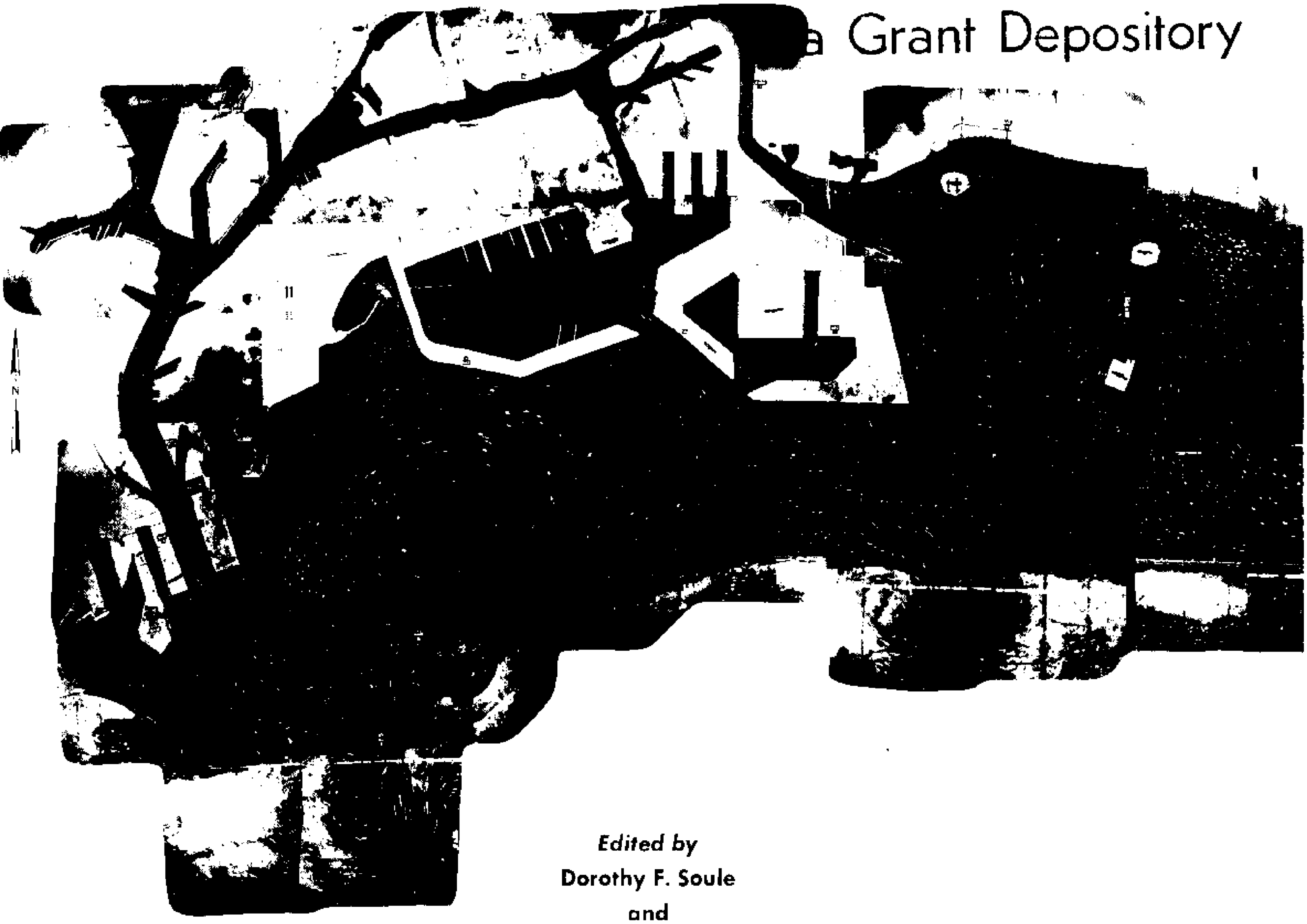
Marine Studies of San Pedro Bay, California

PART 8

ENVIRONMENTAL BIOLOGY



Edited by
Dorothy F. Soule
and
Mikihiko Oguri

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ENVIRONMENTAL BIOLOGY

This volume of Marine Studies of San Pedro Bay is dedicated to Dr. Rita D. Schafer, late Professor of Biology at Immaculate Heart College, and Research Associate of the Allan Hancock Foundation, University of Southern California.

A graduate of USC, Dr. Schafer pioneered studies of variation in free amino acid content in fish and invertebrate tissues as an indicator of pollution, and did extensive work at the Naples Marine Station in Italy with Dr. Antoinette Dohrn. She also initiated a marine station and survey at Las Cruces, Baja California at the home of Bing and Kathryn Crosby. An auto accident at Ensenada while en route to the Las Cruces station with students inflicted injuries from which she passed away in Los Angeles on July 2, 1974.

Dr. Schafer's enthusiasm and drive are greatly missed by students, colleagues, and friends alike. She gave unstintingly of her time to counsel girls at Juvenile Hall, and participated in musical groups and church activities. She was a founder and president of the Irene McCulloch Foundation for research and publication in the biological sciences, honoring her major professor, now emeritus, at USC.

Chamberlain's paper in this volume is an outgrowth of the work by Schafer and Swann published in Marine Studies of San Pedro Bay, Part II.

The Editors

Part 8

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On the cover - composite photograph of simulated tidal flow in model at Vicksburg Waterways Experiment Station, Vicksburg, Mississippi. Photo, courtesy of the U. S. Army Corps of Engineers.

MARINE STUDIES OF SAN PEDRO BAY, CALIFORNIA. PART 8. June 1975

THE ROLE OF FISH CANNERY WASTE IN THE ECOSYSTEM

By

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ABSTRACT. Arrow gobies, *Clevelandia ios* (Jordan and Gilbert), were starved and held in a 1:4 mixture of fish cannery effluent and filtered seawater for 61 days. Thirty-six percent of these survived while 100 percent of a control group of starved arrow gobies, held in filtered seawater only, died. Survival of test fish was presumably due to utilization of substances present in the effluent. All fish exhibited wasting and listlessness.

In additional studies 42 starved arrow gobies were held in seawater to which was added fish cannery effluent and ^{14}C-glutamic acid. Fish accumulated radioactivity over the first 32 days followed by a gradual loss of radioactivity. Radioactivity in test tank water and control tank water declined rapidly over a 10 day period from the start of the experiment. After the 57th day 12 fish succumbed, probably from starvation.

An uptake of glutamic acid directly from the test water is suggested. A fish kill, apparently due to anoxic harbor waters, is also reported.

ACKNOWLEDGMENTS. We wish to thank a number of individuals working in the Harbor Environmental Projects at the University of Southern California for their cooperation and assistance. Appreciation is also extended to Dr. Thomas E. Bowman, National Museum of Natural History, Washington, D. C., for his identification of the parasitic isopod found on a test fish. The work was supported in part by the USC Sea Grant Program and by Harbor Environmental Projects of the Allan Hancock Foundation. We wish to thank Dr. Dorothy Soule for her encouragement in these studies.

THE ROLE OF FISH CANNERY WASTE IN THE ECOSYSTEM

INTRODUCTION. Considerable interest has been generated in recent years regarding the effects of organic, inorganic and thermal pollution on the biota of Los Angeles-Long Beach Harbor (Reish, 1955, 1959, 1961a,b; Soule and Oguri, 1972, 1973, 1974). A number of other works have been briefly reviewed or referenced in Chamberlain (1973), Soule (1974), Soule and Oguri (1972, 1973), Stephens, Terry, Subber and Allen (1974). Some discuss the harmful effects of waste materials being deposited in the harbor and other discuss positive effects. Ten years ago Young (1964), writing on the effects of sewer effluent on various marine organisms, discussed the generally poor condition of certain fish taken from the harbor area. More recently, Stephens, Terry, Subber and Allen (1974) reported exceptionally high fish densities in the harbor, highest for local areas of comparable depths.

Examination of the contents of many trawl catches and a survey of anglers on the inner perimeter of Los Angeles-Long Beach Harbor indicate that, for the most part, the fish in the harbor are healthy. One exception may be the white croaker, *Genyonemus lineatus*, which exhibits more pathological evidence of environmental stress than do others. Liver and caudal fin rot damage (Phillips, unpublished manuscript) and skeletal anomalies (Chamberlain, 1973, 1974, and unpublished data) have been reported in this species. White croaker are the most abundant species found in the harbor. The incidence of pathological conditions may be, in part, a function of their density as well as from other factors. Areas with high croaker abundance are near points of sewage discharge (Stephens et al., 1974).

Since the summer of 1970, factors such as increased oxygen levels that favor the growth of plants and animals in the inner harbor have been improving. Benthic animal populations in parts of the outer harbor now are similar to those in nearby unpolluted marine areas (Reish, 1971). The trend is towards a better harbor environment which has come about primarily by strict enforcement of new, more rigid regulations on waste disposal. Yet the waste disposal problem is complex. Considerable organic waste material from various sources is still being deposited in the harbor. This comes from land run-off, from fish cannery wastes, from primary-treated sewage and from raw sewage from pleasure craft. The sewage treatment plant receives both domestic and industrial wastes.

The present paper deals with two aspects of the relation between organic wastes and the local fish population. The first portion of this paper deals with two experiments designed to indicate whether fish may be able to utilize controlled amounts of cannery effluent as a nutrient source directly, without passing through a food chain. Experiments included 1) utilizing cannery waste as a sole nutrient source, and 2) radioactive tagging of the amino acid glutamic acid, a component of the cannery waste, to determine whether fish were incorporating the amino acid. The second relates to a fish kill, apparently due to anoxic harbor water conditions.

TOXICITY TEST OF CANNERY EFFLUENT

Fish productivity in the Los Angeles-Long Beach Harbor seems to be greater than that in adjacent coastal waters of similar depth and substrate composition (Stephens, et al., 1974). There are indications that this results from the input of nutrients into the harbor. Dissolved free amino acids have been measured in marine waters of the Los Angeles basin, and some of these are utilized directly by at least one invertebrate (Clark, 1969). Patterns of free amino acid within fish and invertebrates have been shown to change with environmental conditions (Schafer, 1966, 1968, 1973).

Fish cannery effluent released into Los Angeles-Long Beach Harbor (Figure 1) contains a number of compounds and elements (see Appendix 1) that have nutrient value and which could be utilized by fish as food, especially the amino acids and compounds containing organic nitrogen, phosphorus, or sulfur. Carbon-containing organic compounds are absorbed by fish and utilized in the formation of various organic substances distributed throughout body organs and tissues (Veltishcheva, 1962). Sturgeon and carp absorb the sulfur-containing amino acids menthionine and cystine through their skin and gills more readily than they absorb inorganic sulfure compounds (Smelova, 1972). It is not known whether fish are able to utilize directly these potential nutrients which find their way into the marine environment.

On 23 November 1973, a preliminary experiment was begun to ascertain whether the arrow goby, *Clevelandia ios*, from Los Angeles-Long Beach Harbor could survive in a 1:4 dilution (EPA guideline criteria) of fish cannery effluent and also possibly utilize these effluent constituents as food. Specimens were caught in outer Fish Harbor on 2 October, 1972, during the period of oxygen depletion described above, which forced them to surface. The fish were held in harbor water at 14.5 C (58.1 F) for about 52 days prior to the start of the experiment to evaluate effects of the low DO episode. Seven fish remained from the initial group collected. Three of these were maintained in a control aquarium containing 2.63 gal (19 liters) of harbor water and four were held in a test aquarium containing a mixture of 0.52 gal (2 liters) of effluent and 2.1 gal (8 liters) of harbor water.

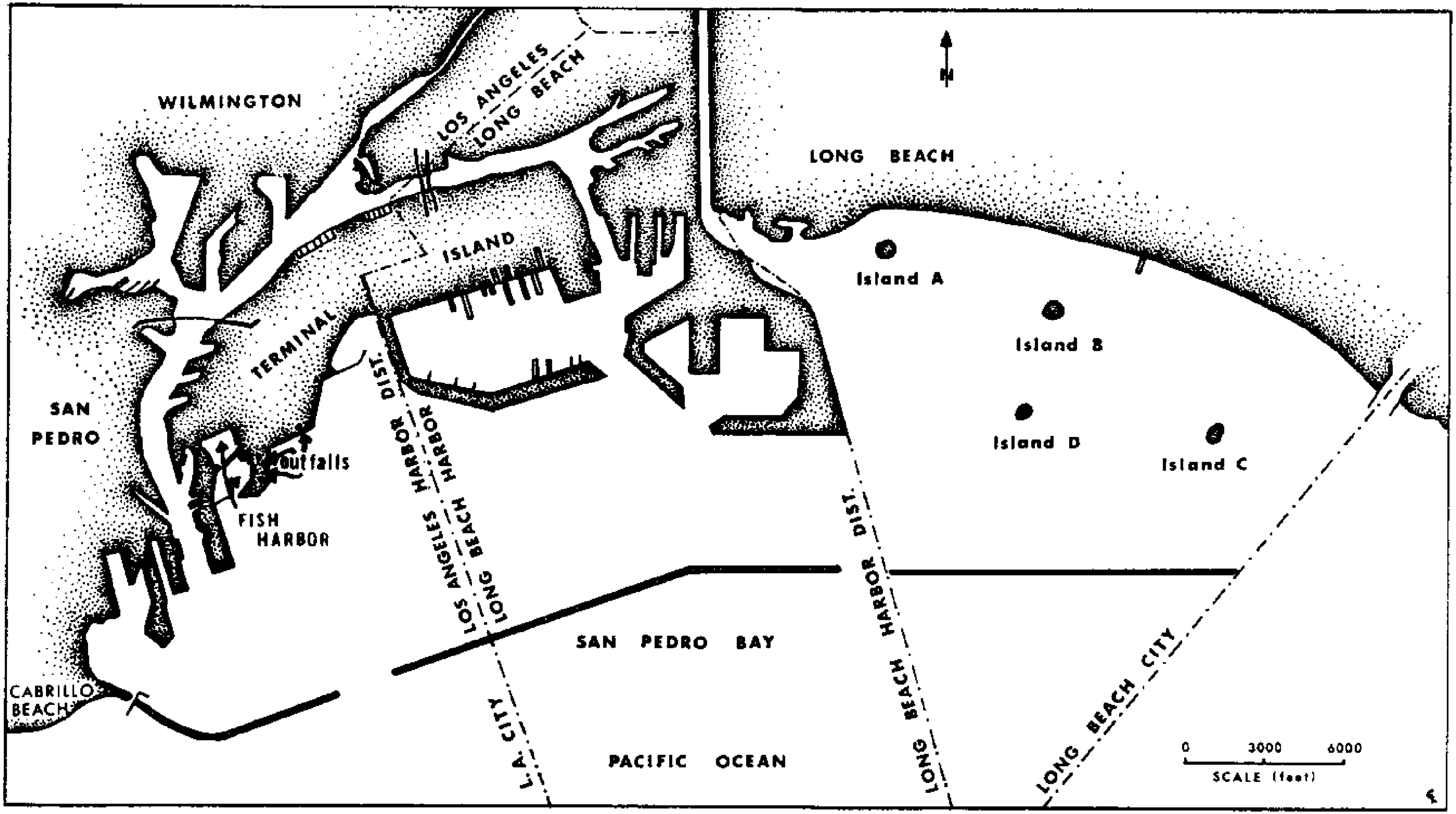

Figure 1. Los Angeles-Long Beach Harbor area. Arrows indicate location of Fish Harbor and outfalls.

Results. All seven (control and test) fish survived for 60 days. Results from this experiment indicate that effluent in the experimental concentration is not toxic or harmful to the arrow goby. It was not possible to determine any utilization of cannery effluent as a food source in this experiment.

A second experiment was undertaken to gain more information on the possible utilization of the materials occurring in cannery effluent by the arrow goby. This experiment is outlined below.

NUTRIENT VALUE OF CANNERY WASTES

Twenty-two test fish were acclimated for 48 hours in 5 gal (18.9 liters) of seawater, that had been filtered and sterilized by exposure to ultraviolet light (UV) after collection in the Los Angeles-Long Beach Harbor. Fish were held at 14.5 C (58.1 F) prior to their placement in the experimental aquaria.

Arrow gobies were chosen for this experiment because of their small size and ease of collection and maintenance in the laboratory, and because they are also found in the shallow areas of local bays, including Los Angeles-Long Beach Harbor. They attain a length of about 2 in (50.8 mm) (Miller and Lea, 1972). An extremely abundant fish, gobies are found from the Gulf of California to Vancouver, B.C., except on the exposed areas of mudflats. (MacGinitie and MacGinitie, 1968). When alarmed they seek refuge in animal burrows such as those of the echiurid, *Urechis caupo* (Ricketts and Calvin, 1952). Their diet includes diatoms, green algae, tintinnids, vertebrate eggs and young crustacea (Hart, 1973).

Fish for this experiment were obtained from a local supplier who collected them at Mission Bay, San Diego, California on 18 February 1974.

Eleven gobies were placed in each of two 5.5. gal (21.0 liters) glass aquaria set up within a constant temperature room at 14.5 C (58.1 F). The control aquarium contained 3.9 gal (15 liters) of sand-filtered, UV irradiated seawater from Los Angeles-Long Beach Harbor. The test aquarium held an equal volume of a 1:4 mixture of fish cannery waste effluent liquid and sand-filtered, irradiated harbor water. Both aquaria were supplied with gentle, continuous aeration. No water filtration system was used. Food was withheld from the fish for the duration of the acclimation period and for the subsequent 61 day (1464 hours) experimental period.

The untreated fish cannery effluent used in this experiment was obtained from sewer outlets at the end of Way Street, Terminal Island, San Pedro, California on 20 February 1974 and held in a stoppered 0.5 gal (1.9 liter) plastic carboy at a temperature of 14.0 C (57.2 F) until used. Aquaria were checked at least once daily during the experiment. Analysis of cannery effluent samples used in this part of the study are not available but values in Appendices 1-4 present analyses conducted on effluent taken previously from the same source by personnel of the Allan Hancock Foundation.

Results. Eleven (100 percent) of the fish in the control aquarium were dead on the 61st day of the experiment. The experiment was terminated at this time. Seven gobies (64.0 percent) in the test aquarium were dead by the end of the same period and four (36 percent) remained alive (Figure 2). Upon introduction of the tuna cannery effluent to the test aquarium, the seawater-effluent mixture became cloudy. Gradual clearing occurred over a period of time as flocculation and coalescence of small suspended particles took place. The resulting larger particles collected on the bottom and around the inner edge of the aquarium at the water surface. On at least two occasions fish were seen ingesting these larger particles. No such particles were present in the control tank.

During the latter half of the experiment, from about the 50th day to its termination, swimming movements of fish in both aquaria became weak, infrequent and a general listless condition developed. Occasionally individual fish would enter the current created by the bubble aerator and be tumbled end over end or rolled over sideways, making no attempt to orient themselves or to escape the current. Fish in both aquaria were much thinner than those of the same species held in a stock aquarium and receiving food twice daily.

On 12 March 1974 one goby in the control aquarium appeared to be dead. On closer inspection a juvenile isopod parasite, *Loroneca californica* Schioodte & Meinert, was observed clinging to the exterior of each gill cover. These were removed and the fish continued having problems for about 24 hours but eventually experienced a full recovery. This episode probably had little effect on the ultimate survival of the fish involved.

Conclusion. Thirty-six percent survival of fish in the test aquarium compared to the 100 percent mortality in the control aquarium seems to indicate that the effluent afforded some nutrients for survival. The wasting and listlessness of fish in both aquaria points also to starvation as a principal cause of death. Foods with less than 6 percent protein content (wet weight) cannot produce growth or sustain fish (Lagler, K.E., J.E. Bardach and R.R. Miller, 1962, p. 167). The effluent-water mixture contained much less than this amount of protein material. Reasons for death of the seven test fish might then be attributed to starvation, to the presence of

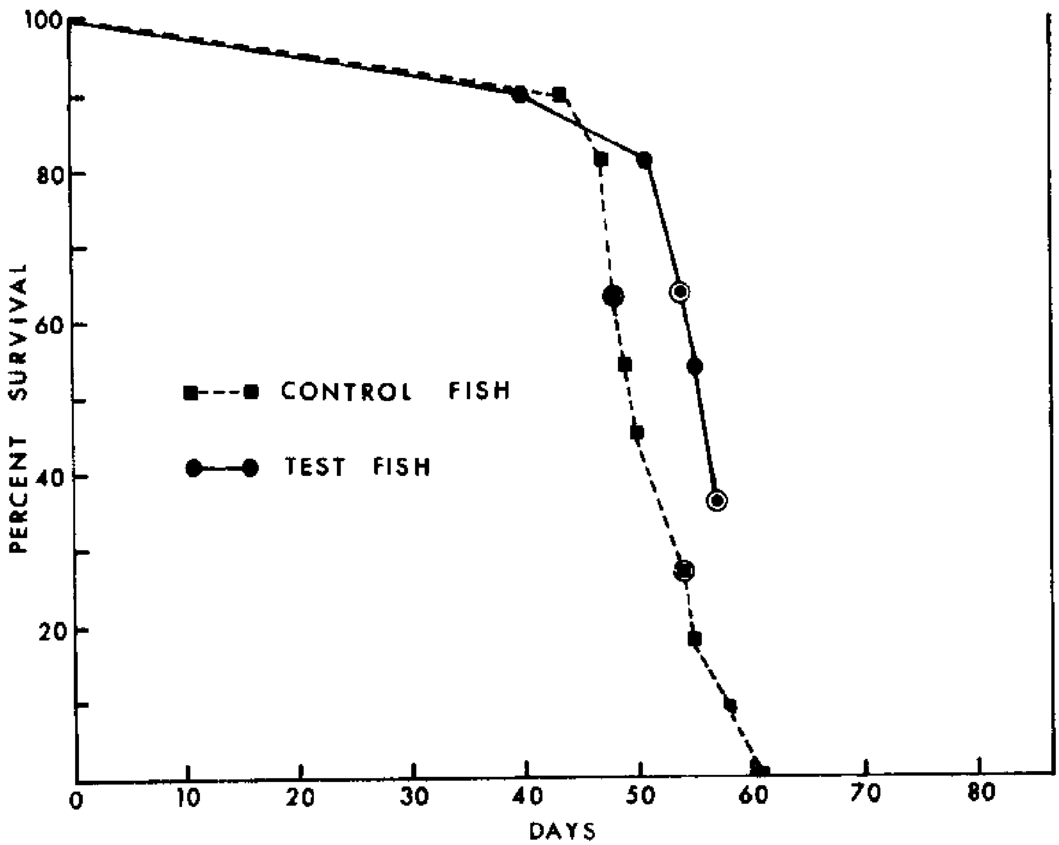

Figure 2. Survival of starved arrow goby, *Clevelandia ios*, in seawater (solid squares = control) and in a 1 : 4 mixture of untreated fish cannery effluent and seawater (solid circles = test). Each solid square or solid circle represents one death. Circled squares or circles represent two deaths.

toxic materials from the breakdown of effluent compounds by bacterial action, to the accumulation of toxic metabolic wastes or to the depletion of an essential element necessary for survival. Mortalities in both aquaria can presumably be attributed to starvation, as water quality remained very near or within values well tolerated by this species (Table 1).

Table 1. Water conditions in test and control aquaria at the end of the experiment. Sp.gr.= specific gravity, S°/oo = salinity.

Aquarium	pH	Nitrite	Sp.gr.	S°/oo	Temp. (C)
Test	7.90	1-5 ppm	1.023	32.7	14.5
Control	8.02	5-10 ppm	1.025	35.0	14.5

AMINO ACID UPTAKE

Schafer had determined that the free amino acid composition of fish muscle differs in fish found in polluted waters as compared with that found in the same species from unpolluted waters. Schafer (1973) suggested that anchovy, if placed in a stressful environment such as that of polluted waters in Los Angeles Harbor, would require a greater than normal supply of energy to meet this stress. The amino acid histidine is readily broken down into glutamic acid, which in turn is a direct energy source. Histidine and glutamic acid were found by analysis to be constituents of the untreated cannery waste in Los Angeles-Long Beach Harbor (Appendix 5). Glutamic acid was also present in greater quantities in arrow goby tissue than other amino acids.

Ammonia (NH_3) is also an important ingredient of sewage outfall waste. The synthesis of glutamine (amide of glutamic acid) is one route for the detoxification of ammonia in fish and ordinarily aids in this detoxification (Webb and Brown, 1974). The un-ionized ammonia molecule is the toxicant harmful to fish, at least in freshwater species (Trussell, 1972). If fish under stress from toxic concentrations of ammonia or other environmental factors are present, and useful levels of these amino acids are also present, the fish could possibly derive considerable benefit from the association.

Materials and Methods. Glutamic acid labeled with ^{14}C was selected for use to test whether a dissolved amino acid could be absorbed by fish directly from the environment. Two 5 gal aquaria, each filled with 2.61 gal (9.9 liters) of sand-filtered, UV irradiated Los Angeles-Long Beach Harbor water, were placed in a constant temperature room at 14.5 C (58.1 F).

One hundred ml of untreated fish cannery effluent, sampled from the Way Street outfall, was added to test and to control aquaria, bringing the total volume in each to 2.64 gal (10.0 liters). Forty-two arrow gobies were placed in the test aquarium only. These fish averaged 15.5 mg in weight (weight range: 1.6-45.0 mg). Gentle aeration was maintained in each with a 3/4 inch (16.8 mm) diameter air stone supplied with compressed air from an aquarium pump. Initial water levels were marked and the tank covered with a sheet of clear plastic to reduce evaporation and contamination. Except for the initial fish cannery effluent no other food or nutrient material was added to the test tank. Fish were held at the experimental temperature at least 30 days before start of the experiment. Food was withheld from the fish for a period of 72 hours prior to the experiment. Fifty international units of buffered potassium penicillin G and 0.05 mg of streptomycin sulfate per milliliter of seawater were added initially to each aquarium to reduce bacterial growth. On the 50th day of the experiment sterile plates containing agar-seawater-peptone growth medium were inoculated with water samples from each tank.

Exactly 0.2 ml of labeled glutamic acid containing 20 micro curies (μ Ci) of ^{14}C was added to each tank, resulting in a concentration of 0.002 μ Ci per milliliter. Two fish were immediately removed from the test tank and thoroughly washed in a standard manner with distilled water to remove any adsorbed radioactivity. They were then placed whole into separate scintillation vials previously weighed to 0.1 mg, and dried for 24 hours at 85-90°C (185-194°F). The cooled vials containing the dried fish were weighed again to obtain dry weight of fish tissue. Two 1 ml aliquots of water from each aquarium were also placed in scintillation vials and dried in the same manner. Ten ml of toluene base liquid scintillator was added to the dry contents of each vial and the gross beta radioactivity was read against a blank of liquid scintillator for 10 minutes in a Nuclear Chicago Unilux II well-type crystal liquid scintillation counter. Specific activity was expressed in counts per milligram of dry fish tissue, and the seawater-effluent solution in counts per ml per minute. Values have been adjusted for background radiation by subtraction of the background count from each initial count for tank water and fish tissue. Background counts averaged 18.1 per minute.

Results. Fish accumulated radioactivity slowly from day 0 to about the 32nd day of exposure and then experienced a gradual loss of radioactivity from that point to the end of the experiment at 72 days(Figure 3a, upper graph).

There was a rather rapid loss of radioactivity from the seawater-cannery effluent solution in each tank between the first day of the experiment and the 20th day (Figure 3b, lower graph).

