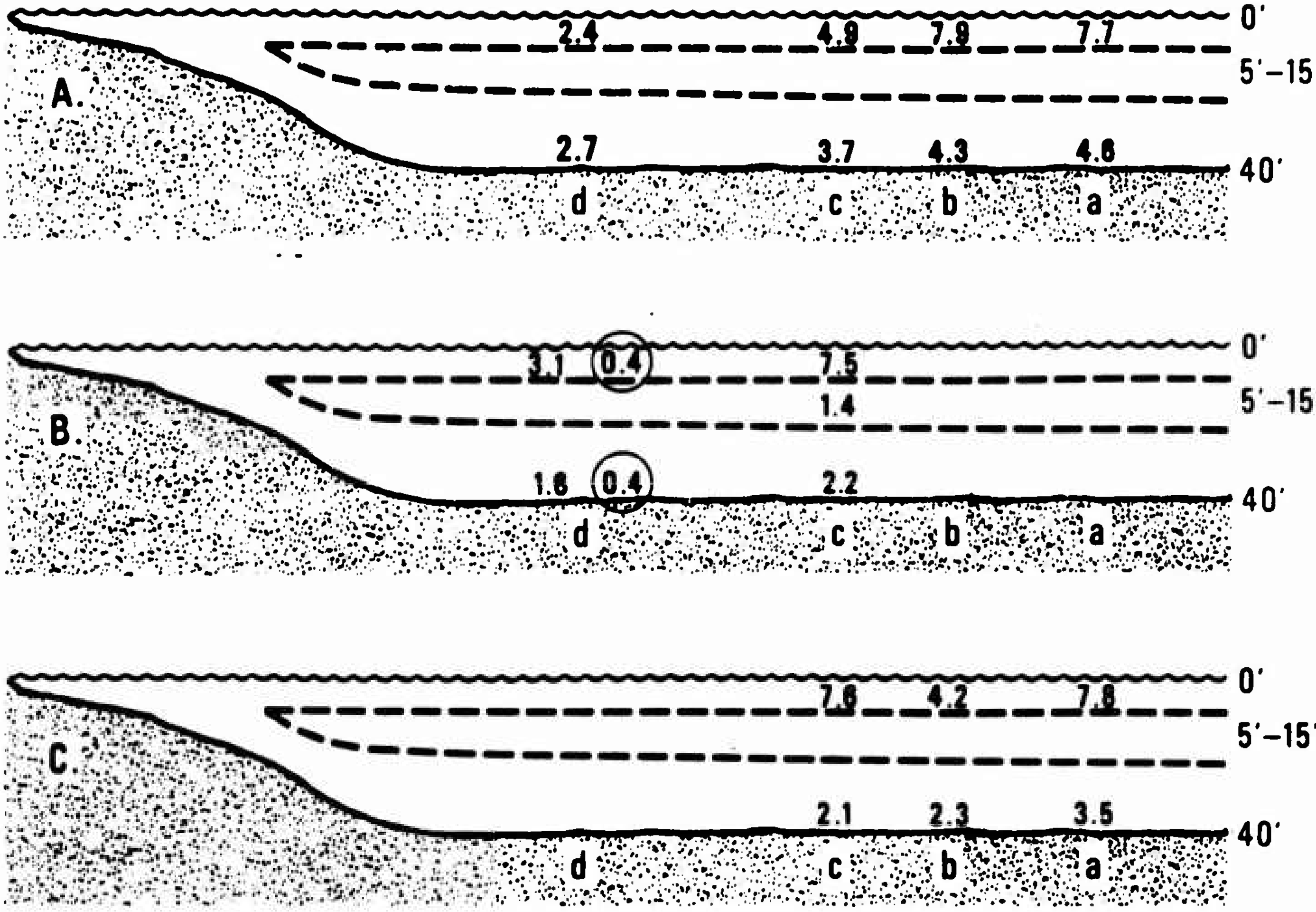


Figure G-4. A LONGITUDINAL SECTION OF MIDDLE LOCH GIVING DISSOLVED OXYGEN VALUES (ppm) FOR VARIOUS SITES AND DEPTHS.

Legend: (a) MA-20; (b) MB-20; (c) BM-07; (d) SM-05
(A) Average of available values for March 1972
(B) Values for 13 June, indicated by a circle, and 15 June 1972
(C) Values for 16 June 1972

Note: Dashed line indicates approximate depths of stratification.

