

# PART II

## BIOLOGICAL INVESTIGATIONS

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edited by  
**Dorothy F. Soule**  
and  
**Mikihiko Oguri**

Published by  
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**University of Southern California**  
**Los Angeles, California 90007**

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**Marine Studies of San Pedro Bay, California**

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Marine Studies of San Pedro Bay  
Part II, Biological Investigations  
June, 1973

Preliminary Investigations of  
the Role of Cannery Wastes in  
the Los Angeles Harbor

An Introduction

by

Dorothy F. Soule  
and  
Mikihiko Oguri  
Allan Hancock Foundation  
University of Southern California



## Introduction

The fishing industry and the canneries associated with it have been located in Los Angeles Harbor since the turn of the century, and have represented a major economic resource for the local southern California Community. Since 1903, when albacore tuna was first canned experimentally, the volume of albacore landings in California has increased by a factor of over 170 times (Gruen *et al*). The industry has become, since the 1940's, a multimillion dollar force in the economy.

In addition, the products of the industry provide hundreds of thousands of pounds of an important high protein, relatively low cost human nutritional resource for a much larger consumer market. Byproducts of nutritional importance also include fertilizers, animal feed and pet food. The socioeconomic impact of the nutritional role of the byproducts is more difficult to evaluate because the secondary effects are far reaching.

In the present period, many industrial and commercial activities are being reevaluated, both from their prospectives as future resources and from present and future environmental impact. It becomes vitally important to examine both the beneficial and negative effects of the local cannery industry.

In a Los Angeles Harbor Commission session in 1971, T.M. Crehan, representing the canneries, issued the following statement on the economics of the industry:

"Since the turn of the century, the fishing industry has played a prominent role in the development of the Los Angeles Harbor. San Pedro and the Port of Los Angeles were known for years as the fishing capital of the world.

At the present time, the industry consists of the owners of approximately 50 commercial fishing vessels which have their home port here, the 500-600 crew members of these

fishing vessels, the 4 national canneries, and the nearly 6,000 persons employed in those canneries. In terms of dollars, the fishing industry means the following:

Payroll	25,199,361.00
Utilities	364,424.00
Steam	567,000.00
Land Rent to LA Harbor Dept.	216,201.00
Wharfage to LA Harbor Dept.	55,780.00
Inspection Fees and Business Licenses	120,038.00
City and County Taxes	695,755.00
Wetfish Purchased from San Pedro Fleet	4,375,700.00
Tuna Purchased from San Pedro Fleet	<u>5,098,537.00</u>
	36,692,996.00

These figures do not include those amounts paid for fish to vessels from San Diego, Port Hueneme, and other Southern California ports.

The fishing industry is important not only to the Harbor in an economic sense, but also to the entire Southern California area since it provides the economic base for almost 25,000 jobs in other industries."

For further analysis of the socio-economic aspects of the commercial fishing industry, see Gruen et al, 1972.

In earlier days, harbors were not only considered to be mechanical transport systems for boats and cargo but also served as giant sewers into which all manner of human and industrial wastes might be dumped, presumably for export to the adjacent unlimited seas. This was true for fish processing wastes as well. Only when workers in the area were sickened by the odors, and gas-

eous discharges, blackened paint and brightwork did economic pressure begin to be exerted for cleaning up the harbor. Gradually it became evident that there were also other pressures to make the harbor itself a living resource once again, and to strive for recreational and esthetic quality as well.

Although the fishing industry has been located in Los Angeles harbor since the turn of the century, little consideration has been given to the role played by the wastes from the canneries in the marine environment. Rather, attention has been directed to the economic role of the products and byproducts of the industry.

Estimates of the amount of waste in the cannery processes range from 30% to 80% of the whole fish. The amount depends on the species of fish, as well as the equipment available for, and the economics of removal of all possible potential byproducts.

The effect of the remaining effluent on the ecology of receiving waters has not been well evaluated. Nakatani *et al* (1971) reported an increase in scavenger fishes, sea urchins and anemones, with a decrease in other animals, in a salmon processing effluent in Alaska.

The purpose of the present study is to investigate the role of the cannery effluent on the ecosystems of adjacent Los Angeles Harbor waters.

Funding for the study was provided in part by the Tuna Research Foundation, representing local canneries; the NOAA Office of Sea Grant, Department of Commerce, Grant No. 04-3-158-45; and the Allan Hancock Foundation, University of Southern California.

#### Area Description

The canneries are located in the area of Fish Harbor in Los Angeles Harbor (Figure 1).

According to Matson (1948) demand for tuna had increased with the start of World War I, when a fire destroyed the canneries in East San Pedro. The southwest end of Terminal Island had previously been filled in and extended to what was originally Deadman's

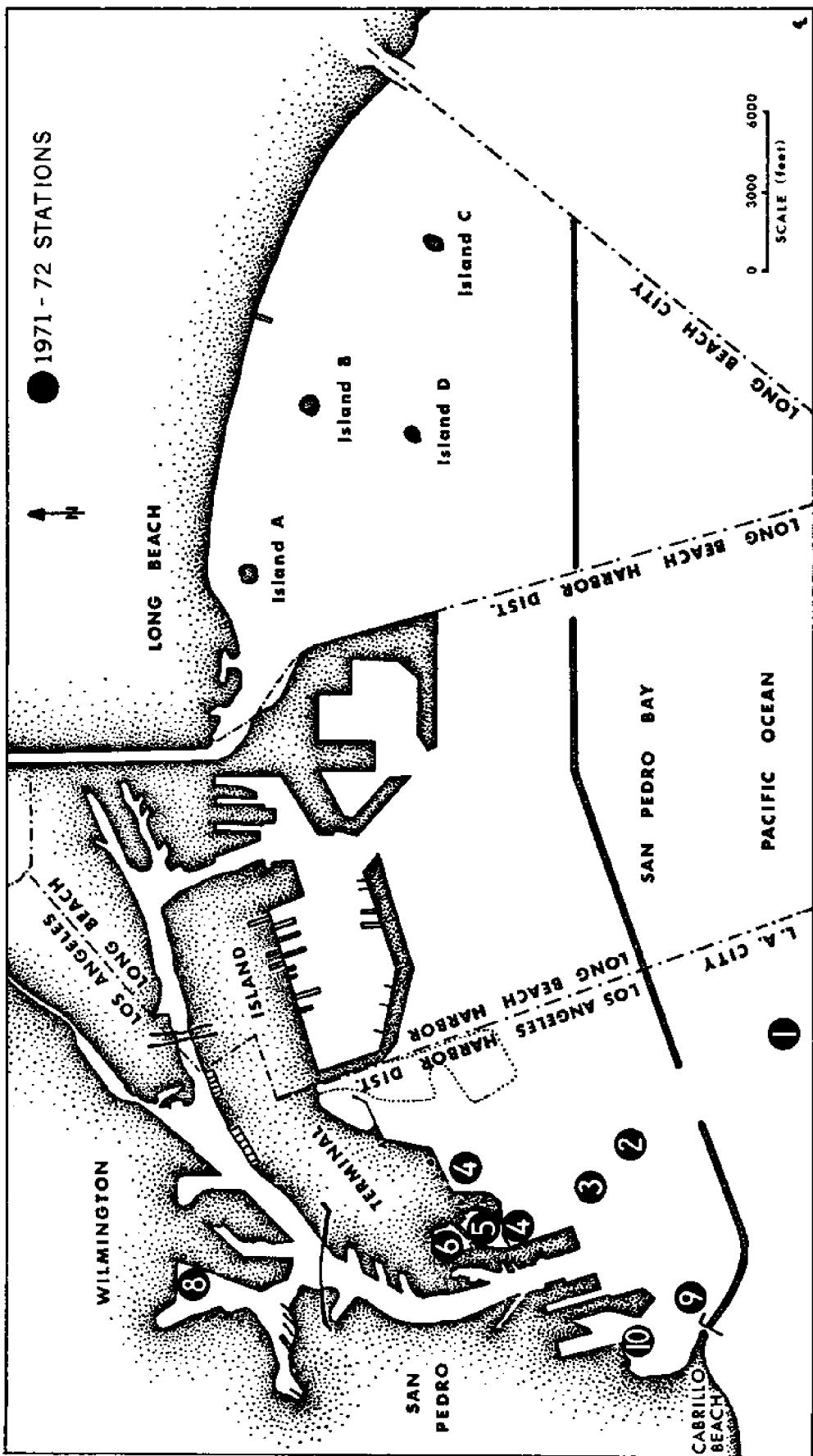


FIGURE 1

Island, the remains of which now form part of Reservation Point. A seawall then was constructed to enclose some thirty acres of water south and east of the fill. A wooden wharf about 2000 feet long was built across the north side and the area behind was filled with dredgings. A low breakwater was built along the southerly side enclosed by the seawall. The land back of the wharf extending to a railroad track and street, was leased to fish canneries for 30 years at an annual rental of three cents per square foot. Canners were permitted to build unloading equipment in front of the wharf to supply their plants.

Cannery wastes, for many years, were dumped into Inner Fish Harbor, along with pumpings from boat holds, and human wastes. In 1964, discharges were relocated and piped to two outfalls on the east side of Pier 301. Also in the area, approximately 1500 feet eastward, is the outfall for primary treated sewage from the Terminal Island sewage treatment plant. Only the sewage treatment plant maintains records of the rate of flow of their effluent; this flow averages about two million gallons per day of fresh water-carried sewage from which the solids have been removed. The cannery effluents fluctuates in volume, and monthly estimates are provided by the industry to the Regional Water Quality Board (see Table 1; pers. comm. Frank Steiger, head, Los Angeles Harbor Department Testing Laboratory).

The area receiving the effluents is shallow, and the bottom slopes gradually from shore to a depth of approximately 20 feet, forming a broad shallow shelf. Dumping has been permitted on the shelf, making the bottom irregular. Sediments range from an organic ooze to broken shell and rocky patches which shift about under water circulation.

#### Circulation Patterns

The only published records of water movement in the outer Los Angeles - Long Beach Harbor area are from a drogue study conducted on June 13-14, 1972 (Soule and Oguri, 1972). The patterns observed

Cannery	Apr 72			May 72			June 72			July 72			Aug 72			Sept 72			Feb 73			Mar 73			Apr 73		
Cal Marine (now Pan Pacific No. 2)	0.900	1.060	0.870				0.810			0.835			0.530			0.768			0.670			0.882					
Pan Pacific No. 1	1.368	1.135	1.207				1.130			1.058			1.080			1.119			0.991			1.230					
Starkist No. 1	1.100	1.400	1.100				3.600			1.100			3.200			1.100			1.100			1.100					
Starkist No. 4	3.200	3.600	3.200				2.800			3.200			2.800			2.800			1.200			3.200					
Van Camp	4.00	5.00	5.00				4.00			4.500			4.00			0.330			3.000			3.500					

Table 1. Estimated Volume of Cannery Effluent (millions of gallons)

during that time suggest that the outfalls lie beyond the edge of a large tidal gyre extending from Angel's Gate to Queen's Gate. Surface waters in general showed the effects of afternoon winds. Drogues carried into the outfall area tended to remain there, indicating a limited exchange of waters from the effluent waters with contiguous waters.

Wind driven circulation patterns are of importance since the cannery effluent contains a high percentage of protein or protein breakdown products which coagulate or flocculate in the sea water. Most of this cream colored material remains floating on the surface, as shown by measurements of water transparency, which indicate clearer water below the surface. Although some of the material sinks to the bottom, it does not result in a significant build-up of bottom organic ooze; perhaps it is rapidly broken down by the aerobic and anaerobic bacterial populations in the bottom muds.

Dye studies on the diffusion rate of the effluent and on the microbiology of the area are discussed elsewhere in this report (Juge; Foxworthy) and substantiate the previous circulation pattern observations.

Aerial photographs of the effluents under various weather conditions show differing dispersal patterns. The two cannery effluents appear to merge into a common pool, which is carried north-easterly by incoming tidal flow under low wind conditions. Flow from the submerged sewer outfall appears as a clear boil of water, with the cannery effluents separating on either side of it and merging beyond it as it moves toward the Navy mole. On windier days, the discolored cannery effluent can be seen as streaks rather than as a pool. With succeeding falling tide and the usually prevailing southwest winds, the effluent becomes diffused and moves toward Queen's Gate or Angel's Gate. On following rising tide, un-dispersed effluent may enter Fish Harbor or the Main Channel. Under northeasterly winds such as the Santa Ana winds, the effluent may not reach the sewer outfall, but moves instead toward Angel's Gate. It may be carried outside the breakwater and move westward in the weak counterclockwise gyre (Jones, 1972). Or, the effluent

may be carried into Fish Harbor, the Main Channel and toward Cabrillo Beach before it is finally broken down biologically and dispersed.

The Allan Hancock Foundation has maintained an environmental quality study in Los Angeles Harbor since 1971, in cooperation with the University of Southern California Sea Grant Program, with local industries and with public agencies. Participants have included the Los Angeles and the Long Beach Harbor Departments, the Tuna Research Foundation and Pacific Lighting Service Company. Preliminary reports from the environmental quality studies outlined the techniques employed (Soule and Soule, 1971; Abbott, et al, 1973).

The basic stations maintained for experimental purposes during 1971-72 are presented in Table 2, and on the Map of the Los Angeles Harbor (Figure 1). Multiple parameters were sampled at these stations. As indicated in Table 2, by asterisk, settling racks were maintained at 8 stations. Wet biomass and identifications of species was done on a monthly basis, in order to determine the quality or living potential of the harbor waters above the polluted bottoms. Comparisons of biomass are shown in Figures 2 and 3. In all cases, the peak weights were caused by populations of one species, a large, white, sausage shaped tunicate, Ciona intestinalis. The species seems to flourish in warmer, shallow waters and to tolerate pollution fairly well.

The productivity of the phytoplankton was measured at the same stations, using Carbon 14 isotopes to measure the amount of photosynthesis carried on by these microscopic plants. It is typical that cyclic blooms of phytoplankton occur near the cannery effluents. Oxygen levels reach supersaturation (12-16 ppm instead of the normal saturation of 8-9 ppm) as the bloom develops. When the nutrient level drops suddenly or the plankton generation dies, aerobic bacteria begin to multiply (see Juge, 1973), rapidly depleting the oxygen supply. If the loading is sufficient, oxygen will drop to zero, and anaerobic bacteria in the muds begin production of sulfide.

TABLE 2  
HARBOR PROJECT STATION LIST  
OUTER LOS ANGELES HARBOR (Chart No. 5148)

<u>Log Book Designation</u>	<u>Chart Designation</u>	<u>Station Description</u>
*1	BW "LA" Bell	3/4 knots SE from L.A. Light
*2	R 4	1/2 knots N of L.A. Light
*3	R 2	1/2 knots S of Fish Harbor Entrance
4		Entrance to Outer Fish Harbor
5	R N "2"	Center of Outer Fish Har- bor adjacent to Channel Marker
*6		Inner Fish Harbor
*7	W OR S "C"	Sewage and Cannery out- falls Area
*8		West Basin, pier no.
*9	W OR NUN (not marked on Chart No. 5148)	Nun Buoy off Cabrillo Beach
*10		Velero Dock in Watchorn Basin adjacent Berth 45

\* Indicates Settling Rack locations.

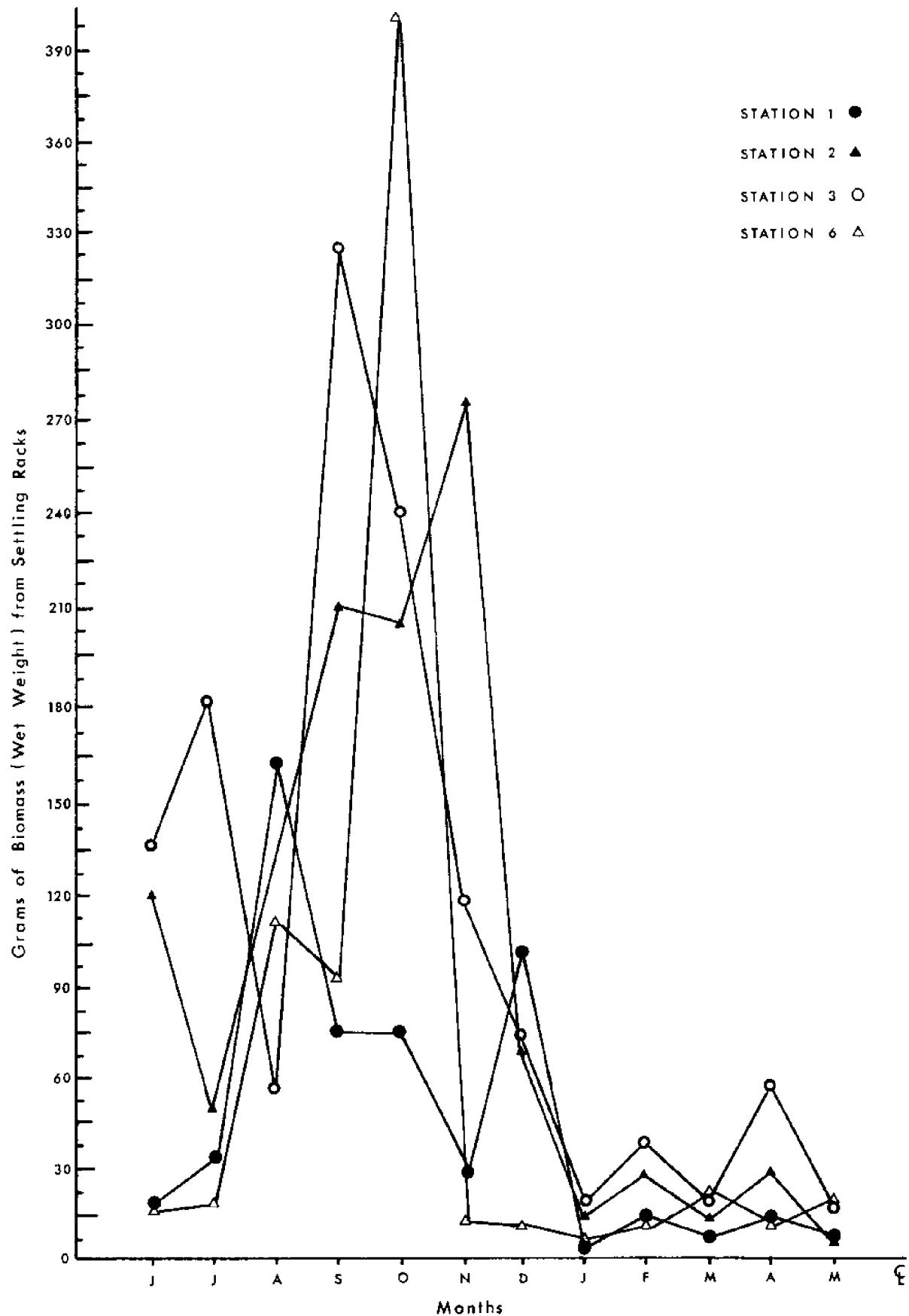


FIGURE 2  
COMPARISON OF SETTLING RACK BIOMASS

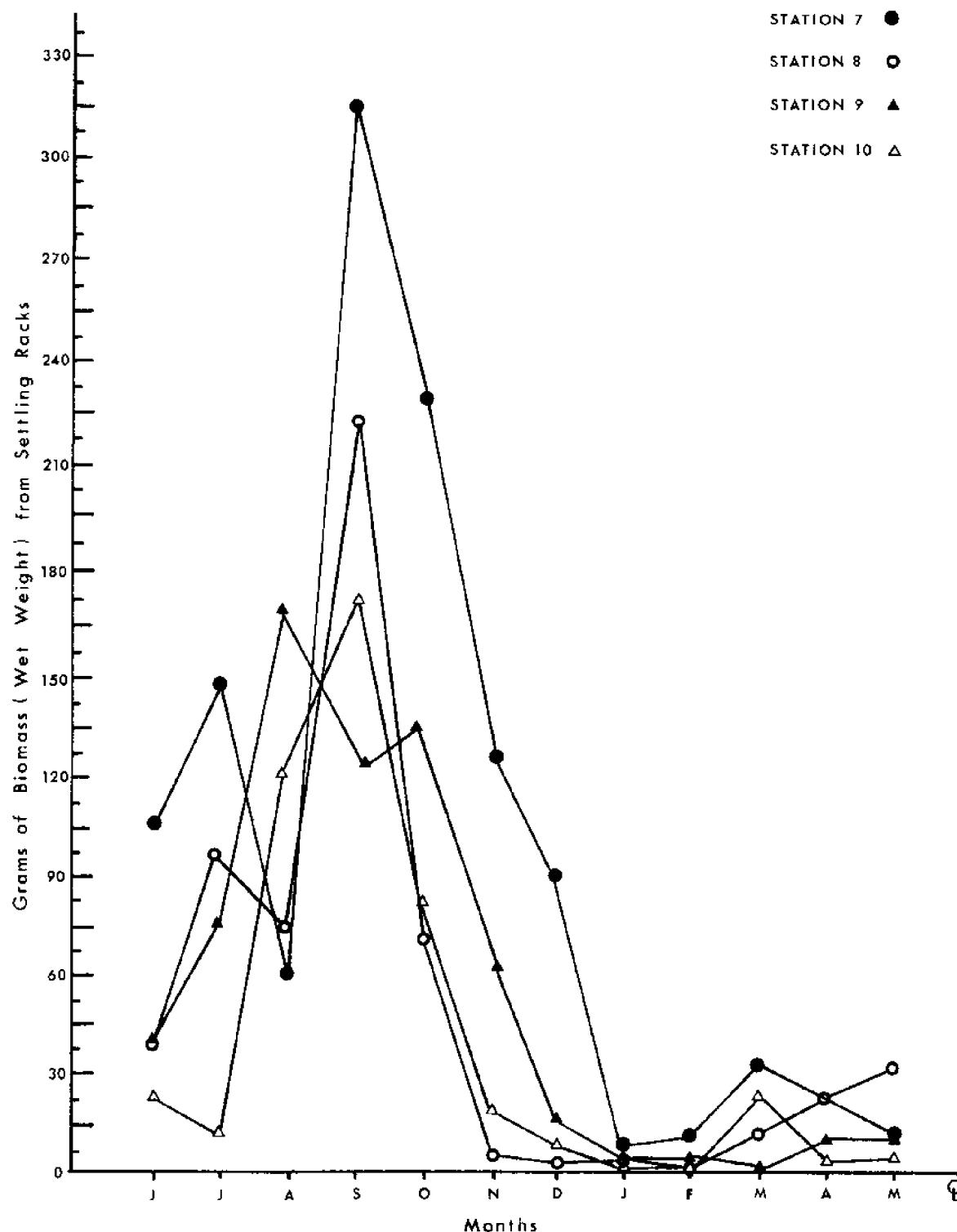


FIGURE 3  
COMPARISON OF SETTLING RACK BIOMASS

In Figure 4, the productivity curves for five stations are shown. The peak at Station 2, buoy R4 in the main channel indicates that there is probably an inhibitory effect area or a latent period involving bacterial breakdown of cannery effluent near Station 7, the closest to the outfalls. Apparently, circulation, plus the continuing subsequent alteration of the effluent carries the nutrients in most usable form to the Station 2 area.

Although the area is undoubtedly very productive, there are questions as to the quality and rates of this production. Eutrophication such as is seen in algae blooms in fresh water lakes, can also occur in semi-enclosed marine waters. Red tide blooms, green, and blue tide blooms can occur. In August, 1972, a green tide bloom was observed at the entrance of Fish Harbor. Microscopic examination showed it to be a protistan euglenoid, similar to Eurtreptia, which is associated with heavily organic wastes. This may indicate the effects of nearby sewage effluent, or possibly the illegal flushing of marine toilets aboard the small boats anchored in Outer Fish Harbor. Local Red tide organisms are not generally toxic but can kill other organisms by depleting the water of dissolved oxygen or by clogging the gills mechanically of filter feeders such as the mussels, Mytilis.

Other parameters being sampled include plankton pigments, settling volumes and species identifications, and benthic (bottom-living) organisms. Physical water quality measurements of temperature, salinity, oxygen and pH are taken and some nutrient chemistry performed. Results are presently being analyzed and will be reported in future studies.

A further indication that the enriched harbor waters alter the environment for certain of the fishes are presented in a summary of research by Schafer and Swann, which follows this paper. Further work would be needed to ascertain the significance of the observed changes in anchovy free amino acid patterns. Nothing is known about the distance traveled by individual anchovies within the harbor, nor about the degree to which they move in and out of the harbor.

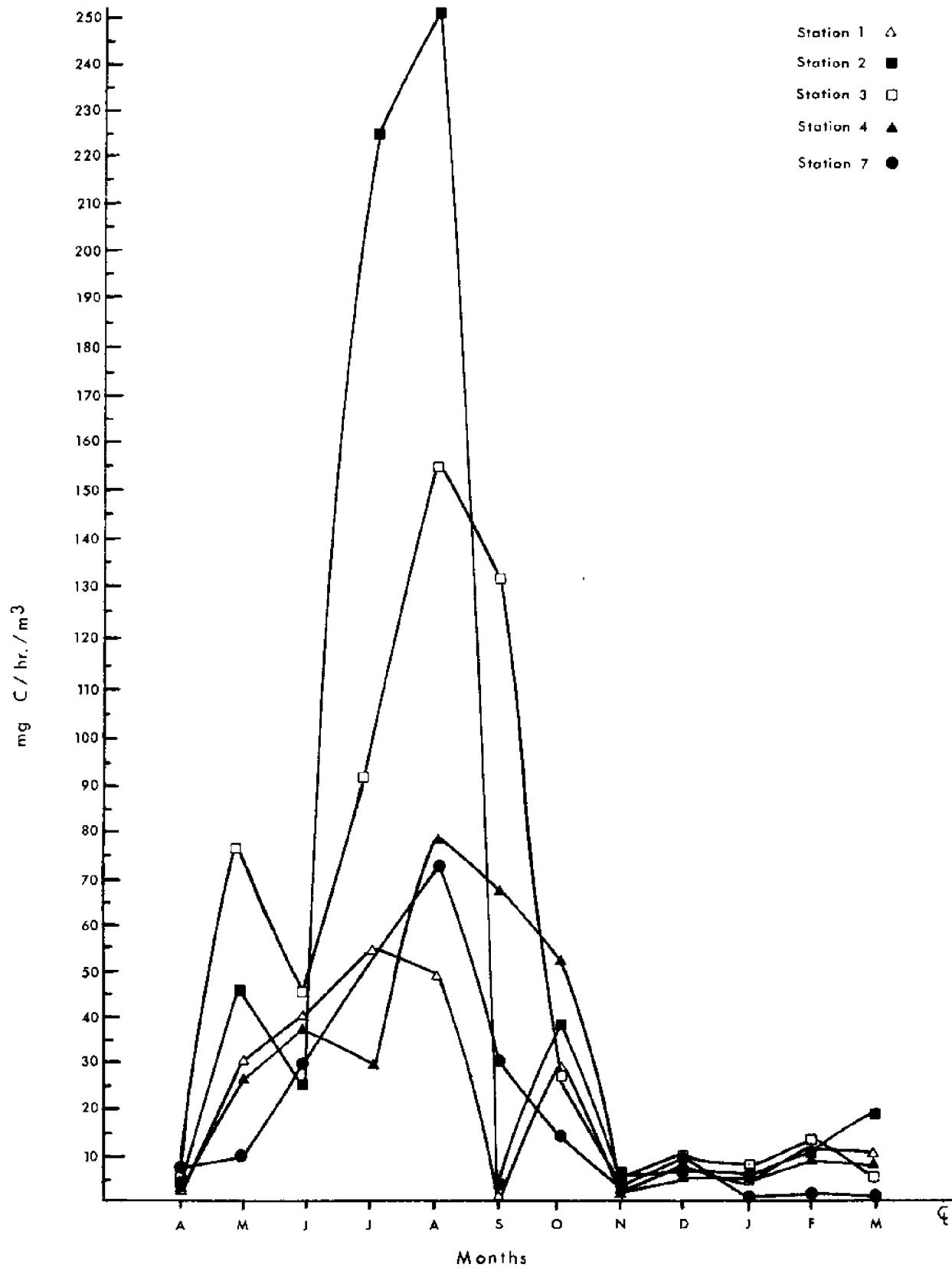


FIGURE 4

COMPARATIVE PRODUCTIVITY MEASUREMENTS  
IN LOS ANGELES HARBOR

Catches by the bait boats, presently being surveyed, indicate that there may be an area of inhibition in the immediate vicinity of the cannery outfalls, as is suggested by the biomass and productivity curves (Figures 2, 3 and 4). There are indications that the anchovies move away from the area when the oxygen is low and also when it is excessively high, during plankton blooms. Weather conditions may exert influence as well, for anchovies apparently disappeared from harbor catches prior to heavy winter storms and subsequent rainwater runoff. They also were not caught in the harbor near the end of the season when the Davidson Current brought warmer southerly waters into the area, but reappeared just after water temperatures dropped.

Examination of the amino acid pool in bottom feeding fish taken inside the harbor, as compared with the same species taken outside the harbor, would perhaps offer further comparative data. It was difficult to obtain an adequate supply of intact, healthy fish from inside the harbor. Easily caught smelt all showed signs of reduced vitality and body lesions. Chamberlain (1973) found a high incidence of pathological conditions in harbor trawl fish.

Chamberlain however indicated that, in fishes of the same species, those from inside the harbor were heavier than those taken outside the harbor, per unit of body length. This would suggest that the food supply might be better in the harbor, if the age classes of the fishes are the same.

Comparison of fish trawl catches by Chamberlain in the harbor and by Stephens (1973) outside the harbor show that the fish population inside the harbor is at least equal to, and perhaps more dense than, at any of the offshore localities along the coast examined by Stephens.

#### Summary

The results of our studies indicate that the harbor waters are highly productive at every trophic level monitored. Some of the factors potentially regulating productivity are discussed.

Studies presently underway are designed to further define the inter-relationships between the biotic and abiotic parameters in the harbor.

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Marine Studies of San Pedro Bay  
Part II, Biological Investigations  
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Free Amino Acid Variations in the  
Anchovy, Engraulis mordax  
from the Los Angeles Harbor

by

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and

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### Introduction

Free amino acids within an organism are an immediate reflection of the protein metabolism of that organism. Amino acids are taken from or added to this pool in a definite manner as a result of the normal enzymatic processes associated with maintaining homeostasis within the animal. Previous work (Schafer, 1966, 1968) with both invertebrates and fish has shown that when environmental conditions change the free amino acid patterns of these organisms are altered.

The present study was undertaken to determine whether or not the conditions within the Los Angeles Harbor were such that a change was being affected in the anchovy which is present there for an undetermined period of time.

### Materials and Methods

Samples of the anchovy, Engraulis mordax, were collected from three locations within the Los Angeles Harbor; a control sample was taken from five miles offshore, northwest of the Long Beach lighthouse. All samples were quick-frozen. White muscle tissue was excised over dry ice and lyophilized without intermittent thawing. Dry weights were determined and the free amino acids extracted with 70% cold ethanol. Each sample was composed of pooled adult specimens, 12 to 15 cm. in length, from the same catch. Sample 1 was extracted from 0.9863 gm., dry weight, sample 2 weighed 0.7191 gm. and sample 3, 0.8545 gm. The control sample was derived from 0.4800 gm.

Analyses were made using a Technicon Sequential Multiple Auto-analyser with resin Type C chromo beads. Mimhydrin was used in the colourimeter.

### Results

The free amino acids present in each sample extracted from the white muscle tissue of the anchovies is given in the accompanying table. Results are recorded both in micro moles/liter and in percentages of composition. The control sample was found to contain twenty-one free amino acids; samples 1 and 2 from the Los Angeles Harbor waters contained twenty-two free amino acids each while sample 3 contained twenty-three different amino acids. Aspartic acid was absent in the control sample but present in the others. Cystine was absent from the control sample and from sample 3 but present in the other two samples. Citrulline was found to be present in sample 3 but absent from all others, including the control. Quantitative differences are evident in the case histidine where the level in the control sample is almost double that of each of the other three samples. Quantitative differences also occur in taurine, glutamic acid, alanine and lysine, each of these being less in the control than in the other three samples.

### Discussion

That three amino acids, namely, aspartic acid, asparagine and cystine are lacking from the controls but present in one or more of the samples taken from the Los Angeles Harbor waters indicate that the metabolism of the anchovy differs when found in the environment provided by those waters. The significance of this change is not evident but it is indicative of either an interruption or alteration in metabolic pathways. It can be deduced that either a breakdown of proteins is occurring which is releasing these amino acids into the amino acid pool more rapidly than they can be utilized, or that protein synthesis, which in the controls is occurring at a rate which removes these amino acids from the pool, has been either reduced or stopped.

The quantitative difference which occurs in the case of histidine where the level of this amino acid in free form in the controls

is almost twice that of each of the other three samples may be indicative of physiological stress in the latter. It is known that histidine readily converts to glutamic acid which in turn becomes a direct energy source. If the anchovy, upon entering the waters of the Los Angeles Harbor, is placed in an environment resulting in stress it would be expected that a greater amount of energy would be expended to meet this stress. Such a demand could result in a greater conversion of histidine to glutamic acid and subsequent utilization of the latter to supply this needed additional energy. If the anchovy is a permanent resident in the harbor rather than a temporary visitor, metabolic pathways may have been permanently altered.

All of the above variations, plus those of lesser magnitude shown in Table I, are evident that changes do occur in specimens of the anchovy, Engraulis mordax, found in the Los Angeles Harbor area.

TABLE I

Amino acid	Control	Sample 1		Sample 2		Sample 3		
	umol/l	%	umol/l	%	umol/l	%	umol/l	%
Taurine	0.50	1.6%	0.223	3.2%	0.638	5.9%	6.60	17.9%
Aspartic Acid	-	-	0.045	.64%	0.015	.14%	0.20	.5%
Hydroxy-Proline	-	-	-	-	-	-	-	-
Threonine	0.60	1.9%	0.238	3.4%	0.361	3.3%	0.60	1.6%
Serine	0.50	1.6%	0.260	3.7%	0.290	2.7%	0.60	1.6%
Asparagine	-	-	0.013	.18%	-	-	-	-
Glutamic Acid	0.20	.64%	0.205	2.9%	0.217	2%	0.50	1.36%
Glutamine	0.10	.32%	0.084	1.2%	0.051	.47%	0.20	.5%
Proline	0.60	1.9%	0.166	2.3%	0.270	2.5%	0.60	1.6%
Glycine	1.50	4.8%	0.552	7.9%	0.673	6.2%	1.90	5.2%
Alanine	2.00	6.4%	0.411	6.7%	1.752	16%	3.30	9.0%
Citrulline	-	-	-	-	-	-	0.10	.27%
L Amino N-Butyric	0.20	.64%	0.013	.18%	0.031	.29%	0.40	1.09%
Cystine	-	-	0.128	1.8%	0.172	1.6%	-	-
Valine	0.70	2.2%	0.123	1.8%	0.287	2.6%	1.0	2.7%
Methionine	0.20	.64%	0.074	1.1%	0.683	6.3%	0.30	.8%
Isoleucine	0.40	1.28%	0.105	1.5%	0.137	1.3%	0.40	1.1%
Leucine	0.50	1.6%	0.186	2.6%	0.228	2.1%	0.60	1.6%
Norleucine	-	-	-	-	-	-	-	-
b-Alanine	-	-	-	-	-	-	-	-
b-Amino	-	-	-	-	-	-	-	-
Tyrosine	0.10	.32%	0.051	.73%	0.049	.45%	0.10	.27%
Phenylalanine	0.10	.32%	0.052	.74%	0.046	.42%	0.20	.5%
Tryptophane	0.10	.32%	-	-	-	-	0.10	.27%
Ornithine	0.10	.32%	0.038	.54%	0.031	2.9%	0.10	.27%
Lysine	0.60	1.9%	0.362	5.15%	0.993	9.2%	1.70	4.6%
Histidine	20.00	70%	2.414	37.8%	3.548	36%	15.40	46%
Methyl Histidine 1	0.00	-	-	-	-	-	-	-
Methyl Histidine 3	0.30	.95%	-	-	-	-	0.20	.5%
Arginine	0.10	.32%	0.049	.70%	0.040	.32%	0.20	.5%

Free amino acid content of white muscle tissue of specimens of Engraulis mordax taken from within the Los Angeles Harbor area compared with that of specimens taken from waters outside the harbor area.

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The Roles of Microbial Activity  
in the Harbor Ecosystem

by

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and

Gail Griest  
Immaculate Heart College



### Abstract

Dye-organism diffusion studies were made to determine water circulation in the area of the cannery and domestic outfalls.

Surface water samples were obtained monthly from ten stations in the Los Angeles Harbor between July, 1972 and March, 1973. Biochemical Oxygen Demand (BOD) determinations, standard plate, and coliform counts were made on all samples. BOD values for samples taken from the area of the cannery outfall reflected the level of waste introduced into the effluent. Standard plate counts ranged from  $6.9 \times 10^2$  to  $2.2 \times 10^7$ . The highest bacterial counts were obtained from samples taken from areas influenced by material from the cannery effluent. The fluctuation present in the counts from station 7 indicate that the effluent may be either beneficial or detrimental depending upon the amount present in the receiving waters. Coliform counts ranged from being always negative at Station 1 to being always positive at Station 4 and 7. At the other stations in the study the counts varied.

## Introduction

Periodic episodes of biological stress have occurred in the Los Angeles Harbor in which dissolved oxygen content dropped from normal to near zero levels. These episodes have been linked in some cases with the processing of unrefrigerated anchovies by the canneries, but they also appear to have a cyclic relationship to severe Red Tide blooms as well as to seasonal changes in water temperature.

The excessively high bacterial counts obtained during the October-November, 1971 episode indicated that a potential health hazard might exist. At this time preliminary investigations were made under emergency funding by the USC Sea Grant Program. Cultures in several types of common media revealed the presence of large numbers of aerobic, anaerobic, and facultatively anaerobic organisms. Sea water cycled for unloading fishing boats contained bacterial counts in excess of 7 million per milliliter, (Soule and Oguri, personal communication). The process water which reaches the cannery outfall with gross solids removed, mixes with the effluent from a primary treatment sewer outfall in an area with limited circulation (4). Although the high protein content (2) of the cannery effluent would support bacterial growth, it might result in a selection of a few species to the exclusion of others. The high protein content may also protect non-marine species from the ultraviolet effect as well as the otherwise antimicrobial action of the marine environment. The latter is particularly important in the case of the cannery effluents because of the close proximity of the domestic sewer outfall of the Terminal Island primary treatment plant. This situation has public health significance because under certain tide and weather conditions this water is carried back into Fish Harbor (4). It also could be a source of danger for low income minority group residents of nearby San Pedro who regularly fish in these waters.

Microbial activity is the first step in the conversion of the

harbor ecosystem. These conditions along with the fact that no bacteriological study has been made of the waters outside the canneries indicated the need for an investigation of both the marine microbiology and the clinical microbiology of the harbor area. Therefore, this study was initiated in June, 1972.

#### Materials and Methods

##### Dye Diffusion and Effluent Dilution

A study of the circulation patterns of the water in the area of the cannery and sewer outfall is in process. Rhodamine B dye solution and a culture of Bacillus subtilis var. niger were introduced continuously into the cannery system at the pumping station. The dye-organism plume was sampled periodically from the time of its appearance at the outfall until the dye-organism waste field dispersed. This procedure was repeated for the sewer domestic outfall using rhodamine B dye and a culture of Serratia indica. Dye-organism studies were conducted by Dr. James Foxworthy who acted as the consultant for this work.

##### Collection of Water Samples

Surface water samples for bacteriological studies were obtained aseptically with sterile BOD bottles secured with one piece of string around the neck and another piece secured to the stopper by which it could be removed at the time of filling. The bottle and strings were packaged and autoclaved so that both remained sterile in the area lowered into the water. Samples were obtained by this method from the deck of the research vessel Golden West. Water samples for Biochemical Oxygen Demand (BOD) determinations were obtained according to standard methods concomitantly with each bacteriological sample.

### Cannery Effluent and Oxygen Demand

Biochemical Oxygen Demand (BOD) determinations were made on all samples using a modification of the method as given in "Standard Methods for the Examination of Water and Wastewater" (1) in that sea water, instead of distilled water, was used for dilution. A series of experiments were run which indicated that a seed culture was not required. Samples were incubated at 20°C for 5 days.

### Aerobic, Heterotrophic Organisms

Standard plate counts were made according to the procedure given in "Standard Methods" with the exception of substituting sea for distilled water in the medium.

### Fecal Indicator Organisms

Total coliform counts were made according to the one-stage membrane filter technique recommended in "Biological Analysis of Water and Wastewater" (3) using MF-Endo Broth (Difco) as the substrate.

Counts for fecal streptococci were initiated in March, 1972. A membrane filter technique (3), using KF Streptococcus Agar (BBL) as the substrate, was used for this study.

## Results and Discussion

### Dye Diffusion and Effluent Dilution

Dye diffusion data were submitted by Dr. James E. Foxworthy and are incorporated into this report as an Appendix. During the period of favorable weather conditions four dye-organism studies were made. Although the dye-organism studies were too few to provide good statistical data, diagrams of the location and shape of

the dye plumes does give information as to the fate of the effluent during a period after the dye is introduced at low tide, and as to what happens to the plume (water mass) when the dye is introduced at high tide (Figures 1-6). From these studies, as well as the previously mentioned drogue studies (4), it is evident that water in this area has a very limited circulation. Continuing study will seek to determine the extent of wind effect on each phase of the tide cycle. This will also increase the information concerning the dilution and dispersion of the dye-organism tag so that conclusions can be statistically supported.

#### Collection of Water Samples

Surface water samples for bacteriological examination and BOD determinations were obtained from nine stations (Figure 7) in the Los Angeles Harbor from July, 1972 through March, 1973. Samples were obtained from a tenth station from October, 1972 through March, 1973.

#### Cannery Effluent and Oxygen Demand

The results of BOD determinations are recorded in Table 2. BOD values for stations 1,2,3 (with one exception), 5 (one exception), 6,7,8,9, and 10 were always lower than the available dissolved oxygen (DO) present at the time samples were taken. Dissolved oxygen values were low periodically at stations 4,5, and to a lesser degree at stations 6 and 8. At station 4 in three instances the BOD value exceeded the DO value but only by a slight amount. As this situation was reversed in the sample of the following month it is doubtful that this was enough to put the area under significant stress as far as oxygen depletion was concerned. At station 7 there was a markedly different situation. In this area the BOD value always exceeded the DO value considerably. The fluctuation in these values can be accounted for when the BOD values for the plant effluent are examined (2).