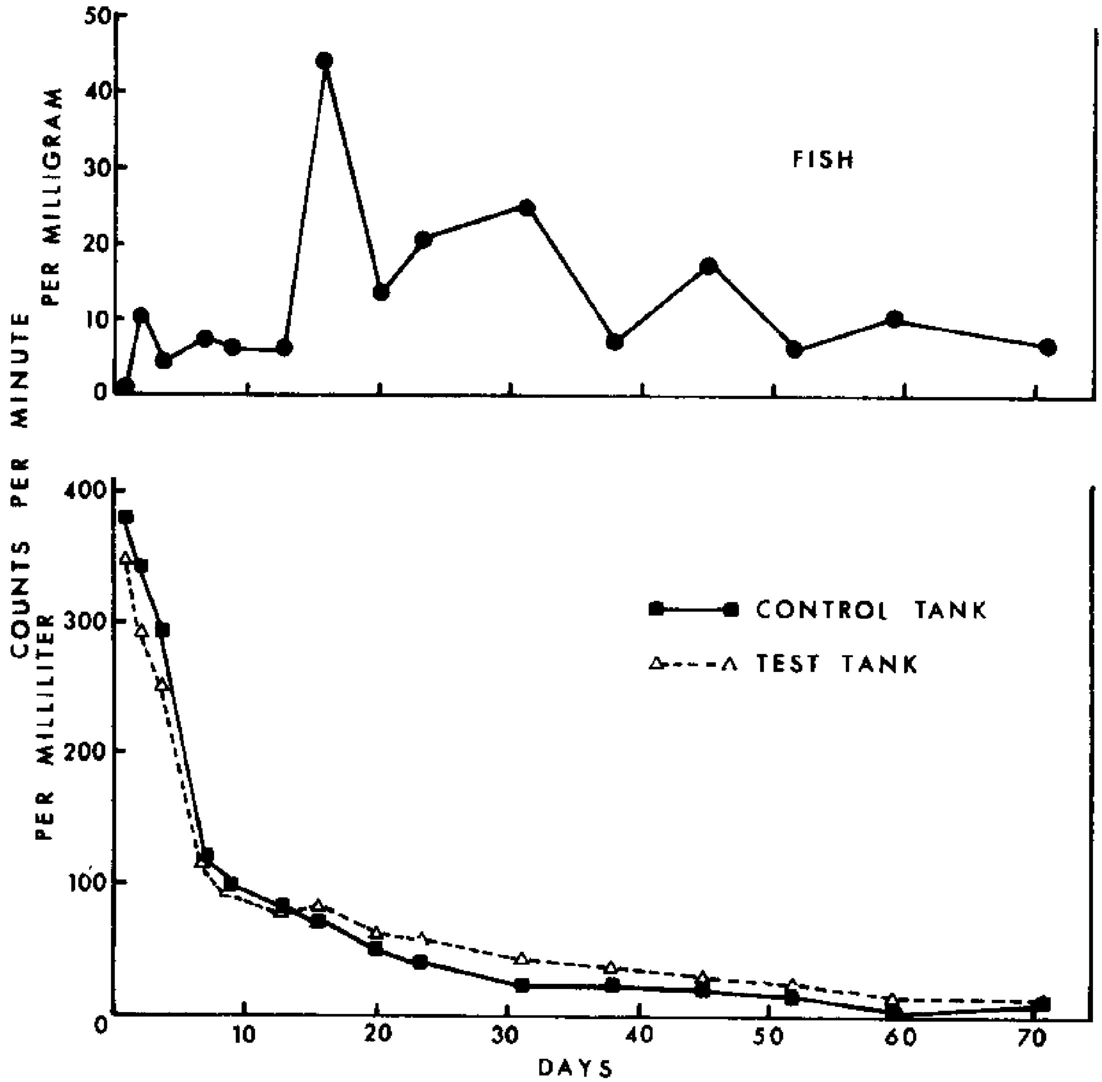

Figure 3. (a) Accumulation of radioactivity by arrow goby, *Clevelandia ios*. Each solid circle represents average values for 2-4 fish. b) Change in radioactivity of the seawater-untreated cannery effluent-^{14}C-glutamic acid solution in the aquaria. The open triangles and solid squares represent the average values for 2 aliquots.

From the 20th day to termination at the 71st day, loss of radioactivity was much more gradual. Values for both test and control aquaria remained close together throughout the experiment. There was, however, a slightly greater loss of radioactivity in the test aquarium during the first 13 days, and then a slightly greater loss in the control aquarium from the 13th day to the end of the experiment. The differences are not considered significant. Small amounts of material scraped from the bottom of the test and control tanks after termination of the experiment showed high levels of radioactivity. An average 157.1 counts per milligram, dry weight, was obtained from 4 samples (2 from each tank). Presumably the radioactivity that was not taken up by the fish in the test bank, and was lost from the water in test and control tanks was incorporated into this material by precipitation or bacterial action. The specific route by which the radioactivity came into this substrate is not known but generally accounts for the radioactivity loss from the solutions.

Table 2 lists average beta radioactivity in counts per minute per ml of seawater-effluent solution and counts per milligram of dry weight of fish, for each day sampled.

On the 57th day the first fish death occurred. From this date to the termination of the experiment an additional 11 fish died from unknown causes, but presumably as a result of starvation.

Penicillin and streptomycin did not entirely eliminate the bacterial colonies in either aquarium. Plate cultures showed greater growth of bacteria on the plate inoculated with water from the test aquarium, suggesting a larger number of bacteria present.

Discussion. The accumulation of radioactivity suggests an uptake of glutamic acid by the gobies. The route of ingestion, whether by absorption through gut, gills or skin, is not known. With an intact epidermis and mucous layer, the most likely route of ingestion would be through the gills or the gut, rather than skin. It is assumed that thorough washing of each fish with distilled water before dehydration eliminated isotopes present in the seawater-effluent solution wetting the body surface.

It is possible that the radioactivity present came from ^{14}C-glutamic acid precipitated on the body surface of the fish by the mucus secretions of the skin, which might remain even following washing with distilled water. If this were the case, however, the radioactivity curve for the fish would differ from that obtained (Figure 3). Mucus is continuously secreted onto the skin surface and is continuously lost. If glutamic acid were being precipitated by the mucus, then specific gravity would be a function of the labeled glutamic acid levels in the seawater-effluent solution at any given time.

Radioactivity curves for fish would be high initially and decrease rapidly, roughly parallel to the curve obtained for the seawater-effluent mixture in the test aquarium. The radioactivity curve obtained for test fish, however, shows an opposite trend. There is an increase from low radioactivity levels on the 2nd day to a high at the 32nd day. This curve suggests an uptake of labeled glutamic acid by the test fish. The gradual loss of activity after the 35th day reflects the lowered levels of labeled glutamic acid in the holding water resulting in less available for uptake by the fish. Also reflected is loss by the fish of radioactivity. The exact route of elimination is not known, but ^{14}C could be present in metabolic waste products produced following ^{14}C-glutamic acid assimilation and protein synthesis. Accumulated radioactivity can be lost by the normal biologic turnover process in which cells that incorporated the radioactive element are replaced by new cells without activity (Arena, 1971, p. 252). The physical radioactive decay process of the isotope itself would not play a significant part in the reduction of specific activity because of the long half-life (5730 years).

Another possibility is that labeled glutamic acid present in water swallowed by the test fish never enters fish tissue but passes through the gut unobserved and is eliminated out the anus. Radioactivity taken up in this manner would result in curves similar to those shown by the test water or those suggested above if labeled glutamic acid were precipitated by the mucus.

The almost equal rate of radioactivity loss in both aquaria strongly suggests bacterial action on the ^{14}C-glutamic acid present. Lower radioactivity levels for water in the test aquarium during the first thirteen days of the experiment can probably be attributed to uptake of ^{14}C-glutamic acid by the fish in addition to concurrent bacterial action. It is not known why, beyond the 16th day, radioactivity was slightly higher in the test aquarium with its supposedly greater bacterial population and greater reduction potential.

There seem to be good indications that glutamic acid can be incorporated directly from the environment, as well as being synthesized or acquired through the food chain by arrow gobies.

The studies reported are preliminary, and limited in scope. Additional studies should include examing 1) the fate of ^{14}C-glutamic acid within fish by radioanalysis of specific tissues, and 2) the role, if any, that glutamic acid plays in aiding a fish under stress.

Table 2. Average radioactivity values in counts per minute per milliliter of water and counts per minute per milligram of fish tissue (dry weight).

Day	Water		Fish
	Control Tank	Test Tank	
1	374.0	343.8	1.5
2	339.3	284.3	10.7
3	287.7	247.5	4.3
7	120.7	117.4	7.9
9	97.5	91.7	6.5
13	84.7	78.7	6.7
16	73.7	81.5	44.8
20	52.6	61.1	13.8
24	43.3	57.5	21.4
32	24.8	44.0	25.4
39	26.5	37.3	7.7
46	21.2	30.6	17.2
53	20.6	23.6	6.9
60	10.0	14.7	10.8
71	13.7	13.9	7.24

The role that fish cannery effluent plays in the harbor ecosystem is a very complex one and at present not adequately defined. Effluent constituents are variable, and the dynamic nature of the receiving waters, the seasonal changes in the harbor fish populations and the influence of climate are important natural variables. Workers concerned with the harbor ecosystem are just now getting a limited picture of this and much more study is needed. It appears at this time that the cannery effluent has some nutrient role in the harbor ecosystem. The total elimination of that effluent, as proposed by regulatory agencies, might have a deleterious effect.

FISH KILL

Overloading of the receiving waters can produce unsatisfactory environmental conditions, especially in the fall of the year, when seasonal die-off of biota and thermal turnover place a heavy natural oxygen demand on the waters. Excessive organic wastes were present when a fish kill occurred in Fish Harbor in October, 1973. Fish Harbor is a double enclosure located at the west end of Terminal Island, and bounded on the west by Reservation Point (Figure 1). East of the area is a shallow water embayment which receives two effluents from the canneries and one of primary treated sewage. The inner and outer sections are divided into approximately equal areas by a rock-fill dike. The outer portion is utilized mainly for anchorage of yachts and small craft and the inner for off-loading of fishing vessels, icing of holds and for minor boat repairs. Entrances to both the inner and outer harbors are approximately 300 feet wide. With a single opening to each harbor, water exchange between inner Fish Harbor, outer Fish Harbor and the outer Los Angeles Harbor is very poor.

During the first part of October, 1973, the waters of inner and outer Fish Harbors underwent an acute episode of dissolved oxygen depletion. The water was a milky-green color, with visibility of about two feet and a strong sulfide odor was present. This presumably was the result of an increased amount of organic material being carried into the enclosed basin from the adjacent fish cannery outfalls and possibly from the illegal emissions by fishing boats following unloading at the Fish Harbor docks. Bacterial reduction of wastes placed a heavy oxygen demand (high BOD) on the receiving waters.

On 2 October, 1973, a number of dead fish were collected from along the western perimeter of inner Fish Harbor. The majority of these were found lying on a cement shelf 6-12 inches below the water surface. An additional 80 dead fish were counted in this area. Undoubtedly many more fish had died and settled to the bottom of the harbor, but due to water opacity this could not be determined.

Fish species collected or observed were opaleye, *Girella nigricans;* white croaker, *Genyonemus lineatus;* spotted sand bass, *Paralabrax maculofasciatus;* and the shiner perch, *Cymatogaster aggregata.* The only live fish seen were arrow gobies, *Clevelandia ios,* in inner Fish Harbor, and juvenile silversides, probably topsmelt,*Atherinops affinis,* in outer Fish Harbor at the yacht club. Both groups of fish were in a very distressed state. The gobies in the inner harbor were positioned vertically in the water column at approximately a 90 degree angle to the water surface with their mouths at the air-water interface. A number of these were collected by dip net, placed in aerated water from the inner harbor and transported to the laboratory. In aerated water, the distressed behavior immediately disappeared and most fish were still alive 16 days after collection. The juvenile silversides observed at the yacht club were also swimming with their mouths at the air-water interface but at a much more acute angle, probably 5-10 degrees. Three shiner perch were found floating near and under the cannery docks at the northwest end of inner Fish Harbor. These were the only dead fish observed floating on the surface and were in an advanced stage of decomposition. It is estimated that they had been dead for at least 24 hours. Other fish collected showed little or no evidence of decomposition, and death for them had probably come a few hours before collection.

The mortalities and distress behavior seen in these fish were most probably caused by depletion of dissolved oxygen and/ or by the large amounts of sulfides which were present in the water. The quick recovery of the distressed arrow gobies when placed in aerated water suggests low oxygen as the cause rather than toxicity, since there were no signs of ulceration, dermatitis, reddening of skin and fin tissues, or of excessive mucus production, or loss of equilibrium, all of which may accompany exposure to caustic or toxic substances. Work done on fresh water fish indicates that high concentrations of the sulfite ion (SO_3^{--}) do not subject fish to a severe osmotic challenge (Lewis, 1970). Presence of the ion, however, does bind oxygen according to the equation $2SO_3^{--} + O_2 \longrightarrow 2SO_4^{--}$, depleting available O_2.

The orientation of fish with their mouths at the air-water interface is a typical behavioral response in oxygen depleted waters. It is not known, however, whether fish are utilizing atmospheric air or air dissolved in the thin, saturated surface film, which is present just below the air-water interface, when they exhibit this type of behavior. It is probably the latter as few fish are able to breathe air directly.

Survival of the small gobies in the inner Fish Harbor was probably a result of better utilization of the air-water interface as an oxygen source because of their long, thin shape and small size. The larger fish with greater oxygen demands were most likely unable to obtain oxygen in sufficient amounts under prevailing conditions. The juvenile silversides in outer Fish Harbor probably survived because the sulfide concentrations were significantly less there and the fish were able to acquire enough oxygen near the water surface. It seems highly improbable that these fish would voluntarily enter the minimum oxygen waters of outer Fish Harbor from the much better water conditions in the outer Los Angeles Harbor. Fish are able to respond to changes in dissolved oxygen thresholds of gradients (Nikolsky, 1963), moving from waters of lowered concentrations to water with higher concentrations. It was reported (Los Angeles Harbor Department, personal communication) that the generation of sulfide and resultant drop in dissolved oxygen was first seen in outer Fish Harbor. This low O_2 content water could have acted as a barrier to fish attempting to escape the deteriorating conditions on inner Fish Harbor.

Conclusion. It is estimated that almost 100 percent of the fish remaining in inner Fish Harbor succumbed. The total number of dead fish is not known, but this fish kill will probably have little effect on the populations of the species concerned in the Los Angeles-Long Beach Harbor as a whole. It is impossible to maintain the 5 ppm dissolved oxygen level required in effluent plumes by water quality enforcement agencies if the entire harbor, and sometimes adjacent coastal waters, do not meet the standards because of seasonal conditions. When conditions are marginal, management decisions must be made to avoid overloading the receiving waters.

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Appendix 1. Forty-eight hour composite analysis of fish cannery effluent sampled during the periods 4-5 December, 1973, and 6-7 December, 1973. ND = not determined.*

Identification number: p73-12-017

Constituents	As Received (unfiltered)	Filtered
Solids, settleable, ml/l	95	ND
	mg/l	mg/l
Solids		
Total	6,020	ND
Dissolved	ND	3,410
Fixed	2,510	2,530
Volatile	3,510	833
Suspended	3,077	ND
Oil & Grease (Hexane extractables)	2,844	149
B.O.D. 5-day @ 20°C	5,360	2,090
Total Organic Carbon	ND	3,100
Chemical Oxygen Demand	11,000	3,370
Nitrogen as N		
Total	541	389
Organic	225	158
Free Ammonia	316	231
Nitrite	ND	0.004
Nitrate	ND	0.06
Phosphorus as P		
Total	58	42.5
Organic	1	0.5
Inorganic	57	42.0
Alkalinity, as $CaCO_3$	ND	1,230
Calcium, Ca	ND	30
Chloride, Cl	ND	1,189
Magnesium, Mg	ND	68
Potassium, K	ND	100
Sulfate, SO_4	ND	285
Cobalt, Co	0.04	0.03
Copper, Cu	0.19	0.028
Iron, Fe	8.20	0.94
Manganese, Mn	0.069	0.027
Vanadium, Va	0.02	0.02
Zinc, Zn	1.64	0.32
Mercury, Hg	0.0023	0.0020
Lead, Pb	0.13	0.03

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Appendix 2. Forty-eight hour composite analysis of fish cannery effluent samples during the periods 4-5 December, 1973, and 6-7 December, 1973. NO = not determined.*

Identification number: P73-12-041

Constituents	As Received (Unfiltered)	Filtered
Solids, settleable, ml/l	9.0	ND
	mg/l	mg/l
Solids		
Total	33,060	ND
Dissolved	ND	31,450
Fixed	27,500	26,367
Volatile	5,560	5,083
Suspended	178	ND
Oil & Grease (Hexane extractables)	632	19
B.O.D. 5-day @ 20°C	342	162
Total Organic Carbon	ND	330
Chemical Oxygen Demand	1,203	371
Nitrogen as N		
Total	ND	28
Organic	43	26
Free Ammonia	6.6	1.0
Nitrite	ND	0.004
Nitrate	ND	0.8
Phosphorus as P		
Total	9.3	8.6
Organic	2.0	1.0
Inorganic	7.3	7.6
Alkalinity, as $CaCO_3$	ND	275
Calcium, Ca	ND	331
Chloride, Cl	ND	15,910
Magnesium, Mg	ND	1,050
Potassium, K	ND	318
Sulfate, SO_4	ND	2,202
Cobalt, Co	0.19	0.16
Copper, Cu	0.07	0.056
Iron, Fe	1.22	1.10
Manganese, Mn	0.046	0.037
Vanadium, Va	0.06	0.02
Zinc, An	0.53	0.22
Mercury, Hg	0.0012	0.0011
Lead, Pb	0.26	0.22

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Appendix 3. Forty-eight hour composite analysis of fish cannery effluent sampled during the periods 4-5 December, 1973, and 6-7 December, 1973. NO = not determined.*

Identification number: P73-12-039

Constituents	As Received (Unfiltered)	Filtered
Solids, settleable, ml/l	28.0	ND
	mg/l	mg/l
Solids		
Total	7,040	ND
Dissolved	ND	6,520
Fixed	5,266	5,310
Volatile	1,774	210
Suspended	900	ND
Oil & Grease (Hexane extractables)	517	87
B.O.D. 5-day @ 20°C	2,970	1,770
Total Organic Carbon	ND	2,450
Chemical Oxygen Demand	4,320	2,550
Nitrogen as N		
Total	ND	325
Organic	149	118
Free Ammonia	248	207
Nitrite	ND	0.004
Nitrate	ND	0.51
Phosphorus as P		
Total	47	38
Organic	2	1
Inorganic	45	38
Alkalinity, as $CaCO_3$	ND	1,284
Calcium, Ca	ND	60
Chloride, Cl	ND	2,825
Magnesium, Mg	ND	114
Potassium, K	ND	115
Sulfate, SO_4	ND	419
Cobalt, Co	0.05	0.05
Copper, Cu	0.88	0.022
Iron, Fe	2.06	0.56
Manganese, Mn	0.072	0.052
Vanadium, Va	0.04	0.02
Zinc, Zn	0.66	0.35
Mercury, Hg	0.0032	0.0021
Lead, Pb	0.10	0.08

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Appendix 4. Forty-eight hour composite analysis of fish cannery effluent sampled during the periods 4-5 December, 1973, and 6-7 December, 1973. ND = not determined.*

Identification number: P73-12-031

Constituents	As Received (Unfiltered)	Filtered
Solids, settleable, ml/l	8.6	ND
	mg/l	mg/l
Solids		
Total	24,630	ND
Dissolved	ND	14,640
Fixed	20,500	10,850
Volatile	4,130	3,790
Suspended	179	ND
Oil & Grease (Hexane extractables)	702	193
B.O.D. 5-day @ 20°C	237	147
Total Organic Carbon	ND	377
Chemical Oxygen Demand	972	376
Nitrogen as N		
Total	ND	30.5
Organic	48.7	25.4
Free Ammonia	9.3	4.1
Nitrite	ND	0.004
Nitrate	ND	0.98
Phosphorus as P		
Total	6.2	5.2
Organic	1.9	0.7
Inorganic	4.3	4.5
Alkalinity, as $CaCO_3$	ND	224
Calcium, Ca	ND	272
Chloride, Cl	ND	12,560
Magnesium, Mg	ND	820
Potassium, K	ND	249
Sulfate, SO_4	ND	1,732
Cobalt, Co	0.14	0.14
Copper, Cu	0.10	0.044
Iron, Fe	2.24	0.80
Manganese, Mn	0.044	0.035
Vanadium, Va	0.07	0.04
Zinc, Zn	0.82	0.15
Mercury, Hg	0.0032	0.0015
Lead, Pb	0.19	0.17

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Appendix 5. Results of amino acid analysis of arrow goby tissue and two untreated fish cannery effluent samples. All values are in percent based on dry weight.

Amino Acid	Fish	Earlier Liquid Sample	Later Liquid Sample
Lysine	5.06	0.047	0.050
Histidine	1.33	0.018	0.021
Arginine	4.07	0.025	0.029
Aspartic Acid	6.16	0.055	0.055
Theonine	3.02	0.027	0.028
Serine	3.65	0.029	0.031
Glutamic Acid	9.15	0.077	0.079
Proline	2.75	0.034	0.031
Glycine	3.92	0.062	0.061
Alanine	3.98	0.049	0.049
Valine	2.82	0.029	0.029
Methionine	2.24	0.014	0.016
Isoleucine	2.32	0.020	0.022
Leucine	4.89	0.041	0.042
Tyrosine	2.46	0.014	0.018
Phenylalanine	2.74	0.021	0.020
Total Cystine	0.85	0.01	0.012
Tryptophane	1.47	0.013	0.010

MARINE STUDIES OF SAN PEDRO BAY, CALIFORNIA. Part 8. June 1975

THE BIOLOGY AND FISHERY OF THE NORTHERN ANCHOVY IN SAN PEDRO BAY

Potential Impact of Dredging and Landfill

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ABSTRACT: The northern anchovy, *Engraulis mordax*, is a small, abundant, schooling species of exceptional importance in the trophic relationships of the marine life off southern California. As a bait-fish, the anchovy is highly prized by sportsmen and intensively pursued by live-bait fishermen within the outer Los Angeles-Long Beach Harbor. Although not essential for spawning, the harbor and other inshore areas are utilized extensively as nursery grounds for juvenile *E. mordax*. Juvenile fish may be attracted to the harbor by increased productivity and warmer water temperatures, relative to offshore areas.

Although temporary dredging operations and associated turbidity will probably not adversely affect anchovy stocks within the harbor, landfill operations in the outer harbor will decrease the area suitable as anchovy habitat; proportional decreases in anchovy biomass can be expected. Bait fishermen would be forced to fish outside the harbor where conditions are less than optimal.

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THE BIOLOGY AND FISHERY OF THE NORTHERN ANCHOVY IN SAN PEDRO BAY

INTRODUCTION. At least 132 species of fishes representing 48 families are known to inhabit or frequent the waters of the Los Angeles-Long Beach Harbor (Chamberlain, 1974). Among this diverse assemblage of fishes, one species, the northern anchovy (*Engraulis mordax* Girard) is of exceptional importance and occupies a central position in the trophic relationships of the harbor fauna. Anchovies rank first or second in abundance among the harbor fishes (Stephens et al., 1974). They are major consumers of zooplankton and, in turn, are fed upon by a variety of predatory fishes, birds, pinnipeds, cetaceans, and invertebrates. Furthermore, anchovies are caught by live-bait fisherman within the harbor for sale to sportsmen from the San Pedro, Long Beach, and Seal Beach sport fisheries as a prized bait for various food and game fishes. The northern anchovy represents the most valuable living marine resource in the harbor. Two other species of anchovy (engraulids), *Anchoa delicatissimi* and *Anchoa compressa*, have been taken infrequently in the harbor but are of no commercial importance there.

Interest in the biology and fishery potential of the northern anchovy has intensified during the past two decades after the total collapse of the once prosperous sardine (*Sardinops sagax caeruleus*) fishery and a concurrent, dramatic increase in anchovy biomass off California and Baja California. The California Department of Fish and Game (1971) considered the anchovy ". . . the most abundant species with immediate harvest potential in the California Current System." The biology of the northern anchovy was reviewed by Clark and Phillips (1952), Miller (1956), Baxter (1967), Messersmith et al. (1969), and the California Department of Fish and Game (1971). An annotated bibliography on *E. mordax* was prepared by Brewer (1973). In light of a number of recent studies on the anchovy, it seems pertinent to present a brief review of the literature, combined with a discussion of anchovy biology and behavior in San Pedro Bay. Lastly, the impact of proposed dredge and landfill operations will be discussed. Because of inherent limitations in the analyses of pelagic fish biology and behavior, all conclusions should be considered tentative, based on numerous discussions with bait fishermen, California Department of Fish and Game personnel, and personal studies of anchovies and bait-fish operations during the past two years.

BIOLOGY

Distribution and Abundance. Northern anchovies have been present off the California coast during both warm and cold periods for at least 12 million years (Fitch, 1969). They have undoubtedly been a dominant component of the pelagic fish fauna for centuries (Soutar and Isaacs, 1969), although their presence off southern California in the 19th and 20th centuries (at least) has been marked by cyclic fluctuations in abundance (Soutar and Isaacs, 1974). Adult northern anchovies are presently known to range from the Queen Charlotte Islands, British Columbia (53^{o} N) to Cabo San Lucas, Baja California (22^{o} N) (Miller and Lea, 1972). However, their center of abundance is off southern California and northern Baja California.

Limiting Biotic and Abiotic Factors. *Engraulis mordax* is a neritic species, apparently limited to coastal waters within 300 miles of shore. These continental shelf waters are relatively high in productivity, and here the integrity of the breeding population may be maintained by prevailing currents and nearshore nursery grounds. Although, in nature, anchovies have been observed to occur in water temperatures between approximately 8^{o} and 25^{o} C (Baxter, 1967), Brewer (1975) has shown that, for anchovies off southern California, the extreme range of thermal tolerance after maximum acclimation to warm or cool temperatures is between 6.5^{o} and 29.5^{o} C. Brewer suggested that the upper environmental temperature range limit (25^{o} C) may be dictated by metabolic demands which outweigh the food ration that can be acquired from the environment.

The stenothermal limits of reproduction undoubtedly play an important role in restricting the distribution of *E. Mordax*. Although spawning has been noted between water temperature extremes (at 10 meters depth) of 9.9^{o} and 23.3^{o} C (Baxter, 1967), perhaps 90 percent of all spawning occurs at surface water temperatures between 13^{o} and 18^{o} C (Brewer, 1975). The oceanic habitat of *E. Mordax* encompasses a salinity range between approximately 32 and $34.6^{o}/_{oo}$ (Lynn, 1967), although the fish apparently tolerate brackish water conditions in bays and estuaries during periods of heavy run-off. No experimental studies have been undertaken on the minimum oxygen requirements of *E. Mordax*, but the closely related Japanese anchovy, *E. Japonica*, died when the oxygen content of the water fell below 2 cc/liter (Suehiro, 1936).

Populations. Three geographically separate populations of northern anchovy were identified by McHugh (1951) on the basis of variation in meristic characters. These findings have been substantiated by more recent genetic studies (Vrooman and Smith, 1971) and age and length-frequency data by Mais (1974) and Tillman (1975). The ranges of these populations apparently vary seasonally, but the winter distribution of the central population is thought to lie between Point Conception, California and Cedros Island, Baja California. The mean total biomass of anchovies between 1962-1966 was estimated to be 6.1 million metric tons. The central population biomass averaged 4.7 million metric tons, while the biomass of the southern and northern populations averaged 1.1 and 0.26 million metric tons, respectively (Vrooman and Smith, 1971). The total anchovy population reached a plateau between 1962 and 1966 when 5-8 million metric tons were recorded. This represents an increase of 5-10 times the anchovy population over 1950-1951 levels. The anchovy biomass estimated for 1969, the most recent published, was 3-4 million metric tons (Smith, 1972). A brackish-water population,inhabiting the upper reaches of San Francisco Bay, has been given sub-specific recognition as *(E. Mordax nanus)* by Hubbs (1925).

Movements and Behavior. Tagging experiments by the California Department of Fish and Game (Haugen, et al., 1969) have shown that anchovies move between offshore and inshore areas and that some fish may move several hundred miles along the coast. Fish tagged off southern California have been recovered in Monterey and San Francisco Bays and off Ensenada; fish tagged in Monterey and San Francisco Bays were later recovered off southern California. Anchovy tagged off Catalina and San Clemente Islands were later caught in the Los Angeles-Long Beach Harbor; fish released in the Los Angeles-Long Beach Harbor have been found in offshore waters and off Ensenada. Generally, tag recoveries suggest a southerly movement of fish in the winter and a northerly movement in the summer. These tagging studies suggest that there is a potential for gene exchange, between the so-called central and northern populations, at least.

Mais (1974) has recently completed a comprehensive survey of anchovy resources off California and Baja California and his findings are summarized here. Anchovy stocks off northern California are largely limited to relatively small concentrations of fish within 0.5 mile offshore, and except during sporadic years of favorable oceanic conditions, the region is best described as a sub-marginal anchovy habitat. Except for some restricted near-shore areas, water temperatures seldom exceed 12° C off northern California; reproduction, therefore, is minimal in this area. The central California coast was described as a marginal anchovy habitat by Mais (1974), with fish concentrated in a narrow (10-mile) coastal strip. Small surface schools (200 pounds to 10 tons) of anchovies were found to be common in this region at depths between 9.2 and 73.2 m during daylight hours. These schools moved to the surface at night and dispersed into a coarse scattering layer. The bulk of the anchovy resource is located off southern California and northern Baja California, particularly in the region of the southern California bight. Although anchovies are distributed widely in this area, large concentrations are often found associated with deep water basins, submarine escarpments and canyons, often within five miles of shore. Santa Monica Basin, Santa Monica Canyon, Redondo Canyon, San Pedro Basin, and the nearshore escarpments off Palos Verdes and Newport Beach were mentioned by Mais (1974) as areas where anchovy school sizes and concentrations were much larger than elsewhere.