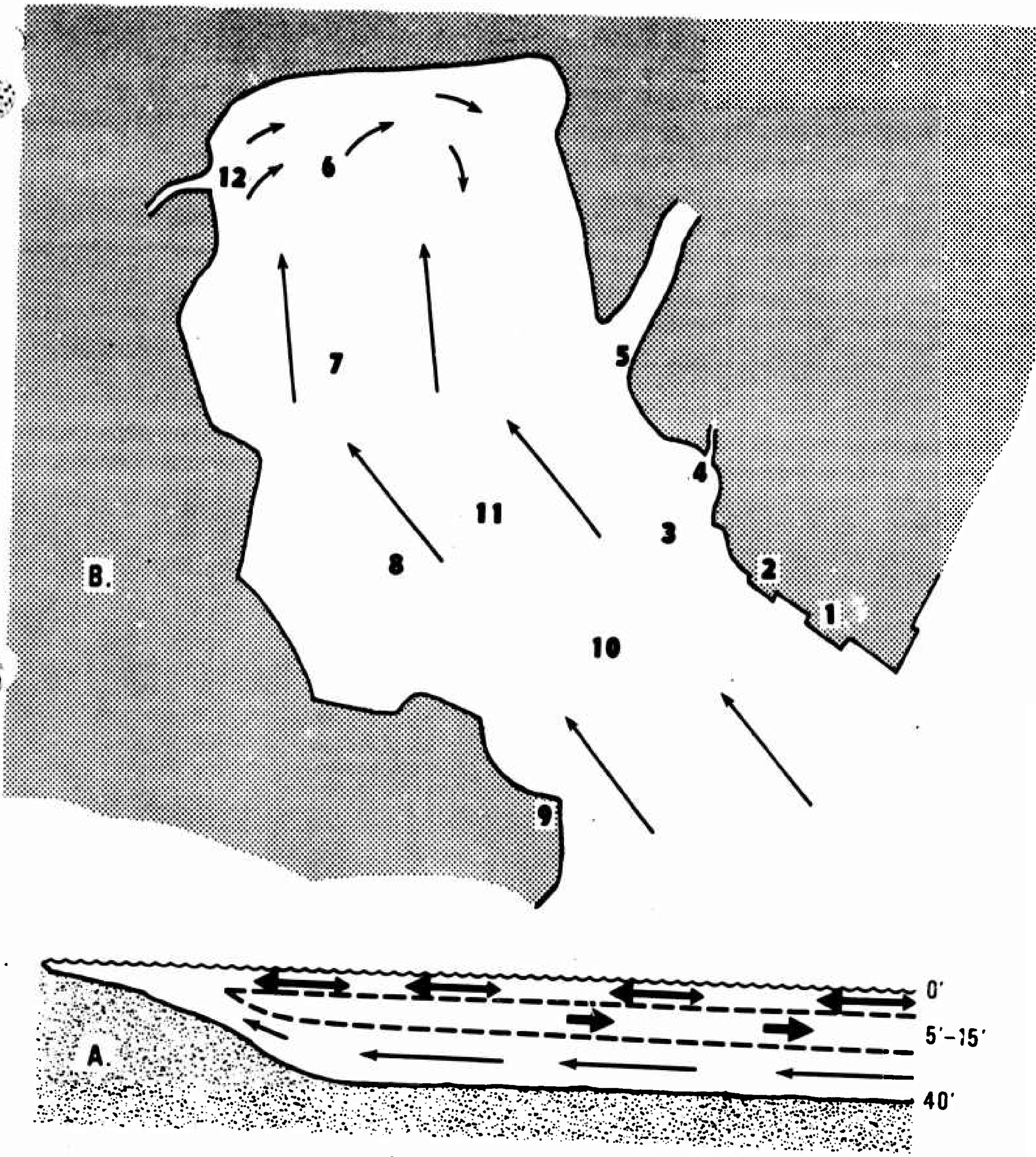


Figure G-5. ESTIMATED WATER MOVEMENT AND CIRCULATION PATTERNS IN MIDDLE LOCH: (A) NET MOVEMENT OF THE STRATIFIED LAYERS, AND (B) INWARD MOVEMENT AND CLOCKWISE GYRE OF THE UPPER AND LOWER LAYER.

6. DO values in the southern part of the loch reached their lowest sometime near the 14th of June but were increasing toward normal values by the afternoon of the 15th.

7. Because of the general movement of upper and lower layer waters into the loch, the water of low oxygen content was contained within the loch, not passing beyond the line shown in Figure G-2.

8. The oxygen content of the affected area reached a low (average less than 1 ppm) sufficient to cause the extensive kill indicated in Figure G-3.

9. Free swimming fishes and other motile animals, with the exception of those trapped at BM-07, evacuated the area until the water could again support life.

10. Although some mortality did occur in the upper layer, that water recovered well and was life-supporting by the morning of the 16th; a fact supported by the observation of numerous fishes at depths above 15 feet on that day.

11. The kill was more complete and lethal conditions persisted longer in the lower layer because of the slower oxygen recovery potential of that layer.

12. By the morning of the 19th the causative substance had been effectively dissipated and the oxygen content of most of Middle Loch was near normal; a fact supported by the observation that fishes had returned to all depths at all points checked on that morning.

13. The cause of the mortality was probably not a toxin since there was no sign of dying or dead fish (other than in the trap) in the loch at any time, even after days of feeding on those animals that did die.

14. Telephone conversations with the Honolulu City and County Sewers Division (which controls the Pearl City STP), with the Navy's Public Works Department, and with the Navy's Fuel Farm Division recovered no information whatever that would clarify any of the occurrences in Middle Loch for the week of the 12th of June.

APPENDIX H

J. Geoffrey Grovhoug

Red Tide Occurrence in Pearl Harbor

GENERAL INFORMATION

Discolored (reddish brown) surface water was sometimes observed by field team members during boat transits along various harbor regions throughout the survey period. In the field, this surface turbid layer was initially attributed to freshwater runoff containing reddish clay sediments. However, upon careful examination of water samples collected from the entrance to Middle Loch (in January 1973), it became readily apparent that a dense concentration of some microscopic organism was causing the observed discoloration. Samples of water containing this organism were examined by Dr. Allen Cattell, Hawaii Institute of Marine Biology, and identified as dinoflagellates (personal communication).

The occurrence of dinoflagellate blooms along coastal waters and in embayments has been documented for decades throughout various global regions. This phenomenon is known as a "red tide" due to the reddish discoloration of the water. Massive mortality of fish and other marine forms has occurred off Florida, Southern California, in the Sea of Cortez, etc. and has been attributed to two dinoflagellate-related causes: 1) oxygen depletion and 2) the production of a neurotoxin by certain dinoflagellate species. Fortunately, no toxic species of dinoflagellates have been observed in Pearl Harbor. Red tide occurrences have thus far been distributed in "patches" (50-150 sq. yards in size) and observed occasionally in all major lochs and channel areas of the harbor.

DISCUSSION

The occurrence of red tides in Pearl Harbor appears to be a relatively recent phenomena, documented only within the past several years. According to Dr. Cattell, several dinoflagellate species identified from Pearl Harbor have also been identified from Kaneohe Bay, Oahu. Several State agencies including the Hawaii Division of Fish and Game, Department of Health and the University of Hawaii (especially HIMB) have become increasingly interested in these phenomena and several meetings of interested groups (including U.S. Navy representatives) have been held to discuss background, predictive and control investigations. Toxicity tests have been performed on the most abundant dinoflagellate species occurring in Pearl Harbor, *Cochlodinium catenatum* Okamura, by Dr. Cattell. These tests revealed that no apparent toxin was being produced by the species under study. In all, eight species of dinoflagellates have been recently identified from Pearl Harbor waters:

Ceratium ferka (Ehrenberg)
Cochlodinium catenatum Okamura
Dinophysis caudatum (Kent)
Gonyaulax minutum Michener
Noctiluca minuta (McCartney & Kofoid)
Peridinium crassipes (Kofoid)
Polykrikos schwartzi (Bütschli)
Prorocentrum gracile Schütt

During the spring of 1973, PHBS and NCEL/EPDB field team members surveyed the harbor in order to map the distributional patterns of red tide patches during a four day period (12-15 March 1973). The results of this mapping effort are displayed in Figure H-1. As may be seen, the patches originated deep within the harbor (East and Middle Loch) and subsequently moved toward the harbor entrance.

The recurrent red tide phenomena in Pearl Harbor certainly merits further study due to the potential ramifications. A need for full ecological understanding, and control of dinoflagellate blooms exists at this time, while Hawaiian environments are presumably in the early stages of experiencing these phenomena.

