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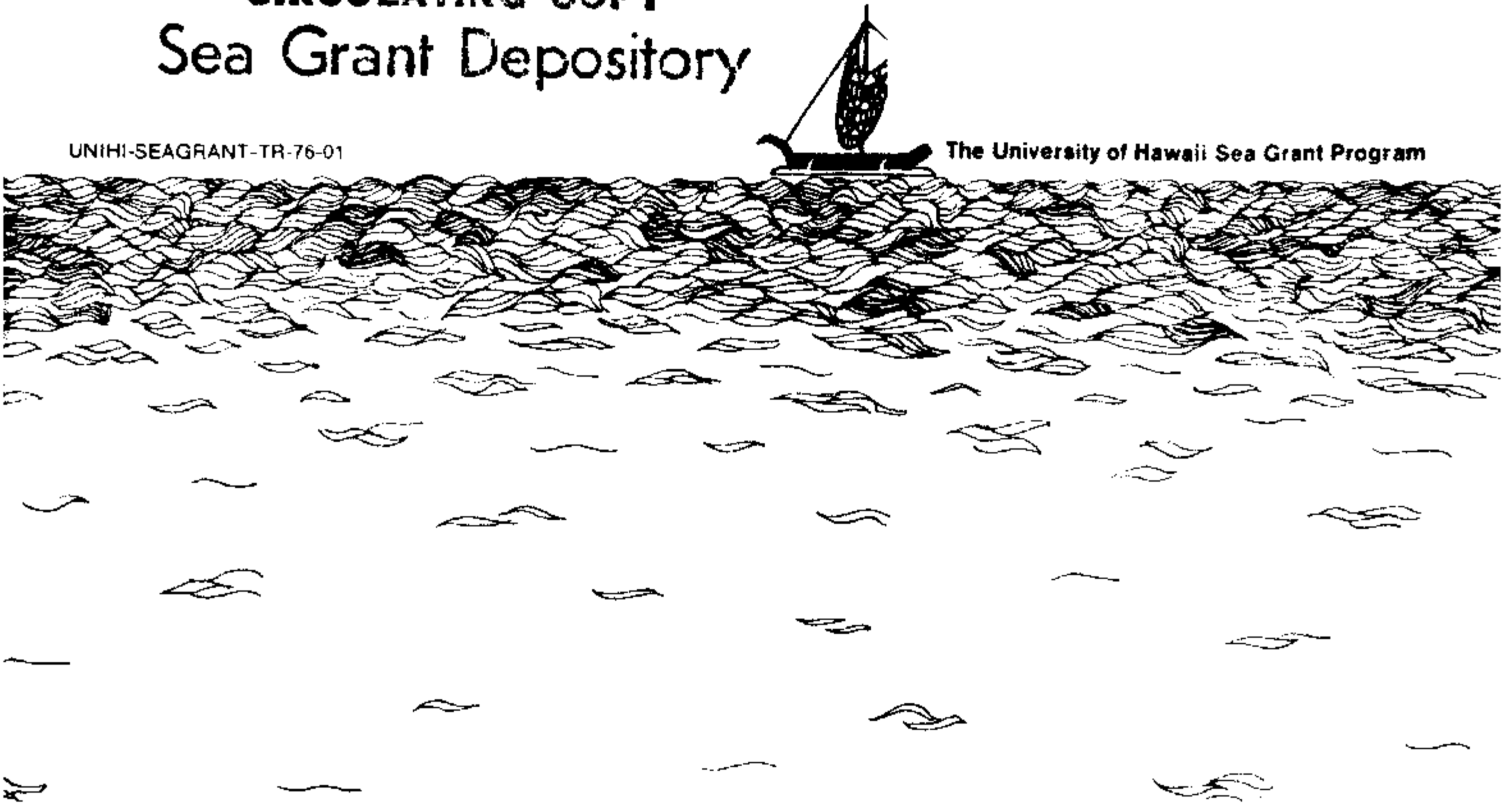

The Marine Biological Impact of the Honolulu Generating Station

John C. McCain, Stephen L. Coles, and James M. Peck, Jr.

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ABSTRACT

Studies of the effects of the Hawaiian Electric Generating Station on the zooplankton, reef corals, and fishes of Honolulu Harbor, Oahu, Hawaii were made during 1972-73. No distinct detrimental effects attributable to the generating station were revealed by these studies. The macrozooplankton community in the outfall basin more closely resembled communities sampled outside the harbor than elsewhere in the harbor, which receives a variety of pollutants. Differences in distribution and abundance of macrozooplankton were more closely related to depth and temporal differences than to power station discharge. Although reef corals were restricted from the wall directly in the path of the outfall jet plume, the total coverage of live corals in the discharge basin exceeded that of the intake basin and discharge basin coral colonies were generally larger. Negligible coral growth was found anywhere else in the harbor. Fish standing crop in the discharge basin was estimated to be approximately twice that of the intake basin and little movement was noted between the two areas. Standing crop in both basins was generally higher than estimates for tropical and subtropical shallow water areas. No clear comparisons were possible concerning weight per unit length of fishes in the intake versus discharge basins.

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INTRODUCTION

Work Statement

In a letter from Dr. Walter B. Quisenberry, Director, Department of Health, State of Hawaii dated August 31, 1971, Hawaiian Electric Company (HECO) was granted a zone of mixing for its cooling water discharge from the Honolulu Generating Station subject to several conditions one of which requires that "bio-assays shall be conducted annually of the benthic and other marine life forms to determine the effects of the thermal discharge on marine life." It is in response to this requirement that the following investigations were conducted.

Location and Setting

The Honolulu Generating Station is located on the south side of the island of Oahu at approximately 21°18'32" north latitude, 157°51'01" west longitude. The station is situated in the eastern part of Honolulu Harbor just south of the downtown Honolulu shopping district. The intake and discharge basins adjacent to the station are separated by Pier 7, which extends about 130 m from Nimitz Highway toward Sand Island. The intake and discharge structures are located in the southeast corners of their respective basins, adjacent to Nimitz Highway (Figure 1a). Both basins are comparable in area, approximately 60 m x 130 m. The sides of the basins are bordered on their southern sides by the concrete structures comprising Piers 7 and 8 and on their eastern sides by the Nimitz Highway wall. These concrete walls extend to about a 1.5-m depth and abut on an ancient reef platform which has been dredged to about a 10-m depth. The discharge basin is bordered on the north by the concrete wall of Pier 7, while the intake basin's north side is formed by the wooden pilings which support Pier 8.

Area Use

Honolulu Harbor is the principal commercial port for the Hawaiian Islands. In addition to the commercial piers, the harbor is fringed by industrial development including the electrical generating plant, pineapple canneries, the gas company, oil storage yards, and numerous small businesses. In addition, the Coast Guard maintains a base on the Sand Island side of the harbor.

Citing references as early as 1920 which describe this pollution, Cox and Gordon (1970) stated that pollution in the harbor has long been noted. Oil contamination is common and sheens are frequently seen on the harbor. Three fish kills have been documented in the Kapalama Canal, one of which killed approximately 100,000 fish.

Honolulu Harbor is currently ranked fifth in importance as a source for nehu (baitfish) fishing (Cox and Gordon, 1970).

Characteristics of Honolulu Harbor

Honolulu Harbor is the result of dredging what was originally the drainage basin of Nuuanu Stream. Dredging of the harbor started as early as the mid-1800's. Sand Island was created by fill from the dredging and by connecting the Nuuanu Stream Basin with Kapalama Basin.

The mean flow of Nuuanu Stream is approximately 0.2 m^3/sec. Kapalama Canal carries the wastes of the pineapple into the harbor at a rate of approximately 0.8 m^3/sec.

Dredging of the harbor took place on July 5 and September 12-19, 1972. Turbidity within the harbor increased considerably after the dredging and pre-dredging water clarity has not been re-established. During the summer of 1973, sediment was discharged into the harbor from the Federal Building site adjacent to Piers 4 and 5 numerous times. The sediment plume was clearly visible and could be seen flowing from the area bounded by the *Falls of Clyde* and the U.S. Coast Guard pier to the mouth of the harbor.

Undoubtedly, sedimentation plays an important role in the establishment and maintenance of marine communities in Honolulu Harbor.

Station Operational Data

The Honolulu Generating Station has a normal generating capability of 180 megawatts. Condenser cooling water is drawn from a single intake located on the northwest side of Pier 7 within Honolulu Harbor (Figure 1a). This water is discharged into the harbor on the southeast side of Pier 7 through three discharge ports at the rate of approximately 13 m^3/sec (205,000 gpm). The cooling water system is one of the once-through nature with a designed temperature rise across the condensers of approximately 5.6°C (10°F). The maximum rate of heat added to the harbor is approximately 76 million gram cal/sec (300,000 BTU/sec).

Daily maximum and minimum temperatures recorded between January 1972 and September 1973 at the intake and discharge ports of units 8 and 9 are shown in Figure 2. Daily maximum temperatures from both units exceeded 30°C throughout the summer and fall months, sometimes reaching as high as 35°C. Intake temperature spikes indicate recirculation to have occurred in July and December of 1972 and March of 1973, probably as a result of kona (south to west) wind conditions. Intake temperatures recorded after August 2, 1973 (540 days) are to be ignored, due to a probable malfunction in the temperature recording apparatus.

Condenser tubes are cleaned mechanically, avoiding the introduction of cleaning chemicals into the condenser circulating water system.

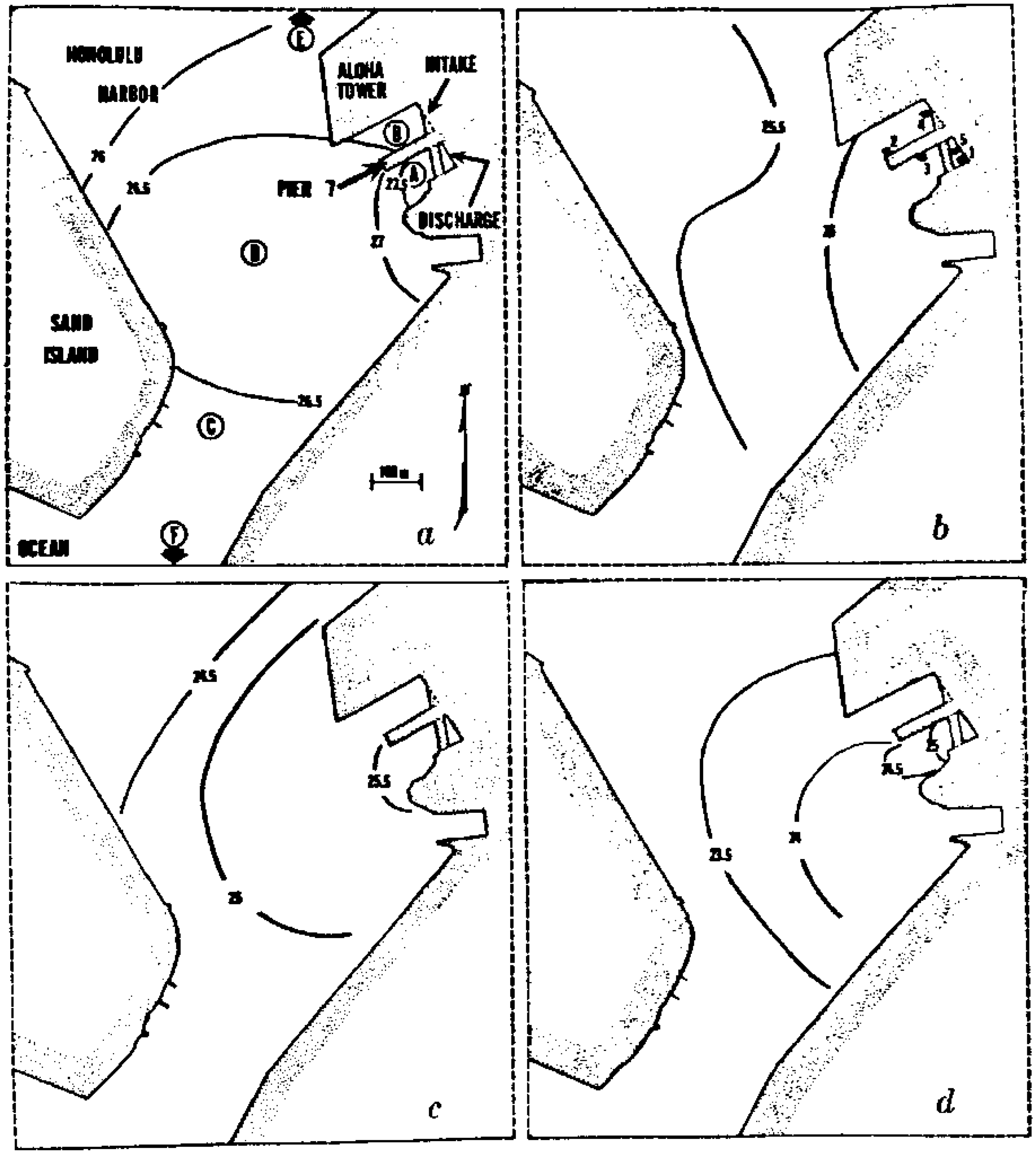

FIGURE 1. Surface isotherms in Honolulu Harbor: (a) October 12, 1971, tradewind; (b) November 17, 1971, tradewind; (c) December 15, 1971, calm; (d) February 9, 1972, calm. Circled letters shown in (a) are zooplankton sampling locations and numbered squares shown in (b) are fish trap locations.

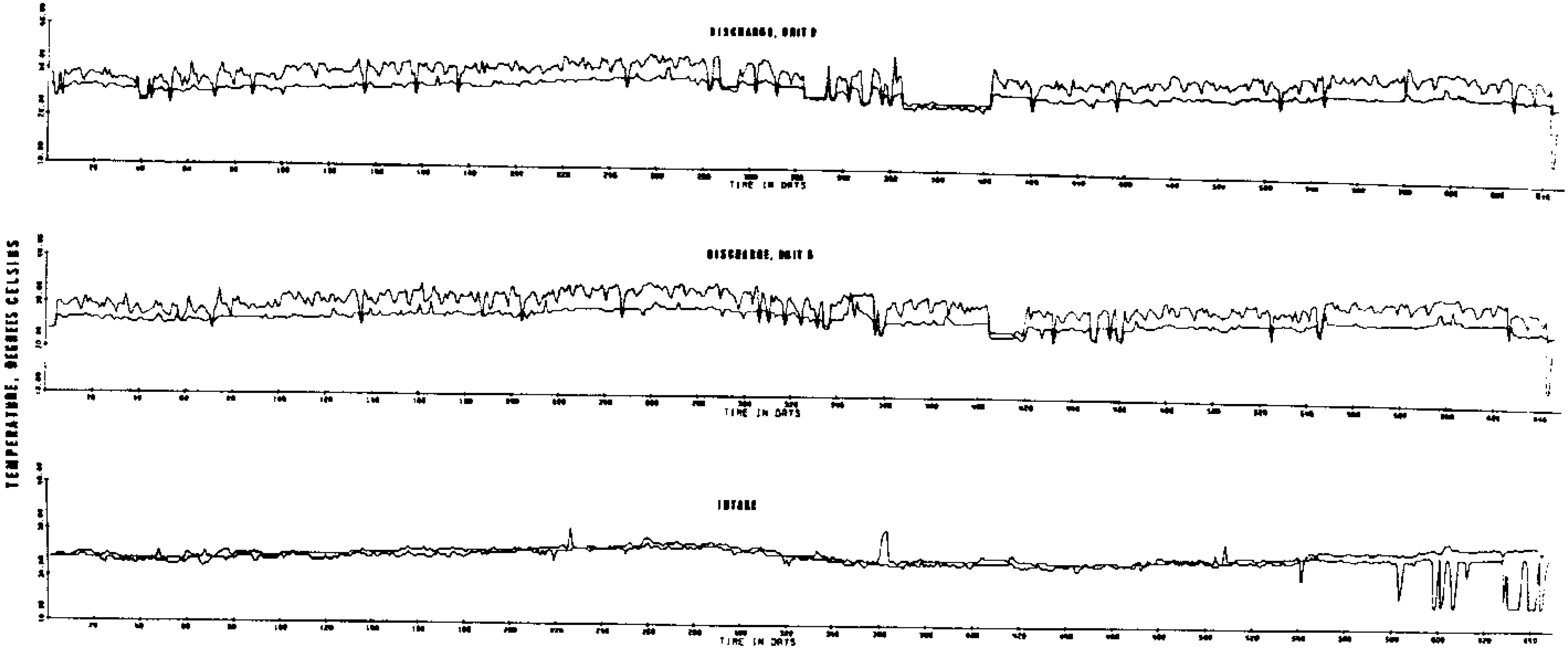

FIGURE 2. Daily maximum and minimum temperatures (°C) at intake and discharge ports from January 1, 1972 to October 2, 1973.