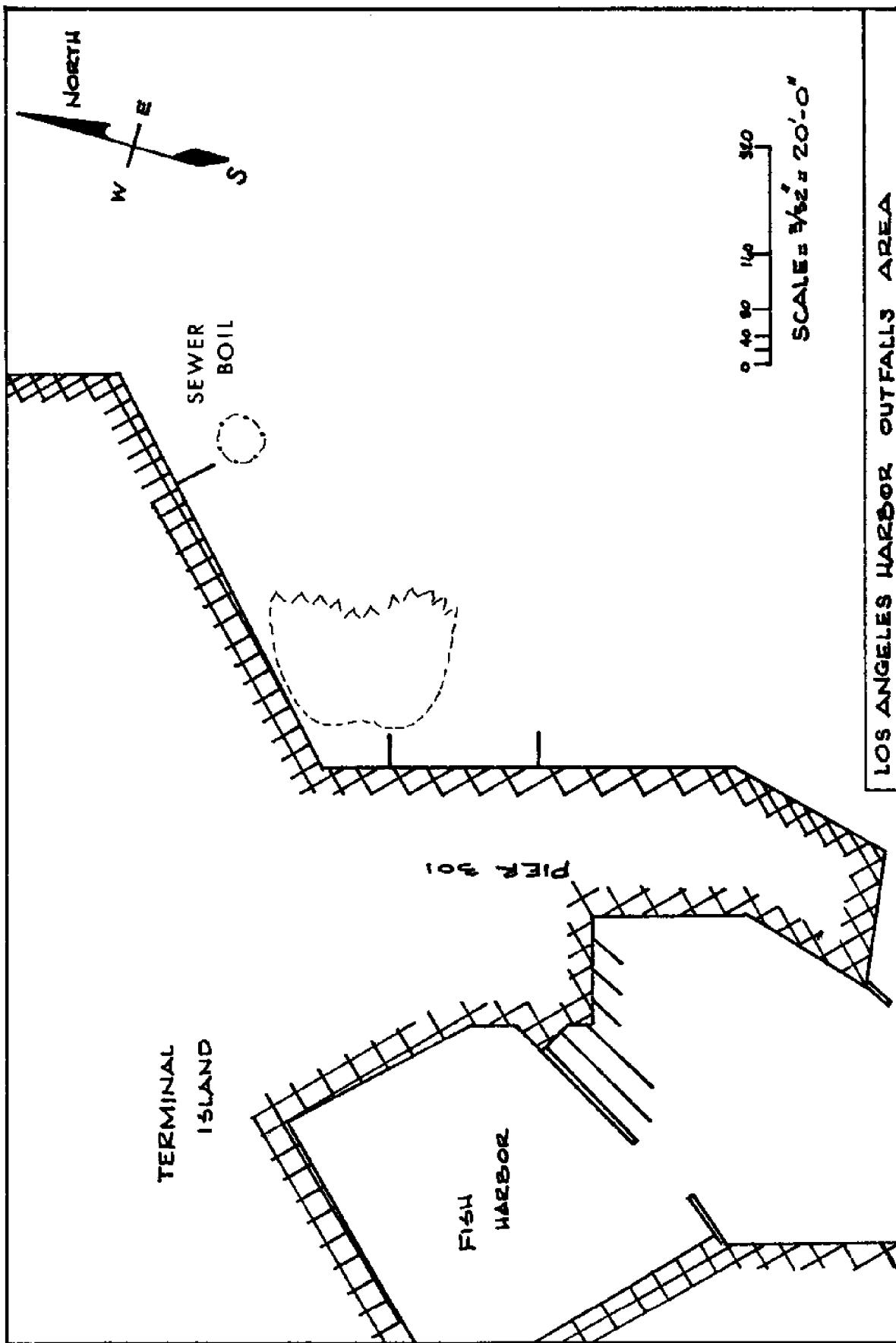


FIG. 1. DYE MOVEMENT, 17. July. 1972. --- 1245

LOS ANGELES HARBOR OUTFALLS AREA

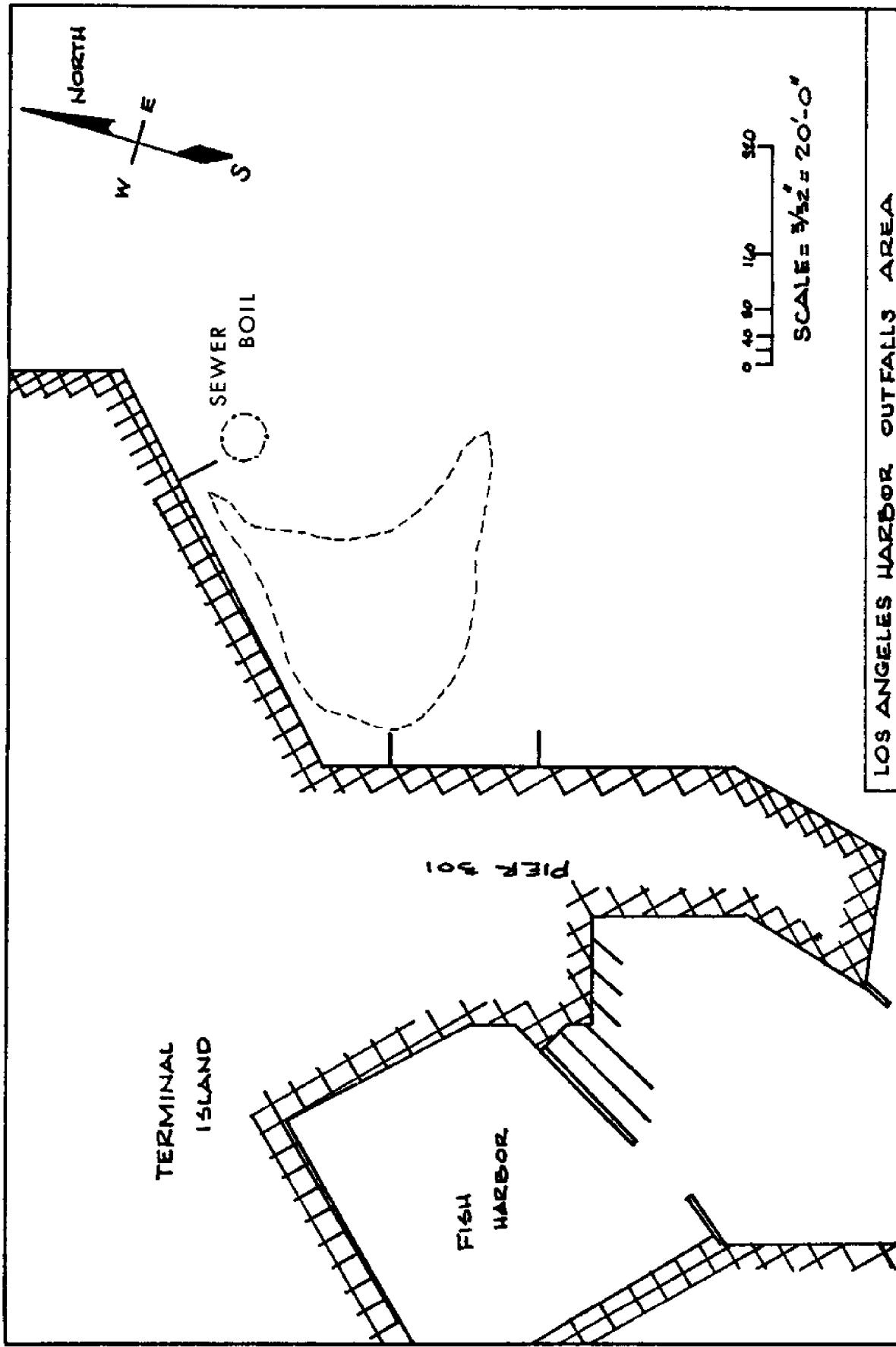


FIG 2 - DYE MOVEMENT. 17 July 1972. ---- 1345

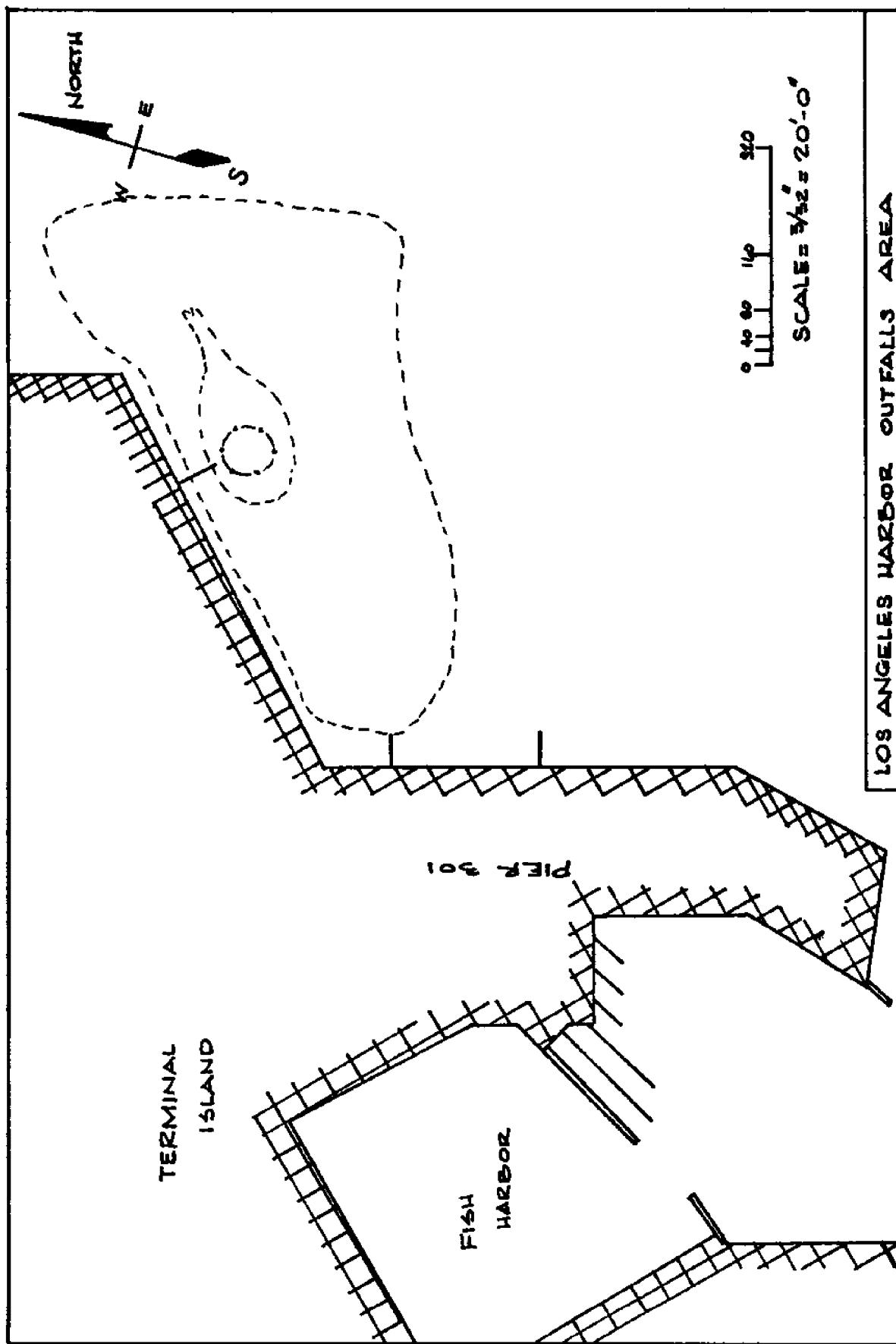


FIG. 3 - DYE MOVEMENT, 17 JULY 1972, --- 1420

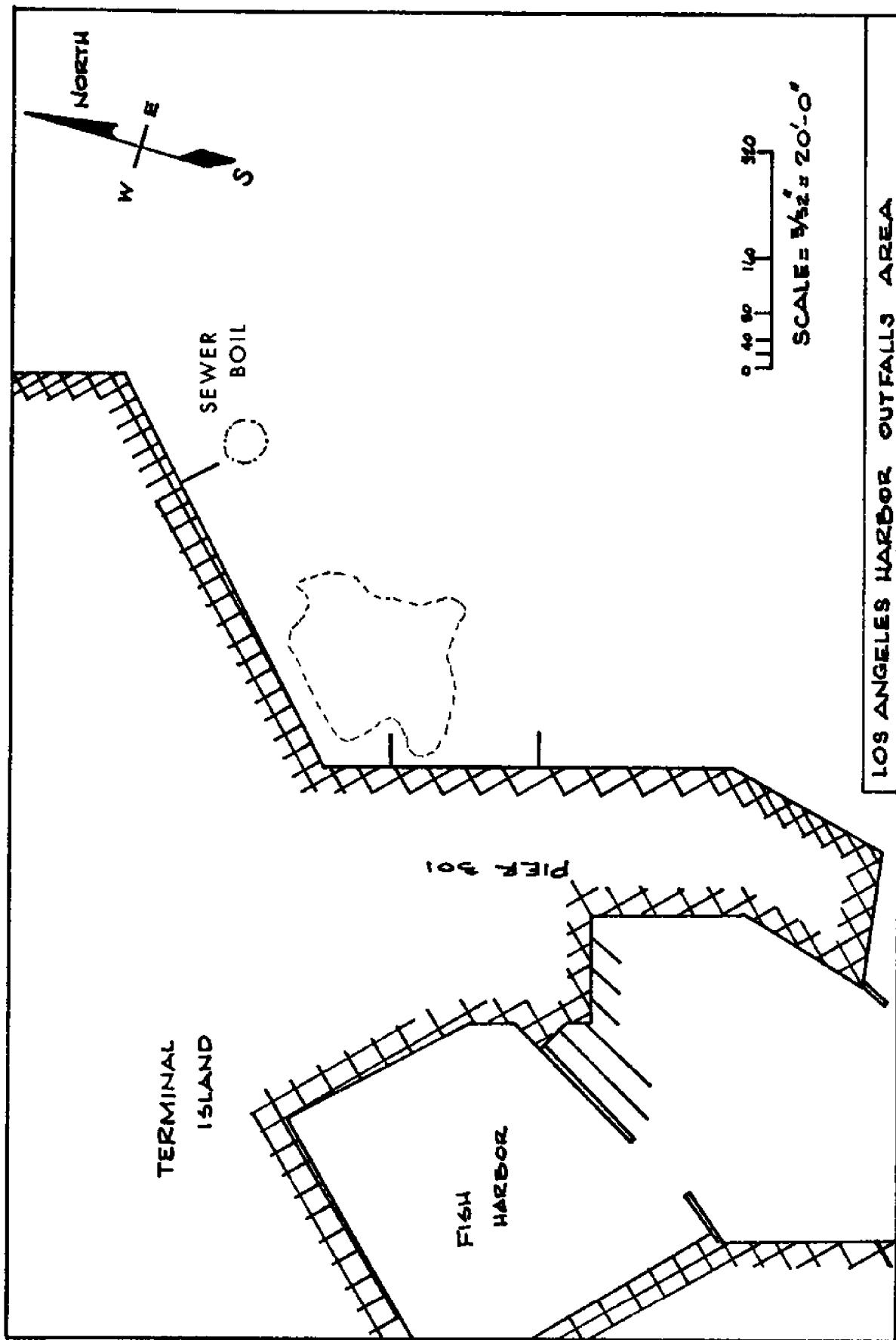


FIG. 4 - DYE MOVEMENT, 15. Aug. 1972, --- 1100

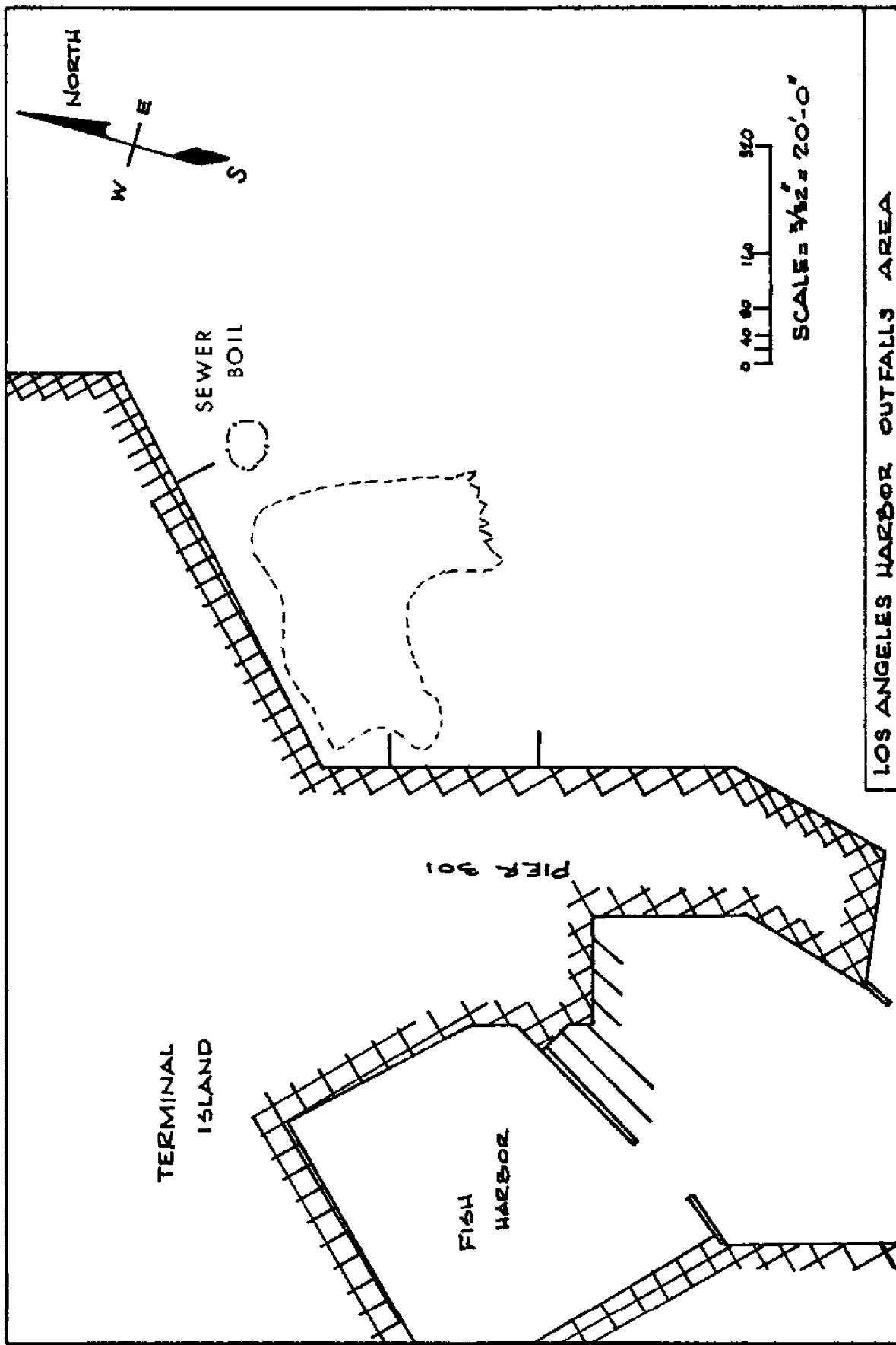


FIG. 5 - DYE MOVEMENT, 15.Aug.1972, --- 1200

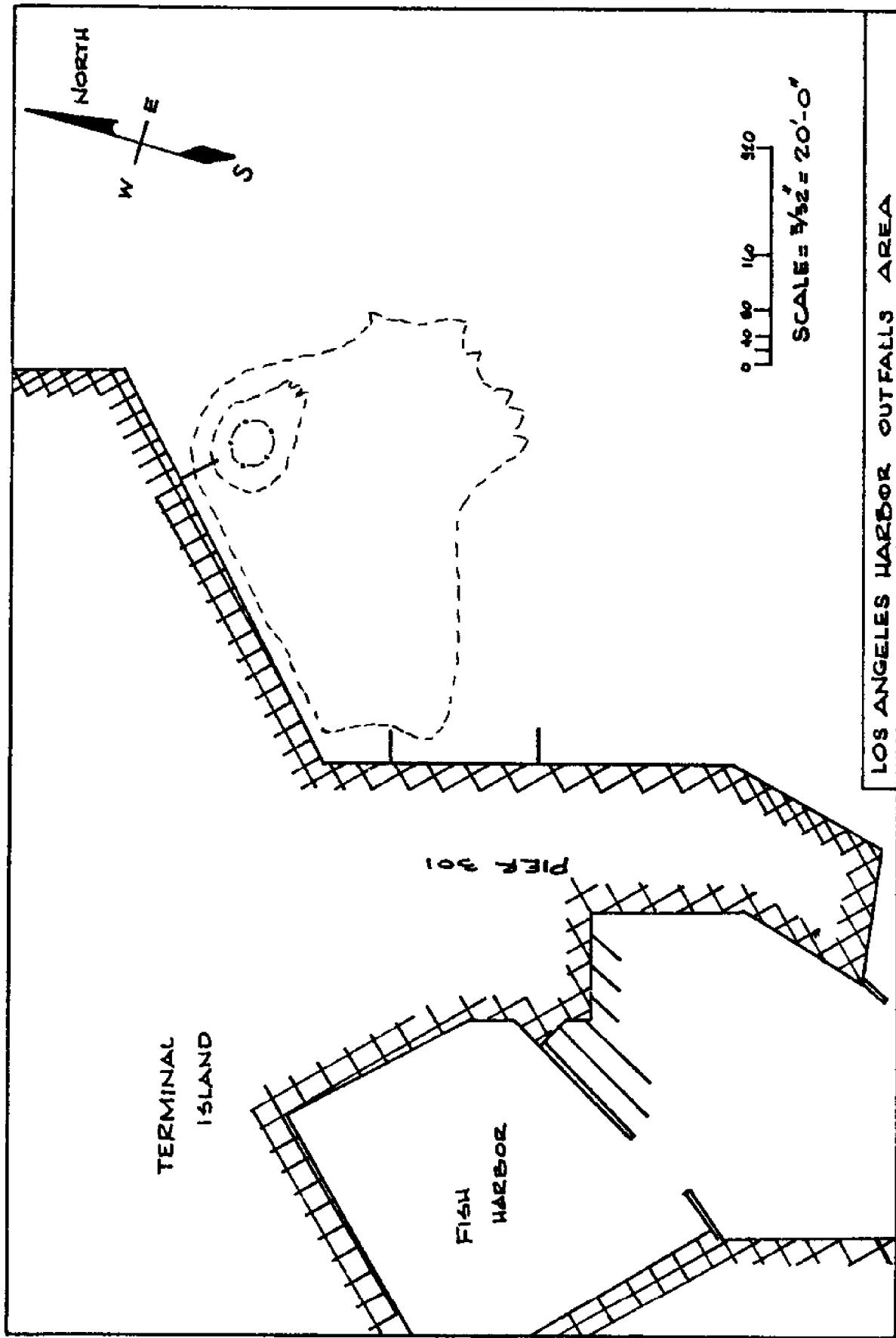


FIG. 6 - DYE MOVEMENT, 15. Aug. 1972, --- 1300

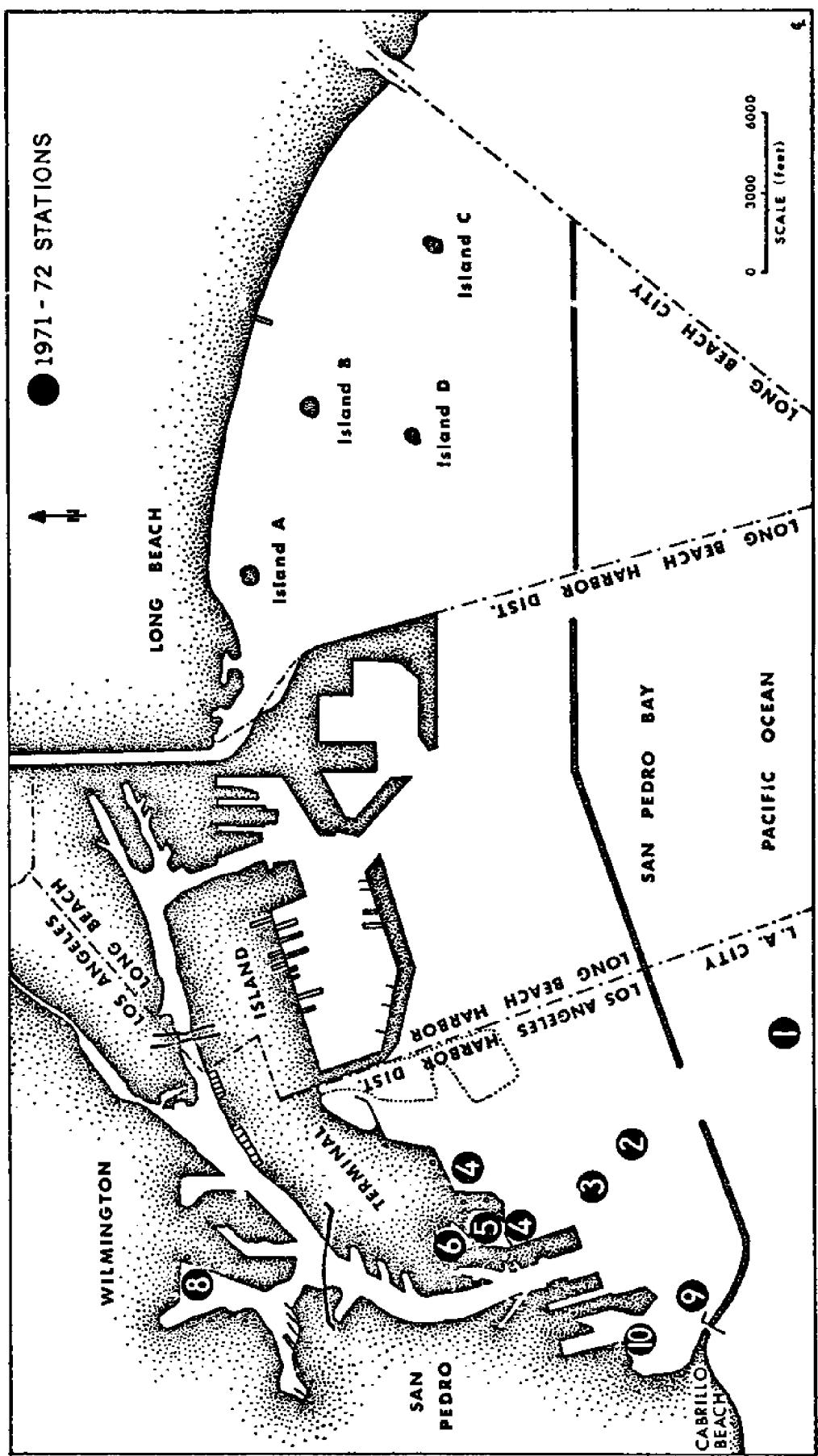


FIGURE 7

TABLE 1

Station	Date	Temp.	DO (mg/l)	BOD (mg/l)	Standard plate count	Coliform (per 100 ml)	Fecal Streptococci (per 100 ml)
1	7/26/72	57.3	7.5	2.7	2.3 x 10 <sup>4</sup>	0	---
	8/09/72	64.04	8.1	1.9	2.4 x 10 <sup>4</sup>	0	---
	9/06/72	67.28	9.2	8.3	8.0 x 10 <sup>2</sup>	0	---
	10/05/72	62.60	8.5	4.9	5.5 x 10 <sup>3</sup>	0	---
	11/21/72	60.08	8.4	2.0	1.8 x 10 <sup>3</sup>	0	---
	12/14/72	58.10	8.5	1.8	9.5 x 10 <sup>2</sup>	0	---
	1/10/73	55.58	8.8	7.2	6.9 x 10 <sup>2</sup>	0	---
	2/07/73	55.58	8.4	3.8	4.0 x 10 <sup>3</sup>	0	---
	3/07/73	60.26	7.6	3.1	3.6 x 10 <sup>3</sup>	0	0
2	7/26/72	66.20	8.0	7.2	4.0 x 10 <sup>6</sup>	2, 400	---
	8/09/72	66.20	6.7	2.0	1.0 x 10 <sup>4</sup>	460	---
	9/06/72	67.64	8.8	6.0	4.2 x 10 <sup>5</sup>	100	---
	10/05/72	63.50	9.6	6.7	1.1 x 10 <sup>5</sup>	0	---
	11/21/72	58.82	7.4	2.4	2.7 x 10 <sup>5</sup>	1, 400	---
	12/14/72	57.20	7.8	1.7	9.5 x 10 <sup>4</sup>	800	---
	1/10/73	55.58	8.2	4.4	1.3 x 10 <sup>5</sup>	700	---
	2/07/73	55.58	7.8	3.6	3.2 x 10 <sup>4</sup>	300	---
	3/07/73	58.28	8.3	4.4	4.1 x 10 <sup>5</sup>	400	---

TABLE 1 (Continued)

Station	Date	Temp.	DO (mg/l)	BOD (mg/l)	Standard Plate count	Coliform (per 100 ml)	Fecal Streptococci
3	7/26/72	66.56	10.6	4.2	1.0 x 10 <sup>6</sup>	460	---
	8/09/72	67.10	7.5	4.3	7.2 x 10 <sup>5</sup>	93	---
	9/06/72	68.00	10.0	12.6	8.6 x 10 <sup>6</sup>	400	---
	10/05/72	64.40	9.0	6.0	3.5 x 10 <sup>6</sup>	1, 100	---
	11/21/72	58.64	6.8	4.0	5.7 x 10 <sup>4</sup>	0	---
	12/14/72	55.76	8.0	2.3	4.2 x 10 <sup>4</sup>	500	---
	1/10/73	55.40	8.1	3.9	3.9 x 10 <sup>4</sup>	0	---
	2/07/73	56.12	7.3	3.3	7.0 x 10 <sup>5</sup>	3, 400	---
	3/07/73	58.64	7.8	5.6	6.4 x 10 <sup>5</sup>	1, 200	0
	4	7/26/72	67.82	6.4	6.6	1.2 x 10 <sup>7</sup>	2, 400
4	8/09/72	65.30	4.3	2.9	1.6 x 10 <sup>5</sup>	43	---
	9/06/72	68.36	5.7	9.6	1.2 x 10 <sup>6</sup>	3, 000	---
	10/05/72	64.40	6.1	4.9	2.4 x 10 <sup>5</sup>	9, 700	---
	11/21/72	59.00	5.0	2.4	3.0 x 10 <sup>5</sup>	5, 500	---
	12/14/72	56.66	4.9	1.2	4.2 x 10 <sup>5</sup>	4, 000	---
	1/10/73	55.22	6.1	8.2	1.3 x 10 <sup>6</sup>	2, 400	---
	2/07/73	56.30	6.4	6.4	2.1 x 10 <sup>6</sup>	7, 100	---
	3/07/73	58.46	7.0	9.0	2.9 x 10 <sup>5</sup>	2, 000	300

TABLE 1 (Continued)

Station	Date	Temp.	DO (mg/l)	BOD (mg/l)	Standard plate count	Coliform (per 100 ml)	Fecal Streptococci
5	7/26/72	69.80	9.3	6.9	1.5 x 10 <sup>5</sup>	0	---
	8/09/72	65.48	4.8	3.7	4.3 x 10 <sup>5</sup>	460	---
	9/06/72	68.18	5.1	4.3	6.6 x 10 <sup>5</sup>	1, 000	---
	10/05/72	64.76	7.7	5.8	3.7 x 10 <sup>5</sup>	2, 900	---
	11/21/72	58.82	4.7	2.5	1.6 x 10 <sup>5</sup>	200	---
	12/14/72	56.66	4.3	1.2	5.4 x 10 <sup>5</sup>	200	---
	1/10/73	55.40	6.5	8.9	3.5 x 10 <sup>5</sup>	0	---
	2/07/73	56.30	6.6	4.0	1.7 x 10 <sup>6</sup>	450	---
	3/07/73	58.46	6.8	5.0	1.0 x 10 <sup>5</sup>	0	0
	7/26/72	70.88	10.6	6.3	1.3 x 10 <sup>5</sup>	0	---
	8/09/72	68.54	8.9	3.9	1.0 x 10 <sup>5</sup>	43	---
	9/06/72	68.54	4.1	2.9	3.7 x 10 <sup>5</sup>	1, 000	---
6	10/05/72	64.76	8.9	3.6	4.5 x 10 <sup>4</sup>	0	---
	11/21/72	59.54	4.8	1.8	3.0 x 10 <sup>4</sup>	0	---
	12/14/72	57.02	4.0	1.7	3.5 x 10 <sup>5</sup>	3, 000	---
	1/10/73	55.22	6.5	4.2	2.0 x 10 <sup>5</sup>	0	---
	2/07/73	56.30	6.6	3.4	1.6 x 10 <sup>5</sup>	2, 700	---
	3/07/73	59.00	7.8	2.6	4.2 x 10 <sup>4</sup>	0	0

TABLE 1 (Continued)

Station	Date	Temp.	DO (mg/l)	BOD (mg/l)	Standard plate count	Coliform (per 100 ml)	Fecal Streptococci
7	7/26/72	69.44	6.5	8.1	2.2 x 10 <sup>7</sup>	2, 400	---
	8/09/72	67.82	7.0	15.1	8.6 x 10 <sup>6</sup>	2, 400	---
	9/06/72	69.08	5.5	35.5	2.6 x 10 <sup>5</sup>	420, 000	---
	10/05/72	---	7.5	9.1	3.1 x 10 <sup>5</sup>	440	---
	11/21/72	59.36	5.3	33.2	1.1 x 10 <sup>5</sup>	370, 000	---
	12/14/72	57.02	5.2	13.5	5.8 x 10 <sup>5</sup>	210	---
	1/10/73	57.02	5.8	33.6	1.8 x 10 <sup>5</sup>	8, 000	---
	2/07/73	57.38	7.2	23.6	1.2 x 10 <sup>5</sup>	900	---
	3/07/73	59.36	6.1	24.1	5.8 x 10 <sup>4</sup>	180, 000	100
8	7/26/72	78.80	6.2	2.7	9.7 x 10 <sup>3</sup>	0	---
	8/09/72	64.46	4.6	0.2	2.2 x 10 <sup>4</sup>	15	---
	9/06/72	---	5.2	2.2	1.1 x 10 <sup>4</sup>	0	---
	10/05/72	---	5.0	2.4	2.7 x 10 <sup>3</sup>	0	---
	11/21/72	68.36	4.8	1.8	1.0 x 10 <sup>4</sup>	100	---
	12/14/72	65.12	6.1	1.2	7.0 x 10 <sup>3</sup>	0	---
	1/10/73	60.80	6.2	4.4	8.0 x 10 <sup>3</sup>	0	---
	2/07/73	61.88	5.7	1.7	1.9 x 10 <sup>3</sup>	900	---
	3/07/73	60.44	6.8	2.3	1.4 x 10 <sup>3</sup>	0	0

TABLE 1 (Continued)

Station	Date	Temp.	DO (mg/l)	BOD (mg/l)	Standard plate count	Coliform (per 100 ml)	Fecal Streptococci
9	7/26/72	64.40	9.1	4.5	9.8 x 10 <sup>3</sup>	9	---
	8/09/72	69.92	6.5	2.1	8.9 x 10 <sup>3</sup>	23	---
	9/06/72	---	7.9	3.8	---	---	---
	10/05/72	---	6.8	3.0	2.5 x 10 <sup>4</sup>	0	---
	11/21/72	59.00	6.8	6.0	9.0 x 10 <sup>4</sup>	6, 000	---
	12/14/72	57.02	6.8	2.6	4.0 x 10 <sup>4</sup>	0	---
	1/10/73	56.12	7.5	4.0	1.4 x 10 <sup>4</sup>	200	---
	2/07/73	55.94	7.4	5.1	8.7 x 10 <sup>4</sup>	200	---
	3/07/73	59.18	7.2	4.6	2.1 x 10 <sup>4</sup>	0	0
10	10/05/72	---	6.4	1.2	9.7 x 10 <sup>3</sup>	0	---
	11/21/72	59.00	6.8	5.9	1.7 x 10 <sup>5</sup>	6, 000	---
	12/14/72	57.02	6.8	2.6	1.7 x 10 <sup>4</sup>	100	---
	1/10/73	56.12	7.5	4.0	4.5 x 10 <sup>4</sup>	0	---
	2/07/73	55.94	7.4	5.1	6.7 x 10 <sup>4</sup>	100	---
	3/07/73	59.18	7.2	4.6	1.4 x 10 <sup>4</sup>	0	100

Table 2

Date	Effluent BOD (mg/l)	Station 7 BOD
7/26/72	580	8.1
8/09/72	27 (admitted error)	15.1
9/06/72	1,270	35.5
10/05/72	159	9.1
11/21/72	977	33.2
12/14/72	570	13.5
1/10/73	415	33.6
2/07/73	276	23.6
3/07/73	231	23.1

With few exceptions BOD values (Table 2) correlate very well with the estimated waste loads of the effluent. The BOD values at Station 7 are much lower than that of the plant effluent because of dilution as the sampling station is about 1,000 feet from the outfall. It is conceivable that this area is under stress.

#### Aerobic Heterotrophic Organisms

The relative positions of the curves resulting from the standard plate counts at each station are according to expectations (Table 1 and Figure 8). That is, Stations 1,8, and 9 have the lowest counts, while counts from Station 6 ran slightly higher. Those from Station 5 were a little higher than those of Station 6 in the months from July through November. Then from December through January, the curve fell closer to that of Station 6 again. In February the bacterial count went considerably higher but it dropped back down to that of Station 6 again in March. The counts from

Station 2 are considerably higher in July but drop back to the same level as that of Stations 5 and 6 from August through March. Although the curve from Station 3 is lower than that of Station 2 in July, it rises in August and remains high until November. It levels out in November, December, and January, rising again in February and March. With the exception of July, August, October, and December, the counts from Station 4 are higher than those at Station 7, a fact which can be explained on the basis of the movement of the water mass as demonstrated by both the drogue study and the fate of the dye plume during the high to low phase of the tide cycle. Counts from Station 7 were very high ( $2.1 \times 10^7$ ) in July and August ( $8.6 \times 10^6$ ) but dropped back into the range of the majority of the stations from September through March.

There is a great deal of fluctuation in the counts, particularly in Stations 2 (Figure 10), 3 (Figure 11), 6 (Figure 14), 7 (Figure 15), and to a lesser degree Station 8 (Figure 16) which peaked in the month of August, and Station 1 (Figure 9) which peaked in July and August. This is undoubtedly at least partially attributable to a seasonal fluctuation. But with less than a year's data it is not possible to be certain. The counts at Station 2 fluctuate by an order of magnitude from one month to the next. This fluctuation is not associated with a significant change in the DO or BOD. The only association that has been made to date is that high counts seem to coincide with high winds. There is a considerable rise in the count at Station 3 in September which could be linked to an elevation in BOD for this month. This reflects a similar rise in the count at Station 2 for September. However, there is no corresponding rise in the count at Station 3 for the peaks which occurred in July, November, and February at Station 2. Another and more probable explanation of this peak in the counts at Station 3 is that it was associated with red tide. At this time there is a low bacterial count. Then as the bloom dies the bacterial count goes up. The peaks in the curves from Station 4 (Figure 12) more or less correspond to elevations in the

BOD. It is fairly certain that the increase in this population results from the intrusion of water from the area of the outfall. The level at which this occurs is again dependent upon the strength and duration of the wind. As the peaks in the curve from Station 6 are not associated with an elevation in BOD determinations but do follow elevations in DO, they are most probably the result of red tide. At Station 7 there was a selection effect which resulted in fewer types of organisms being present on plates from this area. The counts also indicate that after a certain level of effluent (BOD) is reached it becomes detrimental. Counts obtained from Stations 9 (Figure 17), and 10 (Figure 18) do not vary to any extent. They are apparently not influenced by the material from the cannery outfall.

#### Fecal Indicator Organisms

Coliform counts from Stations 2 and 3 (Table 1) fluctuate in the same manner, and most probably from the same cause as the standard plate counts. Considering the distance of these two stations from the source of contamination these counts are fairly high. The counts at Station 4 are always positive and consistently higher than that of Stations 2 and 3. For this location the counts do not exceed expectations. In all but three months, coliforms were present at Station 5 but at a lower level than was found at Station 4. At this location there are most probably a number of contributing causes. Counts from Station 6 vary, being negative as often as they are positive. These counts would most probably be associated with ship traffic in this area. Coliform plates at Station 7 were never found to be negative and occasionally (coincident with high BOD values) were very high. There are two possible sources of these organisms, the effluent from the domestic sewer outfall and the cannery effluent. Counts obtained from samples right at the cannery outfall during the dye study were as high and in a few instances higher. Therefore, there is reason for concern and a need for a closer look at this possibility. Station 8

occasionally has coliforms present. Stations 9 and 10 fluctuate but have a slightly larger number present. The organisms present at these three stations are most probably associated with harbor traffic.

There are certainly only a limited number of conclusions which can be derived from these data. However, considering the limited time involved in observing this multifaceted environment, the study has been fruitfull. The following are the conclusions which have emerged:

1. Nutrients present in the cannery effluent seem to have a beneficial effect on the bacterial population as is evident in the difference in level of the counts at the stations (2,3, and 4) which are receiving some of the effluent after dilution by the receiving water. At station 7 this results in fewer species being present in higher numbers. As bacteria represent the first step in conversion of effluents into the harbor food chain, this can be considered beneficial to the harbor ecosystem, providing that the following factorings are balanced against the beneficial effects.

2. There is also a level of concentration at which the effluent material apparently acts as a deterrent to the growth of this group of organisms. This is conceivably the situation at Station 7. Of the stations studied 7 is the only one which shows this adverse effect. This is difficult to establish because the counts did fall below the level found at some of the other stations. It will take more study to determine what level is beneficial and what is detrimental. Further study will also establish what part of these fluctuations result from seasonal effects.

3. The level of coliform associated with samples from this area suggests that a more detailed study needs to be made to determine the source of these organisms.

