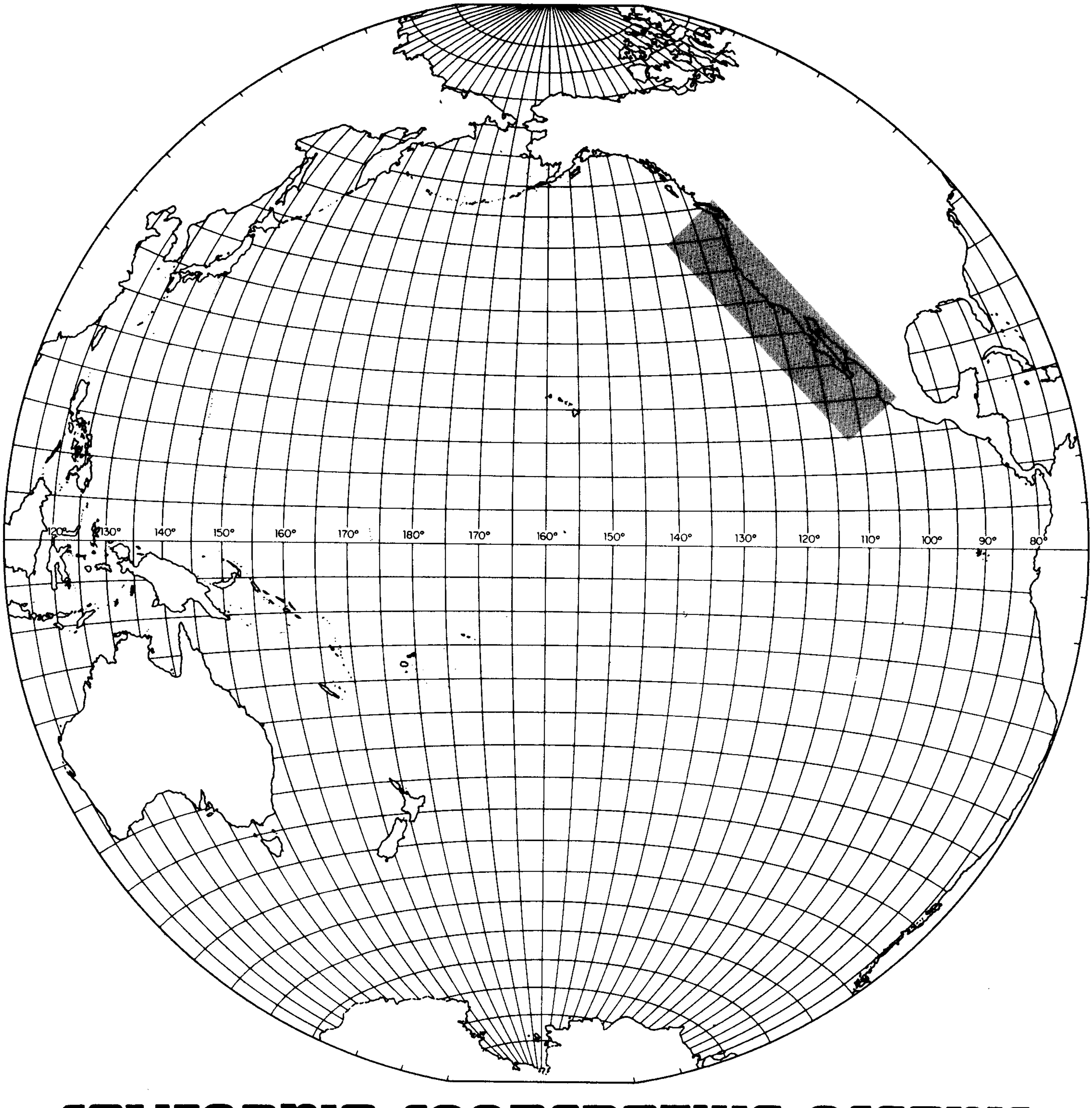
STATE OF CALIFORNIA
MARINE RESEARCH COMMITTEE




# CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

## REPORTS

VOLUME XVI

JUNE 1972

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STATE OF CALIFORNIA
DEPARTMENT OF FISH AND GAME
MARINE RESEARCH COMMITTEE

# CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

## Reports

VOLUME XVI
1 July 1970 to 30 June 1971

*Cooperating Agencies:*

CALIFORNIA ACADEMY OF SCIENCES
CALIFORNIA DEPARTMENT OF FISH AND GAME
STANFORD UNIVERSITY, HOPKINS MARINE STATION
UNIVERSITY OF CALIFORNIA, SCRIPPS INSTITUTION OF OCEANOGRAPHY
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, NATIONAL MARINE FISHERIES SERVICE

1 June 1972

STATE OF CALIFORNIA—RESOURCES AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF FISH AND GAME

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5 January 1973

The Honorable Ronald Reagan
*Governor of the State of California*
*Sacramento, California*

Dear Governor Reagan:

We have the honor to submit the sixteenth report of the California Cooperative Oceanic Fisheries Investigations.

The report consists of three sections. The first contains a review of the administrative and research activities during the period 1 July 1970 - 30 June 1971, a description of the fisheries, and a list of publications arising from the programs.

The second section consists of papers presented at a symposium "Pollutants and Contaminants in the California Current System" held in November 1970, which brought together officials charged with regulating the use of hazardous materials which as wastes or escapes may pollute the environment objectionably.

The third section consists of scientific contributions to knowledge of the distribution of such substances in marine environments, the processes controlling the distribution, and effects on marine organisms.

Respectfully submitted,

Charles R. Carry

THE MARINE RESEARCH COMMITTEE
Charles R. Carry, *Chairman*

# CONTENTS

*Calif. Mar. Res. Comm., CalCOFI Rept.*, 16: 5–16, 1972

## Part I

# REVIEW OF ACTIVITIES

1 July 1970–30 June 1971

## REPORT OF THE CALCOFI COMMITTEE

This volume primarily contains papers presented at the Annual CalCOFI Conference, November 23–25, 1970, as invited contributions to a symposium entitled *Pollutants and Contaminants in the California Current*. Some newsworthy concurrent events were: the Santa Barbara oil spill, February 1969; a shipment of canned mackerel found to contain a DDT concentration above the legal tolerance, December 1969; several lots of canned tuna found to contain mercury concentrations above the legal tolerance, December 1970.

The symposium was therefore timely in examining the state of knowledge of microconstituents in the sea and the measures being taken or planned to minimize possible hazards.

Most speakers were: representatives of public agencies with responsibilities for control of the use of hazardous substances; those directly responsible for safe and efficient operation of waste disposal facilities; and scientists studying distribution and effects of potentially hazardous waste and spilled materials in marine environments. Most of these individuals had only recently been assigned responsibilities with respect to marine pollution or had become interested in it as a field of study in the last few months or years. The speakers clearly were open-minded on questions concerning the origin, extent, effects, and control of pollutants in the sea.

Scientific presentations were concerned chiefly with heavy metals, pesticides and petroleum. Studies in lagoons, harbors, sediments in shallow water near sewer outfalls, and water and organisms in the open sea were described. One participant discussed the occurrence of the lipids or fat-soluble substances that occur naturally in many marine organisms and which are similar to components of petroleum. One presentation described the coastal sea water circulation, which is a major factor in the spread and dilution of materials originating on land. Another speaker discussed the results of a pollution abatement program.

The public officials presented a vivid picture of the number and variety of ways in which pollutants affect or may affect public health and safety and thus require complex, comprehensive, and novel means of monitoring and control.

The general conclusion was that while it is doubtful that catastrophe is imminent, various kinds of pollution already warrant careful study and monitoring. At this date pollution in the sea has been measured or observed with certainty only locally around outfalls, harbors, river mouths and spills. However the waste disposal requirements of the growing population of coastal California, and the importance of the resources of the California Current to the citizens, dictate the necessity of planning effective controls to be applied when and where needed. *Izadore Barrett, Herbert Frey, John Isaacs, and Marston Sargent, August 1972.*

# AGENCY REPORTS

## CALIFORNIA ACADEMY OF SCIENCES

The investigations during 1970–71 have been directed primarily toward study of the food habits of the squid (*Loligo opalescens*) and the Pacific hake (*Merluccius productus*). This work has been carried on by Anatole S. Loukashkin. At the meeting of the Marine Research Committee on October 22, 1970, Mr. Loukashkin asked and received approval of the Committee to also further pursue his previous studies of the food and feeding habits of Pacific mackerel and jack mackerel in order to round out his earlier investigations and clarify certain points that lack of material and insufficient opportunity for field observations had left in doubt. In particular he wishes to obtain more data on food of different age groups, and to observe feeding patterns and feeding behavior at sea, as was done in his study of the northern anchovy.

The investigation of squid has thus far proceeded as follows. Forty-six male specimens were collected for us by Mr. James Hardwick at Pfeiffer Point in Southern California on November 13, 1970, using line and jig. Of these, 42 stomachs were filled with food, mostly crustaceans; a few contained remains and bones of small fish. 120 squids picked up from commercial landings at Monterey Bay on December 10, 1970, (103 males and 17 females) contained no food in their stomachs. 21 specimens (3 males and 18 females) were received from Mr. S. Kato, Fishery Oceanography Center at La Jolla, collected near Catalina Island on January 21, 1971, using an electric lamp and a fish pump. Five stomachs contained some unidentified crustacean remains and some indeterminate fleshy and jelly-like remains. The rest were empty. This suggests a periodic non-feeding time, related to breeding activities or other factors.

Of Pacific Hake, Ken Mais of the California Department of Fish and Game collected 110 specimens ranging in size from 130 mm. to 255 mm. (total length) during a cruise of the M/V ALASKA in the Channel Islands area. Only nine stomachs were empty. The remaining 101 contained food in various quantities, ranging from "very poor" to "well filled" (four were "gorged"). The only food found was euphausiid crustaceans—100 per cent. It cannot yet be said with certainty whether the hake feeds selectively on these, or whether they happened to be the dominant food of suitable size that was available.

Of jack mackerel, 32 specimens ranging in size from 105 to 355 mm. were picked up by Jim Hardwick from commercial landings in Monterey Bay on January 26, 1971. Three stomachs were filled to extreme capacity ("gorged"), containing one or two intact small squids. The rest contained small quantities of fleshy and jelly-like substances, probably remains of fish. 193 specimens were collected in April and May by Ken Mais in a cruise of the M/V ALASKA in the Channel Islands area. Of these, 23 stomachs contained no food. The remaining 168 stomachs contained food, ranging in amounts from "very poor" to "capacity" (four were "gorged"). The food consisted of euphausiids (44.2 per cent), copepods (22.4 per cent), crustacean remains (6.7 per cent), fish remains (3.6 per cent), polychaete worms (1.8 per cent), mysid remains (0.7 per cent), salps (0.6 percent), and indeterminate fleshy remains (20 per cent).

This confirms our previous report, in which we considered jack mackerel to have a dual mode of feeding relative to the food available—particulate feeding on euphasiids or fish, filter feeding on copepods or other small crustaceans.

*Robert C. Miller*

## CALIFORNIA DEPARTMENT OF FISH AND GAME PELAGIC FISH INVESTIGATIONS

### *Sea Survey*

Sea survey cruises this year were more varied in methodology and purpose than those of the past 4 years. Nine cruises, totaling 163 vessel days at sea, were conducted aboard the research vessel ALASKA. Routine acoustic-midwater trawl surveys were made during fall, winter, and spring off southern California. Waters off Baja California were similarly surveyed by two cruises in May and June.

Most work on anchovies this year centered on behavior and commercial availability studies. Results have provided some insight into causes of poor or successful fishing and resultant catch fluctuations. Extreme behavioral patterns of anchovies observed this year indicate anchovy reduction fishery landings can fluctuate rather drastically due to availability to purse-seining gear. The summer months have been periods of poor availability as determined by past surveys, aircraft surveillance, and information gained from a single purse seine vessel fishing out-of-season by special permit. At this time of year, schools are highly scattered over the deep water basins of southern California. The only commercial concentrations were found in shallow inshore waters in the Santa Barbara area which are closed to anchovy purse seine fishing. Large compact schools began to form south of San Pedro by the end of August. In early September, these schools had moved into San Pedro Channel and were highly available to the reduction fishery when the season opened September 15. An acoustical survey in September and October found anchovies highly concentrated within 20 miles of shore between Newport Beach and Point Dume. These fish stayed densely schooled in this area through January, during which time the reduction fleet landed a record catch.

Surface temperatures during late winter of 1970 and spring of 1971 were among the lowest on record in the temperate eastern Pacific and may have been responsible for poor anchovy availability and failure of the spring fishery in southern California. Acoustic surveys during this time found anchovies plentiful but highly scattered in noncommercial schools. These surveys indicated spring commercial concentrations formed much later than usual and after the reduction season had closed. A survey in February, during which a 1 month fishing closure was in effect, detected a mass exodus offshore and scattering of anchovies toward the south and southeast. Anchovies at this time were distributed over a wide area in numerous small surface schools which is a behavioral pattern typical of spawning. An April survey found the population had moved somewhat inshore and northwest, but was still highly dispersed in small schools. Near the conclusion of this cruise, there were indications of large commercial school formation. This was substantiated by sudden improvement of commercial catches that continued for the final 2 weeks of the reduction season. Aircraft surveillance and reports from commercial fishermen indicate availability was good the latter half of May and most of June.

Acoustic surveys of southern and central Baja California waters were made during May and June. These surveys completed temporal coverage of Baja California waters. They found far better anchovy availability than did surveys during other seasons. Both surveys indicated good but limited commercial concentrations of anchovies along the narrow coastal shelf of this region. Schools ranging from 5 to 150 tons were detected and sampled. Age-length data from these fish further substantiated the existence of a separate subpopulation residing in southern and central Baja California.

Studies made on echo sounder and sonar survey methods indicated both equipment systems underestimate the number of anchovy schools. Echo sounder estimates are lower due to the tendency for surface schools to flare from the vessel's path, thereby avoiding detection. Sonar fails to detect small schools at intermediate and long ranges. When the two equipment systems were compared, the echo sounder detected 4 to 6 times as many schools per unit of area as did sonar.

A survey of offshore waters between central California and northern Baja California was made in August to locate and sample large old adult jack mackerel reportedly residing in this area. None was detected or caught. Apparently this population of older fish is located more northward during summer. During fall months in southern California, small jack mackerel from the previous spring spawning were quite vulnerable to our midwater trawl. The September-October cruise took juvenile jack mackerel in 43% of the trawl tows. This was the best catch made for several years and was an indication of a strong 1970 year class.

Acoustic surveys in southern California during the spring of 1971 detected extensive concentrations of juvenile hake ranging from 158 to 187 mm standard length. Schools consisted of small discontinuous groups of fish forming a coarse scattering layer 125 to 145 fathoms from the surface over deep water basins between San Pedro and Port Hueneme. Some layers extended at least 5 miles. This is the first substantial quantity of hake found by our sea surveys, and can be attributed to our recently acquired improved echo sounding system.

A night-light, blanket-net, survey in Baja California and southern California was conducted in September 1970 to assess the incoming year class strength of Pacific mackerel and Pacific sardine. Pacific mackerel of the 1970 year class were taken at 6% of the stations occupied with all but one sample being taken in Sebastian Vizcaino Bay, Baja California. These results indicate another poor year class when compared with similar surveys over the past 20 years.

One postlarval fish was the only sardine taken during the night light survey and none were caught in the 200 midwater trawl tows made in California and Mexican waters during the year. The sardine population apparently is too small to detect by present survey methods.

A special saury survey was conducted in November 1970 to study their distribution and abundance in central and southern California waters. Very few schools were located. The only commercial concentration consisted of a 10 ton school of fish ranging from 182-240 mm fork length. This school was found close to shore in Monterey Bay. Smaller, but more numerous schools of smaller fish were located and sampled in Santa Cruz Basin in southern California. Offshore search was unsuccessful and presented severe operating problems due to prevalent weather conditions. Small quantities consisting of 1 to 50 very small juveniles were frequently attracted by night light stations on other cruises.

Large concentrations of Panama lightfish, *Vinciguerria lucetia,* were located and sampled offshore from southern Baja California. Schools extended over a 10 mile area and were found at 35 to 40 fathoms from the surface during daylight hours. Some schools were nearly 40 fathoms thick and very likely contained over 100 tons of fish. Midwater trawl catches in this area consisted of 97% Panama lightfish and the remainder postlarval northern anchovies. This was the most offshore (165 miles) major concentration of fishes yet discovered by sea surveys. The Panama lightfish appears to be a major potential resource in the subtropic region of Baja California pending development of efficient capture gear and commercial use.

Pelagic red crabs appear to be the largest macroconstituent of the marine biomass in central and southern Baja California. They represent a large latent resource and may have the greatest potential of any unutilized species in the California Current System. The two spring surveys of 1971 indicate spring is favorable for harvesting pelagic red crabs by midwater trawl. Approximately 1,200 pounds of live crabs were delivered to National Marine Fisheries Service for studies of utilization in human and animal consumption. Preliminary reports on both uses have been optimistic.