Currently, boiler and evaporator blowdown and demineralizer regenerants are discharged into the circulating water system. These discharges consist primarily of nitrogen and phosphorus compounds at extremely low concentrations.

Physical Impact of Station

Buske and McCain (1972) surveyed the physical impact of the Honolulu Generating Station. They found that the thermal effluent is discharged at a maximum velocity of approximately 1.5 m/sec from ports located about 1 m below the water surface. The discharge from the two largest units are combined and form a well-defined jet along the southeast side of the discharge basin. This jet normally passes by the seaward end of Pier 7 on the surface with an axial speed of 0.6 m/sec, decreasing thereafter to about 0.3 m/sec. Surface flows of 0.1 m/sec have been measured for the mid-channel and northwestern portions of the discharge basin.

In general, water from the discharge basin flows toward the southwest down the main harbor channel. Circulation of water from the discharge basin into the intake basin (recirculation) occurs to a limited extent during periods of kona wind conditions.

The buoyant effluent rises toward the water surface rapidly with scour and benthic effects limited within 30 m (100 ft) of the direct path of discharge. Mixing is largely wind-driven; the dilution of the effluent decreasing under calm conditions. Calm conditions with winds of less than 4 km/hr (2 knots) occur approximately 10 percent of the time. Mean wind speed is 19 km/hr (10 knots) from the east-northeast. These tradewind conditions predominate, occurring about 60 percent of the time.

Surface isotherms for tradewind conditions are shown in Figure 1a and 1b and those for calm conditions in Figure 1c and 1d. Generally, within about 460 m of the discharge, the surface water temperature enrichment is reduced to at least 0.8°C (1.5°F).

The effects of the generating station upon salinity (> 34 ppt) and dissolved oxygen (> 6.5 ppm) concentrations appear to be negligible.

BACKGROUND

Honolulu Harbor is obviously subject to a variety of stresses from diverse pollution sources. From the onset, it was apparent that no area within the harbor represented a "control" area. Thus, sampling was concentrated in the discharge and intake areas. The area near the entrance to Honolulu Harbor on the Sand Island side was also investigated, not as a true control, but because it probably represented the least stressed area obtainable within the harbor.

Sedimentation is undoubtedly the primary pollution source within the harbor. The dredging of the harbor, the construction of a floating restaurant, and the sediment discharge from the Federal Building site, with their associated increase in turbidity, made visual transects for fish census impossible and in general hampered all field efforts involving diving.

Zooplankton Investigation

Few papers have been devoted to the effects of thermal effluents upon natural communities of marine zooplankton. Heinle (1969) pointed out that "changes in community structure appear to be a very real possibility" with regards to the ecological effects of increased temperatures. Raymont (1964) reported that the copepod, *Acartia tonsa*, increased in abundance near the outfall of a British power plant. Reeves' (1970) work on the Turkey Point, Florida power generating station showed that some differences were present between the number of zooplankters at the beginning of that plant's outfall canal and the canal's exit into Biscayne Bay. These differences reflected killing of zooplankton by entrainment within the plant since dead zooplankters sink from the water column before exiting from the canal. As Reeves pointed out, entrainment may cause a myriad of delayed sub-lethal effects. Thus, estimation of obviously dead or dying plankton at a power station outfall, as commonly attempted, yields only a limited indication of the effects of entrainment upon the plankton community of the receiving waters.

It is apparent that the significance of any discharge must be judged by the community alteration which it induces, not by the number of organisms it kills or displaces. Assuming any damage to plankton during entrainment, an alteration in the community structure (or at least in the abundance of several redundant organisms) in the region of the outfall would be expected. This study documents the occurrence of such an alteration in the zooplankton community in that area of Honolulu Harbor under the influence of the electrical generating station.

Coral Survey

Reef building corals are recognized to be generally intolerant of pollutive disturbances of their physical environment (Johannes, 1972). Because of their inability to isolate their living tissues from toxic substances in their medium or to move themselves from a stressful environment, corals are considered to be conspicuous biotic indicators of the cumulative effects of pollution. A review of the effects of a variety of types of pollution on corals and associated organisms may be found in Johannes (1972). A variety of pollution sources exists in the area of Honolulu Harbor influenced by HECO's generating station, the total effect of which remains in question. However, temperature, turbidity, and sedimentation are water quality parameters, which are likely to be altered by HECO plant effluent, and the effects of these on coral settlement and growth are examined in this report.

Considerable information concerning the upper thermal tolerances of reef corals has been derived in Hawaii (Edmondson, 1928; Jokiel and Coles, 1974; Coles, 1973; Jokiel et. al., 1974). The results of these studies, determined under both field and laboratory conditions, indicate that continuous exposure to temperatures of 31° to 32°C (87.5° to 89.5°F) kills coral and that temperatures above 28°C (82.5°F) are detrimental to coral growth.

As described previously, Honolulu Harbor has recently been subjected to dredging that substantially increased water turbidity. An accompanying increase in rates of sedimentation onto living coral surfaces may be assumed. Coral tolerances to these stresses are less clearly defined than temperature tolerance limits. Reviews of sedimentation effects on coral may be found in Sotddart (1969), Levin (1970), and Johannes (1972).

Preliminary observations along the walls on all sides of the intake and discharge basins indicated living coral to be absent from the south side of the discharge basin, which lies along the direct path of discharged effluent. Corals are also absent from the north side of the intake basin, where the wooden pilings of Pier 8 provide an unsuitable substrate for coral settlement. However, the concrete walls and dredged substrate on the remaining two sides of both basins are populated by reef corals predominated by species of *Porites lobata* Dana, *Pocillopora meandrina* Dana, *Montipora verrucosa* (Lamarck), and *Montipora patula* Verrill. Corals occur from depths of ca 0.25 m to a maximum of 7 m below mean lower low water (MLLW). Most corals occur on the vertical surfaces of the walls, except for those growing on a small ledge which represents the surface of an ancient reef and extends along most of the distance of the four walls at a 1.5 to 2.0-m depth. The maximum depth of coral growth in both basins extends nearly to the bottom of the vertical hard substrate. Below this, a thick layer of silt has accumulated, preventing coral settlement or growth.

Fish Survey

Young and Gibson (1973) gave a vivid description of the effects of a thermal effluent from a Long Island power station on migrating juvenile menhaden. Their description is quoted here because it appears to be diametrical to the effects on fishes caused by the Honolulu Generating Station.

> While SCUBA diving, we observed schools of juveniles (menhaden) swimming from the cool water underlying the effluent into the heated surface water where they suffered immediate thermal shock. The shocked fish, after making gulping motions at the surface, sank to the bottom within one minute after swimming into the discharge water. (Young and Gibson, 1973, p. 95.)

They continued with a description of the flexing and dying of the fish. In contrast, the thermal effluent from the Honolulu Generating Station has not been identified as the cause of fish kills. In fact, the evidence suggests some beneficial effects.

Visual fish transects were attempted during the 1972 survey to document the standing crop of fishes in the discharge basin, but were abandoned because of poor water visibility. A mark-recapture program (Bardach, 1958; Randall, 1961a, 1961b; Springer and McErlean, 1962) was established as an alternative to the transect program. This method allows for comparisons of growth, since fishes can be identified over a period of time, and for comparisons of fish abundance between stations, and provides information on the movement of fishes between areas.

MATERIALS AND METHODS

Zooplankton Investigation

Zooplankton samples were collected by towing a 0.5 m diameter, 215 micron mesh net equipped with a TSK flowmeter. Samples were preserved in saltwater formalin. Settled volume measurements were made using an Imhoff Cone or a 50-ml graduated cylinder. Readings were taken after a 24-hour settling period. Dominant macroplankters (*Lucifer chacei* Bowman and *Sagitta enflata* Grassi) and fish larvae were sorted from the entire sample.

Coral Survey

The coral populations on each of the four walls were surveyed between June 19 and July 14, 1973. Previous to diving surveys, marks were made at 2-m intervals along the Nimitz Highway and Pier 7 walls of the intake and discharge basins. The marks were used by a diver who remained on the surface and maintained a buoy line on position. The buoy line, marked at 0.5-m intervals, was used by another diver to maintain his position while counting and measuring individual coral colonies. All corals 0.5 m to either side of the vertical line were measured and recorded. After completion of observations to the maximum depth of coral growth, the line was moved 1 m and the procedure repeated. This method assured that all corals growing along the basin walls were measured during the survey.

Because the growth form of most of the corals was observed to be lobate (hemispherical) or circularly encrusting, their living surface area could be estimated from a single measurement or pair of measurements. A ruler was used to measure a single diameter of the normal projection of those colonies which appeared circular in outline. Diameters were measured to the nearest 0.5 inch (1.2 cm). For those colonies whose outline was ellipsoid, their long and short diameters were averaged for an estimate of a radius corresponding to a circle most closely corresponding to their surface area. For the few colonies that departed radically from a circular or ellipsoid form, surfaces were visually divided into circular subsections and treated as above. Although this method involved some subjective judgments by the worker, the majority of corals measured during the survey approximated circular or ellipsoid forms whose surface areas were closely estimated by the method. Ten corals of the total number measured had partly dead surface areas. For these specimens, visual estimates were made of the percentage of total colony still living and their total surface areas multiplied by these factors. Surface area (A) for the *Porites* and *Pocillopora* species was derived using the formula for the surface area of a hemisphere ($A = 2\pi \text{ radius}^2$). For the remaining species, which are encrusting in their growth form, the formula for the area of a circle ($A = \pi \text{ radius}^2$) was used.

Fish Survey

Fish traps (1.52 x 1.52 x 6.10 m) were placed at the locations shown in Figure 1b. Traps were set in place as follows:

Trap 1: April 3, 1973 to September 5, 1973
Trap 2: April 3, 1973 to September 5, 1973
Trap 3: April 3, 1973 to June 28, 1973
Trap 4: January 23, 1973 to September 5, 1973
Trap 5: January 23, 1973 to April 3, 1973

These traps were checked weekly. Trapped fish were marked using Floy anchor tags embedded in either the stomach or through the dorsal fin rays, depending upon the size and species. (For a discussion of the effects of these tags on fish consult Carline and Brynildson, 1972.) Fishes were anesthetized using Tricaine Methanesulfonate, tagged, weighed to the nearest gram, and measured (fork or total length) to the nearest 0.25 inch, then allowed to recover in seawater until normal activity was resumed prior to release. Recaptured fish were treated identically, and records maintained for each fish tagged.

RESULTS AND DISCUSSION

Zooplankton Investigation

Figure 1a presents the locations sampled during this survey. Tow records and sorting data for the 174 plankton tows are given in Appendix A.

Highly significant differences ($P < 0.01$, Student's "t" test) exist between means of samples taken on May 11, 1972 in the intake and discharge basins for plankton-settled volume (ml/m^3) for the numbers of *Lucifer chacei* Bowman, *Sagitta enflata* Grassi, and fish larvae and for the plankton-settled volume (ml/m^3) after removal of macroplankters. *S. enflata* and *L. chacei* were more abundant in the discharge basin than in the intake basin, thereby contributing to a greater volume of plankton per cubic meter measured in the discharge basin. Upon removal of these macroplankters, the microplankton volume per cubic meter was greater in the intake basin. Fish larvae were more abundant in the intake basin (McCain and Peck, 1972a).

The May 1972 sampling considered only macroplankters and was confined to surface samples during midday. Obviously, day to night changes in the distribution and abundance of zooplankton may be an important factor in assessing the effect of the power plant. Furthermore, intake water for the plant cooling system is taken from a 2 to 5 m depth rather than at the surface. Subsequent zooplankton samples were therefore taken from surface and a 3 m depth, at both day and night during the 1973 survey. Microplankton was not considered.

Table 1 presents the variance ratios derived from an analysis of variance (ANOVA) for the dominant macroplankters and plankton volume. Duncan's (1955) new multiple range tests for the data grouped by location, without consideration for depth, time or date, are shown in Table 2. Two homogeneous subsets of locations (subsets of means not differing significantly, $P < .05$) are shown for plankton volume data.

TABLE 1. VARIANCE RATIOS FOR MACROPLANKTERS AND VOLUME OF HONOLULU HARBOR ZOOPLANKTON SAMPLES*

Plankton volume (ml/m^3)	Variance ratio (F)
Locations (6)	5.8695**
Locations and Depths (12)	4.2576**
Stations (50)	11.5379**
No. of *Sagitta enflata* per cubic meter	
Locations (6)	6.4525**
Locations and Depths (12)	6.0965**
Stations (50)	13.1834**
No. of *Lucifer chacei* per cubic meter	
Locations (6)	5.1037**
Locations and Depths (12)	4.7356**
Stations (50)	14.3575**
No. of fish larvae per cubic meter	
Locations (6)	7.8359**
Locations and Depths (12)	4.2885**
Stations (50)	11.3235**

*See Appendix A for location, depth, and station description.
**$P > 0.01$

Subset A contains all locations (B, C, D, E) within the harbor except for the discharge site (A). Subset B contains the discharge site (A) and the site near the mouth of Nuuanu Stream (B). The offshore site (F) plankton volume is significantly greater than at all other sites.

TABLE 2. MULTIPLE RANGE TESTS FOR ORGANISMS AND VOLUME OF HONOLULU HARBOR ZOOPLANKTON SAMPLES

Location	Mean	Standard Error	Homogeneous Subset* A	B	C
Plankton volume (ml/m^3)					
C	0.392	0.063	┐		
D	0.410	0.084	│		
E	0.456	0.050	│	●	
B	0.471	0.047	┘	⋮	
A	0.730	0.093		●	
F	1.068	0.148			
No. of *Sagitta enflata* per cubic meter					
C	1.066	0.146	┐		
D	1.467	0.219	│		
B	1.836	0.269	┘		
E	4.708	1.144			●
A	17.066	4.465		┐	⋮
F	18.775	3.725		┘	●
No. of *Lucifer chacei* per cubic meter					
F	0.258	0.126	┐		
B	3.102	0.912	│		
C	3.679	1.040	│		
D	5.167	2.614	│		
A	7.032	2.042	┘		
E	18.208	5.316			
No. of fish larvae per cubic meter					
D	2.558	0.474	┐		
C	2.874	0.243	│		
E	3.050	0.481	│		
A	3.948	0.413	┘		
B	6.715	0.830		┐	
F	8.617	1.845		┘	

*Homogeneous subsets ($P < 0.05$) are connected by vertical lines.

Subset A is limited to harbor locations with low plankton volume. The locations contained in subset B may cluster due to the variability (ranging from 0.10 to 50.10 per cubic meter) in the number of *Lucifer* in the Nuuanu Stream mouth, thereby contributing to a greater standard error. It is obvious that the lumping of all planktonic organisms into a single value such as settled volume can only give an indication of similarity or differences between sites. Even the general category, fish larvae, suffers from the same defect since individual species are not identified. Thus, the abundance of chaetognath *Sagitta enflata* and the sergestid shrimp *Lucifer chacei* provides a more reliable comparison between sites.

Three homogeneous subsets are present within the data on *Sagitta*. Subset A for *Sagitta* contains the same harbor locations (B, C, D, E) as subset A for total plankton volume. Subset B contains the discharge site (A) and the offshore site (F). The Nuuanu Stream site (E) and the offshore site (F) comprise subset C.

All sites comprise a single homogeneous subset for *Lucifer* with the exception of the Nuuanu Stream site (E), which is significantly greater. Subset A for the fish larval data is composed of all of the harbor locations with the exception of the intake site (B). Subset B includes the intake site (B) and the offshore site (F). A high number of fish larvae was also found in the intake basin for the 1972 survey.

Table 3 presents analyses of variance and multiple range tests for combined dates separated by location and depth. The plankton volume data contain four homogeneous subsets. Subset A contains all harbor locations and depths with the exception of the surface tows at the discharge site (A) and the offshore site (F) at both depths. Subset C contains the intake site (B) and offshore site (F) at the surface, the mid-channel harbor site (D) at the 3-m depth, and the Nuuanu Stream site (E) at both depths. Subset C contains those locations not included in subset A. Subset D contains the discharge site (A) and offshore site (F) at the surface and the mid-channel (D) and Nuuanu Stream site (E) at the 3-m depth.

The *Sagitta* data fall into three homogeneous subsets. Subset A contains all locations and depths with the exception of the surface tows at the discharge site (A) and the Sand Island Channel tows (C). Subset B for *Sagitta* duplicates subset A for volume. Subset C contains those locations excluded by subset B as did subset C for plankton volume.

The *Lucifer* data contain five homogeneous subsets. Of particular interest is subset E which contains only the Nuuanu site (E) at both depths. Apparently *Lucifer* attains its greatest abundance in the more "stressed" (thermal or fresh waters) of the harbor.