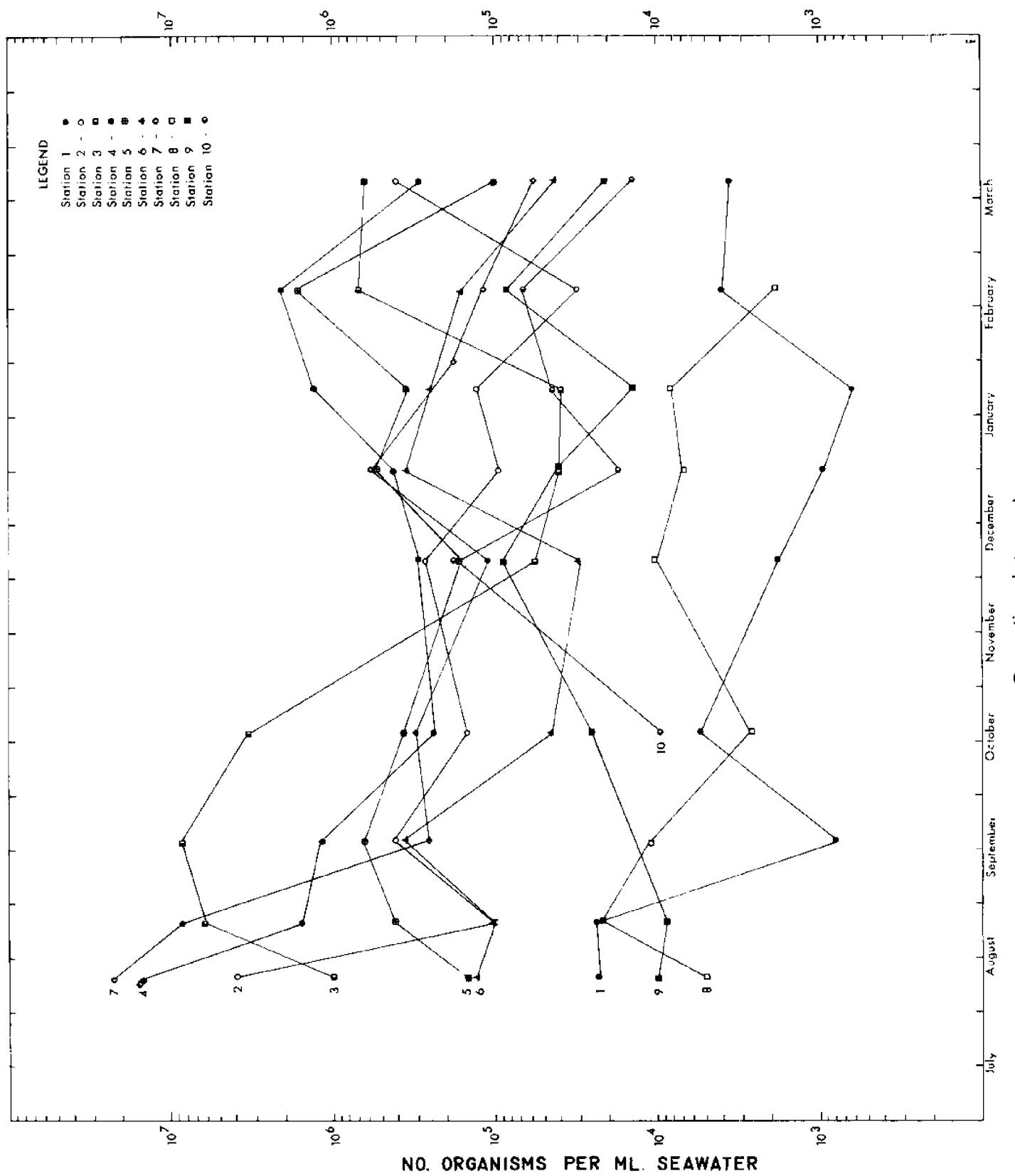


FIG. 8 - STANDARD PLATE COUNTS

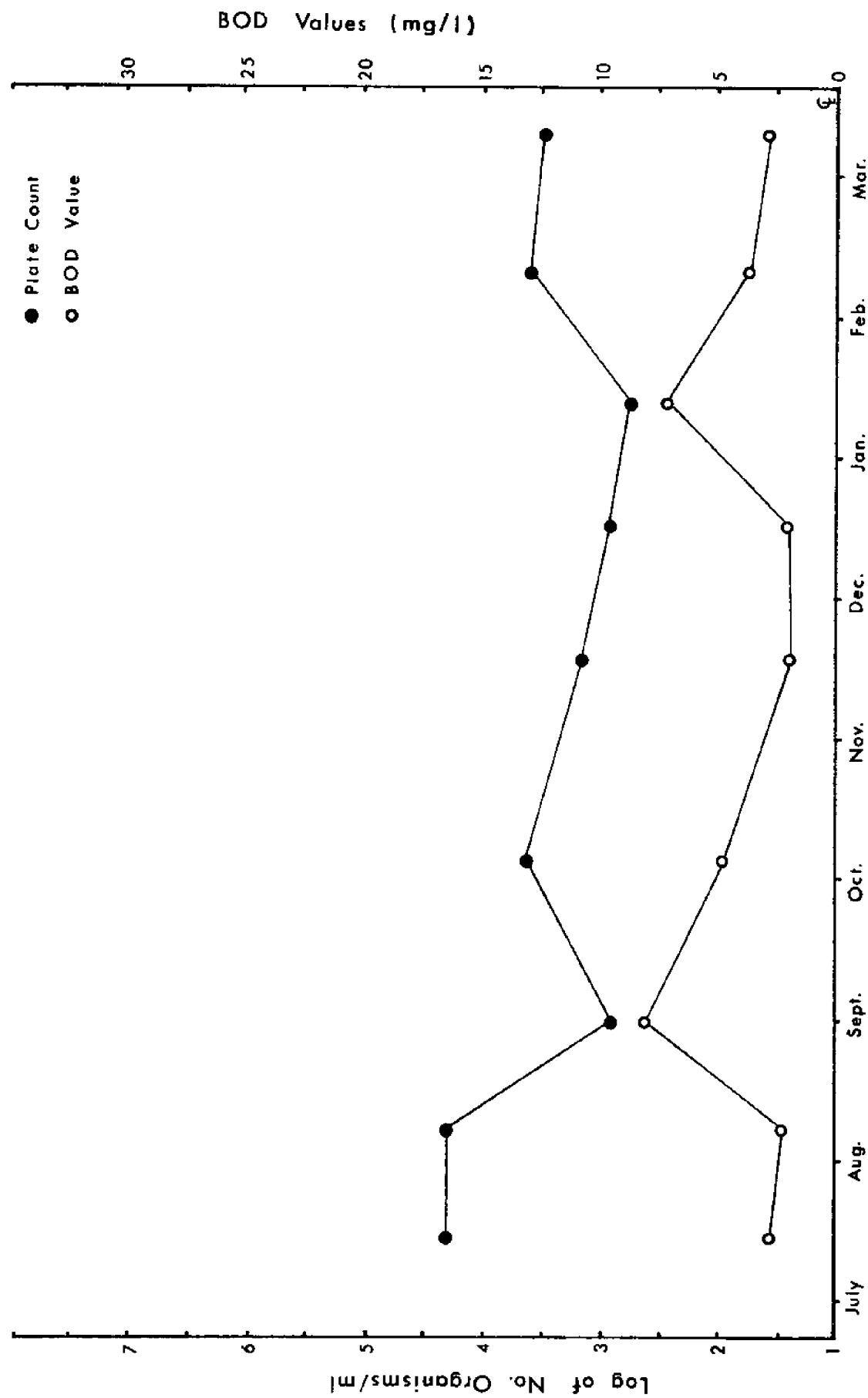


FIG. 9 - STATION 1

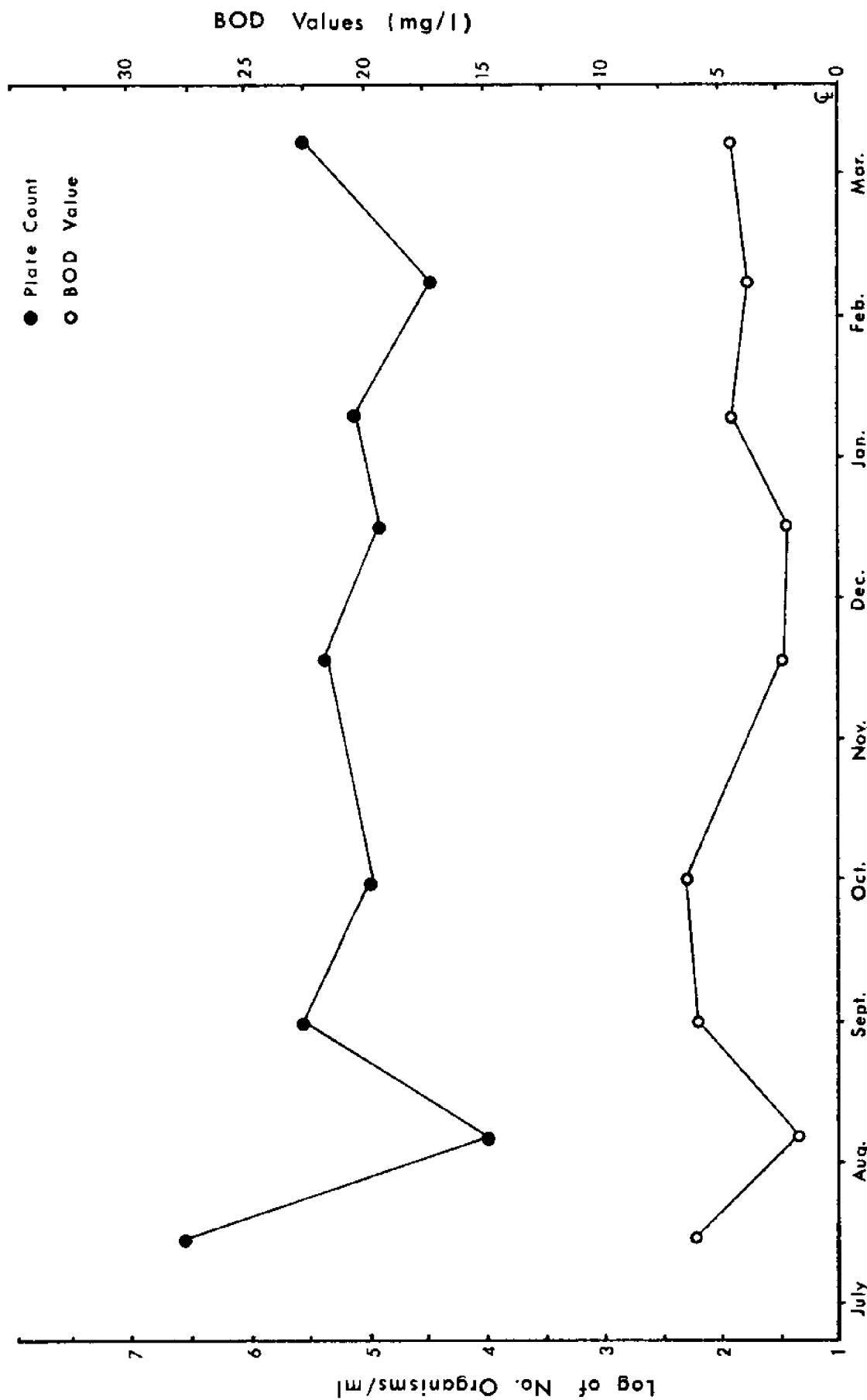


FIG. 10 - STATION 2

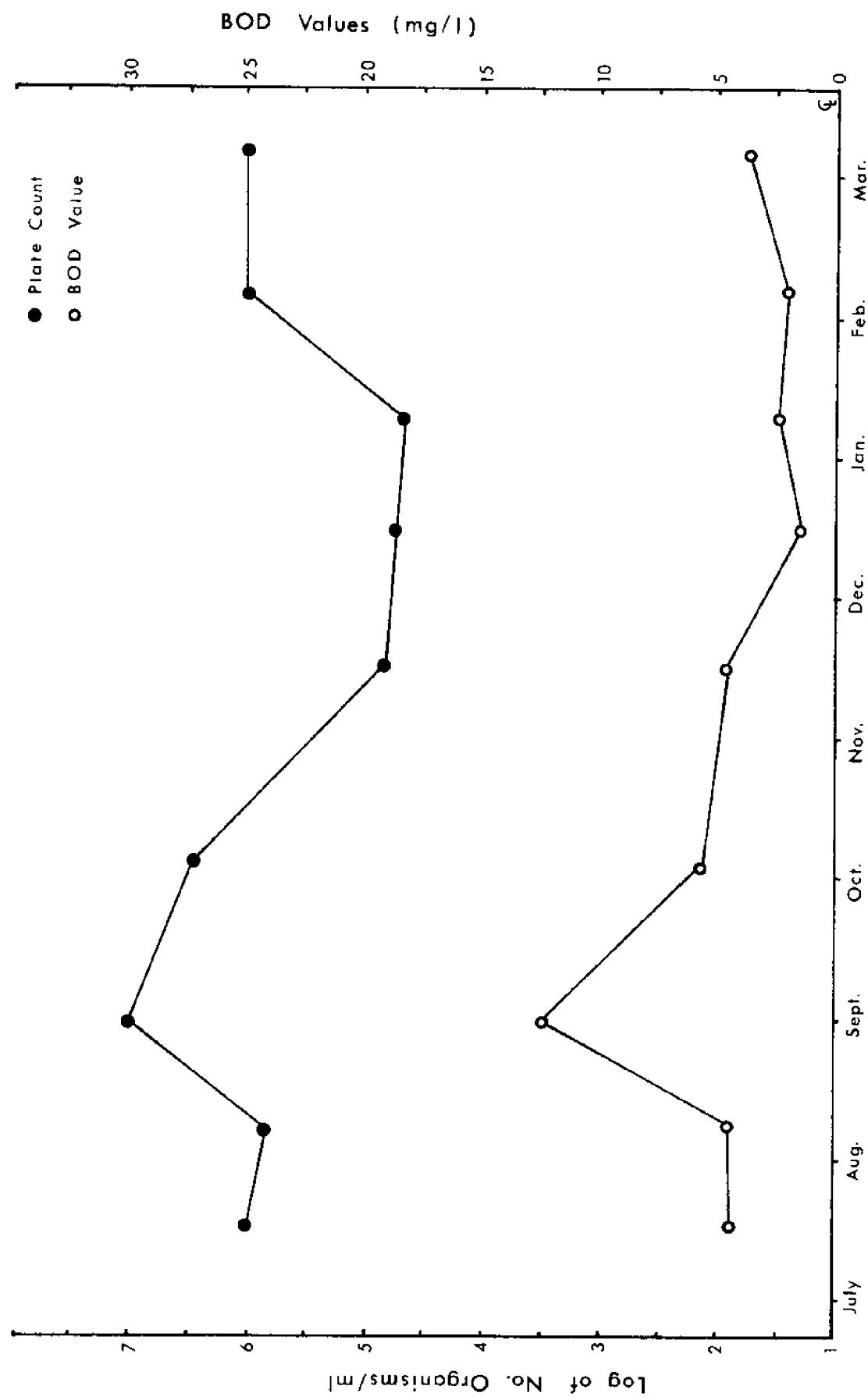


FIG. 11 - STATION 3

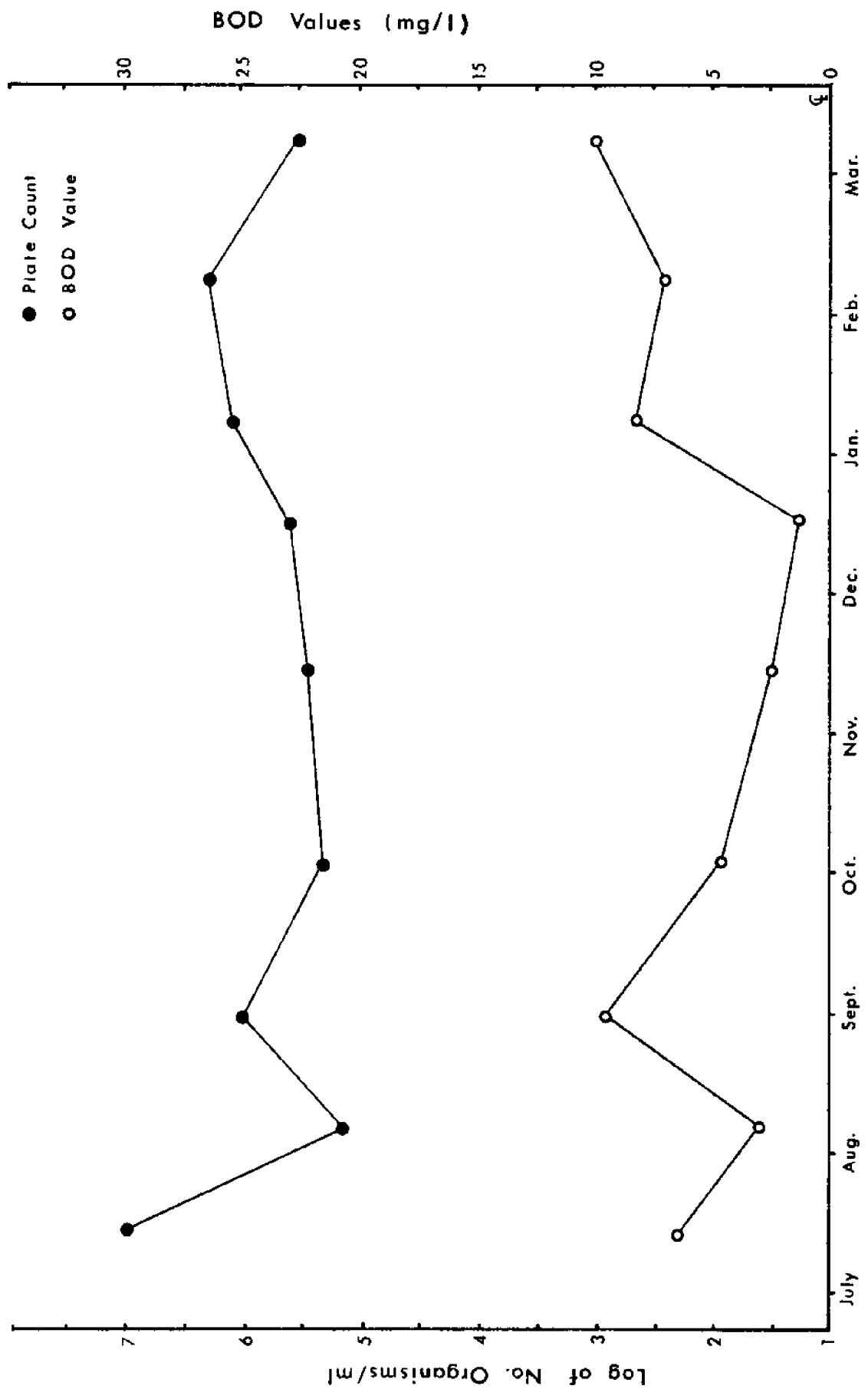


FIG. 12 - STATION 4

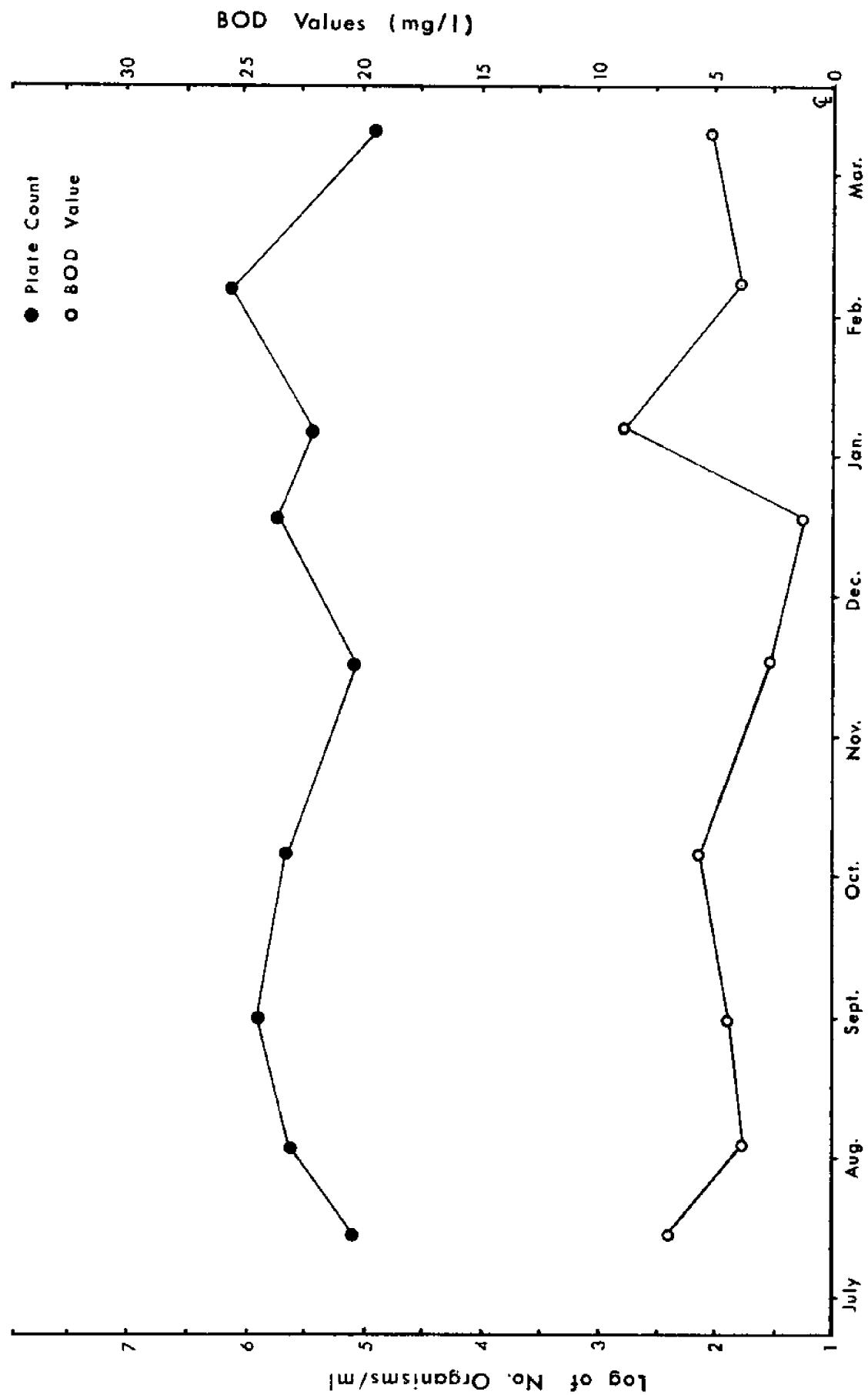


FIG. 13 - STATION 5

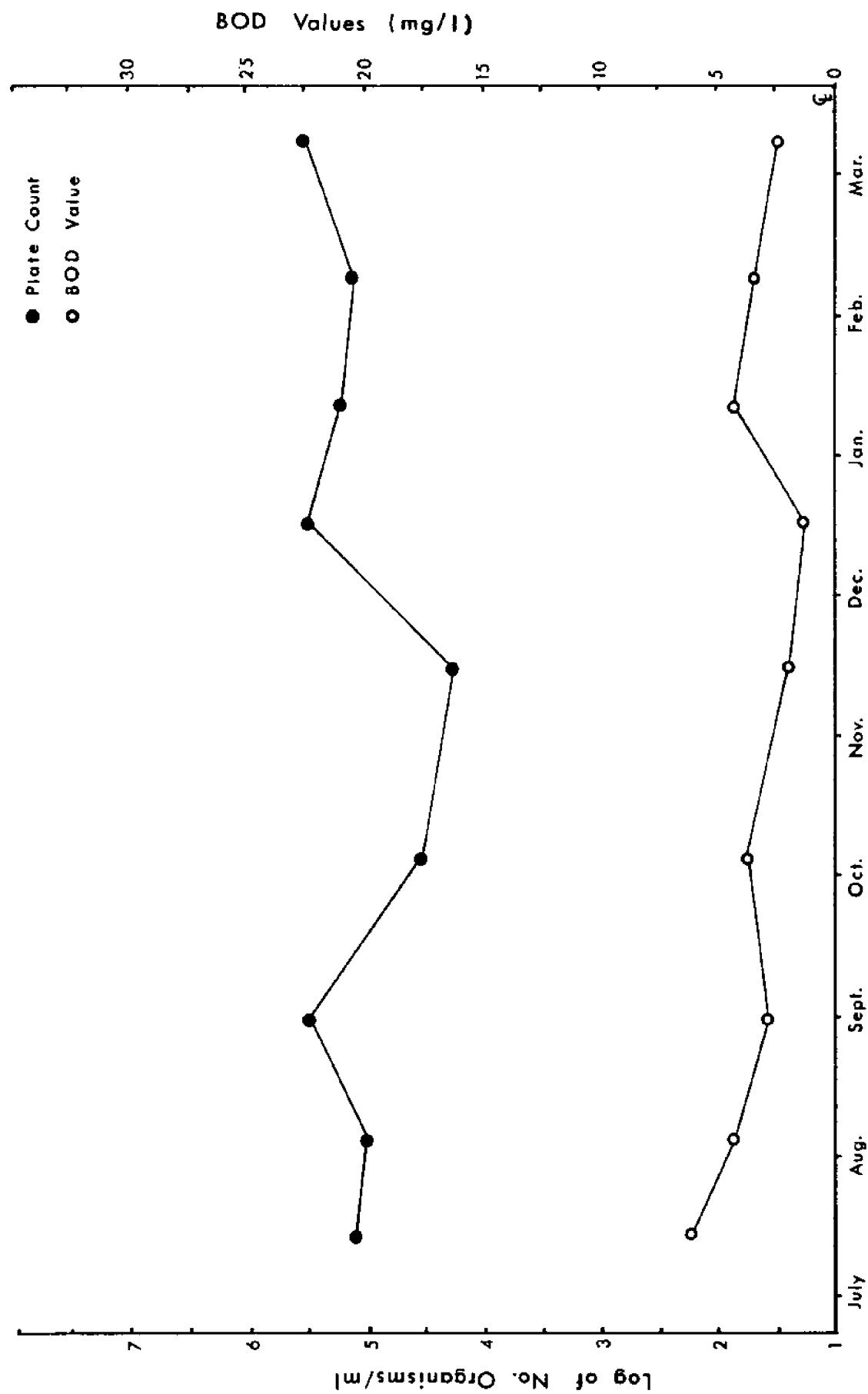


FIG. 14 - STATION 6

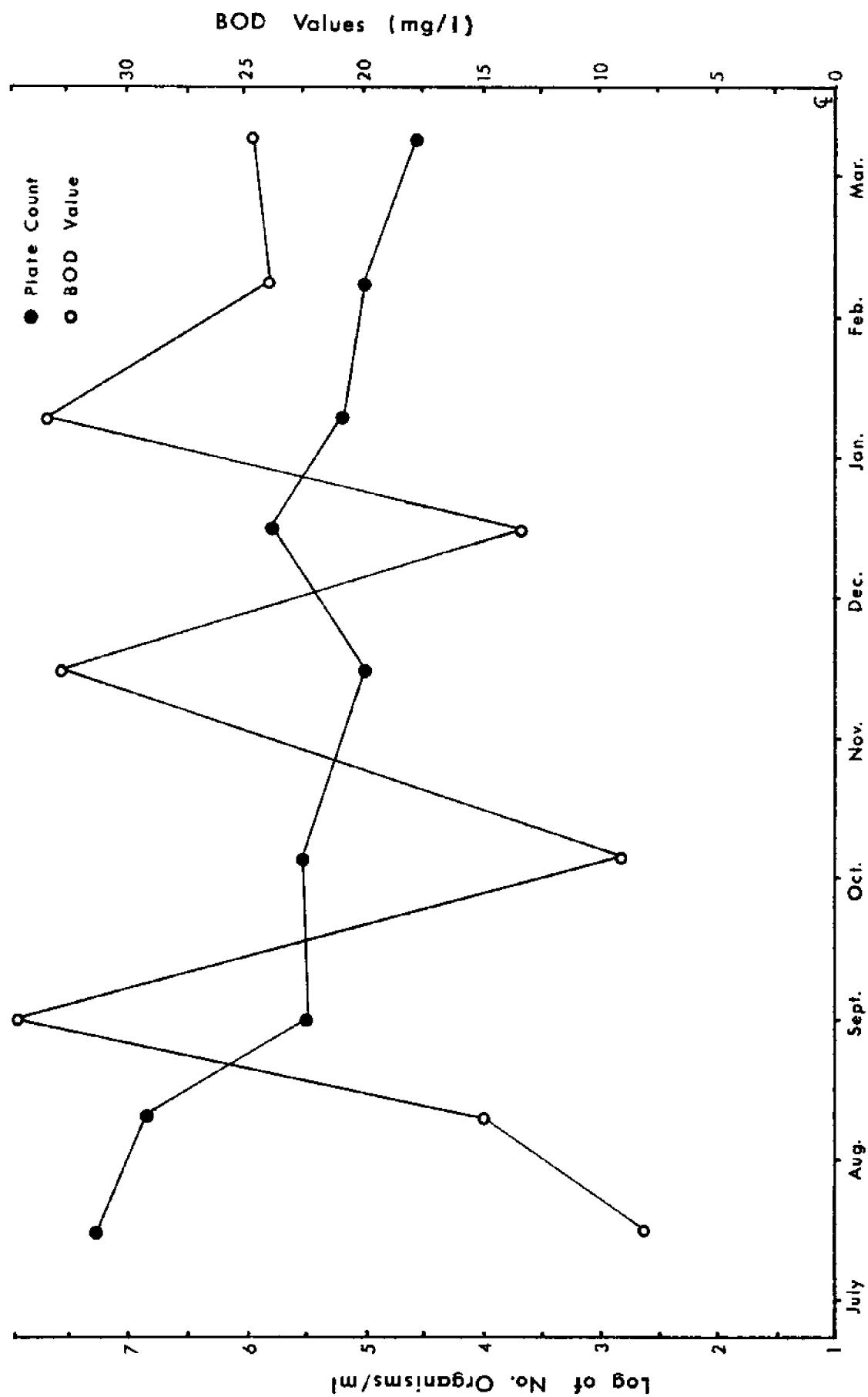


FIG. 15 - STATION 7

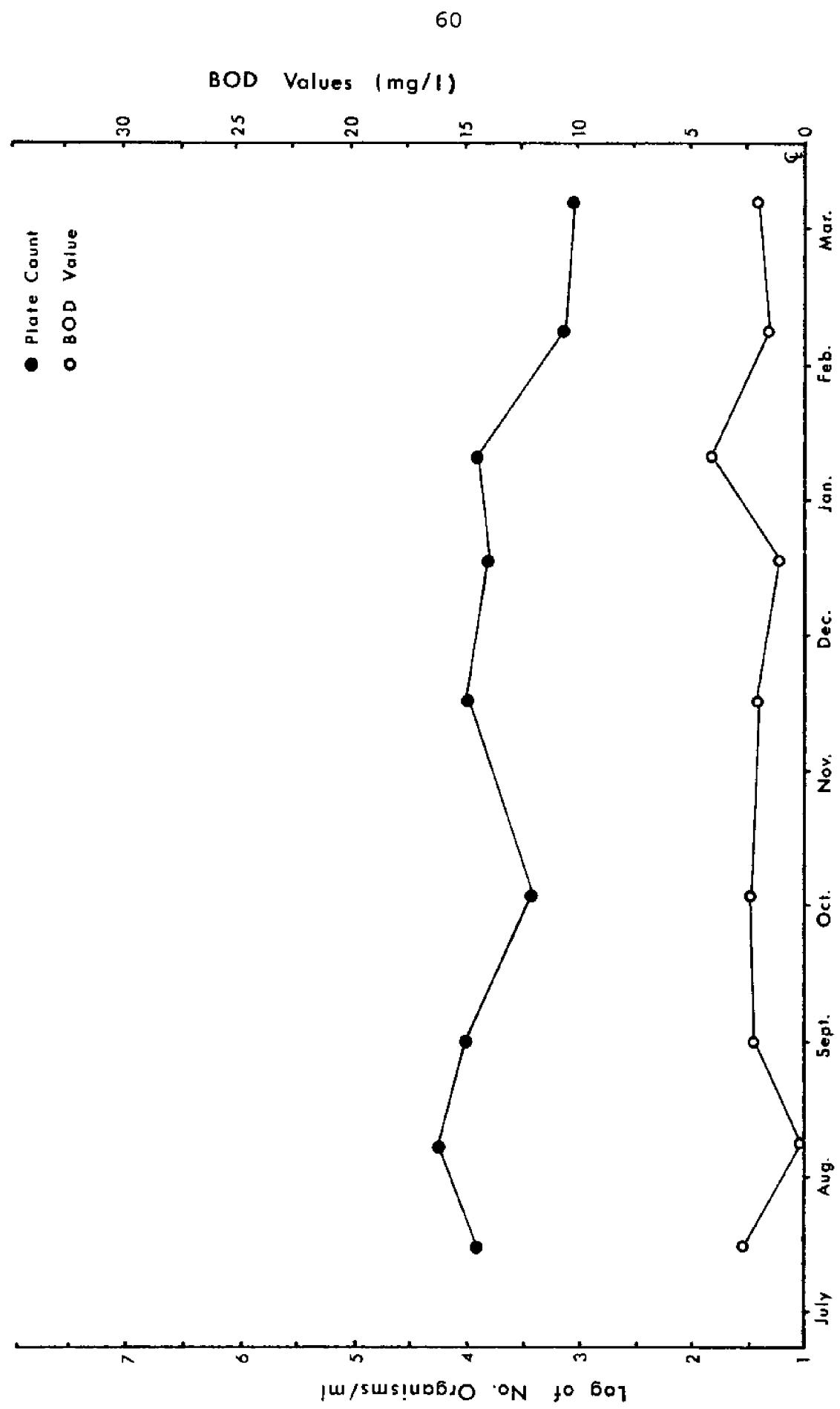


FIG. 16 - STATION 8

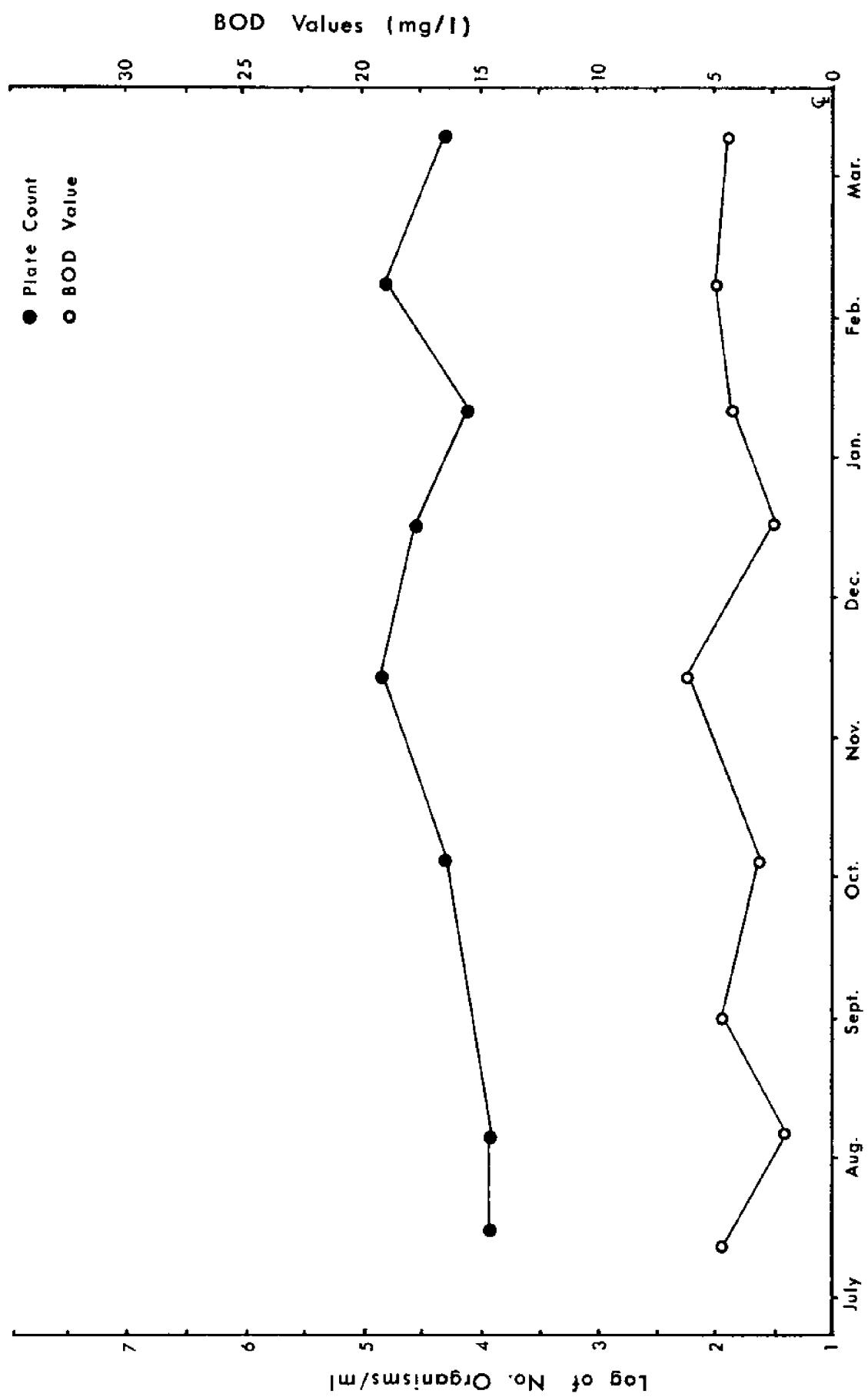


FIG. 17 - STATION 9

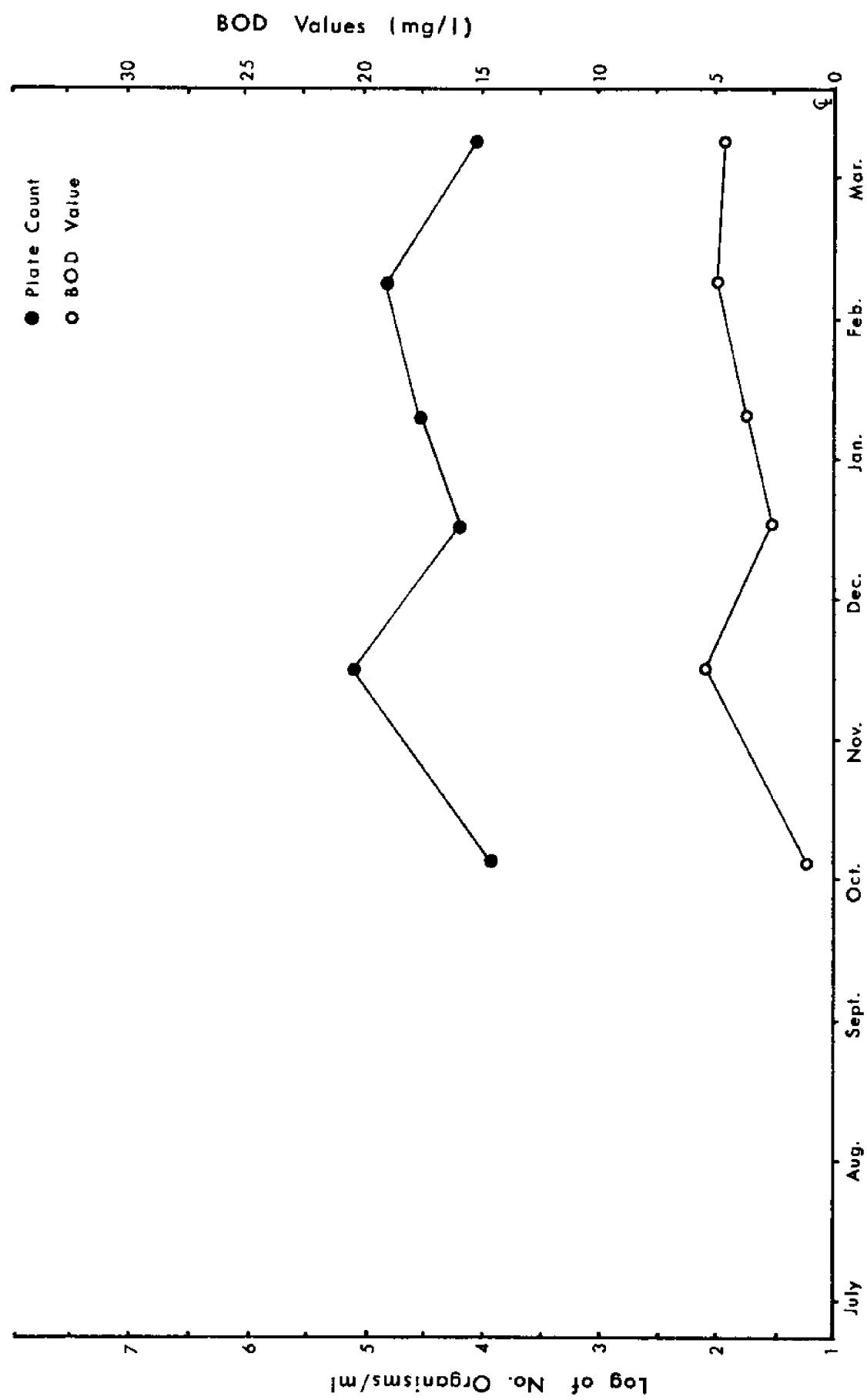


FIG. 18 - STATION 10

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Marine Studies of San Pedro Bay  
Part II, Biological Investigations  
June, 1973

Working Report  
on  
The Dilution of Cannery Wastes  
Discharges into the Los Angeles Harbor

by

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## Introduction

This report contains the results of a series of studies conducted in the Los Angeles Harbor during July and August 1972. The objective of these studies was to determine the fate of bacteria artificially induced into cannery wastes which are ultimately discharged into the waters of the outer harbor. In order to distinguish between the simultaneous processes of mortality and dilution, it was necessary to assess accurately the rate of physical dilution of waste effluent with harbor water. This report is on the later aspects of the studies, i.e., the physical dilution of cannery wastes.

The waste effluent from all canneries located on Terminal Island, with the exception of Star Kist No. 4, is collected at the Way Street pumping and subsequently discharged through a relatively short and shallow outfall located on the east side of pier 301.

A total of four studies were conducted which consisted of continuously tagging the waste effluent with fluorescent dye at the pumping station and later tracking and monitoring the dye concentration of the resulting tagged waste field as it mixed with harbor water.

## Equipment and Field Techniques

The waste effluent from the pumping plant was continuously tagged by injecting rhodamine B dye solution by use of a variable speed positive displacement pump. In the first experiment the dye discharge rate was set at 70 ml/min to provide an estimated dye concentration of 2 mg/l in the effluent. This concentration was found to be too high and it was reduced to 0.5 mg/l in all subsequent studies.

The dye concentration distribution in the waste field was determined by use of a continuous flow fluorometer and strip chart recorder mounted in a small skiff. Water samples from the waste field were obtained by use of a deck mounted pump attached to a

torpedo-like sampler towed from the stern of the skiff. Water was pumped from the sampler through the fluorometer and dye concentrations recorded continuously. Using this it was possible to ascertain dye concentration distribution along the lateral and longitudinal axes of the dye-waste plume. The depth of maximum dye concentration (near the surface in these experiments) was first determined by vertical transects of the plume. The sampler was then set to travel at this depth during all lateral and longitudinal sampling runs.

The approximate speed of the skiff during sampling was determined by use of a pitot tube speed indicator held over the side. Knowing the travel time of the skiff, the speeds of the skiff and the strip chart recording dye concentrations, it was possible to obtain concentration vs distance relationships along various axes of the dye plume.

In those studies in which the field was also tagged with bacteria at the pumping plant, grab samples were taken from within the dye plume while continuously recording dye concentrations. The time of each grab sample was correlated with the travel time of the strip chart recorder. In this manner the location of the grab sample within the dye plume could be determined.

For a more detailed description of the equipment and field techniques employed in these studies, the reader is referred to references 1 and 2 in the bibliography.

#### Data Summary

Table 1 is a summary of the test parameters and some of the oceanographic conditions existing during each study. The first two columns give the rate of dye injection and the estimated dye concentration in the pumping plant effluent ( $C_p$ ).

TABLE 1  
DATA SUMMARY

Dye Injection Rate (ml/min)	Approx. Conc.* Effluent=C <sub>P</sub> (mg/l)	Plant Time Dye Boil	Average Conc. Boil=C <sub>B</sub> (mg/l)	Initial Dilution C <sub>P</sub> /C <sub>B</sub>	Tide Change	Wind Direction (From)	Direction of Plume (toward)	Approx. Current Speed (kts)
7/17/72	70	2	1215	0.9	2.2/1	Low to High	SE (AM) W (PM)	East along breakwater
8/15/72	17.5	0.5	0937	0.17	2.8/1	High to Low	W (PM)	East along breakwater
8/22/72	17.5	0.5	0925	0.18	2.8/1	High to Low	W	East along breakwater til 1130 hrs. then curled South

concentration based on estimated plant effluent discharge rate = 6 mgd

\*\* fluorometer readings doubtful - electrical problem

Values of  $C_p$  were estimated by use of the following equation:

$$C_p = \frac{q}{5.85 Q}$$

where:

$C_p$  = plant effluent dye concentration in mg/l

$q$  = dye injection rate in ml/min

$Q$  = average plant discharge rate in million gallons/day  
(mgd)

5.85 = conversion factor

A value of  $Q = 6$  mgd, as furnished by Miki Oguri of the Allan Hancock Foundation, was used in all calculations for  $C_p$ . In all probability  $Q$  was not constant over a given study period. A highly variable  $Q$  would strongly influence the determination of the dilution of the drifting dye plume. In brief, a variable  $Q$  means a variable  $C_p$  and, thus, unsteady state conditions will result within the plume. This fact should be kept in mind when reviewing the data which follows.

Column 3 gives the time the dye appeared over the terminus of the outfall. This time is used to calculate the longitudinal spread of dye and to estimate current speeds.

Column 4 gives the average value of the maximum dye concentration at the boil ( $C_B$ ) over the outfall. This value was obtained by a simple average of all maximum fluorometer readings at that location.

The average values of the so-called initial dilution (I.D.) are shown in column 5. The I.D. was computed as the ratio  $C_p/C_B$  and gives the average dilution of waste with harbor water between the terminus of the outfall and the water surface. The values are relatively low and range from 2.2/1 to 4.3/1. A low I.D. is to be expected for an outfall without a diffuser section set in shallow water.

Columns 6 and 7 are a qualitative summary of the wind and tide

conditions existing during the studies. In general, the morning winds were slight and variable in direction. Relatively strong westerly winds prevailed during the afternoon hours.

The dye plumes showed a tendency to puddle and form large oval shapes during the early morning hours and move with the direction of the wind in the afternoon. This situation remained for both low to high and high to low tide conditions as described in column 8.

The approximate current speed for three of the studies is shown in column 9. These values were obtained by determining the elongation of the dye plume as a function of time. Calculation of speeds by this method is not highly accurate and, thus, the values obtained are comparable to those observed using surface drogues in the same location in the harbor (ref. 3).

#### Dilution Analysis - Dye Plume

The average dilution of the dye-waste mixture with ocean water is presented graphically in Figure 1. These curves were obtained by plotting the ratio of the maximum dye concentration ( $C_m$ ) to plant effluent dye concentration ( $C_p$ ) vs. distance along the center-line of the plume. After plotting all data for a given study it is usually necessary, because of the scatter of the plotted values, to determine an average  $C_p/C_m$  vs. distance relationship. An outline of the method employed by the author is presented in reference 2. The data shown in Figure 1 show the results of the analysis for three studies. The data for the study of August 29, 1972 are not shown because the data taken on that day showed that a malfunction of the fluorometer occurred. These data indicate that the dilution increased along the plume reaching a maximum value and then decreased with distance. A dilution pattern such as the described could be the result of unsteady state conditions as mentioned earlier, or faulty fluorometer readings. In this investigation problems developed with the generator servicing the fluorometer. Fluctuating frequencies were observed which strongly influence the performance of the fluorometer.

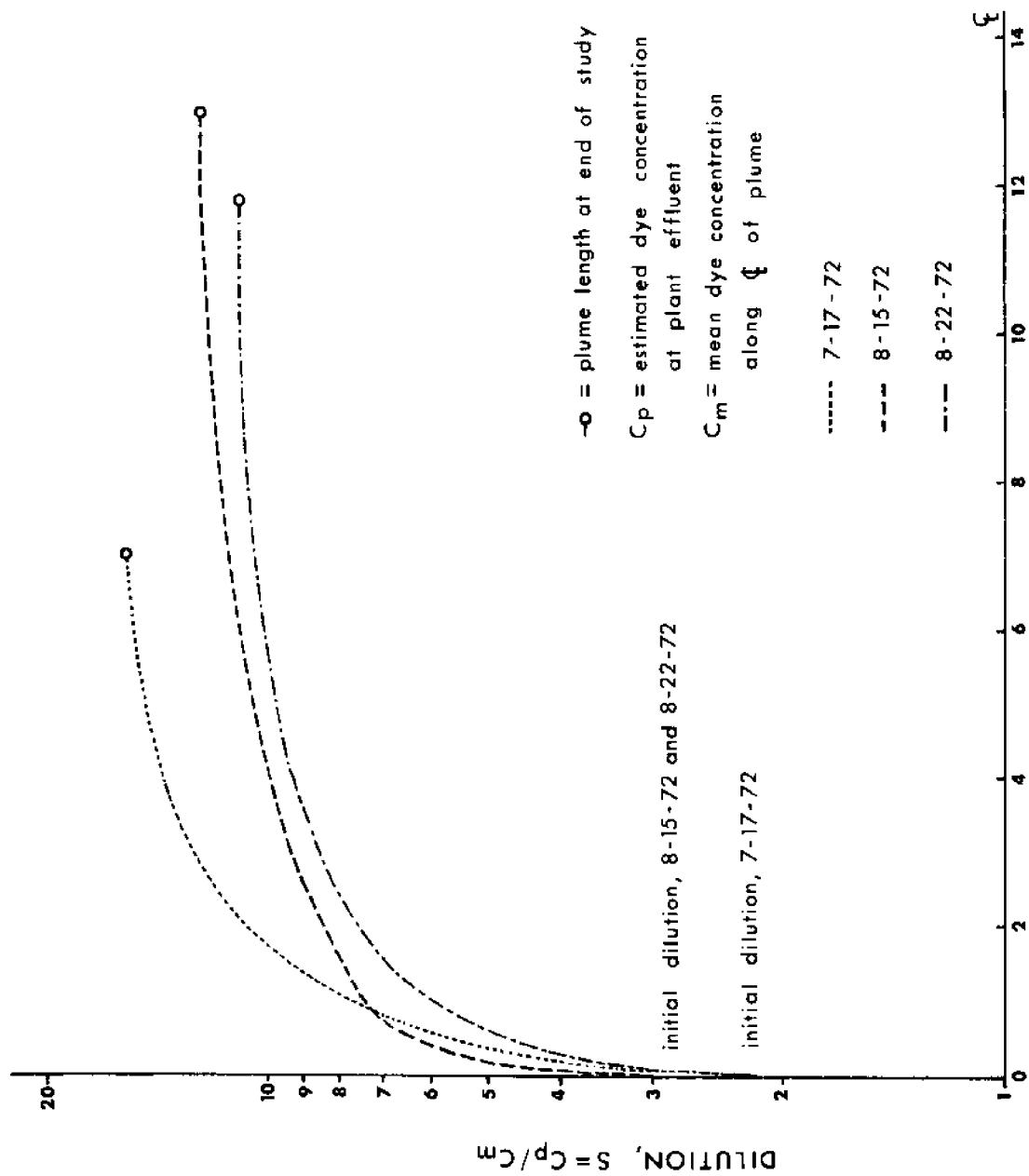


Fig.1 - Average Dilution of Dye-Waste Mixture in Ocean Receiving Waters

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### Appendix

Data for each sampling run for all dilution studies are included in the appendix which follows.

Run No. and Time	Boat Speed (ft/min)	<u>7/17/72</u>		Relative $C_m$	$C_p/C_m = S$
		t (min)	x (ft)		
1 (1316)	250	0	0	87	4.4
		0.2	50	83	4.6
		0.6	150	46	8.3
		0.9	225	32	11.9
		1.2	300	30	12.7
		1.4	350	27	12.7
		1.8	450	28	14.1
		2.2	550	18	13.6
		2.6	650	9	21
		2.7	675	13	42 (?)
		2.9	725		29

8/19/72Relative Cp = 90 units

Run No. and Time	Boat Speed	t (min)	x (ft)	Relative Cm	S = Cp/Cm
1 (1085)	250 l/min	0	0	35	2.6 -
		.2	50	20	4.5 -
		.3	75	18.5	4.85 - 4.7
		.5	125	17	5.3
		.7	175	14.5	6.2
		.9	225	15	6.0
		1.7	425	12.5	7.2
		1.9	475	14	6.4
		2.2	550	11	8.2
		2.5	625	10	9
2 (1143)	250	0	0	26	3.5 -
		0.2	50	12	7.5 -
		0.3	75	10	9 -
		0.6	150	8	11.2
		0.8	200	6	15
		1.2	300	10	7
		1.5	375	10	9
		1.8	450	10.5	8.6
		2	500	8	11.2
		2.2	550	6.5	13.8
		2.6	650	6.5	13.8
		2.9	725	8	11.2
		3.2	800	7	12.8
		3.4	850	7	12.8

8/22/72Relative Cp = 90 units

Run No. and Time	Boat Speed	t (min)	x (ft)	Relative Cm	S = Cp/Cm
1 (0945)	280	0	0	30	3
		0.2	56	7	12.9
		0.6	170	14	6.4
		0.8	225	11	8.2
		1.2	335	5	18
		1.8	505	6	15
		1.9	530	4	22.5
2 (0954)	280	0	0	41	2.2
		0.2	56	34	2.6
		0.5	140	18	5
		0.8	225	10	9
		1.2	335	15	6
		1.3	365	12	7.5
		1.6	450	17	5.3
		1.9	530	7	12.8
3 (1103)	250	0	0	40	2.3
		0.2	50	12.5	7.2
		0.7	175	10	9
		2.3	575	10	9
		2.7	675	9	10
		3.0	750	11	8.2
		3.2	800	7	12.8
		3.5	875	10.5	8.6
		3.7	925	10	9
		4	1000	11	8.2
		4.4	1100	3	30
		4.7	1180	9	10

8/15/72Relative Cp/Cm = 70/cm

Run No. and Time	Boat Speed	t	x	Cm	S = Cp/Cm = 70/cm
3 (1227)	250 ft/min	0	0	34	2.7 -
		0.2	50	12	7.5 -
		0.4	100	11	8.2
		1.1	275	10	9
		1.3	325	10	9
		1.9	475	9	10
		2.2	550	11	8.2
		2.4	600	10	9
		2.7	675	8.5	106
		2.9	725	10	9
		3.5	875	10	9
		3.8	950	8	11.3
		4.2	1050	10	9
		4.5	1125	9	10
4 (1238)	250	0	0	40	2.25 -
		0.3	75	12	7.5 -
		0.6	150	9	10
		0.9	225	9.5	9.5
		1.4	350	10	9
		1.6	400	10.5	8.5
		1.9	475	12	7.5
		2.3	575	7.5	12
		2.7	675	10	9
		3	750	9.5	9.5
		3.5	875	9	10
		4	1000	7	12.9
		4.6	1150	4	



Marine Studies of San Pedro Bay  
Part II, Biological Investigations  
June, 1973

Annotated Bibliography  
on  
Cannery Effluents

by

Penny A. Pinter  
Allan Hancock Foundation and  
University of California, Berkeley



## Introduction

The development of the fish canning industry occurred shortly after World War I. Since that time, sardines, herring, tuna and mackerel have been commercially important fish at various times. The herring industry had two peaks of development (Scofield, 1918; Scofield, 1952), the first from 1916-1919 and the second at the decline of the sardine industry. The sardine industry reached a peak in California in the thirties along with the mackerel industry (Fitch, 1952). With the collapse of these two industries in central California, the boats began using southern California as a base of operations (Croker, 1938). With the annual tonnage decreasing year after year for the sardine, jack and pacific mackerel, the boats began turning their efforts more and more to the catching of tuna. Today these boats are going as far away as Central and South America in an effort to fill their holds before returning to home port.

An obvious characteristic of the cannery industry effluent is grease. In the days of the sardine industry at Monterey (State of California Bureau of Sanitary Engineering, 1951) a common complaint was that grease rafts formed and boats anchored in the area were covered with a grease film. The grease content complicates the treatment of the effluent, poorly treated effluent dumped into an area with poor circulation results in dissolved oxygen crashing to zero, the coliform count increasing.

Chun, Young and Burbank (1968) listed the following as waste characteristics of tuna: ph 6.13 - 6.56; suspended solids 1700 - 1765 mg/l; volatile suspended solids 88 - 82% grease 3840 - 7930 mg/l; 5 day BOD 6200 - 4100 mg/l. These figures vary depending on the kind of fish being processed.

Fish reduction plants create a slightly different pollution problem. Beall (1933) studied the effluent of reducing plants in British Columbia and found the following: .57% oil, 1.91% suspended meal, 2.96% dissolved protein. The surrounding

waters were cloudy. Further analysis of the same effluents (Beall, 1937) revealed 7.6% nitrogenous protein, 35.9% proteose, 26.9% peptone, 28.5% subpeptone. A plant of moderate capacity in the area produced 6000 liters effluent per hour (Hart, Marshall, Beall, 1933). Praessler and Davis (1956) in a general review of the fish reduction processing characterized the wastes by high BOD but limited in volume.

The industry has not concentrated on the clean-up of effluent as such, but has concentrated on better usage of the scrap and the recovery of scrap from the effluent as an added source of revenue. The oils in the effluent which are present both in canning and reduction waste waters, and the industrial utilization of the oils are discussed by Brocklesby and Dendstedt (1933). Cooke and Carter (1947) suggested the following uses for fish scrap: fish meal, protein hydrolysates (in cases of impaired digestion), amino acids (fortify vegetable protein feeds), fish glue, plastics, synthetic egg-white, guanine, cysteine, fish oils, etc. Fladmark (1952) patented a method of rendering fish scraps to "glue water". This substance could be used in cattle feed, soup extracts and glue. Freeman and Hoogland (1956) described a method of treating cod and haddock with either sulfuric hydrochloric or lactic acid bacteria which converts the scrap or offal into ensilage and keeps indefinitely. With the addition of a proper neutralizer, the offal can be mixed with chicken and hog rations. Landgraf, Miyauchi and Stansby (1951) suggest the use of viscera and eggs as food in fish hatcheries. Lee (1958) reported that fungicides could be manufactured from fish oils. Needlen (1931) described the utilization of scrap for oil, fish meal, fertilizer, glue.