A new scientific echo sounder was installed aboard M/V ALASKA in early 1971. This equipment has greatly improved our capabilities to detect deep dwelling midwater and bottomfishes. The recent discovery of large hake concentrations would have been impossible without this new equipment.

Data reports covering sea surveys during 1968, 1969, and 1970 were published in California Cooperative Oceanic Fisheries Investigations Data Report series. Edited reports of cruises completed through June 1971 have been compiled, and will be combined into a single report for publication at year's end.

***Sea Survey Data Analysis***

During the fiscal year, considerable time was spent on developing a plan for a systems analysis of the Pelagic Fish Program. The first phase consisted of determining program objectives, describing the present system, and compiling an inventory and index of relevant historical data. This study is designed to improve the effectiveness of our research efforts.

Analysis of all data pertaining to the jack mackerel resource was continued. Jack mackerel otoliths collected during the 1968–69 and 1969–70 seasons were read. A computer program to determine age composition of catch for these seasons is being developed.

—*K. F. Mais*

## HOPKINS MARINE STATION

The Hopkins Marine Station of Stanford University at Pacific Grove, California, has conducted a continuous hydrobiological survey of Monterey Bay and adjacent waters since 1951. Under the program, the Station monitors the marine environment, and is involved in studies of the pelagic food chains and their relation to the biological oceanography of Monterey Bay.

Collection of basic oceanographic data in Monterey during approximately bi-weekly cruises to six stations continues along with recording of daily shore temperatures at Pacific Grove and Santa Cruz. Both shore and cruise data are compiled and distributed to interested agencies and individuals in the form of an Annual Data Report.

During 1970–71, the study of entry and transfer of DDT residues in pelagic marine food chains was concluded. Under this portion of the program, continuous samples of seawater and organic particulate material collected along linear transects in the California Current system were analyzed for DDT residues, and it was found that DDT residue concentrations in whole seawater, as determined by continuous-flow liquid-liquid extraction, ranged from $2.3 \times 10^{-12}$ g/ml off Oregon and Washington, to $5.6 \times 10^{-12}$ g/ml off Southern California. Geographical patterns in these concentration values were considered in relation to mechanisms of land-sea DDT residue transfer. DDT residue concentrations in particulate material, collected by continuous-flow centrifugation and filtration of the centrifugal pellet onto GFC glass fiber filters, ranged from 1.2 to $5.7 \times 10^{-6}$ g/g carbon (with one exception). These values were related to the density of the standing crop, but DDT residues in this particulate fraction accounted for less than 10% of the DDT residues in the whole seawater samples. However, residues which are fixed to particles of less than 1–2 μ in diameter could have accounted for the balance of the DDT residues in the whole water samples. Certain experimental results implicate adsorption as the uptake mechanism for algal cells; these experiments also support the idea that 1–2 μ diameter particles carry most of the DDT residues in whole seawater.

*Euphausia pacifica* Hansen, an important constituent of the zooplankton in the California Current, was studied. Results indicated that this organism can acquire sufficient DDT residues from its food to account for amounts found in its tissues, and assimilation efficiencies for DDT residues in ingested food were found to be similar to published figures for assimilation of carbon from food. Interestingly, the direct uptake of $^{14}$C-DDT from water was partially reversible by returning animals to unlabelled flowing seawater; $^{14}$C-DDT present in animals after two weeks' exposure to flowing seawater was apparently retained in proportion to the fat percentage of the individual animals. Various effects of dietary change, moulting, and surface to volume ratios on observed natural levels were also evaluated.

In addition to the phytoplankton and zooplankton studies, the DDT residue content of different size classes of *Engraulis mordax* Girard, an important planktotrophic fish of the California Current system, was also analyzed. These were found to range from 0.2 to 2.8 parts per million, wet weight. Highest concentrations were found in fish of 17 to 22 grams wet weight, which correspond to the third year class. Mature male fish had higher DDT residue concentrations than younger sexually maturing fish, possibly due to loss of DDT residues in reproductive materials or other mechanisms related to the annual oil cycle. Fish of less than 13 grams wet weight had a constant amount of DDT residues per unit of fat; they also had much lower wet weight DDT residue concentrations than any of the larger fish. A model of DDT residue assimilation from food and DDT residue loss via transport in the reproductive materials was developed and used to integrate these findings.

—*Malvern Gilmartin*

## MARINE LIFE RESEARCH GROUP SCRIPPS INSTITUTION OF OCEANOGRAPHY

For many years the Marine Life Research program at Scripps concentrated on the ecology of the California Current system. In recent years the program has been broadened to include other topics that affect the resources of the California Current of interest to the people of California. The following are short reports on a few of the studies of Marine Life Research Group. Other reports were given in last year's Annual Report.

Tetsuo Matsui and Richard Rosenblatt have recently begun a study of the little known life history of sablefish and grenadier off Southern and Baja California. In the deep waters off Baja California and Southern California, sablefish (*Anoplopoma fimbria*) are usually found between 200 and 800 fm. To the northward, off Oregon, Washington and Alaska where they are fished commercially, sablefish are found nearer the surface. Off California, there is almost no fishery for sablefish because they inhabit only the greater depths.

Species of grenadier are found at depths within the sablefish range and at greater depths (to at least 3200 fm). The species (*Coryphaenoides acrolepis*) off Southern California are found between 500 and 1300 fathoms. This species is a wide-ranging fish also found off Japan.

The compelling need to study the life history of the sablefish and grenadier off Southern California is that no eggs, larvae or small fish have been found. These two fish constitute a very large portion of the fish population at these bottom depths.

One of the very interesting findings so far in this study is that most of the males and females are separated geographically. Sablefish and grenadier taken at selected stations since February 1971 have been mostly females; for grenadier the ratio has been roughly 5:1. The males have been much smaller than females. From a station in April, 1970, off Guadalupe Island, all 12 grenadier taken were males as large as most females, and one was nearly as large as the largest female caught to date. Of four stations where males dominated, only one had a female. The distances between male dominated and female dominated areas appeared to be related to topography, the female fish being taken on the bottom of the San Clemente trough and the males higher up on the slopes. The few grenadiers taken in trawls show a more equitable sex ratio. Mention of this segregation by sex in these two species is not found in the literature. This research is continuing to determine more about the sex ratio at various locations and to look for the eggs, larvae and young fish.

Estimates of total primary production in the Ocean may have to be revised upward according to the research of John McGowan, Elizabeth Venrick and Arnold Mantyla. Most of the past work on total primary productivity has been based on data that were taken above 25 meters and over half of the measurements were made only from sea surface data. Most estimates of total production in the water column have been strongly dependent upon some assumed depth of zero productivity. This is traditionally taken to be the depth at which the light intensity has been reduced to 1% of the incident radiation. From this recent research it appears that the deep chlorophyll maximum occurs below the depth of penetration of 1% of the incident surface radiation most of the year in the central gyres of both the North and South Pacific. This may represent a major portion of the standing crop of plant material and thus account for a substantial portion of the primary productivity. The rate of production throughout the water column is variable on rather small spatial and temporal scales, but appears to be considerably greater than the maximum estimate of 100 mg $C/m^2/day$ estimated by Koblentz-Mishke and others. From the present data it is expected that a similar chlorophyll maximum may be well developed in other large, persistent temperate gyres, such as the south Atlantic and Indian Ocean. If found, the estimates of world ocean primary productivity will need to be revised upward.

Joseph L. Reid has continued a study of the abyssal circulation of the world ocean. Work at sea during this period included 42 days aboard the *Thomas Washington* in the Antarctic Ocean south of New Zealand. The immediate purpose of the expedition was to make long series of measurements (15–26 days) of the velocity near the bottom of the ocean (about 3000 meters in the area studied) and in particular to confirm an estimate of flow toward the west near the coast of Antarctica. The larger purpose was a continuation of the studies of Antarctic circulation carried out earlier in the Drake Passage; these studies are part of the general study of the exchange of water between the Atlantic, Indian, and Pacific oceans through the Antarctic Circumpolar Current.

Westward flow was found in the deep waters close to Antarctica; the very cold and salty water from the shallow Ross Sea was observed to be moving westward across the Macquarie-Balleny Rise. In addition to the detail near Antarctica, the results have been combined with earlier results to provide a map of the surface currents of the Antarctic Ocean (geostrophic flow at the sea surface relative to about 1000 meters depth) in the Pacific sector south of 40° S. This clearly reveals the nature of the westward flow that exists south of the main eastward flowing Antarctic Circumpolar Current.

In another study the contribution of the Atlantic Ocean (Norwegian Sea and Weddell Sea) to the bottom waters of the North Pacific has been shown. The very saline waters of the North Atlantic are traced into the Antarctic and then eastward with the Antarctic Circumpolar Current (where they are cooled and freshened) into the South Pacific and northward into the North Pacific.

The first phase of the halophyte program, under the direction of John D. Isaacs with the assistance of Walter Schmitt and Peta Mudie, has been nearly completed. It has been clearly demonstrated that some plants can be grown in sea water. Table beets were grown to maturity in sea water after they were started in fresh water for the first two months. Other plants being grown in various concentrations of sea water are Swiss chard, broccoli, bell pepper, cherry tomato, celery, marguerite, calendula, stock, statice and sea pink. As expected, some are doing better than others. These plants are being grown in sand or hydroponic solutions. The specific objectives of the first phase of the programs are: 1. Examine and evaluate accepted concepts regarding factors controlling plant growth under saline conditions, 2. Demonstrate growth in sea water of economically important plants, 3. Evaluate, under controlled conditions, related work on sea water irrigation, 4. Examine the opportunities for exploiting the genetic salt tolerance of halophytes through hybridization or grafting with related economic taxa, and 5. Elucidate research opportunities for improving salt resistance of plants.

Professor Isaacs points out that the greatest potential of the experiments with salt water may be the eventual hybridization of true salt tolerant plants, or halophytes.

There are many other projects in Marine Life Research that cannot be elucidated in this short review. Those that will be reported in the next annual report are: vertical migration, a tactic to maximize net yield of primary production to the zooplankton; enhancement of natural marine productivity by artificial upwelling; and an open ocean wave powered electrical generator. —*John Isaacs*

## NATIONAL MARINE FISHERIES SERVICE SOUTHWEST FISHERIES CENTER

### *CalCOFI Report—FY—1971*

As described in the previous report, the formation of the National Oceanic and Atmospheric Administration (NOAA) in the U.S. Department of Commerce on October 3, 1971, consolidated many of the ocean and atmospheric-oriented activities of the federal government. The Bureau of Commercial Fisheries, one of six agencies transferred into NOAA, was re-named the National Marine Fisheries Service (NMFS).

Nine months after the formation of NOAA, a major reorganization was announced by Dr. Robert White, Administrator of NOAA, which greatly affected the organization of fishery laboratories in NMFS. Among other changes this plan placed laboratories with common interests under single scientific and technical direction. Four major national offshore fishery centers were established among which is the Southwest Fisheries Center (SWFC) with headquarters in La Jolla. The SWFC includes the former Hawaii Area Fishery Research Center, now renamed the Honolulu Laboratory and the Fishery-Oceanography Center, now the La Jolla Laboratory.

During all of FY–1971, however, the La Jolla Laboratory continued to be organized into four multidisciplinary research groups involved in problems associated with the coastal pelagic fisheries of the California Current and with the tuna fisheries of the warmer parts of the Atlantic and Pacific Oceans. Although all of these research groups, with the exception of the Fishery-Oceanography Group which is concerned with research into the ecology and biology of tuna populations and into the processes of their ocean environment, contain some elements of CalCOFI-coordinated research, the Population Dynamics Group has the main responsibility for CalCOFI research at the La Jolla Laboratory.

### *Acoustic Surveys*

An important part of the work of this Group, under Dr. Paul E. Smith concerns the identification and assessment of unexploited resources by fish egg and larval surveys and the development of the methodology of such surveys. During the past 2 years acousticians in this Group have been perfecting techniques for the rapid counting and measuring of pelagic fish schools using scientific fishfinding sonars on the NMFS research vessel, DAVID STARR JORDAN. These have included the development of a first approximation to the number of fish schools in the 200,000 square-mile study area in the California Current, estimation of the horizontal dimensions of fish schools, derivation of a conversion from fish school size to fish school weight and development of a technique for predicting the variability of effective range as affected by internal waves, vertical migration of fish schools, variation of target strength of schooling fish and depth of the towed sonar transducer.

The first of two approaches to estimating the size of clupeoid fish within schools was tried on JORDAN in early January 1971. Small explosions and electrical discharges were triggered near concentrations of fish. Analyses of the sound spectrum of the discharge and the sound spectrum of the echo from the fish aggregation were compared to identify frequencies where the resonance of the fish gas bladder had increased the echo level.

On a subsequent JORDAN cruise in mid-May, Van Holliday, a UCSD graduate student in applied physics, demonstrated that acoustic resonant frequency analysis of fish swim bladders is a practical technique with potentially important applications in monitoring the growth and survival of juvenile fish with air bladders. An example of how this technique may be applied can be illustrated for the Pacific hake. From theoretical considerations and growth information, a hake at a depth of 64 m, would change in resonant frequency from more than 9 kHz (kilocycles per second) to 0.9 kHz in the first year of life. In the second year the fish would further grow and the resonant frequency would lower to 0.5 kHz; by the third year to 0.4 kHz.

Data on resonance peaks and accompanying fish samples have also been collected for the northern anchovy, jack mackerel, and rockfish. Resonance peaks have also been measured near saury and hake schools. Non-resonant return data have been collected for targets which are believed to be either red crab or squid. Resonant frequencies are generally lower than 2,000 cycles per second for commercial fish. Higher resonant frequencies originate in bubbles containing invertebrates, in small midwater fishes, and in the young of commercial fish. The resonant frequency will be important in distinguishing anchovies from other schooling fish in that resonances below ca. 1 kHz would not be expected from this species.

Because the costs of monitoring sound velocity profile changes in time and space were considered prohibitive, the La Jolla Laboratory began a cooperative program with the Fleet Numerical Weather Central and J. H. Johnson, Director of the NMFS Environmental and Fishery Forecasting Center, Monterey, to study a statistical approach to mapping sound velocity climatology by region and season, and to develop a shipboard strategy for predicting vertical profiles of sound velocity in order to determine optimum transducer depth at the time and to analyze the fish school target data collected under these sonar conditions.

To develop the probability model, serial expendable bathythermograms obtained during the original sonar-mapping cruise in the fall of 1968 were used. Effective ranges were estimated from propagation loss estimates derived from ray-tracing models developed for anti-submarine warfare problems. Since a ship-mounted sonar was used, the sound source depth was at a constant depth of 4 m: targets were placed at 4 m, 10 m, 20 m, and 50 m for this model. Depths below 50 m were not evaluated because echo sounders begin to be more effective than sonars below that depth in the California Current region. This model of probability of target detection is an important first step toward compaction-corrected biomass estimates of individual schools and the technique will be applied to the historical sound velocity profiles to make decisions on the best time of year to conduct sonar-mapping surveys in the eastern temperate and tropical Pacific.

In summary, the acoustic survey program has realized most of its original objectives. Biologists in the Population Dynamics Group now have the capability of using sonar mapping for counting and estimating the biomass of schools of pelagic fish from a moving ship proceeding at full speed—a useful supplement to the traditional egg and larval survey methods for fishery resource assessment. Work is now proceeding to distinguish northern anchovy schools from all other pelagic schooling fish. Commercial purse seiners, under charter, will be used to confirm target species identification.

In connection with the hydroacoustic work, two cooperative cruises were made with JORDAN and the research vessels SEARCHTIDE and DEEPSTAR 2000 of the Westinghouse Ocean Research Laboratory in local waters within the Channel Islands and in the area of the San Diego Trough. The objective of this work was to observe fish schools visually and record them photographically while they were being insonified with the Simrad sonar on the JORDAN. Direct observations were made of layers of animals in the ocean and of fish schools. Changes in the size and abundance of the layering organisms were noted and new data obtained on the spacing of fish within fish schools.

## MARMAP TECHNIQUES

In preparation for the nationally-coordinated Marine Resource Monitoring, Assessment and Prediction Program (MARMAP) scheduled to begin in 1972, a cruise was made on JORDAN in late January and early February 1971, to test and compare various types of collecting gear. Four types of collecting gear were used for this study: the standard CalCOFI double net, rigged with a 1 m 505 micron mesh and a ½-m, 333 micron mesh, for oblique tows from 200 m depth to the surface; the bongo net, using two 505 micron mesh nets, for horizontal tows of 10 minutes duration at depths of 9 m, 3 m, and at the surface; the SHAT net (Soutar-Hemingway Animal Trap) with a ½-m mouth opening and 333 micron mesh, for vertical tows from 100-m depth to the surface; and the MARMAP double bongo net, rigged with two 60 cm mouth openings and two 20 cm mouth openings, to make oblique tows at various depths and speeds.