Three homogeneous subsets of locations and depths are present in the fish larval data. Subset A contains all locations and depths with the exception of the surface of the intake (B) and the offshore site (F) at both the surface and 3-m depth. Subset B is a mixture of locations and depths and subset C contains those locations and depths excluded from subset A. Subsets A and C of the location-depth ANOVA are similar to the situation found when only location is considered (Table 3).

TABLE 3. MULTIPLE RANGE TESTS FOR ORGANISMS AND VOLUME OF HONOLULU HARBOR ZOOPLANKTON SAMPLES

Location*	Mean	Standard Error	Homogeneous Subset** A	B	C	D	E
	Plankton volume (ml/m^3)						
D	0.243	0.056	|				
C	0.355	0.108	|				
E	0.377	0.066	|	●			
b	0.394	0.046	|	⋮			
c	0.429	0.068	|	⋮			
a	0.451	0.045	|	⋮			
B	0.518	0.070	|	|			
e	0.535	0.066	|	|		|	
d	0.577	0.129	|	|		|	
A	0.901	0.140		⋮	|	|	
F	0.930	0.180		●	|	|	
f	1.207	0.237			|		
	No. of *Sagitta enflata* per cubic meter						
C	0.695	0.149		|			
a	0.926	0.151	|	|			
D	1.033	0.176	|	|			
c	1.437	0.223	|	|			
b	1.521	0.249	|	|			
d	1.900	0.322	|	|			
B	2.029	0.405	|	|			
E	3.383	0.404	|	|			
e	6.033	2.212	|	|			
f	18.733	5.957	|		|		
F	18.817	5.058	|		|		
A	26.958	6.628			|		
	No. of *Lucifer chacei* per cubic meter						
F	0.133	0.061	|	|	|		
f	0.383	0.244	|	|	|		
B	0.484	0.117	⋮	⋮	|		
D	1.567	0.977	●	|	|		
C	1.868	0.611	⋮	|	|		
A	3.152	0.651	|	|	|		
c	5.489	1.927	|	|	|		
b	7.374	2.071	|	|	⋮	|	
d	8.767	4.891	|	|	●	|	
E	13.250	6.827	|			|	●
a	13.363	5.011				|	⋮
e	23.167	8.241					●
	No. of fish larvae per cubic meter						
D	1.767	0.338	|				
C	2.163	0.245	|				
e	2.817	0.615	|	|			
E	3.283	0.785	|	|			
a	3.305	0.479	|	⋮			
d	3.350	0.790	|	|			
c	3.584	0.357	|	|			
A	4.342	0.593	|	|			
b	5.166	1.024	|	|			
B	7.665	1.163		⋮	|		
F	7.817	1.926		●	|		
f	9.417	3.318			|		

*Upper case = surface tows; lower case = 3-m tows.
**Homogeneous subsets ($P < 0.05$) are connected by vertical lines.

Table 4 presents analyses of variance and multiple range tests for stations where locations, dates, depths, and time are separated. Station numbers correspond to those listed in Appendix A. The ANOVA for the plankton volume contains 15 homogeneous subsets. These subsets are considerably mixed. Of particular interest is subset 0 which contains only the highest volume stations (55 and 7). Plankton tows at station 7 were taken in the discharge during May 1972. This station differed significantly from the intake (Station 22) on that sampling data. In this case station 7 is not significantly different from a station offshore of the harbor.

Station 7 has significantly more individuals of *Sagitta* than all of the other stations. The other stations fall into two homogeneous subsets--subset A containing all but stations 7, 53, and 55 and subset B containing stations 53 and 55, which were both located at the offshore site (F).

The *Lucifer* data contain seven homogeneous subsets. Some of the discharge (14), intake (29), and Nuuanu Stream (50, 52) stations have the greatest number of individuals of *Lucifer*, whereas the numbers are reduced in the offshore stations (F).

The fish larval data contain eight homogeneous subsets. Subset A contains most of the stations except for stations offshore (54, 56), in the intake basin (18, 22, 25, 26), and the May discharge station (7)--all of which have significantly greater numbers. Significantly fewer numbers of individuals than for subset A were found at stations 4 and 5 (discharge), 46 (harbor channel), and 32 (Sand Island Channel). Subsets B, C, D, E, and F overlap these subsets to varying degrees. Subsets F, G, and H show that the high density stations of the intake (B) and offshore (F) areas are not significantly different with regard to fish larvae.

Analysis of variance of single factors as described above becomes increasingly complicated as the number of stations (locations, etc.) is considered and as more variables are examined. To alleviate this situation, correlation coefficients of variables between station pairs were computed. These coefficients were converted to distance measures using an arccosine transformation, then visually displayed as a dendrograph (McCammon, 1968). As for the ANOVA series, times, depths, and dates were combined. In addition, correlation coefficients were compiled between the variables to check for redundancy in the data which seemed a real possibility since volume is to a large extent dependent upon the macrozooplankters.

Table 5 presents the correlation coefficient matrix between variables. High correlation exists between volume and *Sagitta* and, to a lesser extent, volume and fish larvae. Thus the use of volume in the multivariate analyses is somewhat redundant. Therefore, analyses were performed using four variables (volume included) and three variables (macroplankters only). Correlation coefficient matricies have been omitted from the following discussion due to their large size, particularly in the 56-station comparison.

TABLE 4. MULTIPLE RANGE TESTS FOR ORGANISMS AND VOLUME OF HONOLULU HARBOR ZOOPLANKTON SAMPLES

Station	Mean	Standard Error	Homogeneous Subset*														
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Plankton volume (ml/m^3)																	
15	0.067	0.003		│													
31	0.087	0.003		│													
24	0.087	0.009		│													
35	0.090	0.006		│	│												
46	0.130	0.031		│	│												
33	0.140	0.012	│	│	│												
38	0.143	0.003	│	│	│												
20	0.153	0.017	│	│	│												
34	0.173	0.019	│	│	│												
19	0.180	0.040	│	│	│												
5	0.193	0.074	│	│	│	│											
18	0.197	0.009	│	│	│	│	│										
4	0.230	0.021	│	│	│	│	│										
21	0.233	0.049	│	│	│	│	│										
49	0.243	0.009	│	│	│	│	│										
41	0.247	0.013	│	│	│	│	│										
3	0.257	0.028	│	│	│	│	│	│									
40	0.263	0.047	│	│	│	│	│	│									
26	0.273	0.029	│	│	│	│	│	│									
9	0.293	0.007	│	│	│	│	│	│									
13	0.320	0.010	│	│	│	│	│	│	│								
7	0.333	0.012	│	│	│	│	│	│	│								
1	0.347	0.075	│	│	│	│	│	│	│								
6	0.350	0.012	│	│	│	│	│	│	│								
12	0.353	0.090	│	│	│	│	│	│	│								
48	0.357	0.134	│	│	│	│	│	│	│								
45	0.357	0.041	│	│	│	│	│	│	│								
32	0.357	0.027	│	│	│	│	│	│	│								
27	0.357	0.007	│	│	│	│	│	│	│								
28	0.360	0.010	│		│	│	│	│	│								
39	0.413	0.018	│		│	│	│	│	│		│						
51	0.420	0.068	│		│	│	│	│	│		│						
50	0.510	0.061	│		│	│	│	│	│		│		│				
42	0.527	0.143	│		│	│	│	│	│		│	│	│				
29	0.527	0.007	│		│	│	│	│	│		│	│	│				
14	0.600	0.116	│		│	│	│	│	│	│	│	│	│				
52	0.650	0.062	│			│	│	│	│	│	│	│	│				
25	0.697	0.048				│	│	│	│	│	│	│	│	│			
54	0.703	0.125					│	│	│	│	│	│	│	│			
10	0.753	0.033						│	│	│	│	│	│	│			
47	0.797	0.131							│	│	│	│	│	│			
17	0.887	0.209								│	│	│	│	│			
22	0.897	0.035								│		│	│	│			
56	0.937	0.186								│		│	│	│	│		
43	0.983	0.114								│		│	│	│	│		
2	1.067	0.122								│				│	│	│	
53	1.157	0.309												│	│	│	
36	1.357	0.207													│	│	
55	1.477	0.417														│	
7	1.703	0.172															│

Station	Mean	Standard Error	Homogeneous Subset*														
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
No. of *Sagitta enflata* per cubic meter																	
32	0.067	0.033	│														
35	0.133	0.033	│														
15	0.167	0.067	│														
17	0.200	0.058	│														
31	0.267	0.033	│														
24	0.267	0.120	│														
12	0.333	0.133	│														
14	0.367	0.133	│														
38	0.400	0.153	│														
2	0.400	0.200	│														
4	0.467	0.203	│														
39	0.500	0.153	│														
20	0.633	0.133	│														
21	0.667	0.233	│														
29	0.667	0.176	│														
46	0.700	0.153	│														
34	0.767	0.145	│														
10	6.767	0.145	│														
19	0.867	0.088	│														
25	1.133	0.120	│														
9	1.167	0.318	│														
18	1.233	0.088	│														
40	1.267	0.328	│														
41	1.300	0.173	│														
45	1.367	0.145	│														
27	1.367	0.067	│														
11	1.367	0.088	│														
33	1.400	0.153	│														
6	1.433	0.088	│														
52	1.533	0.067	│														
3	1.533	0.033	│														
48	1.567	0.601	│														
13	1.600	0.656	│														
5	1.600	0.321	│														
36	1.667	0.145	│														
28	1.833	0.233	│														
42	1.933	0.328	│														
47	2.233	0.219	│														
43	2.533	0.318	│														
1	2.567	0.376	│														
50	3.033	0.788	│														
26	3.200	0.231	│														
49	3.733	0.273	│														
22	4.225	0.646	│														
54	8.833	1.915	│														
56	9.200	2.397	│														
51	10.533	2.051	│														
55	28.267	8.989															
53	28.800	4.957		│													
7	67.550	8.064		│													

Station	Mean	Standard Error	Homogeneous Subset*														
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
No. of *Lucifer chacei* per cubic meter																	
35	0.000	0.000	│														
20	0.000	0.000	│														
5	0.000	0.000	│														
53	0.033	0.033	│														
45	0.033	0.033	│														
28	0.100	0.000	│														
2	0.100	0.100	│														
55	0.133	0.033	│														
15	0.133	0.088	│														
18	0.133	0.067	│														
49	0.167	0.067	│														
17	0.167	0.033	│														
54	0.233	0.088	│														
31	0.267	0.176	│														
3	0.300	0.050	│														
33	0.333	0.088	│	│													
32	0.367	0.033	│	│													
22	0.408	0.136	│	│													
24	0.600	0.153	│	│													
56	0.633	0.484	│	│													
40	0.800	0.153	│	│													
42	0.900	0.751	│	│													
38	1.033	0.240	│	│													
21	1.033	0.291	│	│													
47	1.100	0.306	│	│													
1	1.233	0.285	│	│													
19	1.900	0.361	│	│	│												
26	2.567	0.381	│	│	│												
11	2.800	0.153	│	│	│												
10	3.000	0.100	│	│	│												
46	3.100	1.557	│	│	│												
39	3.267	0.353	│	│	│												
13	3.367	2.869	│	│	│												
7	3.858	0.651	│	│	│												
34	4.667	0.617	│	│	│	│											
9	4.833	0.784	│	│	│	│											
41	4.867	0.953	│	│	│	│											
4	4.967	1.302	│	│	│	│											
36	6.100	1.510	│	│	│	│											
25	6.233	0.731	│	│	│	│											
51	6.333	5.535	│	│	│	│											
6	10.533	2.749		│	│	│	│										
27	11.500	1.500			│	│	│										
12	13.167	2.892			│	│	│										
48	16.433	7.794					│		│								
43	23.900	1.124						│	│								
29	25.300	2.084						│									
50	22.333	7.864															
52	40.000	5.060															
14	56.433	16.530															

Station	Mean	Standard Error	Homogeneous Subset*														
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
No. of fish larvae per cubic meter																	
4	0.867	0.120		│													
32				│													
46	1.233	0.240		│													
5	1.267	0.186		│													
12	1.333	0.546	│	│													
20	1.400	0.473	│	│													
15	1.600	0.265	│	│													
14	1.600	0.153	│	│													
24	1.633	0.219	│	│													
52	1.700	0.400	│	│													
49	1.767	0.426	│	│													
33	1.800	0.208	│	│													
13	1.800	0.361	│	│													
35	1.900	0.252	│	│													
48	1.967	1.027	│	│													
29	1.967	0.448	│	│													
17	2.000	0.666	│	│													
40	2.033	0.088	│	│													
31	2.100	0.643	│	│													
21	2.100	0.321	│	│													
45	2.300	0.503	│	│													
28	2.367	0.088	│	│													
34	2.467	0.649	│	│													
6	2.633	0.273	│	│													
39	2.667	0.433	│	│													
38	2.733	0.384	│	│													
2	2.800	0.608	│	│													
55	3.867	0.769	│	│		│											
36	3.900	0.306	│	│		│											
27	3.900	0.173	│	│		│											
51	3.933	0.696	│	│		│											
19	4.000	0.436	│	│		│											
3	4.200	0.781	│	│		│	│										
41	4.467	0.033	│	│		│	│										
43	4.583	0.441	│	│		│	│										
53	4.600	1.480	│	│		│	│										
47	4.733	0.393	│	│		│	│										
50	4.800	0.777	│	│		│	│										
10	5.100	0.379	│	│		│	│										
11	5.367	0.376	│	│		│	│										
9	5.600	0.252	│			│	│										
42	5.800	0.802	│			│	│										
1	5.833	1.102	│			│	│										
7	6.800	1.014				│	│										
26	8.367	1.506					│			│							
18	10.033	0.333						│		│							
54	11.033	2.450						│		│							
25	13.483	0.830						│	│								
22	14.492	1.109							│								
56	14.967	4.864							│								

*Homogeneous subsets (P < 0.05) are connected by vertical lines.

TABLE 5. CORRELATION COEFFICIENT MATRIX FOR SETTLED VOLUME AND MACROPLANKTERS FOR THE 56 STATIONS

	Volume	*Sagitta*	*Lucifer*	Fish Larvae
Volume	1.0000			
Sagitta	0.6545	1.0000		
Lucifer	0.1298	-0.0775	1.0000	
Fish Larvae	0.3848	0.2291	-0.1089	1.0000

Figure 3a presents a dendrograph showing the relationship between locations for the four variables and Figure 3b for the three variables. Three clusters are readily apparent in both figures. Cluster I contains three locations (C, D, E) within the harbor, cluster II only the intake site (B), and cluster III the discharge site (A) and offshore site (F). The locations in cluster I have less settled volume than those of clusters II and III, with cluster III having the highest settled volume.

Figure 3c and 3d presents dendrographs of the four and three variables among stations and depths. The surface tows at the discharge site (A) are closely related to the offshore site tows (F, f). The surface tows at the intake (B) form an individual cluster. The remaining cluster or clusters tend to separate by depth, particularly in the three variable case. As might be expected in an estuarine situation, the zooplankton seem to be stratified, with the upper and lower water masses having different zooplankton compositions. The surface tows at the Nuuanu Stream mouth site (E) seem to be more closely allied to the deeper water tows at the other harbor sites. This may be due to increased mixing at the stream mouth.

Figure 4 presents dendrographs of all stations (a station is defined by location, time, date, and depth; see Appendix A). Five clusters are evident in both the three and four variable cases with only one station differing between the cases. Station 32 in cluster I of the four variable case is in cluster II of the three variable case.

Cluster I contains 16 stations in the four variable case (15 in the three variable case) of which 12 (11 in the three variable case) are surface stations. Four stations in this cluster were 3-m samples.

Cluster II for the four variable case contains eight stations (nine in the three variable case). All of the samples from these stations were collected during the February 20, 1973 sampling period except for a single midnight sample collected in June. This June station and one February station were surface tows at midnight; all the remaining stations were from a depth of 3 m in the four variable case. The station (32) which differs between clusters in the three and four variable cases was collected at noon on the surface in February and belongs to cluster II of the three variable case.