Mais (1974) has stressed that the behavior of anchovy ". . . is extremely varied and virtually unpredictable." The most common schooling behavior of anchovies off southern California was observed to be the formation of small, low density schools during daylight hours. They were distributed from the surface to 54.9 meters and most commonly at depths from 9.1 to 18.3 meters. At night, these schools dispersed into a thin, surface scattering layer until the following morning. During fall and winter months very large schools (20-300 tons) were sometimes evident over deep channels and basins at depths of 0-55 meters from the surface. During late summer such large schools were found at depths between 119 and 220 meters during daylight hours. These fish rose to the surface at night. Davies and Bradley (1972) made direct visual observations from a submersible of anchovies as deep as 310 meters off southern California in the fall. Anchovies located over relatively shallow areas were sometimes found in extensive, loose scattering layers at depths of 18 to 91 meters during daylight hours. Such aggregations were uncommonly found on or near the bottom. Relatively small concentrations of fish were found in inshore waters where water depths were less than 91.5 meters. However, acoustic equipment used to detect schools is less efficient in shallow water and the fish may not be detected if they are loosely scattered (Mais, 1974). Length-frequency data on fish sampled from the southern California bight demonstrated that large fish are more prevalent in offshore waters and small fish favor inshore areas. Similar data, comparing the commercial and live-bait fishery, show that the commercial fishermen (required to fish at least three miles from shore) catch larger anchovies than the live-bait fishery (Collins, 1969; Crooke, 1969).

<u>Harbor Abundance</u>. Data on anchovy spawning in San Pedro Bay compiled by Brewer (1975) have shown that adult, sexually mature fish are most abundant outside the harbor. On the average, anchovy eggs were 4-20 times more abundant outside the harbor breakwater when compared to stations in the inner and outer harbor. These data reflect only the relative abundance of spawning fish.

A reliable estimate of total abundance of anchovies in the harbor (i.e. including juvenile fish) is difficult or impossible to make. Acoustic gear can not be used effectively in shallow water (Mais, 1974) and midwater trawls are not effective sampling devices for harbor anchovies (Stephens <u>et al</u>., 1974). Warmer water and higher reproductivity levels in the harbor may attract fish into the harbor, and the density of juvenile anchovies in the harbor may very well exceed their density in inshore areas to the north and south. Schools of anchovies move into or out of the breakwater openings with little predictability or pattern. At times, large concentrations move into the harbor and remain there for weeks; at other times the fish are virtually absent (William Verna, Long Beach live-bait dealer, personal communication). The bait-fishery effort is concentrated within the harbor because the fishermen are usually assured of success. The fish are confined by the shallow depths in the harbor and their behavior is such that they become vulnerable to capture by the fisherman's nets. The harbor provides an ideal location, under almost any weather condition, for the capture, transport, and holding of anchovies for future sale as bait.

Competitors. The Pacific sardine (*Sardinops sagax caeruleus*) is a direct competitor of anchovies over most of the latter's geographic range (Baxter, 1967). Both are planktivorous and compete for similar food resources throughout their life cycles. The striking increase in anchovy biomass during the past 25 years, which coincided with a drastic decline in sardine stocks, has prompted much speculation about the interactions of the two species. For example, Lasker (1964) has suggested that anchovies are at a slight ecological advantage over sardines at low temperatures. Development in anchovy larvae is faster than in sardine larvae at cool temperatures, and normal development of sardine larvae is inhibited at temperatures below 13° C; anchovy development is normal down to 11.5° C (Brewer, 1975). Except for brief periods in the 1850's and 1930's, anchovies have always been more abundant than sardines off southern California during the 19th and 20th centuries (Soutar and Isaacs, 1974).

Juveniles and adults of a number of other pelagic fishes consume food organisms normally eaten by anchovies, i.e., hake (*Merluccius*), jack mackerel (*Trachurus*), Pacific mackerel (*Scomber*), herring (*Clupea*), saury (*Cololabis*), and croaker (family Sciaenidae). Virtually every species of fish with planktonic larvae represent potential competitors to anchovy larvae, since they all occur in the upper mixed layers of the ocean and eat similar planktonic organisms.

Predators. *Engraulis mordax* is a major food item in the diets of a wide variety of marine animals. Virtually every large predatory fish consumes anchovies. For example, Pinkas et al. (1971) found that, off California, anchovies comprised 75, 56, and 80 percent of the diets of bonito (*Sarda chiliensis*), albacore (*Thunnus alalunga*) , and bluefin tuna (*Thunnus thynnus*), respectively. Major carnivores found in or near the harbor area include the tunas and mackeral (Scombridae), lizardfish (Synodontidae), hake (Merlucciidae), barracudas (Sphyraenidae), croakers (Scieanidae), sea basses (Serranidae), billfishes (Xiphidae and Istiophoridae), jacks (Carangidae), flatfishes (Bothidae and Pleuronectidae), and rockfishes (Scorpaenidae). Anchovy eggs and larvae are easy prey for planktivorous fishes (including juvenile and adult anchovies) and for crustaceans, cheatognaths, salps, and jellyfish. Birds (pelicans, cormorants, and seagulls), pinnipeds, and cetaceans also consume substantial quantities of anchovies.

Feeding Habits. A comprehensive study of the diet of juvenile and adult anchovy was conducted by Loukashkin (1970). He concluded that juvenile and adult fish are largely opportunistic omnivorous plankton feeders. Copepods and euphausiids are apparently preferred, but other zooplankters and phytoplankters were sometimes dominant items. Small fish and fish eggs were ingested, but generally in small quantities. Leong and O'Connel (1969) and O'Connel (1972) have described feeding behavior in adult fish. Laboratory observations showed that the anchovy procures food by filtration (straining water through their gill rakers) or by directed predatory biting, depending on the concentration and size of the food particles present. Apparently large crustaceans are taken in preference to smaller organisms, but when such larger food items are not available, the fish actively filter small organisms. Leong and O'Connel (1972) estimated that a 5-g specimen of *E. Mordax* would require 74 mg dry weight (i.e. 1.5 percent of the fish's wet weight) of plankton material per day to satisfy its nutritional requirements. Such an anchovy filters water at a rate of approximately 1.46 liters/minute.

At first feeding, anchovy larvae, as small as 2.5 mm, require food particles between 20 and 90 μ in cross-section. Berner (1959) found that such food items included primarily copepod eggs and nauplii, dinoflagellates, and tintinnids. Anchovy larvae have been reared through metamorphosis in the laboratory by being fed screened wild plankton (Kramer and Zweifel, 1970); unarmored dinoflagellates, gastropod veligers, and brine shrimp nauplii (Lasker et al., 1970); and rotifers (Theilacker and McMaster, 1971). Hunter (1972) suggested that larvae, just after yolk absorption, are highly vulnerable to starvation because very high food densities are required (i.e. 105 rotifers/liter of water) to compensate for the poor capture rate caused by relatively feeble swimming abilities.

Reproduction. Anchovies off southern California may reach sexual maturity at the end of their first year of life when they are approximately 79-84 mm standard length (Brewer, 1975). McGregor (1968) has shown that the number of eggs in the ovaries of female fish increase with the size of the fish, and he counted between 4,000 and 21,000 eggs in fish between 97 and 138 mm standard length. Eggs are spawned into the upper mixed water layers where they are fertilized at temperatures (10 meters depth) between 9.9° and 23.3° C, but over 90 percent of all spawning occurs when surface temperatures are between 13° and 18° C. Anchovies apparently spawn in the evening between approximately 8 and 12 PM (Bolin, 1936; Brewer, 1975). The eggs float passively in the surface layers and hatching takes place 2-3 days after fertilization. Although spawning has been known to occur over most of the anchovy's geographic range, the major spawning areas lie between Point Conception, California, and Magdalena Bay, Baja California. Spawning has been noted during every month of the year off southern California, but is most intense between February and May (Ahlstrom, 1959; Brewer, 1975). Richardson (1974) has captured anchovy larvae off Oregon in the summer months when water temperatures, associated with the Columbia River plume, rose above 14° C.

Brewer (1975) conducted a survey of anchovy spawning in the Los Angeles-Long Beach Harbor and San Pedro Bay during the period between February 1973 and September 1974 by analyzing the distribution and abundance of anchovy eggs and larvae taken by plankton net. Figure 1 shows the distribution of anchovy eggs based on the mean number of eggs collected per trawl throughout the study period. Anchovy eggs were often abundant in the harbor, and at times were present in greater numbers within the harbor than at the offshore stations. During one standardized trawl within the harbor, as many as 146 anchovy larvae and 532 anchovy eggs were captured (i.e. 3 larvae and 11 eggs per m^3 of water filtered); at stations outside the harbor, as many as 812 larvae and 1720 eggs were captured (i.e. 16 larvae and 35 eggs per m^3 of water filtered). Most spawning occurs outside the breakwater; indeed, some portion of the eggs found in the harbor are probably transported into the harbor by currents since the greatest abundance of eggs in the harbor has been found to be around the breakwater openings. Sexually mature fish apparently favor deeper, perhaps cooler, offshore waters.

Development and Growth. The anchovy is a relatively short-lived species; generally, fish may attain lengths of 14-15 cm after 4 years of life, although individuals as long as 24 cm and as old as 7 years have been reported (Baxter, 1967). Anchovies from off central California regions exhibit the most rapid growth. Fish of a given age group in this region are approximately 10 mm longer than fish from off southern California and northern Baja California. Fish from off southern California attain average lengths of 11-12 cm after one year of life. Anchovies sampled from central and southern Baja California, at latitudes below 29°-30° N, are much smaller for a given age group than fish located to the north. These fish attain near maximum length by age 3 when the average length is less than 10 cm (Mais, 1974). Otoliths are now used most often to age anchovies (Collins, 1969) while scales have been used successfully in the past (Miller, 1955).

Brewer (1975) showed that the anchovy incubation period requires approximately 160 hours at 10° C and only 24 hours at 24° C. Eggs hatch at temperatures as low as 8.5° C and as high as 29.5° C, but development of larvae is inhibited at such low and high temperatures. Temperatures of at least 11.5° and 27.5° C or

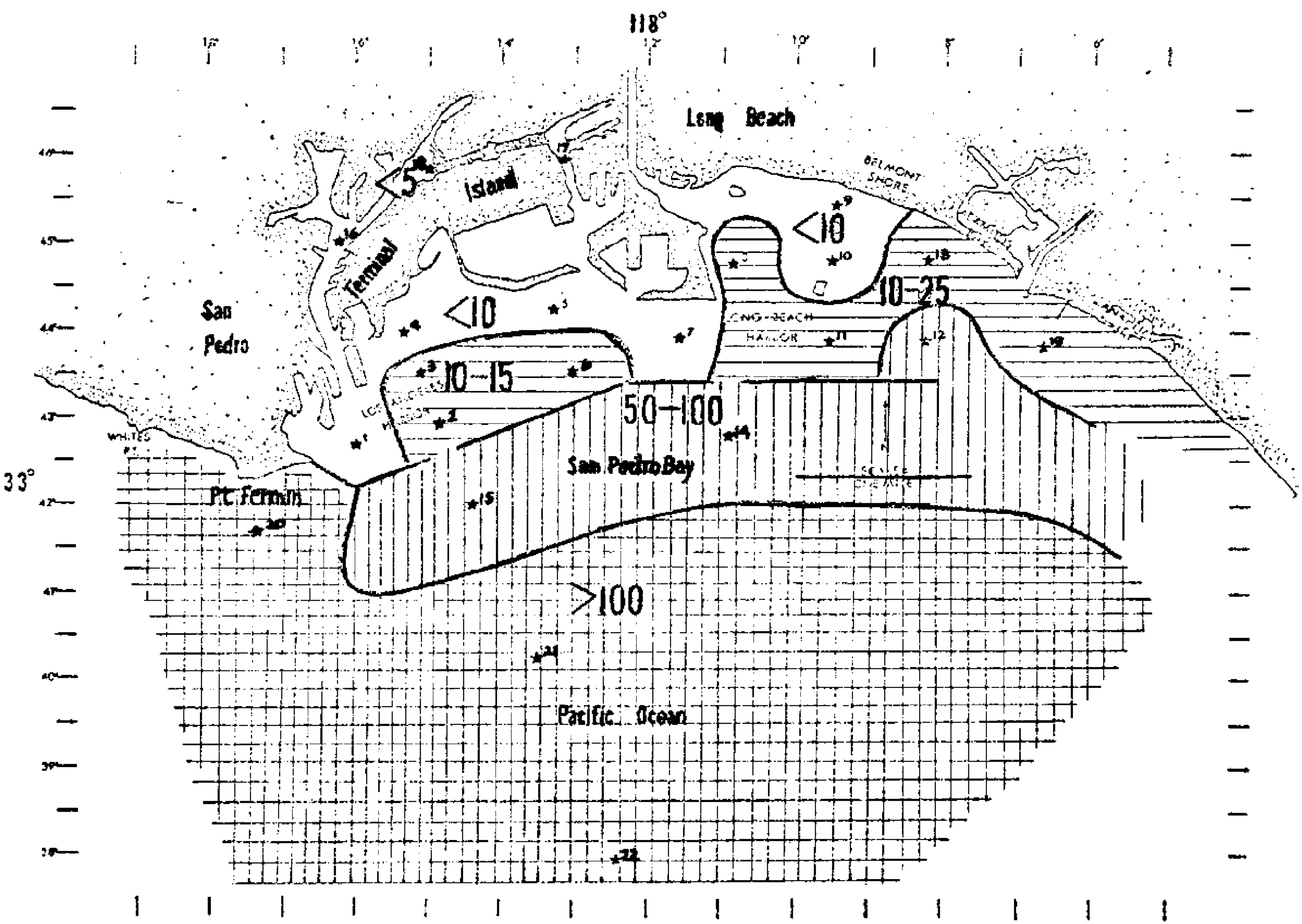


Figure 1. Map of the Los Angeles-Long Beach Harbor and San Pedro Bay, indicating the mean number of anchovy eggs taken per standardized trawl over a 20 month period (from Brewer, 1975).

less were required for normal development (i.e. equal to the control at 16° C). Larvae attained maximum size before exhaustion of yolk reserves at experimental temperatures between 14° and 20° C. Growth was less than maximum at temperatures of 12° C and below, and 24° C and above. Maximum size attained in the growth experiments at any temperature was 4.16 mm before starvation occurred. At extreme high or low temperatures, deformities were common in larvae before death. These included spinal curvatures and lack of complete jaw formation and eye pigmentation.

THE FISHERY

Commercial Fishery. The commercial category includes fish canned for human and animal foods: fresh, frozen, and salted fish sold at fish markets; dead bait used by sportsmen and commercial fishermen; fish used for feeding at fish and animal farms, and fish used for reduction into oil and fish meal (Baxter, 1967). This fishery has caught between 69,000 and 96,000 tons in recent years (1970-1973) but has fluctuated widely in the past 30 years due to unstable market conditions for anchovy products. Commercial fishermen are required to fish at least three miles from shore; therefore, commercial fishing for anchovies is not permitted within the harbor.

Live-Bait Fishery. The California live-bait fishery for anchovies has grown to meet the needs of thousands of California commercial and sport fishermen who prize the live anchovy for bait. The fishery involves catching, transporting, and holding live anchovies until they can be transferred to bait tanks on fishing boats, where they are held until placed on hooks for bait or used as chum to attract fishes to the fishing boat (Wood and Strachan, 1970). Live-bait fishing for anchovies has been carried out in coastal areas between San Diego and San Francisco but the Los Angeles-Long Beach Harbor has often accounted for over 50 percent of the entire, state-wide, live-bait catch. Indeed, the harbor has attracted bait fishermen from as far away as San Diego and Point Conception during the summer months when anchovies are notoriously hard to locate and capture along other parts of the coast (California Department of Fish and Game, 1971). The statewide live-bait catch has totaled some 5,000-7,000 tons annually between 1964 and 1972 (Heinimann and Carlisle, 1970; Pinkas, 1972).

Several methods are used by bait fishermen to locate bait fish: (1) fathometer readings, (2) observations of birds feeding on the surface, (3) direct observation of fish schools, (4) nighttime luminescent glow of schools, and (5) lights suspended over the water from small skiffs. The last method is used extensively in the Los Angeles-Long Beach Harbor (Wood and Strachan, 1970) and is described below. Generators provide electricity to two strong light bulbs suspended over the surface of the water. Anchovy are attracted to the light, or to the concentration of zooplankton below the light, and the fishermen take advantage of this behavior. One end of the lampara net, with an attached, lighted marker buoy is thrown into the water, and as the vessel circles the school the net is pulled over the side, encircling the school. With the circle completed, the end of the net is brought up and the net is pulled aboard by a mechanical net puller. The bait may then be scooped directly from the net and sold to private, sport-fishing, and commercial boats that pull along-side the bait boat. The remaining bait may then be scooped into the large bait wells on the bait boat for subsequent sale to other boats, piers, and fishing barges. Unsold bait is often scooped from the bait boat to stationary, floating, live-bait receivers for future sale (Wood and Strachan, 1970).

The bait-fishery effort and catch is largely dictated by the sportfishing demand for live-bait, which is highest during the summer and lowest in the winter. At the present time, bait is being sold to private fishing boats for $6.00 per scoop (ca. 12.5 pounds). Sport fishing boats, piers, and barges may receive bait at reduced prices or be under contract, in which case the bait dealer receives a percentage of the sportfishing boat's profits.

Figure 2 is a map of the Los Angeles-Long Beach Harbor indicating that area where at least 90 percent of the live-bait fishing effort is concentrated. The remainder of the harbor and areas outside the harbor account for less than 10 percent of the bait-fishing effort. Table 1 gives the estimated catch of live-bait taken from the Los Angeles-Long Beach Harbor for the period between 1972 and 1974 and reflects a decreasing demand for live-bait.

IMPACT OF DREDGING AND LANDFILL

Man's understanding of the environmental cues which govern the migrations and movements of pelagic fishes are poorly understood. Under natural conditions, fish may respond to a host of subtle directive factors associated with temperature, salinity, food, oxygen concentration, water depth, currents, light intensities, predators, noxious substances, and interactions with conspecifics (including breeding and schooling behavior). For example, Brewer (1973) found that under carefully controlled laboratory conditions, juvenile *E. mordax* responded to a horizontal thermal gradient by selecting the warmest section of the gradient apparatus when exposure temperatures were between 13° and 25° C. The fish actively avoided temperatures above approximately 25° C. Such behavior is a response to a thermal gradient when no other environmental cue overrides the "preferred temperature" directive. Modification of any or several of the potential

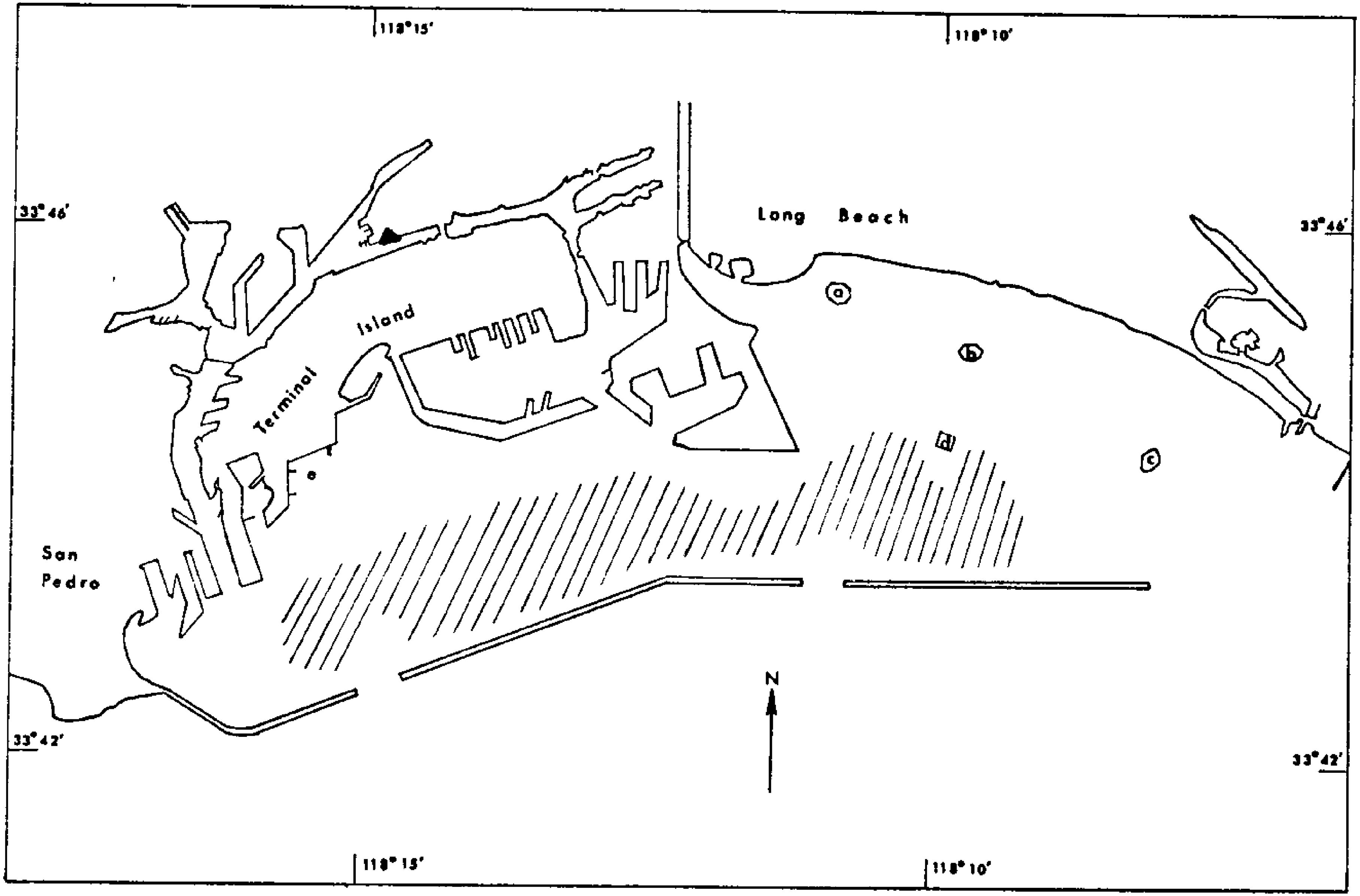


Figure 2. Map of the Los Angeles-Long Beach Harbor. Approximately 90 percent of the bait-fishery effort is concentrated in the shaded area.

TABLE 1. Estimated catch of anchovy for use as live-bait from the Los Angeles-Long Beach Harbor (courtesy of the California Department of Fish and Game).

	Estimated Catch (in tons)		
Month	1972	1973	1974
January	73.0	37.5	38.2
February	71.8	37.5	38.1
March	110.4	37.5	40.0
April	193.0	56.9	108.5
May	189.8	153.7	81.5
June	288.3	150.0	102.3
July	354.2	168.7	124.7
August	318.2	150.0	149.3
September	260.7	198.7	129.1
October	160.7	116.9	62.5
November	121.9	65.9	48.1
December	66.2	39.4	43.5
TOTALS	2208.2	1212.7	965.8

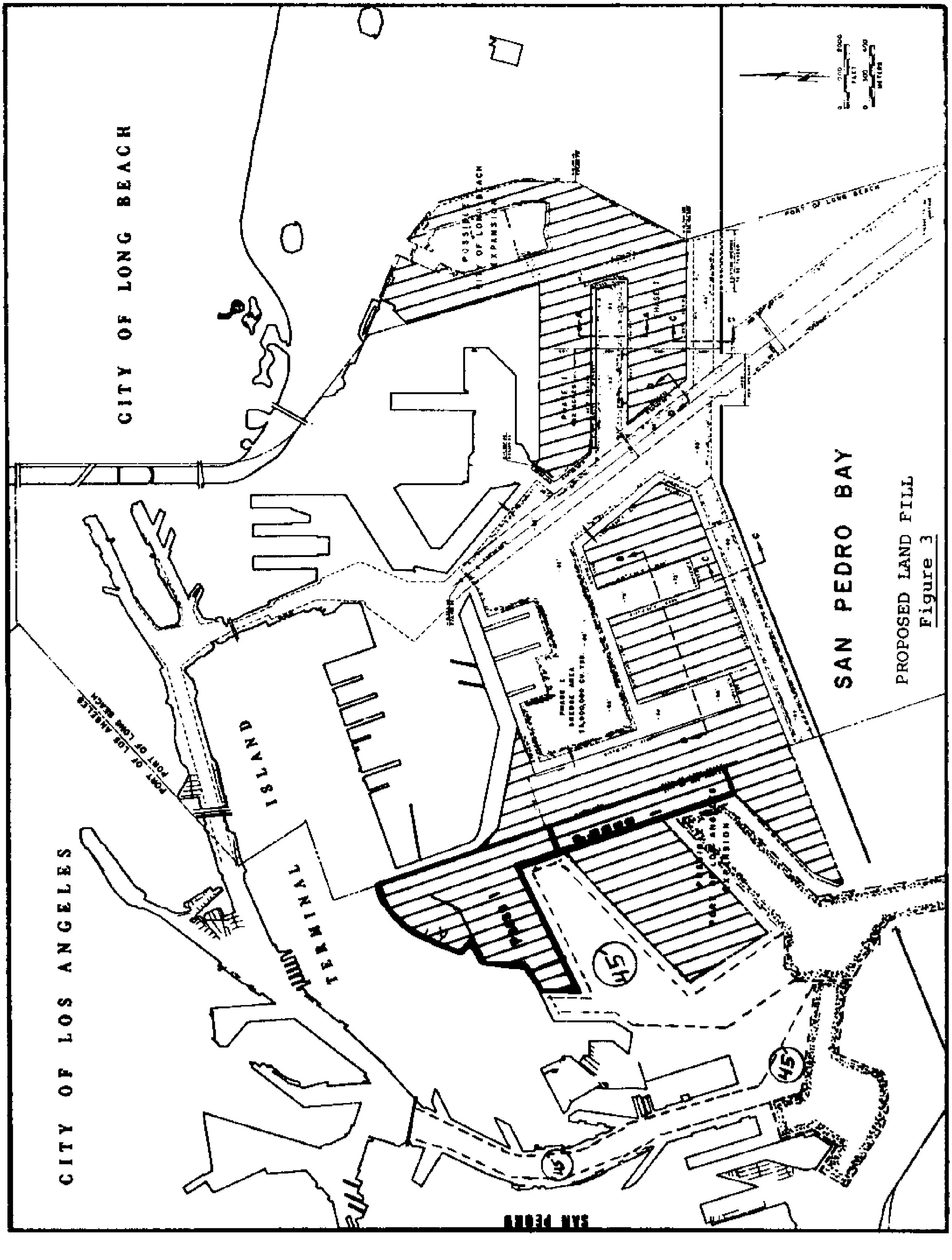
directive factors listed above would be caused by dredge and fill operations. The anchovies' response to the dynamic interaction of such biotic and abiotic factors is difficult to assess. The following discussion of the impact of proposed dredging and landfill operations in the harbor should be understood in this broad context.

Temporary Effects. Field and laboratory observations suggest that dredging operations, with associated turbidity from the resuspension of sediments, will have little or no immediate detrimental effect on the anchovies in the harbor. During the fall of 1974, juvenile anchovies were in abundance within the main channel of the Los Angeles Harbor concurrent with the dredging operations associated with the construction of concrete pilings and docking facilities at berth 235, adjacent to the *Princess Louise*. The feeding activities of diving birds (terns) indicated that fish were present near the surface between the main channel entrance and the east basin on at least several different occasions while the dredging was in progress.

In recent years anchovies have not been abundant within the inner harbor (William Verna, live-bait dealer, pers. comm.). I have not witnessed similar concentrations of birds diving on anchovies within the inner harbor in times previous or subsequent to the dredging period. These observations suggest that anchovies may have been attracted to the dredging area, perhaps indirectly through increased nutrients and productivity of the area.