The objectives of the cruise were: to determine the effect of tow speed on retention of hake and anchovy eggs and larvae and on avoidance of nets by fish larvae; to determine the effect of the internal wave structure on concentration of anchovy eggs in the upper mixed layer; to estimate the dispersal rate of anchovy and hake eggs; to determine the fine structure of plankton distribution in the upper 9 m of the sea; and to study the effect of sample size on variability in numbers of anchovy eggs and larvae.

A special objective of this study was to determine the sampling characteristics of the Woods Hole modification of the SIO bongo in the presence of high concentrations of newly-spawned anchovy and hake larvae in the Los Angeles Bight. For some time biologists have noted apparent anomalies in the ratios of numbers of planktonic to numbers of motile animals in catches by conventional sampling gear. Other apparently anomalous ratios have been observed between numbers of a given motile species in daylight and night samples. In view of the possibility that motile organisms may evade the sampler because they are warned by seeing or receiving other signals from the preceding tow cable or bridle, biologists have been experimenting with designs that are free of these features. In previous tests the bridle-free bongo at 3 and 6 knots has caught more large fish than bridled ring nets at low speeds. In the present tests, at high speeds small fish larvae were extruded and large larvae damaged. The day/night apparent bias was still present.

The objectives of the MARMAP program also require a net capable of collecting small organisms which are able to escape the regular plankton nets. Three types of medium-sized midwater trawls were selected: the 5′ x 5′ Blackburn trawl, the 6′ Isaacs-Kidd trawl, and the Graham, Boothbay larval herring trawl, modified to suit requirements.

### *Anchovy Subpopulations*

In a recent paper, "Biomass of the subpopulations of northern anchovy *Engraulis mordax* Girard," by A. Vrooman and P. Smith, the distribution and abundance of anchovy larvae were used to estimate the spawning biomass of the central subpopulation and those portions of the southern and northern subpopulations which spawn within the regular CalCOFI survey area.

The mean total biomass of anchovies for the 5-year period 1962 through 1966 in the whole CalCOFI area was 6.1 million tons. The Central subpopulation made up 77.3% of that total or 4.7 million tons. The winter range of the Central subpopulation is from Point Conception to about Cedros Island. The Southern subpopulation, south of Cedros, with 1.1 million tons, accounted for 18.5% of the total. The Northern subpopulation ranges from about Point Conception north to at least as far as Newport Oregon. That portion of it which was within the CalCOFI survey area contributed only 0.26 million tons or 4.2% of the 5-year mean.

Subpopulation studies completed have shown the existence of a previously postulated subpopulation of anchovies which has a southern limit in the summer approximately between San Francisco and Monterey. The gene in the serum transferrin protein of the blood is the fourth allele found in this anchovy genetic scheme and is never found south of Monterey, California. Previously, anchovy subpopulations from southern Baja California and the Los Angeles Bight have been defined. It now appears that there are three subpopulations of anchovies occurring along the west coast from the tip of Baja California to Vancouver, B.C.

In a recent paper, Dr. W. Lenarz studied length-frequencies of several species of larval fish taken during the CalCOFI program with standard 505 mesh nets. One of his conclusions was that northern anchovy larvae were undersampled relative to Pacific sardine larvae. This is a significant conclusion, for estimates of the standing stock of anchovies are based on the ratio of anchovy larvae to sardine larvae. Dr. Lenarz concluded that a major cause of undersampling of anchovy larvae is that small anchovy larvae are retained at a lower rate by the mesh of the plankton net used by the CalCOFI program than are small sardine larvae.

### *Hake Spawning—1970*

In 1970, a single Soviet vessel, OGON conducted the hake spawning survey from Cape San Lucas to San Francisco. All the resulting plankton samples were turned over by the Soviets to be scanned by the sorting Group at the La Jolla Laboratory; the halves of each sample were sent to the Vladivostok Laboratory of TINRO.

Preliminary results obtained from samples indicate that hake spawning in 1970 shifted northward. The sea surface temperatures in the area of hake spawning in 1970 were about 1.5° C higher than in 1969. There were also indications that spawning was reduced in the important on-shore areas. There are no apparent quantitative differences between the hake spawning seasons of 1969 and 1970. Areal coverage varied by less than 2% and variation in number of larvae per unit area was normal.

The position of the spawning was markedly different, however, from 1969. Deficiencies of 3 to 50% in coverage in all the inshore areas were noted. These were mostly compensated offshore, especially in the northern part of the survey area. A cursory look at the size frequency of hake larvae shows them to be normal for the years of comparison available.

SESKAR, the third Soviet vessel operated by the Far Eastern Seas Fisheries Research Institute to work in the CalCOFI area under the terms of the bilateral fisheries agreement between the U.S. and U.S.S.R. arrived in July 1970, conducted an acoustic and trawl survey of the hake and rockfish populations off the Pacific Coast between 32° and 44° N. Data from these surveys were slated to be received from the Soviets at a scientific meeting of U.S. and U.S.S.R. fishery specialists held in Moscow in December 1971. As part of the background material for the meeting, Dr. Paul Smith, completed a report, "Spawning biomass of Pacific hake, 1970," based on the cooperative U.S. and Soviet hake egg and spawning surveys earlier in that year. Dr. Smith concluded that the spawning biomass of hake in 1970 was between 2 and 3 million metric tons and was essentially unchanged from 1969.

### *Sardine Biology*

Drs. Smith and Lenarz have re-examined the CalCOFI ichthyoplankton data with particular attention to the status of the northern subpopulation of sardines. Indications are that the present northern population of sardines may now be smaller than 5,000 tons and that the anchovy population, in the period before the sharp decline in the sardine population may have been much larger than thought previously. The CalCOFI data do not appear to support the species-replacement concept, nor the thesis that removal of anchovies will materially hasten the recovery of sardines.

Dr. Lenarz has developed a stochastic model which uses the population parameters developed by Dr. Garth Murphy for the years 1932–1949. Both the Murphy population model and the Lenarz model indicate that periods of several decades are necessary for recovery of non-fished sardine stocks from the postulated levels. Dr. Lenarz thus has developed a table of probability of attaining a given spawning biomass of sardines in 10 years and in 25 years, given some combination of yield and assumed biomass.

In a cooperative study with the California Department of Fish and Game, fishery biologists in the Population Dynamics Group have been systematically sampling San Diego Bay for sardine eggs and larvae. This work was begun in response to the State's need for information on the extent of sardine spawning in San Diego Bay and the possibility of closing the Bay and adjacent areas to sardine bait fishing. State biologists have been conducting similar work at Horseshoe Kelp Point, outside Long Beach, with the resulting samples sent to the Center for sorting. Both groups are finding sardine eggs and larvae at all three stations in each area. The most abundant fish eggs found in San Diego Bay, however, are those of an anchovy whose eggs are much shorter and wider than those of the northern anchovy and which are assumed to be *Anchoa delicatissima.*

### *Handbook of Fish Populations*

Knowledge of the fish populations of California waters is stored in over 1,000 scientific articles. To provide access to this information, work began on compiling a handbook of California fish populations which will include a bibliography, summary of catch records and fecundity, growth, and mortality rates of each population. Working both with published and unpublished data, the population parameters for each species are being compiled in a standardized form that will permit information retrieval with the aid of a computer.

Research in the *Behavior-Physiology* Group during the past year has concentrated on understanding the processes of mortality which determine the survival or lack of survival of larval fish. This problem is particularly important in the California Current area since there is a considerable body of scientific opinion that the important factors which determined the collapse of the great California sardine fisheries of the 1940's were first, a series of extremely poor year-classes of sardines and subsequently, a series of extremely strong year-classes of the competing northern anchovy.

### *Larval Fish Ecology*

Progress has been made by behaviorists and physiologists in this Group in measuring the factors which cause variable mortality in fish larvae and lead to variable year classes of fish. Working with the northern anchovy, a successful technique was developed for the routine induction of spawning in the laboratory in order to obtain supplies of viable eggs and young larvae for experimentation, and also to develop experimental techniques and standard diets for rearing these young larvae through their first weeks of life. Based upon these techniques the studies have now resulted in a quantified description of the development and nature of larval feeding behavior and mechanisms, and of their energy budget during their first few weeks of life.

Details of this work included efforts to find and maintain adequate food sources for larger anchovy larvae to replace the nutritionally inadequate *Artemia,* and the development of successful mass rearing techniques in the laboratory of the rotifer, *Brachionus plicatilis,* as food. Progress was made also in large-scale laboratory production of the copepod, *Eurytemora affinis,* known to be an important food for clupeids. A variety of cultured phytoplankton organisms was tested to ascertain the best one, or several in combination, to serve as a food to stimulate growth and reproduction of the copepod. A manuscript was published describing the mass culture of *Brachionus* as food for larval anchovies between 6 and 20 days of life. The growth rate of anchovy larvae on a diet of *Brachionus* was significantly greater than the maximum rate obtained with a diet of wild plankton and it appears that *Brachionus* is a valuable source of food energy and nutrients to larval anchovies. As a result of the success with *Brachionus,* several mariculture organizations, government laboratories, and universities have requested and been supplied with *Brachionus* cultures from this laboratory.

A parallel line of research within this Group has been concerned with the mechanisms of predation of larval anchovies by crustacean zooplankton and the Group should soon approach a situation in which it will be able to separate the two major forms of mortality of these extremely small larval fish—starvation due to inability to secure sufficient food for growth and maintenance, and predation by other members of the plankton community. Similar studies are now beginning on Pacific sardine larvae, a competitor of the northern anchovy for living space within the ecosystem in the California Current.

Based on the efficiency with which larval anchovies catch their food, the amount of water searched and the metabolic requirements, the density of food particles required by a larva has been ascertained.

These data, probably unmatched for any other species of marine fish, have enabled biologists in this Group to draw conclusions concerning the possibilities of survival of larval anchovies in various situations in the ocean.

### *Pollution in Marine Ecosystem*

There is clear evidence that the pelagic ecosystem has been seriously contaminated by pesticides as shown by the disastrous die-off of fish-eating sea birds in California and the recent difficulties in marketing DDT-contaminated commercial species of fish in the California region. In a new project this year, physiologists began studies of man's chemical invasion of the waters off California and initially directed their attention to a single series of questions: namely, what are the routes and rates of transfer of DDT and other pesticides into the offshore ocean pelagic ecosystem and what is the effect of the observed contamination upon the pelagic fish resources off California?

Since the early 1950's, plankton samples have been routinely and systematically collected by CalCOFI at stations in the California Current. The first problem considered was whether it was possible to use this unique plankton bank to trace the historical origin of DDT contamination of the ecosystem; results have now demonstrated that this approach is completely feasible. Two target species, both small myctophid fishes, were chosen and sorted from selected samples taken from all the major sections of the California Current and extending back 20 years in time. These samples, together with special samples taken over the past year with plankton nets over the same grid of stations, were subjected to precise analyses in order to trace the routes of transfer of hydrocarbon pesticides through the planktonic ecosystem which forms the food of the commercial fish species which have been found to be contaminated. A second line of investigations is proceeding concurrently with these, on the effect of the observed contamination levels in certain fish species upon the survival rates of their pelagic eggs and larvae since it appears that a considerable quantity of the body load of pesticides is transferred during the reproductive cycle.

The Operations Research Group at the Center studies the California fisheries from both the economic and technological viewpoints and suggests ways in which they may be placed on a more rational basis through development of new and more efficient forms of fishing gear and methods and utilization of latent fishery resources.

### *Local Fisheries Development*

Work has continued on systems analysis of, and technical assistance to the southern California fisheries, and in particular, the smaller inshore boats which are technologically out-of-date and economically depressed. In collaboration with the Marine Research Committee of California, scientists in this Group successfully modernized a single San Pedro wetfish purse seiner by replacing its conventional net handling gear with a hydraulic seine-drum, similar to those used in the salmon fisheries of the Pacific Northwest, together with a number of other modern devices. The result of this has been to reduce the number of crew members aboard the vessel markedly and to bring the test vessel, SUNSET, to a position as a front-runner in the wetfish fleet. Since the primary obstacle to the development of the inshore wetfish fisheries has been economic, the demonstrated increase in profitability of this boat has stimulated interest by other boats in the fleet.

In other developments, a study of the operating economics of the San Pedro wetfish fleet, has been completed in cooperation with the NMFS Branch of Economics. Efforts by this Group have also resulted in an improved shrimp trawl, and encouragement of fisheries for such underused resources of the California Current as red crab, sea urchins, and sable fish.

—*Izadore Barrett*

# REVIEW OF THE PELAGIC WET FISHERIES FOR 1970 AND 1971

Total wet-fish landings during 1969 were the highest in 10 years. The statewide yield of 105,307 tons represented a twofold increase over the previous year (Table 1). This increase was due to the increase in anchovy landings which reached 67,639 tons. Mackerel deliveries fell slightly during the year; with Pacific mackerel landings dropping to 1,179 tons and jack mackerel to 25,961 tons. Landings of squid declined to 10,390 tons. Sardine deliveries fell to their lowest point since the Department began keeping records in 1916. Only 53 tons were taken during the year.

During 1970, wet-fish landings again showed an increase (Table 1). The total catch of 133,101 tons was the greatest in 20 years except for 1956 and 1958. Anchovy landings reached 96,243 tons, an all-time high. Deliveries of mackerel slipped for the second straight year. Pacific mackerel landings declined to their lowest point on record, 311 tons, while jack mackerel landings dropped to 23,875 tons. Deliveries of squid increased by 20% and reached 12,295 tons. The take of sardines increased to 221 tons due to legislation which provided for their use as dead bait.

Throughout 1969, the wet-fish fleet working off California consisted of 34 purse seiners and 21 lampara boats (exclusive of those fishing expressly for live bait). There were 20 "large" (60 ft. and over) and 9 "small" purse seiners based at San Pedro. One new vessel was built, the first in 22 years. At Port Hueneme there were two "small" purse seiners, and one "large" and two "small" seiners were at Monterey. However, during anchovy season the "large" Monterey vessel sank. Six lampara boats were active in southern California and 15 at Monterey.

The number of purse seiners fishing in 1970 increased to 39. There were 24 "large" and 10 "small" purse seiners in San Pedro. A lampara boat was converted to a purse seiner and joined the fleet. One "large" seiner, a converted live bait boat, joined the two "small" vessels operating out of Port Hueneme. Two "small" purse seiners landed fish at Monterey. The lampara fleet decreased to 20, five based in southern California and 15 at Monterey.

TABLE 1

**Landings of Pelagic Wet-Fishes in California in Tons; 1964–1970**

| Year | Sardine | Anchovy | Pacific Mackerel | Jack Mackerel | Herring | Squid | Total |
|---|---|---|---|---|---|---|---|
| 1964 | 6,569 | 2,488 | 13,414 | 44,846 | 175 | 8,217 | 75,709 |
| 1965 | 962 | 2,866 | 3,525 | 33,333 | 258 | 9,310 | 50,254 |
| 1966 | 439 | 31,140 | 2,315 | 20,431 | 121 | 9,512 | 63,958 |
| 1967 | 74 | 34,805 | 583 | 19,090 | 136 | 9,801 | 64,489 |
| 1968 | 62 | 15,538 | 1,567 | 27,834 | 179 | 12,466 | 57,646 |
| 1969 | 53 | 67,639 | 1,179 | 25,961 | 85 | 10,390 | 105,307 |
| 1970 | 221 | 96,243 | 311 | 23,873 | 158 | 12,295 | 133,101 |

### *Pacific Sardine*

The moratorium on the take of sardines (except that an incidental catch of 15% may be mixed with other fish) remained in effect until November 10, 1969. Legislation was passed in 1969 which permitted 250 tons per year to be taken for use as dead bait. The law provides that a vessel may possess and land 3 tons per day as long as the season is open or until the quota is reached. The 1969 catch remained low (53 tons) because of the late enactment of the law. However, the 1970 catch increased to 221 tons as fishermen took advantage of the new law. Most sardines taken during this period were caught either in San Diego Bay or off La Jolla. The fish were all large, most being over 3 years old.

### *Northern Anchovy*

The California Fish and Game Commission authorized a quota of 75,000 tons during the 1969–70 season. The northern permit area (10,000 tons) opened August 1, 1969, and the southern permit area (65,000 tons) on September 15. Both areas were closed to fishing on May 15, 1970.

Fishing commenced August 4 at Monterey with the fishermen receiving $19.50 per ton. On August 8, the price increased to $20.50 per ton. Landings continued on a sporadic basis until November. Rough weather and lack of fish then curtailed landings until late April when the last landings of the season were recorded.

Anchovy fishing in the southern permit area started on September 16 with the price set at $20.00 per ton. During the first 5 months of the season, fishermen experienced exceptionally good catches. This resulted in the Commission authorizing (January 9, 1970) an additional 65,000 tons. Fishing was poor during February and March because anchovy schools were deep and wild. On March 23, the Commission closed the inshore waters of southern California to the anchovy fishery (Zones I and III). This action was at the request of southern California sportsmen who were unable to get sufficient anchovies for live bait. Anchovy fishing then ceased since fishable schools were not available in the offshore areas. On May 5, fishing was again permitted in the nearshore zones of southern California (Zone I, beyond 6 miles around the Los Angeles area; Zone III, beyond 3 miles from other southern California shores). Over 8,000 tons of anchovies were then landed in the next 10 days.