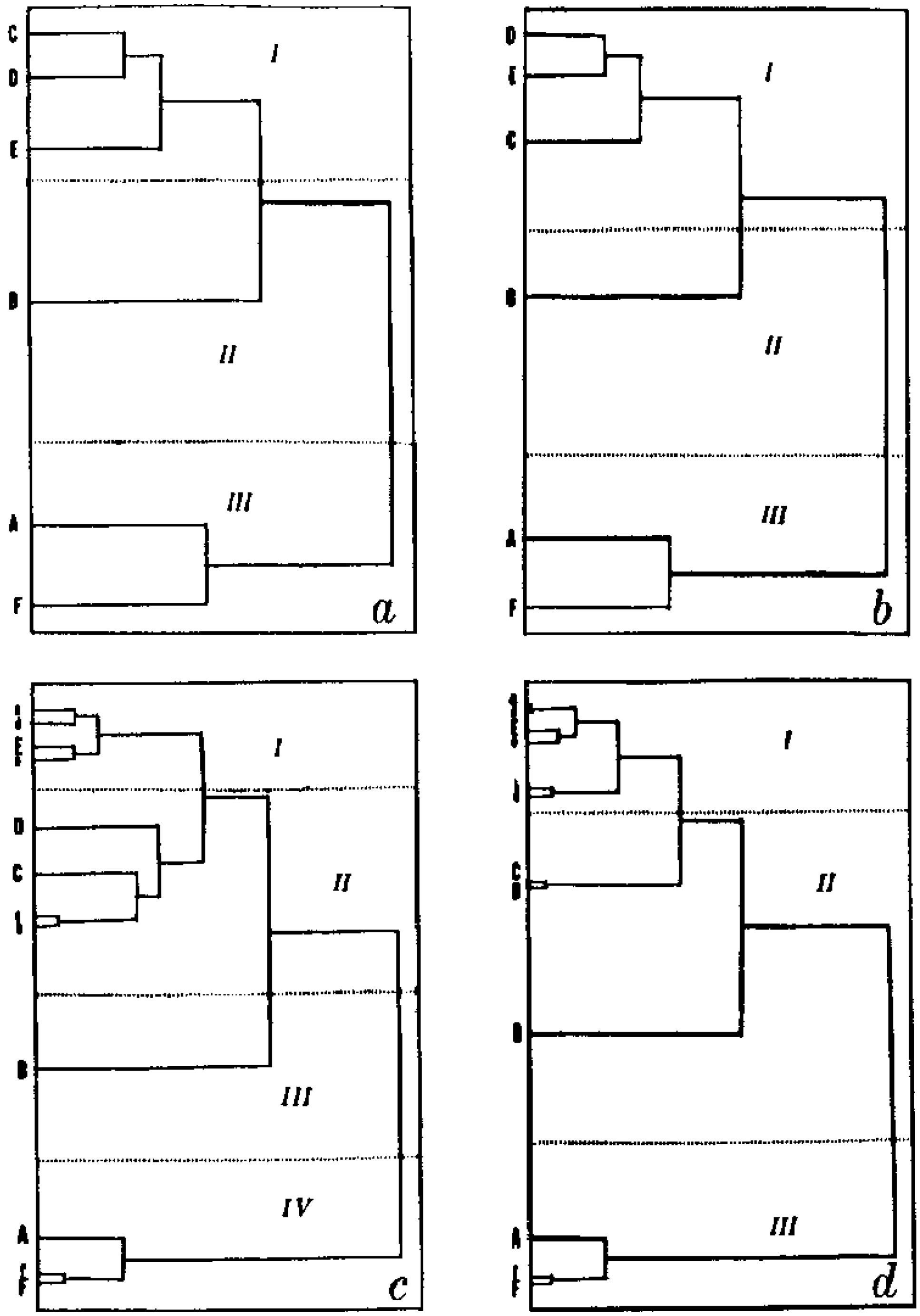

FIGURE 3. Dendrographs showing relationships between zooplankton collection locations and depths based on correlation coefficients: (a) four variable case, locations; (b) three variable case, locations; (c) four variable case, locations and depths; (d) three variable case, locations and depths. Clusters are indicated by roman numerals and, in (c) and (d), upper case letters indicate surface tows and lower case 3-m tows.

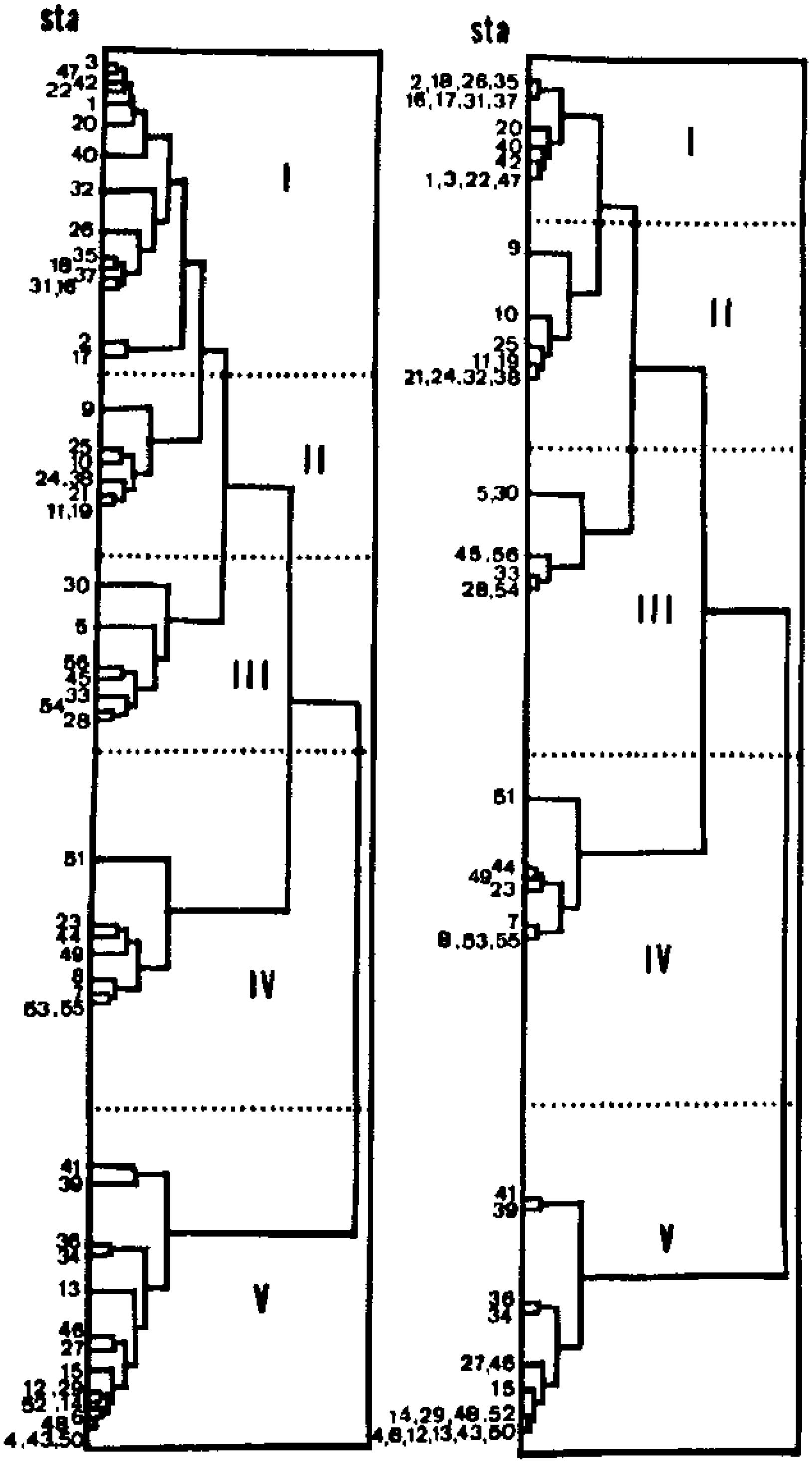

FIGURE 4. Dendrographs showing relationships between zooplankton stations based on correlation coefficients: left, four variable case; right, three variable case. Clusters are indicated by roman numerals.

Cluster III contains seven stations, four surface, and three at the 3-m depth. All but two stations were sampled during June.

Cluster IV consists of eight stations--all of which were sampled at noon and five of which were surface stations.

Cluster V contains 17 stations of which 14 were sampled at midnight. The remaining three stations were sampled at noon and all are from a 3-m depth.

Stations from the discharge site (A) occur in each of the clusters. All midnight discharge stations occur in cluster V and 3-m, non-midnight stations occur in cluster II. Apparently, time and depth are more important factors in determining the distribution of the macrozooplankters than is the power plant discharge.

In general, the discharge site, particularly the surface waters, is more similar to the less polluted offshore site than to the other sampling locations within the harbor. The macrozooplankton of the harbor bottom water is distinct from the surface water macrozooplankton (Figure 3c and 3d).

Possible explanations for the high volume of plankton in the discharge basin compared with other portions of the harbor include greater food supply, low predation, or an optimization of physical factors. The entrainment of plankton in the power station circulating water system could kill or injure microzooplankters, thereby increasing their catchability. An examination of plankton entrainment effects was made. Net hauls were taken directly from the discharge plume, approximately 15 feet from the discharge point. These samples were examined immediately to ascertain the extent of damage to the entrained plankton. Approximately 10 percent of the zooplankton was observed to be killed immediately. Benthic organisms such as gammaridean amphipods and tanaidaceans were abundant in these samples; most were dead. Apparently these organisms are abundant among the fouling within the cooling system and frequently become dislodged.

An enriched phytoplankton standing crop in the discharge basin could result in a greater abundance of herbivorous microplankters and thereby as increase in carnivorous macroplankters. For samples collected on June 19, 1973, chlorophyll values from the discharge basin (A) and the intake basin (B) were not significantly ($P < .05$; student's "t" test) different. Highly significant ($P < .05$) differences were present, however, between day and night samples at each of these locations and in the harbor channel (D). Significant ($P < .05$) differences were found between the harbor channel and the discharge basin both during the day and at night. The intake basin and the harbor channel also were significantly different at night.

Possibly, herbivores are reducing the phytoplankton standing crop during the night while during the day phytoplankton productivity rates outstrip zooplankton grazing rates, thereby replenishing the phytoplankton standing crop. If this were the case, it would be probable that high zooplankton volume (abundance) would occur during the day with minimum volume at night. It is also possible that zooplankton volume would reach a minimum maintenance level at night throughout the harbor. The mean zooplankton volume of all samples collected during the night was lower

(0.431 individuals per cubic meter) than those samples collected during the day (0.546) although these means are not significantly different. Furthermore, cluster V as shown in Figure 3 is composed mostly of night stations from all harbor stations. Thus, there is an indication that at night the zooplankton within the harbor are less abundant than during the day and that a maintenance level is attained throughout the harbor.

Honolulu Harbor is ranked fifth in importance as a site for nehu fishing in Hawaii. The nehu (*Stolephorus purpureus*) is a baitfish used for tuna fishing. Hiatt (1951) stated that *Lucifer chacei* is significant in the diet of the nehu. Presumably, *Sagitta* and *Lucifer* may also be important in the diet of many other small fishes. The exclusion of fishes from the discharge basin to any extent could, therefore, favor an increase in the abundance of these organisms. Appendix B presents the fish larvae collected during the May 1972 tows in the intake and discharge basins. Nehu were present in all but a single sample. The number of nehu in the discharge tows is significantly greater than the intake (Student's "t" test, $P < 0.01$). However, total fish larvae in the intake is greater.

Table 6 presents the total fish larvae collected in tow 166. The 1/25 aliquot used for the May and November 1972 samples probably tended to overestimate the number of larvae present. For example, 450 were estimated but there were only 297 in the case of tow 166. The 1973 fish larval counts were, therefore, taken for the entire sample, not just an aliquot. The large number of apogonid-gobiod type of fish and nehu in these samples is striking.

TABLE 6. FISH LARVAE FROM TOW 166

Number	Type
3	Carangidae
41	*Stolephorus purpureus* (Engraulidae)
83	*Schindleria* sp. (Schindleriidae)
2	*Abudefduf abdominalis* (Pomacentridae)
3	*Abudefduf* sp.
1	Pomacentridae (type 12)
1	Unidentified Pomacentridae (x)
1	Unidentified Pomacentridae (y)
5	*Apogon brachygrammus* (Apogonidae)
16	Apogonidae
1	Apogonidae (unidentified with heavy ventral pigment)
117	Apogonid-Gobioid type
5	*Kellogella oligolepis*? (Gobiidae)
1	Tetraodontidae
2	Labrid-like
11	Unidentified yolk-sac larvae (4 or 5 kinds)
3	Unidentified sp. (with heavy dorsal body pigment)
1	Pomocentrid type 11
297	Total fish larvae

A fish census was attempted to establish the abundance of fish in the various areas of the harbor; however, the limited visibility within the harbor made SCUBA diving counts exceedingly unreliable. Twenty-eight species of fish were sighted within the discharge basin, several in great abundance. The limited, quantitative data on the fishes make it impossible to state differences in predatory pressure upon zooplankton between the various locations. The limited visual counts have not shown a decrease in fish numbers in the discharge basin, but rather have suggested the opposite to be true.

It is quite possible that the increase in circulation within the discharge basin brought about by the pumping of 13 m^3/sec of seawater into the discharge basin by the Honolulu Generating Station may be beneficial to some plankters. Although the general surface movement of water is out of the basin, back-eddies may exist within the water column whereby macrozooplankters could control their position in the discharge basin by vertical movement and thus be carried back into the basin by eddies. Regrettably, the current data necessary to evaluate this possibility are not available.

The increased abundance of zooplankton in the discharge basin may be a result of the synergistic effect of increased food, more optimal physical factors such as temperature and/or circulation, or a reduction in predatory pressure. Predatory reduction appears to be the least plausible explanation, since the limited evidence available suggests otherwise.

Coral Survey

Coral growth and abundance in the intake and discharge basins are summarized in Table 7. The four species previously mentioned were found to comprise 95 to 99.8 percent of the total living surface area on each of the four walls. The remaining five species were encountered infrequently and account for a minor portion of the total coral biomass. *Porites lobata*, followed by *Montipora patula*, is the dominant species in terms of both number of colonies and total surface area in both basins.

The surface area provided by the Pier 7 and Nimitz Highway walls is approximately the same in both intake and discharge basins. Therefore, the effects of plant discharge on coral settlement and growth may be evaluated by comparing the intake and discharge sections of the two walls. Although a greater total number of coral colonies was found in the intake than in the discharge basin (Table 7), the total living surface area of all species in the discharge basin exceeds that of the intake by about 1.6 times. These results indicate that growth of coral in the discharge basin has not been measurably inhibited by plant effluent.

A comparison of the mean radii of the four principal species among the four walls (Table 8) suggests that corals growing in the discharge basin were, on the average, larger than those found in the intake basin. Analyses of variance of colony radii from the four walls were highly significant for all four principal species ($P < .01$, Table 8). Multiple

TABLE 7. LIVE CORAL COVERAGE ADJACENT TO HONOLULU GENERATING STATION

Species	Number of Colonies	Mean ± SE Colony Radius (cm)	Total Colony Area (cm^2)	Percentage of Total Live Coral Area
		Intake basin, Nimitz Highway Wall		
Porites lobata	138	5.2 ± 0.23	30250	79
Montipora patula	19	4.9 ± 1.23	3084	8
Pocillopora meandrina	43	2.4 ± 0.20	1997	5
Leptastrea purpurea	2	13.9 ± 1.27	1236	3
Montipora verrucosa	11	4.0 ± 0.77	755	2
Porites compressa	3	5.5 ± 1.12	618	2
Pavona varians	1	6.35	127	2
Pocillopora damicornis	1	2.03	26	0.3
Total Coverage	218		38093	100
		Intake basin, Pier 7 Wall		
Porites lobata	191	5.4 ± 0.18	42780	51
Montipora patula	196	4.5 ± 0.19	16620	20
Montipora verrucosa	226	4.2 ± 0.14	15320	18
Pocillopora meandrina	65	3.6 ± 0.23	6696	8
Montipora verrilli	11	4.1 ± 0.07	986	1.2
Pocillopora damicornis	9	3.4 ± 0.69	887	1.0
Pavona varians	9	3.4 ± 0.30	344	0.4
Porites compressa	2	3.2 ± 0.63	131	0.1
Total Coverage	709		83754	100
INTAKE BASIN, TOTAL	927		121847	
		Discharge basin, Nimitz Highway Wall		
Porites lobata	73	7.8 ± 0.37	32730	39
Montipora patula	49	12.9 ± 0.99	32840	39
Montipora verrucosa	19	11.8 ± 2.63	15770	19
Pocillopora meandrina	13	5.6 ± 0.58	2869	3
Pocillopora damicornis	2	3.2	132	0.15
Montipora verrilli	1	5.1	82	0.09
Total Coverage	157		84423	100
		Discharge basin, Pier 7 Wall		
Porites lobata	144	6.5 ± 0.34	54340	47
Montipora patula	171	7.0 ± 0.31	35030	30
Montipora verrucosa	124	5.8 ± 0.26	16300	14
Pocillopora meandrina	47	4.0 ± 0.41	6973	6
Porites compressa	2	14.0	2473	2
Pavona varians	5	5.9 ± 0.26	559	0.4
Leptastrea purpurea	3	4.9 ± 1.61	276	0.2
Pocillopora damicornis	3	2.1 ± 0.85	111	0.09
Montipora verrilli	2	3.2	86	0.07
Total Coverage	501		116148	100
DISCHARGE BASIN, TOTAL	658		200571	227

TABLE 8. MEAN RADIUS SIZES OF FOUR PRINCIPAL CORAL SPECIES FROM HECO INTAKE AND DISCHARGE BASINS IN HONOLULU HARBOR. Analysis of variance (ANOVA) compares variances within vs. between the four walls sampled. Homogeneous subsets denote walls where differences among mean radii did not differ significantly (Duncans New Multiple Range Test, alpha = 0.05).