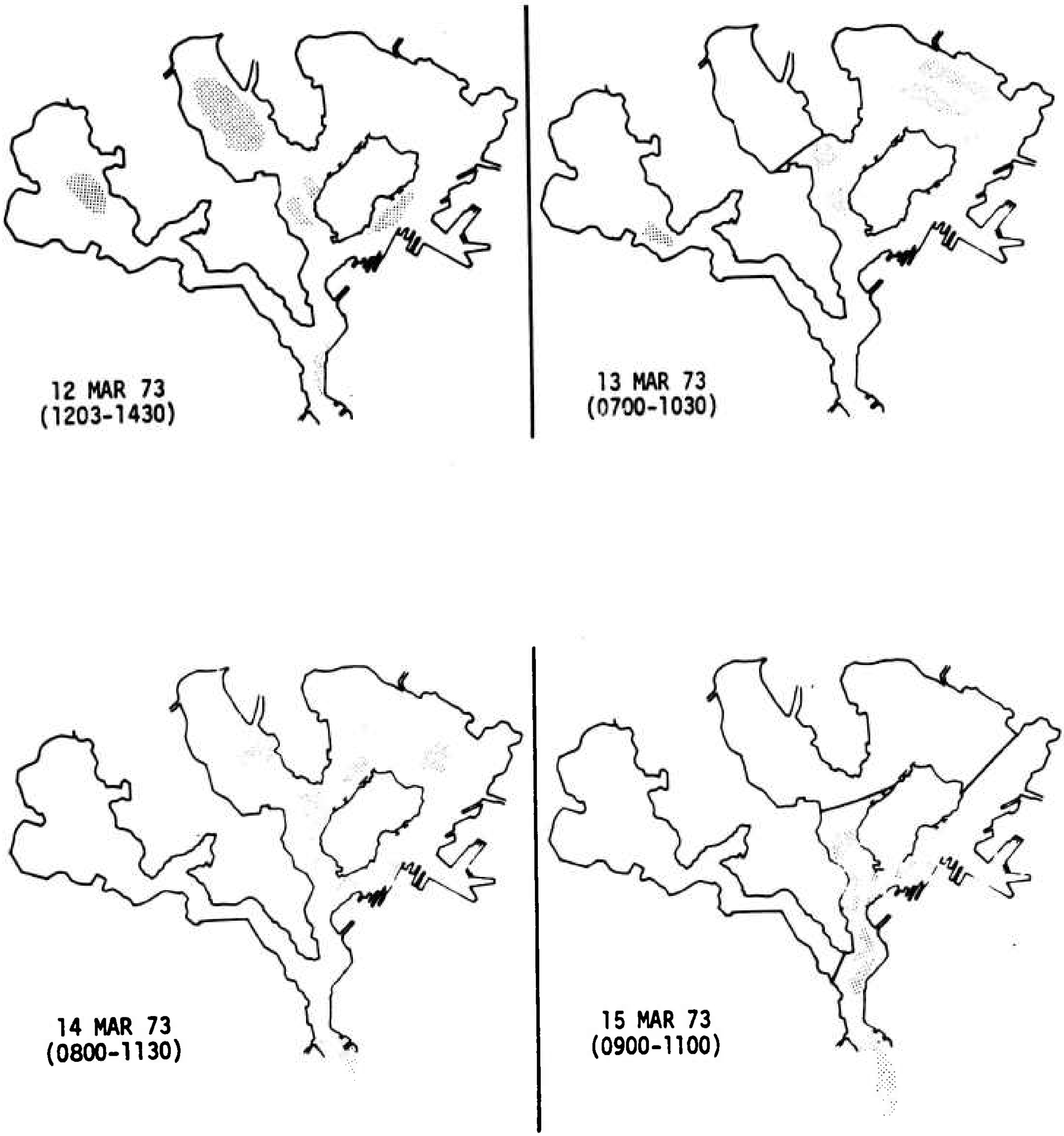


Figure H-1. DISTRIBUTION OF RED TIDE "PATCHES" OVER A FOUR DAY PERIOD IN MARCH, 1973. (SOLID LINES ON MAPS INDICATE BOUNDARIES OF OBSERVATION)

INDEX

INDEX

The various subjects covered in this report have been indexed using an alphanumeric system. Page numbers are indicated followed immediately by a letter indicating the section of the page to be consulted, see letter key at the right of this page. Page number only is given if subject covers entire page; the letters "ff" indicate that the subject continues for some length from the point indicated. Tables are indicated by (T) following key words; figures, by (F).

a

Table 3.2-4. SUMMARY OF HEAVY-METAL WATER ANALYSIS FOR BIO-STA
(number of detections/number of analyses; max value (ppm) gi
whenever a detection is reported)

STA	Ag	Cd	Cr	Cu	Fe	Hg	Mn	Ni	
BE-02S*	0/1	0/1	0/4	1/9 .02	1/2 .50	0/2	0/4	-	
B*	0/2	0/1	0/4	2/8 .03	0/3	0/2	0/4	-	
BE-03S	0/1	0/1	0/4	0/9	1/3 .02	0/2	0/4	-	
B	0/2	0/1	0/4	2/8 .03	2/4 .15	0/2	0/4	-	
BE-04S	0/1	0/1	1/5 .26	0/8	0/2	0/2	0/4	-	
B	0/2	0/1	1/3 .26	1/6 .04	0/1	0/2	0/4	-	
BE-05S	0/1	0/1	0/4	0/7	0/3	0/3	0/4	-	
B	0/1	0/1	0/4	1/6 .04	0/5	0/2	0/4	-	
BM-07S	0/1	0/2	0/4	0/9	1/2 .11	0/2	1/5 .04	-	
B	0/2	0/3	0/4	0/8	2/3 .15	0/2	1/5 .04	-	
BC-09S	0/1	0/1	0/4	0/8	0/3	0/2	0/4	-	
B	0/2	0/1	0/4	0/6	0/3	0/2	0/4	-	
BC-10S	0/1	0/1	0/4	0/8	0/3	0/2	0/4	-	
B	0/2	0/1	0/4	0/6	0/3	0/2	0/4	-	
BC-11S	0/1	0/1	0/4	0/7	0/3	0/2	0/3	-	
B	0/2	0/1	0/4	1/5 .07	0/3	0/2	0/3	-	
BW-13S	0/2	0/1	0/4	0/8	1/3 .20	0/2	1/5 .04	-	
B	0/4	0/1	0/4	0/6	0/5	0/2	0/4	-	
BE-17S	0/1	0/1	0/4	0/9	0/2	0/2	1/5 .04	-	
B	0/2	0/1	0/4	1/8 .04	2/3 .11	0/2	0/4	-	
TOTALS	0/11	0/11	1/41 .26	1/82 .02	4/26 .50	0/21	3/42 .04	-	3
B	0/21	0/12	1/39 .26	8/68 .07	6/33 .15	0/20	1/40 .04	-	1

* B = bottom water; S = surface water.

182

/-METAL WATER ANALYSIS FOR BIO-STATIONS.
:r of analyses; max value (ppm) given
ı detection is reported)

	Hg	Mn	Ni	Pb	Zn	Summary of Metals Detected
0	0/2	0/4	-	0/4	0/8	Cu, Fe
	0/2	0/4	-	0/4	4/8 .04	Cu, Zn
2	0/2	0/4	-	1/6 .10	1/8 .05	Fe, Pb, Zn
5	0/2	0/4	-	1/5 .10	2/8 .05	Cu, Fe, Pb, Zn
	0/2	0/4	-	1/6 .10	0/7	Cr, Pb
	0/2	0/4	-	0/4	4/7 .23	Cr, Cu, Zn
	0/3	0/4	-	0/5	0/8	no detections
	0/2	0/4	-	0/4	4/8 .09	Cu, Zn
1	0/2	1/5 .04	-	0/6	0/9	Fe, Mn
5	0/2	1/5 .04	-	0/4	5/9 1.1	Fe, Mn, Zn
	0/2	0/4	-	1/5 .10	0/8	Pb
	0/2	0/4	-	0/4	3/8 .17	Zn
	0/2	0/4	-	0/6	1/8 .04	Zn
	0/2	0/4	-	0/4	4/8 .14	Zn
	0/2	0/3	-	0/6	0/8	no detections
	0/2	0/3	-	0/4	5/8 .27	Cu, Zn
0	0/2	1/5 .04	-	0/6	0/8	Fe, Mn
	0/2	0/4	-	0/4	4/8 .10	Zn
	0/2	1/5 .04	-	0/4	0/8	Mn
1	0/2	0/4	-	0/4	4/8 .11	Cu, Fe, Zn
0	0/21	3/42 .04	-	3/56 .10	2/80 .05	Cr, Cu, Fe, Mn, Pb, Zn
5	0/20	1/40 .04	-	1/41 .10	39/80 1.1	Cr, Cu, Fe, Mn, Pb, Zn