A total of 83,473 tons of anchovies was landed during the 1969–70 season (Table 2).

The 1970–71 reduction season quota was increased to 100,000 tons in the southern permit area and remained at 10,000 tons in the northern area. Zones were abolished in the southern area, and the month of February was closed as a result of the live bait short-age the prior season. Opening and closing dates for both permit areas were the same as the previous season.

During August, fishermen landed over one half of the seasons total catch at Monterey. The price was $22.00 per ton. Landings ceased in September, but resumed in October and continued through December. The 1970–71 season catch produced the smallest total landings in the northern permit area since the first reduction season (Table 2).

The 1970–71 reduction season in the southern permit area started on September 20 with the price of anchovies being $23.00 per ton. Fishermen experienced 5 months of good fishing, the same as the previous year. February was closed, and when activity resumed in March, no fishable schools could be found. The fish were either scattered on the surface or in large schools at great depths. Poor conditions prevailed until May when fishable quantities were again available.

By the time the season closed, a total of 80,752 tons had been landed (Table 2).

Anchovy behavior during both seasons was similar for the first time since the reduction fishery was authorized. Throughout the fall, boats fishing anchovies worked around the Channel Islands, off Port Hueneme, and outside Santa Monica Bay. As winter approached, the fishery shifted to the southeast. During this time, fishermen worked Santa Monica Bay and the San Pedro Channel. In the spring, fishing effort was concentrated off Newport Beach.

The value of local anchovy meal (65% protein) has increased steadily since the start of the 1969–70 season. During September 1969, it opened at $147.00 per ton. By December, anchovy meal was $165.00 per ton and it remained at that price until March 1970. Then it rose to $170.00 a ton, and in May was quoted at $174.00 per ton. Throughout the 1970–71 season, the price remained at $175.50 per ton.

Live bait fishing during 1969 and 1970 was rated as good except for the winter of 1969. Anchovies did not appear in Los Angeles-Long Beach Harbor nor off San Diego or Port Hueneme during this period. However, they did return in the spring. The reported catch declined in 1969 but increased in 1970 (Table 3). This probably reflects a variation in the number of boats reporting their catch since such records are voluntary.

TABLE 2

**Anchovy Landings for Reduction in the Southern and Northern Permit Areas 1965–66 through 1970–71**

| Season | Southern permit area | Northern permit area | Total |
|---|---|---|---|
| 1965–1966* | 16,468 | 375 | 16,843 |
| 1966–1967† | 29,589 | 8,021 | 37,610 |
| 1967–1968‡ | 852 | 5,651 | 6,503 |
| 1968–1969§ | 25,314 | 2,736 | 28,050 |
| 1969–1970§ | 81,453 | 2,020 | 83,473 |
| 1970–1971§ | 80,095 | 657 | 80,752 |

*Seasons*
* November 12, 1965 through April 30, 1966.
† October 1, 1966 through April 30, 1967.
‡ September 15, 1967 through May 15, 1968.
§ August 1 through May 15.

TABLE 3

**Commercial Landings and Live Bait Catch of Anchovies in Tons; 1964–1970**

| Year | Reduction | Other commercial | Live bait | Total |
|---|---|---|---|---|
| 1964 | 0 | 2,488 | 5,191 | 7,679 |
| 1965 | 170 | 2,696 | 6,148 | 9,014 |
| 1966 | 27,335 | 3,705 | 6,691 | 37,731 |
| 1967 | 32,349 | 2,455 | 5,387 | 40,191 |
| 1968 | 13,795 | 1,743 | 7,176 | 22,714 |
| 1969 | 65,204 | 2,435 | 5,538 | 73,177 |
| 1970 | 92,955 | 3,288 | 6,105 | 102,348 |

### *Mackerel*

Jack mackerel landings declined during 1969 (25,691 tons) and 1970 (23,873 tons). Increased anchovy landings and a ban on canning mackerel for human consumption (November 1969 to May 1970) because of high DDT levels were reponsible for the decline. During both years, the Cortes Bank area and Catalina Island provided most of the fish. The price remained at $75.00 per ton, the level it has been at since 1966. The 1968 year class dominated (70%) the 1969 catch, while the 1968 and 1969 year classes dominated (70%) the 1970 landings. Other year classes (1966 and 1967) accounted for the remainder of the catch during both years.

Pacific mackerel landings declined in 1969 to 1,179 tons and in 1970 to an all time low of 311 tons (Table 1). Most fish delivered in 1969 were taken by purse seiners in either small schools of 100% Pacific mackerel or in schools of mixed fish (jack and Pacific mackerel). Mixed loads accounted for most of the landings during 1970 although a few small loads of 100% Pacific mackerel were delivered. In November 1970, a moratorium on the take of Pacific mackerel took effect. It provided for a mixed load tolerance of up to 18% Pacific mackerel. The 1968 year class contributed heavily to landings both years. Spawning success in 1969 was poor, and 1970 produced a relatively small but noticeable year class.

### *Squid*

Squid landings dropped to 10,390 tons in 1969 (Table 1). This drop reflected a decrease in demand for the canned product. Landings rose to 12,295 tons in 1970 due to increased demand by canners. While the Monterey squid fishery failed, landings in southern California increased to meet the demand.—*Stephan J. Crooke.*

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# SPECIAL REPORT

*Calif. Mar. Res. Comm., CalCOFI Rept.*, 16: 21–24, 1972

# SPECIAL REPORT

## THE FEDERAL REORGANIZATION AND ITS IMPACT ON FISHERIES

PHILIP M. ROEDEL
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Washington, D.C.

Your chairman has asked me to speak today about that new national entity, the National Oceanic and Atmospheric Agency, and in particular about one of its component parts, the National Marine Fisheries Service.

The idea of a NOAA-like organization is far from new, having its genesis at least as early as the 1940's. Over the years, criticism of the existing establishment grew, and during the mid-60's, the Congress considered various bills designed to provide an administration better able to cope with oceanic problems, essentially by placing these activities under one umbrella.

Most significantly in 1966 the Congress established the Commission on Marine Science, Engineering and Resources and the National Council on Marine Resources and Engineering Development (PL 98-454).

The Commission was charged with, among other things, making a ". . . comprehensive investigation and study of all aspects of marine science in order to recommend an overall plan for an adequate national oceanographic program that will meet present and future needs," and recommending "a governmental organizational plan with estimated cost." The Commission, chaired by Dr. Julius A. Stratton, Chairman of the Ford Foundation, published the result of its efforts in the so-called Stratton Report, "Our Nation and the Sea", which appeared in January 1969. One of its recommendations called for the establishment of a National Oceanic and Atmospheric Agency. This recommendation formed the basis for President Nixon's Reorganization Plan Number 4 of 1970, creating the National Oceanic and Atmospheric Administration in the Department of Commerce. The reorganization plan which required Congressional approval was submitted to the Congress on July 9, 1970. It received a generally favorable reception, and NOAA became an entity on October 3, 1970.

The major opposition to the formation of NOAA came from conservation groups. They simply didn't think that changing the name of BCF to NMFS would in any way change the leopard's spots, nor did they think that the Department of Commerce was the proper home for a conservation-oriented organization. Secretary of Commerce Maurice Stans played a very strong role in coping with this problem. He met with many conservation leaders and I believe allayed their fears to a significant degree. On November 12, 1970, the Commerce Department announced that John Gottschalk, former Director of the Bureau of Sport Fisheries and Wildlife, had joined the NMFS as a special assistant to the Director. John is very highly respected in conservation circles, and I believe that his addition to our staff made a great deal of difference in the attitudes and beliefs of the conservation groups. We are working very closely with them trying to develop better rapport and communication so that they have a better appreciation of our role and we in turn have a better understanding of what they regard as significant problems.

NOAA's formation brought together the functions of the Commerce Department's Environmental Science Services Administration; the Interior Department's Bureau of Commercial Fisheries, Marine Game Fish Research Program, and Marine Minerals Technology Center; the Navy's National Oceanographic Data Center and National Oceanic Instrumentation Center; the Coast Guard's National Data Buoy Development Project; the National Science Foundation's National Sea Grant Program; and elements of the Army Corps of Engineers' U.S. Lake Survey.

This structure departs from the recommendation of the Stratton Report in two significant respects:

1. The report recommended that the entire Coast Guard organization be placed under the NOAA and,
2. It recommended that NOAA be an independent agency reporting directly to the President.

The President described NOAA in these terms in his message of transmittal to the Congress:

"[NOAA] would make possible a balanced Federal program to improve our understanding of the resources of the sea, and permit their development and use, while guarding against the sort of thoughtless exploitation that, in the past, laid waste to so many of our precious natural assets. It would make possible a consolidated program for achieving a more comprehensive understanding of oceanic and atmospheric phenomena, which so greatly affect our lives and activities. It would facilitate the cooperation between public and private interests that can best serve the interests of all."

"I expect that NOAA would exercise leadership in developing a national oceanic and atmospheric program of research and development. It would coordinate its own scientific and technical resources with the technical and operational capabilities of other government agencies and private institutions. As important, NOAA would continue to provide those services to other agencies of government, industry, and to private individuals which have become essential to the efficient operation of our transportation systems, our agriculture, and our national security.''

The Administrator of NOAA is at the Under Secretary level, reporting to the Secretary of Commerce. His deputy is at the Assistant Secretary level. So even though NOAA is not an independent agency, its leadership is at a very high governmental level.

The largest component of NOAA is the former ESSA organization, the major units of which were the Weather Bureau, the Coast and Geodetic Survey, Environmental Satellite Center, and Research Laboratories, these latter functioning in the area of the physical sciences. Some 10,000 of the nearly 13,000 NOAA employees were in ESSA. The next largest unit, The National Marine Fisheries Service, is what was essentially the old Bureau of Commercial Fisheries to which was added the Marine Game Fish Research Program of the Bureau of Sport Fisheries and Wildlife. Administratively, the BCF simply ceased to exist on October 2. On October 3 the new organization appeared on the scene full grown with many of the same players and much the same programs, with the addition of marine sport fish responsibility.

NOAA is organized on an interim basis along a typical line and staff pattern. The major line components include:

The Environmental Research Laboratories, from ESSA.

The National Weather Service, from ESSA.

The Environmental Data Service, made up of components of ESSA and the National Oceanographic Data Center.

The National Ocean Survey, formed from the Coast and Geodetic Survey of ESSA and the Army Engineers' Great Lake Survey.

The National Environmental Satellite Service, another component from ESSA, and

The National Marine Fisheries Service.

The staff components currently include an Assistant Administrator for Environmental Systems under whose control are the National Data Buoy Project (from Coast Guard), the National Oceanographic Instrumentation Center (from Navy), and the Marine Minerals Technology Center (from the Bureau of Mines, Department of the Interior). The office of Sea Grant forms another staff section, one which is of particular importance to fisheries interests.

Now, just what is in the Fisheries Service and what is it supposed to do? I mentioned that it was derived largely from BCF. The significant exceptions are the Great Lakes Biological Laboratory at Ann Arbor, Michigan, the Lamprey Control Program in the Great Lakes, and the Reservoir Program in South Dakota, all of which stayed with the Department of the Interior, and the Gulf Breeze Biological Laboratory which became part of the Environmental Protection Agency.[1] NMFS thus consists of the remaining components of BCF, which is the great bulk of the organization, plus the Marine Game Fish Laboratories comprising the migratory marine game fish program of the Bureau of Sport Fisheries and Wildlife. These are located at Narragansett, Rhode Island; Sandy Hook, New Jersey; Panama City, Florida; and Tiburon, California. An additional facility is scheduled to be built at Port Aransas, Texas. The net result is that NMFS's strength is about the same and its budget about the same as the old BCF—namely, some 2,000 people and a budget for 1971 of about $47 million. What NMFS picked up in terms of sport fish personnel and funds was roughly offset by what was lost from BCF.

I would like to turn to the implications of this reorganization as I see them. Abolishing the BCF and adding the Marine Game Fish Program obviously gives the new organization a different role and responsibility. The old BCF was essentially devoted to solving problems that concerned the commercial fishing industry, and it did not take into particular account other user groups. The new organization is resource-oriented with consideration of the resources coming first, then the legitimate demands of all user groups.

I have said before and reiterate again that I believe NOAA's creation marks the beginning of a new era for marine fisheries in the United States. To quote from a talk I gave before a joint meeting of the Gulf States and Atlantic States Marine Fisheries Commission:

> ''Within NOAA, there exists expert knowledge in many fields of ocean science. Research by the various components of NOAA can be planned and coordinated to make readily available to us a great deal more information regarding the mechanisms of the ocean than has heretofore been available. Thus, we anticipate the ability better to carry out our responsibilities.

How do we look at ourselves? Very early in the game, before the Reorganization Plan was approved but after we knew its content, Secretary Stans asked some of us who were scheduled to join NOAA to brief him on our respective organizations' responsibilities as we saw them. My opening remarks at that session held on August 18, 1970, follow:

> ''The primary role of the Bureau of Commercial Fisheries is to obtain, through scientific studies, sufficient knowledge about the magnitude, distribution, basic properties and susceptibility to capture of fish stocks to answer these questions: what are the stocks, where are they in terms of time and space, what is their magnitude, what is their susceptibility to capture, what are the options available for their use, and, most importantly, why do they fluctuate and what is the maximum sustainable biological yield of each of them.
>
> ''This scientific base is prerequisite to our contributing to programs designed to manage domestic and international fisheries for conservation purposes in such a way as to assure that the resources will be maintained in a healthy condition and will be wisely used.

[1] Formed by Reorganization Plan No. 3, submitted to the Congress with Plan No. 4, but not implemented until December 2, 1970.

"Corollary to this is the need to obtain sufficient information to understand the interaction of the aquatic environment on the fish and to ensure protection of this environment.

"A second role now in an early developmental stage is, in cooperation with other entities, to develop adequate management techniques at the international, national and state levels that will permit rational allocations of stocks among nations and among user groups within the U.S. which will permit maximum economic return to investors within the framework of maximum sustainable yield.

"Thirdly, the Bureau provides assistance to industry in those areas where institutional restraints, the common property nature of the resource or both make it impractical for industry to do the job itself. It has as well a responsibility to help in assuring the consumer that he is adequately informed as to the product he is buying.

"A final role played by the Bureau is in cooperation with other Federal agencies and international organizations to assist in the development of emerging nations and to help meet world food needs through fisheries.

"The basic goal of the Bureau is conservation: the wise use of living aquatic resources. This requires fundamentally a strong and sound biological base. It requires further for its proper realization input from a wide variety of other scientific disciplines of which physical oceanography is the most important constituent. Finally to insure conservation in its broadest sense, it requires a sound understanding of the economic, legal, and social factors affecting resource use."

While the statement does not make specific reference to recreational problems (remember I was still representing BCF), I believe its applicability to all interests is evident.

Now, what does all this mean in terms of the CalCOFI group? I think you will see little change in the basic CalCOFI program with one significant exception. We are developing and preparing to implement a program known as MARMAP, the Marine Resources Monitoring, Assessment and Prediction Program. MARMAP is in many ways simply an extension of CalCOFI in that it is designed to provide a systematic approach to resource assessment, in this case, implemented and coordinated on a nationwide scale.

Its genesis lay in the fact that BCF research tended to be highly decentralized with too little attention paid to nationwide goals, let alone national programs. The Stratton Commission recognized this, and in Section F of the Marine Resources Panel we read:

"Simple answers are rarely found for issues as complex as those besetting the U.S. fisheries. . . . The Federal Government has never done justice to its functions in promoting rational use of the living resources of the sea because its fishery agency has never been given broad enough direction by the Congress to permit it to carry out a unified program to suit the needs of the country as a whole. . . . It is clear that the current program and organization of the Bureau of Commercial Fisheries does not reflect an integrated plan geared to an unequivocal set of objectives. . . . A closely related aspect of Bureau operations that has inhibited its effectiveness has been the project orientation stemming from its organizational structure (which is disciplinary in nature) and the dominant position of administrators with narrow scientific or technical backgrounds. The emphasis has been placed on individual projects of merit rather than on programs oriented to the achievement of broader missions that cut across both disciplinary and geographic boundaries. . . . There is a natural tendency to focus attention on problems of regional interest and even more narrowly on those problems for which the region's own personnel are best equipped or in which they are most interested."

Before the development of the MARMAP concept our research coverage was indeed fragmentary, nearly void of coordinated time and space observation and lacking in standardization of sampling techniques.

What really had happened is that we had drifted into a problem-solution mode of a local or regional nature, without a significant national overview.

MARMAP, then, is our national program. It not only ties our resource work together but establishes a common interface with economic and social research programs. It is a coordinated program designed to monitor, assess and predict the type and amount of living marine resources, at the required level of accuracy (which will obviously vary from area to area) and at the least cost. The basic program consists of initiating and conducting three surveys: 1) ichthyoplankton, 2) groundfish, and 3) pelagic fish. The ultimate intent is to define the principal factors that affect changes in populations. Obviously CalCOFI is already deeply involved in surveys of the first and third types.