There are numerous papers dealing with treatment of the effluent. The primary difficulty in any kind of treatment is the high BOD and grease content. Claggett and Wong (1969, 1971) found that a gravity clarification system using K-Flok as a coagulant was quite successful. An engineering firm (Cornell, Howland,

Hayes and Merryfield, 1972) tried using screens to remove the solids in the effluent; they found that the screens were successful but the problem remained of disposal of the solids. Dazai, Ogawa, Misono (1968) used activated sludge for waste treatment and found that as the sludge became adapted to waste water, efficiency was increased. The flotation cell technique (entrainment of minute air bubbles which float particles to the water surface) was used with good results by Dreosti (1967). The best results were obtained with 8000 mg/l of suspended solids, minimum air flotation, short oscillation times. Sludge was skimmed from the surface and the use of coagulants increased efficiency.

Centrifuges have been used to remove fish pulp from waste streams (Jaegers and Haschke, 1956; Sweco, 1972). Stenzel (1943) suggested subdividing the waste material into particles fine enough that cohesion did not occur upon dispersion into water. Pretreatment with  $\text{FeCl}_3$  (Venz, 1971) increased biological purification by 30% for the 5 day BOD. In comparing activated sludge and the trickle filter process, the former was twice as effective as the latter.

The effects on the local marine life from the effluents has not been dealt with to any extent. In an open system such as Hart, Marshall, Beall (1933) investigated on Vancouver Island, there was no evidence that the effluent interferred with spawning in the local herring population; however high pollution was periodic.

Nakatani, Beyer, Staude (1971) observed a change in the animal population in his studies on salmon effluent at Petersburg, Alaska. The fish scavengers, particularly whiting, herring, dolly varden, red irish lord, lemon sole, and sculpin, plus sea urchin and white sea anemone increased in numbers while other animals decreased in numbers.

The direct effect on the environment of the effluents would involve the following parameters: the circulation patterns of the receiving water and whether the effluents are dumped into an

open ocean situation where the maximum effects would be reduced by dispersion or into a closed situation such as a bay or estuary with little to no exchange with the open ocean. A second parameter is the concentration of the effluents. Reduction plants have been characterized as having high concentration, low volume effluent, while the opposite applies to canneries. Obviously the concentration is more important than the volume. A third parameter is the length of time the environment is subjected to the effluents. If the effluents are dispersed into the receiving waters at irregular intervals, the environment will recover between peak periods. The fourth parameter is the BOD. The level of BOD is linked with all of the previously described parameters. If BOD at any time reaches zero, then there is destruction of aerobic organisms and recovery of the area to a "normal condition" depends on reintroduction of animals from nearby "healthy areas".

There appears then to be several pathways to improving the water quality at fish processing plants. One pathway is better utilization of fish wastes, the second is improved methods of treatment of the effluent. In various studies, fish scrap, although varying in amount from fish to fish, has been estimated at 30 - 80% wastage. The grease content also varies not only from species to species (.3% cod and haddock; 6% herring) but from catch to catch for the same fish (6.5 - 7.5% herring, Matusky et al., 1965; 8 - 13% herring, Thomsen, 1970). Therefore the development of a uniform method of treating effluents for the fish industry would be difficult without even considering the fish reduction plants.

In the following pages some of the pertinent literature is listed, along with notations as to the articles' content. The references relate to the history of the fishing industry on the Pacific Coast, products of the industry, processing methods and effluent effects and treatment.

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Pilchards are processed and reduced to oil and meal, the waters surrounding reduction plants are cloudy during peak periods of activity. The effluent consists of .57% oil, 1.91% suspended meal, 2.96% dissolved protein. Article discusses improved ways of processing to reduce waste in the effluent.

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- Compares various water clarification systems, gravity clarification system using K-Flok coagulant showed best results.
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30. Eckenfelder, W.W. and D.J. O'Connor. 1966. Biological waste treatment. Pergamon Press, N. Y.

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32. Fitch, J.E. 1952. The decline of the Pacific Mackerel fishery. Calif. Fish & Game 38(3):381-389.

A commercially important fish for canning, the peak tonnage was in 1935-6 and has since declined. Article outlines method of catching, impact of declining sardine industry on mackerel.

33. Fladmark, M. 1952. Manufacture of oil and food products from herring, whales and other sea animals. United States Patent No. 2,590,303. Chem. Abstr. 46:6855C.

Process for rendering products for "glue water", which would be used for cattle feed, soup extract, glue.

34. Freeman, H.C. and P.L. Hoogland. 1956. Acid ensilage from cod and haddock offal. In: Progr. Rep. Atlantic Coast Stat. No. 65. Fish Res. Bd. Canada, pp. 24-25.

Norwegian fisheries treat cod and haddock offal with sulfuric or hydrochloric acid or lactic acid bacteria. This treatment converts offal into an ensilage which keeps indefinitely.

35. Foess, J. 1969. Industrial and domestic waste testing program for the city of Bellingham. Cornell, Howland, Hayes and Merryfield, Inc. Seattle, Wash. 17 p.

Discusses the character of canning processing wastes.

36. Gallagher, F.S. 1959. Fish meal fertilizer wastes. Industr. Wastes 4(5):87-88.

As a pollution control measure, the clean-up of waste waters in the fish reduction processes was begun.

37. Gilde, L.C. 1967. Experiences of cannery and poultry waste treatment operations. Proc. 22nd. Indust. Waste Conf., Purdue Univ., Eng. Ext. Ser. No. 129, pp. 675-85.

Discusses treatment systems at various Campbell Soup processing plants.

38. Guttman, A. and F.A. Vanderheuvel. 1957. The production of edible fish protein from cod and haddock. In: Prog. Rep. Atlantic Coast Stat. No. 67, St. Andrews, New Brunswick, pp. 29-32.

Describes process of above.

39. Harrison, R.W., A.W. Anderson, A.D. Holmes, M.G. Pigott. 1937. Vitamin content of oils from cannery trimmings of salmon from the Columbia River and Puget Sound regions. In: Invest. Rep. No. 36. Bur. Fish., U. S. Dept. Comm. 8 p.

Not seen.

40. Hart, J.T., H.B. Marshall, D. Beall. 1933. The extent of the pollution caused by pilchard reduction plants in British Columbia. Bull. No. 39. Biol. Bd. Canada. 11 p.

The effluent from the west coast of Vancouver Island reduction plants is acid, contains 1.0% oil, 1.9% meal, 8.3% dissolved solids, 1.0% dissolved nitrogen, 3.8% solids precipitated by alcohol, 10-11% nitrogen from dried meal, 5-6% oil from dried meal. Plant during moderate capacity produced 6000/effluent/hr. In time of severe pollution, water was cloudy 220 yds. from outlet, easily measurable characteristics were greasy, white scum, heavy suspensions of meal, oxygen

deficiencies.

41. Higgin, E. 1926. A study of fluctuations in the sardine fishery at San Pedro. Calif. Fish & Game Comm. Fish. Bull. 11:125-158.

A map is presented giving the fishing areas of the harbor and San Pedro Basin. Fluctuations of the commercial catch are discussed in regards to length of sardines and tonnage of catch.

42. Hopkins, E.S. and J. Einarsson. 1961. Water supply and waste disposal at a food processing plant. Industrial Water and Wastes 6:152-154.

Wastes are treated before discharging into a water body. Method used is flotation unit, flow of .065 mgd. Resultant sludge contained 15.5 lbs. grease and 35 lbs. fish solid per day.

43. Jaegers, K. and J. Haschke. 1956. Waste waters from the fish processing industry. Wasser.-Wass. Techn. 6:311.

Centrifuges can be used to remove fish pulp from waste streams, including fats and proteins.

44. \_\_\_\_\_. 1969. Protein recovery from fish filleting waste waters. Effluent Water Treatment Journal 9:46-47.

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45. Jensen, C.L. 1965. Industrial waste from seafood plants in the state of Alaska. Proc. 20th Indust. Waste Conf., Purdue Univ., Eng. Ext. Ser. No. 118, pp. 329-350.

Proposes utilization of salmon wastes to lower price of canned salmon. Reviews various fishing industries (tuna, crab, shrimp, etc.).

46. Keil, R. and F. Randow. 1962. [Chemical and bacteriological results in waste waters of the Rostock fish works]. Wasser.-Wass. Techn. 12:391-393.

Not seen.

47. Kemp, L.L., N.E. Lake and R.C. Scherr. 1963. The U. S. tuna industry. Good Packaging 24(7):56-76.

Americans consume over 1 billion cans of tuna in a year.

48. \_\_\_\_\_. 1968. Disposal of fish processing wastes. Off. Res. Admin., Univ. Mich. Ann Arbor, Mich. 46 p.

120 gallons of stickwater produced per ton of fish processed.

49. Knowlton, W.T. 1945. Effects of industrial wastes from fish canneries of sewage treatment plants. Sewage Works Journal 17:514-515.

Large quantities of fats and grease are present in waste waters. Sardine canning waste waters produce from 1,000 to 30,000 mg/l of fat and grease compared to 50-200 mg/l from domestic sewage.

50. Landgraf, R.F., D.T. Miyauchi and M.E. Stansby. 1951. Utilization of Alaska salmon cannery waste as a source of feed for hatchery fish. Comm. Fish. Rev. 13(11a): 26-33.

Suggest use of viscera and eggs for fish hatcheries.

51. Lantz, A.W. 1948. Utilization of freshwater fish, trimmings and offal. Progr. Rep. Pac. Coast Stat. No. 76. pp. 78-80, Fish. Res. Bd. Canada.

At a filleting plant, up to 1,000 lb. of waste can accumulate per day.

52. Lassen, S. 1965. Tuna canning and the preservation of the raw material thru brine refrigeration. In: Fish as food, ed. Bergstrom, Academic Press, N. Y.

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53. Lee, C.F. 1951. Chemistry of Menhaden: report on literature study. Comm. Fish. Rev. 13(11a):11-20.

Recommends more complete use of the fish.

54. \_\_\_\_\_ 1958. Report on development of fungicides from fish oils. Comm. Fish. Rev. 20(6):20.

Not seen.

55. Limprich, H. 1966. Abwasserprobleme der Fischindustrie (Problems arising from waste waters from the fish industry). IWL-Forum 66/IV. 36 p.

Removal of grease by applying 2.59 mg clay, 2.59 mg lime and 100 mg ferric chloride/l of water. Results in 75% decrease in BOD<sub>5</sub> by precipitation. Large volumes of sludge resulted.

56. Lopez-Benito, M. 1971. Use of caustic soda to treat mackerel, horse mackerel and sardine before canning. Invest. Pesq. 35(2):531-47.

2% aqueous solution of NaOH for 2 minutes at 60-80%, followed by washing with water, neutralization with citric acid and another washing used without affecting appearance or quality of fish.

57. Lyles, C.H. 1969. *Fisheries of the United States.* 1968. C.F.S. No. 5000, Bur. Comm. Fish., U.S. Fish & Wildlife Serv., U.S.D.I. Washington, D.C. 83 pp.

The annual U. S. catch averages 6 billion pounds. The Menhaden fishery catch for 1968 was 1.4 billion pounds, and is located primarily in Middle Atlantic and Gulf states. Salmon catch in 1968 was 301 million pounds, average previous 5 years was 335 million pounds. Primary harvest area is Alaska, Washington and Oregon.

58. Magnusson, H.W. and W.H. Hagevig. 1950. Salmon cannery trimmings. Part I - Relative amounts of separated parts. *Comm. Fish Rev.* 12(9):9-12.

Discarded portions are head and collar, liver, heart, digestive tract, fins, tail section, milt (male). Trimmings from canneries in Alaska in 1949 that were discarded amounted to 80% of total waste or 251 lbs/48 lbs of canned product.

59. Matusky, F.E., J.P. Lawler, T.P. Quirk and E.J. Genetelli. 1965. Preliminary process design and treatability studies of fish processing wastes. *Proc. 20th Indust. Waste Conf.*, Purdue Univ., Eng. Extens. Ser. No. 118, pp. 60-74.

Paper outlines a process design for a sewage plant for the treatment of both domestic and fish wastes.

60. Motohiro, T. and H. Terachi. 1969. Studies on the prevention of offensive odour from fish processing plants. III. Diffusion of the odorous gas in air and effective height

of an exhaust stack. Bull. Fac. Fish. Hokkaido Univ. 20(3):235-241.

The odorous gases were found to consist of ammonia, trimethylamine, hydrogen sulfide and indol. The authors by use of a formula involving the following factors, concentration of gases, height at which gases diffused, average wind velocity, distance downwind of affected site from fish-processing plant, angle at which gases diffused, were able to determine the height of the emission stack at which odor would be minimized.

61. Nachenius, R.J. 1964. Stickwater evaporator fundamentals. Fishing News International 3(3):53-54.

Not seen.

62. Nakatani, R.E., D.F. Beyer, and C.P. Staude. 1971. The effects of salmon cannery waste on water quality and marine organisms at Petersburg, Alaska. Fish. Res. Inst. Col. Fish., Univ. Wash., Seattle, Wash.

Dissolved oxygen dropped during peak canning. Some fish scavengers, particularly whiting herring, dolly varden, red irish lard, lemon sole, and sculpin plus sea urchin and white sea anemone feed on salmon tissue debris. Other animals decreased in numbers.

63. Needlen, A.B. 1931. The haddock. Bull. 25, Biol. Bd. Canada. 28 p.

Describes the fish, its distribution, habitat, migration, spawning, etc. Also discusses fish industry of haddock and the scrap.

64. North, W.J. and M.B. Schaefer. 1964. An investigation of the effects of discharged wastes on kelp. Calif. State Water Qual. Contr. Bd. Publ. No. 26. 124 p.

Report deals with various effluents which are dumped into southern California waters and their effects on a kelp bed. Considers role of sea urchin in the destruction of kelp beds and methods of control.

65. Pottinger, S.R. and W.H. Baldwin. 1946. The content of certain amino acids in seafoods. Comm. Fish. Rev. 8(8): 5-9.

Analysis of various fish for percentage of various amino acids (arginine, histidine, lysine, tryptophane, cysteine).

66. Power, H.E. 1963. A report to the fishing industry on the characteristics of fish protein concentrates made from various raw materials. N. Ser., Circ. 15, Fish. Res. Bd. Canada, Tech. Res. Lab., Halifax. 2 p.

Not seen.

67. Praessler, A.H. and R.V. Davis. 1956. Waste waters from Menhaden fish oil and meal processing plants. Proc. 11th Industr. Waste Conf., Purdue Univ., Eng. Extens. Ser. No. 71, pp. 371-388.

Map showing distribution of menhaden fish processing plants on both coasts of North America. Waste characterized by high BOD.

68. Roedel, P.M. 1952. A review of the pacific mackerel (*Pneumatophorus diego*) fishery of the Los Angeles region with special reference to the years 1939-51. Calif. Fish & Game. 38(2):253-273.

Not seen.

69. Sanford, F.B. 1951. Utilization of fishery by products in Washington and Oregon. Fishery Leaflet 370. Comm. Fish Rev. 13(11a):35.

Fish waste in Washington and Oregon at a minimum. Almost total utilization of fish scrap.

70. \_\_\_\_\_. 1957. Utilization of fish waste in northern Oregon for mink feed. Comm. Fish Rev. 19(12):40-47.

Not seen.

71. Scofield, W.L. 1952. The Tomales Bay herring industry. Calif. Fish & Game 38(4):499-504.

Article reviews the history of the herring fishing industry in Tomales, discusses various means of catching the fish.

72. Scofield, N.B. 1918. The herring and the development of the herring industry in California. Calif. Fish & Game 4(2): 65-70.

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73. Severence, H.D. 1932. Control of cannery odors at Monterey. Sewage Works Journal 4:152.

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74. Slavin, J.W. and J.A. Peters. 1965. Fish & fish products. In: Industrial Wastewater Control, C. Fred Gurnham, ed., Academic Press, N.Y.

Distinguishes wastes by the type of fish and the technique of processing.

75. Soderquist, M.R., K.J. Williamson, G.I. Blanton. 1970.

Seafoods processing: pollution problems and guidelines for improvement. In: Pacific Northwest Laboratories et al., Proceedings First National Symposium on Food Processing Wastes. Fed. Water Qual. Admin., Water Pollution Contr. Res. Ser. 12060 04/70, pp. 189-225.

A significant portion of the fishes and shellfishes is wasted. The average wastage figure for all fish and shellfish is about 30 percent. In addition to these large volumes of solid wastes, significant waste water flows result from the butchering, washing and processing of the products. The volumes of solids and waste water vary widely with sea foods and processing methods.

76. Soderquist, M.R., K.J. Williamson, G.I. Blanton, D.C. Phillips, D.K. Law, D.T. Crawford. 1970. Current practice in seafoods processing waste treatment. Envir. Protect. Agency Water Quality Off. Dept. Food Sci. & Techn., Oregon State Univ., Cawallis, Oregon.

Discusses processing of various fish and shellfish, product quantity, projected catches, waste quantities, products of the fish industry, treatment of waste water and recommendations for solid and liquid wastes.

77. Stansby, M.E. Processing of seafoods. In: Food Processing Operations.

Details on shore preparation of seafoods. Little discussion as to wastes.

78. \_\_\_\_\_. 1959. The processing of Tuna. In: Tuna Industry Conference Papers, Circ. 65. Bur. Comm. Fish., Fish & Wildlife Serv., U.S.D.I., Wash., D.C. pp. 76-85.

Not seen.

79. \_\_\_\_\_. 1960. Possibilities for applying fish oil to ore-flotations. Comm. Fish. Rev. 22(2):17-21.

Not seen.

80. Stenzel, R.W. 1943. Treating oily waste water such as those from fish-canning vegetable oil plants. U.S. Patent 2,303,588. Chem. Abstr. 37:2500.

Subdivide waste material and dispose it into H<sub>2</sub>O in fine, stable particles 10 m. or less. Particles fine enough so can be dispersed into body of H<sub>2</sub>O and do not cohere.

81. Sweco, Inc. 1972. The Sweco centrifugal waste water concentrator as a means of treating fish canning effluent. Sweco, Inc., 6033 E. Bandini Blvd., Los Angeles, 90054.

Discusses a method of removing solids from the effluent. Blue prints included.

82. Tanzler, K.H. 1942. Waste waters from fish meal factories. Gesundheitsing 65:157.

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83. Tetsch, B. 1954. [Separators from light material in waste waters, technique with special reference to waste waters from the fish industry]. Bu. Abwass. Techn. Verein 9:278-286.

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84. \_\_\_\_\_. 1964. Report on waste disposal in Pago Pago Harbor, Tutuila, American Samoa. Kennedy Engineers. San Francisco, Calif.

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85. \_\_\_\_\_. 1969. Maine sardine waste survey. Res. Rep. 2-69. Wash. Res. Lab., Natl. Canners Assoc., Washington, D.C. 6 pp.

Not seen.

86. Thomsen, V. 1970. Processing of herring for food. In: Proceedings conference on automation and mechanization in the fishing industry. Canadian Fish. Rep. No. 15. pp. 265-6.

Fat content of herring differs from catch to catch and day to day from 8 to 13%.

87. Tschekalin, P.M. 1951. Production of an adhesive substance from waste waters from processing plants. Chem. Zbl. 1228, II:1382-1383.

Not seen.

88. VandenBroek, C.J. 1965. Fish canning. In: Fish as food, vol. IV, ed. Bergstrom, Academic Press, N.Y.

General discussion of the process of fish canning, no mention of wastes.

89. Ventz, D. 1971. Aspects of waste water treatment in the fishing industry. Fortschr. Wasserchem. Ihrer Grenzgeb 13:81-6.

Waste water from fish processing plants contains large amounts of fats and proteins, result is that emulsification and biological purification is less effective. Pre-treatment with FeCl<sub>3</sub> increased purification by 30% in regards to the 5 day BOD. Secondary treatments showed that the activated sludge treatment was twice as effective as the trickle filter process.

90. Washington Sea Grant. 1972. Total utilization concept fish and shellfish processing wastes. Sea Grant Publ.  
WSG-WO-72-1.

Not seen.

91. U. S. Dept. Commerce. 1971. Industrial fishery products, situation and outlooks.

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92. Washington, Univ. of, Fisheries Research Institute. 1971. Salmon cannery waste study, Briston Bay and Kodiak Island, Alaska, 1970. 76 pp.

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Marine Studies of San Pedro Bay  
Part II, Biological Investigations  
June, 1973

Results of Fourteen Benthic Trawls Conducted in the  
Outer Los Angeles - Long Beach Harbor, California,  
May 24, 1972

by

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### Abstract

A preliminary survey of harbor fish populations consisting of fourteen ten-minute bottom trawls, using a 15-foot, semi-balloon, otter trawl, was done in the outer Los Angeles - Long Beach Harbors on May 24, 1972.

Trawling in depths of 20 to 60 feet yielded 3100 fish belonging to 28 species, representing 15 families and 7 orders, for an average of 221 fish per trawl.

Five species made up 85 percent of the total catch. The most abundant species caught was the speckled sanddab, Citharichthys stigmaeus Jordan and Gilbert.

Larvae, juveniles and adults of a number of species were captured.

White croaker, Genyonemus lineatus (Ayres), taken near sewage outfall areas had a high incidence of caudal fin erosion.

Speckled sanddabs taken in the same area had a high incidence of infestation by isopod parasites.

Condition factors for white croaker and white seaperch, Phanerodon furcatus Girard, from the harbor, showed that these two species were heavier for their length than fish from open coast areas.

The harbor has long been one with moderate to heavy pollution and a number of fish taken from it had been reported to be in poor condition. Fish collected in this operation were generally in good health. This may be a reflection of recent pollution abatement activities or of limited sampling.

## Introduction

Pollution surveys and ecological studies have been conducted in the Los Angeles - Long Beach Harbor area for a number of years. These efforts have been concerned primarily with the physical and chemical properties of the harbor waters (Anon., 1957; Los Angeles Regional Water Pollution Control Board, 1952) and with benthic invertebrates (Crippen and Reish, 1969; Menzies, Mohr and Wakeman, 1964; Reish, 1955, 1959, 1961a, 1961b; Stone and Reish, 1965; Soule and Soule, 1971).

Reish (1971), in the most recent survey of overall harbor conditions, reports that since the summer of 1970 environmental factors that favor the growth of animals and plants in the inner harbor have been improving and benthic populations of animals in the outer harbor resemble populations of animals in other, nearby unpolluted marine areas.

The most recent work on fish in the harbor was a study of the California halibut, Paralichthys californicus (Ayres), made by the California Department of Fish and Game near Long Beach during the four year period, 1956-1960 (Young, 1964). The general condition of fish taken at that time was "poor". White seabass, Cynoscion nobilis (Ayres), and white croaker, Genyonemus lineatus, taken then had exophthalmia. Spotted turbot, Pleuronichthys ritteri Starks and Morris, were thin and in "very poor" condition (Young, 1964). The term poor was used by Young, (1964) to describe the state of the fish. Pollution was suggested as the factor influencing these conditions.

Considerable information has been recently collected by a number of workers on benthic fish populations in southern California. The areas sampled are located along the California coast from Pismo Beach south to San Diego and seaward to the northern Channel Islands, and also include Santa Catalina Island, Cortes and Tanner Banks. Areas that have received considerable

attention include: Santa Monica Bay (Carlisle, 1969; Mearns, MS 1971), Palos Verdes Peninsula (Douglass Hotchkiss, Los Angeles County Sanitation District, pers. comm.; Mearns, MS 1971) and San Pedro Bay (John Stephens, Occidental College, pers. comm.; Mearns, MS 1971).

Fish populations in three nearby harbors have recently received greater attention than the Los Angeles - Long Beach Harbor complex. Fish populations and behavior studies have been conducted at King Harbor in Redondo Beach (John Stephens and Harry Hickman, Occidental College, pers. comm.). Reish (1968) has done biological surveys of Alamitos Bay which included the resident fishes. Fish sampling surveys have been done in Anaheim Bay (Lane, 1971). Workers at the Southern California Coastal Water Research Project (SCCWRP) are compiling and summarizing trawl data from various southern California coastal areas exclusive of harbors (Alan Mearns, SCCWRP, pers. comm.).

Twelve years have passed since the fish populations in Los Angeles - Long Beach Harbor have been studied to any extent. The increased use of the harbor by shipping and industry, by anglers, by commercial bait boats, the considerable time span since the last study and the possible effects of recent clean-up efforts served to indicate that an assessment of the fish populations in the harbor was needed.

Under sponsorship of the University of Southern California - Sea Grant Program for harbors and beaches, a preliminary fish survey of the Los Angeles - Long Beach outer harbor area was conducted on May 24, 1972. This paper presents the results of that survey, including the species taken, and the physical condition of the fish populations.

### Methods

The trawling operations were conducted aboard the R/V Vantuna, an 85-foot, oceanographic research vessel owned and operated by Occidental College, Los Angeles, California.

Benthic fishes were collected with a semi-balloon otter trawl having a 15-foot wide mouth. Wooden otter boards were used to spread the mouth of the net and the net and otter boards were attached to a 1/2-inch towing cable by a single bridle. The body of the net was woven of No. 9 nylon and had a mesh size of 1 1/2-inch (stretched measure). A cod end liner of 1/2-inch mesh size (stretched measure) and woven of No. 63 nylon was used.

The net was set and retrieved while the ship was under way at a speed of about 2 knots. A cable length to depth ratio of approximately 5:1 or 6:1 was used to insure bottom contact and proper fishing. A total of 14 trawls (Figure 1) were made and each one (except for trawl No. 1) was for a period of 10 minutes.

Duration of each trawl was taken as the period of time between the point at which the net was on the bottom and the point where retrieval of the net was started.

The trawling was done in outer Los Angeles - Long Beach Harbor, starting at Long Beach with the first trawl and working towards the Cabrillo Beach area in depths of from 20 to 66-feet on a black sandy-mud bottom. Fathometer indications of a rough bottom in addition to a torn net put an end to close inshore trawling in the Long Beach area. Twelve trawls were done parallel to the breakwater and two were at right angles to the breakwater, one parallel to the Main Channel and one parallel to the Long Beach Channel.

All trawling was accomplished during daylight hours between 0800 and 1430 hours. Trawl depths averaged 42 feet with the shallowest at 20 feet and the deepest at 66 feet.

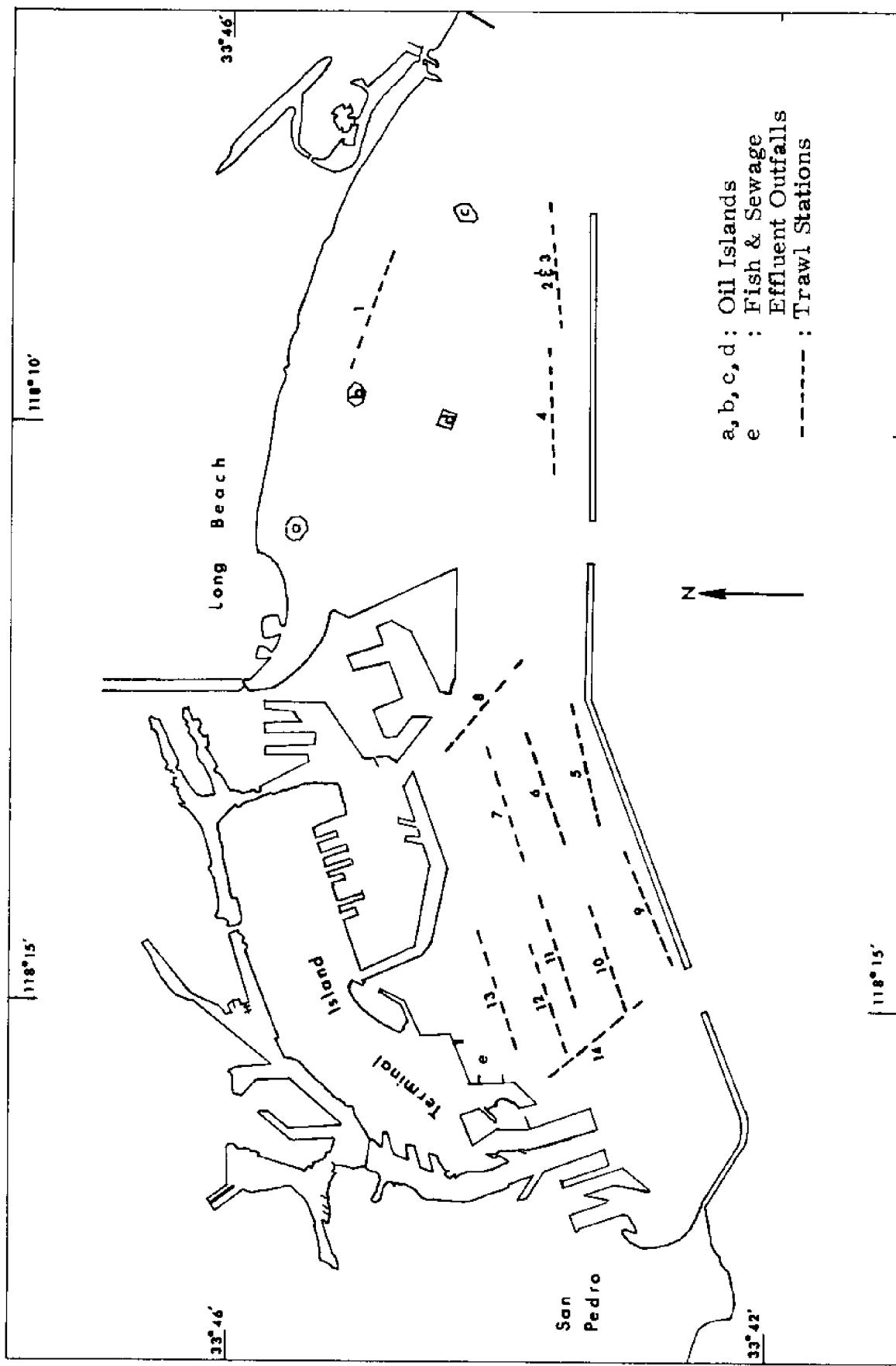


Figure 1. Location of Los Angeles - Long Beach Harbor Trawling Stations.

A Nansen bottle of 1.5 liters capacity with attached protected, reversing thermometer was used to collect bottom water samples and temperatures. Water salinities were measured on a Beckman portable induction-type conductivity salinometer and pH was measured with a Beckman electrical pH meter.

Bottom water salinities averaged 33.813 ‰, bottom water temperatures averaged 14.6°C and bottom water pH averaged 8.11.

The majority of the fish captured were identified, sorted into taxonomic groups, measured and arranged into size classes on board ship. All other fish were preserved in 10 percent formalin and identification, weighing and measuring were completed ashore. All fish were examined for external parasites, disease and growth anomalies. Formalin preserved fish were later washed in water and transferred to 40 percent isopropyl alcohol. The material is presently stored at the University of Southern California.

### Results

A total of 3100 fish representing 7 orders, 15 families and 28 species (Table 1) were collected during the one day sampling effort. Most of the fish collected are considered to be demersal species. Five species made up 85 percent (2653 individuals) of the total catch. The other 23 species were represented by 447 individuals. Only one species was represented by more than 1000 individuals (1025). Five species were represented by more than 100 individuals and 10 species were represented by more than 50 individuals.

The speckled sanddab, Citharichthys stigmatus Jordan and Gilbert, was the most abundant species (1025 individuals), followed by the tongue sole, Syphurus atricauda (Jordan and Gilbert), (601 individuals), and the white croaker, Genyonemus lineatus (Ayres), (545 individuals). Together these three species accounted

TABLE 1

Fishes taken by benthic otter trawling in Los Angeles - Long Beach Harbor, May 24, 1972

Common name	Scientific name	No. of trawls where present	Number collected	Size range (TL, mm)	Largest
Speckled sanddab	<u>Citharichthys stigmatus</u> <sup>2</sup>	9	1025	53	129
Tongue sole	<u>Sympodus atricauda</u> <sup>2</sup>	13	601	55	170
White croaker	<u>Genyonemus lineatus</u> <sup>12</sup>	12	545	19	330
Shiner perch	<u>Cymatogaster aggregata</u> <sup>12</sup>	11	249	34	161
White seaperch	<u>Phanerodon furcatus</u> <sup>12</sup>	11	233	45	250
Specklefin midshipman	<u>Porichthys myriaster</u> <sup>2</sup>	8	74	60	405
Rockfish	<u>Sebastodes</u> sp.	3	65	49	153
Bay goby	<u>Lepidogobius lepidus</u>	7	54	28	89
Hornyhead turbot	<u>Pleuronichthys verticalis</u> <sup>2</sup>	8	54	62	285
Queenfish	<u>Seriophus politus</u> <sup>2</sup>	10	51	80	170
Bocaccio	<u>Sebastes paucispinis</u> <sup>2</sup>	7	36	40	390
Stripetail rockfish	<u>Sebastes saxicola</u> <sup>2</sup>	3	32	52	150
Rubberlip perch	<u>Rhacochilus toxotes</u> <sup>2</sup>	8	22	71	215
Curlfin turbot	<u>Pleuronichthys decurrens</u> <sup>2</sup>	5	18	125	216
Northern anchovy	<u>Engraulis mordax</u> <sup>2</sup>	4	12	78	161
California halibut	<u>Paralichthys californicus</u> <sup>12</sup>	2	5	310	507
Pygmy poacher	<u>Odontopyxis trispinosa</u> <sup>2</sup>	2	4	75	92
English sole	<u>Parophrys vetulus</u> <sup>2</sup>	3	3	298	316
Staghorn sculpin	<u>Leptocottus armatus</u>	3	3	128	142
Black perch	<u>Embiotoca jacksoni</u>	1	2	153	167
Bat ray	<u>Myliobatus californicus</u>	2	2	-	-
Walleye surfperch	<u>Hyperprosopon argenteum</u> <sup>12</sup>	2	2	137	162
Chillipepper	<u>Sebastodes goodei</u> <sup>2</sup>	1	2	128	155
Dogfish	<u>Squalus acanthias</u> <sup>2</sup>	1	2	515	2440
Flag rockfish	<u>Sebastes rubrivinctus</u> <sup>2</sup>	1	1	-	162

TABLE 1 Continued

Fishes taken by benthic otter trawling in Los Angeles - Long Beach Harbor, May 24, 1972

Common name	Scientific name	where present	collected	Size range (TL, mm)	Largest
Diamond turbot	<u>Hypsopsetta guttulata</u> <sup>2</sup>		1	—	212
Spotted cusk-eel	<u>Otophidium taylori</u> <sup>2</sup>		1	—	246
Kelp pipefish	<u>Syngnathus californiensis</u> <sup>2</sup>		1	—	205

1 Found also in Alamitos Bay, California (Reish, 1968)

2 Found also in Santa Monica Bay, California (Carlisle, 1969)

for 70 percent (2171 individuals) of total number taken. The next two most abundant fish were the shiner perch, Cymatogaster aggregata Gibbons, and the white seaperch, Phanerodon furcatus Girard. These two species accounted for 15.5 percent (482 individuals) of the total taken. The remaining 23 species accounted for 14.5 percent (447 individuals) of the total.

Five of the fifteen families represented in the catch had more than one species present. Families represented by four or more species were the Embiotocidae (5 species), the Scorpaenidae (5 species) and the Pleuronectidae (4 species).

An average of 221 fish were captured in each ten minute trawl. The majority of the fish captured were distributed over twelve of the 14 trawls. The first trawl yielded only 3 fish. In this trawl the net fished for only 1.5 minutes before it was torn. The second trawl, although of 10 minutes duration, yielded only one fish. The reason for this low yield is not known, we can only assume that the net did not open properly or did not reach the bottom.

No one species was collected in all 14 trawls. Queenfish, Seriphus politus Ayres, shiner perch, tongue sole, white croaker and white seaperch were all present in 10 or more trawls (Table 1).

#### Condition Factors

Coefficients of condition, K, or condition factors, were calculated from total lengths and round weights of the three most abundant fish species collected in the harbor trawling. These were averaged and compared with the average coefficients of condition for the same three species taken in areas removed from the harbor influence. The coefficients of condition were calculated according to the formula

$$K = \frac{W \times 10^5}{TL^3}$$

where W = the total weight in grams and TL = the total length in millimeters (Hoyt, 1971). Fish with higher K values are heavier for their lengths than those with lower values.

Average coefficient of condition values were higher for white croaker and white seaperch taken in Los Angeles - Long Beach Harbor than K values for these species taken from populations at Port Hueneme, California. The average K value for speckled sanddabs from the Los Angeles - Long Beach Harbor was lower, however, than the K value of fish from Palos Verdes, California, adjacent to the harbor, but were higher than the average K value of speckled sanddabs taken in British Columbia, Canada (Table 2).

Coefficients of condition varied between different length-groups of the same species of harbor fish. The average value of K for 130-180 mm white seaperch was lower ( $K=1.097$ ) than for fish in the 180-240 mm group ( $K=1.139$ ). The average value of K was higher in 150-180 mm white croaker ( $K=1.463$ ) than in the 180-230 mm group ( $K=1.245$ ). The average K value for 50-100 mm speckled sanddabs was lower ( $K=0.893$ ) than the value for the 100-130 mm group ( $K=0.917$ ). A similar trend was observed between the same size class groups of speckled sanddabs from Palos Verdes and British Columbia.

#### Disease and Abnormalities

Caudal fin erosion (fin rot) was present in two species of fish collected in the outer harbor. Of 528 white croaker 96 were affected, giving an incidence of 18.2 percent. Fin erosion was more prevalent in older croakers but was not seen in those above 270 mm in total length. The highest incidence occurred in fish between 180 mm and 240 mm. Thirty-two percent of the 220-240 mm group fish were affected (Figure 2). Severity of fin erosion in

TABLE 2

Average coefficients of condition for three species of fish taken from various locations in California and from one location in Canada.

	White seaperch	Speckled sanddab	White croaker
Los Angeles - Long Beach Harbor, California	1.114	0.916	1.272
Port Hueneme, California	1.103	-	1.062
Palos Verdes Peninsula, California	-	0.986	-
British Columbia, Canada	-	0.815	-

With caudal fin erosion

Figures above shaded areas  
are percentage of size class

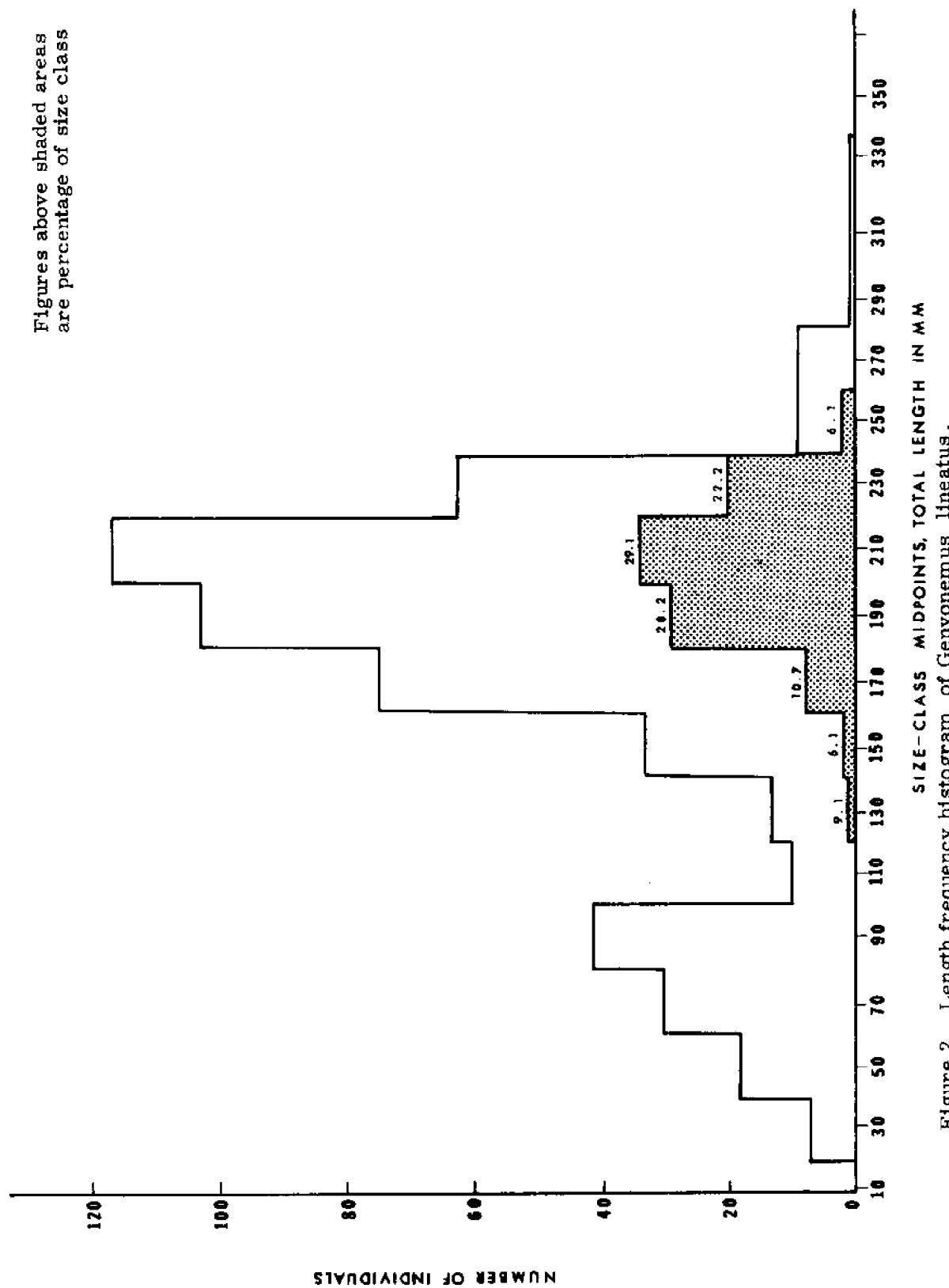


Figure 2. Length frequency histogram of Gennemus lineatus.

the white croaker ranged from light to heavy. Light erosion involved one to a few fin rays and a slight reddish coloration was present. In severe cases the caudal fin was completely eroded away down to the posterior margin of the hypural plate and the surrounding tissues were swollen and hemorrhagic. The majority of the cases of fin erosion seen were moderate to severe. White croaker from trawls No. 12 and No. 13 had a much higher number (36.2 percent) affected with fin erosion than those from the other trawls (2.2 percent) within the outer harbor. These two trawls were in the area where the Terminal Island sewage outfall and two fish cannery outfalls empty (Figure 1).

Two white seaperch out of 122 had caudal fin erosion for an incidence of 1.6 percent. These two individuals were not heavily affected.

Exophthalmia was seen in 2 or 3 white croakers. The exact incidence was not recorded.

External parasites were present on three species of fish. The gill chamber of speckled sanddabs from the harbor were infested with the isopod parasite, Livonica vulgaris Stimpson (Crustacea: Cymothoidae). The parasites were present in 294 out of a total catch of 1010 individuals for an incidence of 29.1 percent (Figure 3). Higher incidences of this parasite were present in sanddabs trawled near the outfalls previously mentioned than from trawls further removed from the area. Livonica vulgaris was found to inhabit the gill chamber either on the blind or on the eyed side, but rarely on both. After death of the host fish, L. vulgaris tends to leave the gill chamber. The site of attachment is well defined since the gills are characteristically pushed aside and deformed. The evidence for the incidence of this parasite was based primarily on the presence of the gill deformity rather than on the actual presence of the parasite at the time of inspection.

The mouth cavity of a number of speckled rockfish, Sebastes ovalis (Ayres), was inhabited by females of the copepod parasite, Brachiella robusta (Wilson, 1912). These were present in small

numbers in each fish parasitized. These parasites are relatively small (ca. 4 mm in length) compared to their host, and are found attached to the inside of the upper and lower jaw, and to the vomer and pharynx. One of the two dogfish, Squalus acanthias L., collected had copepod parasites present on its dorsal, caudal and pectoral fins. These were females of Pandarus bicolor Leach, 1816. Neither species of parasite caused a lesion or ulceration of consequence. Both parasites are of the family Lernaeopodidae (Crustacea).

Three white croakers had small, green, leech-like parasites, probably marine leeches of the family Piscicolidae (Annelida: Hirudinea), attached to the anterior part of the head near the mouth.

A speckled sanddab (111.0 mm total length) had one medium-sized (7.0 x 6.5 mm) tumor present on the caudal fin. This was the only fish observed in the entire catch with a visible tumor.

#### Length Frequencies

Length frequency histograms were constructed from data collected on 9 of the 10 most abundant species of fish captured in this trawl survey. No length frequency data is available for the tongue sole, Syphurus atricauda (Jordan and Gilbert), that were collected.

The size range (total length) of white croaker collected was almost equal to their known size range (Roedel, 1953). Included in the catch of this species were larvae, juveniles and adults. The best represented size-classes were at 190 and 210 mm, with 55 percent of the croakers falling into these two classes (Figure 2). There were two peaks in the numbers of croakers per size-class, one at around 85 mm and a larger one at 210 mm. This species matures at about 50 mm total length and the individuals captured

were mostly adults. Some larvae were taken. The largest individuals taken (330 mm) were slightly under the maximum size that this species reaches (ca. 380 mm).

The lengths of speckled sanddabs collected ranged from 53 to 129 mm and were all adults. The largest individuals taken were somewhat under the maximum length that this species attains which is about 170 mm (Ford, 1965). Over 57 percent of the sanddabs collected were between 70 and 100 mm in total length (Figure 3).

White seaperch ranged from 45 to 250 mm in length; the largest were under the maximum size (ca. 300 mm) for this species. Thirty-three percent were in the 150 mm size-class range. No individuals under 45 mm were taken (Figure 4).

Length frequency histograms (Figure 5) for the shiner perch show two size-groups present in the catch. The smaller fish are in a 40 to 80 mm group and the larger ones in a 100 to 170 mm group. Individuals in the smaller group represent young, born this year (Carlisle, 1960, p. 60). Live young were removed by hand from pregnant females. These young fish were equal in size to young of this species taken in the net.

The specklefin midshipman, Porichthys myriaster Hubbs and Schultz, collected were between 60 and 405 mm in total length. Fifty-six percent of these were in the 70 and 90 mm size-classes, these were the two shortest size classes taken (Figure 6). Only juveniles and adults were captured.

The queenfish, Seriphus politus Ayres, ranged in size from 80 to 170 mm, and these were juveniles and adults. Twenty-eight percent of them were in the 95 mm size-class (Figure 7).

Unidentified rockfish possibly, Sebastes umbrosus (Jordan and Gilbert), ranged from 49 to 153 mm, with 30 percent of those taken falling into the 145 mm size-class. The largest specimens were somewhat shorter than the maximum length recorded (ca. 270 mm) for this species (Figure 8).