292

Table 3.1-1. SUMMARY COMPARISON OF SEDIMENT DATA WITH BIOLO
(values in mg/kg dry wt. unless otherwise noted; * = mult

STA	Ag	Cd	Cr	Cu	Fe*	Hg	Mn	Ni	Pb	Zn	TOT	COD*	Oil	Kj-N	VoSo (%)	PHY Cl
			H-E-A-V-Y		M-E-T-A-L-S							P-O-L-L-U-T-A-N-T-S				
BE-02	-	1.4	24	120	15.	-	128	27	65	110	347	-	-	-	12.99	GE
BE-03	-	4.	100	197	37.	1.2	315	80	100	153	634	-	-	10	19.13	-
BE-04	-	ND	360	227	93.	2.6	513	200	60	137	984	-	-	10	13.53	-
BE-05	2.5	0.5	70	30	24.1	0.074	420	71	22	146	342	-	12650	-	7.73	GE
BM-07	-	ND	150	83	17.	0.36	630	130	20	200	583	105.	6860	10	12.97	GE
BC-09	9.0	ND	110	99	39.	0.67	1100	110	39	280	647	-	-	110	21.71	E
BC-10	5.8	1.2	96	560	43.	3.7	420	190	310	1300	2463	78.2	-	1860	21.07	GI
BC-11	3.5	0.8	9.2	11	4.3	0.081	150	10	15	50	100	-	3920	-	7.46	GI
BW-13	3.8	1.0	62	240	22.	2.1	770	52	110	350	819	91.	-	2480	21.25	GI
BE-17	-	1.8	66	570	28.	-	165	50	530	440	1658	107.	-	-	11.74	GI
correlation coefficients between sediment and biological data																
INFsp	-.06	-.03	-.60	-.45	-.54	-.50	+.14	-.57	-.34	-.20	-.44	-.43	-.45	+.32	-.05	
INFid	-.25	-.33	-.37	-.60	-.37	-.66	+.20	-.41	-.45	-.32	-.53	.20	+.23	+.06	-.33	-
INF$\overline{id}$	-.14	-.36	-.31	-.56	-.29	-.62	+.35	-.32	-.44	-.28	-.48	-.20	+.61	+.06	-.22	
μMLsp	-.12	-.25	-.40	-.57	-.32	-.51	-.01	-.44	-.48	-.33	-.54	-.66	+.58	+.07	-.27	
μMLid	-.31	-.32	-.45	-.68	-.47	-.65	-.11	-.44	-.55	-.33	-.59	-.62	-.02	-.14	-.51	

Key: heavy metals, COD, Oil, and Kj-N given in mg/kg dry wt, (* indicates value should be
given in % of total sample. Ag = silver, Cd = cadmium, CLR = color of sediment, COD = che
Cr = chromium, Cu = copper, c&s = clay and silt, BOT. = bottom, BR = brown, Fe = iron, GBK
ish-green, gr = gravel, Hg = mercury, ind = total number of individuals, $\overline{ind}$ = av. number
al ind., INF$\overline{id}$ = bottom infaunal $\overline{ind}$, INFsp = number of bottom infaunal species, Kj-N = Kj
Mn = manganese, ND = not detected, Ni = nickel, NO = no odor, OD = odor, Oi = oily smell,
sediment, Sa = salty smell, sd = sand, Sf = sulfur smell, SM = sand and mud, sp = number o
TOT = total metals (Ag+Cd+Cr+Cu+Pb+Ni+Zn), μMLsp = number of micromolluscan sp., μMLid = t
= micromollusca.

SON OF SEDIMENT DATA WITH BIOLOGICAL PARAMETERS.
nless otherwise noted; * = multiply by 10^3)

	P-O-L-L-U-T-A-N-T-S				PHYS.	DISCR.		M-E-C-H	A-N-A-L		BOT.	INFAUNA		μMOL.	
OT	COD*	Oil	Kj-N	VoSo (%)	CLR	OD	CP	gr (%)	sd (%)	c&s (%)	sp (#)	ind (#)	$\overline{\text{ind}}$ (#)	sp (#)	ind (#)
47	-	-	-	12.99	GBK	Oi	SM	36.6	45.4	18.0	30	185	21	18	162
34	-	-	10	19.13	-	-	-	0	24.6	75.4	43	308	34	6	59
84	-	-	10	13.53	-	-	-	0	23.6	76.4	8	24	4	7	60
42	-	12650	-	7.73	GBR	Sa	SM	-	-	-	51	5256	584	17	237
83	105.	6860	10	12.97	GBK	Sf	SM	1.6	8.6	89.8	21	155	26	5	84
47	-	-	110	21.71	BR	Sa	SM	0.2	5.0	94.8	70	3945	438	14	168
53	78.2	-	1860	21.07	GBR	NO	SS	67.6	20.3	12.1	32	85	14	7	90
00	-	3920	-	7.46	GGR	Sf	SM	-	-	-	99	4968	331	12	278
19	91.	-	2480	21.25	GBK	Sf	SM	46.4	33.7	19.9	61	1923	214	9	72
58	107.	-	-	11.74	GBK	Sf	SM	3.9	32.8	64.3	25	80	9	5	30
a															
44	-.43	-.45	+.32	-.05	-	-	-	+.15	-.20	-.03	+1	+.82	+.69	+.41	+.71
53	.20	+.23	+.06	-.33	-	-	-	-.28	-.43	+.25	+.82	+1	+.96	+.61	+.85
48	-.20	+.61	+.06	-.22	-	-	-	-.28	-.44	+.25	+.69	+.96	+1	+.64	+.76
54	-.66	+.58	+.07	-.27	-	-	-	+.09	+.30	-.29	+.41	+.61	+.64	+1	+.77
59	-.62	-.02	-.14	-.51	-	-	-	-.02	-.12	-.08	+.71	+.85	+.76	+.77	+1

(* indicates value should be multiplied by 10^3); VoSo and mechanical analysis
= color of sediment, COD = chemical oxygen demand, CP = composition of sediment,
om, BR = brown, Fe = iron, GBK = grayish-black, GBR = grayish-brown, GGR = gray-
individuals, $\overline{\text{ind}}$ = av. number of individuals per sample, INFid = bottom infaun-
om infaunal species, Kj-N = Kjeldahl nitrogen, MECH ANAL = mechanical analysis,
, OD = odor, Oi = oily smell, Pb = lead, PHYS. DISCR. = physical description of
= sand and mud, sp = number of species, SS = shells, VoSo = volatile solids,
micromolluscan sp., μMLid = total number of micromolluscan individuals, μMOL

282

Table 3.1-2. HIGHEST 20 STATIONS, PEARL HARBOR SEDIMENT ANA
(values in mg/kg dry wt.; * = multiply value by 10^3)