How rapidly we will be able to implement these surveys depends quite simply on funding. We hope to mount the first ichthyoplankton survey in 1971, with other surveys following in succeeding years.

Another topic about which you will hear far more in the future deals with resource allocation problems at the international, national and state levels. It is becoming increasingly evident that the existing system, if it can be called that, fails to cope effectively with the social and economic facts of life. We believe we must have a better mechanism for control of international fisheries and that a means must be found through which domestic fisheries can be managed with full regard for economic and social factors as well as biological. The present system under which a given stock may be variously under the control of an international body, the jurisdiction of two or more states, or under nobody's control is patently ineffective. The whole subject of a state-federal partnership in fisheries aimed at effective management is one to which we are devoting great attention.

Looking ahead, those of us who have been working closely with the people in Commerce for the past several months are optimistic indeed about what the future holds. We feel that the opportunities in this new organization are going to be very great. We both hope and plan to capitalize upon them. If you think back upon the units that were brought together to form NOAA, you will recall that they encompass about every discipline concerned with the ocean in which those of us involved in fisheries have a particular interest. Here are all the groups with whom we would have liked to have had a close relationship in the past and with whom we have not been able to work too effectively simply because of the governmental structure. Further, the attitude of the leaders in the Department of Commerce is extremely positive. With this set of circumstances, our optimism seems warranted.

Part II

# SYMPOSIUM ON POLLUTANTS AND CONTAMINANTS IN THE CALIFORNIA CURRENT SYSTEM

Edited by Marston C. Sargent
David Ganssle, *Convenor*
Indian Wells, California
November 23–25, 1970

*Calif. Mar. Res. Comm., CalCOFI Rept.*, 16: 27–28, 1972

# FDA RESPONSIBILITIES AND PROGRAMS IN THE FIELD OF MARINE POLLUTION

FRED SHALLIT
U. S. Food and Drug Administration
Los Angeles, California

The basic responsibility of the Federal Food and Drug Administration is to provide consumer protection through enforcement of the Food, Drug and Cosmetic Act and related laws. The act and its regulations contain certain requirements that manufacturers and interstate shippers must comply with, and it includes penalties if they fail to do so. Accordingly, we are usually thought of as a law enforcement agency in contrast with those government agencies that provide services to the public. However, we also strongly encourage compliance through education and voluntary actions.

Because the Food and Drug Administration is a scientific organization, applied research plays a significant role in furthering consumer protection. We are constantly devising new and better methods of analysis, seeking not only to benefit from our own research but also from the findings throughout the scientific world.

Data emerging from conferences such as this one are valuable tools useful in meeting our daily challenges. Through a cooperative exchange of information and ideas, and working together with state and local agencies, we can expand the benefits and intentions of the Food and Drug act.

An illustration of this type of cooperation is shown by our recent handling of the problem involving the presence of high amounts of DDT and its analogs in canned jack mackerel. About a year ago, one of our eastern districts found high amounts of DDT and its analogs in canned jack mackerel that had been produced in a southern California plant. We began an immediate investigation to determine whether this was an isolated instance or a widespread occurrence. In carrying out this operation, we obtained samples from every jack mackerel packer in southern California. Unfortunately, the results of the analyses showed a number of additional lots that also exceeded the tolerance of 5 ppm.

Our next decision was to make a choice between regulatory action involving seizures or voluntary action under closely supervised conditions. We called a meeting with California State Food and Drug officials and industry representatives and suggested an approach which we felt would provide the maximum consumer protection. An agreement was reached whereby the State Food and Drug, through the facilities of their cannery inspectors, would sample for analysis every lot of canned jack mackerel produced. Meanwhile FDA would conduct a series of spot checks. Any lots found high were to be withheld from distribution through state embargo. In addition, an exchange of both state and federal analytical findings would continue. This agreement is currently in effect, and it has not been necessary to date for the FDA to invoke seizure action on any other violative lots of canned jack mackerel.

Unfortunately, the presence of pesticides in fish caught off the southern California shores is not confined solely to the mackerel family. In April 1970, we initiated a sampling program to cover a variety of fish which were of commercial significance. As a practical approach, the majority of our samples were obtained from wholesale fish dealers whose lots were ultimately destined for consumer consumption. For laboratory purposes, we usually took a minimum of six fish or sufficient to make up to 50 pounds per sample. Because we wished to determine how much pesticide might be present in the fish, as prepared by the housewife, the head, tail, guts and scales were removed prior to grinding and taking of the aliquot.

We are currently evaluating the preliminary results of this survey. In addition, our San Francisco and Seattle districts are also extending this survey so as to include the entire Pacific coastal waters. One development has occurred that will be of interest to you. We have just completed a seizure action on some lots of kingfish which were found to contain excessive amounts of DDT and its analogs. These fish were caught outside of the Santa Monica Bay area. We are making a further investigation to determine whether this may be in any way correlated with the reported findings in Santa Monica Bay which recently received a great deal of newspaper publicity. We are aware of the considerable work many of you have already accomplished and will be interested in what information you may have.

Some of our other programs currently underway relate to certain particular interests of this conference. We are analyzing a number of our fish samples for mercury, PCB, dieldrin and lead.

Our total diet studies are well known to most of you. They represent a market basket collection of food made six times throughout the year and consisting of the recommended two week diet for a 15 to 20 year old male. Our Los Angeles district is responsible for collecting the samples representative of the region identified as the western area of the United States. Various types of fresh, frozen and canned fish are included in the samples obtained. Analyses performed are for the organochlorides, the organophosphates, the polychlorinated biphenyls, the chlorophenoxy acids and metals such as arsenic, cadmium and mercury.

For years, the FDA has had a program in operation involving the analysis of thousands of fruit and vegetable samples. The significance of this program to the CalCOFI conference lies in the usage of these pesticides and the resultant run-off and possible contamination of the oceans. Because sewage treatment plants have difficulty in removing these chemicals, their outfalls are being investigated with increasingly greater interest to determine if there may be any correlation between the chemicals being ejected and the amount of these chemicals that we might find in fish inhabiting the outfall area. Such studies are a part of our continuing California Coastal Fish Survey.

Increasingly sensitive analytical methods and new instrumentation are constantly producing more revealing data. Our programs must necessarily remain flexible and as additional problems are encountered, needed modifications are made. New programs are accordingly being implemented where required and older programs constantly updated or phased out when no longer applicable towards consumer protection.

*Question:* Which heavy metals are you looking at in these thousands of samples collected?

*Shallit:* The thousands of samples I referred to are those collected nationally under our pesticide program. These involve principally fruit and vegetable products. Our analyses by gas chromatograph are principally for revealing the possible presence of the organic phosphates and chlorides. Where we suspect the presence of some chemical not ordinarily revealed through gas chromatographic studies, appropriate analyses are made. The various metals would be such examples and if indicated, atomic absorption or other adequate analytical procedures would be required to reveal their presence.

*Question:* Do you find any difference in the jack mackerel that is caught offshore such as on Cortes and Tanner banks as compared to what is caught inshore?

*Shallit:* We are currently reviewing our data to determine if it is possible to find any difference. Our findings do show that a number of the samples obtained offshore from the White Point discharge area have been high in DDT and its analogs. Yet most of the jack mackerel samples from considerably farther out have been well under the 5 ppm tolerance. Additional study is needed.

*Question:* Are you checking jack mackerel that comes in from Japan and South Africa?

*Shallit:* Products coming into this country from a foreign country are subject to entry through customs. Whenever canned mackerel or any other food products are offered for entry, customs notifies us and we determine whether we should sample for analysis. Our limited facilities do not allow us to check every lot entered, but we keep a constant surveillance on all these products and perform a significant number of analyses.

*Question:* Do you do any monitoring of fish that may be used ultimately for the production of chicken feed?

*Shallit:* We have sampled and analyzed a number of such products. We have found very little DDT in fish meal and believe this is probably due to the fact that fish for fish meal use usually has had the majority of fat expressed from it. As you know, DDT is fat soluble and the absence of fat in fish meal undoubtedly accounts for the very small amounts of DDT found.

*Calif. Mar. Res. Comm., CalCOFI Rept.*, 16: 29–31, 1972

# PESTICIDE PROGRAM OF THE CALIFORNIA DEPARTMENT OF FISH AND GAME, PART I

ELDRIDGE HUNT
California Department of Fish and Game
Sacramento, California

It is certainly a pleasure for me to participate in the CalCOFI Conference Program. This is the first time I have had the opportunity to visit with you people and discuss the involvement of the Department of Fish and Game in pollution problems involving pesticides and heavy metals. We have had considerable experience in working on these types of problems. The Department was the first state conservation agency to assign personnel full time to pesticide matters, and has supported an expanding pesticide investigation program since 1957. The activities involving heavy metals have generally been assigned to the people who are involved in pesticide work and to other personnel of the Department doing other phases of pollution investigations.

The discussion today will pertain to the ongoing pesticide program of the State and of the Department of Fish and Game as well as our current efforts involving the problems relating to heavy metal contamination. I will discuss the broad aspects of our programs and Jack Linn, Fisheries Biologist on the Pesticide Investigations Project will present the more detailed aspects of these programs and include some of our current findings.

The State's pesticide program in a practical sense is a multi-agency approach to problem solving. It involves primarily six State departments; Agriculture, Public Health, Fish and Game, Conservation, Water Resources, and State Water Resources Control Board. Each of these departments has individual responsibility and programs in the pesticide field and also participates in cooperative efforts through administrative and legislative assignment.

A very brief summary of some of the major aspects of state programs might be helpful at this point in illustrating the roles and involvement of various agencies.

The Department of Fish and Game's Environmental Protection Program has surveillance and research aspects, both aimed at problem solving. The fish and wildlife problems result from direct contact with toxicants of various types and other pollutants and also from long-term environmental contamination. We are concerned with the untoward side effects of toxicants on all types of fish and wildlife and their environment.

The Department of Agriculture is the agency responsible for the registration of any and all pesticides used in the state. There are about 16,000 materials registered at the present time. They also have regulatory power over the uses of pesticides which may involve (1) initiation of punitive action for violations of terms of regulation; (2) seizure of crops that are found to have pesticide residues in excess of legal tolerances and (3) punitive action when pesticides are misused.

County Departments of Agriculture, through the Agricultural Commissioner in each county, enforce the state's pesticide regulations at the local level. This system of enforcement is different than those of other states and, in my estimation, is superior; it provides for local control, where the problems and action really are. The Agricultural Commissioners are workhorses both in enforcing the laws of the state and in helping us get at pesticide problems involving fish and wildlife.

The Department of Public Health has major responsibility in protecting the public from harmful exposure to pesticides in processed food. They monitor processed food for "over tolerance" pesticide contamination. The difference between the Department of Agriculture's responsibility and the Department of Public Health's responsibility in testing food for residue content is that Public Health's jurisdiction covers processed food while Agriculture's pertains to raw agricultural products. Foods are considered raw agricultural products until frozen or put in cans.

The Department of Public Health may also take steps to protect public health from contaminants that may exist in the flesh of sportfish or wildlife. The most recent example of this type of action was a warning from the Public Health Department that it is not wise to eat large striped bass from the San Francisco Bay-Delta area more than once a week because of the mercury contamination of that species.

The University of California makes recommendations for proper uses of pesticides and publishes about 1,400 of these recommendations each year. They are made only after the materials are tested for efficacy and side effects by the University staff. If all farmers followed the advice of the University regarding the use of pesticides there would be a lot fewer fish and wildlife problems. Unfortunately, the law does not require that the recommendations of the University be followed. The farm advisor is the "right arm" of the University at the local level; as is the County Agricultural Commissioner for the Department of Agriculture. In terms of involvement in pesticide matters the Agricultural Commissioner enforces the laws; the farm advisor prescribes proper uses.

The State Water Resources Control Board enforces water quality standards relative to pesticides and other pollutants. Recently they have been quite instrumental in developing a plan for a comprehensive statewide monitoring program that would include pesticides and other pollutants. We are hopeful that this program will be implemented as it is sorely needed.

The Departments of Water Resources and Conservation are interested in pesticides as they may affect various projects in which they are involved. For example, Conservation is interested in both beneficial and harmful attributes of pesticides that may be used in forests. The Department of Water Resources is concerned primarily with contamination by pesticides in waters in state water projects.

The State agencies are involved in many cooperative projects with each other as well as their counterparts in the Federal Government such as USDA, U. S. Public Health Service, Fish and Wildlife Service, FWQA, and others.

There are several multi-agency programs participated in by the Department of Fish and Game. For example we are involved in a pesticide registration review committee in which we have an opportunity to review information on toxicity and proposed uses of candidate pesticides. Through this procedure, the Department can and has altered some of the proposed uses of pesticides and in some cases has prevented some pesticide uses employed in other states from being applied in California because of potential hazard to fish and wildlife. However, the large number of pesticides registered each month and the voluminous data required for each product limit the number of products that are subjected to thorough review by our personnel. Our reviews are usually restricted to a few of the pesticides that are known or suspected to be highly hazardous to non-target animals.

The Department is also represented on a newly formed pesticide advisory committee. It was established by the legislature last year to assist the Director of Agriculture in regulating the use of pesticides. The Committee has an interesting composition which includes representatives of six state agencies and a representative from outside state service in the fields of public health, ecology, biology, and agriculture. These people meet together to help the Director of Agriculture with regulatory problems. To date this Committee has been most active in the area of worker safety. The problems that the farm workers have had involving pesticides have been quite numerous but until recently have not been well documented. The Committee, for the first time, has developed guidelines for safe entry by workers into pesticide treated fields that are aimed at preventing harmful exposure to pesticides. Prior to this action there had been a reluctance on the part of manufacturers to provide specific information as to when it was safe to enter a field after a crop was sprayed because of potential liability claims against the pesticide industry for illness attributed to pesticide exposure.

The Pesticide Advisory Committee was also quite active in securing the phasing out of DDT in California.

With the help of the 1969 Legislature, the Department of Agriculture now has a computerized pesticide use reporting system. This system is very helpful to the various state agencies involved in pesticide matters. It provides monthly reports of practically all pesticide uses in the state, including type and amount of material and location of application designated by township, therefore, we now have a very accurate and up-to-date measurement of input of pesticides into the environment. This, of course, is helpful in looking for problems, helpful in establishing monitoring programs, and helpful in directing action programs to the areas of greatest need.

Californians can be proud of their State's efforts in identifying fish and wildlife pesticide problems and taking remedial action to solve these problems. This State is recognized as a national leader in this regard. However, there is room for improvement and we must strive to better the record.

There is one major area where both State and Federal agencies and the pesticide industry is lacking and this is in preventing environmental pesticide problems from developing. What is needed is a preregistration and preuse pesticide testing system that would provide assurance that only those pesticides could be used that do not cause untoward side effects. This would, of course, require changes in current testing programs and in laws governing the use of pesticides. More specifically, the criteria for preregistration laboratory testing of pesticides should be updated and standardized wherever possible and, most important, criteria should be developed for field testing for side effects under actual operational conditions of application. Undoubtedly the most important facet in assessing the potential environmental impact of a new pesticide is to study its effects on key attributes of the environment under "natural" conditions following controlled applications.

The expected benefits of such an approach would be twofold, first, to establish a more standardized and effective method of presale testing of pesticides and second, to develop controls over the use of pesticides that would appreciably reduce the probability of environmental pesticide problems from developing.

Regarding our handling of heavy metals and PCB's. The group in state service that is doing most of the work has basically the same representation as the one working on pesticide problems. Currently there is a mercury monitoring program within the state that has been involved with the public health rather than the biological effects on the organisms directly contaminated with mercury. There is also a limited amount of Fish and Wildlife data on lead contamination that is being generated in the state. This information consists primarily of measurements of residues occurring in marine fish. At the present time, we look forward to becoming more active in this particular area. The Department's pesticide project has been recording the levels of polychlorinated biphenyls, (PCB's) in fish and wildlife samples for several years and have been more or less sitting on this information. This information will be available when it is figured out what biological significance, if any, these PCB's may have.

Briefly I would like to comment on the scope of the Department's pesticide and heavy metal program that is within the Wildlife Management Branch. The program has both surveillance and research aspects. Our budget is approximately $200,000 annually including grants. We have a staff of 11 fulltime employees. These include fish and wildlife biologists, chemists and after July 1, we will have marine biologists added to the staff also. We also call on the field force of Department personnel as needed to handle pollution problems.

Environmental Services Branch has a very active program in the field of water pollution involving various types of pollutants including those types of materials we are discussing today. This Branch provides most of the Department's efforts in analyzing samples for the presence of heavy metals.

At this point, I would like to turn the rest of our presentation over to Jack Linn who will discuss some of the more detailed aspects of our pesticide and heavy metals investigations.