Porites lobata, ANOVA F ratio = 14.8, P < .01

	Location			
Radius (cm)	a*	b†	d§	c#
$\bar{x}$	5.20	5.40	6.50	7.80
SE	0.23	0.18	0.34	0.37
n	138.00	191.00	144.00	73.00
Homogeneous Subsets	└	┘		

Montipora patula, ANOVA F ratio = 59.2, P < .01

Radius (cm)	b	a	d	c
$\bar{x}$	4.50	4.90	7.00	12.90
SE	0.19	1.23	0.31	0.99
n	196.00	19.00	171.00	49.00
Homogeneous Subsets	└	┘		

Montipora verrucosa, ANOVA F ratio = 32.1, P < .01

Radius (cm)	a	b	d	c
$\bar{x}$	4.00	4.20	5.80	11.80
SE	0.77	0.14	0.26	2.63
n	11.00	226.00	124.00	19.00
Homogeneous Subsets	└ └	┘	┘	

Pocillopora meandrina, ANOVA F ratio = 9.8, P < .01

Radius (cm)	a	b	d	c
$\bar{x}$	2.40	3.60	4.00	5.60
SE	0.20	0.23	0.41	0.58
n	43.00	65.00	47.00	13.00
Homogeneous Subsets		└	┘	

*Intake basin, NH wall.
†Intake basin, Pier 7 wall.
§Discharge basin, NH wall.
#Discharge basin, Pier 7 wall.

comparisons of mean radius sizes from the four walls were run using Duncan's new multiple range test with a significance level of .05. The results indicate that, for all four species mean radius was significantly greater on the Nimitz Highway discharge wall than on the three other walls (Table 8). For *P. lobata* and *M. patula*, the two most abundant species by both number and surface area, the Pier 7 discharge wall colony mean radius was significantly greater than the two intake basin walls, which comprised homogeneous subsets. *P. meandrina* shows a significantly smaller mean size on the Nimitz Highway discharge wall and homogeneity between the intake and discharge Pier 7 walls. These species thus indicate significant increases in colony radius with increasing proximity to the discharge. A similar pattern is indicated for *M. verrucosa*; however, homogeneity of radius size between the Pier 7 discharge wall and the two intake basin walls is indicated for this species.

The data were examined for correlation of number of colonies, radius size, and total living surface area with increasing distance from the intake or discharge for all species. Results from all depths were summed for each meter of distance along each of the four walls. The linear distance of points along the Pier 7 discharge wall was calculated as the hypotenuse of a right triangle with a base of 60 m (137 ft).

Despite the significant differences in mean radii among the four walls which indicated increased coral size with approach to discharge (Table 8), no significant correlation was found between radius size, number of colonies, live surface area, and linear distance from intake or discharge (Table 9). Correlations between these variables and linear distance from outfall ranged from r = -0.19 to 0.12. The percentage of variance of the colony number, radius, and area variables explained by distance from intake or discharge was determined by means of stepwise multiple linear regression. The percentage of variance explained by distance (Table 9) was derived from the residual multiple correlation coefficients. This was done by treating, in turn, colony number, mean radius, and total live area for each meter along a wall as a dependent variable and determining its multiple correlation coefficient when plotted against the remaining two variables with and without linear distance as the independent variable. The differences between the squared correlation coefficients x 100, with and without linear distance considered, represent estimates of variance in variables explained by the distance variable.

The results (Table 9) indicate that distance from intake or discharge accounted for no more than 2 percent of the variability of any dependent variable along any of the four walls. Such results indicate a negligible plant effect despite the significant differences among coral mean radii of the four walls and indicate that whatever factors are responsible for the size differences do not change linearly with distance from intake or discharge.

Coral growth does, however, appear to be correlated with depth in both the intake and discharge basins. Figure 5 shows the distribution of mean radius size with depth for the two dominant coral species, *P. lobata* and *M. patula*. All four species showed reduced size for the 0.5-m depth, a peak mean radius at an intermediate depth, and gradual but fairly consistent decreases in radius below the maximum radius depth. The figure indicates a depth zonation by species that was noted during the survey. At depths

TABLE 9. RELATIONSHIPS BETWEEN LINEAR DISTANCE (m), TOTAL NUMBER OF COLONIES, MEAN RADIUS SIZES (cm) AND TOTAL AREAS OF LIVE CORAL COVERAGE ADJACENT TO THE HONOLULU GENERATING STATION

Location	No. of colonies	$\bar{x}$ Radius	Total live area
	Correlation with Distance from Intake or Discharge		
a	0.12	-0.12	0.10
b	-0.03	-0.08	-0.06
c	0.12	0.04	0.11
d	-0.09	-0.22	-0.19
a and b	-0.039	-0.080	-0.084
c and d	-0.05	-0.07	-0.24
All walls combined	-0.090	-0.063	-0.120
	Percentage of Variance Explained by Distance from Intake or Discharge		
a	0.19	2.01	0.65
b	0.04	0.16	0.00
c	0.01	0.17	0.12
d	0.48	1.18	0.01
a and b	0.00	0.07	0.03
c and d	0.03	0.70	0.20
All walls combined	0.10	0.00	0.17

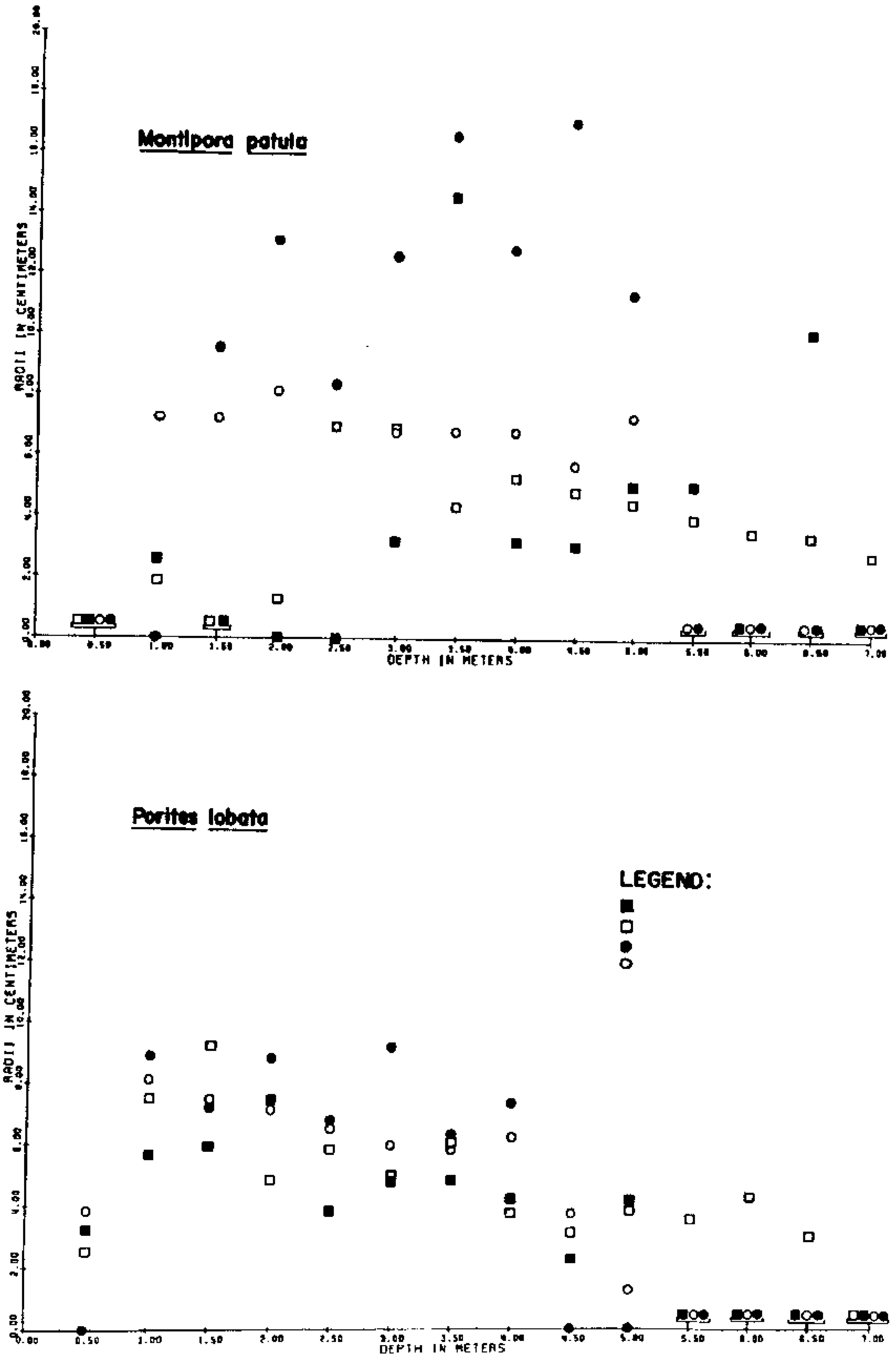

FIGURE 5. Mean radius size at 0.5-m depth intervals on each of the four walls.

of 1 to 2 m, *P. lobata* and *P. meandrina* radii were maximum, hence these species dominated the coral coverage. Maximum radii and dominance of coral coverage by *Montipora* species occurred deeper, at 2.5 to 5.0 m. The mean radius maximum was particularly prominent for both *Montiporas* from the Nimitz Highway discharge wall.

Two other areas in Honolulu Harbor were examined for coral growth at the time of this study. Both areas were selected on the basis of their providing suitable coral settling areas on concrete or dead coral rubble. No living corals were found in the first of these areas, which was located along the harbor shore of Sand Island. The second area examined, a basin bordered by Piers 4 and 5, represents the area most similar in physical configuration to the intake and discharge basins. Hard substrate suitable for coral settlement may be found on the Pier 5 and Nimitz Highway boundaries of the basin. During a brief survey of this area on October 16, 1973, only 12 corals were found on the Pier 5 wall, and 27 corals on the Nimitz Highway wall. Newly settled *P. meandrina* was dominant at Pier 5, which is a recently constructed wall of large basalt stones. *P. lobata* was the dominant species along the concrete and coral rubble at Nimitz Highway. All colonies observed were small (radius less than three inches) and few were found deeper than 1-m depth. Species of *Montipora* were conspicuously rare in this area; only one specimen of *M. verrucosa* was found. This basin was periodically receiving fresh water pumped from the adjacent Federal Building construction site, which might have adversely affected living corals. However, salinity measurements on November 1, 1973 indicated salinity alteration to be limited to a depth of less than 0.5 m and that minimum salinity was about 30 ppt. Moreover, any coral mortality related to construction site de-watering would have been evidenced by recently dead coral skeletons, none of which were noted.

These results suggest that present levels of alteration of "natural" conditions in Honolulu Harbor by the power plant have provided a physical environment more amenable to coral settlement and growth than elsewhere in the harbor at present and perhaps more so than at any other time during recent geological history. Until the time of the dredging of the Kalihi Channel in the 1930's, water movement in the harbor was principally due to Nuuanu Stream drainage, which currently averages 18,750 m^3/day (5 million gal/day). Agassiz (1889) described the entrance to Honolulu Harbor to be merely a channel kept open by Nuuanu Stream, which "killed the corals in its path, scouring at the same time in freshets the whole harbor and the adjacent limestone walls forming the channel" (p. 145).

The present intake and discharge basins adjacent to Pier 7 were dredged in 1905 (Harbormaster's office, 1973: personal communication), which thus is the earliest date coral growth could have occurred in this area. By comparison, the basin bordered by Piers 4 and 5 appears on maps from as early as 1900. Therefore, the lower coral abundance and reduced growth in the latter basin are due to factors other than a shorter time period for growth to occur. Water from the HECO intake basin was first utilized for cooling purposes in June 1920. Usage increased through 1957, at which time water circulation through the plant reached the present mean rate of 660,000 m^3/day (270 million gal/day). Assuming a mean depth in the basins of 10 m, each basin has an approximate volume of 78,000 m^3 and each, therefore, has the potential of being flushed about 8.5 times daily under normal trade wind conditions. This high flushing rate, coupled with the relatively close proximity of the power plant to the harbor's entrance, possibly has concentrated coral planulae in the basins where substrate and physical conditions are suitable for coral settlement and growth.

Within the intake and discharge basins, the comparisons made in Tables 7 and 8 indicate that, although plant discharge has prohibited coral growth along the south side of the discharge basin, thermal enrichment has not measurably damaged living coral elsewhere in the discharge basin and, in fact, may have enhanced growth rates. However, these results may also reflect a reduced rate of planula settlement along the Nimitz Highway discharge wall in recent years. Fewer small, more recently settled corals were noted on this wall compared with the Nimitz Highway intake wall, especially of the species *P. meandrina*. Such results are consistent with findings of Jokiel et al. (1974), who have experimentally determined the temperature requirements for settlement and development of young stages of *Pocillopora damicornis* to be more restricted than the temperature tolorances of the adult colony. Therefore, adult corals might be expected to survive at temperatures higher than suitable for planula settlement, provided no factor necessary for growth, e.g., light or food material, were in short supply.

Extensive measurements of temperatures or other physical factors were not undertaken in this survey. However, data from an earlier study (Buske and McCain, 1972) indicated temperature elevations along the Nimitz Highway discharge wall to range from 0.9° to 5.5°C (2° to 10°F) above temperatures along the Nimitz Highway intake wall at depths through 4.9 m (16 ft). The maximum temperatures at the point of discharge during 1972-73 often exceeded the 30°C (86°F) value demonstrated by previous studies as detrimental to coral survival. However, a continuous in situ temperature recording made using a Peabody Ryan thermograph measured temperature at 1-m depth, 1 m from the discharge port of Unit No. 7, to not exceed 27°C between July 31 and August 7, 1973, when ambient water temperatures approached annual maxima. Substantial thermal alteration of receiving water is therefore principally restricted under normal wind conditions to the basin's south side, with slight surface warming occurring elsewhere within the basin.

Water turbidity and sedimentation rates within the basin were not quantitatively measured during this study, but qualitative observations made weekly while diving indicated turbidity to be highly variable. Underwater visibility during the survey varied from about 10 m to as little as 0.5 m on one occasion during heavy ship traffic. Turbidity appeared generally higher in the discharge than in the intake basin, except near the intake structure. Continuous in-pumping of water from the intake basin by the plant probably disturbs sediments immediately adjacent to the intake, thus reducing water clarity in this area. Such a turbidity increase may in part account for a complete lack of corals on the Nimitz Highway intake wall within 14 m from the intake structure.

Despite substantial accumulation of sediment on the bottoms of both basins, little or no sediment has accumulated on the horizontal ledge that extends along all four walls at about 1.5 m (4.9 ft), probably because of the periodic surge that tends to sweep accumulated sediment from the ledge. Both turbidity and accumulated sediment on horizontal surfaces tend to increase with depth and both factors may contribute to the decrease in mean coral size illustrated in Figure 4. However, because virtually all corals below 2 m are growing horizontally from a vertically oriented surface, the effects of sediment accumulation are probably negligible compared with the effect of decrease in ambient light associated with increasing depth and increasing turbidity with depth.

Salinity variations within the basins probably produce a negligible effect on coral growth. Measurements made in 1971 and 1972 (Buske and McCain, 1972) showed a maximum difference between the basins of only 0.5 ppt and minimum salinity to be 33.8 ppt at surface. Similar results were obtained on November 1, 1973.

The results of this study lead to the conclusion that present levels of thermal discharge by the Honolulu Generating Station have in no way impaired coral growth in Honolulu Harbor, although settlement of coral larval stages may have been inhibited to an unknown degree in the area most proximal to the plant's discharge. However, given the almost complete absence of living coral elsewhere in the harbor, it is likely that the increased circulation of water produced by the station has elicited coral settlement within both the intake and discharge basins that otherwise would not have occurred.

Fish Survey

A checklist of fishes taken during this survey is presented in Table 10. A total of 47 species has been recorded from the harbor, principally from trapping. Peeling et al. (1972) identified 62 species of fish during the Naval Undersea Center (NUC) study of Pearl Harbor. The most recent NUC report (1973) stated that approximately 28 additional species have been identified since the 1972 report bringing the total number of fish species to 90 for Pearl Harbor. The NUC study consisted of trapping, visual transects, and gill net surveys; therefore, a longer species list may be expected.