The few boccacio, Sebastes paucispinis (Ayres), that were collected, exhibited a size range of 40 to 390 mm. These were

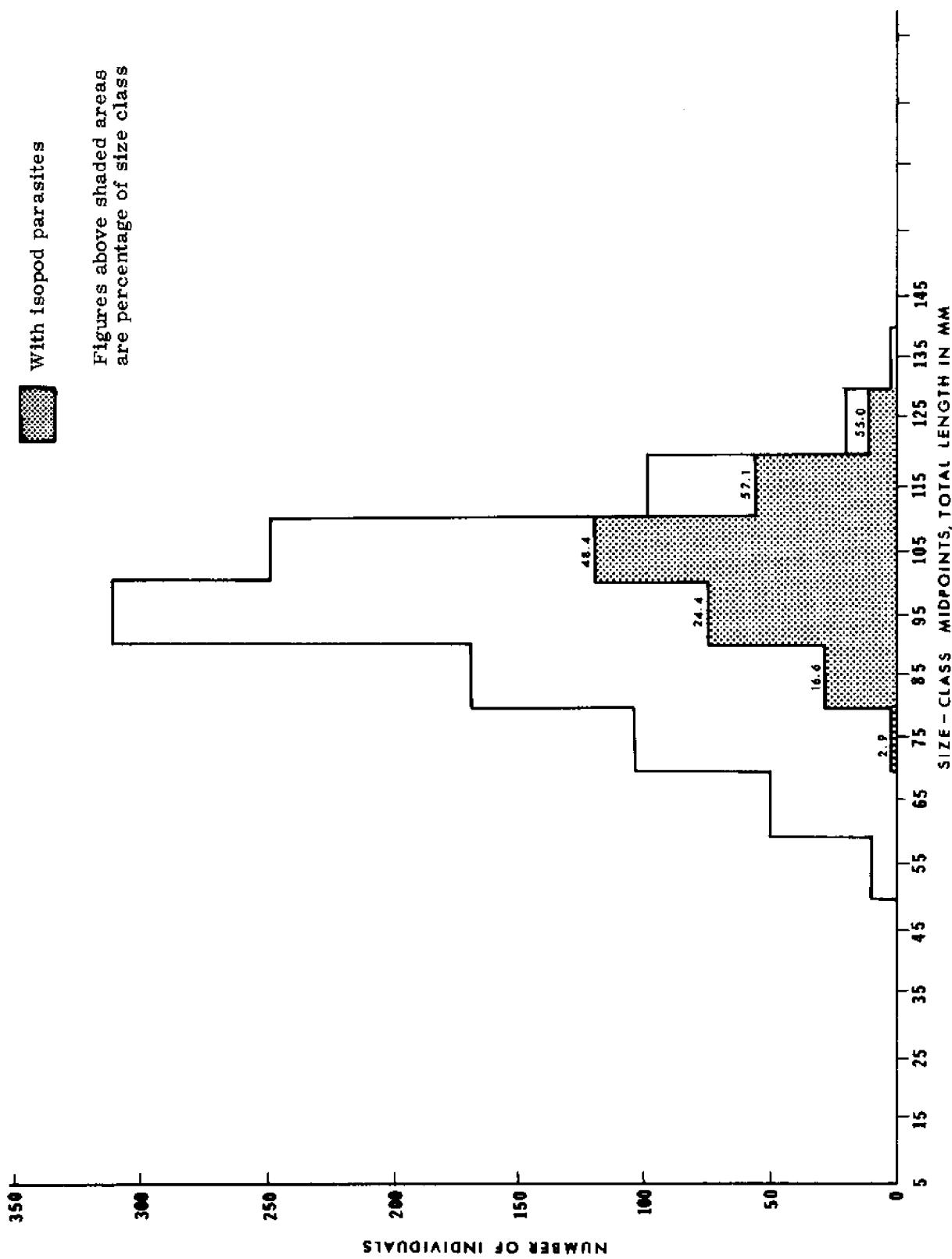


Figure 3. Length frequency histogram of Citharichthys stigmaeus.

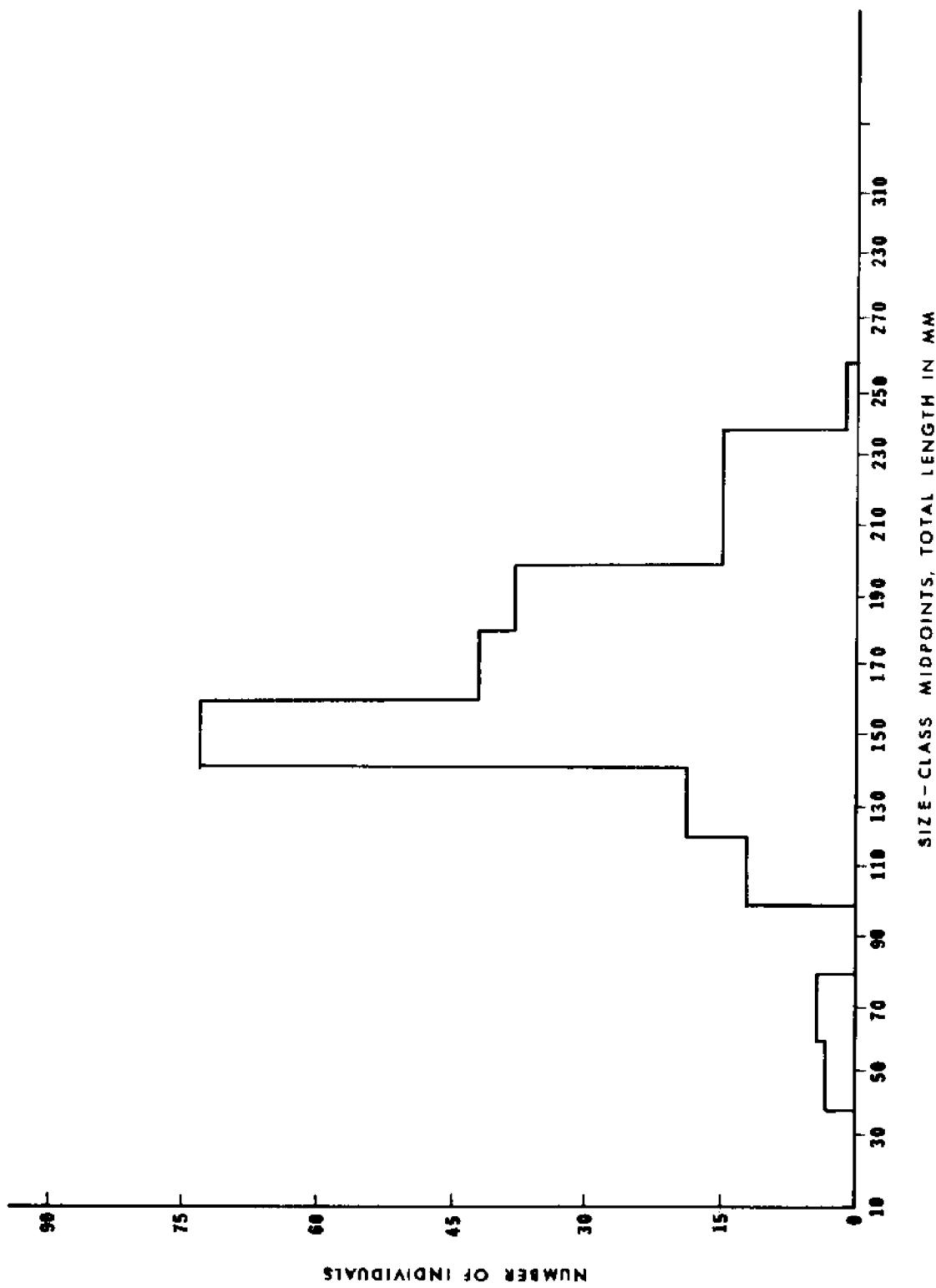


Figure 4. Length frequency histogram of *Phanerodon furcatus*.

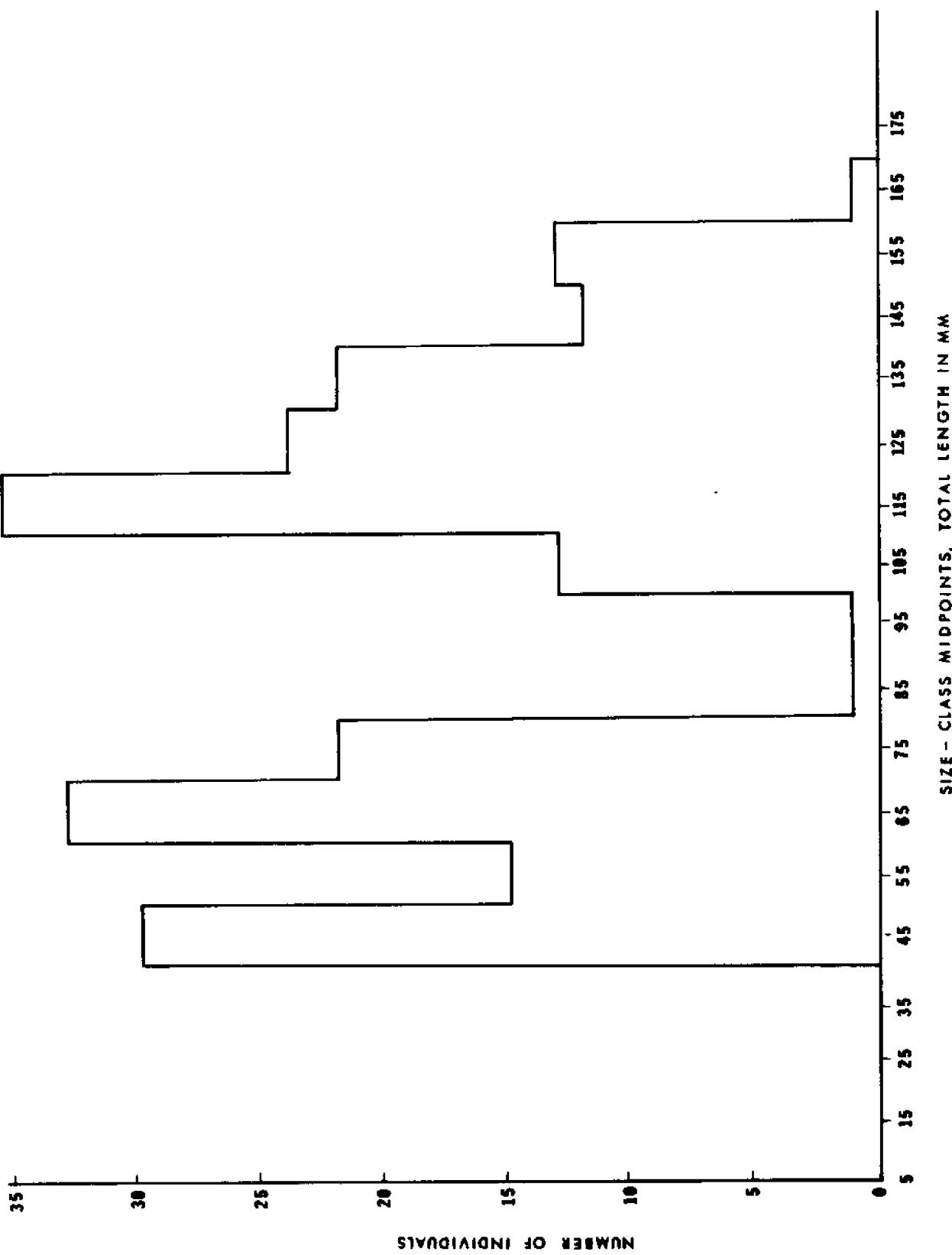


Figure 5. Length frequency histogram of *Cymatogaster aggregata*.

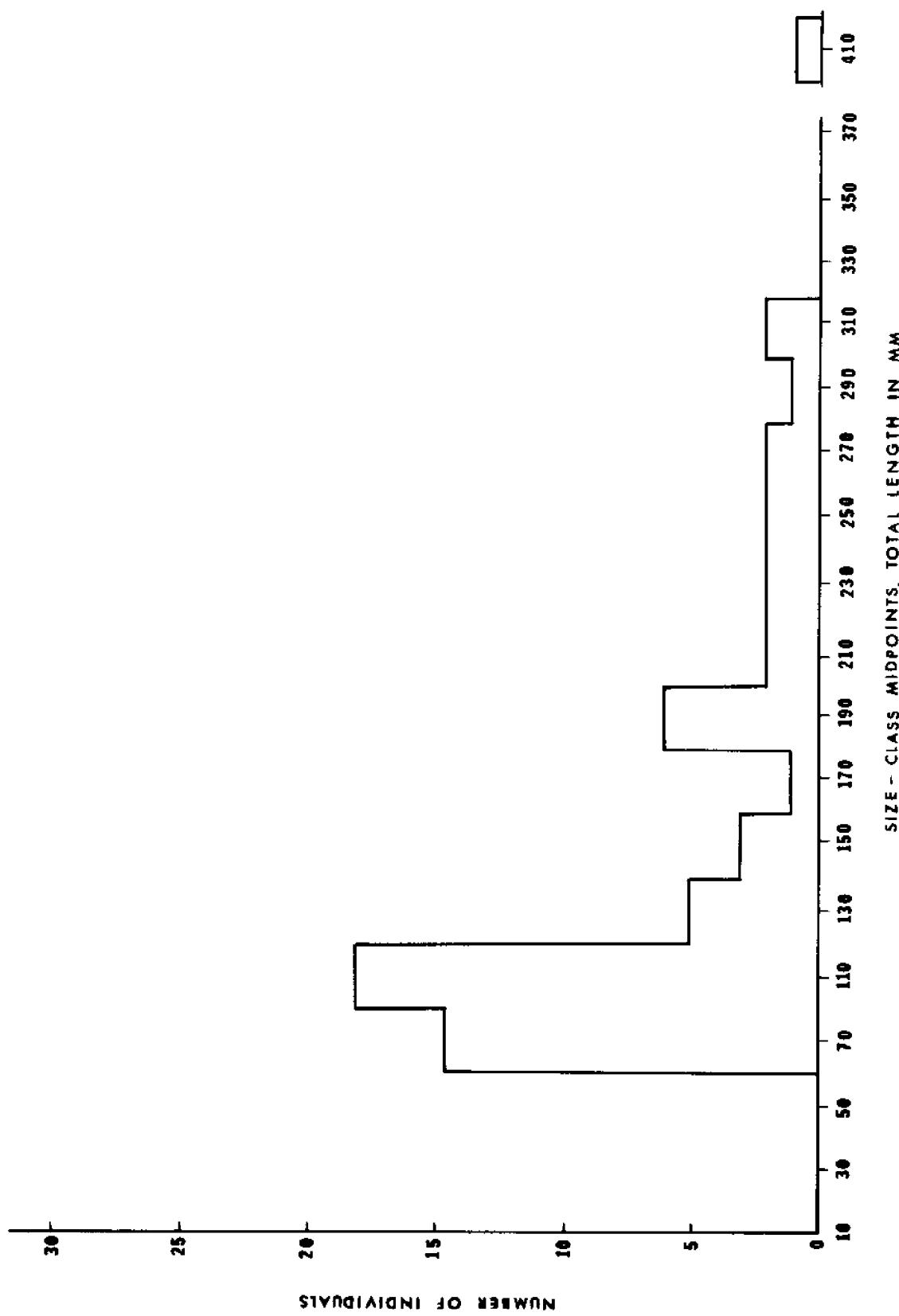


Figure 6. Length frequency histogram of *Porichthys myriaster*.

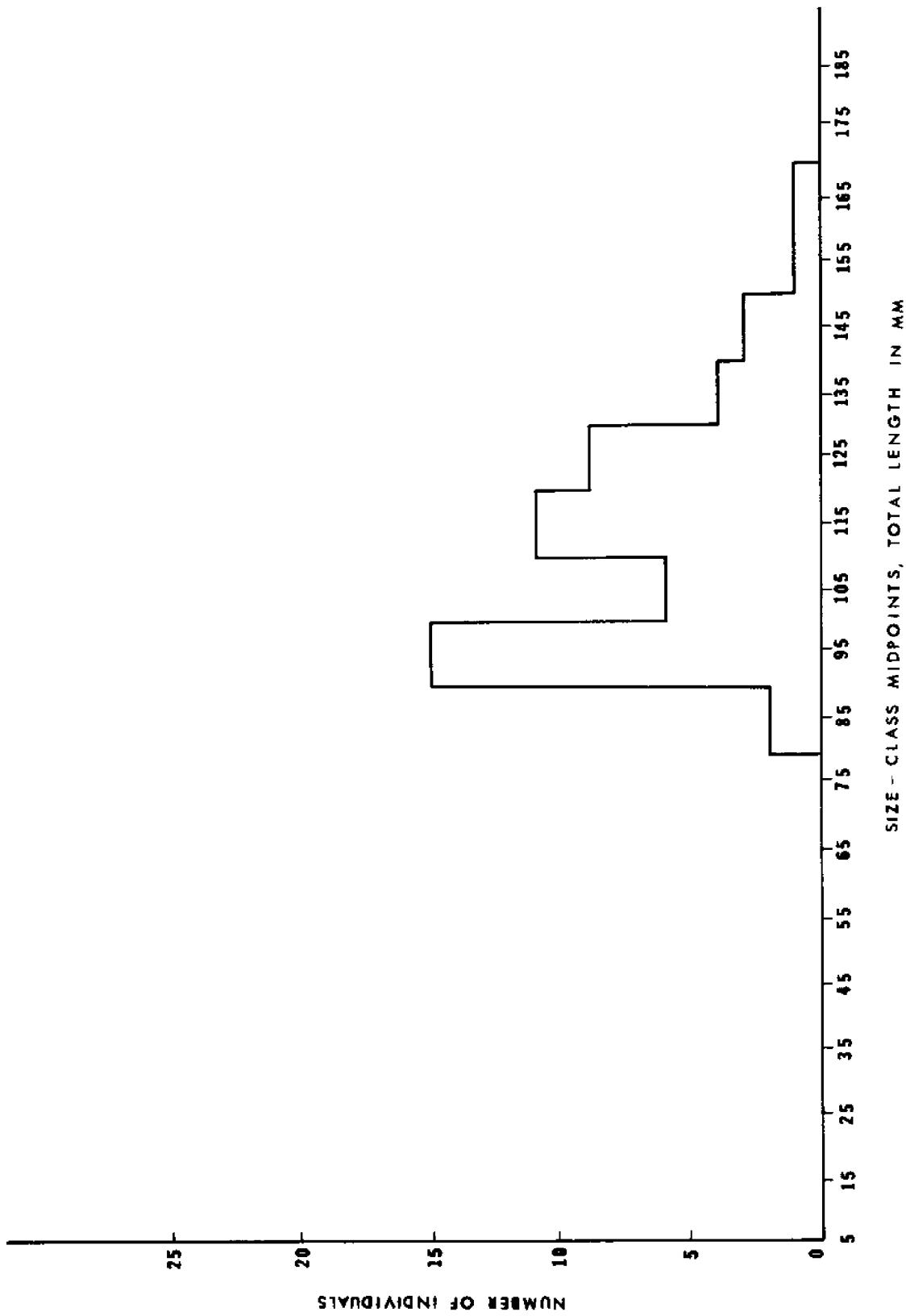
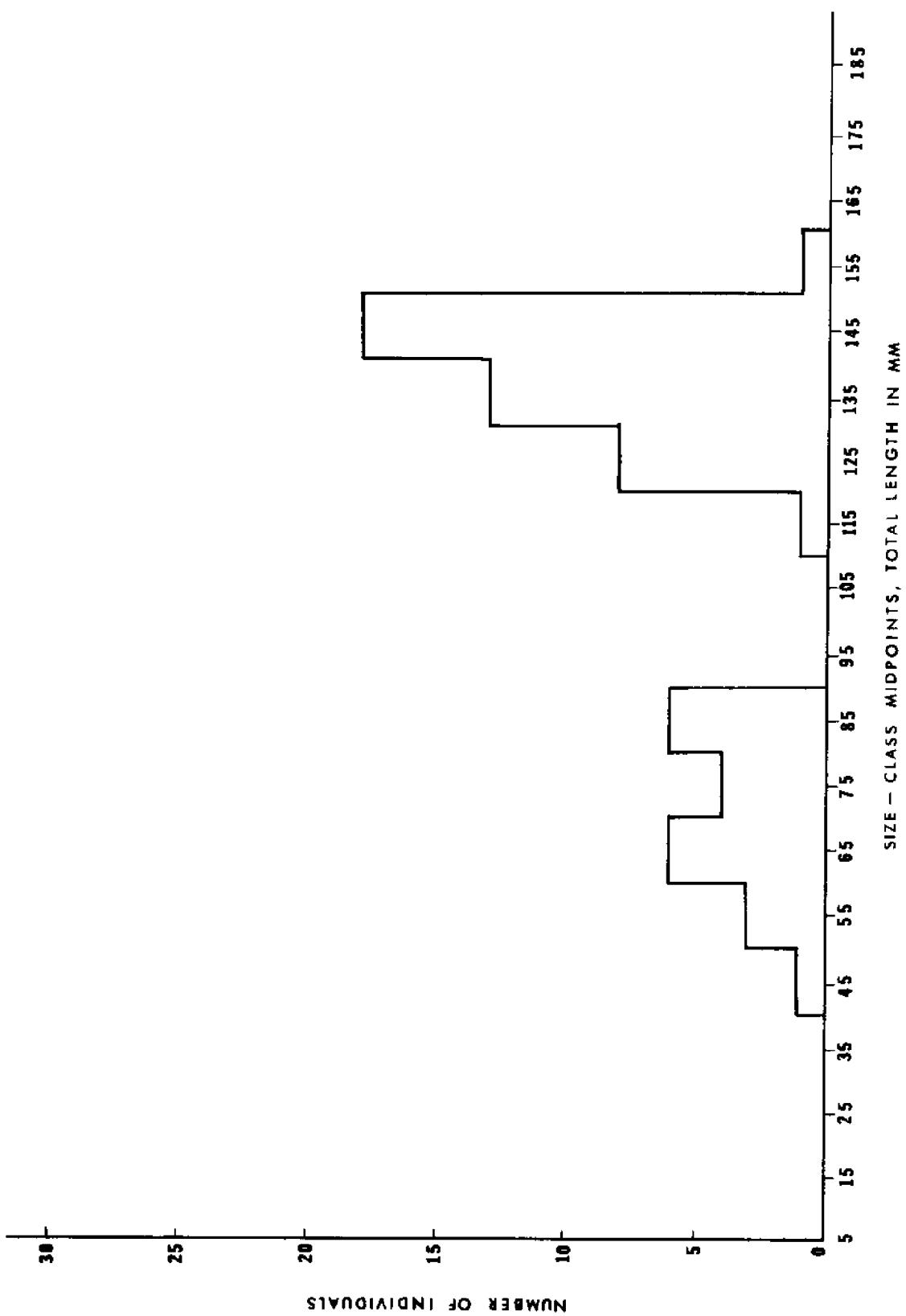


Figure 7. Length frequency histogram of Seriphus politus.

SIZE - CLASS MIDPOINTS, TOTAL LENGTH IN MM



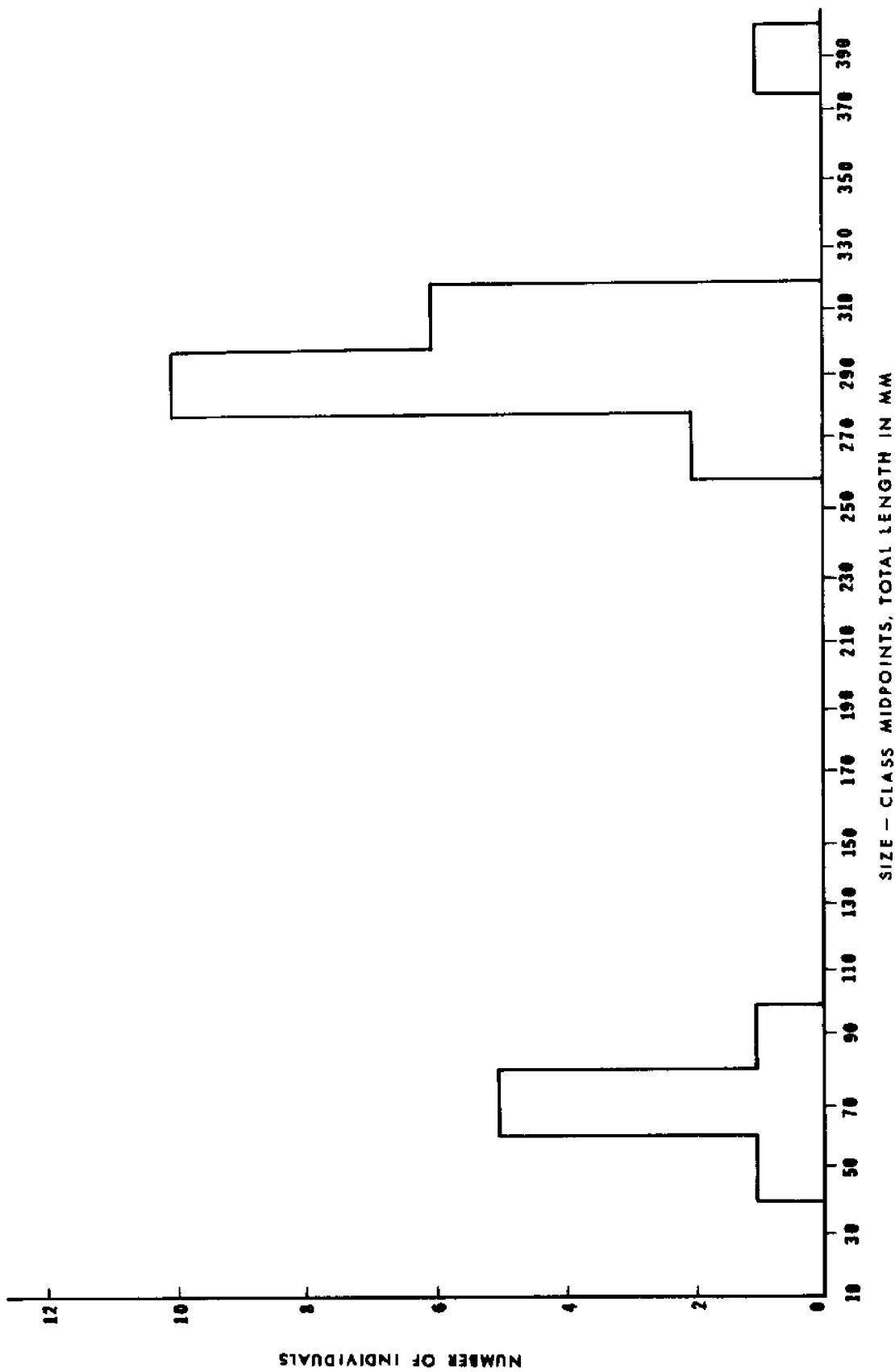


Figure 9. Length frequency histogram of Sebastodes paucispinis.

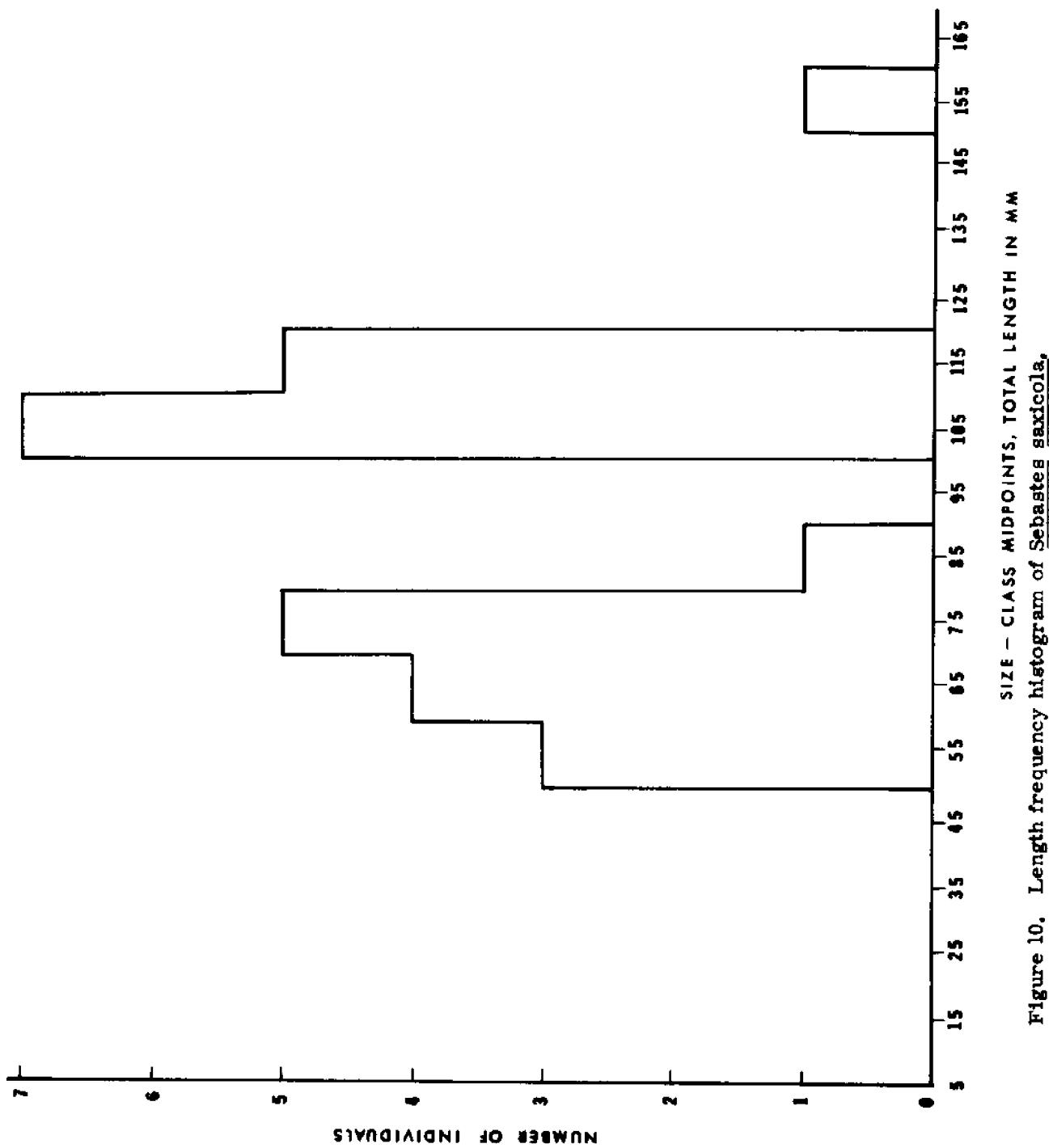


Figure 10. Length frequency histogram of *Sebastes sastecola*.

mostly young adult and juvenile fish. Thirty-eight percent of them were in the 290 mm size class (Figure 9). Stripetail rockfish Sebastes saxicola (Gilbert), ranged in size from 52 to 150 mm with 27 percent of them in the 105 mm size class (Figure 10).

#### Length - Weight Relationships

Estimations of the length - weight relationships for three of the most abundant species of harbor fish, white croaker, white seaperch and speckled sanddab, were made. A "dot diagram" of weight against total length was constructed on double logarithmic paper, according to the method of Ricker (1968). Each of the three species taken from the harbor were compared with populations of the same species living in other areas. Lines representing the length-weight relationship were drawn by inspection. Other species that were abundant in our trawls were not treated in this manner due to lack of sufficient comparative material.

The length-weight relationships of speckled sanddabs from Los Angeles - Long Beach Harbor and from Bute Inlet and Point Grey, British Columbia, were very close to each other (Figure 11). There is indication that the Los Angeles - Long Beach Harbor sanddabs are slightly heavier for their length than those from Canada. However, this difference may be due to differences in the method of preservation. Sanddabs under 60 mm, from Santa Cruz Island, California were slightly lighter for their length than those taken in Los Angeles - Long Beach Harbor (Figure 12). Santa Cruz Island speckled sanddabs above 60 mm tended to be a little heavier for their length than those from the harbor.

Comparison of length-weight relationships between white seaperch from Los Angeles - Long Beach Harbor and from Port Hueneme, California, indicate that harbor fish under 165 mm total length and 50 grams wet weight, tend to be lighter for their length than do

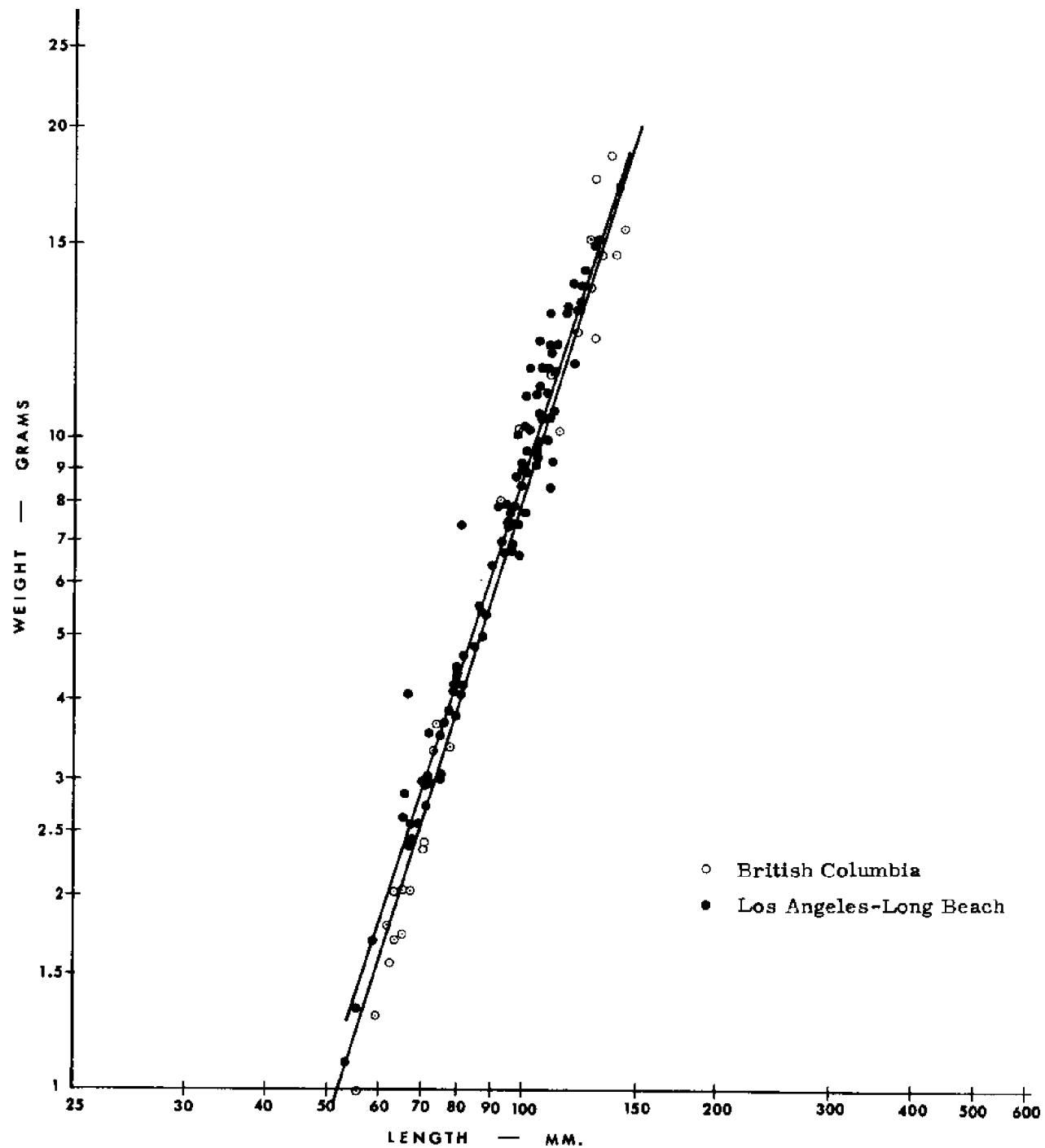


Figure 11. Relationship between total length and total body weight in speckled sanddabs from Los Angeles - Long Beach Harbor and from British Columbia.

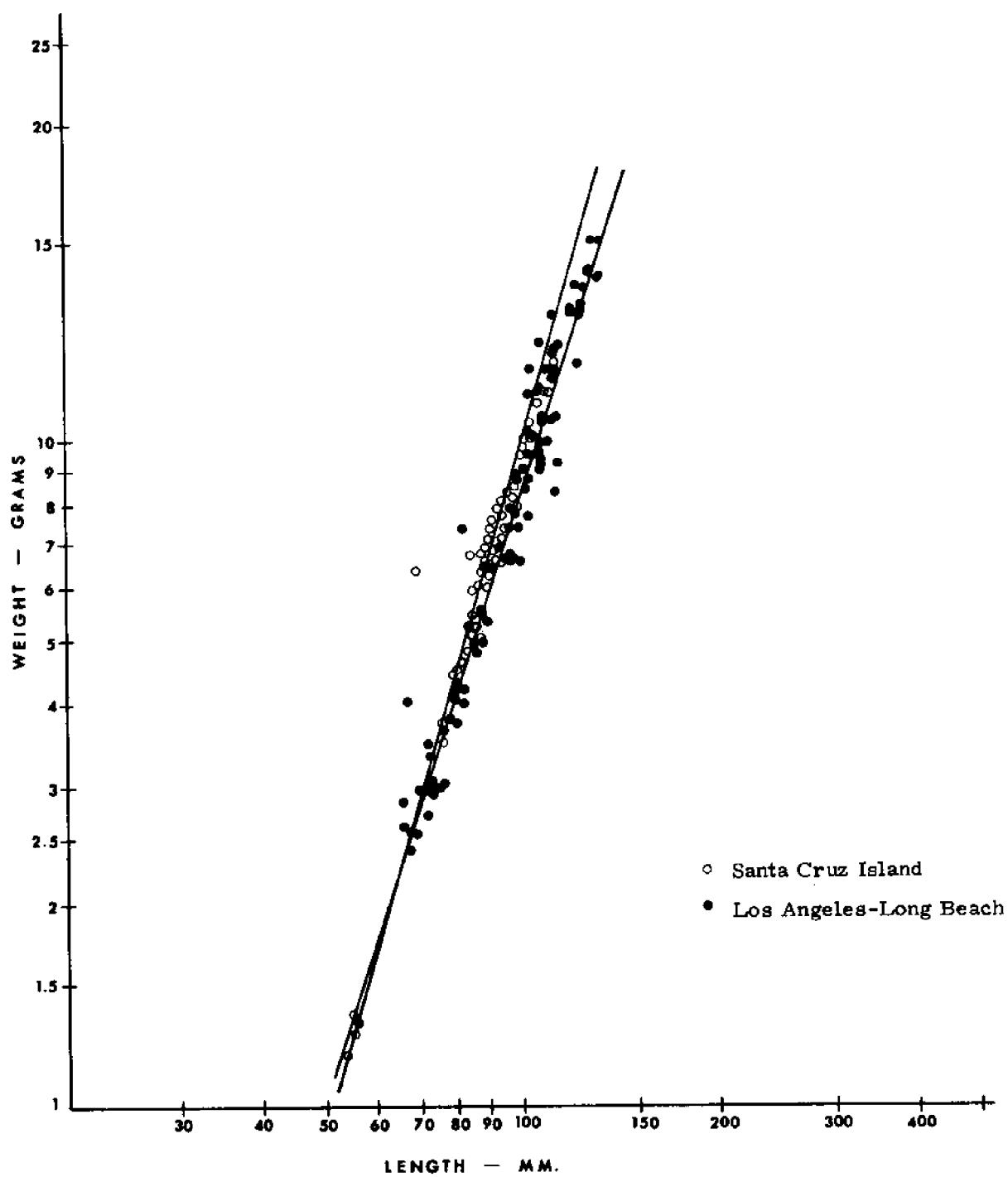


Figure 12. Relationship between total length and total body weight in speckled sanddabs from Los Angeles - Long Beach Harbor and from Santa Cruz Island.

those from Port Hueneme (Figure 13). Fish over this size, from both areas, were fairly close in length-weight relationship with Port Heuneme fish being very slightly lighter for their length. There is a change in the slope of the curve for the Los Angeles - Long Beach Harbor white seaperch at around 165 mm, which suggests a slight increase in the growth rates in fish above this size. White croaker from the Los Angeles - Long Beach Harbors were heavier for their length than those taken at Port Hueneme (Figure 14).

#### DISCUSSION

According to the U.S. Army Corps of Engineers District, Los Angeles, reports (1972), over 53 species of fish are believed to inhabit the waters of the Los Angeles and Long Beach Harbors. The results of our trawling add twelve new species to this list. If the species listed by the Corps of Engineer District are all actually found within the outer harbor, it is evident that there is an extensive and variable fish community present. Species abundance may be equal to, or greater than, that reported by Ulrey and Greely (1928) in their trawl and dredge work within San Pedro Bay before completion of the present breakwater and before the harbor expansion.

All but 3 of the 28 species of fish taken in the present survey were also taken by Carlisle (1969) in his extensive trawling operation in Santa Monica Bay during the years 1958 to 1963. A number of species captured in the Los Angeles - Long Beach Harbor trawling ranked similarly in relative abundance to the abundance of the same species taken in the Santa Monica Bay study.

Environmental conditions such as food and water quality seem to be compatable with the maintenance of these harbor populations. Additional evidence for this was the presence in our trawls of larvae and juveniles of various species, assuming they were not recruited from outside of the harbor. The presence of larvae and

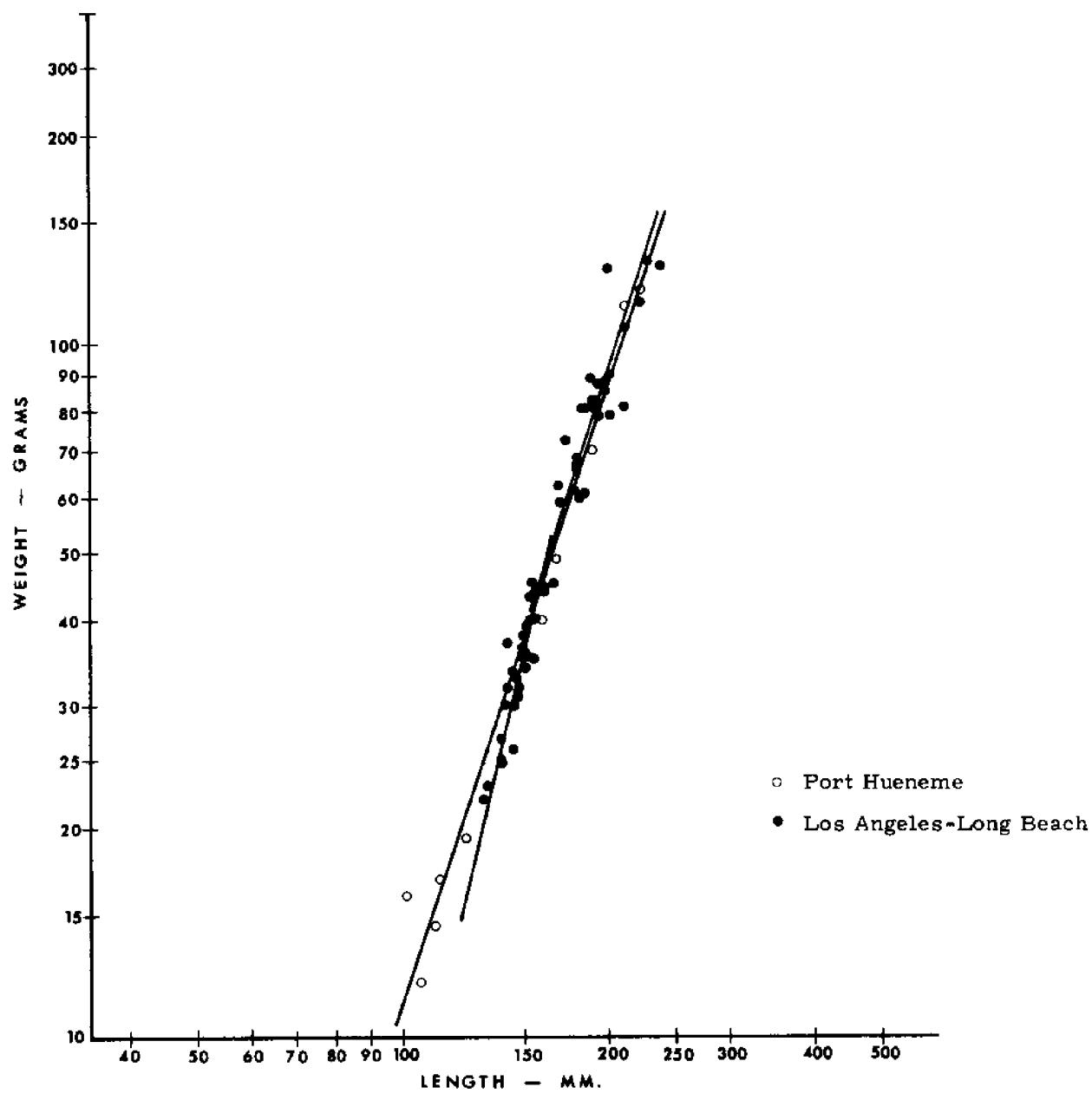


Figure 13. Relationship between total length and total body weight in white seaperch from Los Angeles - Long Beach Harbor and from Port Hueneme.

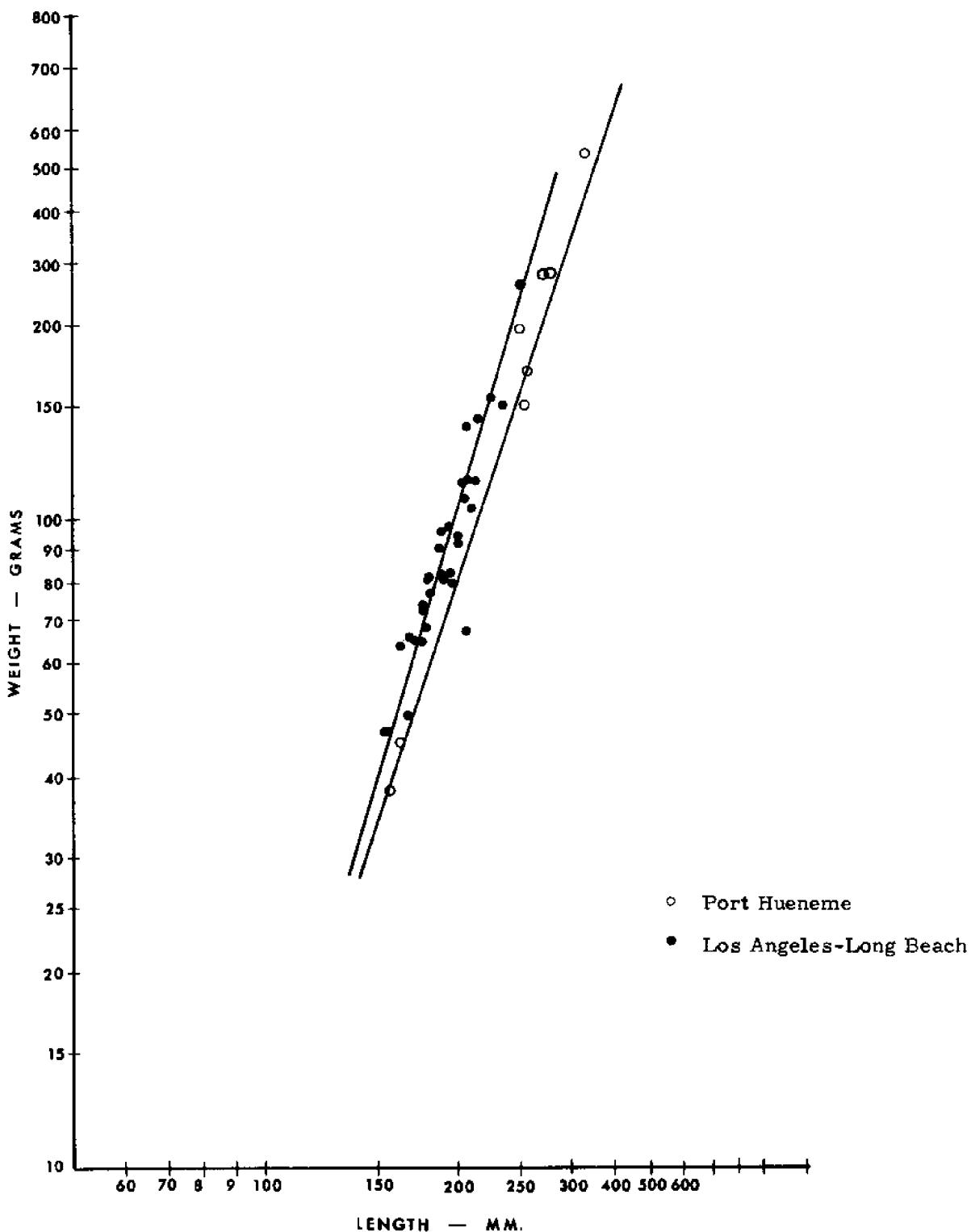


Figure 14. Relationship between total length and total body weight in white croaker from Los Angeles - Long Beach Harbor and from Port Hueneme.

juvenile speckled sanddab, white croaker, bay goby, white seaperch, shiner perch and plainfin midshipmen would indicate that the outer Los Angeles - Long Beach Harbor is a nursery ground for these fish species.