*Calif. Mar. Res. Comm., CalCOFI Rept.*, 16: 32–34, 1972

# PESTICIDE PROGRAM OF THE CALIFORNIA DEPARTMENT OF FISH AND GAME, PART II

JACK LINN
California Department of Fish and Game
Sacramento, California

As mentioned, our project has both fish and wildlife responsibilities. I will briefly discuss our responsibilities in the fisheries pesticide field which are spread over a broad spectrum of programs. We feel all of these programs are essential but because there are so many some do not receive the attention that we feel they should. I think in the past, the investigation in the marine environment is one that should have received a lot more attention than it did.

Among our programs the one that has been given top priority is investigations of fish kills that are caused by pesticides. In this situation our project acts primarily in an advisory capacity to our field force, advising on types of samples to collect, where and when to collect. We handle the analysis and do much of the coordinating with the investigating agencies.

Another major activity is the evaluation of pest control programs. This is done in cooperation with the Department of Agriculture, and sometimes the chemical company. We evaluate the chemicals that are being planned or developed for use and we also evaluate certain application programs that appear to be potential problems. A new program where I feel we have been effective is the case of a new carbamate which is being proposed for the treatment of an insect pest in rice. This chemical is very toxic to fish and in the first studies it was found that five days after it was applied at the rate of one half pound per acre the fish could not survive in the water for more than about ten minutes. The operators changed the approach and decided they could treat the rice field with the chemical prior to flooding. By the time the field was flooded the chemical had combined with soil particles and did not enter the water in concentrations toxic to fish. In this way it still controlled the insect pest. This chemical was recently registered and the label says "In all the rice growing areas of the U.S. it can be applied post flood", which I think is very hazardous to fish life, because in California the only way they can apply it is before they flood the rice field.

One of the old programs that has been in effect for many years which we thought might be hazardous to fish, was on the north coast where they plant thousands of acres of cut-over timberland with endrin-coated conifer seeds. Endrin is probably the most toxic chemical to fish that we know of. We studied and found that they would have to treat 25 times heavier in order to produce any direct toxic effect on the fish in the streams and also there was no build up of endrin so we felt that we couldn't object to this program because of its supposed hazard to fish.

We also have what we call surveillance programs and much of our effort here is keeping track of new chemicals and changes in use practices, and keeping track of other agencies involved in chemical uses.

Our observations on pesticides in the environment cannot be called monitoring studies. Our ability in this line is very limited because monitoring studies are expensive; they take lots of personnel. We have data on a large number of fish species. It gives us some information but is not very useful for analyzing trends of increasing or decreasing levels because none of these species are sampled consistently or on any routine basis. A possible exception is our data on striped bass which we do have for a number of years and we feel that we know more about the levels in this species than in any other. Striped bass is sampled most intensively because it inhabits the Delta. It is the top of the food chain and we would expect, because the Delta receives all of the runoff from the agricultural area of the Sacramento and San Joaquin Valley that this fish would be highly contaminated. This did not prove to be true. Over the years since 1965 the mean level of DDT in this species runs about one and one half parts per million (ppm) and sometimes less than that.

We also have quite a bit of data on salmon. The levels on salmon tend to run less than one ppm with the exception of a winter run in the Sacramento River that we discovered last year. This run apparently doesn't enter the commercial catch, but the levels in this fish are significantly higher than the rest of the fish we have analyzed. This is a light meated salmon that has a very high oil content, something over 20% fat in the flesh.

The residue programs in the marine environment include estuarine monitoring performed by the National Marine Fisheries Service under a contract with the Department. This was started in January of 1966 and was handled by the Marine Resources Region until recently and then the responsibility was given to our project. This program sampled primarily shellfish from estuaries all along the coast of California. The years of data that we have indicate that the levels are relatively constant with the highest levels found in estuaries that drain extensive agricultural areas.

Also, we recently conducted a survey of marine fish along the coast in cooperation with the State Department of Public Health. We sampled Dover sole, boccacio, rockfish, and crab from three broad areas along the coast. We arbitrarily set the limits at the Oregon border and Point Arena for one sampling area, Point Arena and Point Conception for another, and Point Conception and the Mexican Border for the third. The levels found were less than one half ppm, but they were highest in the southern California area.

*Question:* Was that in the flesh?

*Linn:* Yes. Unless I say otherwise I am talking about wet flesh basis and I am talking about total DDT which includes DDE and DDD.

We have quite a bit of data on other marine species—none collected over an extended period of time. The highest levels we have found have been in anchovy and jack mackerel. All of the high levels (by high I mean more than two tenths ppm) have been in the southern California area except one sablefish caught off Eureka that had over nine ppm DDT.

We are presently starting a modest monitoring program in cooperation with the Marine Resources Region. We plan to sample quarterly six species of fish in five stations along the coast. These species would be boccacio, rockfish, anchovy, and white croaker in the south, and surf perch in the north. We want to sample the anchovy because it is a forage fish, it has high levels and it is migratory. The boccacio is more of a localized species and the white croaker and surf perch reflect the levels in inshore waters.

In addition to this program, we also plan a more intensive sampling of the white croaker population between Dana Point and Pt. Conception. We want to see if we can pinpoint the source of heavy DDT concentrations in the Los Angeles area. We plan to have in the neighborhood of 100 sampling stations in this case.

As mentioned earlier, most of our data on metals is on mercury and most of our data on mercury is from the striped bass population. The situation appears that all fish that are over or slightly over the legal minimum size of 4 lbs. (legal limit, 16 inches) have between one half and one ppm mercury.

That concludes my presentation.

*Question:* Will this PCB data be made available?

*Linn:* Yes.

*Question:* I wanted to ask about your registration program. I gathered that you actually determine what pesticides are used in the fields, that you don't actually keep track of the pesticides prior to the time they are in the field. Is that correct?

*Linn:* Any pesticide sold in California must be registered by the state. Most have a federal label or federal registration also, but a chemical manufactured and sold exclusively in California, has only a state registration.

*Question:* Does that mean that each branch has—that each drug is tagged—and you can follow it to the time of original production?

*Linn:* No. Chemicals are re-registered every year. In that time, if there is anything that needs to be done in terms of further restriction of the pesticide or abolition or rejection of the chemical, existing supplies can be withheld, but there is no way to tag batches that I know of.

*Question:* It is not that there is no way, other than there is no law to take care of this. Apparently this is one of the missing links right now. You don't really discover where it is until you get into the field and there must be other uses or other handlings of pesticides which are very difficult to locate. You mentioned you did some sampling on shellfish in estuaries. What levels did you find?

*Linn:* Generally less than one ppm.

*Question:* The shellfish population doesn't seem to be as drastically affected as the fish population?

*Linn:* Right. They don't have as high levels. What the influence is we don't know.

*Question:* Do you have any levels of DDT on things like carp and catfish in the Delta?

*Linn:* We have limited amounts of data on carp and catfish. It is generally lower than striped bass.

*Question:* Do you know if there has been any sampling analyzed for striped bass 10 or 15 years old that have been preserved, analyzed for mercury?

*Linn:* We haven't done any, someone else may have.

*Question:* What plans are there that you can see in the near future for getting legislative action regarding strengthening the advisory capacity of the University—some way of getting at the farmers—is there any chance that through the Fish and Game Department you could get more strength?

*Linn:* One of the things that you get asked, and it has been tried several years and it is closer to passing now than ever before, is to require that pesticide use be controlled through prescription and that the people that do this be entomologists like Dr. Vandenbosch and some of the people that understand both the need for pest control and the adverse effects that might result. Sort of like prescribing drugs. A committee is looking into the data to make this acceptable to the agricultural community and this appears to be a fine approach to controlling the use of pesticides and hopefully preventing some of the harmful effects.

*Question:* Is DDT being used today? *Yes.* You say you control the application per acre?

*Linn:* No. What I said is that we have a computerized reporting system that puts practically all uses of pesticides on cards (some minor uses aren't reported) and relays the data to Sacramento once a month. So what we have is a reporting of how much, where, for what purpose, etc.

*Question:* What is the phasing out program?

*Linn:* The phasing out program was designed to get rid of major uses of DDT by the end of 1971. This is a program depending on the University's ability to come up with a satisfactory replacement. At present there have been 50 or 60 uses of DDT that have been discontinued, but there are still considerable amounts being used. One of the major crops on which it will not be used after this year is cotton.

*Question:* I know you haven't been monitoring the mercury very long but would you care to speculate at all on what the possible sources might be?

*Linn:* Well it is hard to say. The most extensive levels have been found in the Delta and you would think this might be three things—industry pollution, mercury mines, or mercury lost used during the gold mining era. We also found mercury contamination in fish, from e.g., Gibraltar Reservoir near Santa Barbara where there is no industry but there is an active mercury mine draining into it.

*Question:* I was wondering if this is the probable source. If so, this same level of contamination may have existed for a number of years without our knowing it.

*Linn:* This is certainly possible.

*Calif. Mar. Res. Comm., CalCOFI Rept.*, 16 : 35–43, 1972

# DEVELOPMENT OF A TEMPERATURE CONTROL POLICY FOR THE COASTAL AND INTERSTATE WATERS OF CALIFORNIA

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State Water Resources Control Board
Sacramento, California

The State Water Resources Control Board is involved in the development of a policy for the control of temperature in the interstate and coastal waters of California. I hope to stimulate your interest and encourage you to participate in this process. The Board is making a special effort to obtain input from marine biologists and others who are concerned with protection of the ocean environment.

Water quality control policies for the coastal and interstate waters were adopted by the Board in 1967. As required by the Federal Water Quality Control Act, these policies were submitted to the Secretary of the Interior for approval and adoption as federal water quality control standards. The policies were accepted by the Secretary of the Interior with certain exceptions. The temperature control standards were not accepted because they were in the form of general statements rather than in a form containing definite numerical standards which could be applied either to the waste discharge or the receiving waters.

The Board has been in the process of developing temperature control standards since that time. They solicited advice from many agencies, private companies, and individuals. Public hearings were called in March 1969, and April 1970, to obtain comments and recommendations on proposed standards. Review of the testimony from these hearings led the Board to decide that it would be preferable to develop a general policy for temperature control in the coastal and interstate waters rather than simple numerical standards. The policy would serve as a planning guide for state agencies and waste dischargers and it would guide the Regional Water Quality Control Board in the establishment of waste discharge requirements and water quality control plans. The draft of a proposed policy was sent to agencies, companies, and individuals who had expressed an interest in the subject, and their comments and recommendations were requested. A special effort was made to obtain recommendations from marine institutions and professional marine biologists. Recommendations received by the Board have resulted in a draft of a temperature control policy which will be considered for adoption by the Board at a special hearing on December 16, 1970.

The primary sources of heated discharges to water are industrial cooling and process waters and municipal discharges. Very little factual data on the problems caused by these heated discharges had been presented, but the Board was convinced that there could be a problem in the future unless controls were established. The increasing demand for electrical power is causing utilities to plan large steam generating plants fired by nuclear energy. These plants must waste about 65 percent of the heat generated. The most economical way for them to dissipate the waste is to use a large volume of cooling water which is pumped past condensers and then discharged back to the receiving water. There is also a suprising amount of heat discharged into the ocean from municipal wastes. Several speakers at this conference have discussed the effects of sewage and toxic materials contained in major discharges in Southern California, but there has been no reference to amount of heat discharged from these outfalls.

It is not unusual to observe a 10–20°F difference in temperature between municipal waste at the point of discharge and the temperature in the receiving water. These facts emphasize that a great deal of heated water is discharged into sewers and much of this waste heat is transferred to the ocean environment.

In the development of a temperature control policy, the Board has divided interstate waters, that is, waters which flow across or form part of the boundary of the state, into various classes. "Cold interstate waters" are those characterized as being suitable for trout and salmon. "Warm interstate waters" are those which are generally suitable for bass and catfish. Estuaries and coastal lagoons where there is a mixing of fresh and saline water are a separate class because of their special characteristics. There is also a class for "enclosed bays" which are defined as coastal indentations where the distance between headlands or harbor works is less than 75 percent of the maximum dimension of the bay. This class was developed in recognition of the need for special controls in coastal waters where there is little circulation. All other oceanic waters between the coastline and the territorial limits of California outside of enclosed bays and estuaries are classified as "coastal waters".

The proposed policy specifies particular controls for each class of water. The controls are based on concepts developed by the Board after consideration of past evidence and future conditions. The concepts for temperature controls in enclosed bays serve as an example. In effect, the Board is saying that existing sources of heated waste may continue their past operation in enclosed bays, but each discharger will be required to conduct an environmental impact study to allow the Regional Water Quality Control Board to determine if it is necessary to revise the waste discharge requirements to adequately protect aquatic resources. No evidence presented to the Board has demonstrated that there is a problem with existing heated waste discharges in enclosed bays, but the Board is convinced that the threat of water quality impairment is real and the environmental impact studies will be designed to allow us to review the possibility of existing effects, the potential hazards to water quality, and the type of control measures required. It is entirely possible that this first study will demonstrate the need for additional more detailed studies.

New sources of thermal wastes having a temperature greater than 4°F above the natural temperature will be prohibited in enclosed bays. This statement is made to encourage planning since it clearly informs potential dischargers that we do not want more large sources of heat in enclosed bays.

The most stringent controls have been proposed in estuaries because the Board is convinced these are the areas that need the maximum protection. Existing sources of heated wastes will be limited to a maximum rise of 20°F above the natural temperature of the estuary. The maximum temperature at the point of discharge will be limited to 86°F. A zone of passage will be provided for migrating fish and aquatic life in an estuary by limiting the effect of the discharge to not more than 25 percent of the cross-sectional area of well defined channels. In addition, the surface temperature of the water cannot be increased by more than 4°F as a result of heated waste discharges. New discharges proposed for estuaries will also be limited to a maximum discharge temperature of not more than 4°F above the natural temperature. In this way, the Board intends to advise future dischargers that estuaries should not be considered for the disposal of waste heat.

It is recognized that if new discharges are essentially prohibited from enclosed bays and estuaries, some alternative must be provided for the disposal of waste heat until better methods are available for the control or use of waste heat. For this reason, the Board intends to establish controls which will allow the discharge of heated waste into coastal waters except in those areas where it can be demonstrated that adverse effects would result, or where the aquatic environment is of such critical value that no risk of damage should be allowed. By making it possible for discharges of heated waste to go to the ocean, we do not intend to imply that it will always be safe to discharge increasing amounts of heated wastes into the ocean, but we do believe that this alternative provides the least chance for significant damage to the environment considering the new sources of heat that will be developed in the near future and our lack of knowledge of how to control them.

Existing dischargers of heated wastes into coastal waters will be required to conduct an environmental impact report to provide a basis for revised waste discharge requirements. New discharges will not be permitted in areas where the effects of the discharge may increase the temperature in designated areas of biological significance. This will mean, for example, that if you have a kelp community which has been established by the Board as an area of biological significance, that no heated waste discharge will be allowed to change the temperature in that kelp community at any time.

It is conceived at this time that the Board will ask the Departments of Fish and Game and Parks and Recreation and others to recommend areas of special significance. The regional boards will consider the recommendations of these agencies and others, and make a recommendation to the State Board. The State Board will conduct a public hearing on this recommendation to determine if it is in the public interest to designate the area for special protection from heated waste discharges.

Discharges will also be limited to a maximum rise above natural temperature of not more than 20°F. There may be individual discharges which will be limited to a lower temperature rise for the protection of particular aquatic organisms which pass through the condensers of power plants, or may be swept into the discharge plume from the surrounding water.

Potential dischargers of waste heat into the ocean must also make a predischarge study before waste discharge requirements are requested from the regional board. The study will be required to contain oceanographic and biological information, and predict the effect of the discharge on the environment. This study will be reviewed by the Regional Water Quality Control Board which will either establish waste discharge requirements or prohibit the discharge. If waste discharge requirements are established the potential discharger will be required to make a predischarge base line study to measure conditions before the actual discharge of waste and to conduct a post discharge study to determine the validity of his predictions and demonstrate compliance with the requirements.

It is not intended that there will be a general rise in temperature of the coastal waters as a result of the cumulative effect of discharges. This will require that the Board establish monitoring stations to continually evaluate the possibility of changes in natural conditions.

The environmental impact studies on existing thermal discharges are to be completed by January 1, 1973. Revised waste discharge requirements will be established by July 1, 1973. All discharges will be required to be in compliance with the revised requirements by January 1, 1976.

Copies of this policy are available from the State Water Resources Control Board in Sacramento.

NOTE: by editor: This policy was adopted by the Board January 7, 1971 and submitted to the Environmental Protection Agency for possible use in setting federal standards.

*Question:* Is the company the one that will do the survey or is your agency going to be doing the survey?

*Dunham:* The company will generally be the one that conducts it. There may be certain parts of the studies that will be done by someone else. In all cases, the Regional Water Quality Control Board will set certain specifications for the study and a study plan will be developed by the discharger. The plan will then be reviewed by the regional board to determine if it complies with the specifications.

*Question:* The data is the important thing. Why can't you have it built in? And then it will really be a safeguard with no chance of finagling the data.