All but seven of the species recorded for Honolulu Harbor have been recorded in Pearl Harbor. These species are *Acanthurus nigrofuscus*, *A. nigrosis*, *Adioryx xantherythrus*, *Chaetodon unimaculatus*, *Chromis ovalis*, *Myripristis borbonicus*, and *Pomacentrus jenkinsi*. Table 10 gives the classification of feeding habits of these based on foraging methods as given in Hiatt and Strasburg (1960). Three of the seven species are classified as algal feeders, two as carnivores, one as a plankton feeder, and one (*Chaetodon unimaculatus*) as a coral polyp feeder. The lack of living coral within Pearl Harbor probably explains why *C. unimaculatus* does not occur there. The reason for the absence of the other species is not obvious.

The environmental preference values Q and f in Table 10 are taken from the 1973 NUC study. "Q" values represent environmental preferences rated on a 0 to 100 scale from clear to most polluted waters and the f values refer to the strength of preference. Using these values an environmental preference index can be calculated as follows:

TABLE 10. CHECKLIST OF FISHES FROM HONOLULU HARBOR

Species	Feeding Habit	Location*	Collection Method†	Environmental Preference		Motility§
				Q	f	
Abudefduf abdominalis	plankton	D	T	50	1.5	1
Abudefduf sordidus	omnivore	D	T	50	1.5	1
Acanthurus dussumieri	algal	I, D	T, V	22	2.3	2
Acanthurus mata	algal	D	T	32	1.8	2
Acanthurus nigrofuscus	algal	I, D	T, V			2
Acanthurus nigrosis	algal	D	T, V			2
Acanthurus triostegus	algal	I, D	T, V	42	1.0	2
Acanthurus xanthopterus	algal	I, D	T	50	1.2	2
Arothron hispidus	omnivore	I, D	T, V	50	0.6	2
Adioryx xantherythrus	carnivore	I, D	T			1
Aulostemus chinensis	carnivore	D	V	10	2.7	2
Canthigaster jactator	omnivore	D	V			1
Caranx ignobilis	carnivore	I, D	T	50	1.5	3
Caranx melampygus	carnivore	I, D	T	36	1.8	3
Caranx sexfaciatus	carnivore	D	T	36	1.8	3
Chaetodon auriga	omnivore	I, D	T, V	48	1.4	2
Chaetodon lunula	coral polyps	I, D	T, V	34	1.9	1
Chaetodon miliaris	plankton	D	T, V	40	1.6	1
Chaetodon unimaculatus	coral polyps	D	V			1
Chromis ovalis	plankton	D	T			1
Conger marginatus	carnivore	I, D	T	30	1.8	1
Ctenochaetus strigosus	algal	I, D	T, V	36	1.8	2
Dascyllus albisella	plankton	D	V	32	1.8	1
Diodon holocanthus	carnivore	D	T, V	26	2.1	2
Diodon hystrix	carnivore	D	T	26	2.1	2
Elops hawaiiensis	carnivore	D	T	50	1.5	3
Flammeo sammara	carnivore	I, D	T, V	22	2.3	1
Gymnothorax flavimarginatus	carnivore	D	T	30	2.1	1
Gymnothorax undulatus	carnivore	D	T	40	1.2	1
Kuhlia sandvicensis	omnivore	I	T	50	1.5	3
Lutjanus fulvus	carnivore	I	T	34	1.9	3
Microcanthus strigatus	omnivore	I, D	T	10	2.7	1
Mulloidichthys auriflamma	carnivore	I, D	T, V			3
Mulloidichthys samoensis	carnivore	I, D	T, V	32	1.8	3
Myripristis borbonicus	carnivore	I	T			1
Myripristis murdjan	carnivore	I, D	T	22	2.3	1
Naso unicornis	algal	D	T	10	2.7	2
Ostracion meleagris	omnivore	I, D	T	10	2.7	3
Parupeneus multifasciatus	carnivore	I	T, V	22	2.3	3
Parupeneus porphyreus	carnivore	I, D	T, V	46	1.3	3
Pervagor spilosoma	omnivore	D	V	10	2.7	1
Pomacentrus jenkinsi	algal	D	T			1
Scomberoides sanctipetri	carnivore	D	V	50	1.5	3
Stethojulis balteatus	algal	D	V	28	2.0	2
Upeneus arge	carnivore	I, D	T, V	50	1.5	3
Zanclus canescens	omnivore	I, D	T, V	22	2.3	2
Zebrasoma flavescens	algal	I	T, V	32	1.8	2

*I = Intake; D = Discharge

†T = Traps; V = Visual

§1 = low; 2 = moderate; 3 = high

$$\text{Index B}'' = \frac{\Sigma fi\ Qi}{n\Sigma fi}$$

where n = the number of species and Q and f the environmental preferences and preference strengths, respectively. Based on the species which are shared with Pearl Harbor and for which Q and f values have been generated, an Index B" value of 0.87 is obtained for the discharge with 34 species and 1.40 for the intake with 22 species. These values compare closely with the Index B" value for NUC station BC-11 located near the mouth of Pearl Harbor which was considered the least polluted station of the NUC survey. The discharge basin B" value is lower than that of the intake suggesting less pollution in the discharge in terms of this index.

Approximately 1,200 fishes were tagged during the mark-recapture survey. Forty-five fishes of 11 species moved between traps as summarized in Table 11. Movement was primarily between traps within either the intake or discharge basins; however, movement from basin to basin did occur. A total of 11 fishes of six species (*Acanthurus nigrofuscus*, *A. triostegus*, *A. xanthopterus*, *Arothron hispidus*, *Ostracion meleagris*, and *Parupeneus porphyreus*) moved between the intake and discharge basins, a distance of 120 to 300 m. Kumu (*Parupeneus porphyreus*) migrated between the basins in five of the 11 moves. Five fishes of four species migrated from the intake to the discharge basin and eight fishes of five species moved from the discharge to the intake. A single individual of each of two species, *Ostracion meleagris* and *Acanthurus nigrofuscus*, went from the discharge basin to the intake and then returned to the discharge.

The modified Schnable equation (Ricker, 1958) was applied to the fish tagging data to obtain an estimate of population size. This equation is as follows:

$$\Theta_t = \frac{\Sigma(C_t M_t)}{\Sigma(R_t + 1)}$$

where Θ_t = population estimate for day $\underline{t}$; M_t = total number of tagged fish at large at start of day $\underline{t}$; C_t = total number of fish captured on day $\underline{t}$; R_t = number of recaptures in sample C_t. The results of this computation applied to the various traps for fish species recaptured are shown in Table 12. This estimate is useful when dealing with a large number of tagged and trapped fish; however, it tends to underestimate the size of small populations. Estimates were made, therefore, for only the more common species with at least five or more individuals in any one trap.

The fishing area of a trap varies with physical influences near the trap as well as with the foraging area of the species. McCain and Peck (1972b) compared adjacent fish trap and transect data from the reef area off Kahe Point and estimated trap fishing areas between 0.016 and 0.057 hectares (0.04 and 0.14 acres). The area varies with the species, wide-ranging fish like goatfish obviously covering a large area and narrow-ranging fish like damselfish covering a small area. Motility values are given in Table 10. Table 13 presents fish standing crop estimates based on a species with a motility rating of one having a trap fishing area

TABLE 11. FISH MOVEMENT BETWEEN HONOLULU HARBOR FISH TRAPS

Tag No.	Species	Originating Trap	Second Trap	Subsequent Traps
H-00104	*Acanthurus dussumieri*	5	3	
H-00130	*Arothron hispidus*	4	2	
H-00136	*Acanthurus triostegus*	5	3	1
H-00213	*Ostracion meleagris*	5	1	
H-00223	*Ostracion meleagris*	5	1	2, 1
H-00271	*Mulloidichthys samoensis*	4	2	
H-00883	*Zanclus canescens*	2	4	
H-01052	*Arothron hispidus*	4	2	
H-01101	*Parupeneus porphyreus*	4	2	
H-01119	*Chaetodon auriga*	2	4	
H-01153	*Acanthurus nigrofuscus*	1	3	
H-01199	*Acanthurus triostegus*	1	3	
H-01200	*Acanthurus triostegus*	1	3	
H-01202	*Acanthurus triostegus*	1	3	
H-01208	*Acanthurus xanthopterus*	1	2	
H-01218	*Acanthurus xanthopterus*	1	3	
H-01222	*Acanthurus nigrofuscus*	1	2	3
H-01244	*Parupeneus porphyreus*	1	4	
H-01267	*Parupeneus porphyreus*	4	1	
H-01301	*Acanthurus triostegus*	3	1	
H-01311	*Acanthurus triostegus*	3	1	
H-01389	*Acanthuris triostegus*	3	1	
H-01395	*Acanthurus xanthopterus*	3	1	
H-01401	*Parupeneus porphyreus*	4	1	
H-01417	*Caranx melampygus*	4	2	
H-01420	*Parupeneus porphyreus*	4	2	
H-01421	*Arothron hispidus*	4	2	
H-01443	*Arothron hispidus*	2	3	
H-01519	*Acanthurus nigrofuscus*	1	4	
H-01536	*Parupeneus porphyreus*	1	4	
H-01541	*Acanthurus triostegus*	1	4	
W-02126	*Acanthurus xanthopterus*	3	1	
W-02135	*Acanthurus triostegus*	3	1	
W-02137	*Acanthurus triostegus*	3	1	
W-02138	*Acanthurus triostegus*	3	1	
W-02144	*Acanthurus triostegus*	3	1	
W-02149	*Acanthurus triostegus*	3	1	
W-02152	*Acanthurus triostegus*	3	1	
W-02167	*Acanthurus triostegus*	3	1	
W-02172	*Acanthurus triostegus*	3	1	
W-02179	*Acanthurus triostegus*	3	1	
W-02196	*Acanthurus triostegus*	3	1	
W-02204	*Acanthurus triostegus*	3	1	
W-02211	*Acanthurus triostegus*	3	1	
HO-00183	*Parupeneus porphyreus*	5	4	

(area factor) of 0.016 hectare, two with a 0.036-hectare area, and three with a 0.057-hectare area.

TABLE 12. SCHNABEL ESTIMATE OF POPULATION SIZE OF FISH IN FISHING AREA OF TRAP

Species	Trap 1	Trap 2	Trap 3	Trap 4	Trap 5
Abudefduf abdominalis	23	--	--	--	--
Acanthurus dussumieri	22	--	11	42	33
Acanthurus mata	--	--	--	17	15
Acanthurus nigrofuscus	81	--	9	--	--
Acanthurus triostegus	511	36	2,172	30	226
Acanthurus xanthopterus	211	13	98	83	18
Arothron hispidus	56	21	--	52	19
Caranx ignobilis	--	303	--	7	--
Caranx melampygus	902	14	49	325	94
Chaetodon auriga	51	47	--	27	--
Chaetodon lunula	150	--	--	65	--
Ctenochaetus strigosus	--	--	--	10	--
Diodon holocanthus	11	--	--	--	--
Kuhlia sandvicensis	--	--	--	144	--
Mulloidichthys auriflamma	6	--	--	--	--
Mulloidichthys samoensis	298	25	28	282	91
Naso unicornis	6	--	--	--	--
Ostracion meleagris	10	--	--	--	9
Parupeneus multifasiatus	--	--	--	6	--
Parupeneus porphyreus	645	400	388	419	18
Upeneus arge	147	83	51	--	--
Zanclus canescens	65	11	13	67	43

Standing crop estimates were calculated using the length-weight factors developed by the State Division of Fish and Game, the Naval Undersea Center, and from the data developed during this study by applying the formula:

$$W = cL^3$$

where W = weight; c = factor; L = length.

TABLE 13. STANDING CROP ESTIMATES OF FISHES

Species	Trap 1 kg/hectare (lb/acre)	Trap 2 kg/hectare (lb/acre)	Trap 3 kg/hectare (lb/acre)	Trap 4 kg/hectare (lb/acre)	Trap 5 kg/hectare (lb/acre)
*Abudefduf abdominalis**	74 (66)				
*Acanthurus dussumieri**	53 (47)		24 (21)	150 (134)	63 (56)
*Acanthurus mata***				53 (48)	31 (28)
*Acanthurus nigrofuscus**	97 (87)		7 (6)		
*Acanthurus triostegus**	702 (627)	47 (42)	3318 (2961)	36 (32)	258 (230)
*Acanthurus xanthopterus***	451 (402)	28 (25)	131 (117)	307 (274)	35 (31)
*Arothron hispidus**	257 (229)	174 (156)		395 (353)	96 (86)
*Caranx ignobilis****		606 (540)		6 (6)	
*Caranx melampygus***	4658 (4156)	50 (45)	106 (95)	396 (353)	90 (80)
*Chaetodon auriga**	386 (345)	100 (89)		41 (36)	
*Chaetodon lunula**	663 (592)			464 (414)	
*Ctenochaetus strigosus**				19 (17)	
*Diodon holocanthus**	77 (68)				
Kuhlia sandvicensis				160 (143)	
*Mulloidichthys auriflamma**	8 (7)				
*Mulloidichthys samoensis**	436 (389)	33 (29)	43 (38)	437 (390)	219 (196)
*Naso unicornis**	6 (5)				
*Ostracion meleagris**	22 (20)				20 (18)
*Parupeneus multifasciatus**				13 (11)	
*Parupeneus porphyreus**	1832 (1635)	1141 (1018)	1351 (1206)	1592 (1420)	49 (44)
*Upeneus arge***	465 (415)	266 (237)	270 (241)		
*Zanclus canescens**	168 (150)	18 (16)	18 (16)	122 (109)	74 (67)
Total	10355 (9240)	2463 (2197)	5268 (4701)	4191 (3740)	935 (836)

*Cube Equation Coefficient (c) from Hawaii Fish and Game Division
**Cube Equation Coefficient (c) from Naval Undersea Center (NUC)
***Cube Equation Coefficient (c) from Honolulu data

The standing crop for the fishing area of individual traps for each species of fish taken was calculated. Then a ratio was formed with the Schnabel estimate to obtain the estimated weight of fish in the trap fishing area. This estimate was then converted to a kilogram per hectare (pounds per acre) estimate by applying the area factor. For example, 11 *Acanthurus dussumieri* were taken and measured in trap 4. These fish had a total weight of 1.43 kg (3.155 lb). The Schnabel estimate for this species in trap 4 is 42 individuals. Therefore:

$$\frac{11}{1.43}\ (3.155\ \text{lb}):\ \frac{42}{x}$$

$$x = 5.46\ \text{kg}\ (12\ \text{lb})$$

Dividing by the area factor of 0.036 hectares (0.90 acres), an estimate of 150 kg/hectare (134 lb/acre) is obtained. Obviously, this estimation of standing crop is dependent upon the size and frequency of fishes taken in a particular trap. It is possible, therefore, for the Schnabel estimate for a trap to be higher than another, yet have lower standing crop.

The subjectivity of these estimates is obvious, but they do give some indication of fish standing crops in the various areas of the harbor. The discharge traps (1 and 3) with the exception of trap 5 have considerably larger standing crops than do those of the intake (traps 2 and 4). Listed according to feeding habits (Table 14), carnivores dominate the standing crop of all traps with the exception of the two traps (3 and 5) which were sampled only a short period of time. Carnivorous standing crop is obviously higher in the trap directly in the discharge of the power station than in the other traps. The percentage of composition does not appear to be altered appreciably in the discharge trap.

TABLE 14. STANDING CROP ESTIMATES OF FISHES BY FEEDING HABIT

Feeding Habit	Trap 1 kg/hectare (lb/acre)	Trap 2 kg/hectare (lb/acre)	Trap 3 kg/hectare (lb/acre)	Trap 4 kg/hectare (lb/acre)	Trap 5 kg/hectare (lb/acre)
Algal	1309 (1168)	75 (67)	3480 (3105)	565 (505)	387 (345)
Plankton	74 (66)	--	--	--	--
Omnivore	833 (744)	292 (261)	18 (16)	718 (641)	190 (171)
Carnivore	7476 (6670)	2096 (1869)	1770 (1580)	2444 (2180)	358 (320)
Coral polyp	663 (592)	--	--	464 (414)	--
Total	10355 (9240)	2463 (2197)	5258 (4701)	4191 (3740)	935 (836)
			Percentage of Total		
Algal	12.6	3.0	66.1	13.5	41.4
Plankton	0.7	--	--	--	--
Omnivore	8.0	11.8	0.3	17.1	20.3
Carnivore	72.2	85.1	33.6	58.3	38.3
Coral polyp	6.4	--	--	11.1	--
Total	99.9	99.9	100.0	100.0	100.0

These standing crop estimates are generally higher, particularly the discharge trap, than standing crop estimates for tropical and subtropical shallow water reef areas. McVey (1970) summarized fish standing crop estimates stating that natural reef areas range from 360 to 1,590 kg/hectare (320 to 1,420 lb/acre) and artificial reefs from 260 to 6,980 kg/hectare (230 to 6,230 lb/acre). Brock (1954) found an average of 360 kg/hectare (320 lb/acre) for nine Hawaiian natural reef areas and Wass (1967) reported 1,255 kg/hectare (1,120 lb/acre) for a Kaneohe Bay patch reef. McCain and Peck (1973) estimated that the non-thermal influenced reefs near the Kahe Generating Station had from 450 to 1,960 kg/hectare (4,000 to 1,750 lb/acre) of fishes whereas the standing crop of fishes at the thermal discharge reached 6,230 kg/hectare (5,555 lb/acre). Grimes (1971) found that fish abundance was greater in the thermally affected shallow areas near Crystal River Steam Electric Station in Florida. The abundance of fishes in discharge trap 1, 10,355 kg/hectare (9,240 lb/acre) suggests a similar increase in fish standing crop at the Honolulu Generating Station outfall.