Ag STA	Ag METL	Cd STA	Cd METL	Cr STA	Cr METL	Cu STA	Cu METL	Fe* STA	Fe* METL	Hg STA	Hg METL	Mn STA	Mn METL
ES03	21.	ES08	11.	→BE04	360	ES06	1200	→BE04	93.	ES06	9.5	WC20	4800
ES08	19.	SE04	10.	SM01	220	ES08	840	SE05	84.	SE05	5.3	WB20	3000
$\bar{X}+\sigma$ =	14.3	ES22	8.8	SM06	210	TB30	800	WE20	83.	ES08	4.9	ES17	1600
ES06	10.	SE02	5.	ED30	200	SE04	698	ES13	78.	→BC10	3.7	ES18	1600
ES28	10.	→BE03	4.	ES13	200	SE05	695	ES11	72.	SE04	2.9	SW01	1600
→BC09	9.	SE03	4.	MB20	200	→BE17	570	SE04	72.	ES18	2.8	WD20	1200
ES19	8.5	ES06	2.8	MC20	200	→BC10	560	WF40	72.	→BE04	2.6	$\bar{X}+\sigma$ =	1150
ES21	7.0	$\bar{X}+\sigma$ =	2.71	SE02	200	EA30	390	ES14	69.	ES20	2.4	→BC09	1100
CC30	6.5	→BE17	1.8	SE04	200	SE06	372	ES10	67.	$\bar{X}+\sigma$ =	2.39	MB10	1000
CD10	6.2	ES23	1.7	SE05	200	$\bar{X}+\sigma$ =	348	SE02	65.	ES24	2.2	SM01	970
ES18	6.0	ES03	1.5	$\bar{X}+\sigma$ =	160	ES02	290			→BW13	2.1	WE20	890
→BC10	5.8	ES04	1.5	ES08	180	ES20	280	ES09	65.	ES29	2.1	ES16	870
WF40	5.7	ES19	1.5	ES11	180	ES21	260	WC20	62.	ED30	1.9	MA30	850
ES20	5.5	ES21	1.5	ES10	170	ES28	260	WD10	61.	ES04	1.9	WF40	840
ES23	5.0	→BE02	1.4	ES28	170	→BW13	240	ES15	58.	ES05	1.9	WA20	800
TB30	4.9	TB30	1.4	WE20	170	SE02	236	WD20	58.	SE06	1.9	SM06	790
ES15	4.7	WF40	1.4	MB30	160	→BE04	227	SM05	56.	ES27	1.8	→BW13	770
ES07	4.6	ES02	1.3	SM05	160	ES23	220	SM04	55.	ED20	1.7	CD10	770
ES22	4.5	→BC10	1.2	→BM07	150	SE03	219	SW01	55.	ES28	1.7	SM03	680
ES02	4.3	→BW13	1.0	ES14	150	ES07	210	$\bar{X}+\sigma$ =	54.5	CF20	1.6	ES09	660
ES05	3.9	CB20	1.0	ES29	150	ES04	200	ES29	53.4	SE01	1.6	ES24	650
								MB30	52.				
→BW13	3.8	CC30	1.0	MB10	150	→BE03	197	WF20	52.	ES22	1.5	MA20	630
		CD10	1.0	SM04	150			ES28	47.1				
		ES01	1.0	SM03	140								
		ES17	1.0										
		ES20	1.0										
		ES26	1.0										
		ES28	1.0										
		CC20	0.9										

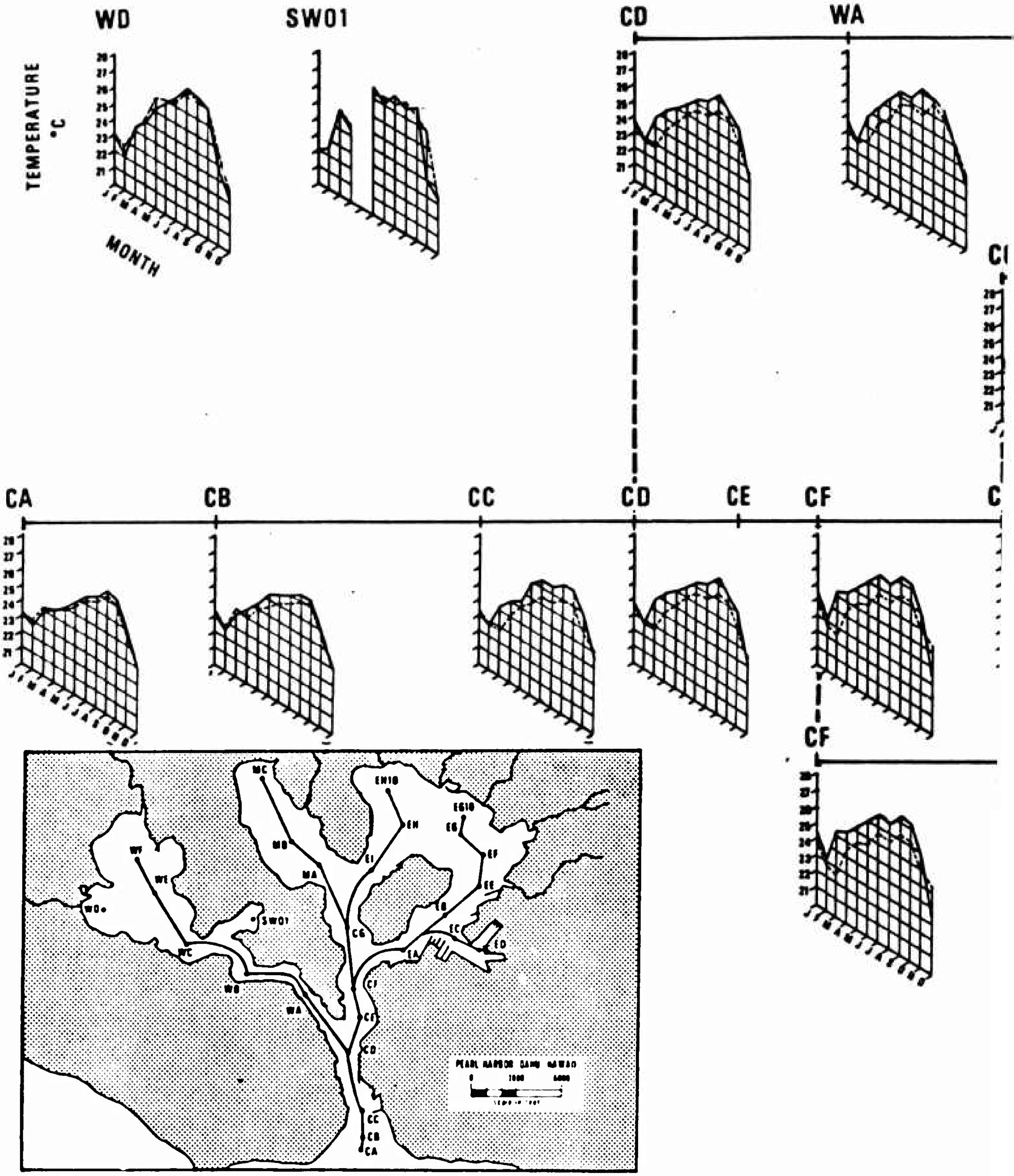
Repeat stations in the top 10: BC09 Ag, Mn; BC10 Cu, Hg, Pb, Zn ES03 Ag, Cd; ES06 Ag, Cd, Cu, Hg, Pb, Zn; ES08 Ag, Cd, Cu, Hg, ES14 Fe, Ni; ES17 Mn, Zn; ES18 Ag, Hg, Mn; ES19 Ag, Cd; ES20 Hg Zn; MB10 Mn, Ni; SE02 Cr, Fe; SE04 Cd, Cr, Cu, Fe, Hg; SE05 Cr, Cr, Ni; TB30 Cu, Pb, Zn; WE20 Fe, Mn.