*Dunham:* We hope to forestall that by having someone like the Department of Fish and Game evaluate the data.

*Question:* But your department is not the Department of Fish and Game. You are the one that is controlling the water quality.

*Dunham:* Right. We can review the data but we don't have enough people to go out and gather it. The discharger will have to gather the data or pay to have it gathered. We will try to watch and see that there is no finagling of the data. If necessary, we will employ consultants of our own choosing for review of the studies and analysis of the data.

*Question:* What is the absolute rise that you are going to allow in an estuary for more than one plant?

*Dunham:* We are saying that outside of a limited diffusion area there will be no general rise in temperature. Other limits will help guarantee this. At the end of the pipe, a discharge can't be more than 86°F. There cannot be more than a 4°F increase at the surface of the water.

*Question:* In other words, if you have an estuary and there is more than one plant discharging water are you going to monitor the absolute rise and the ambient temperature? I question this because estuaries are breeding grounds or nurseries for many types of animals and even a small rise—say $\frac{1}{2}$°F—could be fatal to the larvae of these types of things.

*Dunham:* There is no intent that the estuary would be allowed to rise in temperature. This is going to be very difficult. I'm not sure the Board realizes what a difficult task this will be. Recently I heard a talk in Sacramento by a man from the U. S. Geological Survey who had made studies on various streams to determine the impact of heated discharges. They measused the temperature at various distances from the sources. They went as far as 30 kilometers from the source of a nuclear powered plant, and as far as I recall, they found that 40 to 65 percent of the total heat put in the water was still there, 30 kilometers downstream. They conducted studies in several types of waters from North Carolina to the North Platte River in Wyoming where it was winter. I believe there were four different types of streams. From this type of information we are aware that in estuaries it is going to be a tremendous problem to try to monitor and determine what is the ambient or natural temperature, and whether there has been an increase or not.

January 7, 1971

State Water Resources Control Board

# POLICY REGARDING THE CONTROL OF TEMPERATURE IN THE COASTAL AND INTERSTATE WATERS AND ENCLOSED BAYS AND ESTUARIES OF CALIFORNIA[1]

## *Definition of Terms*

1. *Thermal Waste.* Cooling water and industrial process water used for the purpose of transporting waste heat.
2. *Elevated Temperature Waste.* Liquid, solid, or gaseous material including thermal waste discharged at a temperature higher than the ambient temperature of receiving water. Irrigation return water is not considered elevated temperature waste for the purpose of this policy.
3. *Ambient Receiving Water Temperature.* The temperature of the receiving water at locations, depths, and times which represent conditions unaffected by any elevated temperature waste discharge.
4. *Interstate Waters.* All rivers, lakes, artificial impoundments, and other waters that flow across or form a part of the boundary with other states or Mexico.
5. *Coastal Waters.* Waters of the Pacific Ocean outside of enclosed bays and estuaries which are within the territorial limits of California.
6. *Enclosed Bays.* Indentations along the coast which enclose an area of oceanic water within distinct headlands or harbor works. Enclosed bays will include all bays where the narrowest distance between headlands or outermost harbor works is less than 75 percent of the greatest dimension of the enclosed portion of the bay. This definition includes but is not limited to the following: Humboldt Bay, Bodega Harbor, Tomales Bay, Drakes Estero, San Francisco Bay, Carmel Bay, Morro Bay, Los Angeles Harbor, Upper and Lower Newport Bay, Mission Bay, and San Diego Bay.
7. *Estuaries and Coastal Lagoons.* Waters at the mouths of streams which serve as mixing zones for fresh and ocean water during a major portion of the year. Mouths of streams which are temporarily separated from the ocean by sandbars shall be considered as estuaries. Estuarine waters will generally be considered to extend from a bay or the open ocean to the upstream limit of tidal action but may be considered to extend seaward if significant mixing of fresh and saltwater occurs in the open coastal waters. This definition includes but is not limited to the following: Smith River, Klamath River, Mad River, Eel River, Noyo River, Russian River, Sacramento River (including Suisun Bay), downstream to Carquinez Bridge, Sacramento-San Joaquin Delta as defined by Section 12220 of the California Water Code.
8. *Cold Interstate Waters.* Streams and lakes having a range of temperatures generally suitable for trout and salmon including but not limited to the following: Lake Tahoe, Truckee River, West Fork Carson River, East Fork Carson River, West Walker River and Lake Topaz, East Walker River, Minor California-Nevada waters, Klamath River, Smith River, Goose Lake, and Colorado River from the California-Nevada stateline to the Needles-Topock Highway Bridge.
9. *Warm Interstate Waters.* Interstate streams and lakes having a range of temperatures generally suitable for warm water fishes such as bass and catfish. This definition includes but is not limited to the following: Colorado River from the Needles-Topock Highway Bridge to the northerly international boundary of Mexico, Tijuana River, New River, and Alamo River.
10. *Existing Discharge.* Any discharge (a) which is presently taking place or (b) for which waste discharge requirements have been established and construction commenced prior to the adoption of this policy, or (c) any material change in an existing discharge for which construction has commenced prior to the adoption of this policy. Commencement of construction shall include execution of a contract for on-site construction or for major equipment which is related to the condenser cooling system.

    Major thermal discharges under construction which are included within this definition are:

    A. Diablo Canyon Units 1 and 2, Pacific Gas and Electric Company
    B. Ormond Beach Generating Station Units 1 and 2, Southern California Edison Company
    C. Pittsburg No. 7 Generating Plant, Pacific Gas and Electric Company
    D. South Bay Generating Plant Unit 4 and Encina Unit 4, San Diego Gas and Electric Company
11. *New Discharge.* Any discharge (a) which is not presently taking place unless waste discharge re-

[1] The latest revision of this Policy, now entitled "Water Quality Control Plan for Control of Temperature in the Coastal and Interstate Waters and Enclosed Bays and Estuaries of California," dated March 4, 1972 can be obtained from the State Water Resources Control Board, 1416 Ninth Street, Sacramento, California 95814.

quirements have been established and construction as defined in Paragraph 10 has commenced prior to adoption of this policy and (b) which is presently taking place and for which a material change is proposed but no construction as defined in Paragraph 10 has commenced prior to adoption of this policy.

## SPECIFIC WATER QUALITY OBJECTIVES

1. *Cold Interstate Waters*
   A. Elevated temperature waste discharges into cold interstate waters are prohibited.
2. *Warm Interstate Waters*
   A. Thermal waste discharges having a maximum temperature greater than 5°F above ambient receiving water temperature are prohibited.
   B. Elevated temperature wastes shall not cause the temperature of warm interstate waters to increase by more than 5°F.
   C. Lost River—Elevated temperature wastes discharged to the Lost River shall not cause the temperature of the receiving water to increase by more than 2°F when the receiving water temperature is less than 62°F, and 0°F when the receiving water temperature exceeds 62°F.
3. *Coastal Waters*
   A. Existing discharges:
      (1) Elevated temperature wastes shall comply with specific temperature limitations and other restrictions necessary to assure protection of the beneficial uses including areas of special biological significance.
   B. New discharges:
      (1) Elevated temperature wastes shall be discharged a sufficient distance from areas of special biological significance to assure the maintenance of ambient temperature in these areas.
      (2) The maximum temperature of thermal waste discharges shall not exceed the ambient temperature of receiving waters by more than 20°F.
      (3) Additional limitations shall be imposed when necessary to assure protection of beneficial uses.
4. *Enclosed Bays*
   A. Existing discharges:
      (1) Elevated temperature waste discharges shall comply with specific temperature limitations and other restrictions necessary to assure protection of beneficial uses.
   B. New discharges:
      (1) Elevated temperature waste discharges shall comply with specific temperature limitations and other restrictions necessary to assure protection of beneficial uses. The maximum temperature of waste discharges shall not exceed the ambient temperature of the receiving waters by more than 20°F.
      (2) Thermal waste discharges having a maximum temperature greater than 4°F above the ambient temperature of the receiving water are prohibited.
5. *Estuaries*
   A. Existing discharges:
      (1) Elevated temperature waste discharges shall comply with the following:
         a. The maximum temperature shall not exceed the ambient receiving water temperature by more than 20°F.
         b. Elevated temperature waste discharges either individually or combined with other discharges shall not create a zone, defined by water temperatures of more than 1°F above ambient receiving water temperature, which exceeds 25 percent of the cross-sectional area of a main river channel at any point.
         c. No discharge shall cause a surface water temperature rise greater than 4°F above the ambient temperature of the receiving waters at any time.
         d. Additional limitations shall be imposed when necessary to assure protection of beneficial uses.
      (2) Thermal waste discharges shall comply with the provisions of 5A(1) above and, in addition, the maximum temperature of thermal waste discharges shall not exceed 86°F.
   B. New discharges:
      (1) Elevated temperature waste discharges shall comply with item 5A(1) above.
      (2) Thermal waste discharges having a maximum temperature greater than 4°F above the ambient temperature of the receiving water are prohibited.
      (3) Additional limitations shall be imposed when necessary to assure protection of beneficial uses.

## GENERAL WATER QUALITY PROVISIONS

1. Additional limitations, including discharge prohibitions, shall be imposed if necessary for the protection of specific beneficial uses including areas of special biological significance.
2. The cumulative effects of elevated temperature waste discharges shall not cause temperatures to be increased except as provided in specific water quality objectives contained herein.
3. The reclamation of waste heat energy from cooling water shall be encouraged.
4. Exceptions to the provisions of this policy may be included in waste discharge requirements to allow the use of heat on an intermittent basis to control fouling organisms if it has been determined that other alternative methods will result in a greater potential for deleterious effects upon beneficial uses.

5. A conditional modification of the objectives of the policy may be authorized upon a finding that an elevated temperature waste discharge operating in compliance with modified objectives will result in the enhancement of beneficial uses.
6. Ambient water temperature will be compared with waste discharge temperature by near-simultaneous measurements accurate to within 1°F. In lieu of near-simultaneous measurements, measurements may be made under calculated conditions of constant waste discharge and receiving water characteristics.
7. Areas of special biological significance shall be designated by the State Board after review of regional board recommendations and public hearing.

## IMPLEMENTATION

1. The State Water Resources Control Board and the California Regional Water Quality Control Boards will administer this policy by establishing waste discharge requirements for discharges of elevated temperature wastes.
2. This policy is effective as of the date of adoption by the State Water Resources Control Board and the sections pertaining to temperature control in each of the 32 policies for the individual interstate and coastal waters shall be void and superseded by all applicable provisions of this policy.
3. Existing discharges:
   A. All dischargers of thermal waste shall be required to conduct a study to define the effect of the discharge on beneficial uses and submit the results thereof to the appropriate regional board prior to January 1973.
   B. Waste discharge requirements for elevated temperature wastes shall be reviewed to determine the need for studies on the effect of the discharge on beneficial uses, changes in monitoring programs and revision of waste discharge requirements.
   C. The scope of any necessary studies shall be as outlined by the regional board or State Board for each discharge.
   D. The regional board shall review all studies and shall make necessary revisions to waste discharge requirements prior to July 1973 to assure compliance with all applicable provisions of this policy.
   E. Revised waste discharge requirements shall include a time schedule which assures compliance at the earliest possible date but not later than January 1976.
4. New discharges:
   A. Every discharger of thermal waste shall submit a predischarge study to the appropriate regional board defining the effect of the discharge on beneficial uses prior to the establishment of waste discharge requirements. Dischargers of elevated temperature wastes may be required by the regional board to submit such studies prior to the establishment of waste discharge requirements. The regional board shall include in its requirements appropriate postdischarge studies by the discharger.

State of California
STATE WATER RESOURCES CONTROL BOARD

# PROCEDURES FOR IMPLEMENTATION OF THE POLICY REGARDING THE CONTROL OF TEMPERATURE IN THE COASTAL AND INTERSTATE WATERS AND ENCLOSED BAYS AND ESTUARIES OF CALIFORNIA

## 1. *Purpose of the Studies*

The temperature control policy adopted by the State Water Resources Control Board on January 7, 1971 requires that all dischargers of thermal wastes conduct a study to define the effect of the discharge on beneficial uses. The regional board may require dischargers of elevated temperature wastes to conduct such a study in any case where there is reason to believe adverse effects may be occurring to beneficial uses and existing monitoring programs are not adequate to allow a determination. The results of the studies will be utilized as a basis for the revision of waste discharge requirements and the development of monitoring programs.

Reports of waste discharge submitted to a regional board after January 7, 1971 must contain sufficient information to permit the board to determine if the waste can be classified as an elevated temperature or thermal waste. All proposed dischargers of thermal wastes and those proposing to discharge significant quantities of elevated temperature waste will be required to submit a pre-discharge report containing results of a study which predicts the effect of the waste on beneficial uses. The results of these studies will be used by the regional boards to develop waste discharge requirements and monitoring studies. A post-discharge study will then be required to verify the predictions and determine if effects occur which were not anticipated in the pre-discharge study.

## 2. *Definitions*

A. Beneficial Uses—''Beneficial uses'' of the waters of the state that may be protected against quality degradation include, but are not necessarily limited to, domestic, municipal, agricultural and industrial supply, power generation, recreation, esthetic enjoyment, navigation, and preservation and enhancement of fish, wildlife and other aquatic resources or preserves. Section 13050(f) Water Code.

B. Elevated Temperature Waste—Liquid, solid, or gaseous material including thermal waste discharged at a temperature higher than the ambient temperature of receiving water. Irrigation return water is not considered elevated temperature waste for the purpose of the policy.

C. Thermal Waste—Cooling water and industrial process water used for the purpose of transporting waste heat.

D. Existing Discharge—Any discharge (a) which is presently taking place or (b) for which waste discharge requirements have been established and construction commenced prior to the adoption of the policy, or (c) any material change in an existing discharge for which construction has commenced prior to the adoption of the policy. Commencement of construction shall include execution of a contract for on-site construction or for major equipment which is related to the condenser cooling system.

E. New Discharge—Any discharge (a) which is not presently taking place unless waste discharge requirements have been established and construction as defined in ''Existing Discharge'' has commenced prior to adoption of the policy and (b) which is presently taking place and for which a material change is proposed but no construction as defined in ''Existing Discharge'' has commenced prior to adoption of the policy.

F. Ambient Receiving Water Temperature—The temperature of the receiving water at locations, depths, and times which represent conditions unaffected by any elevated temperature waste discharge.

## 3. *Procedures Required for Existing Discharges*

A. Existing waste discharges into interstate and coastal waters shall be reviewed to determine if they can be classified as elevated temperature or thermal wastes.

B. The discharger shall be informed of any prohibitions or other specific limitations which will be imposed on the discharge as a result of the temperature control policy.

C. All dischargers of thermal wastes or significant quantities of elevated temperature waste shall be requested to furnish a technical report to the regional board within the meaning of Section 13267 of the Water Code at a time specified by the board. All reports must be submitted prior to January 1973.

D. The scope of the technical report shall be specified by the regional board in sufficient detail to require the following information:

1. A description of the discharge works and their location or relationship to the receiving water.

2. Temperature characteristics and volume of the waste, including daily, weekly, monthly or seasonal variations in terms of average, maximum and minimum values observed. Other statistical data of importance to the board may be specified.
3. Sources of waste and treatment prior to discharge in sufficient detail to permit classification as either thermal waste or elevated temperature waste.
4. Ambient temperature characteristics and physical description of the receiving water including important daily, weekly, monthly or seasonal variations reported in a statistical form acceptable to the board.
5. Area of the receiving water influenced by the discharge of waste as determined by a difference in temperature of more than 1°F greater than the ambient temperature of the receiving water which can be attributed to the discharge. In estuaries, the area of influence must be related to the cross-sectional area of main river channels when applicable.
6. Other water quality parameters or factors associated with the receiving water in the area of influence of the discharge which are of importance in evaluating the effect of the discharge on beneficial uses.
7. Beneficial uses of the receiving water in the maximum area of influence of the discharge together with any important dependent or incidental factors which might reasonably be expected to influence the amount of use or effect of the discharge. Such factors may include season of the year, climate, water quality, currents, stream flow, public access or other features of the environment. Beneficial uses are intended to include maintenance of a healthy aquatic environment. Therefore, it will be necessary to describe important biological forms and associated ecological factors. Uses should be described in quantitative terms whenever possible. Trends in the quantity of use or predictions of changes in use in the near future may be important in some cases.
8. Analysis of the effects of the waste discharge on the beneficial uses described in Item 7. Effects of the discharge on each use should be reported as beneficial, adverse, unknown, or no significant effect. Supporting information should be provided. An estimate of the change in use before and after the discharge may be helpful.
9. A description of any methods used to maintain the discharge works and the frequency of use, together with a review of alternative methods available and a comparison of costs and effects on beneficial uses. Methods considered should particularly include use of heat or chemicals to control fouling organisms but may also include dredging of outfall channels or areas near the discharge. cleaning of intake screens and regular replacement of major components of the treatment works or outfall structures.
10. Other information specifically necessary to permit the regional board to develop waste discharge requirements or monitoring studies for a particular discharge.