The average coefficients of condition for white croaker and white seaperch taken from the outer harbor also suggest favorable growth conditions. It was not possible, in this limited study, to isolate the factors contributing to the higher condition coefficients yielded by these fish. An abundant food supply, increased water temperature and only moderate pollution are possible factors.

The lower K value for white seaperch under 180 mm in length, and for speckled sanddabs under 100 mm in length, are probably due to the faster growth rates of younger fish which decrease as they become older and larger.

The higher average K value for 150 - 180 mm white croaker, as opposed to the value for larger, 180 - 230 mm, individuals might be related to the high incidence of fin erosion in the 180 - 230 mm group. The K value for white croaker over 230 mm was higher but not over that of the 150 - 180 mm group. Calculation of the K value for this larger group (over 230 mm) was based on measurements from only two fish and should not be weighted too heavily. Calculations for the white croaker were based on fish that had none or slight to moderate caudal fin erosion and therefore more accurate total lengths could be obtained. This K values of fish with severe erosion were not calculated, since these values would tend to be higher.

The lower K value for fish with slight to moderate fin erosion may be caused by a concurrent internal infection with the same organism which attacks the caudal fin. A great deal more study and information is needed to clarify this relationship if indeed there is one.

It is interesting to note that caudal fin erosion is generally not seen on younger white croaker or on older fish of the larger

size-classes (Figure 2). Other investigators have also noticed this (Alan Mearns, SCCWRP, pers. comm.). It is not known whether young fish are immune for a time to infection or whether there is a long incubation period before there are visible manifestations of the disease. The higher K value obtained for younger fish suggests that the infecting organism may not have a long incubation period or if it has it does not appreciably affect the condition of the younger fish. Differences in behavior between young and old fish may also play a part in the course of infection. The young may be removed from the source of infection by feeding and schooling behavior different from that of adults and become infected when they join adult populations. Absence of older infested fish might indicate that the disease is fatal after a time or that the loss of the caudal fin causes a reduced mobility which results in a lessened ability to compete with healthy fish for food. The ability to escape predation may also be decreased with shortening or loss of the caudal fin. More information is needed to answer these questions.

There is indication of a positive relationship between the incidence of fin erosion and the proximity of white croaker populations to the Terminal Island sewage and fish cannery outfalls. This is suggested by the high incidence of affected fish from trawls in that locality (36.2 percent). The overall incidence of fin erosion in white croaker from the Los Angeles - Long Beach Harbors area (18.2 percent) approaches that found in populations of this fish near the Santa Ana River jetty (26.0%) and Newport Beach (22.0%) where waters are considered to be moderately to highly polluted. However, the incidence, is only about one half of that found in populations at Laguna Beach (45.0%), which are areas considered to have light to moderate pollution (Calif. Regional Water Quality Control Board, L.A. Region, MS 1971).

The parasites present on sanddabs taken in our trawls had been previously observed on these and other species of fish. Livonica vulgaris is a common parasite on flatfish in southern

California. A range of incidence for this parasite has not been tabulated but it has been observed on numerous sanddabs taken at Santa Catalina Island, Port Hueneme and other southern California waters.

The single speckled sanddab with a tumor was the only fish found in the entire catch with an abnormality of this kind. Tumors have been reported in the Pacific sanddab, Citharichthys sordidus, by Young (1964), but this is the first record, as far as we know, of similar tumors reported for the speckled sanddab. The latter seem to have a degree of resistance to abnormalities of this type.

No epidermal papillomas were seen on any of the white croakers such as these reported for these fish taken in the Long Beach and Santa Monica Bay areas a few years ago (Calif. Reg. Water Qual. Cont. Bd., MS 1971; Halstead, 1970; Russell and Kotin, 1956; Young, 1956). Absence of white croakers with tumors is possibly due to our limited sampling. At least one such fish with tumor has recently been taken in the Seal Beach area, adjacent to Long Beach (Peter Haaker, Calif. Fish and Game, pers. comm.).

The length frequency data may strongly reflect selectivity of the gear type used and/or fish behavior because only 10 fish under 40 mm were taken and no fish over 510 mm, except a 2440 mm dogfish. In fact there seems to be considerable loss of fish below 70 mm total length. Shiner perch and white seaperch are exempt from this consideration because they are live bearers with young born at around 35 - 40 mm in total length and therefore do not appear in the trawl before reaching that length.

Individuals of a number of fish species found in our trawls reach a larger size than those captured (Roedel, 1953). Since there is usually considerable avoidance of the net by larger fish of some species we can assume that larger fish are present in the harbor. Additional sampling is needed to confirm this assumption.

Our survey, as the histograms appear to indicate, was not adequate for a complete length-frequency picture of the populations sampled. If these are normal populations with young and old fish,

and if there is sufficient recruitment, one could predict a histogram pattern similar to that exhibited by the plainfin midshipman (Figure 6) with more younger fish being taken than older individuals. This would reflect the increase of young by recruitment and the subsequent decrease in numbers of older, larger individuals as they are lost from the population through attrition factors such as death, migration and predation.

Length-weight relationships agree with condition factors for sanddabs, indicating again that fish from the outer Los Angeles - Long Beach Harbors area were heavier at the same length than those from British Columbia and those under 60 mm from Santa Cruz Island, California. It is not known why sanddabs over 60 mm from Santa Cruz Island are heavier. Again more sampling information is needed.

Length-weight relationships and condition factor values show similar trends when white seaperch from Port Hueneme and L.A. - Long Beach Harbor are compared. Both methods show that younger white seaperch from the harbor are lighter for their length, and fish over 180 mm are heavier for their length than those from Port Hueneme.

This survey was intended only as a preliminary one to gain some background information on the condition of fish populations in Los Angeles - Long Beach Harbors. It answered a few questions but raised a number of others yet to be answered. We have however, gained useful information on which to base a more intensive harbor sampling program which is planned for 1972 - 1973 under partial support of the University of Southern California Sea Grant Program. Additional information on fish population sizes and their condition, and on reproduction, recruitment, migration, feeding habits and disease is being sought.

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Marine Studies of San Pedro Bay  
Part II, Biological Investigations  
June, 1973

The Demersal Fish Populations  
of San Pedro Bay

by

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### Abstract

Studies of demersal fishes of San Pedro Bay, outside of Los Angeles - Long Beach Harbor, were made on 61 trawls since 1970. Community analysis was carried out showing that the five characteristic deep water species all have a center of distribution north of Pt. Conception. The mid-depth species group was consistently variable, and the strongest shallow water association was between three species of flatfish.

The average catch per trawl outside the harbor is lower than that found by Chamberlain (1973) inside the harbor, and indicated that the harbor waters may support at least as rich a fish fauna, if not richer than that of adjacent areas.

## Introduction

Because the demersal fishes of southern California have not been exploited by a trawl fishery, there has been a dearth of information concerning local ground fish populations. The only studies available prior to 1969, were occasional trawling explorations by state or federal fisheries agencies. The first comprehensive trawl study for southern California was Carlisle's (1969) 6-year analysis of fish populations adjacent to the Hyperion sewage discharge in Santa Monica Bay. In 1971, Ebling *et al.* published a shallow water trawl survey carried out as part of the Environmental Protection Agency sponsored study of the 1969 Santa Barbara Oil spill. Recently (1973) the southern California Coastal water Research Project (SCCWRP) has published a review of unpublished data on the coastal fish populations of southern California. That review includes much of the data to be presented here, but we feel that it is reasonable to present our San Pedro Bay data separately since these populations may be considered baseline studies in the examinations of the fishes of Los Angeles-Long Beach Harbor.

The San Pedro channel methods were initiated aboard the R/V Vantuna, an oceanographic research vessel owned and operated by Occidental College. Funds to begin this study were derived from the Occidental College Faculty research fund and subsequent support was received from SCCWRP. The study was begun by David Gardiner in January, 1971 and continues to the present. Most of the fishes collected in this study were taken with a Marinovich (16 foot head rope) otter trawl using 20 minute bottom tows. Occasionally a 25' head rope net was utilized. Recently the trawl period has been reduced to 10 minutes. In all analyses, attempts have been made to standardize the results of each trawl, although quantification of such studies, especially the deep water collections, is almost impossible. Standardization has been accomplished using the Gear Characteristic Table (7.6) presented in the SCCWRP Report.

We wish to thank Captain Kenneth Hudson and the crew of the Vantuna for their indispensable aid in this study. We also wish to thank the numerous students of Occidental College who helped collect data for this project, particularly Dave Eckert, Harry Hickman, Cassie Cusick, Laurie Phillips, and Ricard Gammon. Alan Mearns and the SCCWRP staff were exceptionally helpful in coordinating data, and we are especially indebted to James Allen for his review of techniques of analysis of demersal fish communities.

The data presented here includes 61 trawls throughout San Pedro Bay, not including Los Angeles - Long Beach Harbor. Figure 1 is a map of the trawl stations. A total of 16,686 specimens were collected for an average catch of 273.5 fish/haul. Table 1 lists the San Pedro Bay species taken by the Vantuna since 1970.

### Results

The demersal fishes of the San Pedro Bay can be divided into a number of communities that are distributed according to depth. Table 2 presents data for 1971-2 showing depth distribution and percent composition of those species making up greater than 1% of the catch at that depth. Few benthic species have extensive bathymetric ranges and those that do often show a change of depth with age, as for example, young fishes settling in shallow water and moving offshore with maturation. Microstomus pacificus is an excellent example here, with settling sometimes occurring in 20 meters and adults taken in our deepest trawl station of 700 meters. Occasional individuals or schools are taken as expatriots well outside of their apparent normal bathymetric range. For instance, Genyonemus lineatus, the white croaker is rarely taken deeper than 30 meters, yet this winter (1972-3) a school was taken from a trawl fishing between 120 and 180 meters. Such exceptions aside, the characteristic differences in species composition with depth requires that bathymetry be taken into account in any discussion of frequency of occurrence. For example, the fact that the speckled sanddab Citharichthys stigmatus is the most abundant species in our

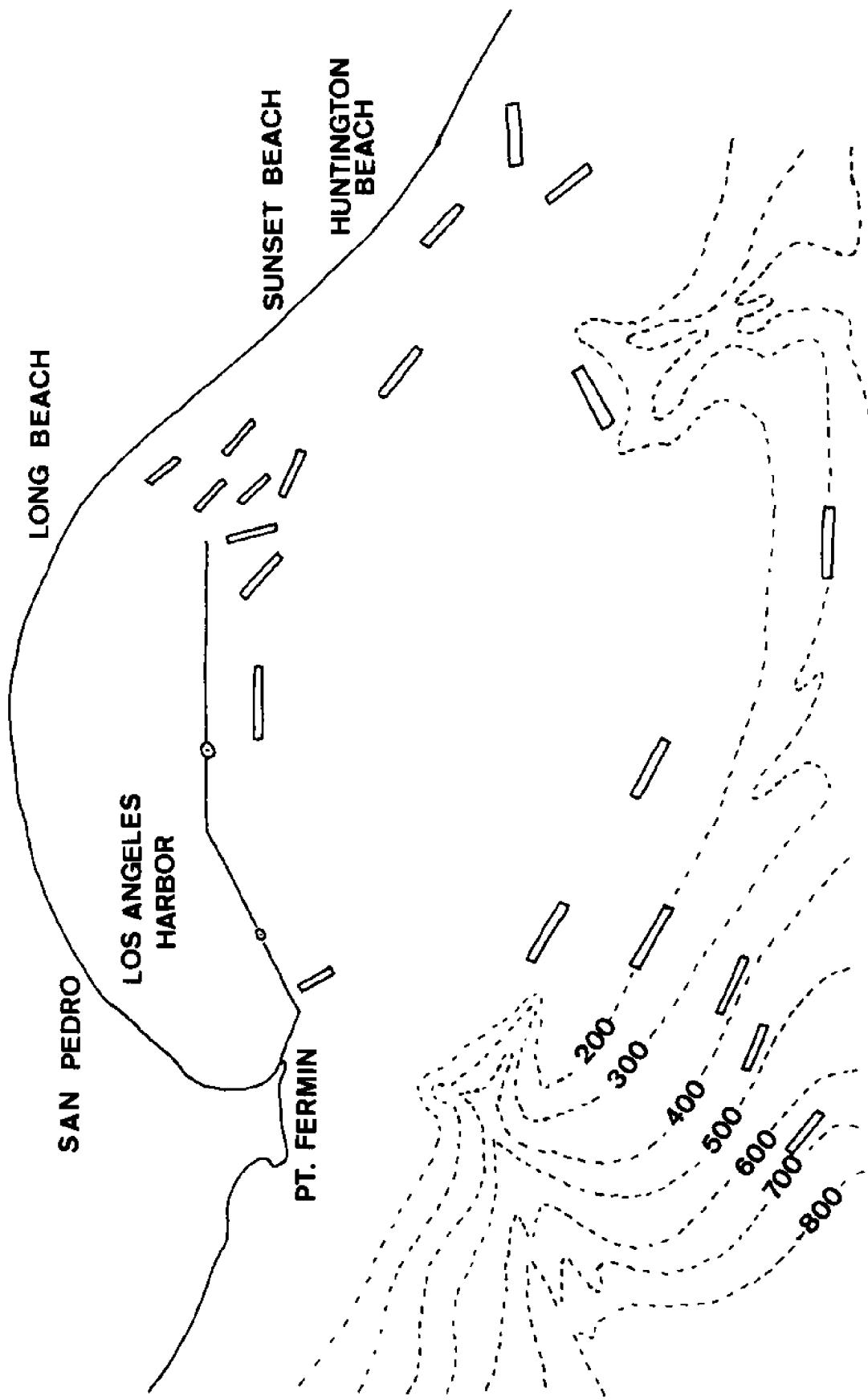


FIGURE 1  
MAJOR TRAWLING STATIONS  
SAN PEDRO BAY 1971-3

Table 1  
SAN PEDRO BAY FISHES (EXCLUSIVE OF LOS ANGELES HARBOR)  
TAKEN BY THE VANTUNA 1971-PRESENT

<i>Eptatretus stouti</i>	<i>Neoclinus blanchardi</i>	<i>Citharichthys sordidus</i>
<i>Cephaloscyllium ventriosum</i>	<i>Neoclinus uninotatus</i>	<i>Citharichthys stigmatus</i>
<i>Mustelus californicus</i>	<i>Plectobranchus evides</i>	<i>Citharichthys xanthostigma</i>
<i>Squalus acanthias</i>	<i>Lythrypnus dalli</i>	<i>Hippoglossina stomata</i>
<i>Squatina californica</i>	<i>Coryphopterus nicholsi</i>	<i>Paralichthys californicus</i>
<i>Platyrrhinoidis triseriata</i>	<i>Peprilus simillimus</i>	<i>Kystreurus liolepis</i>
<i>Rhinobatos productus</i>	<i>Scorpaena guttata</i>	<i>Eopsetta jordani</i>
<i>Torpedo californica</i>	<i>Sebastes chlorostictus</i>	<i>Glyptocephalus zachirus</i>
<i>Raja kincaidi</i>	<i>Sebastes crameri</i>	<i>Hypsopsetta guttulata</i>
<i>Raja stellulata</i>	<i>Sebastes dalli</i>	<i>Lyopsetta exilis</i>
<i>Urolophus halleri</i>	<i>Sebastes diploproa</i>	<i>Microstomus pacificus</i>
<i>Myliobatis californica</i>	<i>Sebastes elongatus</i>	<i>Parophrys vetulus</i>
<i>Hydrolagus colliei</i>	<i>Sebastes eos</i>	<i>Pleuronichthys coenosus</i>
<i>Gnathophis catalinensis</i>	<i>Sebastes goodei</i>	<i>Pleuronichthys decurrens</i>
<i>Facciolella gilberti</i>	<i>Sebastes hopkinsi</i>	<i>Pleuronichthys ritteri</i>
<i>Anchoa compressa</i>	<i>Sebastes jordani</i>	<i>Pleuronichthys verticalis</i>
<i>Anchoa delicatissima</i>	<i>Sebastes levius</i>	<i>Syphurus atricauda</i>
<i>Engraulis mordax</i>	<i>Sebastes melanostomus</i>	
<i>Argentina sialis</i>	<i>Sebastes miniatus</i>	
<i>Synodus lucioceps</i>	<i>Sebastes mystinus</i>	
<i>Porichthys myriaster</i>	<i>Sebastes paucispinis</i>	
<i>Porichthys notatus</i>	<i>Sebastes rosaceus</i>	
<i>Physiculus rastrelliger</i>	<i>Sebastes rosenblatti</i>	
<i>Merluccius productus</i>	<i>Sebastes rubrivinctus</i>	
<i>Chilara taylori</i>	<i>Sebastes sxicola</i>	
<i>Otophidium scrippsi</i>	<i>Sebastes semicinctus</i>	
<i>Aprodon cortezianus</i>	<i>Sebastes serranoides</i>	
<i>Lycodopsis pacifica</i>	<i>Sebastes serriceps</i>	
<i>Lyconema barbatum</i>	<i>Sebastes umbrosus</i>	
<i>Nezumia stolidolepis</i>	<i>Sebastolobus alascanus</i>	
<i>Syngnathus californiensis</i>	<i>Anoplopoma fimbria</i>	
<i>Paralabrax nebulifer</i>	<i>Zaniolepis frenata</i>	
<i>Caulolatilus princeps</i>	<i>Zaniolepis latipinnis</i>	
<i>Genyonemus lineatus</i>	<i>Chitonotus pugetensis</i>	
<i>Menticirrhus undulatus</i>	<i>Icelinus filamentosus</i>	
<i>Seriphus politus</i>	<i>Icelinus quadriseriatus</i>	
<i>Amphistichus argenteus</i>	<i>Icelinus tenuis</i>	
<i>Cymatogaster aggregata</i>	<i>Icelinus fimbriatus</i>	
<i>Embiotoca jacksoni</i>	<i>Radulinus asprellus</i>	
<i>Hyperprosopon argenteum</i>	<i>Rhamphocottus richardsoni</i>	
<i>Phanerodon furcatus</i>	<i>Agonopsis sterletus</i>	
<i>Rhacochilus vacca</i>	<i>Asterotheca pentacanthus</i>	
<i>Zalembius rosaceus</i>	<i>Odontopyxis trispinosa</i>	
<i>Rathbunella hypoplecta</i>	<i>Xeneretmus latifrons</i>	
<i>Kathetostoma averruncus</i>	<i>Xeneretmus triacanthus</i>	

TABLE 2  
MEAN RELATIVE % COMPOSITION BY DEPTH OF DOMINANT FISH SPECIES TRAWLED 1971-2

	Depth in Fathoms							
	5-6	10-13	25-45	50	60-70	100	150	200
<i>Genyonemus lineatus</i>	22.5	7.9						
<i>Cymatogaster aggregata</i>	15.7	1.3						
<i>Syphurus atricauda</i>	14.8	23.7	16.1					
<i>Citharichthys stigmaeus</i>	13.4	58.2	10.5					
<i>Hyperprosopon argenteum</i>	11.4							
<i>Engraulis mordax</i>	7.3							
<i>Phanerodon furcatus</i>	6.4							
<i>Pleuronichthys verticalis</i>	4.4	6.8	4.32					
<i>Porichthys myraster</i>		1.9						
<i>Leptocottus armatus</i>			7.7					
<i>Icelinus quadriseriatus</i>			7.7					
<i>Citharichthys sordidus</i>			37.6	27.7	13.5			
<i>Porichthys notatus</i>				6.9	16.3			
<i>Zalembius rosaceus</i>				8.3				
<i>Zaniolepis frenata</i>				7.6	6.1	3.4		
<i>Zaniolepis latipinnis</i>				5.0				
<i>Sebastes saxicola</i>				14.3	21.2	18.4		
"Juvenile <i>Sebastes</i> "					30.1			
<i>Lyopsetta exilis</i>						40.4	44.6	12.4
<i>Glyptocephalus zachirus</i>				6.6	9.5	2.4	5.9	.7
<i>Microstomus pacificus</i>							9.3	36.55
<i>Sebastes diploproa</i>					5.6	5.3		
<i>Sebastolobus alascanus</i>							8.3	
<i>Xeneretmus latifrons</i>							17.7	39.3
							14.2	1.7

trawls were in very shallow water. It also seems reasonable to consider only certain depth ranges in tabulating species association or diversity indices. Using our trawl data alone and comparing only fishes occurring in previously determined depth limits, recurrent group associations can be calculated (Fager 1957, 1963; SCCWRP, 1973).

There are five characteristic species in our deep water community, (Figure 2) at 200-400 meters. All are species whose center of distribution is north of Pt. Conception. These represent cool or cold water faunal elements from below the thermocline. This faunal grouping is quite distinctive. The three flatfish species, Glyptocephalus zachirus, Lyopsetta exilis, and Microstomus pacificus continue to be characteristic species to depths as shallow as 100 meters, while the two rockfishes, Sebastolobus alascanus and Sebastes diploproa are uncommon shallower than 200 meters.

Our mid-depth species group at 80-200 meters is consistent in its variability. The most abundant and consistent species is the stripetail rockfish Sebastes saxicola which at this depth strongly associates with the three deep water flatfish elements. If we disregard these three deep water flatfish species, the largest inclusive associative group is made up of pink seaperch, Zalembius rosaceus, stripetail rockfish Sebastes saxicola, shortspined combfish, Zaniolepis frenata, the plainfin midshipman, Porichthys notatus, and pacific sanddab, Citharichthys sordidus. This differs from the mid-depth group listed by SCCWRP only in their replacement of S. saxicola by M. pacificus, a species we have here allied to the deeper faunal association. Three species including English sole, Parophrys vetulus, greenspotted rockfish, Sebastes chlorostictus, and blackedge poacher, Xeneretmus latifrons appear as satellites to this association. SCCWRP allies the latter species X. latifrons to its deep water fauna while they list P. vetulus, as a characteristic shallow water species. Our data on this latter species places it as a satellite of both the shallow and mid-depth communi-

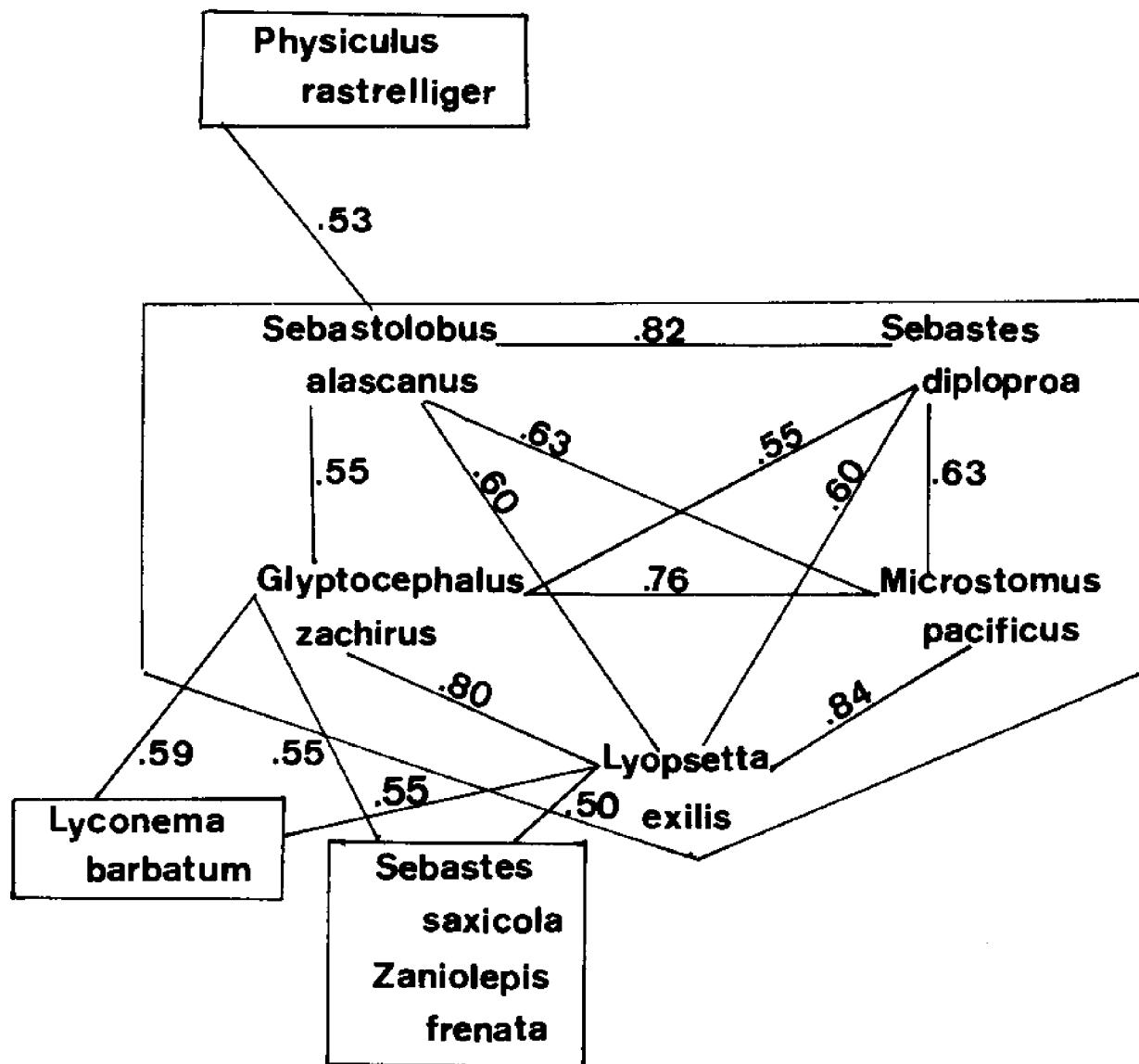


FIG. 2

## RECURRENT GROUP SPECIES ASSOCIATIONS

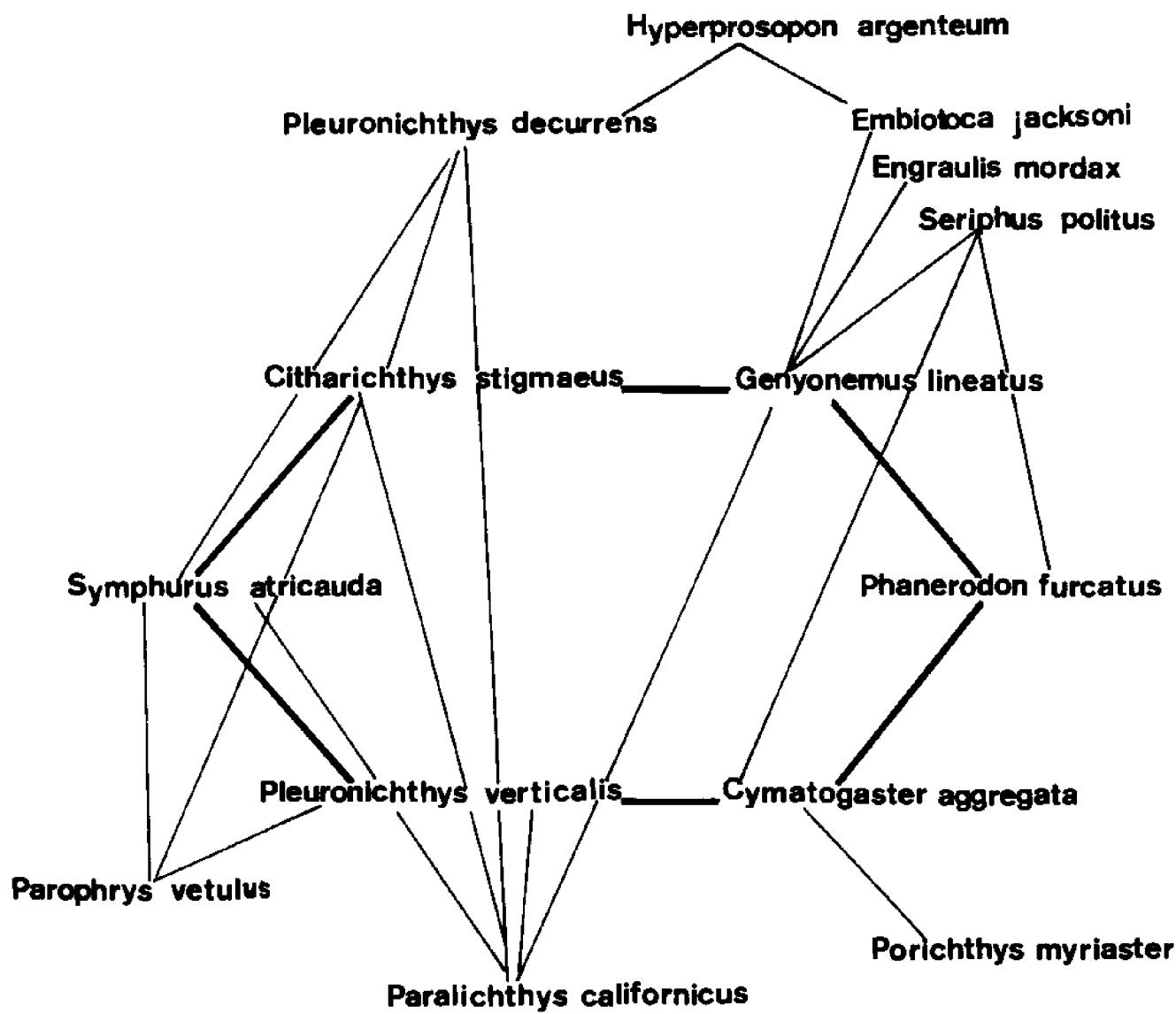
Deep water (200-400 m.), primary group of 5 species + satellites

ties which indicates common occurrence, but relatively low fidelity in each depth range. SCCWRP lists three shallow water species groups, each of which is made up of a single ecotype, i.e., a flatfish group of four species, a croaker-perch group (swimmers), and a sculpin-combfish pair (bottom sitters). In San Pedro Bay our data shows the strongest association between three of the four species of SCCWRP's flatfish group; speckled sanddab, Citharichthys stigmaeus, the tonguefish, Syphurus atricauda, and the hornyhead turbot, Pleuronichthys verticalis, all associating above the .8 level. When the group is defined at the .7 level, two surfperch Phanerodon furcatus and Cymatogaster aggregata and the white croaker Genyonemus lineatus, associate with speckled sanddab and tonguefish but not with hornyhead turbot. The most characteristic association appears to be represented by the .6 level of discrimination. Here the six above cited species all coassociate, and in addition, eight satellite species are represented (Figure 3). These six species certainly represent the typical shallow water fauna of San Pedro Bay.

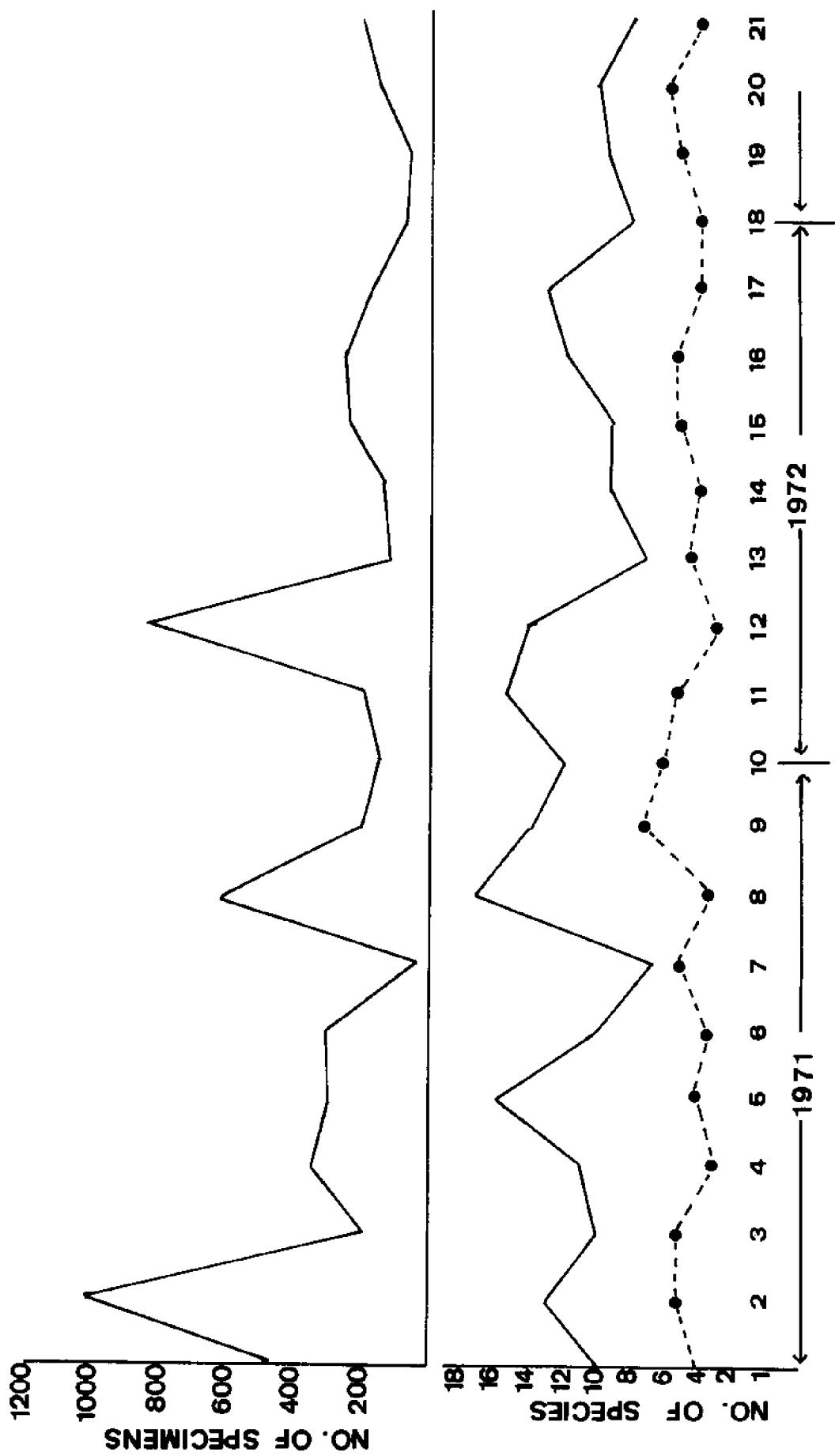
The differences between our associations and those listed by SCCWRP can probably be attributed primarily to differences in distributions outside of San Pedro Bay as well as slight modifications in methodology (their data includes stations from all of the Southern California Bight region). Our technique of comparing only certain depth ranges may also bias our data.

The shallow water and to some extent the shallower mid-depth fishes are the fishes that might make use of the Los Angeles - Long Beach Harbor waters. Our data includes 33 trawls outside of the Harbor at depths between 10 and 30 meters. We have presently taken 44 species within this depth range outside of the harbor.

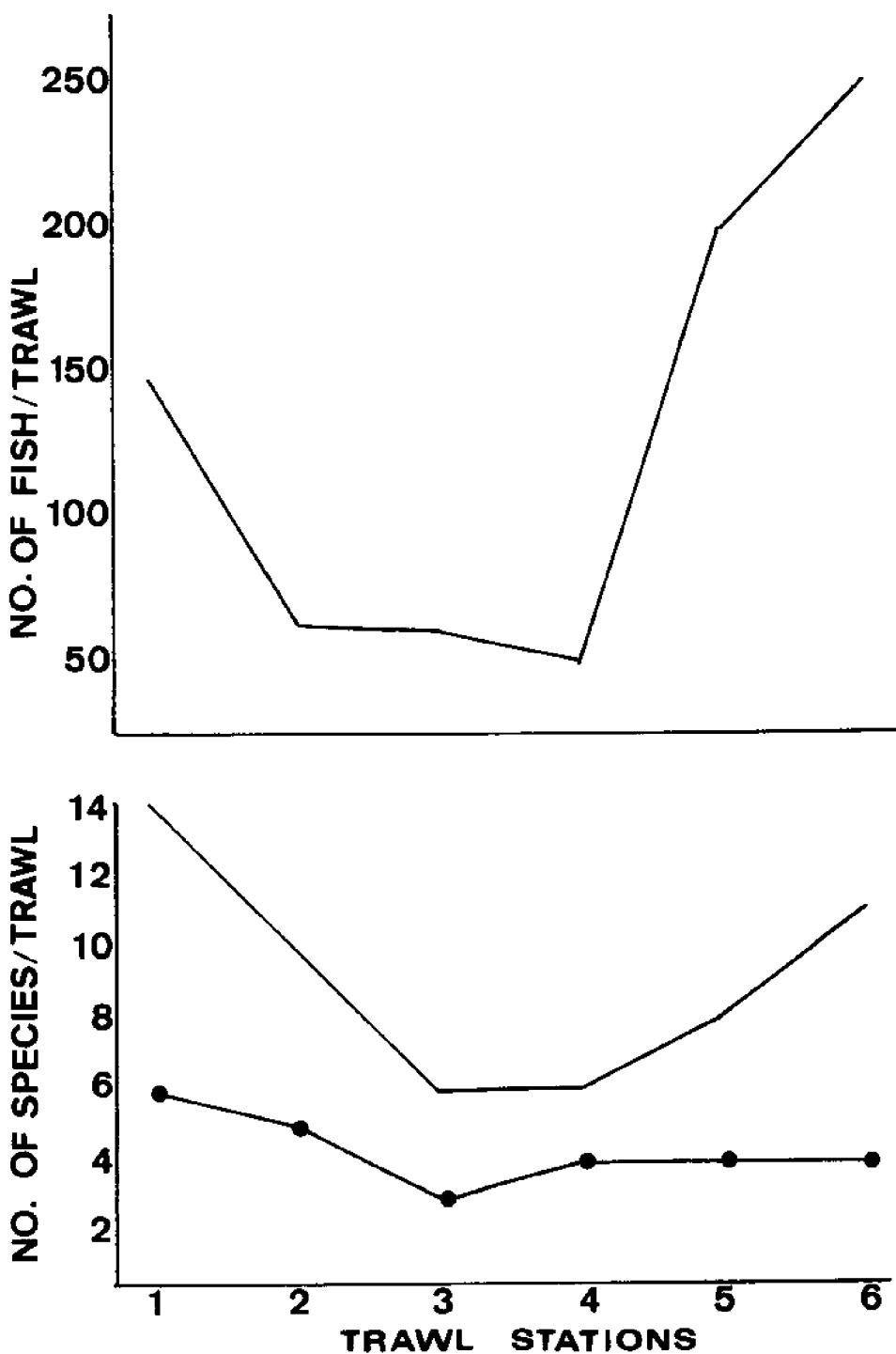
Our shallow trawls have yielded 8,327 fish for an average of 252.3 fish/trawl. The range in catch varied from 26 to 1,099 fish. Figure 4 compares total catch against number of species and dominant species for each trawl date. The inverse relationship between number of species and size of catch is not well demonstrated by



**FIGURE 3**  
**RECURRENT GROUP SPECIES ASSOCIATIONS**  
**SHALLOW WATER (10-30 m.), MAJOR**  
**SPECIES GROUP INDICATED BY HEAVY**  
**LINES (.8 level of co-association)**



**FIGURE 4**  
**VARIATION IN CATCH PER TRAWL**  
**21 STATIONS, 10-30 METERS IN DEPTH; 1971-3**  
**(○—○ ONLY SPECIES MAKING UP >5% OF CATCH)**



**FIGURE 5**  
**VARIATION IN CATCH PER TRAWL; APRIL 14, 1972**

6 STATIONS, 10-16 METERS IN DEPTH, 10 MINUTE TOWS. (●—REPRESENTS ONLY SPECIES MAKING UP > 5% OF SAMPLE )

this data. Table 3 lists the shallow water species as percent of catch by date. The variation in catch per trawl is emphasized in Figure 5 which compares the data for six successive collections on the same day at the same depth. Two species of flatfishes, Citharichthys stigmatus and Syphurus atricauda make up 61.7% of the shallow water fishes taken, 39.5% and 22.2% respectively. These two species, along with Pleuronichthys verticalis are also the most regularly occurring species, the latter two being present in all but one trawl sample, while C. stigmatus was missing from only two. The high fidelity of their occurrence can be compared to that of the other three most common species, Genyonemus lineatus (9.8%, absent from 16 trawls), Phanerodon furcatus (7.7%, absent from 10), and Cymatoqaster aggregata (3.3%, missing from 13). This comparative fidelity indicates the ecological mode for each of these species groups; those with lower fidelity are schooling, swimming species, while the very regularly occurring forms are bottom dwelling flatfishes. From the standpoint of percentage of catch, it should be noted that P. verticalis is by far the largest of the three flatfish species and its lower number/catch certainly reflects greater spacing of individuals in this species which probably is associated with its higher energy needs. By contrast, the largest regularly occurring swimming species G. lineatus occurs with the lowest fidelity of the six members of the association, but when it is taken it is usually caught in large numbers.

The shallow water species data can be compared with the preliminary trawling data collected by Chamberlain in May, 1972 at Los Angeles - Long Beach Harbor (see Chamberlain 1973). Chamberlain took 28 species which is relatively high diversity for a single day's trawling in a limited geographic area. However, our maximum diversity is 17 species in a single trawl, which would appear to equal or exceed the diversity per catch within the harbor. Three species, C. stigmatus, S. atricauda, and G. lineatus were numerically dominant and together made up 70% of the collections in the harbor. These same species in the same order represented

TABLE 3 SHALLOW WATER  
(Circled numbers represent)

Species	Trawling Date 1971							
	1/27	2/24	3/24	4/29	5/6	7/8 <sup>②</sup>	9/28	10/31
<i>Citharichthys stigmaeus</i>	84.7	21.7	10.5	83.9	30.8	63.9	42.3	3.3
<i>C.</i> <i>sordidus</i>								
<i>Pleuronichthys verticalis</i>	1.7	1.18	2.4	3.7	3.9	4.5	19.2	1.3
<i>P.</i> <i>decurrens</i>	.4		.5			1.6	3.9	.2
<i>P.</i> <i>ritteri</i>	1.1							
<i>P.</i> <i>coenosus</i>								
<i>Parophrys vetulus</i>	.2	.1		2.0	.6		11.5	
<i>Hypsopsetta guttulata</i>								
<i>Hippoglossina stomata</i>				.3				
<i>Microstomus pacificus</i>				.8			.8	
<i>Xystreurus liolepis</i>								
<i>Paralichthys californicus</i>								.8
<i>Syphurus atricauda</i>	7.2	38.9	7.7	7.6	35.1	24.0	11.5	5.5
<i>Genyonemus lineatus</i>		7.9		.3	6.8			1.6
<i>Seriphis politus</i>		1.6	13.4		1.9			2.5
<i>Menticirrhus undulatus</i>								
<i>Phanerodon furcatus</i>		1.0	7.7		1.0			3.4
<i>Cymatogaster aggregata</i>		.3	2.4	.3	.3	1.20		4.9
<i>Embiotoca jacksoni</i>	.2				.3			.8
<i>Rhacochilus vacca</i>								
<i>Hyperprosopon argenteum</i>								1.8
<i>Amphistichus argenteus</i>								
<i>Zalembius rosaceus</i>								
<i>Porichthys myriaster</i>	1.1	.3	1.4	.3	1.3	1.0		
<i>P.</i> <i>notatus</i>	1.3				.3	.3		
<i>Chilara taylori</i>								
<i>Otophidium scrippsi</i>						1.0		
<i>Peprilus simillimus</i>		.3				.3		.2
<i>Paralabrax nebulifer</i>								.2
<i>Chitonotus pugetensis</i>								
<i>Icelinus quadriseriatus</i>					.3			
<i>Zaniolepis latipinnis</i>								3.3
<i>Scorpaena guttata</i>	1.9			.5			.2	
<i>Sebastes saxicola</i>					.6			
<i>S.</i> <i>unident. juveniles</i>						8.7	2.4	
<i>Syngnathus</i> sp.		6.1				3.9		
<i>Engraulis mordax</i>		20.1	53.1			3.3		2.5
<i>Anchoa compressa</i>								
<i>A.</i> <i>delicatissima</i>								
<i>Lycodopsis pacifica</i>							.2	
<i>Squalus acanthias</i>		.1						.5
<i>Rhinobatos productus</i>								
<i>Platyrrhinoidis triseriata</i>								.3
<i>Urolophus halleri</i>								
N	471	1099	209	355	308	626	26	612

TRAWLING SPECIES COMPOSITION  
 summed data two or more trawls)

	11/22-3	3/3-4	3/31	4/14	5/5	7/17	8/8	12/16	1/4	1/14	3/2
	18.0	42.2	44.6	32.5	34.3	2.3	16.32	71.1	25.5	5.2	2.0
5.4	.3	21.5	7.3	1.2	.8	3.1	7.2	4.1	2.6	.7	2.4
	1.4		3.1			1.3	7.2	3.1			
	.1						1.2				
	.1										
	.7	2.5	1.9	1.7		2.9	1.2				
.3	1.2		.7								
	.1	.8		.7			2.4				
	.4			2.7	.4						
	.1										
1.9	.9		1.4			1.30					
12.5	17.3	28.9	26.7	4.2	.4	15.3	8.4	5.1			
6.0	6.5		4.9			3.7	2.6	6.12	7.2		
1.6	11.9		5.3			8.7	2.1			50.9	8.3
.9	.4					.4	.3	1.2	2.0		
9.2	8.7		4.5			44.8	24.3		28.6	16.3	3.9
17.3	1.1		1.7			15.7	26.4			7.2	1.0
.6	.6		.4			.8	.8		19.4		
	.1								1.0		
14.4	1.4		1.8			20.3				6.5	
.3	.4				.4						
	.3					1.6					
	.2					.8					
	.1										
	.1		.5	.1		.3			3.1		
	.1										
	.1					.5					
	.2										
	.3										
.3	.8										
	.4			4.8		29.4	.8				
	.5			.1							
	.1			.1							
369	1626	93	772	965	241	386	83	98	153	205	

72.5% of our collections. The major differences in dominant species appears to be an increase in number of shiner perch C. aggregata (ranked fourth at 8%) in the harbor while this species ranked 6th at 3.3% outside of the harbor, and a decrease in hornyhead turbots P. verticalis, which ranked 9th in the harbor and 5 outside. Only two species, the bay goby, Lepidogobius lepidus, and Rhacochilus toxotes a relatively large, rocky shore surfperch (uncommon over sand or mud bottom) were taken in the harbor but not elsewhere in our San Pedro Bay trawl collections. Three species of rockfish, S. paucispinis, S. rubrivinctus, and S. goodei are more properly species of mid-depth waters and were not taken in the adjacent shallow coastal areas. It seems possible that these rockfish may be associated with a special breakwater rocky shore fauna not encountered on the unmodified shallow sandy shelf zone. Their absence from our inshore census represents our bias towards rock-free trawling stations.

#### Conclusions

The average catch figure of 221 fish/trawl for the harbor is high compared to our shallow San Pedro Bay collections. This average in the harbor includes two trawls with a total of four fish, one of which was interrupted when the net was ripped would not normally be considered in average data. Average catch outside the harbor varied with depth: 252.4 fish in 10-30 meters, 291.6 in 30-90 meters, 347.3 in 100-200 meters, and 258.8 in 200-400 meters, with an overall average of 273.5 fish/trawl. All of these tows deeper than 30 meters, however, represent an estimated 20-minute bottom time and below 100 meters they actually represent considerably longer periods. SCCWRP estimated the area trawled by the Vantuna (16' net, 20 minute tow) as  $7,540 \text{ m}^2$ . Our shallow water studies and Chamberlain's trawls represent only half that area,  $3770 \text{ m}^2$ . If density is estimated based on the estimated base on the estimated area and mean catch size, the harbor and in-

shore waters appear to support a relatively rich fish fauna compared to that of the adjacent areas. Our deeper water, 30-400 meter trawls averaged 316 fish for an estimated area of 7,540 m<sup>2</sup> or an estimated density of 1 fish per 23.9 m<sup>2</sup>. Our shallow water study averaged 252.4 fish for an area of 3770 m<sup>2</sup> or a density of 1 fish per 14.9 m<sup>2</sup>. This compares to Chamberlain's slightly higher yield of 1 fish/12.5 m<sup>2</sup>.