Brewer (unpublished results) has conducted studies of the effects of resuspended sediment elutriate on anchovy embryos and larvae. Bottom sediments from proposed deep-water channel sites (three sites) within the harbor were resuspended by standard EPA procedures. The elutriate was assayed full strength on *E. mordax* embryos from the blastopore-closure stage (32-36 hours after fertilization) through hatching and larval development for 96 hours. Examination of the larvae under magnification showed normal development, with no obvious physical deformities when compared to larvae reared under control conditions. These early developmental stages can be considered the most susceptible to environmental stress from heavy metals and other toxins. Fears that dredging operations will create undesirable effects from turbidity, release of toxic materials, suffocations of fish, etc., seem unwarranted.

Long Term Effects. Sustained, long term effects would be created by a decrease in the harbor habitat available to the anchovy due to permanent land fill, with consequent impact on the live-bait fishery. Figure 2 shows the area most heavily fished by the bait fishermen; Figure 3 shows the projected land fill area in Los Angeles-Long Beach Harbor. Obviously, normal bait-fishery operations will be disrupted and forced to move elsewhere. There is no



PROPOSED LAND FILL
Figure 3

reason to believe that the average biomass of anchovies that are normally found throughout the harbor at the present time will simply be directed into the Long Beach area or into the narrow channels of the proposed harbor, unless there is a corresponding change in the "attractiveness" of these waters, such as changes in productivity, or temperature, for example. Deepening the shipping channel may be a positive attractant for anchovies; however, fishing operations for live-bait may be impossible in narrow, busy shipping lanes. It must be emphasized that the success of the bait-fishery is dependent not only on the presence of anchovies, but also on their behavior patterns which make them available for harvesting. The bait fishermen utilize the area outlined in Figure 2 simply because the fish are normally most easily caught in this area. Anchovies may, at times, be more abundant 3-5 miles off Palos Verdes; however, fish in these areas are generally not easily caught by the bait-fishermen's nets.

Changing the configuration of the harbor will not only remove potential habitat but may alter currents and indirectly influence productivity of the remaining harbor waters. Any substantial increase in tidal currents within the harbor would almost certainly have adverse effects on the bait-fish operations.

In light of the items outlined above, and based on our limited knowledge of the complex biotic and abiotic interactions, the proposed landfill operations would decrease the biomass of anchovy in the harbor. Proportional decreases in predatory (game) fishes could be expected. The live-bait fishery would have to respond by fishing outside the harbor. The abundance and/or behavior of the fishes in these areas is less than optimal for a successful bait fishery. The fishery would be forced to increase its fuel consumption, increase fishing effort, and cope with increased mortality of bait during transport. During periods of rough weather and high seas, fishing outside the breakwater would be impossible. Increased costs would, necessarily, be passed on to the sport fisherman.

SUMMARY AND DISCUSSION

In summary, the following aspects of anchovy biology and details of the live-bait fishery operations seem most pertinent to the impact of proposed landfill in Los Angeles-Long Beach Harbor.

1. The anchovy is a key component of the harbor's ecology as a major consumer of zooplankton and as an important forage item in the diets of a variety of invertebrates, fishes, birds and mammals.

2. The inshore environment off southern California, including the harbor, is an important nursery ground for juvenile

anchovies. The biomass of mature, reproducing anchovies is concentrated offshore; however, spawning is at times heavy within and just outside the harbor.

3. There is extensive interchange of fish from inshore waters, including the harbor, and offshore waters, as well as movements of fish north and south along the coast. No separate stock of anchovies occurs in the harbor.

4. No reliable methods are available to assess the average biomass of juvenile anchovies in the harbor. Juvenile fish are at least as abundant within the harbor as in other inshore locations along the coast, perhaps attracted to warmer water temperatures and higher productivity in the harbor.

5. The protected nature of the harbor waters creates ideal conditions for capturing, transporting, transferring, and holding bait-fish. The behavior of the fish in the confined, shallow harbor waters make them vulnerable to the bait fisherman's nets. A successful live-bait fishery takes advantage of these unique conditions.

6. Field and laboratory observations suggest that temporary dredging operations, creating turbidity from the resuspension of sediments, will not adversely affect anchovy development from eggs and will not exclude juvenile fish from the harbor.

7. Proposed landfill operations will cause a substantial reduction in habitat available to anchovies within the harbor and will cover a portion of the area heavily fished by bait fisherman. Proportional decreases in predatory fishes can be expected. Deepening the harbor channels may slightly offset the negative effects of landfill, but bait fishing in busy shipping channels may be impossible. Substantially increased fishing effort and operating costs can be expected by the bait fisherman.

8. Any substantial increase in tidal currents in the new harbor can be expected to have detrimental effects on bait-fish operations.

9. These effects will be strictly local, and will not affect fish abundance or availability in adjacent regions.

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MARINE STUDIES OF SAN PEDRO BAY, CALIFORNIA. Part 8. June, 1975

A MODIFICATION OF B.O.D. METHOD FOR USE IN THE MARINE ENVIRONMENT

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ABSTRACT. A method is proposed for modifying the "standard method" (APHA, 1971) for determining the biochemical oxygen demand (BOD) of non-marine waters. This modification was derived to more accurately assess the organic load in marine waters. The study included the use of distilled, sea, and seeded seawater as the diluent in a series of BOD tests. The seed was composed of organisms isolated from representative areas of the Los Angeles and Long Beach Harbors. Data from five-day BOD curves, run with samples from two environmentally different stations, and data compiled from monitoring studies during the past year from 43 stations in the area, were analyzed. With few exceptions significantly higher BOD values were obtained using the method with a standardized seed. The exceptions were in those instances where conditions, known to exist at a particular station, caused the seed culture to be ineffective.

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A MODIFICATION OF B.O.D. METHOD FOR USE IN THE MARINE ENVIRONMENT

INTRODUCTION. Determination of dissolved oxygen (DO) and biochemical oxygen demand (BOD) are significant factors in areas where water quality is being monitored. The amount of oxygen present reflects the balance between the production of oxygen by photosynthesis and its consumption by respiration and other chemical reactions. In the areas under investigation in Los Angeles and Long Beach Harbors there are varying types and amounts of effluents being introduced into the receiving waters. In addition, the level and occurrence of Red Tide changes conditions, both by oxygenating the water during growth and by increasing the organic load when a bloom dies off. The increased activity accelerates eutrophication, changes the rate of oxygen consumption, and significantly effects the food web.

Acknowledging the limitations inherent in BOD methods(Stack, 1972), it is still a practical method of monitoring the quality of seawater. Therefore, a modification which allows a more accurate estimation is of particular importance to those who are concerned with the operation and future planning for industrial as well as recreational uses of these waters. When BOD determinations were first begun for this study, aerated seawater was used as the diluent, on the advice of The Terminal Testing Laboratory of Los Angeles (personal communications). A literature search has produced papers which mention the use of seawater as the diluent. However, it was not used in BOD tests monitoring pollution. In one instance it was used in studying the biodegradation of petrochemicals, and the incubation period was 20 days (Price, et al., 1974). In another instance, (Kuftarkova, 1972), seawater was used as diluent, but the paper was concerned with a study of the efficacy of different sized vessels for running BOD tests with an incubation period of 85 days.

One of the most significant contributions resulting from our study of the microbiology of Harbor waters during the past year is the data compiled from 43 stations which support the modification proposed for running BOD determinations. This method will more accurately determine the organic load in marine water than application of the method recommended for non-marine waters (A.P.H.A.,1971). The modification involves the use of seeded seawater as the diluent. The seed was composed of organisms isolated from representative areas of the Los Angeles and Long Beach Harbors.

The results of monitoring studies done with a seawater diluent were evaluated by comparison with results obtained in a similar study (carried out by another segment of the Harbor Project) which used distilled water as a diluent according to "Standard Methods". Values obtained at comparable stations were always higher with seawater as the diluent, and usually ten times higher with seeded seawater as the diluent. The validity of the results were checked further by running 5-day curves on samples obtained from stations D-2 and D-8. Both stations are located to the east of Long Beach Harbor (Figure 1). Station D-2 is situated near the mouth of the Los Angeles river and therefore has a mixture of fresh and sea water present. Station D-8 is located out from shore and is considered to be relatively clean water.

METHODS AND MATERIALS. Curves obtained for each station included an undiluted sample, a 50-ml, and a 100-ml sample diluted with seawater; a 50-ml and a 100-ml sample diluted with seeded seawater; and a 50-ml and a 100-ml sample diluted with distilled water. In addition, a curve was obtained from controls of each type of dilution water.

Sampling Procedure. Sample water at each station was collected in a bucket that had been rinsed twice with seawater before filling. Individual 300-ml, BOD bottles were filled by introducing a piece of tubing to the bottom of the inverted bottle which was carefully submerged under the water. As the water entered the bottle, air escaped through the tube until each bottle was filled. The tube was removed and the bottle was stoppered before removing from the water. A water seal was put around the stopper of each bottle and the samples were transported to the laboratory in a chilled ice chest. One sample bottle at each station was fixed immediately and sealed for the initial dissolved oxygen (DO) determination.

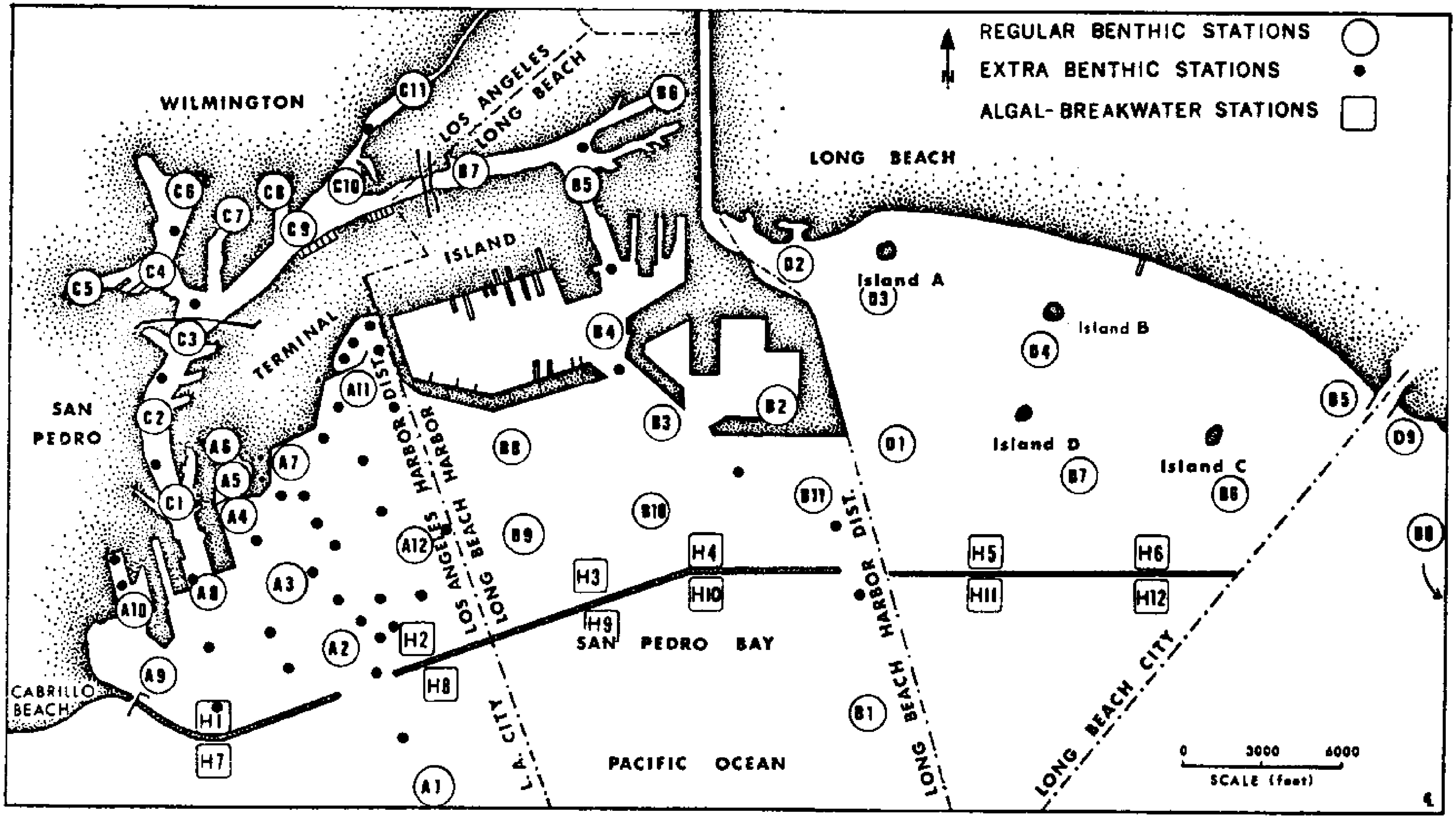
Preparation of Dilution Water. Seawater was collected from station A-1 (Figure 1) which is located outside the breakwater in Los Angeles Harbor, and aerated 24 hours before use. This water has been monitored for standard plate count and BOD levels since July, 1972. Both standard plate counts and BOD levels are relatively low and constant. Before use, 1 ml each of phosphate buffer, magnesium sulfate, calcium chloride, and ferric chloride solutions were added per liter of seawater (A.P.H.A., 1971).

The distilled dilution water was prepared according to "Standard Methods".

Preparation of Seed. The seed was derived from ten cultures of organisms isolated from environmentally different areas of the Los Angeles and Long Beach Harbors. Individual cultures were inoculated into marine broth (Juge, 1971) and incubated for 48 hours. Cultures were spun down and the broth removed. The pellets were taken up in seawater, combined, and washed before resuspension in seawater. The mixed suspension was adjusted to contain from 7.9×10^{9} to 1.05×10^{10} organisms per milliliter. One tenth ml of this suspension was added per liter of dilution water.

ALLAN HANCOCK FOUNDATION MONITORING

STATIONS IN LOS ANGELES-LONG BEACH HARBORS



Test Procedure. Required amounts of carefully mixed sample were measured, using a volumetric pipet, directly into clean BOD bottles that were partially filled with dilution water. The bottles of the mixture were then filled with the corresponding dilution water. Water seals were placed around the stopper and the bottles were incubated at 20°C. Sample bottles were removed at 24 hour intervals, fixed, and titrated by the method described in "Standard Methods" to determine their DO.

RESULTS AND DISCUSSION. Five-day curves were repeated at Stations D-2 and D-8 (Figure 1) on three different occasions; October, January, and March. With samples from both stations, BOD values at day five were as much as 100% higher when the diluent was seawater rather than distilled. The DO values of samples run in October from Station D-8, diluted with distilled water, remained at the same levels as the initial DO value for the diluted sample; this showed that no oxygen depletion occurred in the five day period of incubation. On the other hand, from Station D-2 in October, samples mixed with distilled water showed a limited oxygen depletion. This and the discrepancy which can be observed in Figure 2 is explained by the fact that Station D-2 is located near the mouth of the Los Angeles river. Therefore, one would expect to find some fresh water organisms at this site. Results obtained in three studies were essentially the same. Those obtained in March, the latest study, are representative and are shown in Figures 2 and 3.

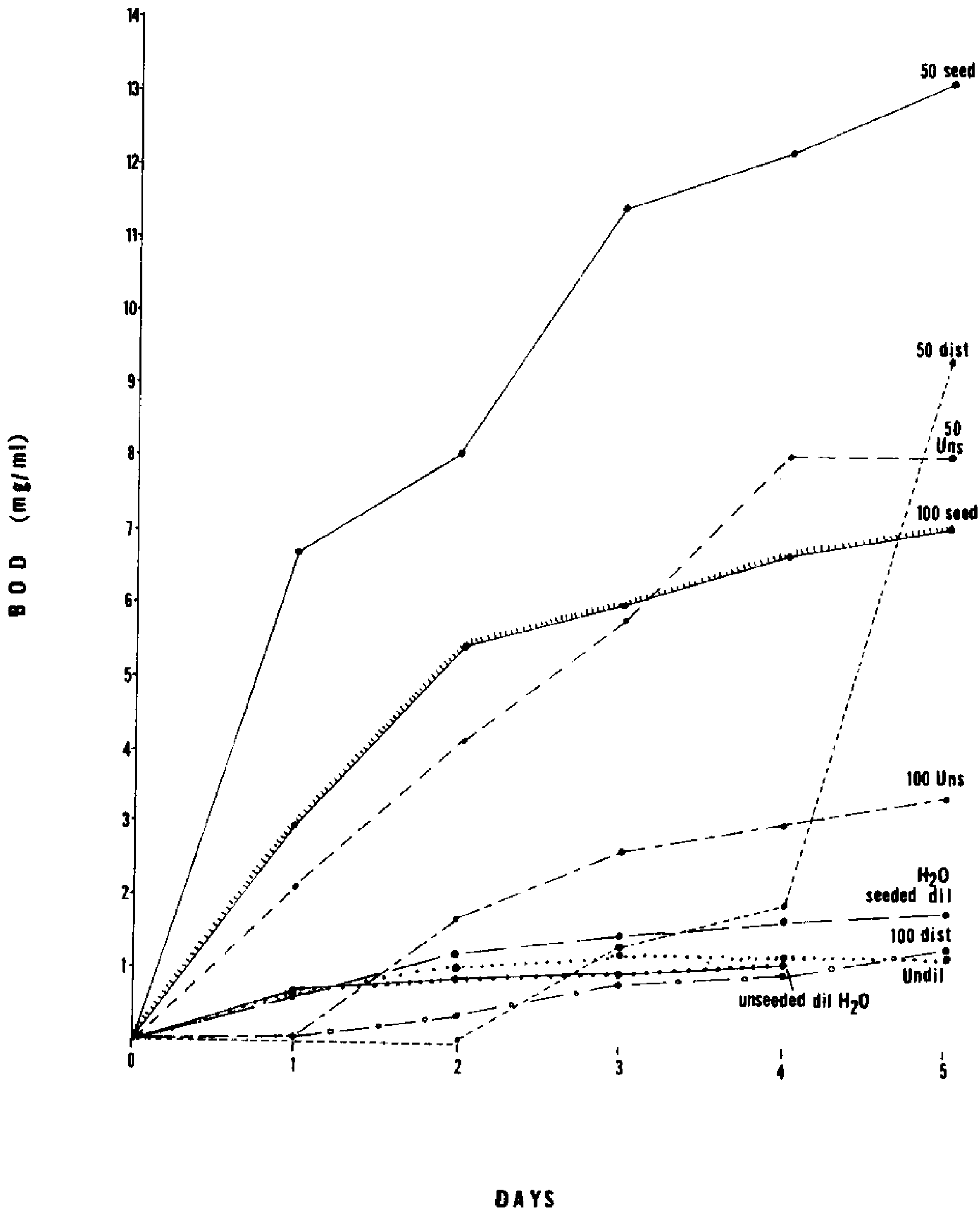
All BOD values using 50-ml samples gave higher values than those of the 100-ml of undiluted samples. In this, and in the monthly monitoring studies in which appropriate dilutions were used, higher dilutions seem to be needed to decrease a depressing effect evident in lower and undiluted samples.

In samples from Station D-2(Figure 2) the undiluted sample gave very low BOD values (0.0 - 1.35 mg/liter). BOD values of 100-ml samples diluted with distilled water also remained very low (3.8 mg/liter). The 50-ml sample diluted with distilled water remained essentially at zero for 48 hours. The the populations gradually began to acclimate or increase to a sufficient level so that between the fourth and fifth day the oxygen depletion increased rapidly; the slope of the curve suggests that a longer incubation period would give a more representative BOD value. As mentioned previously, this seems to be compatible with the location of this station. The fact that this effect was more extensive than in previous experiments most probably resulted from the fact that the samples were taken after a period of rain. The unseeded seawater sample utilized the organic material more rapidly, and gave high results (except for day five results with the 50-ml distilled water sample). According to the results obtained at this station, the seeded seawater BOD samples were as much as 100% higher than that obtained with unseeded, distilled or undiluted samples.

Data obtained for Station D-8 (Figure 3) also show that there

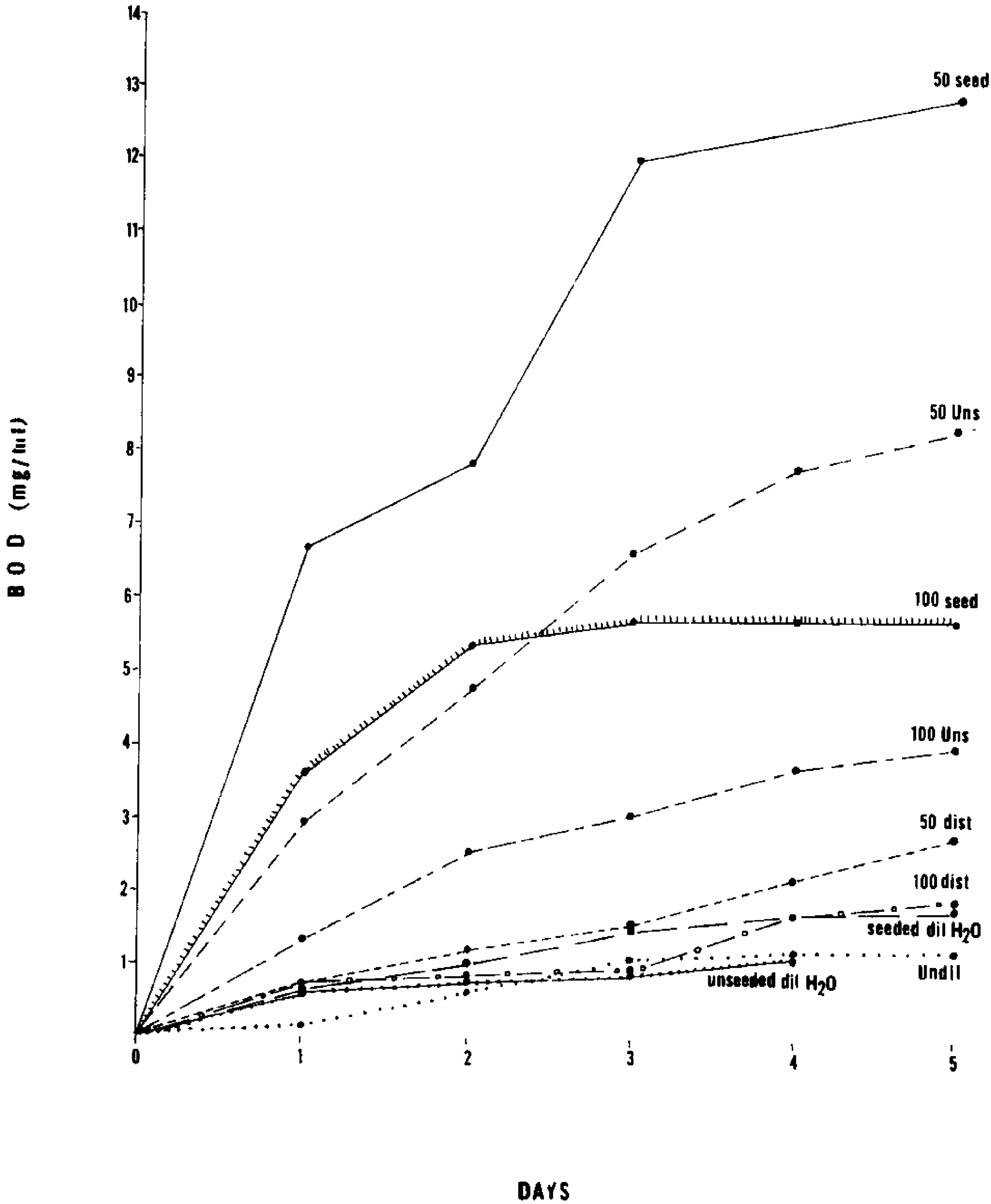
March 1975

Figure 2
Station D 2



March 1975

Figure 3
Station D 8



is some depressing effect in undiluted samples. They also reflect the fact that the organisms present at this station are predominantly marine. This is demonstrated by the fact that oxygen depletion was more rapid in all samples diluted with seawater. Samples diluted with distilled water did not exhibit a significant depletion in any of the curves from five day BOD experiments. Again the 50-ml sample diluted with seeded seawater gave the highest BOD consistently through the five day period.

At the beginning of this investigation the premise was that seawater was more adequate for determining BOD's in the marine environment than distilled water, but the results obtained were frequently nil for areas that obviously contained organic material. Population counts suggested that the organisms present were not always sufficient to utilize the organic load. Therefore, in order to take advantage of the population present, fresh seawater with a low organic content was used as the diluent. This gave better results; however, as the area of investigation increased (Figure 1) discrepancies were observed in the results. In some instances, these could be attributed to an inadequate population in the diluted mixture, resulting from having increased the dilution ratio. The ratio of increase was necessary because of the high organic load resulting from phytoplankton die-off that was present due to Red Tide. Even with the population in the dilution water, results were still too low, so isolations were begun to develop a seed from the environment. Once the seed was developed, a more stable system could be attained by using aged seawater with an appropriate seed.

With few exceptions, significantly higher BOD values were obtained using a method with a standardized seed. The exceptions are in those instances where environmental conditions existing at a particular station cause the seed culture to be ineffective. This can be eliminated by isolating organisms from the station in question for a seed culture. The most effective dilution will vary with the condition of the water (organic load) at the site being tested.

Having standardized the method it is now recommended that aged seawater, with an appropriate, cultured seed, be used for polluted marine water so that the method may be evaluated.

TABLE 1 - Station D2

BOD Values

SAMPLE	DAY 0	1	2	3	4	5
Undiluted	0.0	0.55	0.95	1.25	1.25	1.25
Seeded-50ml	0.0	6.6	8.1	11.4	12.3	13.2
Seeded-100ml	0.0	2.85	5.4	6.0	6.6	6.9
Unseeded-50ml	0.0	2.1	4.2	5.7	8.1	8.1
Unseeded-100ml	0.0	0.15	1.65	2.55	2.85	3.45
Distilled -50ml	0.0	0.0	0.0	1.32	1.92	9.42
Distilled -100ml	0.0	0.0	0.3	0.75	0.9	1.35
Seeded Dilution water	0.0	0.5	1.2	1.5	1.7	1.8
Unseeded Dilution water	0.0	0.55	0.75	0.9	1.15	--

TABLE 2 - Station D8

BOD Values

SAMPLE	DAY 0	1	2	3	4	5
Undiluted	0.0	0.1	0.5	1.1	1.2	1.2
Seeded-50ml	0.0	6.6	7.8	12.3	12.0	12.9
Seeded-100ml	0.0	3.6	5.4	5.7	5.7	5.7
Unseeded-50ml	0.0	2.94	4.74	6.54	7.74	8.34
Unseeded-100ml	0.0	1.3	2.49	3.09	3.69	3.99
Distilled -50ml	0.0	0.65	1.25	1.548	2.15	2.75
Distilled -100ml	0.0	0.65	0.81	0.96	1.71	1.86
Seeded Dilution water	0.0	0.5	1.2	1.5	1.7	1.8
Unseeded Dilution water	0.0	0.55	0.75	0.9	1.15	--

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MARINE STUDIES OF SAN PEDRO BAY, CALIFORNIA. PART 8. June, 1975

SEASONAL OCCURRENCE AND DISTRIBUTION OF BENTHIC AND FOULING SPECIES OF POLYCHAETES IN LONG BEACH NAVAL STATION AND SHIPYARD, CALIFORNIA

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ABSTRACT. A twelve-month, seven-station, 131-sample survey was conducted in the Long Beach Naval Station and Shipyard, Long Beach, California. The established study sites were analyzed biologically (fouling and benthic polychaete distribution), chemically (dissolved oxygen, chlorinity, nitrites and nitrates) and physically (temperature). Fouling samples were taken by scraping floating pier logs and camels. Benthic biological samples were taken with a Hayward orange-peel bucket. Chemical and physical analyses of the surface water were conducted. The data on seasonal variation indicate that the polychaete populations are most abundant during the summer months with a lower number recorded during the winter period. Chemical data showed little correlation with the population distribution.

ACKNOWLEDGMENT. We would like to extend our gratitude to the United States Navy, Long Beach Naval Station and Shipyard Service Section for providing a boat and crew to conduct the twelve surveys.