TATIONS, PEARL HARBOR SEDIMENT ANALYSIS.
y wt.; * = multiply value by 10^3)

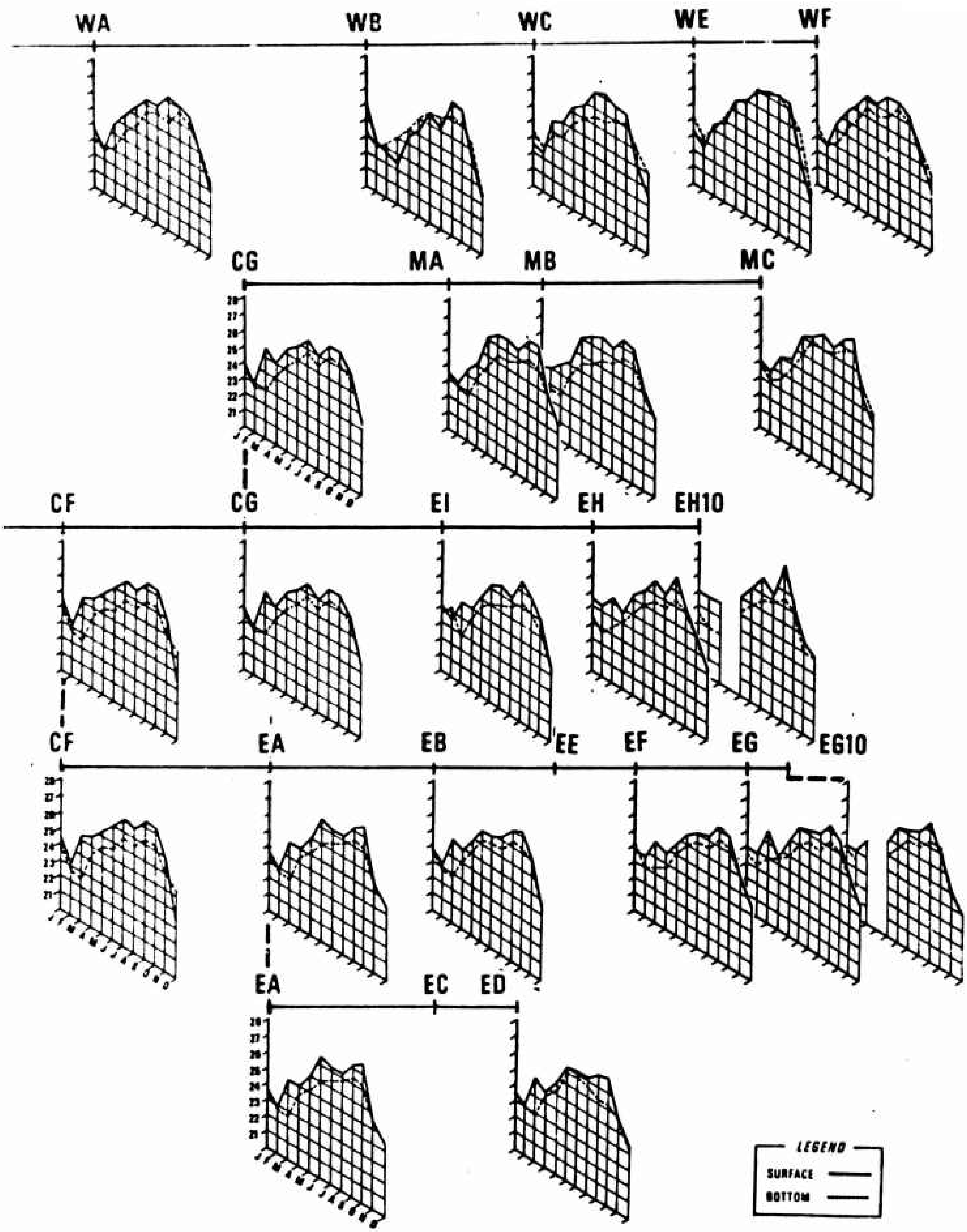
	Fe*	Hg		Mn		Ni		Pb		Zn		TOTAL	
	METL	STA	METL	STA	METL	STA	METL	STA	METL	STA	METL	STA	METL
	93.	ES06	9.5	WC20	4800	SM01	930	SE05	1700	ES08	1900	ES08	3777
	84.	SE05	5.3	WB20	3000	SM06	830	ES06	800	→BC10	1300	ES06	3497
!	83.	ES08	4.9	ES17	1600	MB10	610	ES08	740	ES06	1300	SE05	3211
,	78.	→BC10	3.7	ES18	1600	SM03	470	→BE17	530	ES22	1100	→BC10	2463
	72.	SE04	2.9	SW01	1600	ES11	410	TB30	470	ES21	990	TB30	1896
.	72.	ES18	2.8	WD20	1200	ES10	380	ES20	380	ES20	820	ES22	1744
|	72.	→BE04	2.6	$\bar{X}+\sigma$ =	1150	ES13	380	$\bar{X}+\sigma$ =	327	ES23	815	ES21	1733
,	69.	ES20	2.4	→BC09	1100	ES15	290	→BC10	310	ES17	566	SE04	1715
)	67.	$\bar{X}+\sigma$ =	2.39	MB10	1000	ES12	280	ES21	310	$\bar{X}+\sigma$ =	543	ES20	1664
!	65.	ES24	2.2	SM01	970	$\bar{X}+\sigma$ =	273	EA30	300	TB30	510	→BE17	1658
		→BW13	2.1	WE20	890	ES14	270	ED30	300	→BE17	440		
)	65.	ES29	2.1	ES16	870	WF40	260	ES19	300	ES04	440	SM01	1649
)	62.	ED30	1.9	MA30	850	WE20	210	ES22	300	ES28	428	ES23	1418
]	61.	ES04	1.9	WF40	840	→BE04	200	SE06	300	SE05	416	$\bar{X}+\sigma$ =	1402
5	58.	ES05	1.9	WA20	800	BE06	200	ES26	240	SE04	407	MB10	1093
)	58.	SE06	1.9	SM06	790	MB20	200	SE04	200	ES02	390	SE06	1086
5	56.	ES27	1.8	→BW13	770	SE04	200	ES02	190	ES26	383	ED30	1005
4	55.	ED20	1.7	CD10	770	SE05	200	ES23	190	ES27	368	ES02	996
1	55.	ES28	1.7	SM03	680	→BC10	190	ES04	120	ES19	360	ES04	959
=	54.5	CF20	1.6	ES09	660	ES28	150	ES17	120	→BW13	350	EA30	950
9	53.4	SE01	1.6	ES24	650	ES09	140	→BW13	110	ES01	310	→BE04	924
0	52.											ES19	909
0	52.	ES22	1.5	MA20	630	WF20	140	ES18	110	ED30	287	ES17	891
8	47.1					→BM07	130	SE01	110				
								→BE03	100				

: BC09 Ag, Mn; BC10 Cu, Hg, Pb, Zn; BE04 Cr, Fe, Hg; BE17 Cd, Cu, Pb, Zn; ED30 Cr, Pb
Hg, Pb, Zn; ES08 Ag, Cd, Cu, Hg, Pb, Zn; ES10 Fe, Ni; ES11 Fe, Ni; ES13 Cr, Fe, Ni;
8 Ag, Hg, Mn; ES19 Ag, Cd; ES20 Hg, Pb, Zn; ES21 Ag, Cd, Pb, Zn; ES22 Cd, Zn; ES23 Cd,
SE04 Cd, Cr, Cu, Fe, Hg; SE05 Cr, Cu, Fe, Hg, Pb; SE06 Cu, Pb; SM01 Cr, Mn, Ni; SM06
Fe, Mn.