It appears from Chamberlain's preliminary study that the fauna of Los Angeles - Long Beach Harbor and the adjacent sandy or sand-mud shelf are basically similar. The degree of interchange between fish stocks of these two areas is of great importance in any speculation concerning recruitment to the harbor or the use of harbor waters as a nursery by shelf fishes. There is some indication that, at least in white croaker populations (Phillips, Terry, and Stephens 1973), the harbor elements are endemic.

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5. \_\_\_\_\_. 1963. Communities of organisms. In: *The Sea*, vol. 2, M.N. Hill, ed. John Wiley, New York. pp. 415-437.
6. Phillips, Laurie, C. Terry, and J. Stephens, Jr. 1973. Status of the white croaker (Genyonemus lineatus) in the San Pedro Bay Region. A preliminary report to the Southern California Coastal Water Research Project. SCCWRP TR 109; Nov. 23, 1972: 49 pp.
7. SCCWRP. 1973. The ecology of the Southern California blight: implications for water quality management. SCCWRP TR 104: 531 pp.

Marine Studies of San Pedro Bay  
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Annotated Bibliography  
on  
The Northern Anchovy, Engraulis mordax Girard  
by

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## Introduction

The northern anchovy, Engraulis mordax, is a small, pelagic, schooling fish found in coastal waters throughout the California Current system. During the past two decades, the anchovy has been the subject of intense interest, as indicated by the number of publications that have appeared describing its fishery and general biology in that period. The increased interest has been given impetus by the decline in the sardine (Sardinops caerulea) fishery and a concurrent increase in anchovy biomass. The anchovy is now the most abundant fish off the California coast.

The presented annotated bibliography was prepared to provide a quick reference to published literature on the northern anchovy, Engraulis mordax, prior to 1973. An attempt has been made, through an extended literature search to include all published papers that concern the anchovy. Exceptions have been some short statements that summarize research published elsewhere (i.e. government agency reports), and some articles that appeared in popular magazines.

For each paper cited, annotations are given that summarize the paper or describe those aspects of the paper that deal with the anchovy. For convenience, a subject index is also provided. It is hoped that this paper will be a useful reference to those interested in the fishery and the biology of this ecologically and economically important species--the northern anchovy.

### Bibliography

1. Ahlstrom, E.H. 1952. Pilchard eggs and larvae and other fish larvae, Pacific Coast, 1950. U.S. Fish Wild. Serv., Spec. Sci. Rept., Fish. 80, 58 p.

This paper and the following two papers by Ahlstrom include data on the distribution and abundance of anchovy eggs and larvae in the California Current region.

2. \_\_\_\_\_ . 1953. Pilchard eggs and larvae and other fish larvae, Pacific Coast, 1951. U.S. Fish Wild. Serv., Spec. Sci. Rept., Fish. 102, 55 p.
3. \_\_\_\_\_ . 1954. Pacific sardine (pilchard eggs) and larvae and other fish larvae, Pacific Coast, 1952. U.S. Fish Wild. Serv., Spec. Sci. Rept., Fish. 123, 76 p.
4. \_\_\_\_\_ . 1956. Eggs and larvae of anchovy, jack mackerel, and Pacific mackerel. Calif. Coop. Ocean. Fish. Invest., Prog. Rept. 1 April 1955- 30 June 1956:33-42.

The distribution of anchovy larvae in relationship to water temperature is discussed. The eggs and yolk-sac larvae of the anchovy are pictured.

5. \_\_\_\_\_ . 1958. Sardine eggs and larvae and other fish larvae, Pacific Coast, 1956. U.S. Fish Wild. Serv., Spec. Sci. Rept., Fish. 251, 84 p.

Data on the distribution and abundance of anchovy eggs and larvae in the California Current region are given in this paper and the following paper by Ahlstrom.

6. \_\_\_\_\_ . 1959. Sardine eggs and larvae and other fish larvae, Pacific Coast, 1957. U.S. Fish Wild. Serv., Spec. Sci. Rept., Fish. 155, 74 p.

7. \_\_\_\_\_. 1959. Vertical distribution of pelagic fish eggs and larvae off California and Baja California. U.S. Fish Wild. Serv., Fish Bull. 60 (161): 107-146.

Ninety-five percent of all anchovy larvae captured were taken in water temperatures between 14.0° and 17.4° C. Larvae were captured between the surface and 110 m, but were most abundant between 20 and 60 m. Anchovy eggs were taken as deep as 50 m.

8. \_\_\_\_\_. 1965. A review of the effects of the environment on the Pacific sardine. Int. Comm. Northwest Atl. Fish., Spec. Publ. 6: 53-74.

A discussion of the decline in sardine abundance with speculation on the anchovy as chief competitor.

9. \_\_\_\_\_. 1965. Kinds and abundance of fishes in the California Current region based on egg and larval surveys. Calif. Coop. Ocean. Fish. Invest., Rept. 10: 31-52.

A comparison of the relative abundance of fish larvae in the California Current region ranked the anchovy as number one in abundance. The anchovy comprised 37 percent of all larvae captured.

10. \_\_\_\_\_. 1966. Distribution and abundance of sardine and anchovy larvae in the California Current region off California and Baja California, 1951-64: A summary. U.S. Fish Wild. Serv., Spec. Sci. Rept., Fish. 534, 71 p.

A compilation of previous data showing a rise in anchovy abundance concurrent with a decline in sardine abundance.

11. \_\_\_\_\_. 1966. Method of deriving our present estimate of abundance of the anchovy population. In Calif. Mar. Res. Comm., Minutes, 2 and 3 August 1966: 13-15.

The anchovy population size was estimated at between 4 and 5 million tons.

12. \_\_\_\_\_ . 1967. Size composition of larvae of the Pacific sardine and northern anchovy obtained on CalCOFI cruises 1960-1964: A preliminary report. La Jolla Fishery-Oceanography Center, 98 p.

A report on occurrence, abundance, and sizes of anchovy larvae off California and Baja California.

13. \_\_\_\_\_ . 1967. CalCOFI Committee recommendation on the anchovy fishery. In Calif. Mar. Res. Comm., Minutes, 28 February 1967, App. 4.

A 400,000 ton quota was proposed for the anchovy reduction fishery, based on the estimated population biomass.

14. \_\_\_\_\_ . 1967. Co-occurrences of sardine and anchovy larvae in the California Current region off California and Baja California. Calif. Coop. Ocean. Fish. Invest., Rept. 11:117-135.

This study documents the rise in anchovy larvae abundance over sardine larvae abundance since 1950.

15. \_\_\_\_\_ . 1968. An evaluation of the fishery resources available to California fisherman. In The future of the fishing industry of the United States, D. Gilbert (editor), pp. 65-80. Univ. Wash. Publ. Fish., New Ser. 4, 346 p.

An evaluation of the anchovy population off California in relation to its potential exploitation.

16. Ahlstrom, E.H., J.L. Baxter, J.D. Issacs, and P.M. Roedel. 1967. Report of the CalCOFI Committee. Calif. Coop. Ocean. Fish. Invest., Rept. 11:5-9.

A proposal to study the impact of a new anchovy reduction fishery in the California Current system.

17. Ahlstrom, E.H., and D. Kramer. 1955. Pacific sardine (Pilchard) eggs and other fish larvae, Pacific Coast, 1953. U.S. Fish Wild. Serv., Sci. Rept., Fish. 155, 74 p.

This paper and the following two papers give data on the distribution and abundance of anchovy eggs and larvae off California and Baja California.

18. \_\_\_\_\_. 1956. Sardine eggs and larvae and other fish larvae, Pacific Coast, 1954. U.S. Fish Wild. Serv., Spec. Sci. Rept., Fish. 186, 79 p.

19. \_\_\_\_\_. 1957. Sardine eggs and larvae and other fish larvae, Pacific Coast, 1955. U.S. Fish Wild. Serv., Spec. Sci. Rept., Fish. 224, 90 p.

20. Anonymous, 1971. Northern anchovy. In California's living marine resources and their utilization, H.W. Frey (editor), pp. 48-51. Calif. Dept. Fish and Game, 148 p.

A brief account of the anchovy fishery and the status of biological knowledge of the anchovy.

21. Arthur, D.K. 1956. The particulate food and the food resources of the larvae of three pelagic fishes, especially the Pacific sardine, Sardinops caerulea. Ph.D. Thesis, Univ. Calif. Scripps Inst. Oceanogr. 231 p. (Typewritten).

An analysis of the food habits of the sardine, anchovy, and jack mackerel larvae showed their diets to be similar.

22. Baxter, J.I. 1966. Anchovy population size. Calif. Dept. Fish and Game MRO Ref. (66-21): 1-2.

This account estimates the anchovy biomass to be 4 to 5 million tons, with 2-2 1/2 tons off California.

23. \_\_\_\_\_ 1967. Summary of biological information on the northern anchovy Engraulis mordax Girard. Calif. Coop. Ocean. Fish. Invest., Rept. 11: 110-116.

One of the more complete summaries of anchovy biology to date.

24. Bayliff, W.H. 1967. Growth, mortality and exploitation of the Engraulidae, with special reference to the anchoveta, Centengraulis mysticetus, and the colorado, Anchoa naso, in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 12(5): 367-432.

Growth and mortality data for E. mordax is compared to other members of the family.

25. Berner, L. Jr. 1959. The food of the larvae of the northern anchovy Engraulis mordax. Inter-Amer. Trop. Tuna Comm., Bull. 4(1): 1-22.

Crustacea, mainly copepods, were the major food item of anchovy larvae, with dinoflagellates abundant in some instances. A low incidence of food in the gut (1.5 percent) prompted speculation on the reasons for low feeding incidence in larvae.

26. Berry, F.H., and H.C. Perkins. 1966. Survey of the pelagic fishes of the California Current area. U.S. Fish Wild. Serv., Fish. Bull. 65(3): 625-682.

This study includes occurrences of the anchovy off California and Baja California from CalCOFI station data.

27. Bolin, R.L. 1936. Embryonic and early larval stages of the California anchovy Engraulis mordax Girard. Calif. Fish and Game 22(4): 314-321.

According to Bolin, anchovy eggs have been taken during every month of the year in Monterey Bay, and anchovies spawn at approximately 10 p.m. The ovoid eggs and yolk-sac larvae of anchovy are pictured.

28. Chapman, W.M. 1944. The osteology of the Pacific deep-bodied anchovy, Anchoa compressa. J. Morph. 74 (2): 311-329.

A synopsis of the family Engraulidae is included.

29. \_\_\_\_\_ 1967. Statement of W.M. Chapman. In Calif. Mar. Res. Comm., Minutes, 8 August 1967, App. 2: 1-14.

This statement discusses the anchovy fishery, anchovy population size, impact of the fishery on the environment, and the fishery's regulation.

30. Clark, F.N., and J.B. Phillips 1952. The northern anchovy (Engraulis mordax mordax) in the California fishery. Calif. Fish and Game 38(2): 189-207.

The fishery, weight-length relations, and age and growth of the anchovy are considered. A few female anchovies mature at 90-100 mm, at ages between 1 and 2 years; fifty percent are mature at 130 mm, when they are 2 and 3 years old; almost all fish are mature at 150 mm, when they are 4 years or older.

31. Clemens, W.A., and G.V. Wilby. 1961. Fishes of the Pacific Coast of Canada. Bull. Fish. Res. Bd. Canada, 60:1-443.

This account includes records of anchovies captured off British Columbia. A note is also made that "spawning occurs apparently during July and Agust".

32. Collins, R.A. 1969. Size and age composition of northern anchovies (Engraulis mordax) in the California anchovy reduction fishery for the 1965-66, 1966-67, and 1967-68 seasons. In The northern anchovy and its fishery, J.D. Messersmith (editor), pp. 56-63. Calif. Dept. Fish and Game, Fish Bull. 147, 102 p.

Anchovy ages were determined by scale and otolith readings. The two and three year age-classes dominated the samples.

33. \_\_\_\_\_ 1971. Size and age composition of northern anchovies (Engraulis mordax) in the California reduction and canning fisheries, 1968-69 season. Calif. Fish and Game 57 (4): 283-289.

An usually large 1967 year-class accounted for the dominance of one year-old fish during the 1968-69 season.

34. Collins, R.A., and J.D. Spratt. 1969. Age determination of northern anchovies Engraulis mordax, from otoliths. In The northern anchovy and its fishery, J.D. Messersmith (editor), pp. 39-55. Calif. Dept. Fish and Game, Fish Bull. 147, 102 p.

A comparison of age determination techniques using scales and otoliths found otoliths to be a more reliable method for the anchovy.

35. Craig, W.L. 1960. Food and feeding. In a study of the yellowtail Seriola dorsalis (Gill), J.L. Baxter (editor), pp. 35-46. Calif. Dept. Fish and Game, Fish Bull. 110, 91 p.

The anchovy constituted 12.8 percent by volume of the diet of the yellowtail.

36. Croker, R.S. 1942. Latent marine fisheries resources of California and western Mexico. Calif. Fish and Game, 28 (4): 175-181.

A general discussion of the anchovy fishery, anchovy abundance, and speculation that the fishery could be greatly expanded.

37. Crooke, S.J. 1969. Results of a live bait sampling study. In The northern anchovy and its fishery, J.D. Messer-smith (editor), pp. 90-102. Calif. Dept. Fish and Game, Fish Bull. 147, 102 p.

The anchovy accounts for 98 percent of the live bait catch in California, and the Los Angeles - Long Beach Harbor provides the majority of the catch. A 1968 sampling program showed that age-class I (1967 year-class) accounted for 60 percent of the catch by weight. Age groups 0 and II contributed 14 and 18 percent of the catch weight, respectively.

38. Davies, I.E., and R.P. Bradley. 1972. Deep observations of anchovy and blue sharks from Deepstar 4000. Fish. Bull., U.S. 70 (2): 510-511.

Anchovies were observed at 310 m from a deep submersible, and the sighting was correlated with echograms of fish schools taken on the surface.

39. Eigenmann, C.H. 1892. The fishes of San Diego, California. U.S. Nat. Mus., Proc. 15: 123-178.

Included in this account of fishes from the San Diego region is a description of egg morphology and development of the anchovy, but Eignmann misidentifies the fish as Stolephorus ringens Jenyns. The discription is certainly that of E. mordax.

40. Fitch, J.E. 1969. Fossil records of certain schooling fishes of the California Current system. Calif. Coop. Ocean. Fish. Invest., Rept. 13: 71-80.

A study of fish remains from several localities in California shows that "Engraulis has been present off our coast during warm as well as cold periods, and in both shallow and deep areas for upwards of 12 million years...."

41. Ganssle, D. 1961. Northern anchovy Engraulis mordax. In California Ocean Fisheries Resources to the Year 1960,

pp. 21-22. Calif. Dept. Fish and Game, 79 p.

A short account of anchovy biology and its fishery.

42. Girard, C. 1854. Description of new fishes... Proc. Acad. Nat. Sci. Phila. 7: 129-156.

This paper provides the original description of E. mordax.

43. Hardwick, J.E. 1969. The 1967-68 anchovy reduction fishery. In The northern anchovy and its fishery, J.D. Messersmith (editor), pp. 23-38. Calif. Dept. Fish and Game, Fish. Bull. 147, 102 p.

A discussion of the anchovy reduction fishery, its regulations, quotas, total catch, and gross value during the 1967-68 season.

44. Haugen, C.E., J.D. Messersmith, and R.H. Wickwire. 1969. Progress report on anchovy tagging off California and Baja California, March 1966 through May 1969. In The northern anchovy and its fishery, J.D. Messersmith (editor), pp. 75-87. Calif. Dept. Fish and Game, Fish Bull. 147, 102 p.

Between March 1966 and May 1969, 380, 815 anchovies were tagged and 1,080 tags were recovered. Results indicate anchovy movement north during the late summer between southern and central California, and a southerly movement during the winter.

45. Heimann, R.F.G., and J.G. Carlisle. 1970. The California marine fish catch for 1968 and historical review, 1916-68. Calif. Dept. Fish and Game, Fish Bull. 149, 70 p.

Included in this report is a summary of yearly anchovy landings-- a low of 30 tons in 1926, a high of 43,000 tons in 1953, and 15,500 tons in 1968.

46. Hildebrand, S.F. 1943. A review of the American anchovies (Family Engraulidae). Bull. Bingham Ocean. Coll. 8 (2): 1-165.

This study is a taxonomic treatise which attempts to clarify synonymy.

47. Hildenbrand, S.F. 1963. Family Engraulidae. In Fishes of the Western North Atlantic, Memoir One, Part 3, pp. 152-249, Sears Found. Mar. Res., 630 p.

An expanded account of Hildebrand's previous work on members of the family found in the western North Atlantic.

48. Hubbs, C.L. 1925. Racial and seasonal variation in the Pacific herring, California sardine, and California anchovy. Calif. Dept. Fish and Game, Fish Bull. 8: 1-23.

An analysis of meristic variation of the anchovy along the California Coast, and the description of a subspecies, Engraulis mordax nanus, a brackish water form from San Francisco Bay.

49. Hunter, J.R. 1972. Swimming and feeding behavior of larval anchovy, Engraulis mordax. Fish. Bull., U.S. 70 (3): 821-838.

Cruising speed, proportion of time spent at rest, burst speed, tail beat frequency, and tail beat amplitude were determined for larval anchovies. Feeding sequences are described including reactive perceptive field, feeding success, and density of food required to meet metabolic requirements are computed.

50. Isaacs, J.D. 1965. Larval sardine and anchovy interrelationships. Calif. Coop. Ocean. Fish. Invest., Rept. 10: 102-140.

An analysis of stomach contents showed that the anchovy comprised 39 percent by volume of the diet of the striped bass.

52. Jordan, D.S., and A. Seale. 1925. Analysis of the genera of anchovies or Engraulidae. Copeia 141: 27-32.

This paper includes a key to the genera of the family Engraulidae.

53. \_\_\_\_\_. 1926. Review of the Engraulidae, with description of new and rare species. Mus. Comp. Zool. Harvard, Bull. 67 (11): 353-418.

A key to the genera of Engraulidae, and a description of the known species are provided.

54. Kramer, D., and E.H. Ahlstrom. 1968. Distributional atlas of fish larvae in the California Current region: Northern anchovy Engraulis mordax Girard, 1951-1965. Calif. Coop. Ocean. Fish. Invest., Atlas 9, 269 p.

Distributional charts of anchovy larvae occurrence off California and Baja California are given.

55. Kramer, D., and J.R. Zwiefel. 1970. Growth of anchovy larvae Engraulis mordax Girard in the laboratory as influenced by temperature. Calif. Coop. Ocean. Fish. Invest., Rept. 14: 84-87.

A comparison of larval anchovy growth rates at temperature of 17° and 22° C. Growth at 22° was about 1.75 times faster than at 17° C.

56. Lasker, R. 1964. An experimental study of the effect of temperature on the incubation time, development, and growth of Pacific sardine embryos and larvae. Copeia (2): 399-405.

Anchovy development was contrasted with the development of the sardine. The anchovy was shown to have a competitive advantage at low temperatures (11° and 12°C) over sardine because jaw development is complete in the anchovy but not in the sardine at these low temperatures.

57. Lasker, R., H.M. Feder, G.H. Theilacker, and R.C. May. 1970. Feeding, growth, and survival of larval anchovies reared in the laboratory. *Mar. Biol.* 5: 345-352.

Anchovy larvae were successfully reared when successively fed dinoflagellates (Gymnodinium), gastropod veligers (Bulla), and brine shrimp maupli (Artemia).

58. Lenarz, W.H. 1972. Mesh retention of larvae of Sardinops caerulea and Engraulis mordax by plankton nets. *Fish. Bull.*, U.S., 70 (3): 839-848.

This study demonstrates that a 0.505 mm mesh-width net retains "most if not all anchovy larvae", while a 0.55 mm mesh-width net (which until 1969 was standard equipment for the CalCOFI larvae sampling program) undersamples larvae.

59. Leong, R.J.H. 1971. Induced spawning of the northern anchovy Engraulis mordax. *Fish. Bull.* U.S. 69 (2): 357-360.

An artificial photoperiod of 4 hours light and 20 hours dark induced gonad maturation in anchovies. An injection of human chorionic gonadotropin followed by salmon or carp pituitary extract injection induced spawning.

60. Leong, R.J.H., and C.P. O'Connell. 1969. A laboratory study of particulate and filter feeding of the northern anchovy (Engraulis mordax). *J. Fish. Res. Bd. Canada*.

Whether anchovies procured food by filtration or by directed predatory biting was found to depend on the size of the organism. Laboratory experiments indicate that the anchovy cannot achieve the required daily ration of food in nature by filtering alone, based on the amount of food available in their natural environ-

ment.

61. Lillelund, K., and R. Lasker. 1971. Laboratory studies of predation by marine copepods on fish larvae. Fish. Bull., U.S. 69(3): 655-667.

The marine copepods Labidocera jollae, L. trispinosa, and Pontellopsis occidentalis were found to be effective predators on anchovy larvae in the laboratory. It was calculated that 1 to 4 anchovy larvae would be required per day to satisfy the metabolic needs of Labidocera.

62. Loukashkin, A.S. 1970. On the diet and feeding behavior of the northern anchovy, Engraulis mordax Girard. Proc. Calif. Acad. Sci., Fourth Series, 37(13): 419-458.

The frequency of food types found in 840 anchovy stomachs consisted of 51 percent crustaceans, 36 percent other zooplankters, 11 percent phytoplankton, and 2 percent foreign matter.

63. Loukashkin, A.S., and N. Grant. 1965. Behavior and natural responses of the northern anchovy, Engraulis mordax Girard under the influence of light of different wavelengths and intensities and total darkness. Proc. Calif. Acad. Sci., Fourth Series, 31(24): 631-692.

This study found the anchovy capable of discriminating qualitatively between green, blue, red, and white lights. Experiments also tested their reactivity to different light intensities ranging from 2 to 500 foot-candles.

64. MacGregor, J.S. 1968. Fecundity of the northern anchovy Engraulis mordax Girard. Calif. Fish and Game, 54(4): 281-288.

The mean number of eggs per spawning for the anchovy was calculated to be 574 per gram. On the basis of one spawning,  $3.0 \times 10^8$  eggs would be produced per short ton of spawning adult anchovies.

65. McCarthy J.J., and T.E. Whittlege. 1972. Nitrogen excretion by anchovy (Engraulis mordax and E. ringens) and jack mackerel (Trachurus symmetricus). Fish. Bull., U.S. 70(2): 395-401.

Ammonia, urea, and creatine accounted for 83 percent of all nitrogen excreted by the anchovy, and the identified fraction was 83 percent ammonia, 16 percent urea, and 1 percent creatine.

66. McHugh, J.L. 1951. Meristic variations and populations of northern anchovy (Engraulis mordax mordax) Bull., Scripps Inst. Oceanogr. 6(3): 123-160.

On the basis of meristic variation, three populations of anchovies were found to exist. They occur off British Columbia and northern California, off southern California and northern Baja California, and off central and southern Baja California.

67. Marr, J.C., and E.H. Ahlstrom. 1948. Observations on the horizontal distribution and the numbers of eggs and larvae of the northern anchovy Engraulis mordax off California in 1940 and 1941. U.S. Fish Wild. Serv., Spec. Sci. Rept., Fish. 56, 13 p.

Data is given on the spawning distribution of the anchovy.

68. May, R.C. 1970. Feeding larval marine fishes in the laboratory: A review. Calif. Coop. Ocean. Fish. Invest., Rept. 14: 76-83.

A review of attempts to rear larval marine fishes in the laboratory; included are several concerned with the anchovy.

69. May, R.C. 1971. An annotated bibliography of attempts to rear the larvae of marine fishes in the laboratory. NOAA Tech. Rept., NMFS SSRF-632, 24 p.

Included in this paper are several reports of rearing anchovies.

70. Merkel, T.J. 1957. Food habits of the king salmon, Oncorhynchus tshawytscha (Walbaum), in the vicinity of San Francisco, California. Calif. Fish and Game, 43(4): 249-270.

Anchovies constituted 29.1 percent by volume of the diet of the king salmon off San Francisco.

71. Messersmith, J.D. 1967. Tagged anchovies move from southern California to Monterey Bay. Calif. Fish and Game 53(3): 209.

Four anchovies, tagged in coastal waters off southern California were later recovered in Monterey Bay.

72. \_\_\_\_\_. 1969. A review of the California anchovy fishery and results of the 1965-66 and 1966-67 reduction seasons. In The northern anchovy and its fishery, J.D. Messersmith (editor), pp. 6-31. Calif. Dept. Fish and Game, Fish Bull. 147, 102 p.

This paper describes the events that culminated in the authorization of a reduction fishery for anchovies. Also included are the procedures used to regulate the fishery, catch statistics, and the value of the anchovy catch.

73. Messersmith J.D., J.L. Baxter, and P.M. Roedel. 1969. The anchovy resources of the California Current region off California and Baja California. Calif. Coop. Ocean. Fish. Invest., Rept. 13: 32-38.

A summary of anchovy biology, distribution, populations, movements, availability, and proposal for stock utilization.

74. Messersmith, J.D., and Staff. 1969. The northern anchovy (Engraulis mordax) and its fishery 1965-68. Calif. Dept. Fish and Game, Fish. Bull. 147, 102 p.

This bulletin includes several papers on anchovy biology and the anchovy fishery listed elsewhere in this bibliography.

75. Miller, D.J. 1955. Studies relating to the validity of the scale method for age determination of the northern anchovy. In Age determination of the northern anchovy, Engraulis mordax, pp. 6-34. Calif. Dept. Fish and Game, Fish Bull. 101, 66 p.

This study concluded that otoliths and skeletal structures were of little value in age determination of anchovies, but that scales were useful.

76. \_\_\_\_\_. 1956. Anchovy study shows gain in southern waters. Outdoor Calif., 17(12): 3, 8-9.

A popular account of the anchovy catch, population densities, fish movements, and fishery laws.

77. \_\_\_\_\_. 1956. Anchovy. Calif. Coop. Ocean. Fish. Invest., Prog. Rept., 1 April 1955 to 30 June 1956: 20-26.

A discussion of the fishery in relation to the anchovies life history, subpopulations, abundance, and reproductive potential.

78. Miller, D.J., A.E. Daugherty, F.E. Felin, and J. MacGregor. 1955. Age and length composition of the northern anchovy catch off the coast of California in 1952-53 and 1953-54. In Age determination of the northern anchovy, Engraulis mordax, pp. 37-66. Calif. Dept. Fish and Game, Fish. Bull. 101, 66 p.

A series of tables and data which consider anchovy age and length composition in relation to the fishery.

79. Miller, D.J., and R.N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dept. Fish and Game, Fish. Bull. 157, 235 p.

A popular account of coastal fishes with a brief outline of life history notes on the anchovy as well as other California fishes.

80. Moss, S.A., and W.N. McFarland. 1970. The influence of dissolved oxygen and carbon dioxide on fish schooling behavior. Mar. Biol. 5(2): 100-107.

The responses of anchovy schools to fluxuations in dissolved oxygen and pH included school density and nearest neighbor orientation changes, and mean swimming velocity changes.

81. Miller, D.J., and R.S. Wolf. 1958. Age and length composition of northern anchovy catch off the coast of California in 1954-55, 1955-56, and 1956-57. In Age and length composition Pacific coast catches sardines and Pacific mackerel 1955-56 and 1956-57 seasons and the northern anchovy 1954-55 through 1956-57 seasons, pp. 27-72. Calif. Dept. Fish and Game, Fish. Bull. 106, 72 p.

This paper present year-class data for the anchovy fishery.

82. O'Connell, C.P. 1963. The structure of the eye of Sardinops caerulea, Engraulis mordax, and four other pelagic marine teleosts. J. Morph., 113(2): 287-329.

Included is a description of retinal density distribution of cones, rods, and neurons. The author suggests that Engraulis is better equipped than the other fish studied for vision in dim or turbid waters and that anchovies have better visual acuity than

Sardinops.

83. O'Connel, C.P. 1972. The interrelation of biting and filtering in the feeding activity of the northern anchovy (Engraulis mordax). J. Fish. Res. Bd. Canada 29: 283-293.

This study showed the relationship of feeding by biting and feeding by filtering to the relative size and concentration of food organisms in laboratory experiments. The nutritional requirements of the anchovy in nature are considered on the basis of the laboratory experiments.

84. Phillips, J.B. 1949. Anchovy. In The commercial fish catch of California for the year 1947 with an historical review. p. 89. Calif. Dept. Fish and Game, Fish. Bull. 74, 263 p.

A short discussion of anchovy landings in California

85. Pinkas, L., M.S. Oliphant, and I.L.K. Iverson. 1971. Food habits of albacore, bluefin tuna, and bonito in California waters. Calif. Dept. Fish and Game, Fish Bull. 152, 105 p.

Anchovies made up 43.7 percent by volume of the diet of the albacore, 80 percent by volume of the diet of the bluefin tuna, and 76 percent by volume of the diet of the bonito.

86. Radovich, J., and E.D. Gibbs. 1954. The use of a blanket net in sampling fish populations. Calif. Fish and Game, 40(4): 353-365.

A description of a blanket net and its use in capturing anchovies and other species for census data.

87. Reid, J.L. 1967. Oceanic environments of the genus Engraulis around the world. Calif. Coop. Ocean. Fish. Invest.,

Rept. 11: 29-33.

A description of anchovy habitats around the world and speculation on environmental limiting factors for the genus Engraulis.

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### Subject Index

The numbers refer to the numbers preceding each citation in the bibliography.

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Numerical Analysis of a Benthic Transect  
in the Vicinity of Waste Discharges in  
Outer Los Angeles Harbor

by

Robert W. Smith  
Allan Hancock Foundation

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### Introduction

There are presently several different approaches in the study of the environmental effects of waste discharge on the benthos.

1) The direct effects of the constituents of the wastes can be determined experimentally. SCCWRP (1973) contains a review of the literature on the effects of trace metals and pesticides on various organisms, and Reish (1966) studied the effects of low-oxygen concentration on some polychaetes commonly employed as indicators of varying degrees of pollution. 2) The degree of abnormalities and disease in organisms in the vicinity of discharges can be an indicator of the harmful effects of the wastes. The incidence of disease and abnormalities in fish, algae, crabs and sea urchins around outfalls is reviewed in SCCWRP (1973). 3) There have been several benthic ecological surveys in the vicinity of waste outfalls. It is sometimes possible to approximate the level of pollution by noting the level of dominance of certain known "indicator species," which are organisms commonly found at certain known levels of pollution. For a discussion of the concept of indicator species, see Reish (1973) and Olson and Burgess (1967); the idea is criticized by Stirn (1973). In other studies, the benthos in the area of an outfall is compared with a suitable control area or period, and the differences are attributed to the effects of the wastes (McNulty, 1970). When both biotic and abiotic measurements are taken, the distributions of the benthic organisms can be correlated with the environmental data. This can help the ecologist develop hypotheses concerning the dynamics of the local biotic-abiotic relationships.

Besides indicator species, there are several different biological measures which are used in these ecological surveys.

1) The distribution of the individual species can be considered one at a time (National Marine Fisheries Service, 1972). However, as the number of species considered increases, the data can become too complex for normal human comprehension. Compared with some of

the more economical and simpler methods, the large amount of time and effort required with this approach will not necessarily result in more accurate conclusions. 2) The total number and/or biomass of all the organisms in a sample has been used as a biotic measure in some studies (Water Resources Engineers, 1972). Sanders (1969) shows a relationship between biomass and a stress gradient. According to Stirn (1970), however, these measures have little interpretive value when considered apart from the species diversity. 3) In some studies, the organisms in a sample are grouped into phyla or some other taxonomic group above the species level. The abundance or biomass of these groups are then used as a biological measure (Water Resources Engineers, 1972). This is objectionable on ecological grounds, since there may be a wide range of ecological requirements represented by the species in a group. 4) Species diversity indices are often considered a biotic measure of the stability and "health" of a community (Sanders, 1969). For examples of studies using species diversity see SCCWRP (1973), National Marine Fisheries Service (1972), Department of the Environment (1972), Borowitska (1972), and Boesch (1972). Although there is a fairly consistent relationship between species diversity and biological stress from pollution (Sanders, 1969; Stirn, 1970), this measure is still not completely adequate. Presently, all the causes of variation in the species diversity are not completely understood. Furthermore, two or more communities with equal diversity can contain completely different assemblages of organisms. The failure of a species diversity index to detect this important qualitative difference represents a significant loss of information which could be useful in ecological interpretation. 5) The distribution of "communities" or associations of organisms is often used as a biotic measure. Benthic ecologists using the classical methods of community analysis in the marine environment, dating from Petersen (1914), consider only the dominant species when delimiting communities. Studies related to pollution which use classical community analyses include Reish (1959), Hartman (1956), Jenkinson (1972), McNulty (1970), and Wade *et al* (1972). However,

as the co-dominance and complexity in the data increases, these classical methods require more difficult and less clear-cut decisions on the part of the ecologist. Furthermore, since only the dominant organisms are considered, large amounts of potentially useful information will be ignored.

All but one of the above biological measures are an attempt to simplify the analysis by utilizing only a single index or a small number of species (or other categories). As noted, however, the process is usually accompanied by the loss of potentially important information. This shortcoming can be overcome by the use of objective numerical methods, which allow consideration of a greater proportion (or all) of the total data. Since extensive calculations are normally required, these methods were not developed for ecological use until the advent of the electronic computer. Assuming that a computer is available, the only limitations to the amount of data which can be analyzed at any one time by these methods are 1) the storage capacity of the computer, and 2) the funds available for the costs of computer time. For a general discussion of these methods, see Greig-Smith (1967), Pielou (1969) and Lambert and Dale (1964). Almost all these techniques are considered in the general category of either classification or ordination.

Classification methods attempt to group entities in the data into discrete groupings which subsequently can be interpreted. Examples include the trellis diagram (Southwood, 1966, p. 342), recurrent groups (Fager, 1957), and the hierarchical methods utilizing a dendrogram (Williams, 1971; Stephenson et al., 1970; Field, 1971; Day et al., 1971; Stephenson and Williams, 1971; Stephenson et al., 1972; Jones, 1969; Sokal and Sneath, 1963). In ordination, on the other hand, entities in the data are considered along some continuum or continua. Examples include the "simple ordination" methods of Bray and Curtis (1957) and Orloci (1966), canonical analysis (Seal, 1964), canonical correlation (Anderson, 1958; Morrison, 1967), and factor analysis (Harmon, 1967). In ecology, the most frequently used method of factor analysis is principal

component analysis (Seal, 1964; Cassie, 1963; Austin, 1968; Austin et al., 1972; Johnson and Risser, 1972). These objective methods can help summarize the main trends in both the biotic and abiotic ecological data; frequently these trends are not readily apparent solely from visual inspection of the data lists. Up to the present, these methods have been infrequently used by ecologists studying the effects of pollution. Hierarchical classification methods have been used by Cairns and Caesler (1969), Roback et al. (1969) [thermal pollution]; Cimberg et al. (1969) [oil pollution]; and Stephenson et al. (in ms.) [sewage pollution]. Department of the Environment (1972) used a trellis diagram, and SCCWRP (1973) employed Fager's recurrent-group analysis to delineate species groups in the general area of a sewage outfall.

The present study utilizes principal component analysis and a hierarchical classification method to sort out some of the biotic-abiotic relationships of the benthos in the vicinity of waste outfalls in outer Los Angeles Harbor. Only polychaetous annelids were identified to the species level and used in the numerical analysis. Since the polychaetes are by far the most abundant group of animals found in the benthos of this area, they should reflect any major biotic trends in the samples taken (Day, 1963; Day et al., 1971).

In 1954, Reish (1959) used classical methods to delineate the animal assemblages in the harbor. He found that the dominant fauna in an area was largely determined by the general level of pollution, which seemed to be related to the level of dissolved oxygen in the bottom water and the amounts of organic material and sulfides in the sediment. Only one station location (station 7) in the present study coincides with a station location (LA20) in the Reish study.

#### Materials and Methods

All samples were taken in triplicate with a  $.10\text{ m}^2$  modified Campbell grab at each of seven stations (Figure 1). The date of

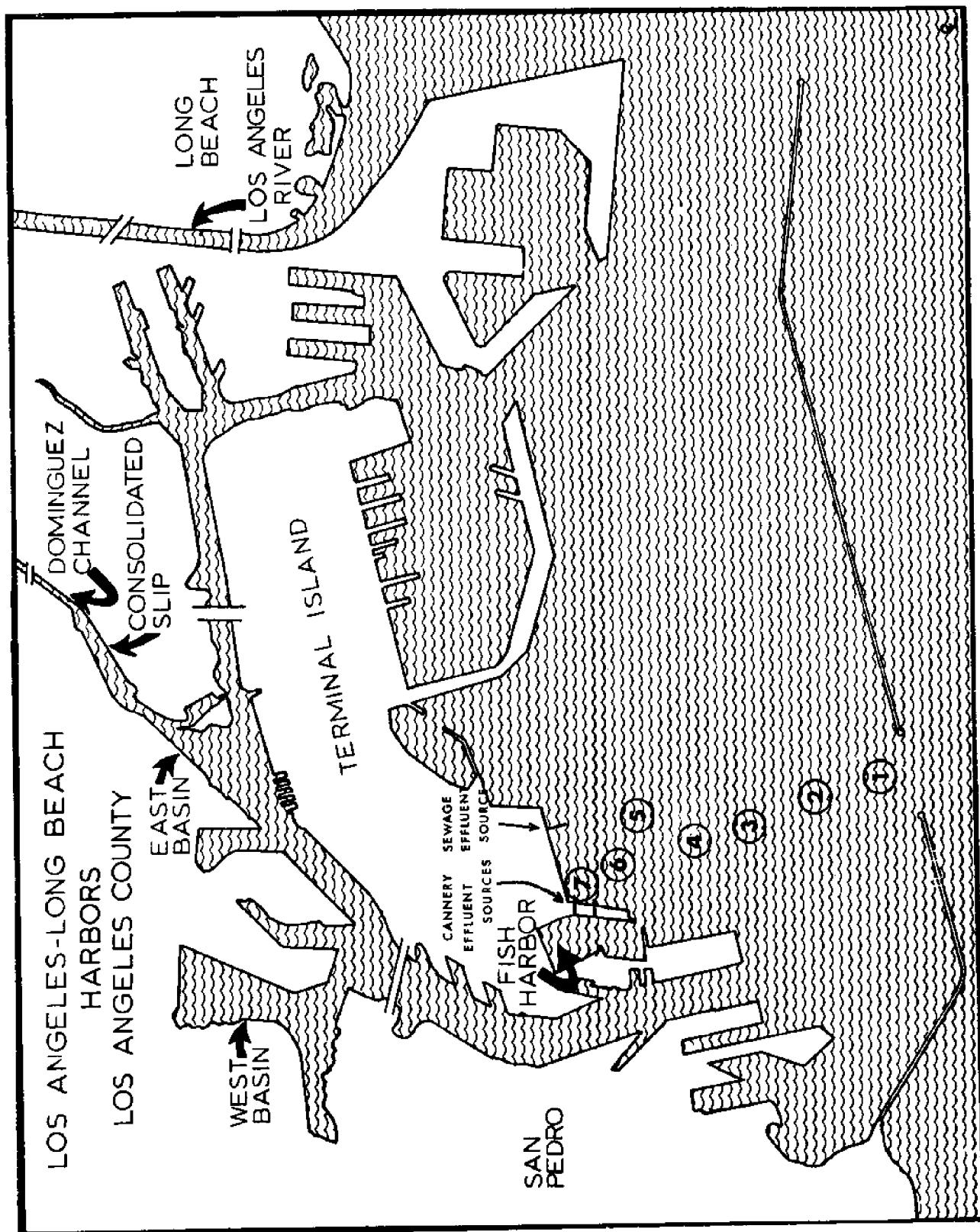


Fig. 1 - STATION AND DISCHARGE LOCATIONS

sampling was September 27, 1972.

#### Biotic Data

The sediment from each grab was washed through a .5 mm mesh screen on board ship. The material left in the screen after washing was immediately preserved in 10% formalin. Within 24 hours the samples were washed with water and transferred into 70% isopropyl alcohol. In the laboratory, the animals were removed from the remaining sediment and debris of each sample with the aid of a large magnifying lens (3X).

As mentioned, only polychaetes were identified to the species level and used in the numerical analysis. However, in order to calculate the species diversity, all other animals were sorted into what appeared to be different species, and were specified by a number. All animal species were also used in the biomass determinations.

#### Abiotic Data

At the time of sampling, the pH, conductivity, temperature, and depth of the bottom water were measured at each station. Subsamples were taken of the sediment from each grab and frozen for later analysis. The sediment variables which were measured on at least one of the three samples at a station were as follows:

sediment-size distribution: Percent sediment in 13 successive intervals of 1  $\phi$  unit, standard deviation, skewness, and kurtosis (Krumbein and Pettijohn, 1938);

elements: C, N, P, S, Zn, Cu, Cd, Pb, Ni, and Hg;

pesticides: DDD and DDE;

other compounds: oil and  $\text{CaCO}_3$ ;

oxygen demand: chemical oxygen demand (COD) and Immediate oxygen demand (IOD).

Appendix A indicates the methods used in the determination of the abiotic data. All parameters except sediment size, carbon and nitrogen were determined by Dr. Kenneth Y. Chen, of the Department

of Environmental Engineering, University of Southern California.

### Analysis of the Data

#### Classification

An agglomerative, hierarchical method (Williams, 1971) was used to classify the species into ecologically-meaningful groups. A general description of the method follows. The first step is the calculation of a matrix of indices which will describe the relationship of each entity with every other entity. Entities are the units which are being classified. The calculations are based on the measurements of a set of attributes which are measured at or on each entity. There are several such similarity or "distance" indices available, each with certain associated biases and assumptions; therefore it is important that the index is appropriate for the situation in which it is used. The next step in the process is the construction of a dendrogram, which gives a two-dimensional picture of the relationships between the entities being classified. As the dendrogram is constructed, entities or groups of entities are joined by lines which extend into one dimension a distance proportional to the relationship between the entities joined. In agglomerative dendrogram-strategies the process starts with the connection of the two entities with the greatest similarity (or the least "distance") and continues until all entities are represented.

There are several alternate sorting strategies which use different criteria for joining a group of entities with another entity (or group of entities) in the process of building the dendrogram. The properties of the different strategies are discussed in Pritchard and Anderson (1971), Williams, Clifford and Lance (1971) and Stephenson (1973).

In the present study, the group-average sorting strategy and the "Bray-Curtis" distance measure (Bray and Curtis, 1957; Day et al., 1971) were used. A description of group-average sorting is in Sokal and Sneath (1963). The Bray-Curtis index is as follows:

$$D_{jk} = \frac{\sum_{i=1}^n |x_{ij} - x_{ik}|}{\sum_{i=1}^n (x_{ij} + x_{ik})}$$

where  $D_{jk}$  is the distance between entities j and k; n is the number of attributes; and  $x_{ij}$  is the measurement of attribute i in entity j. This index is especially sensitive to the magnitude of the numbers in the attribute data.

When classifying species, using their occurrences at the various stations as attributes, the proportion of a species at a station is more informative than the raw species count (Stephenson et al., in ms.). For this reason, the raw data was standardized by dividing the number of each species at each station by the sum of all specimens of that species found at all stations.

#### Data reduction prior to classification.

There were several species which occurred infrequently and in a small proportion of the samples. Since such species would have little influence on the final results, it would seem justified to drop them from the analysis. This procedure not only simplifies the analysis, but also saves considerable amounts of computer time and core. Prior to classification, all species which occurred in fewer than three samples were eliminated, except for those species which occurred more than a total of ten times in the samples in which they were found. Using this criterion, 62 out of a total of 120 species were retained.

#### Ordination.

The trends in the abiotic data were determined by principal component analysis. The theory behind principal component analysis is as follows: 1) all entities are originally pictured as points in a theoretical multidimensional space. Each dimension of the space represents one attribute of the entities; the distance of an

entity into a dimension is proportional to the measurement (on the entity) of that attribute. 2) The resulting pattern of points will define the interrelationships of the entities. 3) Since it is difficult to visualize points in more than three dimensions at a time, it is necessary to project the points onto one or a few axes at a time. Before doing so, it is advantageous to translate and rotate the axis system such that a) each successive axis accounts for a maximum amount of the variance remaining in the system, and b) the new axes, or the factors they now possibly represent, are uncorrelated. The variance in each axis of the new system is called an eigenvalue, and the new axes are called principal component axes. 4) The coordinates of the entities in the new system are assumed to be linearly related to the coordinates of the original system. The set of coefficients which transforms the original coordinates to the final coordinates are called the eigenvectors. Each principal component axis has its own set of eigenvectors, and each eigenvector of the set will correspond to one of the attributes. The absolute value of an eigenvector is proportional to the importance of the corresponding attribute in determining the position of an entity on the axis. The sign of an eigenvector indicates the direction of this influence, i.e., for positive eigenvectors, this influence will be toward the positive end of the axis, and for negative eigenvectors the influence will be toward the negative end.

The eigenvectors and eigenvalues are normally calculated from the variances and covariances of the attributes. If the attributes are standardized by their standard deviations, the variances and covariances become correlation coefficients, which were used in the present study. See Seal (1964), Harman (1967), Orloci (1967), Gower (1966), and Anderson (1971) for mathematical discussions of principal component analysis.

## Results

### Local effluent output

Figure 1 shows the locations of the effluent sources in the area of the study. See Juge and Griest (1973) for a discussion of the cannery output. The sewage effluent receives primary treatment and averages about two million gallons per day; the biological oxygen demand of the effluent is between 200 and 600 mg/l (M. Oguri, personal communication).

### Preliminary data analysis

Prior to analysis, the biotic and abiotic variables were averaged at each station. Since several of the physical variables were measured in only one of the three sediment samples at a station, it was necessary to generalize the results of the measurements of the one sample to the other two samples at the same station. This is justifiable as long as the two samples in question were not observed to be radically different, biotically or abiotically, from the sample on which all measurements were made. A preliminary classification of all the samples showed that one of the samples at Station 4 and one at Station 7 were drastically different from the other two samples at the same station. Consequently, these two anomalous samples were not included in the average for their station.

Seventeen sediment distribution parameters and six heavy metals were measured. Since many of these measurements are certainly dependent on one another, the use of all of them would disproportionately weight the analysis toward sediment size and heavy metals. Consequently, two main independent trends in each of these two categories were separately extracted by principal component analysis. The scores of the stations on the first two component axes of these analyses were used instead of all the measured values. See Austin *et al* (1972, p. 310) for a similar preliminary

analysis. The first component of sediment variables (SED 1) is mainly related to the mean particle size, and the second component (SED 2) is associated with the distribution of the sand fraction regardless of the mean particle size. The first component of the heavy metals (HM 1) is related to the general level of all the heavy metals, and the second component (HM 2) is mainly related to the levels of cadmium and nickel, independent of the level of zinc and lead. The terms SED1, SED2, HM1, HM2 respectively, will refer to these components in the rest of this paper. The values of these components are listed in Table 2.

#### Results of the analyses.

The average species count at each station is shown in Table 1, and the average values for the abiotic variables are given in Table 2. The dendrogram showing the relationships between the species groups is shown in Figure 2. The species in the different groups are shown in Table 3. Six main species groups are recognized. Group 1 consists of nine species and is numerically dominated by Spiophanes bombyx, Chaetozone sp 1, Lumbrineris californiensis, and Chone sp 1. Group 2 contains 32 species and is dominated by Tharyx sp, Chaetozone corona, Haploscoloplos elongatus, Pectinaria californiensis newportensis, Sigambra tentaculata, Nephtys cornuta franciscana, and Paraonis gracilis oculata. Group 3 contains 14 species and is dominated by Cossura candida, Capitita ambiseta, and Prionospio pygmaeus. Group 4 contains five species, and is dominated by Capitella capitata and Armandia bioculata. Group 6 contains only 2 species of which Polydora ligni is most abundant.