I. INTRODUCTION

Benthic quantitative surveys in southern California marine waters were initiated in the early 1950's by the Allan Hancock Foundation. Hartman (1955) found a rich and diverse fauna in the area between the mainland and Santa Catalina Island. These studies were expanded to include much of the mainland shelf area of southern California (Calif. State Water Quality Control Board, 1965; Jones, 1969) and to canyons and basins (Hartman, 1963a,b; Hartman and Barnard, 1958, 1960). Concurrent with the offshore studies were the benthic studies in protected waters including Los Angeles-Long Beach Harbors (Anon, 1952b; Reish, 1955, 1959a, 1971b; Smith, 1973), Alamitos Bay (Reish, 1961, 1963), San Gabriel River (Reish, 1956; Turner and Strachan, 1969), Anaheim Bay (Reish and Kauwling, 1971), Newport Bay (Barnard and Reish, 1959), and San Diego Bay (Anon, 1952a).

Studies dealing with fouling organisms have been primarily concerned with the settlement of organisms on test panels. The earlier work of the eastern Pacific Ocean was summarized by Reish (1961). Recent studies have emphasized the relationship of settling organisms to degrees of pollution (Reish, 1971a). The distribution of polychaetes present within the fouling community on boat docks was correlated to the degree of pollution in Los Angeles Harbor (Crippen and Reish, 1969).

In all three of these types of studies, a relationship between the polychaete species composition and the degree of pollution was found to exist. It was, therefore, possible to assess the degree of pollution based on the species composition present at a particular locality. In the benthos the healthy bottom was characterized by *Tharyx parvus*, *Cossura candida*, and *Nereis procera*. The semi-healthy bottom had either *Polydora paucibranchiata* and *Stauronereis rudolphi* or *Cirriformia luxuriosa* present. The polluted bottom was defined by the presence of *Capitella capitata*. The very polluted bottom lacked macroscopic animal life (Reish, 1959a). Polychaete diversity on test panels was greater in the unpolluted areas of Los Angeles--Long Beach Harbors. *Capitella capitata* was generally the only species present on boat docks. Each station was characterized by a unique species of polychaete (Crippen and Reish, 1969).

The environment of the Los Angeles-Long Beach Harbors is a constantly changing one largely the result of man's activities. These changes are primarily the result of new construction and changes in the waste disposal patterns in the harbors. Recently a pollution abatement program was initiated which has resulted in the appearance of benthic and fouling organisms previously unknown from the inner harbor area (Reish, 1971b). A possible major change in the harbor area is proposed termination of

U.S. Naval operations in Long Beach Harbor (Figure 1). During this study there were basically three sources of discharge into the naval facility waters: (1) storm drains (Figure 1), (2) waste water of various types from naval ships, and (3) petroleum products. Since this area had not been studied previously and because of the possible cessation of naval activity, the purpose of this study was two-fold: (1) to record the biological, chemical, and physical characteristics of the naval station prior to cessation of operations and (2) to correlate benthic and fouling species composition at the same station over a period of one year.

II. MATERIALS AND METHODS

Twelve surveys of the Long Beach Naval Station and Shipyard were made at seven stations for biological, chemical, and physical characteristics during the period from September 1970 through September 1971. Sampling included the polychaetes, nitrates, nitrites, salinity, dissolved oxygen and temperature. Dates of sampling are given in Table 1.

Station Descriptions (Figure 1)

Station 1 was located at the end of pier 19. This area is frequently occupied by destroyers which agitated the benthos. The mean depth of water was 15 m. Station 2 was located at the end of pier 14 which was infrequently visited by naval vessels. The mean depth of water was 15 m. Station 3 was located at the sailing facility mooring pier "A." The vessel activity of this vicinity was one of frequent movement of small sailing and power boats. The mean depth of water was 10 m. Station 4 was located at the end of pier 8. This was in an area with heavy traffic of tugboats. The mean depth of water was approximately 8 m. Station 5 was located at the end of pier 6. An adjacent dry dock had an agitating influence upon the benthos. The mean depth of water was 15 m. Station 6 was located at the end of pier 1. This station was frequently visited by aircraft carriers. The mean depth of water was 15 m. Station 7 was located at a permanently anchored buoy approximately 450 m southwest of the mole terminus. This station was established in order to compare the findings within the naval area to the outer harbor. Only benthic samples were taken because of the lack of docks.

Biological Techniques

Benthic samples were taken with a size 1 Hayward orange-peel bucket (Reish, 1959b). The contents were emptied into a bucket and the nature of the substrate noted. The sample was placed in gallon jars containing 10% formalin. Fouling species

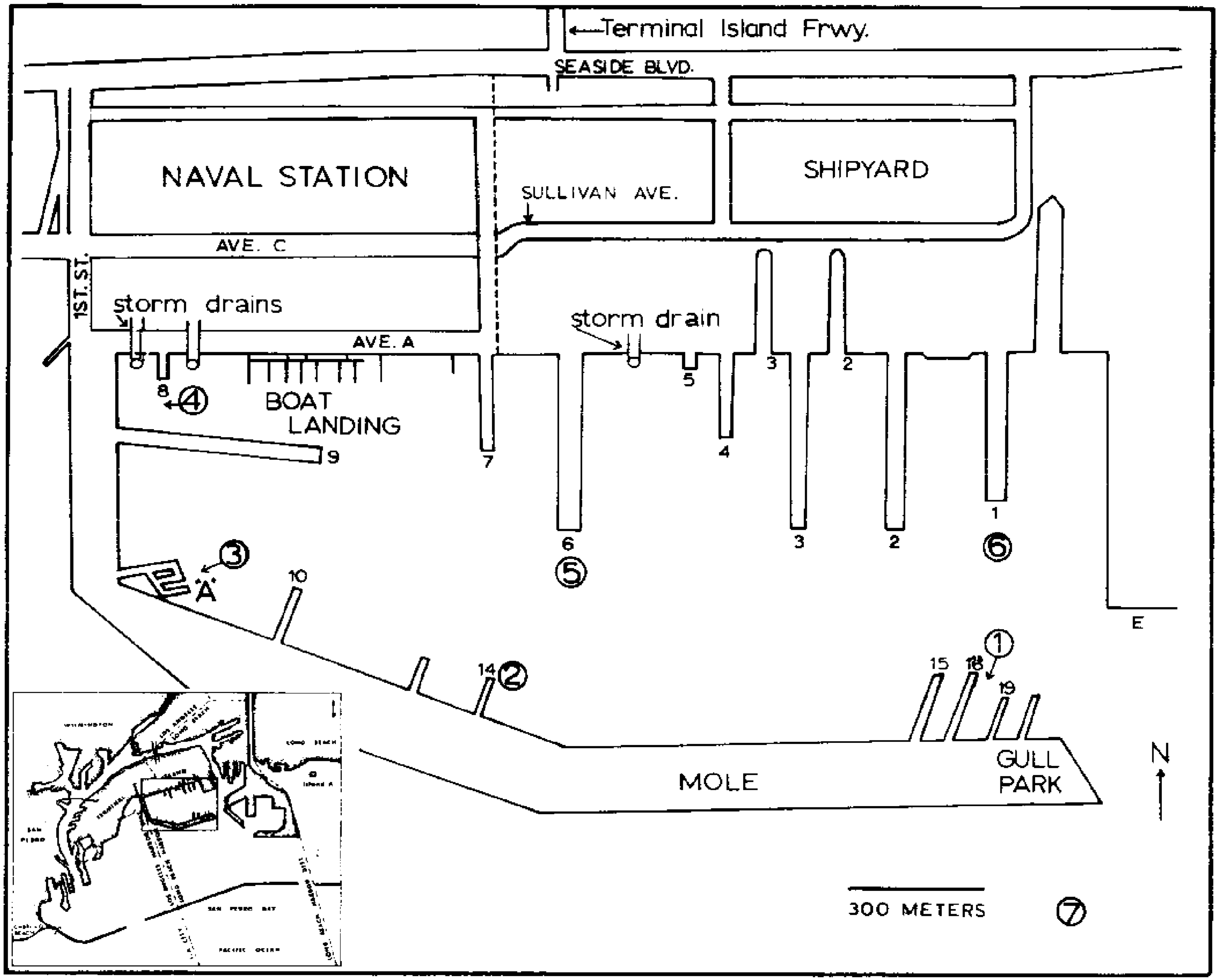

FIGURE 1

Long Beach Naval Station and Shipyard (Regional Insert Map in Lower Left Corner). The Study Sites are Circled Numbers.

of polychaetes were taken by scraping a 15 cm^2 area of a floating pier log (Figure 2), then placed in gallon jars and preserved with 10% formalin. In the laboratory the samples were washed through a 0.246 mm mesh screen and preserved in 70% ethanol. If the washed sample exceeded an area of 1256 cm^2, a one-quarter aliquot was taken. Identification of polychaetes was according to Hartman (1968, 1969).

Chemical and Physical Techniques

Each sea water sample was collected from the top 10 cm in a 500 ml plastic bottle, chilled in an ice bath, and brought to the laboratory within 4 to 6 hours. Nitrates and nitrites were analyzed according to the technique in Strickland and Parsons (1969). Dissolved oxygen was determined by the Winkler Method (American Public Health Association et al., 1965) and chlorinity was measured by the Mohr Method (Barnes, 1959). Temperatures were measured 5 cm below the surface, out of direct sunlight, to the nearest 0.5 C.

III. RESULTS AND DISCUSSION

The data compiled in this study include polychaete species and specimen counts (monthly, annual and total) for benthic and fouling communities. Complimenting these data, mean surface temperature, dissolved oxygen, chlorinity, nitrite and nitrate values were recorded annually and monthly for the seven stations sampled.

Chemical and Physical Characteristics

Temperature. If a correlation is drawn between monthly polychaete distribution (Table 1) and monthly mean temperatures (Table 2), it is seen that during the higher temperature months, September 1970, June, July, August and September, 1971, the monthly total of benthic species seems to be higher. Also, the August 1971 benthic specimen count was the highest of the twelve month survey.

With the exception of the December 1970 species count, the monthly fouling species and specimen counts (Table 1) were highest during the highest temperature months. Therefore, temperature seems to be an important factor in the distribution and diversity of marine polychaetes with increased numbers of species and specimens being associated with higher temperatures. Previous investigators, such as Reish (1961, 1971b) found this to be true while using sediment bottles and test panels as a means of collecting animals in Los Angeles Harbor.

FIGURE 2

Floating Pier Log with the 15 cm^2 Biological Scraping Outlined

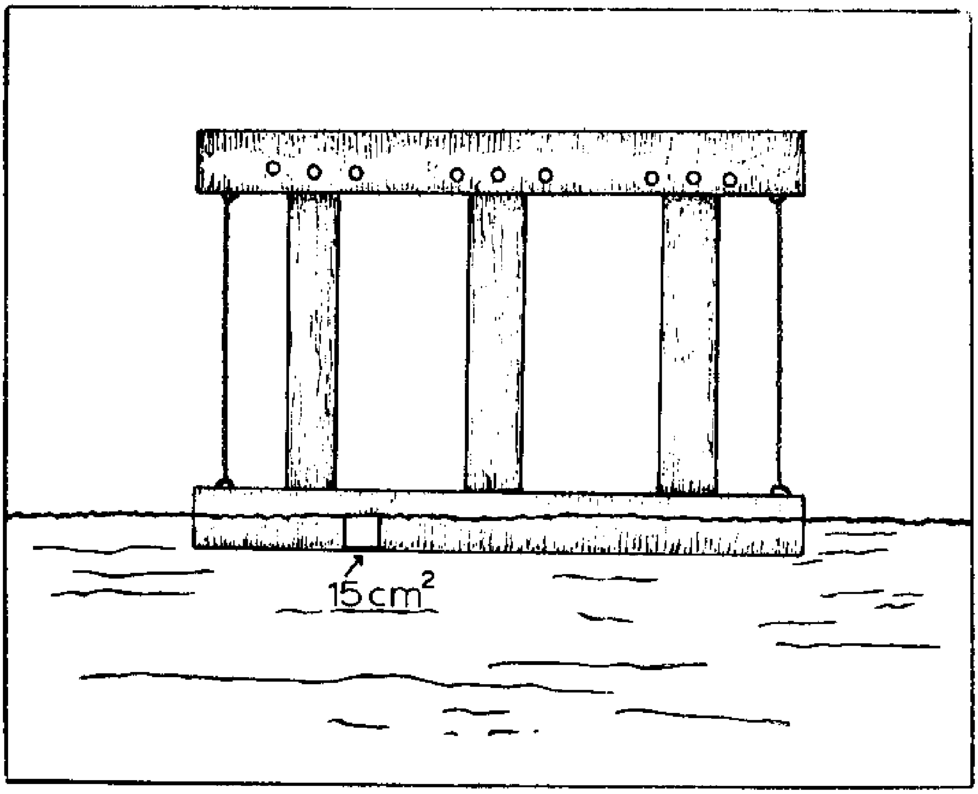

Table 1

Monthly Occurrence of Benthic and Fouling Polychaetous Annelids in the Long Beach Naval Station and Shipyard

Date	Benthic		Fouling	
	No. of Species	No. of Specimens	No. of Species	No. of Specimens
September 1970	24	431	13	206
October 1970	-	-	16	242
December 1970	17	662	22	1343
January 1971	17	1161	21	759
February 1971	14	846	19	778
March 1971	18	912	21	1920
April 1971	22	1896	21	2510
May 1971	22	1990	19	3511
June 1971	18	1436	22	3334
July 1971	24	510	22	5132
August 1971	23	3300	21	3624
September 1971	24	495	17	2784

TABLE 2. **Monthly Mean Values for All Monitored Parameters**

	9/70	10/70	12/70	1/71	2/71	3/71	4/71	5/71	6/71	7/71	8/71	9/71
Temperature (°C)	18.1	15.7	15.8	13.6	14.2	13.6	13.7	16.4	19.6	23.2	27.4	19.1
Chlorinity (0/00)	17.5	18.0	17.9	18.4	18.6	17.4	18.8	18.2	15.4	18.4	18.3	18.3
Dissolved Oxygen (mg/1)	10.0	5.6	5.0	7.8	7.4	7.8	9.9	9.5	7.4	8.2	7.9	9.9
Nitrite (NO_3) (μg-at/1)	0.51	0.55	0.59	0.79	0.37	0.29	0.27	0.09	0.30	0.23	0.30	0.39
Nitrate (NO_2) (μg-at/1)	12.1	8.9	11.4	4.2	4.9	7.4	6.0	2.7	5.3	4.6	5.8	10.5

TABLE 3. **Annual Station Mean Values for Chemical and Physical Monitored Parameters**

	Station Number						
	1	2	3	4	5	6	7
Temperature (°C)	17.0	17.0	17.3	17.3	17.2	17.3	16.8
Chlorinity (0/00)	17.8	18.2	17.7	17.7	18.2	18.3	17.4
Dissolved Oxygen (mg/1)	8.0	8.0	7.8	7.5	7.4	7.8	9.3
Nitrite (NO_3) (μg-at/1)	0.51	0.38	0.34	0.37	0.47	0.43	0.12
Nitrate (NO_2) (μg-at/1)	10.4	6.8	7.3	6.8	6.5	6.1	3.0

Chlorinity. The monthly mean chlorinity values (Table 2), with the exception of June, were rather constant throughout the year. If a correlation is drawn between the number of species and specimens (Table 1) and chlorinity values there seems to be no obvious relationship.

The mean chlorinity values are generally below the offshore waters chlorinity values, 18.4-18.9 °/₀₀ as reported by Reish (1970). Natural run-off of the storm drains (Figure 1) may have contributed to these lower mean values.

Dissolved Oxygen. Dissolved oxygen (D.O.) is one of the most critical parameters in determining population distribution of polychaetes (Crippen and Reish, 1969). Previous studies in Los Angeles Harbor have shown that polychaete distribution was reduced when the dissolved oxygen was below 7 mg/l and totally eliminated below 1 mg/l (Crippen and Reish, 1969). Offshore surface waters range from 7.7 to 8.5 mg/l. Alamitos Bay, California has 6.5 mg/l of D.O. and Orange County outfall sewers measure 5.9 mg/l of D.O. (Reish, 1970).

The annual mean dissolved oxygen values of this study suggest an area of chemical reduction in the vicinity of stations 4 and 5 (Table 3). These stations are among the innermost stations and contain a lower number of species and specimens in both benthic and fouling studies as compared to fouling stations 6 and 1 and benthic stations 7 and 1 (Table 5). The range values for stations 4 and 5, 4.5-10.55 mg/l, were greater than the offshore values previously mentioned (Reish, 1970).

The annual station mean dissolved oxygen readings are generally lower within the Naval complex as stations 3 and 4 are approached (Table 3). The total species and specimen counts for both benthic and fouling, follow a similar pattern of lower counts as the interior of the Naval complex is approached (Table 4).

The monthly species and specimen counts (Table 1) follow a general pattern of higher counts during the summer months and lower during the winter months. The monthly mean dissolved oxygen (Table 2) demonstrates no obvious seasonal trends. Therefore, no conclusion can be drawn on a monthly basis.

Nutrients. Nitrate and nitrite values were parallel to each other, so they will be discussed as a single parameter. Generally, the monthly mean nutrient values are lower during January through August (Table 2). The periods of highest monthly total species and specimens (Table 1) seems to occur during this same time span. Therefore, there may exist an inverse relationship between the available nutrients and the polychaete population, although previous studies have conflicting interpretation of the relationship between nitrates and polychaetes.

In one study in Los Angeles Harbor, dealing with large quantities of industrial waste, Crippen and Reish (1969) observed that low nutrient values were recorded in areas with low species and specimen counts. In a later study of Alamitos Bay, California, Reish (1970) recorded low nitrate values of 2.4 µg-at/l and Orange County outfall sewer of 4.0 µg-at/l with a considerably higher number of species and specimens.

The nutrient characteristics of the oceans are discussed in Horne (1969) and Sverdrip, et al (1942). Horne describes the production of nitrite and nitrate as being directly dependent upon the oxidizing and fixing ability of bacteria. The utilization of nitrogenous material is related to marine algae. Therefore, since the quantity of nutrients is not directly related to the polychaete population, it is difficult to draw a strong correlation between monthly mean nutrient values and monthly total species and specimen counts (Tables 1 and 2).

Biological Characteristics

This study is unique in that benthic and fouling polychaete surveys were conducted simultaneously. For convenience, both benthic and fouling polychaete populations can be discussed together. All polychaetes identified in this study are listed in Table 6. There were 32 species unique to station 7 of which the dominants were *Tharyx parvus*, *Cossura candida* and *Haploscoloplos elongatus* (Table 5). A species is considered dominant if it comprises in excess of 11 percent of the total specimen count (Kauwling, 1972). It is therefore possible to have more than one dominant at any one station.

Two previous studies were conducted in the Los Angeles-Long Beach harbor complex that emphasized the distribution of benthic (Reish, 1959a) and the fouling (Crippen and Reish, 1969) populations. The fouling survey demonstrated that each station was characterized by one unique species. It also concluded that the number of species decreased as the degree of pollution was increased. This study draws similar conclusions in that the number of species and specimens decreases with decreased D.O. concentration which may be taken as an indicator of increased pollution (Tables 1 and 2). A more recent study (Abbott, et al., 1973), found that settling rack organisms are indicators of short term stress whereas the benthic populations are indicators of long term stress. The character of the benthic and fouling communities in the present study, would therefore seem to indicate long term stress conditions.

In the benthic community, both the number of species and

Table 4

Annual Station Mean Values for Polychaetous Annelids in the

Long Beach Naval Station and Shipyard

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7
Number of Species	34	38	25	31	24	27	43
Number of Specimens	10,225	3,883	1,640	6,032	3,869	9,589	14,725*

*Adjusted total to compensate for a fewer number of samples taken at this station (5 vice 6)

Table 5

Summary of Biological Data for Dominant Species of Benthic and Fouling Polychaetous Annelids

	Station Numbers						
	1	2	3	4	5	6	7
Benthic:							
Number of Species	25	18	16	22	13	15	43
Number of Specimens	4,155	589	240	2,071	595	1,177	5,890
Dominant Species							
Stauroneris rudolphi	863	206	59		248	690	
Haploscoloplos elongatus							365
Polydora ligni				328			
Tharyx parvus		106					1,384
Cossura candida							1,134
Capitella capitata			48	878	115	373	
Capitita ambiseta	1,436	92		207			
Armandia bioculata	926		38				
Fouling:							*
Number of Species	22	20	17	20	18	23	
Number of Specimens	5,955	3,238	1,377	3,599	3,221	8,412	
Dominant Species							
Typosyllis fasciata	2,107					753	
Boccardia proboscidea			190	2,191	630	3,685	
Polydora ligni	626	476	178				
Chaetozone corona		642					
C. multioculata		904					
Cirriformia spirabrancha					752		
Ctenodrilus serratus	1,512		397	154	606	1,390	
Capitella capitata				733			
Total Number of Benthic and Fouling Species	35	38	25	31	24	27	43

* No fouling samples taken

specimens were reduced as the inner stations were approached (Table 5). A similar result was observed in the study of Reish (1959a).

When parallels are drawn between Reish's (1959a) pollution zone indicators and species found within the benthos of this study, two patterns emerge. Station 7 is characterized by two of the healthy bottom species, Tharyx parvus and Cossura candida. Secondly, at the innermost station 4 there was a dominance of Capitella capitata within the benthos and fouling communities. This station could thus be identified as polluted.

Station 5 could be identified as semi-healthy bottom I due to the dominance of Stauronereis rudolphi. This community structure is also seen in the benthos of stations 3 and 6 (Table 5). Station 2 benthos demonstrates an overlap of pollution zones where Stauronereis rudolphi and Tharyx parvus occur as dominating the benthos.

The attempt to categorize these pollution zone indicators seems to develop "gray" areas of definition. The lack of definition may stem from the close proximity of the stations, but generally it is seen that station 4 is polluted and station 7 is healthy.

The presence and dominance of the cosmopolitan organism Capitella capitata has been previously reported in areas of pollution (Reish, 1955, 1957b, 1959a, 1971a, 1971b; Crippen and Reish, 1969; McNulty, 1970; Cognetti, 1972). Filice (1954a, 1954b, 1959) reported the presence of C. capitata in polluted areas of San Francisco Bay. Therefore, the presence of C. capitata within this study area suggests a polluted condition within the inner areas of the Naval complex. Another important factor outlined by Filice (1959) was the type of substrate at the station. The sulphide-odor and silty black sediment, at stations 4 to 6, chemically inhibits the development of a healthy community. Similar substrate characteristics were recorded in the Los Angeles Harbor studies by Reish (1959a).

The data on seasonal variation indicate that the polychaete populations are most abundant during the summer months with a lower number recorded during the winter period (Table 1). The distribution pattern is concluded to be based on temperature as seen in similar studies of Reish (1961, 1971b) and Kinne (1963). The seasonal variation of polychaetes in this study seems to be unaffected by the chemical parameters of chlorinity and nutrients, with a slight influence due to dissolved oxygen conditions.

Species analysis revealed a decline of benthos at stations 5 and 6 as compared to station 7 located outside the Naval complex (Table 5). The number of species within the fouling community seems to parallel the benthic population, reaching the lowest number at stations 2 through 6. Similar parallels are seen in an Outer Los Angeles Harbor study by Smith (1973). Smith's study concluded that there are species groups correlated with the distance from the effluent sources.

Therefore, the entire polychaete community demonstrated a general reduction in numbers of species and specimens within the inner portion of the Naval complex and a gradual enhancement as the outer harbor is approached.

V. SUMMARY

1. From September 1970 through September 1971, a twelve-month, seven-station, 131-sample survey of biological, chemical and physical parameters was conducted in the Long Beach Naval Station and Shipyard, California.

2. There were 78 species collected at the study sites and more than 39,000 specimens of polychaetes examined from both the fouling and benthic communities. The data demonstrated an area of pollution occurring at the innermost stations of the Naval complex. Capitella capitata expressed increasing dominance as the innermost stations were approached. The innermost station 4 was identified as polluted and the outermost station was designated as healthy. The stations located between these extremes demonstrated an overlap between other polychaete zones, i.e., semi-healthy I and semi-healthy II.

3. The surface water was examined for nitrates, nitrites and dissolved oxygen. The concentrations of nitrates and nitrites were lowest at the innermost stations and at the control station 7. Dissolved oxygen demonstrated a slight depression at the innermost stations.

4. The surface water was also examined for chlorinity and temperature. No correlation seemed to exist between the chlorinity measurements and the polychaete distribution, but during higher temperature months increased numbers of polychaete specimens and species were observed.

TABLE 6. Systematic List of Polychaetous Annelids Found in the Long Beach Naval Station & Shipyard

Family Polynoidae

- *Halosydna johnsoni* (Darboux, 1899)
- *Harmothoe hirsuta* Johnson, 1897
- *Lepidonotus squamatus* (Linnaeus, 1767)
- Polynoid, fragment
- Polynoid, juvenile

Family Sigalionidae

- *Sthenelanella uniformis* Moore, 1910

Family Chrysopelalidae

- *Paleonotus bellis* (Johnson, 1897)

Family Phyllodocidae

- *Anaitides williamsi* Hartman, 1936
- *Eteone dilatae* Hartman, 1936
- *Eulalia quadrioculata* Moore, 1906
- *Eulalia viridis* (Linnaeus, 1767)
- *Eulalia* sp.
- *Eumida sanguinea* (Oersted, 1843)
- Phyllodocid, juvenile

Family Hesionidae

- *Ophiodromus pugettensis* (Johnson, 1901)

Family Pilargidae

- *Sigambra bassi* (Hartman, 1945)
- *Sigambra tentaculata* (Treadwell, 1941)

Family Syllidae

- *Autolytus* sp.
- *Autolytus prismaticus* (Fabricius, ?)
- *Exogone* sp.
- *Odontosyllis parva* Berkeley, 1923
- *Syllis gracilis* Grube, 1840
- *Typosyllis fasciata* (Malmgren, 1867)
- *Typosyllis hyalina* (Grube, 1863)
- Syllid, juvenile

Family Nereidae

- *Nereis pelagica neonigripes* Hartman, 1936
- *Nereis procera* Ehlers, 1868
- *Platynereis bicanaliculata* (Baird, 1863)
- Nereid, fragment
- Nereid, juvenile

Family Nephtyidae

- *Nephtys cornuta franciscana* Clark and Jones, 1955

Family Glyceridae

- *Glycera americana* Leidy, 1855
- *Glycera convoluta* Keferstein, 1862
- *Glycera* sp.

Family Onuphidae

- *Diopatra ornata* Moore, 1911
- *Diopatra splendidissima* Kinberg, 1865
- *Nothria iridescens* (Johnson, 1901)

Family Eunicidae

- *Marphysa disjuncta* Hartman, 1961
- *Marphysa* sp.

Family Lumbrineridae

- *Lumbrineris* sp.

Family Arabellidae

- *Drilonereis falcata* Moore, 1911
- *Drilonereis* sp.

Family Dorvilleidae

- *Stauronereis rudolphi* (delle Chiaje, 1828)
- Dorvilleid, juvenile

Family Orbiniidae

- *Haploscoloplos elongatus* (Johnson, 1901)

TABLE 6 (continued)

Family Paraonidae

Paraonides platybranchia (Hartman, 1961)
Paraonis gracilis (Tauber, 1879)

Family Spionidae

Boccardia basilaria (Hartman, 1961)
Boccardia polybranchia (Haswell, 1885)
Boccardia proboscidea (Hartman, 1940)
Boccardia redeki (Horst, 1920)
Laonice cirrata (Sars, 1851)
Nerinides acuta (Treadwell, 1914)
Polydora ligni Webster, 1879
Polydora limicola Annenkova, 1934
Polydora sp.
Prionospio heterobranchia newportensis Reish, 1959
Prionospio malmgreni Claparede, 1870
Prionospio pinnata Ehlers, 1901
Prionospio pygmaeus Hartman, 1961
Spiophanes bombyx (Claparede, 1870)
Spiophanes missionensis Hartman, 1941
Spiophanes sp.
Streblospio benedicti Webster, 1879
Spionid, juvenile
Spionid, fragment

Family Magelonidae

Magelona sacculata Hartman, 1961

Family Chaetopteridae

Phyllochaetopterus prolifica Potts, 1914
Telepsavus costarum Claparede, 1870

Family Cirratulidae

Caulleriella bioculata (Keferstein, 1862)
Chaetozone corona Berkeley and Berkeley, 1941
Chaetozone setosa Malmgren, 1867
Chaetozone multioculata Hartman, 1961
Cirriformia luxuriosa (Moore, 1904)
Cirriformia spirabrancha (Moore, 1904)
Tharyx monilaris Hartman, 1960
Tharyx parvus Berkeley, 1929
Tharyx sp.

Family Cossuridae

Cossura candida Hartman, 1955

Family Ctenodrilidae

Ctenodrilus serratus (Schmidt, 1857)

Family Flabelligeridae

Pherusa sp.