272



2. GENERAL LAYOUT OF PEARL HARBOR SHOWING MEAN MONTHLY TEMPERATURE VARIATION BY RANGE FOR SURFACE AND BOTTOM WATERS.


WA
WB
WC
WE
WF
CG
MA
MB
MC
CF
CG
EI
EH
EH10
CF
EA
EB
EE
EF
EG
EG10
EA
EC
ED
LEGEND
SURFACE
BOTTOM

2 of 2

Table 3.2-2. SUMMARY COMPARISON OF WATER QUALITY DATA WITH B

STA	Temperature (°C) range	mean (n)	Salinity (‰) range	mean (n)	Diss Ox (mg/l) range	mean(n)	Total P (ppm) range	mean (n)
BE-02S	22.9-28.3	26.5(19)	28.8-35.5	34.1(17)	4.2- 6.8	5.2(18)	.010-.070	.030(13)
B	22.9-28.1	26.1(17)	29.4-35.7	34.4(12)	3.9- 5.6	4.7(18)	.005-.050	.022(12)
BE-03S	24.1-28.5	26.6(17)	29.9-35.8	34.2(16)	4.8- 8.6	5.9(17)	.005-.046	.015(12)
B	23.9-27.4	26.0(15)	34.7-36.0	35.4(14)	1.8- 8.0	4.2(15)	.005-.070	.022(12)
BE-04S	24.0-28.3	26.6(18)	28.8-35.9	34.2(16)	3.7- 6.7	5.2(17)	ND-.052	.022(12)
B	23.5-27.8	26.0(17)	34.7-36.0	35.2(14)	3.1- 5.0	3.8(16)	ND-.060	.026(12)
BE-05S	24.0-29.8	26.5(21)	31.1-35.2	34.1(18)	4.8- 6.8	5.8(19)	.005-.070	.029(14)
B	24.9-28.5	27.1(11)	33.5-35.4	34.6(10)	4.0- 6.6	5.5(13)	.010-.112	.034(12)
BM-07S	24.6-29.9	27.4(17)	23.7-35.2	33.5(16)	4.4- 8.0	5.8(16)	.028-.200	.090(13)
B	23.4-27.3	25.9(16)	34.6-36.9	35.8(15)	1.0- 9.4	3.9(16)	.012-.070	.040(14)
BC-09S	22.8-29.1	26.4(18)	19.4-34.3	32.3(16)	4.1- 8.6	6.1(17)	.035-.270	.109(13)
B	24.1-28.3	26.7(14)	31.4-35.0	33.7(13)	4.3- 6.4	5.3(14)	.008-.129	.066(12)
BC-10S	22.5-40.0	32.4(18)	24.5-40.0	34.6(14)	4.9- 9.2	5.9(17)	ND-.102	.030(12)
B	23.0-27.7	25.4(17)	32.4-36.6	35.2(13)	4.4- 9.1	5.4(17)	ND-.045	.019(12)
BC-11S	23.4-29.3	26.6(17)	20.5-35.4	33.1(15)	4.8- 9.8	6.4(14)	.010-.086	.040(10)
B	23.8-27.5	26.4(14)	34.0-36.7	35.3(13)	3.8- 6.5	5.2(12)	.005-.070	.028(10)
BW-13S	21.5-29.5	26.7(18)	18.1-34.8	32.4(16)	4.4- 7.2	5.7(16)	.025-.125	.073(13)
B	21.9-28.0	25.8(17)	34.4-36.9	35.5(14)	2.9- 5.8	4.2(17)	ND-.060	.028(13)
BE-17S	25.0-28.3	26.7(17)	25.6-36.0	33.6(16)	4.7-10.0	6.2(16)	ND-.090	.037(12)
B	24.0-27.8	26.3(15)	32.5-35.8	35.0(14)	3.6- 8.0	4.8(16)	ND-.090	.025(12)

highest and next highest correlation coefficients (positive or negative) between water

FidB -0.45	PspJB +0.48	FidB +0.80	PspJS -0.43
PspNS +0.38	PidNS -0.45	FidS +0.72	PspNS -0.40

Key: B = bottom water, F = fish, id = individual count, J = June survey, N = November sur
These abbreviations are combined, thus FidB = fish, individual count vs bottom water
pared with both surface and bottom water quality parameters; piling surface biota we
parameters; piling 10-foot biota to bottom water quality parameters only.

182

RISON OF WATER QUALITY DATA WITH BIOLOGICAL POPULATIONS.

Ox e	(mg/l) mean(n)	Total P range	(ppm) mean (n)	Tot Or Car range	(ppm) mn.(n)	FISH sp	 ind	PILING COMM. sp Jn/Nv	 ind Jun/Nov
6.8	5.2(18)	.010-.070	.030(13)	ND- 8.0	2.7(9)	31	82	15/ 9	99/ 85
5.6	4.7(18)	.005-.050	.022(12)	ND- 5.5	2.3(8)			17/18	41/ 38
8.6	5.9(17)	.005-.046	.015(12)	ND- 6.0	3.0(10)	29	138	25/20	1023/ 78
8.0	4.2(15)	.005-.070	.022(12)	ND- 5.5	2.2(9)			21/20	287/178
6.7	5.2(17)	ND-.052	.022(12)	ND-12.0	3.8(9)	10	41	5/ 1	140/ 1
5.0	3.8(16)	ND-.060	.026(12)	ND- 5.0	2.8(8)			11/16	261/228
6.8	5.8(19)	.005-.070	.029(14)	ND-14.0	4.5(8)	28	221	8/29	23/ 99
6.6	5.5(13)	.010-.112	.034(12)	ND- 7.0	2.8(7)			19/20	62/ 62
8.0	5.8(16)	.028-.200	.090(13)	ND- 5.5	2.9(9)	22	133	8/10	108/ 56
9.4	3.9(16)	.012-.070	.040(14)	ND- 5.5	2.2(6)			35/20	281/118
8.6	6.1(17)	.035-.270	.109(13)	ND- 5.0	2.9(9)	24	140	no data	
6.4	5.3(14)	.008-.129	.066(12)	ND- 7.0	2.2(6)			no data	
9.2	5.9(17)	ND-.102	.030(12)	ND- 7.0	3.0(10)	42	186	16/25	186/'56
9.1	5.4(17)	ND-.045	.019(12)	ND- 6.0	2.3(8)			25/18	93/ 51
9.8	6.4(14)	.010-.086	.040(10)	ND-13.5	4.7(9)	70	227	30/14	224/ 78
6.5	5.2(12)	.005-.070	.028(10)	ND- 7.0	2.3(7)			41/39	1106/722
7.2	5.7(16)	.025-.125	.073(13)	1.0- 7.0	4.0(8)	43	65	21/21	669/943
5.8	4.2(17)	ND-.060	.028(13)	1.0- 8.5	3.9(6)			19/20	384/269
0.0	6.2(16)	ND-.090	.037(12)	ND- 6.0	2.5(11)	19	134	17/14	490/ 65
8.0	4.8(16)	ND-.090	.025(12)	ND- 5.0	1.6(8)			16/14	145/ 59

ositive or negative) between water quality and biological data

idB	+0.80	PspJS	-0.43	FspS	+0.52	all intercorrelations
idS	+0.72	PspNS	-0.40	FidB	-0.35	are high (0.6 to 1.0)