Landry and Strawn (1973) cited warm water, current, and abundance of prey fishes as reasons for attracting sportfishes to heated effluents. Based on percentage of composition (Table 14), sportfishes (carnivores) are not "attracted" to the Honolulu discharge any more than non-sportfish; however, the standing crop of carnivores in the discharge area (trap 1) is higher than in the intake area (traps 2 and 4). Apparently the potential danger of an undesirable replacement fauna as pointed out by Naylor (1965) has not happened at the Honolulu outfall.

Hile (1936) discussed the use of the cube equation ($W = cL^3$) in fisheries statistics and concluded that it does not adequately describe the length-weight relationship in some species of fish. He gave the equation $W = aL^b$ as a more satisfactory method of describing this relationship since both $\underline{a}$ and $\underline{b}$ are determined empirically. He stated further that the coefficients calculated using the cube equation and the empirical exponent equation are not of parallel significance as measures of condition. The coefficient calculated by the empirical exponent equation does not give us as satisfactory a measure of condition as does the coefficient calculated by the cube equation, although the empirical exponent equation does provide a much more accurate representation at the actual growth curve equation. Therefore, both the empirical exponent equation and the cube equation coefficients were computed for fish taken in traps during this survey (Table 15).

Ricker (1973) discussed the use of regression lines for estimating the length-weight relation. He concluded that most exponents calculated, using the log transformation of the empirical exponent equation, are biased in the direction of being too small. He suggested the use of the geometric mean estimate ($\underline{v}$) of the functional regression of $\underline{y}$ (weight) on $\underline{x}$ (length) as follows:

$$v = \pm \sqrt{\frac{\Sigma y^2}{\Sigma x^2}} = \pm \frac{b}{r}$$

where b = slope and r = correlation coefficient.

TABLE 15. LENGTH-WEIGHT RELATIONS BASED ON INCHES-POUNDS MEASUREMENTS

Species	Trap	NUC	Cube Equation Coefficient (C) (No. of Individuals) Div. of Fish & Game	NECO	Empirical Equation Coefficient (a)	Empirical Equation Exponent (b)	Geometric Mean of Functional Regression (v)	Correlation Coefficient (r) length-weight
Abudefduf abdominalis	1	--	.00080 (171)	.00108 (6)	.00049	3.51023	3.6436	0.9634
Acanthurus dussumieri	4	.00110 (3)	.00072 (21)	.00091 (14)	.00078	3.08430	3.1098	0.9918
Acanthurus nigrofuscus	1	--	--	.00083 (23)	.00089	2.95270	3.2768	0.9011
Acanthurus triostegus	1	--	--	.00097 (121)	.00144	2.73126	3.3018	0.8277
Acanthurus triostegus	4	--	--	.00093 (8)	.00118	2.83638	3.0955	0.9163
Acanthurus triostegus	Total*	.00157 (12)	.00132 (113)	.00097 (129)	.00138	2.75494	3.3037	0.8339
Acanthurus xanthopterus	1	--	--	.00089 (24)	.00098	2.94039	3.0220	0.9730
Acanthurus xanthopterus	2	--	--	.00591 (3)	.00043	3.43923	3.4382	1.0000
Acanthurus xanthopterus	4	--	--	.00087 (5)	.00260	2.31482	3.2995	0.9847
Acanthurus xanthopterus	Total*	.00100 (23)	.00102 (4)	.00090 (27)	.00096	2.95899	3.0377	0.9747
*Arothron hispidus***	1	.00136 (9)	.00145 (10)	.00094 (6)	.00217	2.55012	2.6179	0.9798
Caranx ignobilis	2	--	--	.00070 (9)	.00045	3.22135	4.1576	0.9712
Caranx melampygus	1	--	--	.00068 (14)	.00081	2.91424	2.9259	0.9960
Caranx melampygus	4	--	--	.00067 (15)	.00075	2.94449	3.0497	0.9655
Caranx melampygus	Total	.00078 (25)	.00064 (7)	.00065 (30)	.00080	2.89747	2.9917	0.9685
Chaetodon auriga	1	--	--	.00106 (5)	.00094	3.07858	4.0484	0.9658
Chaetodon auriga	4	--	--	.00103 (6)	.00063	3.31330	3.3765	0.9807
Chaetodon auriga	Total	.00152 (3)	.00100 (26)	.00104 (11)	.00080	3.17619	3.2430	0.9794
Chaetodon lunula	1	--	.00124 (25)	.00102 (12)	.00120	2.89617	3.2414	0.8935
Mulloidichthys samoensis	1	--	--	.00059 (6)	.00057	3.02025	3.0415	0.9930
Mulloidichthys samoensis	4	--	--	.00052 (12)	.00028	3.30182	3.7045	0.8913
Mulloidichthys samoensis	Total	.00078 (13)	.00039 (39)	.00054 (19)	.00058	2.97197	3.1991	0.9290
*Ostracion meleagris**	1	--	.00157 (20)	.00120 (8)	.00215	2.65953	2.6937	0.9873
Parupeneus porphyreus	1	--	--	.00073 (36)	.00124	2.71420	2.9151	0.9311
Parupeneus porphyreus	2	--	--	.00078 (4)	.00148	2.67939	3.6544	0.7332
Parupeneus porphyreus	4	--	--	.00071 (17)	.00110	2.78061	2.9368	0.9566
Parupeneus porphyreus	Total	.00088 (33)	.00084 (15)	.00073 (57)	.00113	2.76770	2.9100	0.9511
Upeneus arge	1	--	--	.00052 (10)	.00057	2.96168	3.1404	0.9431
Upeneus arge	2	--	--	.00056 (9)	.00024	3.40338	3.5068	0.9705
Upeneus arge	3	--	--	.00060 (6)	.00061	2.99172	2.9980	0.9979
Upeneus arge	Total	.00069 (4)	.00048 (7)	.00056 (28)	.00029	3.30284	3.3976	0.9721
Zanclus canescens	1	--	--	.00119 (7)	.00048	3.54246	3.6177	0.9792
Zanclus canescens	4	--	--	.00118 (17)	.00064	3.38310	3.5084	0.9643
Zanclus canescens	Total	--	.00102 (28)	.00115 (24)	.00061	3.40589	3.5094	0.9705

*Total of fish weighed and measured regardless of trap

**Calculation based on total length, otherwise based on fork length

Geometric mean values are given in Table 15. Generally the more weight per unit addition of length is reflected in a higher v value.

Three of the five species with five or more individuals in traps 1 and 4 have lower v values in the discharge area than in the intake. These three species, *Caranx melampygus, Mulloidichthys samoensis,* and *Parupeneus porphyreus,* are, therefore, less "plump" in the discharge area than are their counterparts in the intake area. Convict tangs, *Acanthurus triostegus,* and moorish idols, *Zanclus canescens,* collected in the discharge area have higher v values than those of the intake area.

Cube equation coefficient (c) values are higher for all five of the species taken in the discharge area than those taken in the intake. This indicates, in opposition to the geometric mean, that these fishes in the discharge area are more "plump" than their intake area counterparts. Except for *Zanclus canescens*, all of these fishes have lower empirically derived exponents (b) and higher coefficients (a) in the discharge than in the intake. Thus, the results of a comparison of growth by means of the coefficient of condition (c) based on the cube equation yields divergent results from the geometrics mean (v) comparison and comparison of the empirically derived exponents (b) and coefficients (a).

Ricker (1973) stated that predictive regressions based on the empirical equation would have a systematic bias related to the range of lengths involved in the two series being compared whereas the geometric mean would not. Hile (1936) holds, as stated above, that the coefficient (c) of cube equation serves as a better measure of condition than does the empirically derived exponents (b). Since these two growth indicators do not agree for three of the five species mentioned above, it is not clear whether growth (plumpness) is better in the discharge or intake area. However, from the data it is evident that the fishes taken in the discharge area grow with a different length-weight relation than those of the intake.

An analysis of co-variance (Snedecor and Cochran, 1967) was performed on the five species to determine if significant differences existed between the length-weight regressions of specimens from the discharge area (trap 1) and intake area (trap 4). No significant difference was present between the regression slopes from the two areas for any of the five species. However, three species, *Caranx melampygus, Mulloidichthys samoensis,* and *Zanclus canescens*, had highly significant ($P < .01$) differences in the elevation of the population regression lines. Therefore, the population regressions of these three species do not coincide in the intake and discharge areas. Based on the cube equation coefficients (c), all three species add more weight per unit change of length in the discharge than in the intake area. The geometric mean (v) also shows this increase for *C. melampygus* and *M. samoensis,* but not for *Z. canescens.*

SUMMARY AND CONCLUSIONS

Zooplankton Investigation

One hundred and seventy-four plankton tows were made at six stations in Honolulu Harbor using a 0.5-m diameter, 215-micron mesh net. An analysis of these samples showed that the macrozooplankton populations in the Honolulu Generating Station discharge basin are more similar to those populations found in offshore (less polluted?) waters than to those populations found elsewhere in the harbor. This applies particularly to surface water. The abundance of macrozooplankters in the harbor surface water differs from that of bottom water. Time and depth appear to be more important factors in determining the distribution and abundance of macrozooplankters in the harbor than in the power station discharge. The increased circulation produced by the pumping of 13 m^3/sec of seawater into the discharge basin may be beneficial to some plankters, as evidenced by their greater abundance in the discharge basin than other areas of the harbor.

Coral Survey

All corals growing on the walls and hard substrate surrounding the Honolulu Generating Station intake and discharge basins were counted and their diameters measured. Ten species were found, four of which comprised 95 to 99 percent of the total living coral surface in either basin. These four species were: *Porites lobata*, *Pocillopora meandrina*, *Montipora verrucosa*, and *Montipora patula*.

Results indicate that the increased circulation of water imparted by the generating station has created an environment more conducive to coral settlement and growth than elsewhere in Honolulu Harbor. Although corals do not occur in the immediate path of the discharge plume along the south wall of the discharge basin, the total living surface area of corals growing on the remaining two discharge basin walls exceeds by 1.6 times the surface area of live corals in the intake basin. Negligible coral growth was found at other areas surveyed in the harbor.

The mean radius size of corals growing on the wall closest to the discharge significantly exceeded mean radii of corals on the remaining three walls that were surveyed. Also, for the two most abundant species (*P. lobata* and *M. patula*), mean radius size was significantly larger for colonies on the remaining discharge basin wall than on the two intake basin walls. However, despite these significant differences, no significant correlation was found between linear distance from intake or discharge and colony numbers, mean radius size or living surface for the combined species.

A correlation between mean radius size and depth is suggested for all four principal species, and differences among species in depth zonation were found. Maximum mean radius size of *P. lobata* and *P. meandrina* occurred at 1 to 2 m, while maxima for both *Montipora* species occurred at 2.5 to 5.0 m.

Fish Survey

Approximately 1,200 fishes were tagged during an eight month mark-recapture survey of the fishes in the intake and discharge basins of the Honolulu Generating Station. A total of 47 species was identified from Honolulu Harbor during this survey and previous visual SCUBA surveys. The environmental preference index values for fishes in these basins compare closely with the least polluted station examined during the Naval Undersea Center's survey of Pearl Harbor. Some movement of fishes between the intake and discharge basins occurred; however, most movement was within the same basin. The estimated standing crop of fishes in the discharge (10,355 kg/hectare) of the Honolulu Generating Station is approximately twice that of the intake area (5,228 kg/hectare).

Based on cube equation (weight = c length^3) coefficients (c), the fishes of the discharge basin add more weight per unit of length than do those of the intake basin. It may be concluded, therefore, that they are "plumper," more healthy fishes. This conclusion is not substantiated by the geometric mean of functional regression of weight on length ($v = \pm \sqrt{\Sigma y^2/\Sigma x^2}$) nor by the empirical equation coefficients (a) or exponents (b) (weight = a length^b) in most cases. No significant differences existed between the empirical equation regression slopes (b) for five species of fishes, *Acanthurus triostegus*, *Caranx melampygus*, *Mulloidichthys samoensis*, *Parupeneus porphyreus*, and *Zanclus canescens*, taken in the intake and discharge basins. Significant differences were present in elevation (a) between three of these species from the intake and discharge basins.

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APPENDICES

APPENDIX A. ZOOPLANKTON TOW RECORDS AND SORTING DATA

Station No.	Location	Date	Time	Depth	Tow No.	Duration (sec)	Volume Sampled (m³)	Settled Volume (ml)	Volume* (ml/m³)	*Sagitta enflata* (#/m³)	*Lucifer chacei* (#/m³)	Fish Larvae (#/m³)
1	Discharge Basin (A)	20 Feb 1973	0600	Surface	1	95	15.59	7.50	0.48	3.2	1.8	8.00
					2	101	18.22	4.00	0.22	2.6	1.0	4.40
					3	109	14.72	5.00	0.34	1.9	0.9	5.10
9	Discharge Basin (A)	20 Feb 1973	0600	3 m	4	128	18.17	5.50	0.30	1.7	4.1	5.90
					5	143	18.63	5.25	0.28	0.6	4.0	5.10
					6	141	17.25	5.15	0.30	1.2	6.4	5.80
16	Intake Basin (B)	20 Feb 1973	0600	Surface	7	120	17.37	1.25	0.07	0.1	0.3	1.20
					8	130	19.67	1.40	0.07	0.1	0.1	1.50
					9	128	20.47	1.30	0.06	0.3	0	2.10
24	Intake Basin (B)	20 Feb 1973	0600	3 m	10	125	19.44	1.30	0.07	0.1	0.3	1.20
					11	150	18.40	1.80	0.10	0.5	0.8	1.80
					12	155	18.86	1.70	0.09	0.2	0.7	1.90
31	Sand Island Channel (C)	20 Feb 1973	0600	Surface	13	131	18.63	1.65	0.09	0.2	0	3.30
					14	137	20.70	1.60	0.08	0.3	0.2	1.10
					15	128	18.86	1.65	0.09	0.3	0.6	1.90
36	Sand Island Channel (C)	20 Feb 1973	0600	Surface	16	130	16.10	2.25	0.14	0.5	0.7	2.30
					17	145	20.01	2.90	0.14	0.6	0.9	3.50
					18	160	21.97	3.25	0.15	0.1	1.5	2.40
2	Discharge Basin (A)	20 Feb 1973	1200	Surface	19	113	17.83	18.00	1.01	0.2	0	1.80
					20	120	18.06	16.00	0.89	0.2	0	2.70
					21	109	15.34	20.00	1.30	0.8	0.3	3.90
10	Discharge Basin (A)	20 Feb 1973	1200	3 m	22	157	22.10	17.00	0.77	0.5	2.9	4.50
					23	165	22.54	18.00	0.80	1.0	2.9	5.80
					24	153	21.74	15.00	0.69	0.8	3.2	5.00
17	Intake Basin (B)	20 Feb 1973	1200	Surface	25	115	18.06	8.45	0.47	0.1	0.1	0.70
					26	120	17.83	20.00	1.12	0.2	0.2	2.90
					27	---	19.55	21.00	1.07	0.3	0.2	2.40
25	Intake Basin (B)	20 Feb 1973	1200	3 m	28	150	23.46	17.50	0.75	1.2	7.6	13.00
					29	160	25.76	15.50	0.60	1.3	6.0	15.10
					30	145	21.05	15.50	0.74	0.9	5.1	12.35
32	Sand Island Channel (C)	20 Feb 1973	1200	Surface	31	140	25.65	10.50	0.41	0.1	0.3	1.00
					32	140	25.19	8.00	0.32	0.1	0.4	1.60
					33	130	23.81	8.00	0.34	0	0.4	0.80
39	Sand Island Channel (C)	20 Feb 1973	1200	3 m	34	168	26.11	11.50	0.44	0.4	3.8	3.40
					35	168	23.58	10.00	0.42	0.8	3.4	2.70
					36	140	24.27	9.20	0.38	0.3	2.6	1.90
3	Discharge Basin (A)	20 Feb 1973	1800	Surface	37	120	21.62	4.40	0.20	1.6	0.4	2.80
					38	117	18.86	5.40	0.29	1.5	0.3	5.50
					39	105	17.14	4.80	0.28	1.5	0.2	4.30
11	Discharge Basin (A)	20 Feb 1973	1800	3 m	40	135	21.97	6.80	0.31	1.2	2.6	5.40
					41	136	21.62	7.60	0.35	1.5	3.1	4.70
					42	152	22.08	7.50	0.34	1.4	2.7	6.00
18	Intake Basin (B)	20 Feb 1973	1800	Surface	43	115	18.86	3.90	0.21	1.2	0.2	10.70
					44	120	17.60	3.20	0.18	1.4	0.2	9.50
					45	120	17.71	3.50	0.20	1.1	0	9.90
26	Intake Basin (B)	20 Feb 1973	1800	3 m	46	150	24.27	6.90	0.28	3.2	2.6	9.40
					47	135	18.86	6.00	0.32	3.6	3.1	10.30
					48	145	28.18	6.30	0.22	2.8	2.0	5.40
33	Sand Island Channel (C)	20 Feb 1973	1800	Surface	49	136	22.66	3.20	0.14	1.5	0.5	1.90
					50	120	19.21	3.00	0.16	1.1	0.3	2.10
					51	125	23.00	2.80	0.12	1.6	0.2	2.20
40	Sand Island Channel (C)	20 Feb 1973	1800	3 m	52	135	21.74	4.20	0.19	1.9	0.9	2.20
					53	160	27.95	7.10	0.25	0.8	1.0	2.00
					54	150	25.76	9.00	0.35	1.1	0.5	1.90
4	Discharge Basin (A)	20 Feb 1973	2400	Surface	55	125	17.48	4.80	0.27	0.5	7.3	0.80
					56	130	20.13	4.00	0.20	0.1	2.8	0.70
					57	125	18.40	4.00	0.22	0.8	4.8	1.10