Opheliidae

Armandia bioculata Hartman, 1938

Family Capitellidae

Capitella capitata (Fabricius, 1780)
Capitita ambiseta Hartman, 1947
Captellidae

Family Maldanidae

Axiothella sp.
Praxillella affinis pacifica Berkeley, 1929
Praxillella sp.
Maldanid, fragment
Maldanid, juvenile

Family Sabellariidae

Idanthyrsus ornamentatus Chamberlin, 1919
Sabellaria alcocki Gravier, 1907

Family Pectinariidae

Pectinaria californiensis Hartman, 1941

Family Ampharetidae

Amphicteis glabra Moore, 1905
Melinna oculata Hartman, 1969

Family Terebellidae

Amaeana occidentalis (Hartman, 1944)
Pista cristata (Muller, 1776)
Streblosoma crassibranchia Treadwell, 1914
Terrebelid, juvenile

Family Sabellidae

Chone mollis (Bush, 1904)
Euchone limnicola Reish, 1959
Megalomma pigmentum Reish, 1963
Sabellid, juvenile

Family Serpulidae

Hydroides pacificus Hartman, 1969
Spirobis sp.
Serpelid, juvenile

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MARINE STUDIES OF SAN PEDRO BAY, CALIFORNIA. Part 8. June, 1975

INTERTIDAL SANDY BEACH MACROFAUNA AT LOS ANGELES-LONG BEACH HARBOR

PART 1

by

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PART 2

by

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ABSTRACT (Parts 1 and 2): Beaches inside and outside Los Angeles-Long Beach Harbor were surveyed monthly between September, 1971 and September, 1972 (Inner Cabrillo and Outer Cabrillo Beaches), and bimonthly between March, 1973 and July, 1974 (Inner Cabrillo, Outer Cabrillo and Long Beach) to determine the ecological status and establish an ecological baseline. Inner Cabrillo was the richest both in terms of number of species and number of specimens. The dominant species were characterized as those found in low intertidal, fine grain sediments. Outer Cabrillo Beach supported fewer species and specimens, but the dominant species were characterized as those found in coarser sediments than those at Inner Cabrillo Beach. This difference in number of species and specimens is consistent with the general trend of fewer organisms on coarse grain, exposed beaches than on fine grain, sheltered beaches. Long Beach, which is a sheltered beach, was depauperate, both in terms of number of species and number of organisms. This does not fit the expected ecological trend but the reasons for the sparse fauna are unknown. The only similarity between all three beaches was the lack of invertebrate macrofauna in supra- and upper-intertidal areas. This could be the result of frequent beach maintenance activities in these areas.

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PART 1

INNER AND OUTER CABRILLO BEACHES

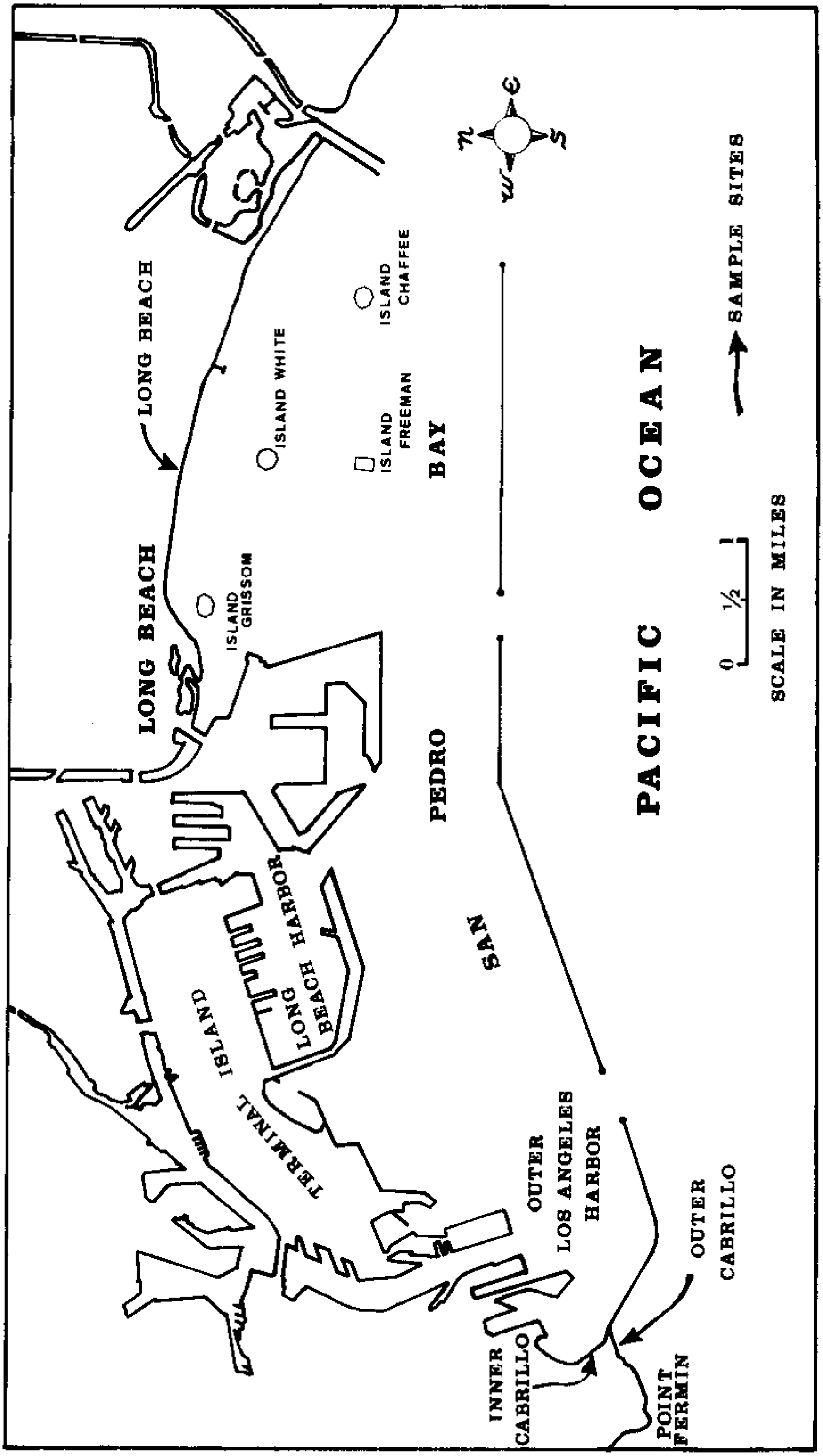
September 1971 - September 1972

INTRODUCTION. While sandy beaches are probably the most familiar areas of the marine environment, they are some of the least studied areas. This is no doubt due to their generally sparse infauna, which renders such ecological studies hard work and time consuming. Patterson (1974) published one of the first accounts of the intertidal biota in southern California. A less extensive study was conducted by Trask (1971), with further work by Straughan (1973), both in the Santa Barbara Channel. None of these reports considered any intertidal areas,either within the greater Los Angeles area or in a harbor situation.

The present study was designed to describe the intertidal ecology of macro-invertebrates on beaches that are widely used by the public and are adjacent to both domestic and industrial effluents. Part 1 covers studies of Inner and Outer Cabrillo Beaches, located inside and outside of Los Angeles Harbor respectively, with monthly surveys conducted from September, 1971 to September, 1972. Part 2 presents the results of bimonthly surveys conducted at these sites, plus one in Long Beach, which were surveyed from March,1973 until July, 1974 (Figure 1).

Inner and Outer Cabrillo Beaches were formed in 1927 during dredging operations on either side of the San Pedro Breakwater. Because Outer Cabrillo Beach has been protected as a marine preserve, and is adjacent to the Cabrillo Beach Marine Museum, it is visited by many classes. Both beaches are sites of grunion runs. Inner Cabrillo Beach is sheltered from wave action within Los Angeles Harbor while Outer Cabrillo Beach, on the edge of San Pedro Channel, is exposed to wave action.

METHODS. The two sites were sampled on two consecutive days once a month from September, 1971 through August, 1972, and both were sampled on the same day in September, 1972. A stratified random sampling method was used to collect the infauna. A tape marked at ten foot intervals was laid from the previous high tide line to the low tide line in front of a constant basepoint. A forty-foot tape similarly divided was placed along the high tide line. Four ten-foot square quadrats were thus formed every ten feet across the intertidal area. Random numbers determined the point where three separate core samples were taken within each quadrat. Each core measured eight inches (20.6 cm) deep and three inches (7.7 cm) in diameter. The three sand cores were combined and sieved through a 1 mm mesh screen in the field. Animals retained on the sieve were placed in 10% formalin and returned to the


LONG BEACH
LONG BEACH
ISLAND GRISSOM
ISLAND WHITE
ISLAND FREEMAN
ISLAND CHAFFEE
SAN PEDRO BAY
PACIFIC OCEAN
SAMPLE SITES
0 ½ 1
SCALE IN MILES
LONG BEACH HARBOR
TERMINAL ISLAND
OUTER LOS ANGELES HARBOR
OUTER CABRILLO
INNER CABRILLO
POINT FERMIN

laboratory for identification. Middle fragments of polychaetes were not included in the data results unless they represented the only appearance of a species at a particular survey.

Beach profiles were measured as the change in elevation every twenty feet along the intertidal transect, using the staff and horizon method (Emery, 1961). Sand samples were collected every twenty feet as normal cores split lengthwise. Sediment fractions greater than 2 mm were determined by coarse sieving, while a settling tube was used to analyze the remaining fine material. Sediment phi diameter and degree of sorting were calculated with a computer program. Median grain diameters are measured in phi units, which are the negative log to the base 2 of the diameter in millimeters. Degree of sorting refers to the proportion of grains which are the same diameter as the median grain size. At low tide, shaded air and swash zone water temperatures were recorded.

Data were analyzed using the Spearman Rank Correlation Coefficient (Siegel, 1956):

$$r_s = 1 - \frac{6 \sum_{i=1}^{N} d_i^{2}}{\quad}$$

or, when there were a number of tide ranks:

$$r_s = \frac{\sum x^2 + \sum y^2 - \sum d^2}{2\sqrt{\sum x^2 \sum y^2}}$$

RESULTS. A comparison of temperatures recorded on both sites during surveys indicates that air and water temperatures were generally higher at Inner Cabrillo Beach than at Outer Cabrillo Beach (Table 1). Water temperatures exhibited a predictable seasonal trend,with minimum temperatures recorded in December-January (15.0°C, 16.5°C at Inner Cabrillo,and 12.5°C, 13.0°C at Outer Cabrillo Beaches respectively), and maximum temperatures in September (20.9°C and 19.5°C at Inner Cabrillo and Outer Cabrillo Beaches. Exceptions to generalized seasonal warming and cooling of water were recorded during the March-April surveys,when warmer water (20.0°C and 18.0°C at Inner Cabrillo Beach and 15.0°C and 17.0°C at Outer Cabrillo Beach) was recorded,than in the following two months (17.0°C at Inner Cabrillo Beach and 14.0°C and

TABLE 1. Air and Water Temperatures (°C) and Height (feet) of Low Tide on Each Monthly Beach Survey.

Month	Air Temperature		Water Temperature		Height of Low Tide	
	Inner Cabrillo	Outer Cabrillo	Inner Cabrillo	Outer Cabrillo	Inner Cabrillo	Outer Cabrillo
September 1971	22.7		20.9		0.1	0.2
October 1971	20.6	20.0	18.5	16.0	0.2	0.4
November 1971	17.2	14.3	17.8	14.2	-0.3	-0.4
December 1971	15.6	13.4	15.0	12.5	-0.1	-0.4
January 1972	14.4	15.8	16.5	13.0	-1.2	-1.4
February 1972	13.7	14.4	16.8	14.4	-0.5	-0.2
March 1972	18.0	15.0	20.0	15.0	-0.4	-0.2
April 1972	21.0	14.9	18.0	17.0	-0.1	-0.2
May 1972		15.0		14.0	-0.8	-0.4
June 1972	18.4	21.0	17.0	16.5	-0.7	-0.1
July 1972		17.0		18.0	-0.8	-0.2
August 1972	19.0	19.5	19.0	18.7	-0.5	-0.1
September 1972	22.0	19.5	19.5	19.5	-0.2	-0.2

16.5°C at Outer Cabrillo Beach). This trend was also recorded in Los Angeles Harbor in 1972 and 1973 by Soule and Oguri (1974).

Most surveys were conducted on low spring tides of similar heights (Table 1), but those in September-October, 1971 were during slightly higher spring tides; the surveys in January, 1972 were during exceptionally low tides.

Intertidal areas on Inner Cabrillo Beach were usually steeper (1:13 to 1:16) than Outer Cabrillo Beach (1:17 to 1:25) in 1971-72 (Table 2). The exception was recorded on the survey of Inner Cabrillo Beach in January, 1972 when the beach slope averaged 1:23. This survey was conducted on a tide at least 0.6 feet lower than on all other surveys of this beach, exposing a low, relatively flat, intertidal area. The length of the intertidal area was 220 feet as compared to 110 to 160 feet on the other surveys (Table 5). There was more variability in the intertidal slope on Outer Cabrillo Beach than on Inner Cabrillo Beach. This is probably due to the greater wave action on Outer Cabrillo Beach than on Inner Cabrillo Beach.

The deposits at Inner Cabrillo were often heterogeneous, and oscillation in sediment parameters was common between the tide lines. Medium or coarse deposits (phi less than 2), with the consistency of gravel, formed horizontal bands across the intertidal every month. The coarse, poorly sorted material was usually collected around the midtide level (40 to 80 feet) in bands covered by a thin layer of fine material and not superficially visible. In lower intertidal areas, the substratum became very fine (phi greater than 3) and well sorted. In contrast to Inner Cabrillo, more homogeneous material was consistently present on Outer Cabrillo (Table 2). The extremes on particle diameters found at Inner Cabrillo were lacking.

Tables 3 and 4 show the monthly abundance of macro-invertebrates on both beaches. Up to 15 species out of a total of 40 were common to both sites. However, nemertean and annelid fragments that could not be identified to species were included in this total. A total of 10 out of 30 invertebrates, separated to species level, occurred at both sites. These included such widespread southern California species as the sand crab *Emerita analoga*, and the polychaete worms *Nephtys californiensis*, *Nephtys ferruginea*, and *Nerinides acuta*.

Nephtys californiensis and *Nerinides acuta* were generally present at both sites, although they were more important in terms of percent composition of the total fauna at Outer Cabrillo Beach than at Inner Cabrillo Beach (31.7% and 23.6% respectively at Outer Cabrillo as compared with 6.6% and 10.0% respectively at Inner Cabrillo). Several shared species were more often present at one site than at the other; the polychaetes *Dispio* sp., *Hemipodus borealis*, and *Lumbrineris zonata* occurred more frequently

TABLE 2. Beach Slope, Maximum, Minimum and Mean of Mean Grain Size (ϕSize), Maximum, Minimum and Mean of Mean Standard Deviation (Sorting Index) on Each Monthly Beach Survey.

	Inner Cabrillo					Outer Cabrillo				
		Mean Grain Size		Sorting Index			Mean Grain Size		Sorting Index	
Month	Slope	Range	Mean	Range	Mean	Slope	Range	Mean	Range	Mean
September 1971	1:13.20	1.28 - 2.89	2.32	0.80 - 1.30	1.11	1:18.46	2.15 - 2.80	2.47	0.41 - 0.59	0.48
October 1971	1:14.35	1.74 - 3.10	2.49	0.70 - 1.84	1.18	1:17.32	2.17 - 2.88	2.57	0.39 - 0.56	0.46
November 1971	1:15.41	1.48 - 3.62	2.59	0.34 - 1.66	0.99	1:19.20	2.07 - 2.96	2.70	0.34 - 0.62	0.46
December 1971	1:15.48	2.07 - 3.42	2.83	0.39 - 1.10	0.76	1:18.62	2.24 - 2.93	2.68	0.34 - 0.93	0.64
January 1972	1:23.44	0.77 - 3.78	2.92	0.41 - 2.15	0.84	1:20.72	1.95 - 2.70	2.41	0.41 - 1.05	0.69
February 1972	1:14.69	0.79 - 3.28	2.32	0.66 - 1.73	1.03	1:20.87	2.26 - 2.76	2.48	0.42 - 1.36	0.80
March 1972	1:15.00	0.51 - 3.17	2.29	0.59 - 1.70	1.22	1:19.59	1.01 - 2.76	2.25	0.39 - 1.25	0.66
April 1972	1:15.21	0.66 - 3.76	2.57	0.42 - 1.41	0.78	1:22.70	0.95 - 2.45	1.99	0.75 - 1.65	1.05
May 1972	1:13.05	0.44 - 3.62	2.45	0.41 - 2.00	1.07	1:17.23	1.64 - 2.52	2.13	0.73 - 1.46	1.07
June 1972	1:13.46	1.78 - 3.24	2.35	0.67 - 1.45	1.67	1:25.26	2.24 - 3.00	2.72	0.81 - 0.99	0.53
July 1972	1:14.11	0.80 - 3.53	2.25	0.29 - 2.09	1.15	1:19.29	2.38 - 3.02	2.76	0.27 - 0.51	0.35
August 1972	1:16.23	0.52 - 3.48	2.16	0.62 - 1.90	1.28	1:21.39	2.32 - 2.82	2.63	0.32 - 0.51	0.41
September 1972	1:16.60	1.86 - 2.90	2.38	0.65 - 1.80	1.01	1:16.33	1.14 - 2.70	2.05	0.58 - 2.88	1.18

Table 3. Species Recorded on Inner Cabrillo Beach Between September 1971 and September 1972

Species	September 1971	October 1971	November 1971	December 1971	January 1972	February 1972	March 1972	April 1972	May 1972	June 1972	July 1972	August 1972	September 1972
CRUSTACEA													
Blepharipoda occidentalis													
Caprella sp.											1		
Cirolana chiltoni													2
Emerita analoga		2	1										
Heterophoxus sp.													
Isochelespilosus		3			3								
Lepidopa myops													
VERMES													
Capitella capitata										7	1		
Capitellidae					2						1		
Cirriformia spirabranchia					2								
Dispio sp.			36	1	47	3		4	5	4	6		3
Eunicidae					1								
Euzonus dillonensis													
Glycera convoluta			1	4	1	1			1		3		
Glycera branchiopoda					1								
Glyceridae					1								
Hemipodus borealis	3	5	4	1	1	3	3		12	7	2	7	2
Lumbrineris zonata			1		2					2			
Lumbrineridae				2	3	1					4		1
Magelona pitelkai			130	75	102	43	7	2	37	22	34		2
Mageloniidae					4								
Nephtys californiensis		4	1	1	4		1			3			
Nephtys caecoides					3								
Nephtys ferruginea			1	2					1	1	1		
Nephtys sp.		1	2	2	4	1			3			3	2
Nephtyidae					1								
Nerinides acuta		4	2	2			8	8	16	14	9	5	4
Notomastus tenuis													
Notomastus sp.													
Spiophanes bombyx					2								
Spionidae													
Paranoides platybranchia											2	9	1
Pectinaria californiensis					2								
Unidentified species													
Annelid fragments													
Nemertea fragments			1		11	3				1	2		
Sipunculida					3								
MOLLUSCA													
Donax gouldii													
Olivella biplicata		1	51	5	23	2	10	1		7			
Tivela stultorum													

Table 4. Species Recorded on Outer Cabrillo Beach for September 1971 to September 1972

Species	September 1971	October 1971	November 1971	December 1971	January 1972	February 1972	March 1972	April 1972	May 1972	June 1972	July 1972	August 1972	September 1972
CRUSTACEA													
Blepharipoda occidentalis										2			
Caprella													
Cirolana chiltoni													
Emerita analoga	2	4	2	4	4	2	1		6	4		11	
Heterophoxus sp.											1		
Isochelespilosus													
Lepidopa myops			1	1			1						
VERMES													
Capitella capitata													
Capitellidae											2		
Cirriformia spirabrancha													
Dispio sp.													
Eunicidae													
Euzonus dillonensis						4							
Glycera convoluta													
Glycera branchiopoda													
Glyceridae											1		
Hemipodus borealis				1		1						1	
Lumbrineris zonata								2					
Lumbrineridae										2			
Magelona piteikai											1		
Magelonidae													
Nephtys californiensis	1		3	3	3	3	3		4	3	3		
Nephtys caecoides													
Nephtys ferruginea	1		1	1	2	2				3	1	1	
Nephtys sp.	2	4	5	4	1	1	2			1	3	4	3
Nephtyidae					2								
Nerinides acuta	4		9	21	3	8	4	7	4	3	4	5	
Notomastus tenuis											1		
Notomastus sp.													
Spiophanes bombyx													
Spionidae									1				
Paranoides platybranchia				1		5					14	3	1
Pectinaria californiensis													
Unidentified species												1	
Annelid fragments							1						
Nemertea fragments	5						1			1	1		
Sipunculida													
MOLLUSCA													
Donax gouldii					1							1	1
Olivella biplicata													
Tivela stultorum			1										

TABLE 5. Number of Species and Organisms and Length of Intertidal Area on Each Monthly Beach Survey.

Month	Number of Species		Number of Organisms		Intertidal Length (feet)	
	Inner Cabrillo	Outer Cabrillo	Inner Cabrillo	Outer Cabrillo	Inner Cabrillo	Outer Cabrillo
September 1971	1	6	3	15	120	150
October 1971	7	2	20	8	120	150
November 1971	12	7	231	22	150	170
December 1971	10	8	95	36	130	190
January 1972	22	7	223	16	220	250
February 1972	8	8	57	26	130	170
March 1972	4	10	29	16	110	170
April 1972	5	2	12	9	100	150
May 1972	7	4	75	15	140	150
June 1972	10	8	68	19	130	170
July 1972	12	12	66	34	160	190
August 1972	4	8	24	27	150	190
September 1972	8	3	17	5	130	170

on Inner Cabrillo Beach, while Emerita analoga occurred more frequently on Outer Cabrillo Beach.

An unexpected similarity between the beaches was the near absence of typical southern California high intertidal species (Patterson, 1974), such as the amphipod beach hoppers of the genus Orchestoidea, Cirolana chiltoni and other scavenger isopods, and the polychaete Euzonus mucronata (bloodworms). In fact, the upper levels of the intertidal zone were generally devoid of species.

More species (22) and more organisms (920) were recorded on Inner Cabrillo Beach than on Outer Cabrillo Beach (16 species and 248 organisms). The most obvious difference centered on the abundance of a polychaete, Magelona pitelkai, and a gastropod Olivella biplicata in the lower intertidal areas of Inner Cabrillo Beach, in contrast to the crustaceans Blepharipoda occidentalis, Emerita analoga, and Lepidopa californica and the bivalves, Donax gouldii and Tivela stultorum in similarly low intertidal areas of Outer Cabrillo Beach.

Data was analyzed using the Spearman Rank Correlation Coefficient to determine possible patterns in numbers of species and organisms. There were significant correlations in 1971-72 between numbers of species and both water and air temperature and between number of specimens and air and water temperature at Inner Cabrillo Beach. In other words, species and specimens were more abundant during the winter (low temperatures) than during the summer (high temperatures). There was no significant correlation between these parameters on Outer Cabrillo Beach. In the subsequent study, however, there was no significant correlation (Part 2) between temperature and species, suggesting that these parameters are not related.

There was also a significant correlation between mean of mean grain size and range of mean grain size and the number of species at Outer Cabrillo Beach. The correlation was nearly in the significant range (0.5) for these variables on Inner Cabrillo Beach.

There was no significant correlation between any of the other factors (e.g., sorting index or intertidal slope) tested and total number of species and/or specimens collected on a survey.

Table 6 presents a summary of the mean grain size (ø) from the collection level for each species. It is apparent that most species occur in sediments of a well defined range. Emerita analoga was found in relatively coarse sediments of a mean ø range (1.85 - 2.78) on Outer Cabrillo Beach and of a mean ø range (1.79-2.06) on Inner Cabrillo Beach. In general, more variation was observed in ø on Inner Cabrillo Beach than on Outer Cabrillo Beach. This is no doubt related to the more heterogeneous distribution of sediment at Inner Cabrillo Beach than at Outer Cabrillo Beach.

TABLE 6. Summary of Mean Grain Size (ø) Where Organisms Were Collected

Species	Outer Cabrillo	Inner Cabrillo
CRUSTACEA		
Blepharipoda occidentalis	2.68	
Cirolana chiltoni		1.93
Emerita analoga	1.85 - 2.78	1.79 - 2.06
Heterophoxus sp.	2.94	
Isochelespilosus		2.72 - 2.76
Lepidopa myops	2.77	
VERMES		
Capitella capitata	2.55	2.21
Capitellidae		3.58 - 3.72
Cirriformia spirabrancha		2.49 - 3.78
Dispio sp.		3.24 - 3.72
Eunicidae		3.56 - 3.78
Euzonus dillonensis	1.01 - 2.60	
Glycera convoluta		3.28 - 3.62
Glycera branchiopoda		3.72
Glyceridae	2.66	
Hemipodus borealis	2.57 - 2.67	1.71 - 3.0 (0.44, 0.99)
Lumbrineris zonata		3.62 - 3.78 (0.95)
Lumbrineridae	2.87	3.21 - 3.78
Magelona pitelkai		3.16 - 3.72 (2.49)
Magelonidae		3.56
Nephtys californiensis	2.15 - 2.93	2.61 - 3.72
Nephtys caecoides		3.72
Nephtys ferruginea	2.59 - 2.96	3.42 - 3.62
Nephtys sp.	2.31 - 2.90	2.74 - 3.62
Nephtyidae	2.46 - 2.50	2.67
Nerinides acuta	2.15 - 2.77	1.74 - 2.94 (0.66, 0.44)
Notomastus tenuis	2.80	
Notomastus sp.	2.76	
Spionidae	2.15	
Paranoides platybranchia	2.69 - 2.93	2.79
Pectinaria californiensis		3.58
Nemertea sp. A	2.35 - 2.80	2.79 - 3.72
Sipunculida		3.72 - 3.78
MOLLUSCA		
Donax gouldii	2.46	
Olivella biplicata		2.76 - 3.78
Tivela stultorum	2.96	

( ) - isolated occurrence

Many of the differences between species composition on the two beaches appears related to grain size (Table 6). Cirriformia spirabrancha, Dispio sp., Eunicidae, Glycera convoluta, Lumbrineris zonata, Magelona pitelkai, Sipunculida, and Olivella biplicata all occur in sediments on Inner Cabrillo Beach which are generally finer than those found on Outer Cabrillo Beach. Emerita analoga, Hemipodus borealis, Nephtys californiensis, Nephtys sp., Nerinides acuta, Paranoides platybranchia and the nemerteans, which tolerate slightly coarser sediments, occur on both beaches. One species, Nephtys ferruginea, which occurs at both sites, is found in a different sediment regime at each site (mean ϕ range Outer Cabrillo Beach = 2.59 - 2.96; mean ϕ range Inner Cabrillo Beach = 3.42 - 3.62). This could indicate a wide tolerance of the species or that more than one species is involved.

DISCUSSION. Temperature differences between Inner and Outer Cabrillo Beaches are probably due to the sheltered location of Inner Cabrillo, where higher air and water temperatures were recorded, as compared to the exposed location of Outer Cabrillo Beach. The apparent increase in water temperatures of the April-May period, followed by a decrease in water temperature at the time of survey, is probably a function of the time of day of the survey and weather conditions. In southern California, early morning fogs are common in late May and June, and low spring tides occur early in the morning. Surveys conducted in March and April were in late morning or mid-afternoon with no fog, while those in May and June commenced about dawn and were in foggy conditions.

The data presented on other physical parameters showed no consistent seasonal trend. There was an overall seasonal trend in numbers of species and specimens related to temperature trends at Inner Cabrillo Beach. However, such a trend was not recorded at Outer Cabrillo Beach. This was probably due to the greater sand movement and exposure of rock in lower intertidal areas, which limited the area available for sandy beach organisms. The importance of availability of substrate is emphasized by the direct significant correlation between the length of intertidal area surveyed and number of species and specimens present, and conversely the lack of correlation between low tide level and number of species and specimens. The lack of a correlation between length of intertidal area surveyed and low tide is due to changing beach profiles and presence of rocks in low intertidal areas on some occasions.

The lack of correlation between total numbers of species and total numbers of specimens is due to the variability in abundance in different species; some species occur in high densities but others maintain low population levels.