Figure 3 shows the results of the principal component analysis of the abiotic data, and Table 4 contains the eigenvectors for the principal components. As mentioned, the trends of the abiotic variables along each axis can be determined from examination of the eigenvectors. The first axis is mainly related to the mean sediment size, percent carbon, percent nitrogen, immediate

TABLE 1  
Biotic Data

Species counts are averaged at each station.

Species	Stations		1	2	3	4	5	6	7
<u>Laonice foliata</u> (Moore)	0.67	2.33	4.67	0.50	1.33				
<u>Polydora brachycephala</u> (Hartman)		0.33		8.33					
<u>Polydora ligni</u> Webster			1.00	3.33	0.33	22.00			
<u>Polydora</u> sp. #1	2.00								
<u>Polydora</u> sp. #2							7.50		
<u>Polydora socialis</u> (Schmarda)	0.67	0.33		1.00					
<u>Prionospio heterobranchia</u> <u>newportensis</u> Reish				0.67	0.33				
<u>Prionospio cirrifera</u> Wieren	1.33	1.33	22.00	68.00	1.00	6.00			
<u>Prionospio malmgreni</u> Claparedé	7.00	0.33	0.50	1.00					
<u>Prionospio pinnata</u> Ehlers	0.33	3.33	2.67	1.00	1.00				
<u>Prionospio pygmaeus</u> Hartman	38.33	2.33	6.33	7.50	47.00	0.33	0.50		
<u>Pseudopolydora paucibranchiata</u> Okuda	0.33	2.67	9.00	7.33	7.00				
<u>Spiophanes berkeleyorum</u> Pettibone	6.00	0.33		2.67					
<u>Spiophanes missionensis</u> Hartman	5.67	1.33	5.67	7.50	13.33	0.50			
<u>Spiophanes bombyx</u> (Claparedé)	30.33	0.33	1.67		0.67				
<u>Haploscoloplos elongatus</u> (Johnson)	1.67	21.33	9.00	6.00	13.00				
<u>Paraconis gracilis oculata</u> (Hartman)	0.33	201.33	33.00	12.00	53.33	0.67			
<u>Aricidea suecica</u> (Eliason)	1.00	0.33	0.50	0.33					

TABLE 1 (continued)

Species	Stations	1	2	3	4	5	6	7
<u>Magellona pitelkai</u> Hartman		2.67	1.00			0.33		
<u>Teles savus costatum</u> Claparedé	1.00	1.67	0.33			0.67		
<u>Chaetozone corona</u> Berkeley & Berkeley	1.67	34.67	3.67	1.00		15.33		
<u>Chaetozone</u> sp. #1	23.67							
<u>Tharyx</u> sp.	13.67	2838.33	1236.00	87.50	1015.67	2.00	2.00	
<u>Cossura candida</u> Hartman	337.33	27.33	25.50	552.67	5.33			
<u>Armadia bioculata</u> Hartman			115.50	2.00	18.00	1.50		
<u>Capitella capitata oculata</u> Hartman	1.33	2.67	179.00	8.33	119.33	14.00		
<u>Capitita ambiseta</u> Hartman	15.00	412.67	148.33	257.00	404.33	2.00	9.00	
<u>Notomastus (clistomastus) tenuis</u> Moore	12.67	4.33	1.00	5.33				
<u>Axiothella rubrocincta</u> (Johnson)	6.33	2.67	0.50	0.67				
<u>Pectinaria californiensis</u> newportensis Hartman	89.00	9.67	0.50	3.33				
<u>Ampharete labrops</u> Hartman	1.67	1.33		3.00				
<u>Amphicteis sphaerobranchiata</u> Moore	7.67	8.00	3.00	14.67				
<u>Melinna oculata</u> Hartman	4.33	3.00		1.00				
<u>Pista fasciata</u> (Grube)	0.33	2.00	7.33	0.50	2.67			
<u>Streblosoma crassibranchia</u> Treadwell	2.00							
<u>Nephtys cornuta franciscana</u> Clark & Jones	36.67	14.00	7.50	15.33				

TABLE 1 (continued)

Species	Stations	1	2	3	4	5	6	7
<u>Nephrys caecoides</u> Hartman		0.33	0.33			0.50	0.50	0.67
<u>Glycera americana</u> Leidy		0.33	4.33			7.50	13.33	1.00
<u>Diopatra</u> juv.		1.00		0.33		1.50	0.67	0.50
<u>Nothria elegans</u> (Johnson)	2.67	0.67	1.33		1.33	0.67		
<u>Lumbrineris bifilaris</u> (Ehlers)		18.00	4.33		3.50	6.00	0.33	
<u>Lumbrineris californiensis</u> Hartman	15.00	2.67	0.33					
<u>Lumbrineris index</u> Moore		3.00	0.67					
<u>Lumbrineris</u> nr. <u>inflate</u>		9.67	1.33				0.67	
<u>Lumbrineris</u> nr. <u>limicola</u>	5.33	0.67	1.00				2.33	
<u>Lumbrineris zonata</u> (Johnson)	5.67	8.33	2.33		1.00		3.33	0.33
<u>Chone</u> sp. #1	20.00	5.67	7.67		1.50		4.00	
<u>Euchone limnicola</u> Reish		1.67	0.67		1.00		4.00	
<u>Euchone incolor</u> Hartman		0.33	1.00		0.50		1.00	
<u>Megalomma pigmentatum</u> Reish		2.33	3.00					
<u>Harmothoe priops</u> Hartman	0.67	1.67	1.33		1.50		0.33	
<u>Pholoe glabra</u> Hartman		1.67	0.67		0.50		0.33	
<u>Anaitides williamsi</u> Hartman	2.33	5.67	1.67		2.00		1.67	
<u>Eteone californica</u> Hartman		2.33	1.00		0.50		0.67	
<u>Eumida sanguinea</u> (Oersteds)			1.00		2.00		1.00	0.33
<u>Stauronereis rudolphi</u> (delle Chiaje)	0.67	3.00	3.33	24.00	2.67	1.00	0.50	0.50
<u>Gyptis arenicola glabra</u> (Hartman)		7.00			1.00		5.00	

TABLE 1 (continued)

Species	Stations	1	2	3	4	5	6	7
<u>Ophiodromus pugettensis</u> (Johnson)		1.67	0.67					
<u>Sigambla tentaculata</u> (Treadwell)		64.33	1.33	1.50	7.67			0.33
<u>Spaerosyllis californiensis</u> Hartman		6.67	4.00					
<u>Nereis procera</u> Ehlers	0.33	10.00	4.67	2.50	3.00			2.33
<u>Pherusa neopapillata</u> Hartman	0.33	0.67		0.50				

TABLE 2  
Sediment Measurements

Stations	1	2	3	4	5	6	7
<u>Heavy Metals (mg/kg)</u>							
zinc (Zn)	86.700	175.000	109.000	68.300	95.500	191.000	138.000
copper (Cu)	25.000	119.000	89.300	52.200	82.900	434.000	62.200
cadmium (Cd)	74.500	100.000	89.800	81.900	88.600	85.300	98.800
lead (Pb)	65.300	137.000	131.000	91.100	112.000	171.000	98.800
nickel (Ni)	53.800	94.000	89.800	58.300	71.800	76.600	72.800
mercury (Hg)	0.066	0.623	0.365	0.231	0.406	3.050	0.318
HML*	-1.0	.6	.1	-.8	-.3	-1.4	-.1
HM2*	-.5	.7	.4	-.3	1.0	-.8	.4
<u>Sediment Distribution Parameters (Intervals in %)</u>							
mean particle size ( $\bar{X}_\phi$ )	2.50	6.09	4.83	4.55	4.67	4.10	5.35
standard deviation ( $\sigma_\phi$ )	0.74	2.47	2.38	2.35	2.37	2.40	1.80
skewness (SK)	-0.55	0.31	0.49	0.66	0.61	0.45	0.81
kurtosis (KT)	2.79	-0.88	0.16	0.71	0.58	1.17	1.97
-2 to -1 $\phi$	0.10	0.00	0.00	0.00	0.00	1.03	0.00
-1 to 0 $\phi$	0.80	0.00	0.00	0.00	0.00	1.60	0.00
0 to 1 $\phi$	2.80	0.00	0.23	0.05	0.83	3.57	0.00
1 to 2 $\phi$	11.30	0.17	2.90	0.85	1.67	7.63	0.10

\* see text for explanation

TABLE 2 (continued)

Stations	1	2	3	4	5	6	7
2 to 3 $\phi$	61.37	3.43	20.70	26.10	18.00	17.80	0.35
3 to 4 $\phi$	23.70	16.00	26.10	34.35	37.63	22.70	12.65
4 to 5 $\phi$	0.00	27.20	16.07	11.85	13.00	23.53	48.15
5 to 6 $\phi$	0.00	11.60	7.33	4.60	5.73	6.90	16.20
6 to 7 $\phi$	0.00	9.63	6.60	5.70	6.50	3.93	8.25
7 to 8 $\phi$	0.00	7.97	5.80	4.85	4.60	2.43	4.20
8 to 9 $\phi$	0.00	5.27	3.60	3.00	2.07	1.73	1.95
9 to 10 $\phi$	0.00	5.17	4.07	2.10	3.03	1.70	1.45
> 10 $\phi$	0.00	13.53	6.57	6.50	6.87	5.47	6.65
SED1*	-2.5	1.7	.5	.2	.2	-.8	.7
SED2*	.3	.06	.4	.6	.5	-.9	-1.0
<u>Other Elements (% or mg/kg)</u>							
organic carbon (% C)	0.093	2.320	1.187	0.725	0.580	0.617	0.810
nitrogen (% N)	0.013	0.176	0.095	0.070	0.052	0.052	0.086
carbon to nitrogen ratio (C/N)	11.200	13.187	12.483	10.550	11.307	11.980	9.210
phosphorus (P)	7.700	43.000	21.000	23.000	29.000	3.700	22.000
sulfide (S <sup>-</sup> )	96.500	344.000	303.000	366.000	257.000	1145.000	265.000

\* see text for explanation

TABLE 2 (continued)

Stations	1	2	3	4	5	6	7
<u>Oxygen Demand (mg/kg)</u>							
immediate oxygen demand (IOD)	66.000	1110.000	714.000	523.000	548.000	768.000	578.000
chemical oxygen demand (COD)	0.750	6.550	3.370	6.380	5.100	5.880	6.460
<u>Compounds (% or mg/kg)</u>							
calcium carbonate (% CaCO <sub>3</sub> )	3.145	3.983	3.013	2.450	2.173	2.307	2.010
oil	9.300	23.600	16.100	15.300	5.910	16.600	8.500
dichlorodiphenylchloro- ethane (DDE)	0.033	1.880	0.650	0.200	0.185	0.066	0.135
dichlorodiphenyldi- chloroethane (DDD)	0.000	0.324	0.090	0.031	0.023	0.038	0.000
Bottom Water Measurements							
temperature (°C)	15.400	17.500	18.400	19.000	19.400	19.500	19.600
conductivity (in millimhos)	45.100	46.300	47.000	47.200	47.100	47.000	47.000
pH	8.320	8.320	8.320	8.320	8.280	8.270	8.170
depth (in feet)	45.000	40.000	28.000	20.000	18.000	13.500	4.600

TABLE 3

Species Groups Formed by the Classification Analysis\*

Group 1

Polydora sp. #1  
Chaetozone sp. #1  
Spiophanes bombyx (Claparede)  
Lumbrineris californiensis Hartman  
Prionospio malmgreni Claparede  
Chone sp. #1  
Nothria elegans (Johnson)  
Aricidea suecica (Eliason)  
Lumbrineris nr. limicola

Group 2

Lumbrineris nr. inflata  
Pectinaria californiensis newportensis Hartman  
Lumbrineris index Moore  
Eteone californica Hartman  
Streblosoma crassibranchia Treadwell  
Notomastus (clistomastus) tenuis Moore  
Tharyx sp.  
Sigambra tentaculata (Treadwell)  
Nephtys cornuta franciscana Clark & Jones  
Lumbrineris bifilaris (Ehlers)  
Phloe glabra Hartman  
Haploscoloplos elongatus (Johnson)  
Nereis procura Ehlers  
Prionospio pinnata Ehlers  
Axiothella rubrocincta (Johnson)  
Magelona pitelkai Hartman  
Ophiodromus pugettensis (Johnson)  
Spaerosyllis californiensis Hartman  
Melinna oculata Hartman  
Chaetozone corona Berkeley & Berkeley  
Spiophanes berkeleyorum Pettibone  
Paraonis gracilis oculata (Hartman)  
Gyptis arenicola glabra (Hartman)  
Glycera americana Leidy  
Lumbrineris zonata (Johnson)  
Telepsavus costarum Claparede  
Anaitides williamsi Hartman  
Pherusa neopapillata Hartman  
Harmothoe priops Hartman

\* For the relationships between the groups, see Figure 2.

TABLE 3 (continued)

Pista fasciata (Grube)  
Laonice foliata (Moore)  
Megalomma pigmentum Reish

Group 3

Nephtys caecoides Hartman  
Polydora socialis (Schmarda)  
Prionospio pygmaeus Hartman  
Amphicteis scaphobranchiata Moore  
Ampharete labrops Hartman  
Euchone limnicola Reish  
Cossura candida Hartman  
Capitata ambiseta Hartman  
Euchone incolor Hartman  
Spiophanes missionensis Hartman  
Diopatra juv.  
Prionospio cirrifera Wieren  
Prionospio heterobranchia newportensis Reish  
Polydora brachycephala (Hartman)

Group 4

Stauronereis rudolphi (delle Chiaje)  
Armandia bioculata Hartman  
Capitella capitata oculata Hartman  
Eumida sanguinea (Oersted)  
Pseudopolydora paucibranchiata Okuda

Group 5

Polydora sp. #2  
Polydora ligni Webster

TABLE 4

The Eigenvectors for the Principal Components in the  
 Analysis of the Abiotic Data\*

	I	II	III	IV	V	VI
HM 1	-0.18	-0.18	<u>-0.40</u>	0.12	<u>0.36</u>	0.15
HM 2	-0.24	0.01	<u>0.38</u>	0.20	<u>0.35</u>	-0.29
SED 1	<u>-0.30</u>	-0.15	0.21	-0.06	0.04	-0.13
SED 2	-0.01	0.24	0.24	<u>-0.60</u>	0.03	0.07
organic carbon	<u>-0.35</u>	0.03	0.02	0.08	-0.02	-0.11
calcium carbonate	-0.05	<u>0.39</u>	-0.08	0.21	-0.09	-0.02
nitrogen	<u>-0.34</u>	-0.01	0.07	0.12	-0.10	-0.19
carbon to nitrogen ratio	-0.21	0.19	-0.29	-0.22	<u>0.47</u>	0.13
depth	-0.06	<u>0.40</u>	-0.06	0.01	-0.01	0.09
oil	0.28	0.08	-0.27	-0.06	<u>-0.41</u>	<u>-0.52</u>
immediate oxygen demand	<u>-0.33</u>	-0.12	-0.13	-0.02	0.10	0.04
chemical oxygen demand	-0.20	-0.29	0.03	-0.04	<u>-0.53</u>	0.36
phosphorus	-0.28	0.03	0.33	-0.06	-0.04	<u>0.49</u>
sulfide	-0.03	-0.21	<u>-0.51</u>	-0.08	-0.08	0.11
DDE	<u>-0.33</u>	0.14	0.01	0.09	-0.01	0.09
DDD	<u>-0.33</u>	0.13	-0.06	0.07	-0.07	0.21
temperature	-0.05	<u>-0.39</u>	0.04	-0.22	0.10	0.03
conductivity	-0.09	<u>-0.34</u>	0.07	-0.38	0.09	-0.29
pH	-0.06	<u>0.30</u>	-0.14	<u>-0.50</u>	-0.11	-0.08

\* The most important eigenvectors for the respective component axes are underlined. The absolute value of an eigenvector is proportional to the importance of the corresponding variable in the placement of a station along the axis in question. The sign of an eigenvector determines the direction of this influence.

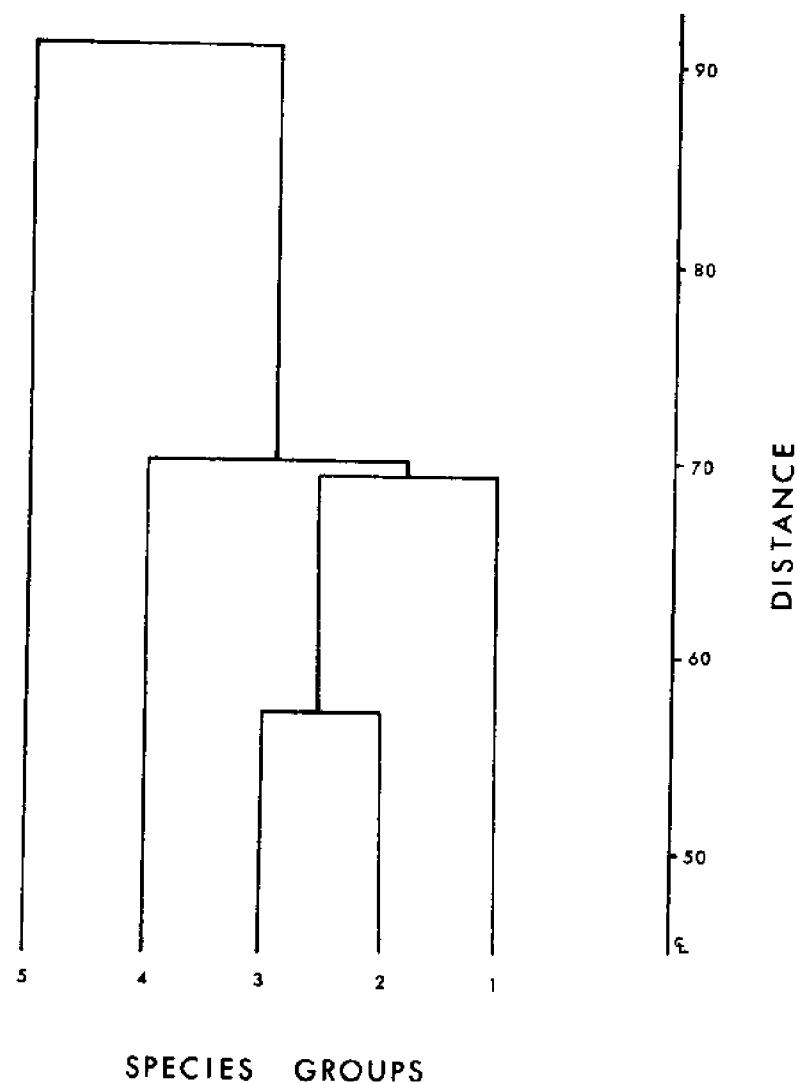


Figure 2. Dendrogram showing the relationships between the species groups. The data was standardized by species total; the Bray-Curtis distance measure and group-average sorting were used. See Table 3 for the species in each of the groups.

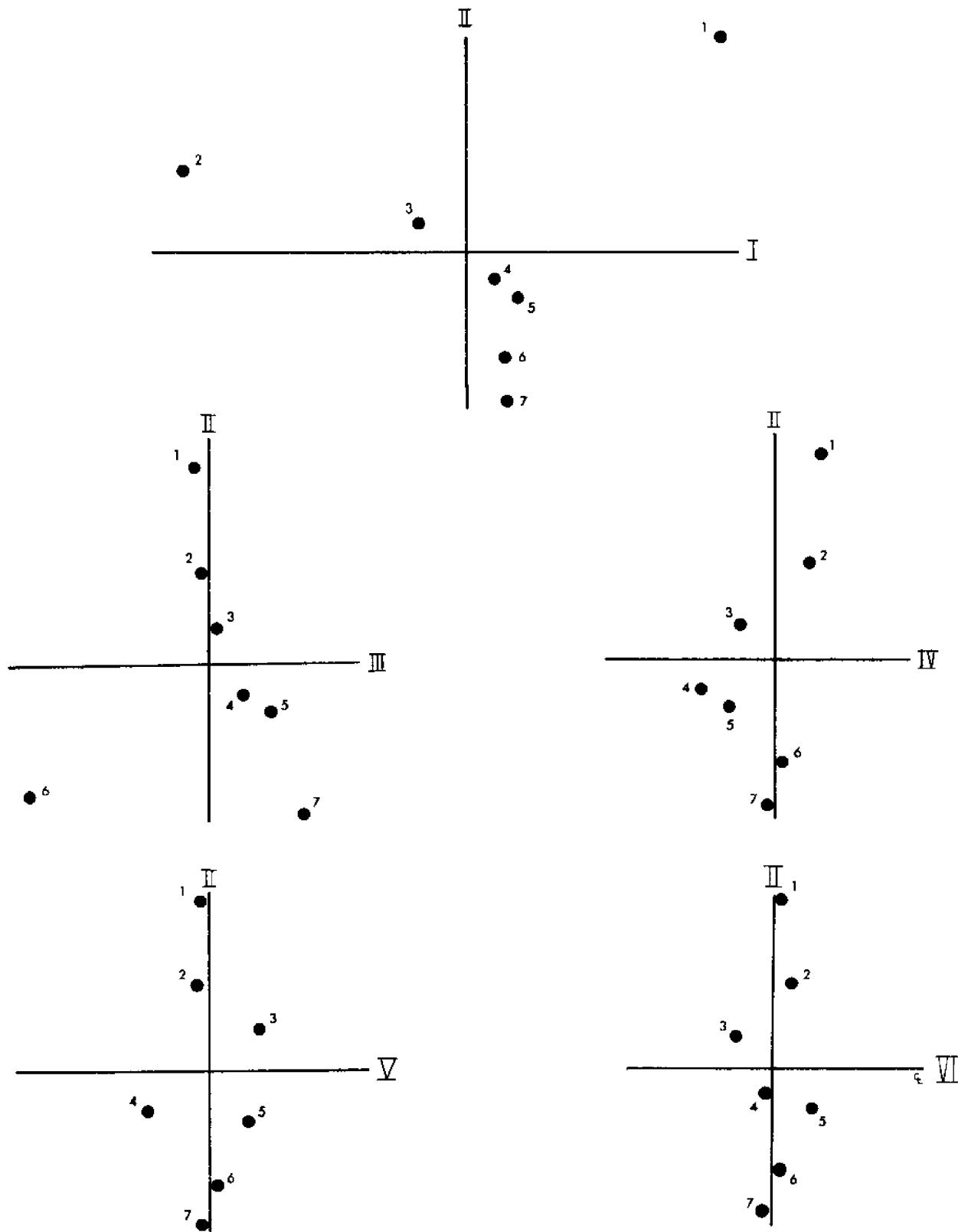


Figure 3. The results of the principal component analysis of the abiotic data. The positions of the stations on the first six axes are shown. The axes are displayed with the second axis, which best reflects the topographic positions of the stations. The amounts of variance in the successive axes are 43%, 32%, 15%, 7%, 2%, and 1% respectively. The axis numbers are indicated by Roman numerals.

oxygen demand, and the pesticide residues DDD and DDE. All these variables tend to increase toward the negative end of the axis. The second axis is plainly related to the distance of the station from shore and the effluent sources, since the sequence of stations on this axis is the same as the topographic sequence. The variables which tend to change along this axis are percent Calcium Carbonate, pH, depth, temperature and conductivity. The latter two variables tend to decrease, and the others tend to increase toward the positive end of the axis. The third axis is mainly related to the level of sulfides and heavy metals. The general level of heavy metals and the sulfides tends to increase toward the negative end of the axis. The second heavy metal component (HM2), which is mainly related to the level of cadmium and nickel, increases toward the positive end of the axis. The fourth axis is related to pH and SED2, both of which tend to increase toward the negative end of the axis. The fifth axis is related to Chemical oxygen demand, oil, carbon to nitrogen ratio, HM1 and HM2. The first two variables tend to increase toward the negative end of the axis and the rest tend to increase toward the positive end. On the last component, oil tends to increase toward the negative end and Phosphorus tends to increase toward the positive end of the axis.

#### Species diversity and biomass.

Table 5 shows the average species diversity and biomass at the stations. The Gleason richness index (Margalef, 1958) was used in calculating the species diversity. The index is as follows:

$$SD = \frac{S - 1}{\log_e N},$$

where SD equals the species diversity, S equals the number of species in the sample, and N is the number of individuals in the sample. Compared to other species-diversity indices, this index is known to emphasize the number of species present.

TABLE 5  
Average Species Diversity and Biomass\*

Station	1	2	3	4	5	6	7
Species Diversity	8.7	11.0	9.3	7.8	9.2	3.2	2.4
Biomass	.5	11.3	5.3	2.1	10.3	1.3	.1

\*Species diversity was determined by the Gleason index, and biomass is in grams.

The relationships between the biotic and abiotic patterns.

These relationships are best shown by superimposing the distribution of each species group on an appropriate abiotic principal component diagram. The first step of this process would consist of developing some numerical measure which reflects the relative proportion of a species group which is found at each station. Such a measure was calculated in the following manner: 1) a cube-root transformation was applied to the species data in order to prevent the few very abundant species from completely dominating the results. 2) The transformed species counts for all the species in a group were totalled over all stations. 3) The transformed species counts for all species in a group were totalled for each station separately. 4) The percent of a species group found at a station was calculated by dividing the total at the station by the total at all stations; this fraction was then multiplied by 100. The percentages of the species groups at each station are shown in Table 6.

Considering one group at a time, these percentages can now be recorded at the position of the corresponding station on the principal component diagram. If a consistent trend in the distribution of the species group results, then there is a probability that some of the factors related to the component axes used are important in the distribution of that species group. Consequently, it becomes a question of hunting for the axes that give the most consistent and meaningful pattern of species-group distribution.

Initially, it would be natural to try combinations of the first few axes, since these axes contain most of the variance. However, there is not a priori reason why the variables most important to the distribution of a species group would have to be related to these axes. Therefore, if combinations of the first few axes are not found to be satisfactory, other axes with less variance should be considered. To find the best sets of axes, each species group distribution could be plotted on different combinations of axes, and the axes giving the most consistent results

TABLE 6  
 Percent of each Species Group Found at each station\*

Group #	Station	1	2	3	4	5	6	7
1	<u>0.444</u>	0.168	0.143	0.093	0.153	0.000	0.000	
2	0.066	<u>0.349</u>	0.222	0.126	0.207	0.025	0.006	
3	0.072	0.199	0.153	0.167	<u>0.309</u>	0.050	0.049	
4	0.017	0.065	0.105	<u>0.335</u>	0.152	0.223	0.103	
5	0.000	0.000	0.000	0.126	0.188	0.087	<u>0.599</u>	

\*The station at which a group is most concentrated is underlined.

could be used. However, there seems to be sufficient information in table 4 to indicate which axes may be important in this study. First of all, topographic position appears to be very important in the distribution of the species groups. This is evident from the fact that all species groups tend to be distributed over adjacent or near-adjacent stations. The second axis best reflects the topographic relationships of the stations; consequently this axis is used as one of the axes for all the species groups. However, for each species group, there is at least one case where there is not a consistent trend among topographically adjacent stations. For these particular cases it is evident that the axis which would cause the greatest separation between the station breaking the trend and the other stations conforming to the trend would contribute to the most consistent picture of species-group distribution. Using this criterion, the fifth axis was chosen as one of the axes for the first four species groups, and the third axis was used with species group 5. The distributions of the species groups on the resulting principal component diagrams are shown in Figure 4. Subjective isolines are drawn on the diagrams to emphasize the trends.

Species diversity and biomass are also plotted on component diagrams in Figure 5. The combination of axes II and V was again found to give the most consistent pattern.

It appears that all the biotic patterns found are somehow related to one or many of the variables associated with the second axis of the abiotic analysis. However, a close look at fig. 3 shows that the first and second axes are not independent over most of the transect. If Stations 1 and 7 are disregarded, the sequence of stations on the first axis is 2,3,4,6,5; the sequence on the second axis is 2,3,4,5,6. Consequently, the same general abiotic trends that were found along the first axis will also be found along the second axis. This idea is summarized in Figure 6. This situation would seem contradictory to the idea that the component axes are independent. However, since Station 1 is so drastically different (abiotically) from the other stations, the first two

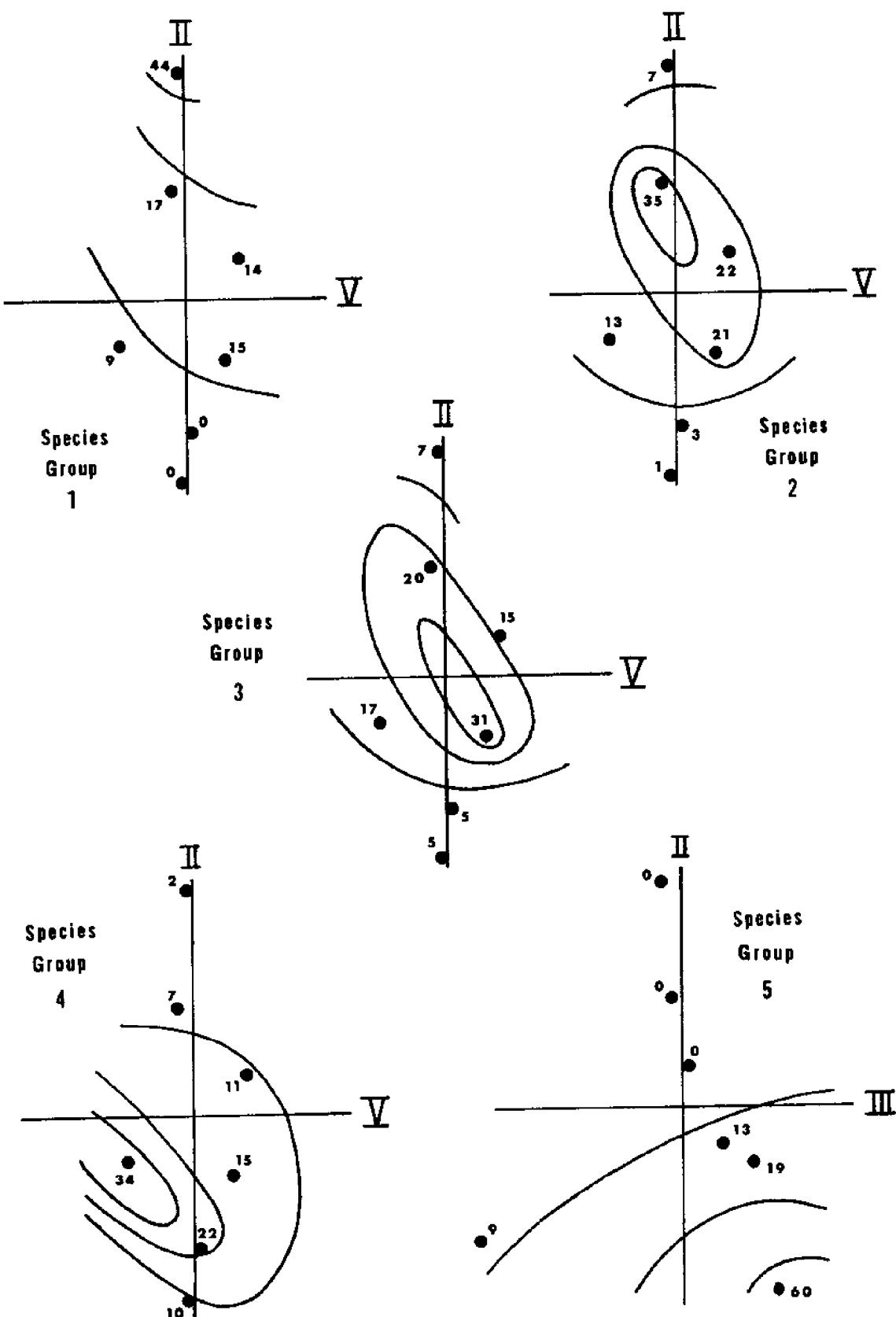


Figure 4. The distribution of species groups in the abiotic principal component system. The choice of axes is discussed in the text. See Figures 6 and 7 for a summary of the abiotic trends along the axes used. The isolines are subjective.

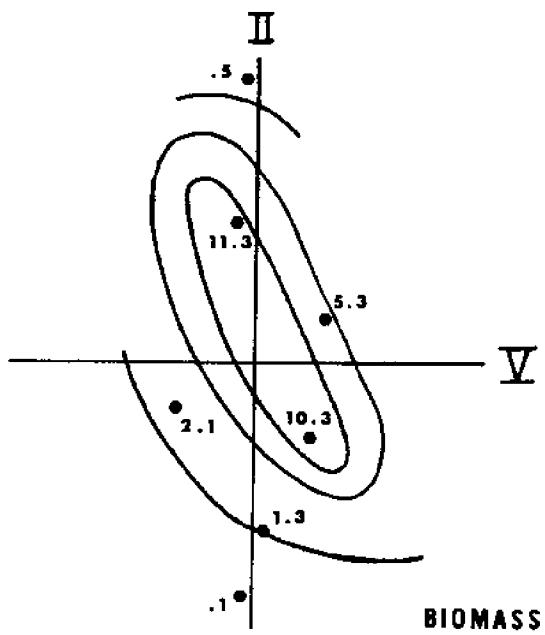
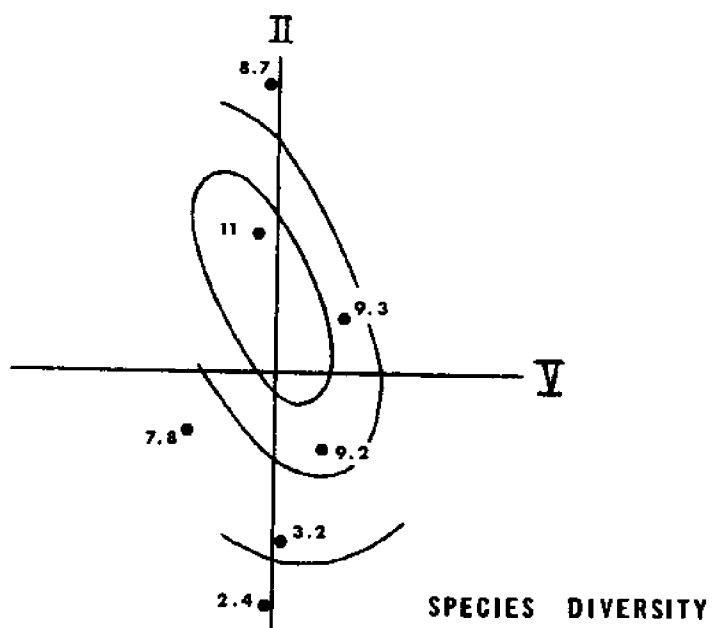


Figure 5. The pattern of species diversity and biomass in the abiotic principal component system. See Figures 6 and 7 for a summary of the trends along the axes. Isolines are subjective.

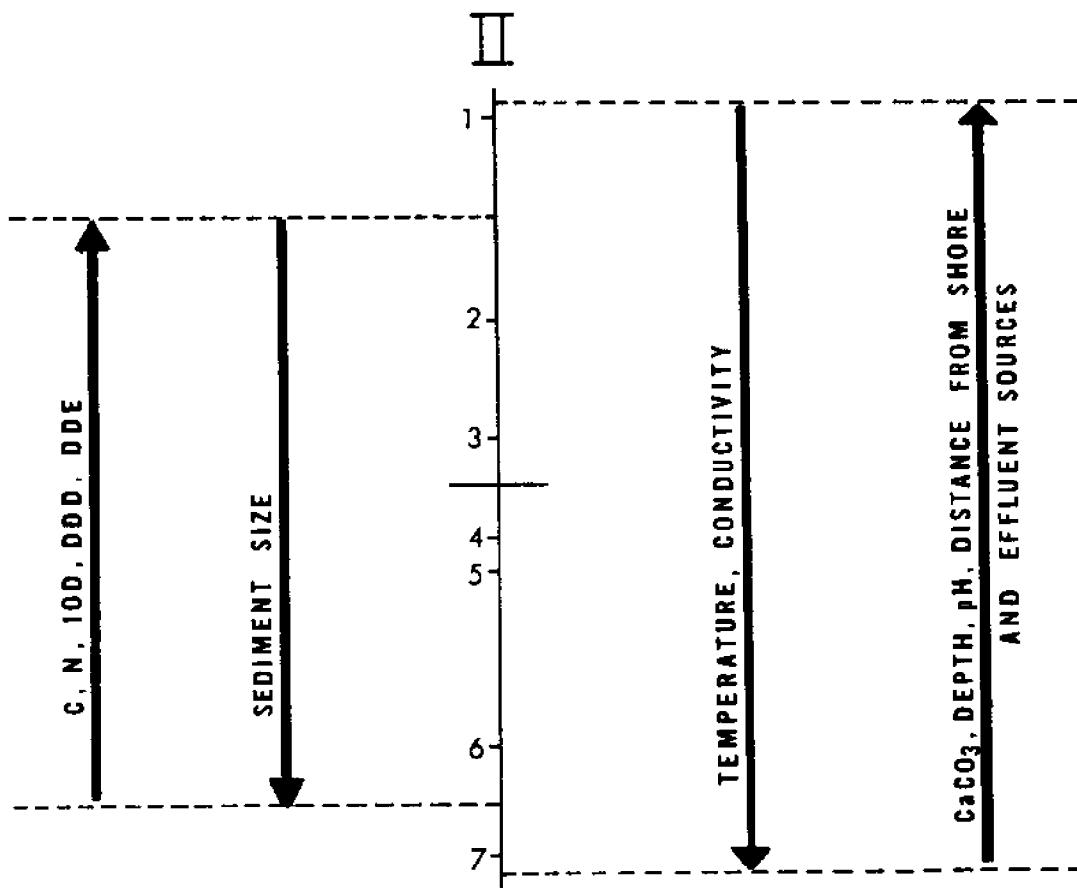


Figure 6. The main abiotic trends along the second axis when the relationship to the first axis is considered. The variables tend to increase in the direction of the associated arrow. The trends for the variables on the left exist only at the five middle stations, while the trends for the variables on the right include all stations. The positions of the stations on the axis are indicated by the corresponding numbers.

axes are indeed uncorrelated when all stations are considered together. There seems to be adequate information available to determine the reasons the stations on the extreme ends of the transect do not completely follow the same abiotic pattern as the middle stations. Station 1 is near an opening in the breakwater, and the tidal currents in this area are undoubtedly substantial. This would account for the relatively coarse-grained sediment and low organics at this station. Station 2, the next station, is evidently far enough from the breakwater opening and the associated currents for considerable deposition of fine sediments and particulate matter. Station 7, on the other hand, has relatively fine sediments in spite of the trend of coarser sediments toward the shore. Furthermore, this sediment is relatively low in organics considering the sediment size and proximity of effluents. Riesh (1959) noted that this is an area where dredgings were dumped, and this would explain the source of fine sediment. The surge from wave action in such a shallow area could prevent a larger build-up of organic material from the effluents.

The abiotic trends along the third and fifth axes have also been shown to be potentially important in the biotic patterns. These trends are summarized in Fig. 7.

#### Discussion and Summary

The distributions of the species groups, biomass, and species diversity all showed a relationship to the distance from shore and the effluent sources. The many variables which change in this direction (Figure 6) are associated with the second axis of the ordination analysis. It is not possible from the data alone to determine the relative importance of each of these variables in the observed biotic patterns. However, some generalizations can be made. The trend of the pH measurements indicates a general decrease in the level of dissolved oxygen toward the sources of discharge. One would expect to find species which are adapted to low-

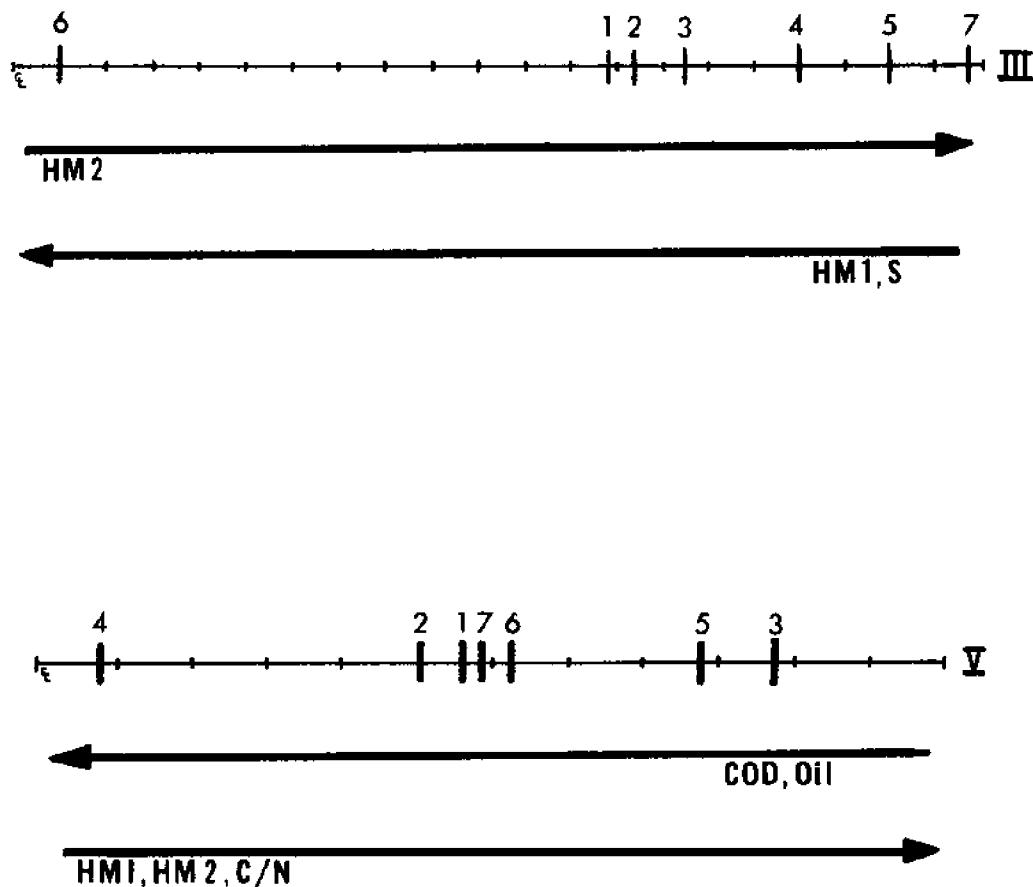


Figure 7. Summary of the main abiotic trends along the third and fifth axes in the principal component analysis of the abiotic data. The positions of the stations on the axes are indicated by the corresponding numbers. Table 4 shows the relationships between less-important variables and these axes.

dissolved oxygen conditions (and associated phenomena) at the inner stations. The polychaetes in species groups 4 and 5 predominated at the inner stations. The dominant polychaete in species group 4, Capitella capitata, is commonly found to be dominant in situations characterized by relatively low dissolved oxygen (Reish, 1973). The trend of the carbon, nitrogen, and sediment size suggests that there is sufficient turbulence and current at the inner stations to prevent a larger build-up of organic waste material in the area. The highest levels of organic matter are found at station 2, which is far from the points of discharge.

The biotic patterns, however, could not be completely explained only in terms of the variables associated with the second axis. Except for species group 5, it was necessary to refer to the fifth axis to obtain consistent biotic patterns among the inner stations. The association of chemical oxygen demand and oil with this axis hints at the possible importance of the levels of various chemical compounds in the sediments. Finally, to discern the pattern of species group 5, it was necessary to refer to the third axis, which is mainly related to the general level of heavy metals and sulphide.

More information was obtained by considering the species groups than was obtained by consideration of species diversity or biomass alone. The level of species diversity and biomass generally followed the distribution of the two largest species groups (2 and 3); thus the information contributed by the other species groups would be lost if only species diversity or biomass were considered.

There is some correspondence between the dominant species in the species groups and the species defined by Reish (1959) to characterize different levels of pollution in the harbor. Reish found Capitella capitata to be characteristic of "polluted" bottoms; this polychaete was dominant in species group 4, which occurred mostly at stations closer to the effluent sources. The animals characterizing a "semi-healthy" bottom, Pseudopolydora paucibranchiata [= Polydora paucibranchiata] and Stauronereis rudolphi

[= Dorvillea articulata], are also in species group 4, although they are not dominant. The dominant animal in species group 2, Tharyx sp. [= Tharyx parvus] corresponds to one of the polychaetes characteristic of a "healthy bottom". Species group 2 is mostly found at the stations further out from the effluent sources. Cossura candida, a dominant in species group 3, was also found to be characteristic of a "healthy" bottom. Group 3 is found mostly at the stations near the middle of the transect.

Because of the small sample size and small area involved in this study, the results must be considered with caution. At any rate, the numerical methods used are only intended to assist the ecologist in the generation of hypotheses, which can subsequently be tested under more controlled conditions. A more extensive sampling program is currently in progress throughout the Los Angeles - Long Beach Harbor. More detailed analyses and comparisons with other studies will be made in subsequent papers using the additional data.

## Appendix

## Methods Used to Measure Variables

<u>Variable</u>	<u>Method</u>
1. Sediment size distribution	Felix settling tube and pipette analysis
2. Carbon analysis	LECO carbon analyser
3. Nitrogen analysis	micro-Kjedahl
4. Oil	extraction with petroleum ether
5. Immediate oxygen demand	sodium thiosulphate titration
6. Chemical oxygen demand	potassium dichromate method
7. Phosphorus	spectrophotometer
8. Sulfide	titrimetric method
9. Zinc	atomic absorption spectrophotometer
10. Copper	atomic absorption spectrophotometer
11. Cadmium	atomic absorption spectrophotometer
12. Lead	atomic absorption spectrophotometer
13. Nickel	atomic absorption spectrophotometer
14. Mercury	flameless atomic absorption
15. Dichlorodiphenylchloroethane	gas chromatograph
16. Dichlorodiphenyldichloroethane	gas chromatograph
17. Bottom water measurements	MARTEK probes

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## ERRATA

- Page 23, line 27. analyser with resin Type C chromo beads. Ninhydrin was used in the
- Page 31, line 10. ranged from  $6.9 \times 10^2$  to  $2.2 \times 10^7$ . The highest bacterial counts
- Page 35, line 31. values for the plant effluent are examined (Table 2).
- Page 51, line 18. following factors are balanced against the beneficial effects.
- Page 87, line 26. 14. Claggett, F.G. and J. Wong. 1966. Industrial waste survey
- Page 88, line 3. Circ. 38, Fish. Res. Bd. Canada. Vancouver. 9 p.
- Page 88, line 13. Fish. Res. Bd. Canada. Vancouver. 25 p.
- Page 88, line 29. No. 71. Fish. Res. Bd. Canada. Vancouver. pp. 5-10.
- Page 95, line 3. pp. 78-80, Fish. Res. Bd. Canada. Vancouver.
- Page 98, line 19. Ser. No. 91, pp. 371-388.
- Page 115. Table 1. All superscripts 12 should read 1,2.
- Page 143, line 17. for of a bothid flatfish, Citharichthys stigmaeus. PhD.
- Page 150, line 20. The San Pedro channel studies were initiated aboard the R/V
- Page 151, add following last line samples probably reflects the fact that half of our
- Page 166, line 25. 7. SCCWRP. 1973. The ecology of the Southern California bight:
- Page 179, add following last line An attempt to understand some factors of anchovy and sardine growth, mortality, and larva sampling efficiency, in relation to the increased dominance of anchovies over sardines.
- Page 180, add preceding first line 51. Johnson, W.C. and A.J. Calhoun. 1952. Food habits of California striped bass. Calif. Fish and Game, 38(4), 531-534.
- Page 182, line 33. spawning,  $3.0 \times 10^8$  eggs would be produced per short