*$\left(\frac{\text{settled volume}}{\text{sampled volume}}\right)$

Station No.	Location	Date	Time	Depth	Tow No.	Duration (sec)	Volume Sampled (m^3)	Settled Volume (ml)	Volume* (ml/m^3)	*Sagitta enflata* (#/m^3)	*Lucifer chacei* (#/m^3)	Fish Larvae (#/m^3)
12	Discharge Basin (A)	20 Feb 1973	2400	3 m	58	150	23.58	5.00	0.21	0.8	7.5	0.60
					59	135	20.24	10.50	0.52	0.6	17.0	2.40
					60	150	22.08	7.20	0.33	0.2	15.0	----
19	Intake Basin (B)	20 Feb 1973	2400	Surface	61	120	17.37	4.50	0.26	0.9	1.7	4.10
					62	128	21.39	3.00	0.14	0.7	1.4	4.70
					63	122	17.94	2.50	0.14	1.0	2.6	3.20
27	Intake Basin (B)	20 Feb 1973	2400	3 m	64	153	22.20	8.30	0.37	1.3	14.5	3.90
					65	140	21.16	7.50	0.35	1.5	10.0	3.60
					66	140	20.01	7.00	0.35	1.3	10.0	4.20
34	Sand Island Channel (C)	20 Feb 1973	2400	Surface	67	130	19.09	4.00	0.21	0.8	5.9	3.70
					68	130	22.54	3.30	0.15	0.5	4.0	1.50
					69	140	21.62	3.50	0.16	1.0	4.1	2.20
41	Sand Island Channel (C)	20 Feb 1973	2400	3 m	70	147	22.89	6.00	0.26	1.0	6.5	4.40
					71	152	23.12	6.00	0.26	1.6	4.9	4.50
					72	138	26.91	6.00	0.22	1.3	3.2	4.50
5	Discharge Basin (A)	19 Jun 1973	1200	Surface	73	110	18.40	4.40	0.24	2.1	0	1.40
					74	125	19.09	3.40	0.18	1.7	0	0.90
					75	110	19.32	3.00	0.16	1.0	0	1.50
13	Discharge Basin (A)	19 Jun 1973	1200	3 m	76	140	22.08	7.50	0.34	0.8	9.1	1.30
					77	125	19.55	6.10	0.31	2.9	0.3	2.50
					78	125	19.21	6.00	0.31	1.1	0.7	1.60
20	Intake Basin (B)	19 Jun 1973	1200	Surface	79	127	21.74	3.80	0.17	0.5	0	1.20
					80	118	20.47	3.50	0.12	0.9	0	2.30
					81	135	20.24	3.40	0.17	0.5	0	0.70
28	Intake Basin (B)	19 Jun 1973	1200	3 m	82	130	21.51	7.50	0.35	1.6	0.1	2.20
					83	145	22.31	8.50	0.38	2.3	0.1	2.40
					84	133	20.01	7.00	0.35	1.6	0.1	2.50
35	Sand Island Channel (C)	19 Jun 1973	1200	Surface	85	123	22.08	2.30	0.10	0.2	0	2.10
					86	118	23.50	2.30	0.09	0.1	0	1.40
					87	130	23.69	2.00	0.08	0.1	0	2.20
42	Sand Island Channel (C)	19 Jun 1973	1200	3 m	88	180	31.05	13.00	0.42	2.1	0.1	5.10
					89	115	19.78	7.00	0.35	1.3	0.2	4.90
					90	125	19.78	16.00	0.81	2.4	2.4	7.40
45	Harbor Channel (D)	19 Jun 1973	1200	Surface	91	120	22.89	6.50	0.28	1.4	0	1.70
					92	118	16.68	7.00	0.41	1.2	0.1	1.90
					93	115	17.14	6.40	0.37	1.6	0	3.30
47	Harbor Channel (D)	19 Jun 1973	1200	3 m	94	120	15.30	9.00	0.59	1.8	0.5	4.20
					95	125	18.40	14.00	0.76	2.4	1.3	4.50
					96	130	14.49	15.00	1.04	2.5	1.5	5.50
49	Nuuanu Stream Basin (E)	19 Jun 1973	1200	Surface	97	108	18.98	4.50	0.24	4.1	0.3	2.60
					98	108	19.21	4.50	0.23	3.9	0.1	1.50
					99	112	19.32	5.00	0.26	3.2	0.1	1.20
51	Nuuanu Stream Basin (E)	19 Jun 1973	1200	3 m	100	150	21.97	12.00	0.55	14.0	17.4	2.80
					101	135	19.90	7.80	0.39	10.7	1.0	3.80
					102	139	20.13	6.50	0.32	6.9	0.6	5.20
53	Offshore (F)	19 Jun 1973	1200	Surface	103	120	22.77	14.50	0.64	20.7	0	2.20
					104	155	13.80	15.50	1.12	27.9	0.1	4.30
					105	140	14.03	24.00	1.71	37.8	0	7.30
55	Offshore (F)	19 Jun 1973	1200	3 m	106	120	16.33	12.00	0.73	11.3	0.1	2.40
					107	125	19.55	30.00	1.53	31.6	0.2	5.00
					108	115	16.10	35.00	2.17	41.9	0.1	4.20
6	Discharge Basin (A)	19 Jun 1973	2400	Surface	109	120	18.86	6.30	0.33	1.6	10.9	2.10
					110	115	16.91	6.00	0.35	1.4	5.6	3.00
					111	118	16.56	6.20	0.37	1.3	15.1	2.80
14	Discharge Basin (A)	19 Jun 1973	2400	3 m	112	113	16.33	9.50	0.58	0.5	45.6	1.70
					113	123	19.55	8.20	0.42	0.6	34.8	1.30
					114	118	14.26	11.50	0.81	0.1	88.9	1.80
21	Intake Basin (B)	19 Jun 1973	2400	Surface	115	113	15.30	3.00	0.10	0.3	1.1	1.50
					116	113	15.18	4.00	0.33	1.1	1.5	2.60
					117	110	14.49	2.50	0.17	0.6	0.5	2.20

Station No.	Location	Date	Time	Depth	Tow No.	Duration (sec)	Volume Sampled (m^3)	Settled Volume (ml)	Volume* (ml/m^3)	*Sagitta enflata* ($\#/m^3$)	*Lucifer chacei* ($\#/m^3$)	Fish Larvae ($\#/m^3$)
29	Intake Basin (B)	19 Jun 1973	2400	3 m	118	117	16.22	8.50	0.52	1.0	21.2	2.20
					119	115	16.33	8.50	0.52	0.4	28.0	2.60
					120	125	20.47	11.00	0.54	0.6	26.7	1.10
36	Sand Island Channel (C)	19 Jun 1973	2400	Surface	121	120	18.98	18.00	0.95	1.9	9.1	4.10
					122	120	19.67	32.00	1.63	1.4	4.9	3.30
					123	115	18.17	27.00	1.49	1.7	4.3	4.30
43	Sand Island Channel (C)	19 Jun 1973	2400	3 m	124	118	15.18	13.50	0.89	2.0	21.7	4.70
					125	120	19.44	23.50	1.21	3.1	24.6	5.20
					126	122	18.75	16.00	0.85	2.5	25.4	3.70
46	Harbor Channel (D)	19 Jun 1973	2400	Surface	127	110	16.91	3.20	0.19	0.6	6.2	1.60
					128	112	16.22	1.80	0.11	1.0	1.8	1.00
					129	110	17.02	1.50	0.09	0.5	1.3	1.10
48	Harbor Channel (D)	19 Jun 1973	2400	3 m	130	120	17.94	8.50	0.47	2.4	19.7	3.90
					131	122	17.60	1.50	0.09	0.4	1.6	0.40
					132	130	21.39	11.00	0.51	1.9	28.0	1.60
50	Nuuanu Stream Basin (E)	19 Jun 1973	2400	Surface	133	113	16.56	10.50	0.63	2.8	42.0	5.90
					134	112	18.98	9.00	0.47	4.5	17.3	5.20
					135	111	18.75	8.00	0.43	1.8	19.7	3.30
52	Nuuanu Stream Basin (E)	19 Jun 1973	2400	3 m	136	125	19.78	11.00	0.56	1.4	34.4	1.30
					137	123	19.44	15.00	0.77	1.6	50.1	2.50
					138	121	23.46	14.50	0.62	1.6	35.5	1.30
54	Offshore (F)	19 Jun 1973	2400	Surface	139	115	19.32	12.00	0.62	9.6	0.4	12.30
					140	120	18.40	10.00	0.54	5.2	0.1	6.30
					141	110	15.76	15.00	0.95	11.7	0.2	14.50
56	Offshore (F)	19 Jun 1973	2400	3 m	142	127	18.06	12.00	0.66	5.1	0.2	6.20
					143	128	16.33	21.00	1.29	13.4	1.6	23.00
					144	124	16.22	14.00	0.86	9.1	0.1	15.70
7	Discharge Basin (A)	11 May 1972	1200	Surface	145	115	14.81	25.00	1.69	48.5	8.3	5.10
					146	187	17.52	27.00	1.57	44.1	3.5	4.30
					147	137	17.88	20.00	1.19	44.4	2.6	4.20
					148	137	18.79	25.00	1.33	47.2	4.9	8.00
					149	143	17.88	23.00	1.29	48.8	3.7	16.80
					150	81	17.52	34.00	1.94	79.2	4.1	8.60
					151	145	18.24	24.00	1.32	53.3	1.5	5.50
					152	145	18.78	36.00	1.92	78.3	1.9	4.00
					153	156	19.14	24.00	1.25	70.4	3.0	5.20
					154	147	18.24	35.00	1.92	73.5	1.8	6.90
					155	163	19.50	66.00	3.38	143.2	8.1	7.70
					156	145	18.96	31.00	1.64	79.7	2.9	5.30
22	Intake Basin (B)	11 May 1972	1200	Surface	157	176	21.13	23.00	1.09	7.4	1.7	16.60
					158	147	17.52	15.00	0.86	2.1	0.2	8.60
					159	120	21.13	19.00	0.90	3.1	0.3	10.60
					160	162	19.14	16.00	0.84	3.9	0.5	15.70
					161	119	20.95	20.00	0.96	4.2	0.5	19.10
					162	152	18.42	20.00	1.09	9.3	0.8	16.30
					163	166	19.14	14.00	0.73	1.9	0.1	11.80
					164	152	17.70	15.00	0.85	2.0	0	9.90
					165	161	18.78	13.00	0.69	5.2	0.3	14.60
					166	175	20.77	20.00	0.96	4.9	0.4	20.50
					167	157	18.06	17.00	0.94	3.1	0.1	18.00
					168	138	16.43	14.00	0.85	3.6	0	12.20
8	Discharge Basin (A)	8 Nov 1972	1200	Surface	169	150	17.83	3.00	0.17	1.1	0	0.20
15	Discharge Basin (A)	8 Nov 1972	1200	3 m	170	157	17.94	11.00	0.61	0.8	3.1	0.40
23	Intake Basin (B)	8 Nov 1972	1200	Surface	171	143	19.78	3.00	0.15	0.9	0	0.30
30	Intake Basin (B)	8 Nov 1972	1200	3 m	172	140	16.91	10.00	0.59	3.5	1.2	3.00
37	Sand Island Channel (C)	8 Nov 1972	1200	Surface	173	103	14.38	2.00	0.14	0.3	0.3	1.20
44	Sand Island Channel (C)	8 Nov 1972	1200	3 m	174	114	14.15	6.00	0.42	3.5	0	1.40

APPENDIX B. LARVAL FISH FROM MAY 11, 1972 TOWS (1/25 ALIQUOT)

Tow No.	Total No. of Fish	No. and Type of Fish Larvae
145	3	2 *Stolephorus purpureus* (Engraulidae) 1 Gobiidae
146	2	1 *Stolephorus purpureus* 1 Unidentified sp. (yolk-sac)
147	3	1 *Stolephorus purpureus* 1 Blenniidae 1 Unidentified sp.
148	5	4 *Schindleria* sp. (probably *S. praematurus*) 1 *Stolephorus purpureus*
149	12	8 *Stolephorus purpureus* 2 *Schindleria* sp. 2 Unidentified spp. (yolk-sac)
150	3	3 *Stolephorus purpureus*
151	4	2 *Stolephorus purpureus* 1 *Apogon brachygrammus* (Apogonidae) 1 Apogonidae (type 8)
152	3	3 *Stolephorus purpureus*
153	4	2 *Stolephorus purpureus* 1 *Apogon* sp.? 1 Unidentified sp. (in slender "sac")
154	5	3 *Stolephorus purpureus* 2 Unidentified spp. (yolk-sac)
155	6	3 *Stolephorus purpureus* 2 Carangidae 1 Unidentified sp. (only head remaining)
156	4	2 *Stolephorus purpureus* 1 *Apogon brachygrammus* 1 *Schindleria* sp.
157	14	2 *Stolephorus purpureus* 1 Carangidae 1 Gobiidae 1 Apogonid-like 6 *Schindleria* sp. 3 Unidentified spp. (two kinds of yolk-sac)
158	6	3 *Schindleria* sp. 1 *Apogon brachygrammus* 1 *Stolephorus purpureus* 1 Gobiidae (type 8A)
159	9	2 *Stolephorus purpureus* 2 *Schindleria* sp. 5 Unidentified spp. (two kinds: four enclosed in compressed sacs)

Tow No.	Total No. of Fish	No. and Type of Fish Larvae
160	12	1 *Stolephorus purpureus*
		6 *Schindleria* sp.
		1 *Apogon* sp.?
		1 Apogonid-like (type M-13)
		1 Mullid-like (Mullidae)
		2 Unidentified spp. (one in "sac"; one tail only)
161	16	2 *Stolephorus purpureus*
		1 *Apogon brachygrammus*
		7 *Schindleria* sp.
		1 Apogonidae (unidentified sp.)
		5 Unidentified spp. (four kinds: two Labrid-like yolk-sac larvae; three nondescript spp.)
162	13	1 *Abudefduf abdominalis* (Pomacentridae)
		3 *Stolephorus purpureus*
		3 Schindleriid? (damaged)
		1 *Apogon* sp.
		4 Apogonid-like
		1 Unidentified sp. (gut torn)
163	10	5 *Schindleria* sp.
		2 Carangidae?
		1 Gobiidae
		2 Unidentified spp. (damaged yolk-sac larvae)
164	7	2 Gobiidae
		1 *Stolephorus purpureus*
		1 *Schindleria* sp.
		2 Apogonid-like
		1 Unidentified sp. (cut in half)
165	11	1 Gobiidae (only head and shoulder remaining)
		1 Pomacentridae (type 12, head only)
		1 *Stolephorus purpureus*
		4 Apogonid-like
		2 Schindleriid? (yolk-sac larvae)
		2 Gobiidae (yolk-sac)
166	18	11 *Schindleria* sp.
		2 *Apogon brachygrammus*
		1 Pomacentridae (type 11?)
		1 *Stolephorus purpureus*
		1 Labrid-like (yolk-sac)
		2 Unidentified spp. (damaged)
167	12	9 *Schindleria* sp.
		1 *Stolephorus purpureus*
		2 Apogonidae
168	8	1 *Stolephorus purpureus*
		1 Gobiidae (type 8A)
		4 Apogonid-like
		2 Unidentified spp. (head, gut torn: yolk-sac)