Normally there are more species and specimens associated with fine grain than coarse grain areas. This overall association was recorded on Outer Cabrillo Beach but not on Inner Cabrillo Beach. Such a relationship probably occurs on Inner Cabrillo Beach, as indicated by the summary of mean grain size for each species. It is not revealed in the total species and total organism analyses because the variations in grain size at different strata and on different levels of the beach were combined for the analyses. However, the summary of mean grain size for each species shows a strong relationship between species distribution and grain size.

The lack of *Orchestoidea* may be a function of the beach maintenance program on public beaches in southern California. These species feed on kelp and other vegetable material deposited near high tide level. This is mechanically removed daily on public beach areas. Hence, these species have no readily available food source. The isopods usually are most abundant slightly lower intertidally than the amphipods, while the *Euzonus* are usually most abundant slightly below the isopods. No obvious reason can be given for the sparsity of isopods and *Euzonus* on these beaches.

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PART 2

INNER AND OUTER CABRILLO BEACHES AND LONG BEACH

March 1973 - July 1974

INTRODUCTION. Part 2 of this study of sandy beaches in the Los Angeles-Long Beach Harbor area was expanded to include a survey site at Long Beach (Part 1, Fig. 1), which is northeast of the two Cabrillo sites and east of Long Beach Harbor, and to examine the supra-tidal area. The additional site was added to determine whether the conditions found at Inner Cabrillo Beach characterized conditions within the Harbor complex. The supra-tidal area was examined to determine if any species inhabited the areas above high tide mark. All three beaches are well used by the public. Observations on other beaches have shown that public usage is heaviest above high tide mark. The area above high tide mark extending into the swash zone is also raked frequently to collect garbage, algae and tar.

MATERIALS AND METHODS. A permanent bench mark was established above high tide mark at all three study sites. All profiles were measured from U.S. Geological Survey bench marks. The biological survey commenced at the base of bench marks at Inner Cabrillo Beach and Long Beach, and at the edge of the sand and grass (now marked with a wooden stake) in front of the bench mark at Outer Cabrillo Beach.

The biological survey methods were the same as those described in Part 1, except they commenced at a fixed point which was above high tide mark, rather than a variable point governed by high tide mark. Profile measurements were recorded every five feet as compared with 20 feet in Part 1 (Emery, 1961). Records were also made of exposed rocks, and algae or tar washed onto the beach. Tar samples were collected from the survey area and weighed.

Biological specimens were preserved directly in 70% ethanol after sieving from sand in the field. This is an adequate method of preservation as long as a high fluid:animal ratio by volume was maintained. Salinity measurements were recorded using a refractometer. Both salinity and water temperature data presented in this paper were recorded in the edge of the water. The Spearman Rank Correlation Coefficient was again employed in data analysis (Siegel, 1956).

RESULTS. Locally, water temperatures generally show predictable seasonal trends, increasing from May to a maximum in September and then decreasing to a minimum in January (Table 1). Temperatures usually increased through March and may decrease in May. Temperatures during the survey either fell or were the same in May as they were in March, except at Outer Cabrillo in May, 1973. In that instance, the water temperatures were higher in May (14.4^{o}C) than in March (13.8^{o}C). Similar trends were observed in air temperatures, except for the anomalous trend in May, 1973 when air temperatures of 21.8^{o}C were recorded, as compared to 14.9^{o}C in March, 1973 at Outer Cabrillo Beach. Monthly water temperatures were lower at Outer Cabrillo Beach than at Inner Cabrillo Beach and Long Beach, while there is no consistent difference between air temperatures (Table 1).

Salinity was reduced (31-32%) in March and May, 1974 at all sites, and at Long Beach in May, 1973 (Table 1). High (38^{o}/oo) salinities were recorded at Inner and Outer Cabrillo Beaches in March 1973. This may have been due to interference in refractometer readings by sand suspended in the water sample.

In most of the surveys of the two harbor beaches, algal debris was deposited in the lower intertidal areas or floated in the water's edge, while this was never observed at Outer Cabrillo Beach. The algae at Outer Cabrillo Beach consisted of isolated patches of kelp in the mid-intertidal area, while the algae at Inner Cabrillo and Long Beach often formed a continuous mat consisting of smaller algal species.

All beaches are raked above the intertidal area and along the swash zone "as often as is necessary". This means daily, during the summer months to remove trash and natural algal deposits, which are unsightly to the general public. This also removed larger pieces of tar from the upper intertidal areas. Hence, the tar recorded on these beaches is not entirely indicative of the amount that washes ashore.

Tar was most frequently recorded at Long Beach and least frequently at Outer Cabrillo Beach (Table 1). In most instances the tar collected was very small, dry pieces of less than 1 gram. However, 200 grams of tar which was soft but not sticky was collected in a forty foot square area just above low tide level at Long Beach on 18 March, 1974. On the same day 2 grams of the usual dry tar was collected higher on the beach. On the next day 255 grams of tar that appeared similar to that found at Long Beach, was collected from an area 40 feet along the beach by 10 feet across the beach at high tide level on Outer Cabrillo Beach. At Inner Cabrillo Beach 130 grams of tar that appeared similar was recorded in an area 40 feet along the beach by 50 feet across the beach, extending just above low tide level on 19 March 1974. While the source of this tar was unknown, it probably all originated from the same spillage of oil.

During the second study the variability in the average beach slope was similar at Outer Cabrillo Beach (1:14.5-1:20) and Inner Cabrillo Beach (1:14-1:20) while less variability was recorded at Long Beach (1:15-1:18) (Table 1). Rocks were exposed at Outer Cabrillo Beach on the steeper profiles (1:14.5-1:15.5) after sand loss from this beach. Comparison with the data from the 1971-72 survey indicates that the cut and fill on these beaches varies annually,and not necessarily in the same way,on both Cabrillo beaches.

There is no apparent seasonal pattern of cut and fill on any of the beaches (Figures 1, 2, 3). However, any seasonal pattern could be obscured by the beach cleaning and maintenance program at each site. The movement of sand at Outer Cabrillo Beach (Figure 1) is much greater throughout the year than at either Inner Cabrillo Beach (Figure 2) or Long Beach (Figure 3).

Beaches were surveyed on spring tides and subsequently tides of comparable height were worked as far as possible. However, there is a range of 1.1 feet between the highest low tide (+0.1 feet) and lowest low tide (-1.0 feet) on which surveys were conducted (Table 2). The length of beach surveyed also varied (Table 2). However, using the Spearman Rank Correlation Coefficient there was no significant correlation between the length of beach and height of low tide at the time of the survey.

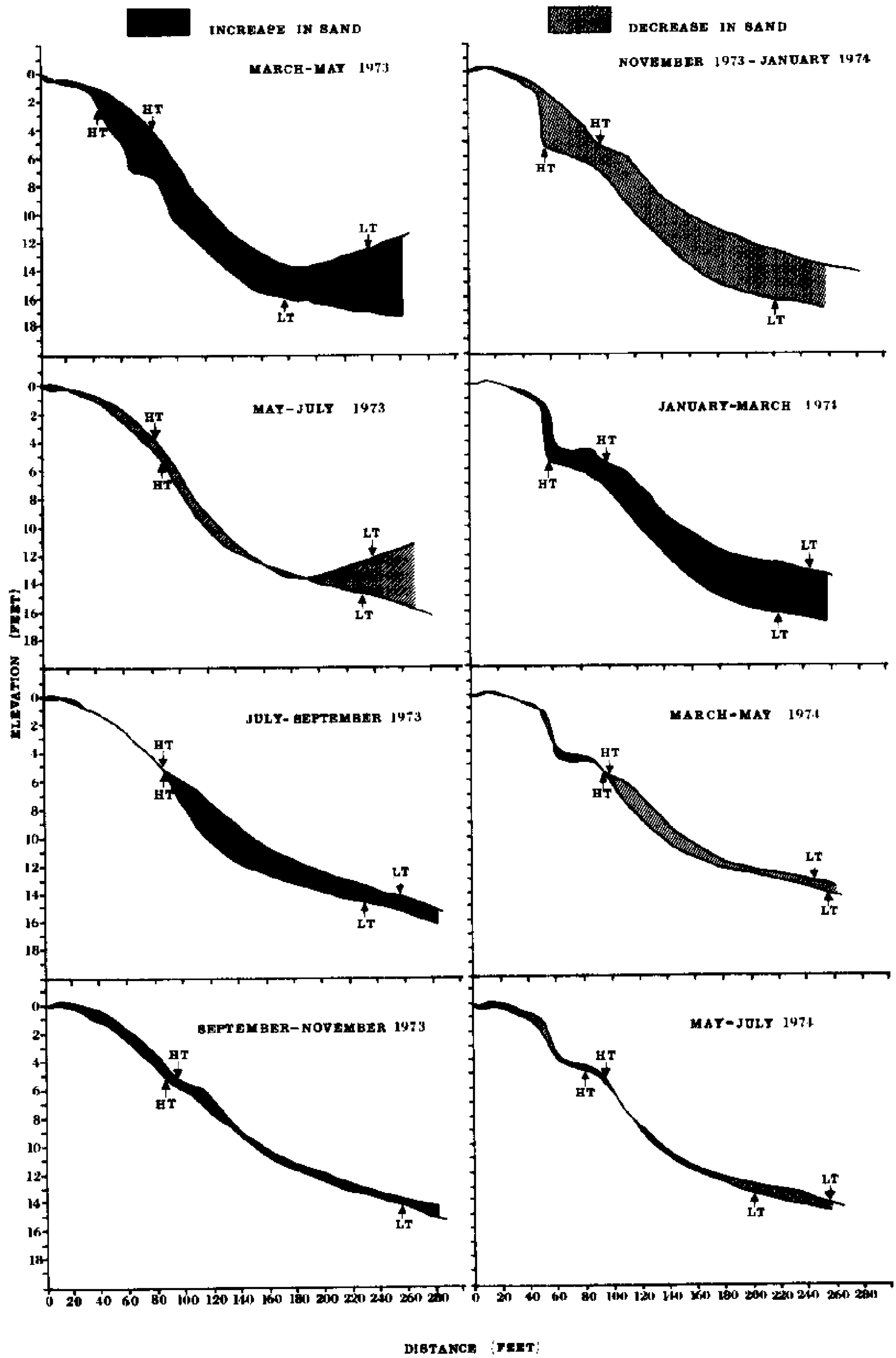
Both species and organisms were most abundant on Inner Cabrillo Beach and least abundant on Long Beach (Table 2). There is no significant correlation between the number of species and number of organisms on a beach (Spearman Rank Correlation Coefficient).

There was a significant correlation ($p<0.5$) between both number of species and number of organisms and linear length of survey on Inner Cabrillo Beach but not on either Outer Cabrillo Beach or Long Beach. There was no significant correlation between either number of species or number of organisms and either water or air temperature at any of the beaches.

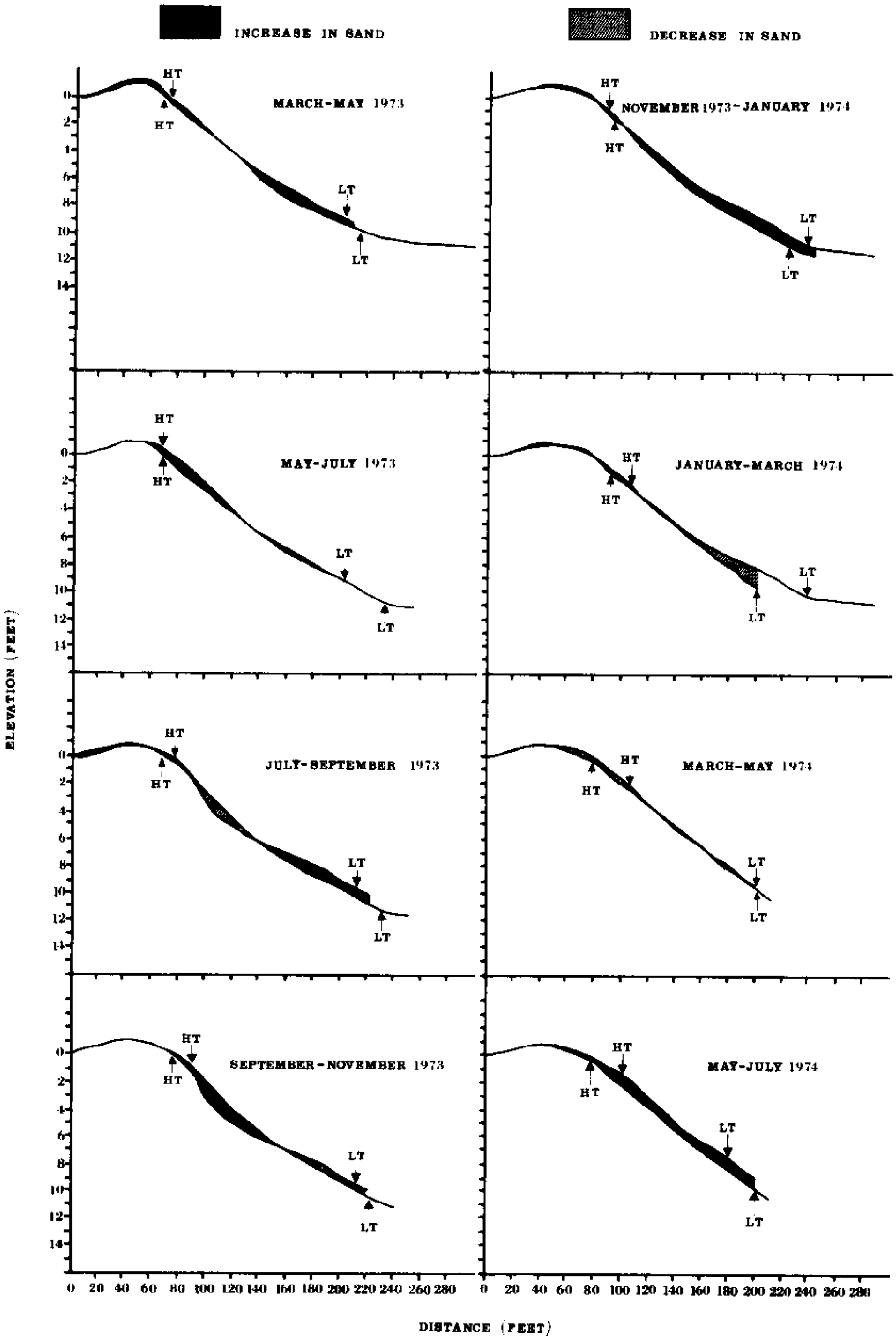
Table 3 lists all organisms identified to species, while Tables 4, 5, and 6 list the monthly distribution and abundance of all species at each site. Only six species categories were recorded from all three sites in 1973-74 (Table 7). _Emerita analoga_ and _Nerinides acuta_ are the only two of these positively identified. Glyceridae, Nephtyidae, and _Nephtys_ sp. could not be positively identified to species because parts of the animals were missing. Hence, each category could contain a mixture of species. _Nephtys ferruginea_ may actually be two species or two subspecies, as suggested by two completely different distributions in relation to grain size (see Part 1).

A total of 29 species was recorded on Inner Cabrillo Beach,

OUTER CABRILLO



INNER CABRILLO



LONG BEACH

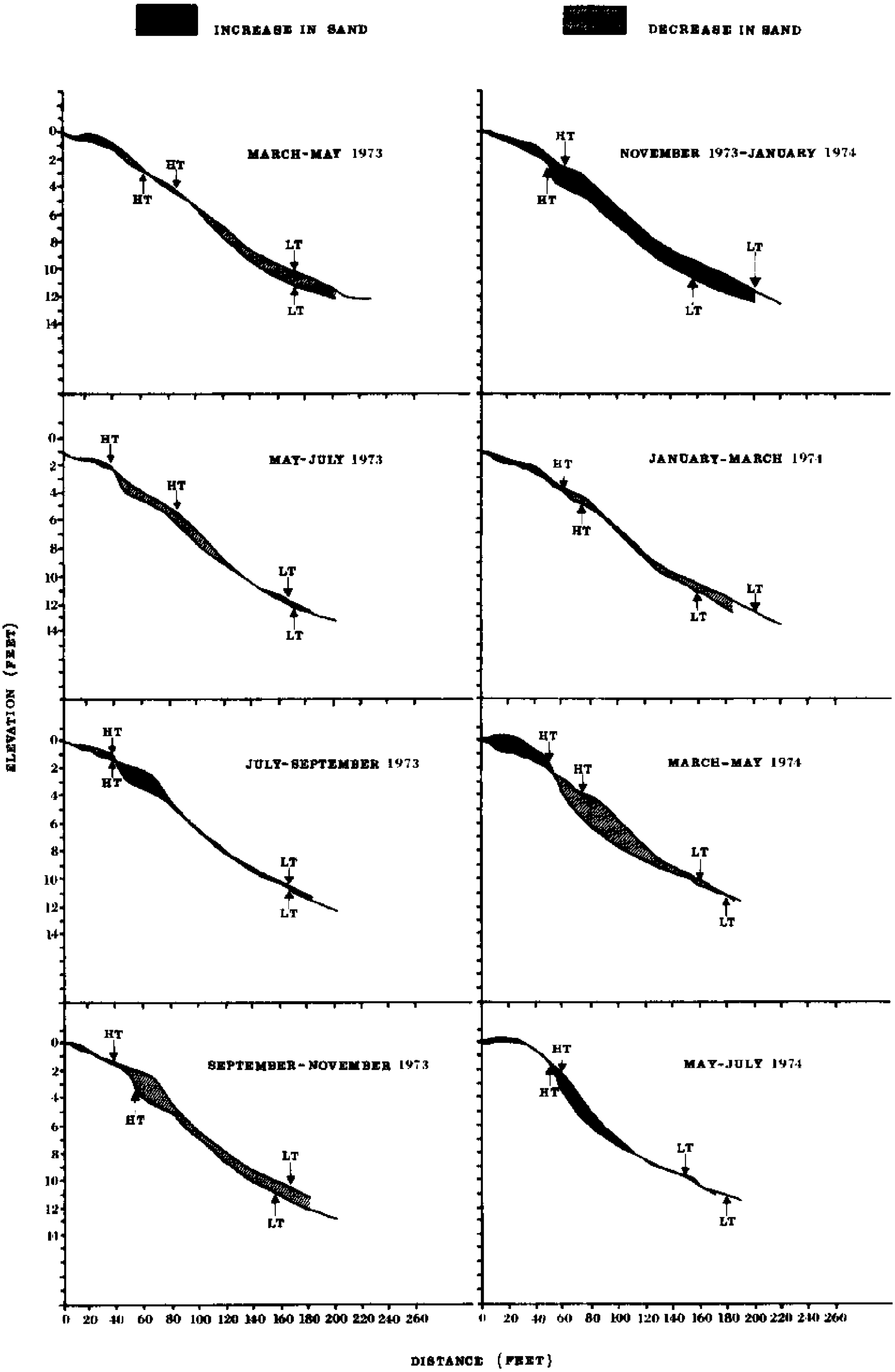

INCREASE IN SAND
DECREASE IN SAND
MARCH-MAY 1973
NOVEMBER 1973-JANUARY 1974
MAY-JULY 1973
JANUARY-MARCH 1974
JULY-SEPTEMBER 1973
MARCH-MAY 1974
SEPTEMBER-NOVEMBER 1973
MAY-JULY 1974
HT
LT
ELEVATION (FEET)
DISTANCE (FEET)
0 20 40 60 80 100 120 140 160 180 200 220 240 260
0 2 4 6 8 10 12 14

TABLE I. Physical Parameters During Beach Survey

	Outer Cabrillo Beach							Inner Cabrillo Beach							Long Beach						
		Temp. °C							Temp. °C							Temp. °C					
Date	Slope	Water	Air	(°/00)	Tar	Algae	Raked	Slope	Water	Air	(°/00)	Tar	Algae	Raked	Slope	Water	Air	(°/00)	Tar	Algae	Raked
1973																					
Mar.	1:15.5**	13.8	14.9	38+	-	-	R	1:19.5	19.5	18.5	38+	-	A	R	1:18	18.7	18.8	34	-	-	R
May	1:14.5*,***	14.4	21.8	34	-	-	?	1:14	14.4	14.6	34	-	A	?	1:16.5	16.7	14.4	31	T	-	?
July	1:15***	14.0	22.5	34	-	-	?	1:16.5	16.0	16.8	35	-	A	R	1:16.5	20.2	20.0	34	T	A	R
Sept.	1:18.5	18.0	25.0	36	-	-	?	1:16.5	20.0	33.0	36	-	A	?	1:16	21.0	29.5	36	T	A	?
Nov.	1:20	16.0	18.2	34	-	A	?	1:16.5	18.0	21.8	35	T	-	?	1:16	18.2	22.0	35	-	A	R
1974																					
Jan.	1:15***	10.5	13.1	35	-	-	R	1:20	12.0	19.5	34	-	A	R	1:18	13.0	20.0	35	-	A	R
Mar.	1:18	15.3	20.1	32	T	-	NR	1:16	15.0	15.2	32	T	A	?	1:15	16.5	18.0	32	T	A	R
May	1:18	14.1	14.2	32	-	-	?	1:14.5	15.0	15.2	32	T	A	R	1:17	15.0	14.5	31	T	A	NR
July	1:18	16.0	15.0	34	T	-	?	1:16	16.3	17.0	32	T	A	R	1:15.5	19.9	17.8	32.5	T	-	R

T - tar present in survey area; A - algae present on lower intertidal portion of survey area; R - upper beach raked on morning of the survey;

NR - upper beach not raked prior to survey.

* - slope to low point at 200 feet from basepoint only; ** - rocks exposed on part of profile; *** - Cobbles in sand.

- Slope on beach averaged from top of berm; + - probable instrument error.

TABLE 2. Monthly Beach Intertidal Data

Month	Number of Species			Number of Organisms			Survey Length (feet)			Low Tide Height (feet)		
	OC	IC	LB	OC	IC	LB	OC	IC	LB	OC	IC	LB
1973												
March	1	3	1	31	5*	1	190	210	180	-0.7	-0.8	-0.7
May	6	8	3	74	13*	7	260	200	170	-0.8	-0.4	-0.1
July	6	14	3	16	146	12	250	230	170	-1.0	-1.0	+0.4
Sept.	2**	11	3**	3	33	5	180	220	140	+0.1	+0.1	+0.1
Nov.	9	15	3	29	294	4	300	240	170	-0.7	-0.2	+0.4
1974												
January	10	10	3	33	114	4	180	240	200	-0.6	-0.6	-0.6
March	6	5	2	39*	8	5	160	200	170	+0.0	+0.0	+0.1
May	5	16	1	67*	130*	1	170	210	190	-0.2	-0.5	-0.7
July	3	6	1	23	7	1	200	190	170	+0.5	+0.5	+0.2

OC = Outer Cabrillo Beach; IC = Inner Cabrillo Beach; LB = Long Beach.

* = Grunion eggs (Leuresthes tenuis) not included; ** = Polychaete samples missing.

18 species on Outer Cabrillo Beach and only 9 species on Long Beach (Table 7). The total number of species remained constant between the 1971-72 survey and the 1973-74 survey at Inner Cabrillo Beach. However, 11 species from the first survey were replaced by 11 other species. In contrast, Outer Cabrillo Beach had a total of 26 species from the 1971-72 survey reduced to 18 species in the 1973-74 survey. The total loss of 13 species from the 1971-72 survey was only partially counterbalanced by a gain of 5 other species. Inner Cabrillo and Outer Cabrillo Beaches had 15 species in common in the 1971-72 survey, 12 species in common in the 1973-74 survey, but a total of 22 species in common if the data from both surveys are combined.

Two possible seasonal trends were recorded. At Outer Cabrillo Beach the greatest numbers of _Emerita analoga_ were recorded in March and May (Table 4). At Inner Cabrillo the least organisms were recorded in March. If _Emerita analoga_ is not considered, the same trend is evident at Outer Cabrillo Beach (Table 5). There were no obvious seasonal trends at Long Beach (Table 6).

The distribution of species relative to intertidal height is presented in Table 8. Intertidal height is presented in feet levels above and below mean water level. The differences in tidal range did not result in any major shift of species distribution in terms of feet above or below mean water level. The range of each is relatively consistent between different beaches. Variations are due to small sample size and suggest that in those cases the limits of distribution for any site may be incompletely defined. For example, very few _Euzonus dillonensis_ were found. On Outer Cabrillo Beach they occurred at the -3.0 and -4.0 feet levels below mean water level, while at Long Beach they occurred at the -2.0 feet level below mean water level. This suggests _E. dillonensis_ could extend 1.0 to 4.0 feet below mean water level.

The most striking aspect is the lack of upper intertidal species. Only 8 species extended above mean water level, and the insects were the only species that extended to the high tide area. None of the _Orchestoidea_ species that are expected to live in the high tide area were collected. Isolated organisms of the more abundant species were sometimes recorded outside a species range. _Nerinides acuta_ which ranges from level -7 to level +1 was recorded in one sample at level +2. An isolated specimen of _Nephtys ferruginea_ was likewise recorded at level -1 as was a specimen of _Blepharipoda occidentalis_. _Emerita analoga_ was distributed intertidally according to size with the smaller animals higher on the beach and the adults lower on the beach.

Figure 4 shows the distribution of the more common species using grain size data from Part 1,Table 6 and intertidal data recorded in Part 2,Table 8. The data show two separate species groups,with a third overlapping group of species. The major

TABLE 3. List of Species Identified* from Inner Cabrillo, Outer Cabrillo, and Long Beach 1971-1974.

CRUSTACEA

Allorchestes compressa (Dana)
Blepharipoda occidentalis Randall
Caprella brevirostris Mayer
Caprella californica Templeton
Caprella verrucosa Boeck
Cirolana chiltoni Richardson
Emerita analoga (Stimpson)
Lepidopa myops Stimpson
Paraphoxus epistomus (Shoemaker)

VERMES

Capitella capitata (Fabricius)
Cirriformia spirabrancha (Moore)
Dispio sp. (probably new species)
Euzonus dillonensis (Hartman)
Glycera convoluta Keferstein
Glycera branchiopoda Moore
Glycera tenuis Hartman
Hemipodus borealis Johnson
Lumbrineris zonata (Johnson)
Magelona pitelkai Hartman
Nephtys californiensis Hartman
Nephtys caecoides Hartman
Nephtys ferruginea Hartman
Nerinides acuta (Treadwell)
Nothria elegans (Johnson)
Notomastus tenuis Moore
Spiophanes bombyx (Claparede)
Spiochaetopterus costarum (Claparede)
Paranoides platybranchia Hartman
Pectinaria californiensis Hartman
Platynereis bicanaliculata (Baird)

MOLLUSCA

Donax gouldii Dall
Olivella biplicata (Sowerby)
Tivela stultorum (Mawe)

PISCES

Leuresthes tenuis (Ayres)

* This does not include organisms identified only to family or generic levels.

TABLE 4. Species Recorded at Outer Cabrillo Beach (March 1973 - July 1974).

OUTER CABRILLO

Species	March 1973	May 1973	July 1973	September 1973*	November 1973	January 1974	March 1974	May 1974	July 1974
CRUSTACEA									
Allorchestes compressa									
Blepharipoda occidentalis		1	1	1	3	1			
Caprella brevirostris									
Caprella californica									
Caprella verrucosa									
Cirolana chiltoni									
Emerita analoga	31	60	11	2	12	5	31	58	20
Heterophoxus sp.									
Isochelespilosus									
Lepidopa myops									
Paraphoxus epistomus					1	5			
INSECTA									
VERMES									
Capitella capitata									
Capitellidae									
Cirriformia spirabrancha									
Dispio sp.									
Eunicidae									
Euzonus dillonensis		4							
Glycera convoluta									
Glycera branchiopoda									
Glycera tenuis									
Glyceridae								1	
Hemipodus borealis									
Lumbrineris zonata									
Lumbrineridae			1				1		
Magelona pitelkai									
Magelonidae					1	2			
Nephtys californiensis									
Nephtys caecoides									
Nephtys ferruginea		6	1		7	7	2	5	2
Nephtys sp.			1		1	2			
Nephtyidae							1	3	1
Nerinides acuta		2			2	5			
Nothria elegans									
Notomastus tenuis									
Notomastus sp.									
Orbiniidae sp.									
Spiophanes bombyx									
Spionidae						2			
Spiochaetopterus costarum									
Paranoides platybranchia									
Pectinaria californiensis									
Platynereis bicanaliculata									
Unidentified species									
Annelid fragments		2							
Nemertea sp. A			1			2			
Nemertea sp. B						2			
Sipunculida									
MOLLUSCA									
Dentalium sp.									
Donax gouldii									
Olivella biplicata					1				
Tivela stultorum					1		4		
PISCES									
Leuresthes tenuis eggs									
Leuresthes tenuis larvae							2,120	4,800	

* - Polychaete samples missing.