J = June survey, N = November survey, S = surface water, sp = species count. , individual count vs bottom water quality parameter, etc. Fish were com- arameters; piling surface biota were compared only to surface water quality uality parameters only.

282

Table 3.2-2. SUMMARY COMPARISON OF WATER QUALITY DATA WITH
(continued: biological parameters in fir

STA	pH		Turbidity (JTU)		Secchi (m)		Kjeldahl-N (ppm) ND = <.005*		Ammon ND =
	range	mean(n)	range	mean (n)	range	mean(n)	range	mean(n)	rang
BE-02S	7.9-8.5	8.1(19)	0.6- 3.3	1.6(18)	1.0-5.0	3.2(19)	ND	ND (6)	ND-.
B	8.0-8.5	8.2(17)	0.8-23.0	4.3(18)			ND-.081	.023(6)	ND-.
BE-03S	8.0-8.5	8.2(18)	0.8- 5.7	2.0(18)	1.4-4.8	3.2(17)	ND-.486	.069(7)	ND-.
B	7.9-8.5	8.1(17)	1.7-55.0	7.3(17)			ND-.050	.007(7)	.010-.
BE-04S	8.0-8.5	8.2(18)	1.2- 7.5	3.0(17)	1.5-4.8	3.1(18)	ND-.062	.009(7)	ND-.
B	8.0-8.4	8.1(17)	2.1-11.0	4.0(17)			ND-.110	.016(7)	.005-.
BE-05S	6.8-8.6	7.7(23)	1.1-36.0	4.0(20)	1.1-3.4	2.0(16)	ND	ND (6)	ND-.
B	7.9-8.3	8.1(11)	2.3- 4.1	3.2(13)			ND-.078	.013(6)	ND-.
BM-07S	7.4-8.7	8.1(18)	1.8- 6.0	3.5(19)	0.6-2.5	1.6(16)	ND-.147	.061(6)	ND-.
B	7.1-8.4	7.9(18)	1.5-37.0	10.7(18)			ND-.099	.026(6)	ND-.
BC-09S	7.9-9.0	8.2(18)	2.2-15.0	4.4(18)	0.7-3.0	1.7(8)	ND-.121	.063(6)	ND-.
B	7.9-8.5	8.1(16)	1.1- 5.0	3.2(17)			ND-.054	.017(6)	ND-.
BC-10S	8.0-8.5	8.2(18)	1.1- 3.0	1.8(17)	2.0-4.0	2.8(18)	ND-.097	.016(6)	ND-.
B	8.0-8.6	8.2(19)	1.9- 7.9	3.3(17)			ND-.075	.015(5)	ND-.
BC-11S	8.0-8.4	8.2(17)	1.6- 9.2	2.8(17)	0.8-3.2	2.3(16)	ND-.068	.025(5)	ND-.
B	8.0-8.3	8.1(16)	2.4- 7.3	4.1(16)			ND-.445	.110(5)	ND-.
BW-13S	7.9-8.5	8.2(19)	1.4- 7.2	2.6(19)	1.0-3.5	2.2(18)	ND-.061	.010(6)	ND-.
B	8.0-8.5	8.1(19)	1.1- 4.9	3.0(19)			ND-.116	.037(6)	ND-.
BE-17S	8.0-8.6	8.2(18)	1.2-14.0	2.8(18)	1.0-4.2	2.8(18)	ND-.099	.017(6)	ND-.
B	8.0-8.5	8.1(17)	1.1-14.0	4.3(17)			ND-.053	.009(6)	ND-.

highest and next highest correlation coefficients (positive and negative) between wat

PspNS -0.46	PspJS -0.64	PidJS +0.41	PspNB +0.95	P
PspJB -0.42	PidJS -0.46	PspJS +0.37	PidJB +0.94	P

Key: Same as first section of table.

* Means < detection limit are reported for statistical pu

N OF WATER QUALITY DATA WITH BIOLOGICAL POPULATIONS.
biological parameters in first section)

(n)	Kjeldahl-N (ppm) ND = <.005* range	mean(n)	Ammonia-N (ppm) ND = <.005* range	mean(n)	Fecal Coliform (MFC/100ml) range	mn(n)	Total Coliform (MFC/100ml) range	mean (n)
19)	ND	ND (6)	ND-.030	.008(7)	2- 20	6(4)	10- 5500	47(12)
	ND-.081	.023(6)	ND-.015	.007(7)				
17)	ND-.486	.069(7)	ND-.023	.010(7)	2- 40	11(4)	10- 2100	82(11)
	ND-.050	.007(7)	.010-.028	.020(7)				
18)	ND-.062	.009(7)	ND-.030	.012(7)	2-154	44(4)	16- 14700	460(11)
	ND-.110	.016(7)	.005-.035	.020(7)				
16)	ND	ND (6)	ND-.011	.004(7)	2	2(4)	10- 430	49(10)
	ND-.078	.013(6)	ND-.023	.009(7)				
16)	ND-.147	.061(6)	ND-.090	.015(7)	14-120	60(4)	30- 9100	400(11)
	ND-.099	.026(6)	ND-.072	.022(7)				
8)	ND-.121	.063(6)	ND-.038	.015(7)	6-120	54(4)	28-107000	2800(11)
	ND-.054	.017(6)	ND-.050	.014(7)				
(18)	ND-.097	.016(6)	ND-.035	.015(7)	2- 2	2(4)	100- 2600	200(11)
	ND-.075	.015(5)	ND-.021	.014(6)				
(16)	ND-.068	.025(5)	ND-.006	.002(7)	2- 10	6(4)	8- 1710	180(11)
	ND-.445	.110(5)	ND-.309	.054(7)				
(18)	ND-.061	.010(6)	ND-.019	.004(7)	2-130	46(4)	16- 8000	240(11)
	ND-.116	.037(6)	ND-.035	.025(7)				
(18)	ND-.099	.017(6)	ND-.035	.010(7)	2-110	32(4)	62- 8900	250(11)
	ND-.053	.009(6)	ND-.028	.012(7)				

tive and negative) between water quality and biological data

.41	PspNB	+0.95	PidJB	+0.99	PspNS	-0.61	PspNS	-0.60
.37	PidJB	+0.94	PidNB	+0.98	FidB	-0.61	PspJS	-0.60

re reported for statistical purposes.

272