TABLE 5. Species Recorded at Inner Cabrillo Beach (March 1973 - July 1974).

INNER CABRILLO

Species	March 1973	May 1973	July 1973	September 1973	November 1973	January 1974	March 1974	May 1974	July 1974
CRUSTACEA									
Allorchestes compressa								9	
Blepharipoda occidentalis									
Caprella brevirostris								1	
Caprella californica									
Caprella verrucosa								5	
Cirolana chiltoni		1	1	3		1	1	1	
Emerita analoga				1		1			
Heterophoxus sp.									
Isochelespilosus									
Lepidopa myops									
Paraphoxus epistomus									
INSECTA		+		+					
VERMES									
Capitella capitata									
Capitellidae									
Cirriformia spirabrancha					1				
Dispio sp.			38	1	15	9		2	
Eunicidae									
Euzonus dillonensis									
Glycera convoluta			1	2					
Glycera branchiopoda				1					
Glycera tenuis			2		1				
Glyceridae	2	4	4		3	4	3	3	1
Hemipodus borealis		2	1	4				2	2
Lumbrineris zonata					1			1	
Lumbrineridae		1	1		2				
Magelona pitelkai			53	3	118	86	2	99	
Magelonidae									
Nephtys californiensis									
Nephtys caecoides					1				
Nephtys ferruginea			4	4	6	5	1	1	1
Nephtys sp.			1			1			
Nephtyidae			1		1			2	1
Nerinides acuta		4	36	13	18	2		12	1
Nothria elegans								1	
Notomastus tenuis									
Notomastus sp.									
Orbiniidae sp.		1							
Spiophanes bombyx						1			
Spionidae			2	1	2	4	1	1	1
Spiochaetopterus costarum			1		1				
Paranoides platybranchia									
Pectinaria californiensis									
Platynereis bicanaliculata									
Unidentified species									
Annelid fragments									
Nemertea sp. A									
Nemertea sp. B					3			1	
Sipunculida									
MOLLUSCA									
Dentalium sp.									
Donax gouldii									
Olivella biplicata	3	D			121				
Tivela stultorum									
PISCES									
Leuresthes tenuis eggs	300	11,000							
Leuresthes tenuis larvae		300							

+ - unidentified larvae and pupae present; D - dead *O. biplicata*

TABLE 6. Species Recorded at Long Beach (March 1973 - July 1974).

LONG BEACH

	March 1973	May 1973	July 1973	September 1973	November 1973	January 1974	March 1974	May 1974	July 1974
CRUSTACEA									
Allorchestes compressa									
Blepharipoda occidentalis									
Caprella brevirostris									
Caprella californica			2						
Caprella verrucosa									
Cirolana chiltoni									
Emerita analoga	1				2	1		1	
Heterophoxus sp.									
Isochelespilosus									
Lepidopa myops									
Paraphoxus epistomus									
INSECTA									
VERMES									
Capitella capitata									
Capitellidae									
Cirriformia spirabrancha									
Dispio sp.									
Eunicidae									
Euzonus dillonensis							3		
Glycera convoluta									
Glycera branchiopoda									
Glycera tenuis									
Glyceridae				1					
Hemipodus borealis									
Lumbrineris zonata									
Lumbrineridae									
Magelona pitelkai									
Magelonidae									
Nephtys californiensis									
Nephtys caecoides									
Nephtys ferruginea		3	2		1	1	2		
Nephtys sp.					1	2			
Nephtyidae									
Nerinides acuta		3	8	3					1
Nothria elegans									
Notomastus tenuis									
Notomastus sp.									
Orbiniidae sp.									
Spiophanes bombyx									
Spionidae									
Spiochaetopterus costarum									
Paranoides platybranchia									
Pectinaria californiensis									
Platynereis bicanaliculata				1					
Unidentified species									
Annelid fragments									
Nemertea sp. A									
Nemertea sp. B									
Sipunculida									
MOLLUSCA									
Dentalium sp.					1**				
Donax gouldii		*							
Olivella biplicata									
Tivela stultorum									
PISCES									
Leuresthes tenuis eggs								18,400	
Leuresthes tenuis larvae								12,300	

* Specimen in survey area but not collected in cores; ** - empty shell.

TABLE 7. Occurrence of Species at Each Site (1971 - 1974)

Species	Outer Cabrillo 1971-72	Outer Cabrillo 1973-74	Inner Cabrillo 1971-72	Inner Cabrillo 1973-74	Long Beach 1973-74
CRUSTACEA					
Allorchestes compressa				+	
Blepharipoda occidentalis	+	+			
Caprella brevirostris				+	
Caprella californica			+		+
Caprella verrucosa				+	
Cirolana chiltoni			+	+	
Emerita analoga	+	+	+	+	+
Heterophoxus sp.	+				
Isochelespilosus			+		
Lepidopa myops	+				
Paraphoxus epistomus		+			
INSECTA				+	
VERMES					
Capitella capitata			+		
Capitellidae	+		+		
Cirriformia spirabrancha			+	+	
Dispio sp.	+		+	+	
Eunicidae			+		
Euzonus dillonensis	+	+		+	+
Glycera convoluta			+	+	
Glycera branchiopoda			+	+	
Glycera tenuis				+	
Glyceridae	+	+	+	+	+
Hemipodus borealis	+		+	+	
Lumbrineris zonata	+		+	+	
Lumbrineridae	+	+	+	+	
Magelona pitelkai	+		+	+	
Magelonidae		+	+		
Nephtys californiensis	+		+		
Nephtys caecoides			+	+	
Nephtys ferruginea	+	+	+	+	+
Nephtys sp.	+	+	+	+	+
Nephtyidae	+	+	+	+	
Nerinides acuta	+	+	+	+	+
Nothria elegans				+	
Notomastus tenuis	+				
Notomastus sp.	+				
Orbiniidae sp.				+	
Spiophanes bombyx			+	+	
Spionidae	+	+		+	
Spiochaetopterus costarum				+	
Paranoides platybranchia	+		+		
Pectinaria californiensis			+		
Platynereis bicanaliculata					+
Unidentified species	+				
Annelid fragments	+	+			
Nemertea sp. A	+	+	+		
Nemertea sp. B		+		+	
Sipunculida			+		
MOLLUSCA					
Donax gouldii	+				+
Olivella biplicata		+	+	+	
Tivela stultorum	+	+			
PISCES					
Leuresthes tenuis		+		+	
TOTAL	26	18	29	29	9

TABLE 8. Intertidal Distribution of Species (1973 - 74).

Species	Outer Cabrillo	Inner Cabrillo	Long Beach
CRUSTACEA			
Allorchestes compressa		(-5)	
Blepharipoda occidentalis	(-5)-(-7)		
Caprella brevirostris		(-5)	
Caprella californica			(-6)-(-3)
Caprella verrucosa		(-5)	
Cirolana chiltoni		(+1)-(+3)	
Emerita analoga	(-6)-(+2)	(-5)	(-4)-(+1)
Paraphoxus epistomus	(-4)-(-3)		
INSECTA		(+3)-(+6)	
VERMES			
Cirriformia spirabrancha		(-6)	
Dispio sp.		(-7)-(-5)	
Euzonus dillonensis	(-4)-(-3)		(-2)
Glycera convoluta		(-6)-(-3)	
Glycera branchiopoda		(-5)	
Glycera tenuis		(-6)-(-5)	
Glyceridae	(+1)	(-3)-(+6)	(-3)-(-2)
Hemipodus borealis		(-2)-(+3)	
Lumbrineris zonata		(-6)	
Lumbrineridae	(-5)-(-4)	(-5)-(+3)	
Magelona pitelkai		(-7)-(-3)	
Magelonidae	(-4)		
Nephtys caecoides		(-6)	
Nephtys ferruginea	(-6)-(-3)	(-6)-(-3)	(-6)-(-4)
Nephtys sp.	(-6)-(-2)	(-3)	(-6)-(-5)
Nephtyidae	(-6)-(-2)	(-6)-(-3)	
Nerinides acuta	(-6)-(-2)	(-7)-(-1)	(-4)-(+1)
Nothria elegans		(-6)	
Orbiniidae sp.		(-4)	
Spiophanes bombyx		(-6)	
Spionidae	(+1)	(-6)-(-1)	
Spiochaetopterus costarum		(-6)	
Platynereis bicanaliculata			(-3)-(-2)
Annelid fragments	(-4)-(-3)		
Nemertea sp. A	(-5)-(-2)		
Nemertea sp. B		(-6)	
MOLLUSCA			
Olivella biplicata	(-6)-(-4)	(-7)-(-5)	
Tivela stultorum	(-5)		
PISCES			
Leuresthes tenuis	(+4)-(+5)	(+2)-(+5)	
Maximum Tidal Range	14	11	10

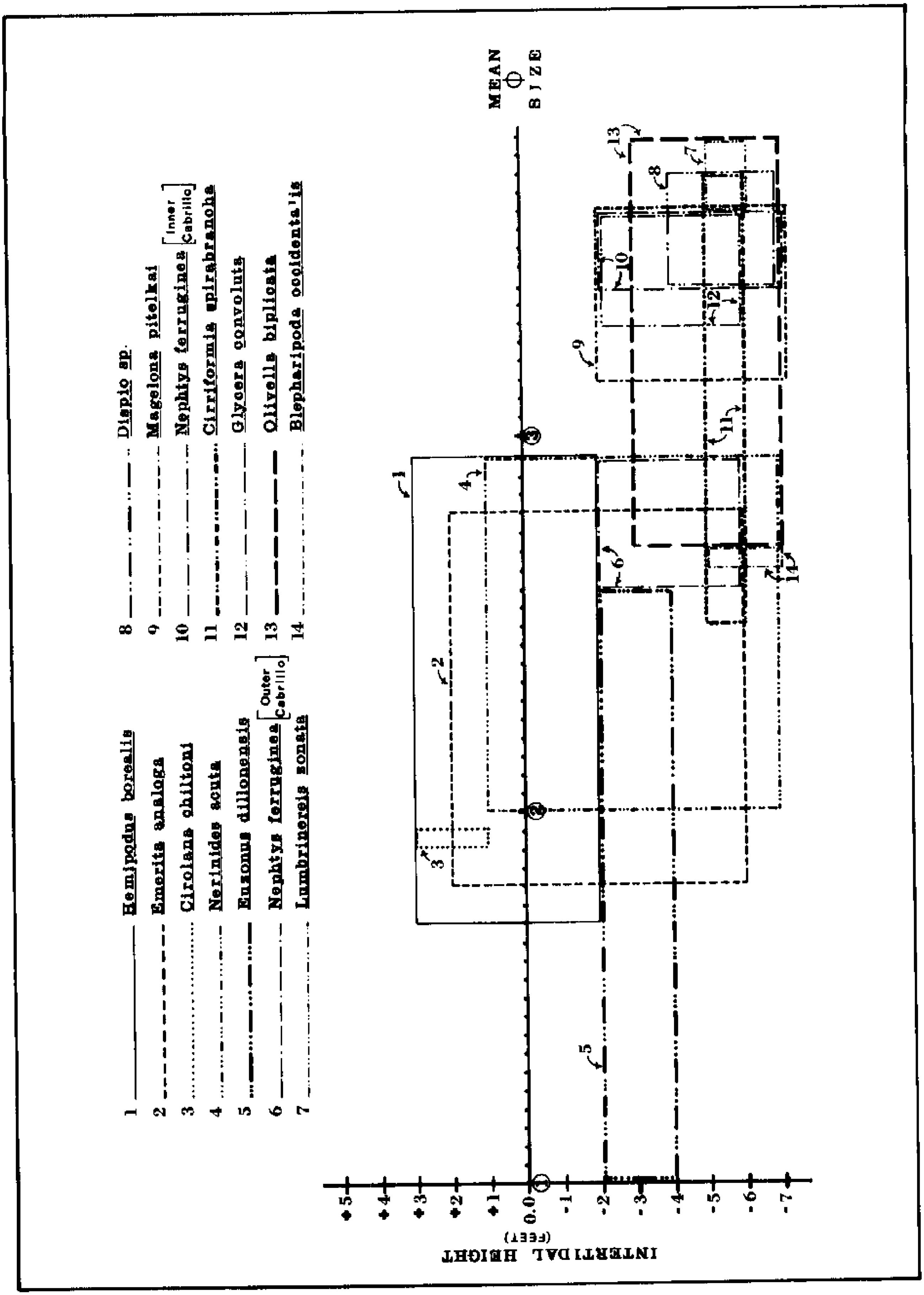
Note. (+1) means a species is found between 0.0 and 1.0 feet above mean water level. (-6)-(-3) means a species is found from 6.0 feet to 2.0 feet below mean water level.

factor causing the division is grain size. Group 1 consists of *Emerita analoga*, *Nerinides acuta*, *Hemipodus borealis*, *Cirolana chiltoni*, *Blepharipoda occidentalis*, *Euzonus dillonensis*, *Nephtys ferruginea* (as found on Outer Cabrillo Beach). All these species except *C. chiltoni* occur at Outer Cabrillo Beach. *Cirolana chiltoni* has been recorded only from Inner Cabrillo Beach. *Emerita analoga* and *N. acuta* are common to all three sites, while *H. borealis* has been recorded from Inner Cabrillo Beach, and *E. dillonensis* from Long Beach. However, this is basically a group of animals found on Outer Cabrillo Beach in a coarse sand environment and exposed to wave action. *C. chiltoni* is commonly found in such an environment (Patterson, 1974).

Group 2 species, *Glycera convoluta*, *Lumbrineris zonata*, *Magelona pitelkai*, *Dispio* sp., and *Nephtys ferruginea* (as found on Inner Cabrillo Beach) live in finer sand sediments and do not extend as high in the intertidal zone as Group 1 species. *Glycera convoluta* is recorded only from Inner Cabrillo Beach, while *Lumbrineris zonata*, *Magelona pitelkai* and *Dispio* sp. are more abundant on Inner Cabrillo Beach than on Outer Cabrillo Beach. In fact, the three latter species were absent from Outer Cabrillo Beach during the 1973-74 survey.

The overlapping Group 3 species are *Olivella biplicata* and *Cirriformia spirabrancha*. Both occur at Inner Cabrillo Beach. *Cirriformia spirabrancha* has not been recorded from the other sites. *Olivella biplicata* is rarely found at Outer Cabrillo Beach, and has not been recorded from Long Beach. These species are found in the fine grain sediments in lower intertidal areas.

DISCUSSION. Intertidal sand temperatures are governed by water temperatures at high tide, and air temperatures at low tide. As a result the distribution of intertidal species is governed by both air and water temperatures. Temperature is probably the most important seasonal influence on the distribution of these species. In both the 1971-72 and 1973-74 surveys, both water and air temperatures exhibited a consistent seasonal pattern. The decrease in temperature generally recorded on May and June surveys is related to a seasonal change in the time of day of surveys and the increase in foggy conditions. It may also be related to changes in water current patterns because a similar change was detected by Soule and Oguri (1974). The data for Outer Cabrillo Beach in May 1973 demonstrates the important influence of weather conditions on water temperatures in shallow inshore areas. The weather was clear and sunny on this occasion and the air temperature was 21.8°C. On consecutive days, when Inner Cabrillo Beach and Long Beach were surveyed, the weather was cloudy and foggy and the air temperature 14.6°C and 14.4°C respectively. However, while there was a numerical correlation between number of species and number of organisms with water and air temperatures in 1971-72, no such relationship was recorded in 1973-74. The


1 Hemipodus borealis
2 Emerita analoga
3 Cirolana chiltoni
4 Nerinides acuta
5 Euzonus dillonensis
6 Nephtys ferruginea [Outer Cabrillo]
7 Lumbrineris zonata
8 Dispio sp.
9 Magelona pitelkai
10 Nephtys ferruginea [Inner Cabrillo]
11 Cirriformia spirabrancha
12 Glycera convoluta
13 Olivella biplicata
14 Blepharipoda occidentalis
MEAN Φ SIZE
INTERTIDAL HEIGHT (FEET)
+5
+4
+3
+2
+1
0.0
-1
-2
-3
-4
-5
-6
-7

possible trends of seasonal increases in populations of *Emerita analoga*, as well as decreases in total biota in March found in the 1973-74 survey, were not recorded in 1971-72. It is concluded that no consistent seasonal trends were observed on these beaches.

The three beaches studied revealed three very different biological communities. The only really consistent factor was the complete absence of species above high tide level and the lack of species at upper intertidal levels. This is no doubt associated with the beach cleaning activities, which remove the needed food sources for the species that would normally inhabit these areas (i.e., *Orchestoidea* sp.)

Outer Cabrillo Beach is exposed to the open ocean, lower water temperatures and greater sand movement, while Inner Cabrillo Beach and Long Beach are exposed to more sheltered harbor waters, higher water temperatures, and less sand movement. Outer Cabrillo Beach is characterized by species found in relatively coarse-sand, open-ocean beaches (Group 1) while Inner Cabrillo Beach is dominated by species found in finer sand areas usually exposed to less wave action (Groups 2, 3).

Long Beach has very few species and organisms. The reasons for this are unknown but are apparently unrelated to natural variables. A sheltered beach such as this would theoretically be inhabited by more species and organisms. Visual examination of the sediment samples suggests that the sand is of a size that normally supports a more abundant community than that reported in this study. Long Beach is adjacent to several possible sources of oil pollution. However, this is probably not the cause of the sparsity of the biota. Sandy beach studies (Straughan 1973) of beaches that receive heavier amounts of oil than recorded in this area, showed that many species absent from Long Beach were abundant in these areas. There was also no evidence of a decrease in organisms or of dead animals specifically associated with the oil contamination of Long Beach, Inner Cabrillo Beach, and Outer Cabrillo Beach in March of 1974. At this time one can only suggest that there is probably some pollution source adjacent to, or which influences, the Long Beach study area, and is responsible for the sparsity of the biota. The Los Angeles River bed, which carries intermittent flow and storm drain runoff, lies immediately to the west of the beach.

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MARINE STUDIES OF SAN PEDRO BAY, CALIFORNIA. PART 8. June 1975

RED TIDES IN THE LOS ANGELES-LONG BEACH HARBOR

by

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Abstract:

The major organism producing Red Tides in the San Pedro Bay area is *Gonyaulax polyedra*. Extracts from laboratory cultures are toxic to fish, but assays on similar extracts from cells harvested from Red Tides show a very wide range of toxicity.

Our studies on Red Tides are made for predictive purposes and in order to establish the sequence of events leading to Red Tides in a highly developed industrial-commercial area. The blooms can follow certain weather conditions which cause stirring of the shallow harbor and resuspension of organic detritus from the sediments. There is also an apparent relationship between the patterns of waste discharge and the appearance of Red Tide. Increased discharge at the opening of the anchovy season is followed in some conditions by a bloom in the outer harbor. Regular monitoring is carried out of coliform bacteria and total plate count of marine microbes. Of particular interest are the recent measurements of bacteriophages present in greater numbers than anticipated and which are being investigated for their role in bacterial breakdown and resultant mineralization processes. Controlled laboratory cultures of dinoflagellates are used to test the influence of compounds from the natural environment and of breakdown products from cultures of the marine bacteria on patterns of growth and toxicity.

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Dinoflagellates are normal components of the phytoplankton in southern California inshore coastal waters throughout the year. Sporadic "blooms" occur, however, which may produce localized patches or cover large areas with muddy, reddish colored waters.

Conditions which may account for the sporadic blooms are beginning to be delineated, so that prediction of blooms may be possible.

With minor exceptions, red tides are restricted by the longshore current to a narrow band of inshore waters along the coast, or to headlands or embayments. Thus, two of the three initial conditions postulated by Ryther (1954) are present; one, the normal dinoflagellate population, and two, a reduced or restricted circulation which prevents a reproducing population from dispersing.

The third condition is a supply of nutrients, although in local waters enriched by sewer outfalls nutrients are probably not a limiting factor. In certain coastal areas, bottom nutrients may be redistributed in surface waters by upwelling,and extensive blooms may occur. Other possible sources of nutrient input might include storm water runoff, but this does not seem to coincide with blooms in local southern California waters.

Although sporadic blooms may occur throughout the year, the most predictable and extensive episode is likely to be in late summer and early fall. The Los Angeles-Long Beach Harbor is a relatively shallow dredged basin with low tidal flushing and low current velocities (less than 0.5 knots near the Los Angeles entry)(Robinson and Porath 1974). The principal driving mechanism is wind, which is usually southwesterly and light. The bottom sediments are mostly fine black silt, contaminated with a high incidence of trace and heavy metals, chlorinated hydrocarbons, microbial populations, and organic detritus (Chen and Lu 1974).

Stirring of the harbor appears to be a fourth condition for blooms. In the late summer and early fall thermal inversion such as can be found in fresh water lakes may occur. Chilling of surface waters causes warmer bottom waters to rise, resuspending bottom sediments and nutrients.

At various times throughout the year, the wind direction changes to the northeast and strong, warm gusty "Santa Ana" winds blow from the desert areas. These cause stirring of the harbor and also may spread clouds of dust over the waters. Red tide blooms may follow such winds within a week or two.

Another potential triggering mechanism may be warm water effluents from cooling systems, such as are found at power plants and oil islands, or from sewer and industry outfalls.

Warm ponds or patches or water may provide a microcirculation, and may also stimulate reproductive cycles in the phytoplankton.

The presence of the organisms, existing low circulation, adequate nutrients, stirring mechanisms, and possibly warm temperature areas all appear to be conditions conducive to local red tide blooms. But these conditions do not provide an adequate explanation of the mechanisms involved in the bloom.

Various organisms have been associated with phytoplankton blooms in the harbor. On several occasions a localized bright "green tide" patch was observed which consisted of a euglenoid bloom. Other greenish and brownish blooms occur occasionally, but the most pronounced and widespread red blooms are caused by Gonyaulax polyedra. Densities of these organisms may range from less than 1/ml to 15,000 cells per ml.

Within the Los Angeles-Long Beach Harbor, several sites have been identified as potential foci of red tide occurrence. These include the area around Fish Harbor, Channel 2 in Long Beach, and near the mouth of the Los Angeles River in the bay where the oil islands are located.

The Fish Harbor area has been studied extensively by our group, Harbors Environmental Projects. It is sponsored by the USC Sea Grant program and by the Allan Hancock Foundation, with funds from the Los Angeles Harbor Department, the Army Corps of Engineers, the Tuna Research Foundation and Pacific Lighting International. A pilot project was begun almost five years ago to conduct biological baseline and monitoring studies in the area. This has since been expanded to include microbiology, benthic organisms, phytoplankton productivity, zooplankton, fish populations, intertebrate settling potential, physical water quality, nutrient chemistry, hydrology, sediment chemistry, biomass and bioassay.

Fish Harbor consists of two basins; outer Fish Harbor, which contains a yacht anchorage, and Inner Fish Harbor around which the canneries are located.

Wastes from the canneries and fishing boats were formerly dumped into Fish Harbor, but some years ago the cannery discharges were relocated to the east, in the vicinity of the Terminal Island primary treatment sewage outfall. The area is very shallow, since dumping of dredge spoil and land fill was permitted in the area. Thus conditions of high biochemical oxygen demand (BOD) and chemical oxygen demand(COD) are present(Chen and Lu, 1974).

Drogue and current meter studies (Soule & Oguri, 1972) show that the waste input is on the north edge of a clockwise gyre, which under normal Southwest winds, carries the waste waters east toward the navy mole. The falling tide pulls the water mass toward Angels Gate, and the incoming tide directs it back into Fish Harbor or up the main channel. Thus poor mixing and dispersal results, but normally the receiving waters have sufficient capacity to maintain required water quâlity criteria of 5 ppm at 1,000 feet from point of discharge. Under Santa Ana (NE) wind conditions, wastes tend to remain in the outfall area rather than be dispersed and diluted in the gyre.

Oxygen depletion in these waters may lead to sulfide production by bacteria and a "white tide" composed of a mixture of bacteria and colloidal sulfur may result.

The normal seasonal wind and water changes, temperature changes and nutrient input may cause localized blooms at any time of the year. However, in the late summer and early fall, natural turnover may coincide with the opening of the anchovy (wet fish) season in mid-September. This results in a cannery waste discharge increase from about 2 MGD to about 10 MGP, and has in the past reached as high as 25 MGD. In 1974, however, the fishermen were on strike and no anchovies were processed, but a severe red tide occurred. It appeared first in the Long Beach area and ultimately covered all the adjacent inshore waters of both south and west coasts.

A sequence of events has been noted in the oxygen curves for the Fish Harbor area. Shortly after the appearance of white tide, red tide begins to appear in waters peripheral to the white tide. Dissolved oxygen (DO) drops rapidly in the white tide area from 7-8 ppm to zero or near zero. White tide then begins to disappear and red tide proliferates. Daylight oxygen readings climb rapidly and readings may reach 14-16 ppm. At night, the phytoplankton apparently utilize the oxygen, because oxygen is greatly reduced just before dawn.

Red tides in the Los Angeles-Long Beach Harbor have been cited as being involved in fish kills on several occasions. However, circumstances suggest that these may be due to oxygen depletion rather than to toxicity of the phytoplankton. Fish have been observed swimming through the red tide in the early stages of a bloom with no apparent problem. As the bloom becomes senescent and oxygen levels fall, fish in the bloom area appear at the surface, gasping, as though for oxygen. Chamberlain (1974 in press) suggests that at the air-water interface minute amounts of dissolved oxygen may be present. Chamberlain transferred some apparently moribund fish to well oxygenated aquaria, and they recovered, with normal swimming behavior.

Cells from red tides in the harbor have been recovered during the past four years and extracted for toxins. Crude ethanol extracts were added to tanks containing mosquito fish Gambusia affinis, at a concentration of 0.5%. Extracts from blooms in the late summer of 1971 and 1972 showed ample evidence of toxicity, but blooms from 1973 and 1974 showed greatly reduced toxicity. This suggests that the toxicity is induced by some external factor which may be incorporated into the phytoplankton.

Regardless of whether the biological kills are due to oxygen depletion or toxicity, they set the scene for another bacterial bloom. Mussels (Mytilus) on pilings show gills clogged mechanically by the Gonyaulax cells; they smother and fall to the bottom, where they decay. Given (pers. comm.) reported a white, presumably bacterial film over much of the bottom, along with remains of decaying organisms when he conducted a diver survey in Long Beach following the red tide.

At times the bacterial-red tide cycle will not produce a bloom when it might be expected. Seasonal wind or rain storms from the northwest or south and peak high tides may cause sufficient mixing and dispersal to break the cycle. Such storms may at the same time cause stirring, but if the water temperature decreases as well, bacterial activity may decrease sufficiently to prevent bloom conditions.

In normal bacterial cycles, mass, sudden die-off rarely occurs. Rather, mixed populations will move in the direction of dominance by one or several species until nutrients are exhausted. Research is presently underway to identify factors which might serve to cause a restricted cycle in the marine bacteria. We have recently detected higher levels of bacteriophage activity in the harbor than would normally be anticipated in marine waters, especially in the Fish Harbor area. Plaque formation of up to 40 per ml. have been recorded in culture tests, whereas less than 1 per ml would be expected in coastal marine waters (C. Frey, pers. comm.)

In attempting to correlate these observations with studies in the laboratory we have been hindered by the absence of axenic cultures of the causative organism *Gonyaulax polyedra*. Parallel experiments have been carried out on another dinoflagellate, *Gymnodinium breve*, which is responsible for the ichthyotoxic Red Tides of the Gulf of Florida. We have these in pure culture, bacteria free and in defined growth medium.

Earlier studies showed that when cultures of *G. breve* were made bacteria free by the action of antibiotics and grown in a Minimal Experimental Medium (MEM) there was a delay time of up to 8 days before the cells entered a logarithmic phase of growth. This delay was immediately eliminated if very low (hormonal) levels of gibberelic acid were added to the medium (now labelled MEG).

During the past months we have extended these studies to investigate the effect of added naturally occurring marine bacteria to the axenic cultures grown in Minimal (MEM) medium. When contamination by the bacteria is permitted the delay time of the growth phase after the procedure of subculture is reduced and the addition of gibberelic acid has little or no effect.

Thus we believe that the presence of natural bacteria provides an environment probably by the release of some chemical compound at low level which stimulates the division of the cells in culture. It is possible that some such event occurs in nature as suggested by the bacterial bloom in Fish Harbor running ahead of a Red Tide there. Thus the link between bacterial blooms and Red Tide blooms appears to be consistent and probably significant.

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