E. Review of technical reports for existing discharges and revision of waste discharge requirements is required prior to July 1973. Waste discharge requirements for all elevated temperature wastes should contain numerical temperature limits for both the discharge and the receiving water at appropriate locations and in statistically significant terms. Temperature limits must provide a margin of safety for established beneficial uses. Limits related to the ambient temperature of the receiving water will require the establishment of locations and procedures for determining ambient temperature and comparison with temperatures within the area of influence of the discharge. Revised requirements must also contain any limitations or prohibitions imposed by the temperature control policy.

F. Revised waste discharge requirements shall include a time schedule which assures compliance at the earliest possible date but not later than January 1976.

### 4. *Procedures Required for New Discharges*

A. Reports of Waste Discharge submitted to a regional board will be considered incomplete until they contain sufficient information to permit the board to determine if the waste can be classified as an elevated temperature or thermal waste.

B. Dischargers of elevated temperature or thermal waste shall be informed by the regional board of any prohibitions or other specific limitations which will be imposed on the discharge as a result of the temperature control policy and the existence of designated areas of special biological significance prior to the request for a specific pre-discharge study.

C. All dischargers of thermal wastes or significant quantities of elevated temperature waste shall be requested to conduct a pre-discharge study defining the effect of the proposed discharge on beneficial uses and include the results of the study as a part of their Report of Waste Discharge. If a material change in an existing discharge is proposed, the study should define the effect of the total discharge before and after the material change.

D. The scope of the pre-discharge study shall be specified by the regional board in sufficient detail to require the same general type of information as described in 3(D) above, recognizing that it will be necessary for the discharger to predict the temperature characteristics of the waste, area of influence of the discharge, post-discharge, beneficial uses and the effects of the waste on beneficial uses.

5. *General Considerations*

A. The discharger should be informed that results of previous studies or monitoring reports by the discharger or others may be utilized in the conduct of required studies if the information is representative of conditions in the area of influence of the discharge and applicable to the time period under study. Acceptance of information from previous studies or conclusions reached as a result of using such information will rest with the regional board. Questions as to the acceptance of such information should be resolved early in the study whenever possible.

B. Areas of special biological significance are to be designated by the State Board after review of regional board recommendations. Such areas may be recommended by a regional board without reference to a particular discharge, or the need for such areas may become apparent when a particular discharge is proposed in the vicinity of such an area. The State Board assumed that such areas as marine preserves designated by the Department of Parks and Recreation or Department of Fish and Game, and large kelp beds designated by the Fish and Game Commission would be considered for this type of designation. However, the Board intended that this designation could be used for any area which contained forms of life which deserved special protection from increases in temperature. The designation of such an area is equivalent to stating that the area is so important that we cannot take the risk of allowing changes in the biological forms as a result of temperature increases.

Calif. Mar. Res. Comm., CalCOFI Rept., 16: 44–50, 1972

# WASTEWATER TREATMENT AND DISPOSAL SYSTEM

FRANKLIN D. DRYDEN
Los Angeles County Sanitation Districts
Los Angeles, California

I have been asked to describe the Districts' operations, indicate some of the things we know or don't know about our system's effect upon the ocean and describe some of the programs we are involved in to evaluate what is happening to the environment as a result of our waste discharges.

Figure 1 is a map of the Sanitation Districts of Los Angeles County. These colored areas are the districts. We serve some 4 million people in some 71 incorporated cities and considerable unincorporated territory, but we do not include the City of Los Angeles, which has its own treatment plant and outfall system at Hyperion.

Our major system, the area on the southern and eastern portion of Los Angeles County, includes 15 sanitation districts, united into a single treatment system. This system has a large primary treatment facility called the Joint Water Pollution Control Plant and it has a number of upstream plants. We are in the process now of expanding our system in the upstream area. The joint plant has a present capacity of 450 million gallons per day and a present flow of 380 million gallons per day. It is planned that this plant will remain at that capacity over the next 40 years, and all additional flow or increase in capacity will be accomplished by providing secondary treatment at 4 major inland treatment plants.

Some of the water from these plants is currently reused and more will be in the future. Water that is not reused is discharged to the lined portion of the San Gabriel River and passed out to the ocean through the San Gabriel River estuary.

Figure 2 shows an aerial view of the Joint Water Pollution Control Plant. The major components are primary sedimentation tanks. This is the form of treatment where you use gravity separation of heavy materials and light materials, both of which are removed from the flow. About 50% of the suspended materials are removed from the flow and fed into anaerobic digesters which are located toward the back of the picture. The anaerobic digestion process is designed to biologically and anaerobically decompose approximately 50% of the organic matter which enters the digesters; the heavy materials which remain in the digested sludge are separated from the smaller, lighter fraction by means of a centrifuge and converted to fertilizer. Only about 40% of the solids are converted to fertilizer—the remainder, a fine material which will pass a 200 mesh screen, remains in the centrate and is reconstituted with the primary effluent and discharged to the ocean. The combined discharge from our present system has an average suspended solids concentration of about 325 mg per liter, and an average BOD of about 275 mg per liter. These values are above the limits which were established on September 23, 1970, by the Regional Water Quality Control Board and we are in the process of designing additional sedimentation tanks and in an extensive research program to do something different with the centrate solids so that they will no longer be discharged to the ocean at all. We are in full swing on the studies to accomplish this but it is still going to require some time to make this fairly major change in our treatment process.

Historically speaking, the development of waste treatment for this plant was begun in the late 20's—some 40 years ago. The original purpose of waste treatment was to protect the public health. We feel we have been fairly successful at that. Later on there was a concern about esthetics and we feel we are doing reasonably well there. However, in the area of the protection of the environment, which is a relatively recent concern in the waste treatment field, we all have a lot to do to determine what needs to be done and how we can accomplish it most satisfactorily.

After the treatment plant, the flow passes through two 8 mile tunnels under the Palos Verdes hills and into the outfall system at Whites Point (Figure 3). We have 4 outfalls—the smallest one (60″ in diameter and built about 1935) and the 72″ diameter outfall (built about 1945) are no longer in use, because they are both too shallow. We have two outfalls in operation. One is a 90″ diameter outfall with 2400 feet of 60″ diffuser on the end. The last outfall, put into service about 1965, is 120″ in diameter at its start, dropping to 72″ at the end and has about 4,000 feet of diffuser length. In the diffuser, 3″ ports every 12 to 24 feet distribute the wastewater into a large volume of sea water. In a sense, these progressions represent our increased knowledge as to what is happening in the environment and how we can better engineer the utilization of that corner of the ocean.

Figure 4 shows what we are discharging through. This is the transition from the 102″ to the 72″ portion of the 4th outfall. In the side of the pipe two 3″ ports are visible about 12 feet apart. These are now at a depth of approximately 200 feet.

We are monitoring, and have monitored for many years, the ocean in the vicinity of the outfalls. Historically, most of our monitoring has been on the physical characteristics making depth profiles, temperature, currents, bacteriological studies and things like that. Here is a limited summary of some of the data developed over the years.

We have two relatively distinct periods with variations in both. Looking at the summertime (Figure 5),

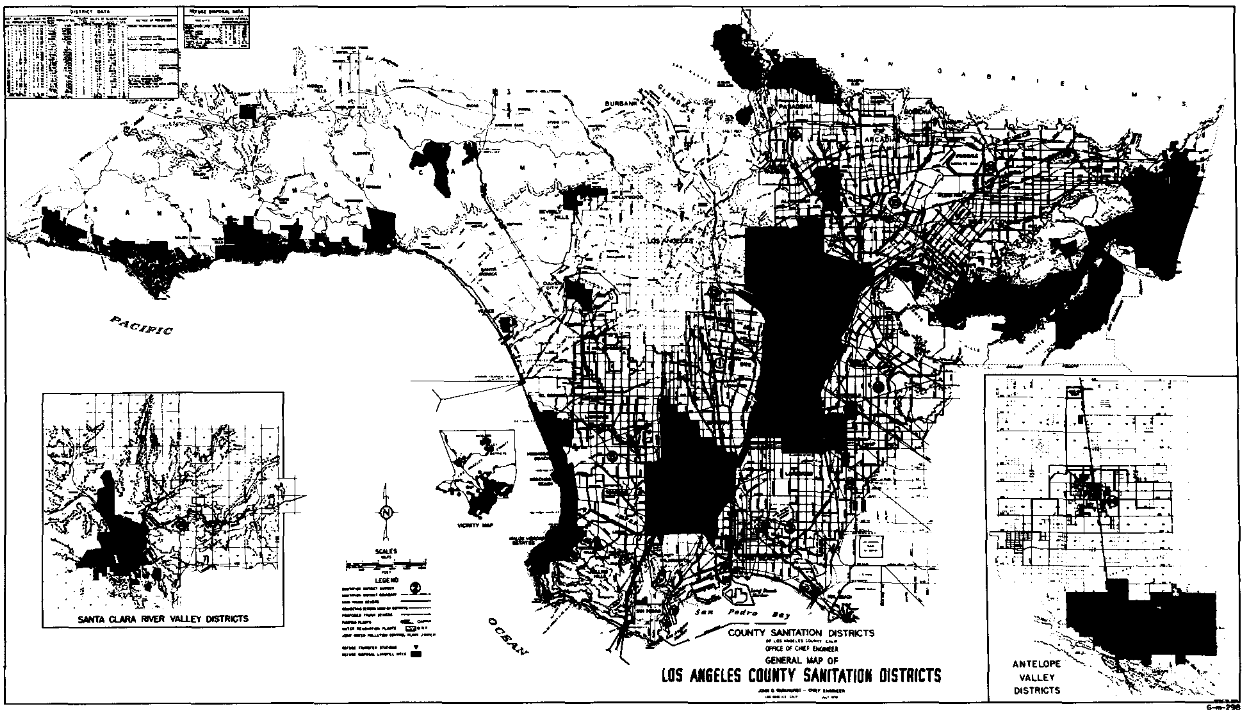


FIGURE 1. General map of Los Angeles County sanitation districts.

FIGURE 2. Aerial view of Joint Water Pollution Control Plant.

we see a temperature gradient from 70° F at the surface to about 52° F at 200 ft. with a well defined thermocline in the vicinity of about 50 feet. In the wintertime, the temperature profile is much straighter with a lower gradient and weaker thermocline. In the summertime and really for 9 months of the year, we have generally very optimal conditions for discharging a diffused wastewater into 200 foot depth. With these very small ports and long diffuser areas, we achieve mixing of about 1 part wastewater with 200 to 300 parts of the cold and denser bottom waters which results in a mixture having an intermediate density and a field that stays below the 50 foot level. Work still has to be done on the rate of dilution and diffusion that goes on beyond this point, as the field travels away with the currents and diffuses out into the ocean.

In the wintertime, with our presently designed outfall and with a temperature differential of only 3 to 4 degrees, we can accomplish our objective of keeping the field in a submerged level. However, if we have storms or other conditions which mix the entire water column then we have a surface field and at those times we have to chlorinate to protect the public health.

I would like to give you some other data. This is fairly recent data and therefore some of it is still questionable, both in terms of where we are sampling and as to whether it is truly accurate.

Figure 6 shows our best estimates of some of the heavy metals in our effluent. We just got the results of our first samples for mercury, which was run by an outside laboratory because we are still unable to run it, and found it to be about 0.006 ppm or milligrams per liter (mg/l). The other thing you will notice is that most of our heavy metals are in some sort of precipitate form. We believe most of them are in a precipitate with sulphide, the soluble portion is noted on the right. In addition to heavy metals, we believe we have about 6 mg/l of phenol, about 9 mg/l phosphorous, ammonia levels of about 50–70 mg/l, cyanide of 0.2 mg/l, and arsenic of 0.01 mg/l. We have also checked radioactivity for many years and it runs about $0.2 \times 10^{-7}$ microcuries per ml. We have just recently begun toxicity studies with the assistance of Marineland, and determined an approximate 96-hour TLM of about 60% for killifish, which was frankly a lot higher than we thought it would be.

We have, for many years, been conducting a monitoring program on stations established by the Regional Water Quality Control Board. Figure 7 shows

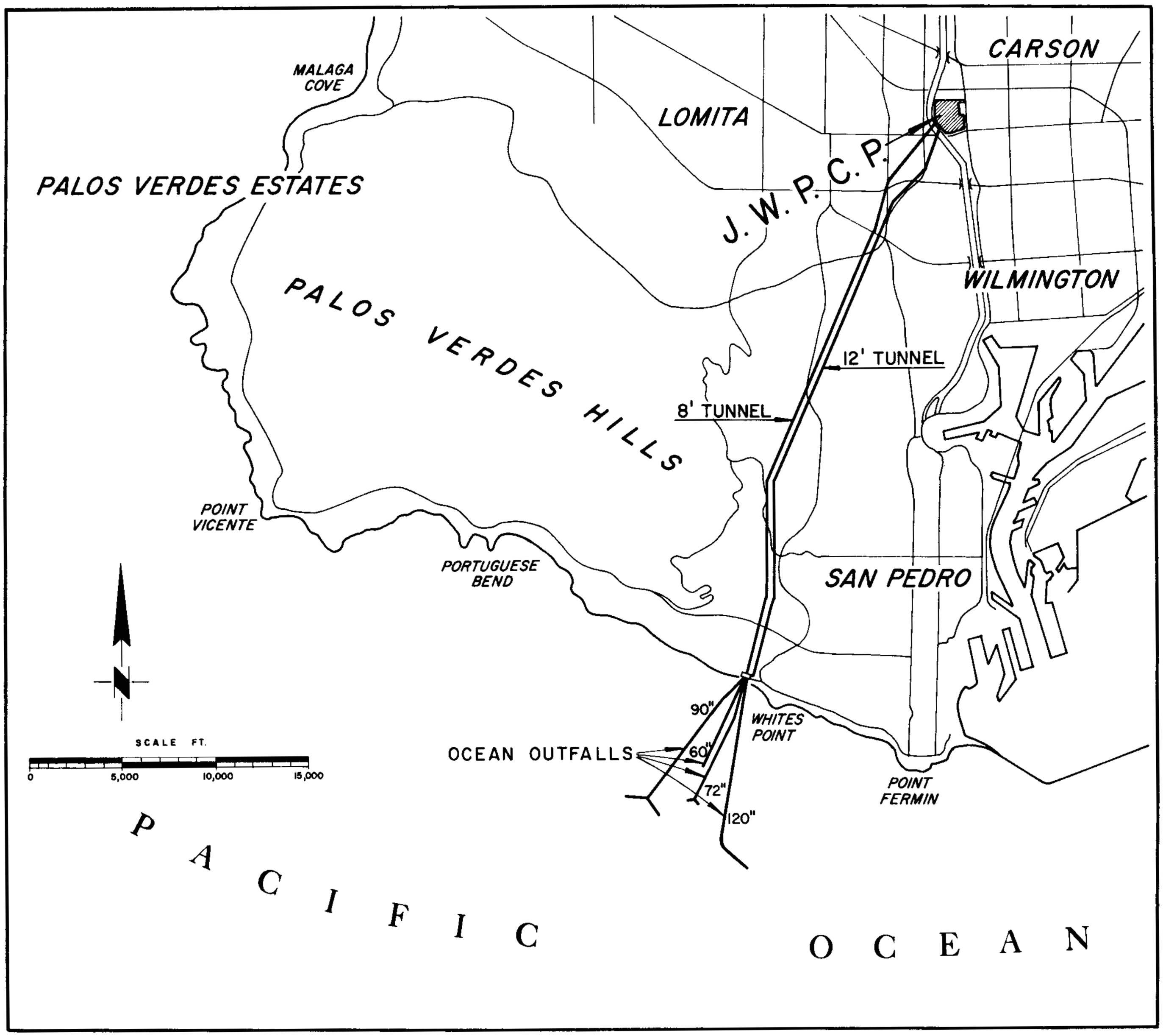


FIGURE 3. Tunnels through Palos Verdes into outfall system.

the outfall area and the dark dots represent the various sampling stations we occupy.

We have recently spent another $200,000 to equip a boat to do the monitoring which we think is necessary particularly in the biological area where we have not been involved in the past. Figure 8 shows the SEA-S-DEE, our new marine research vessel. It is equipped with an articulating crane and davits for its various types of instrumentation packages.

Figure 9 summarizes the monitoring we are now conducting. These various programs are performed *weekly*. We measure these parameters at the various stations shown on the previous map. This is all in accordance with the requirements of the Water Quality Control Board. On a *monthly* basis (Figure 10) we take depth profiles of these same parameters including dissolved oxygen, temperature, grease and turbidity.

Semiannually, we get into some of the biological parameters with use of the otter trawl and scuba diving surveys to observe the sediments and count the fish found in the area (Figure 11). This program is just getting under way and therefore we are not prepared to report on the findings, but this information will be available as well as that of the Southern California Coastal Water Research Project.

I think what I would most like to say to you is that you represent a scientific community concentrating upon the marine environment and we look to you to tell us what to be concerned with in our waste. The pesticide DDT, for example, had never been analyzed for in our wastewater. It was generally believed that

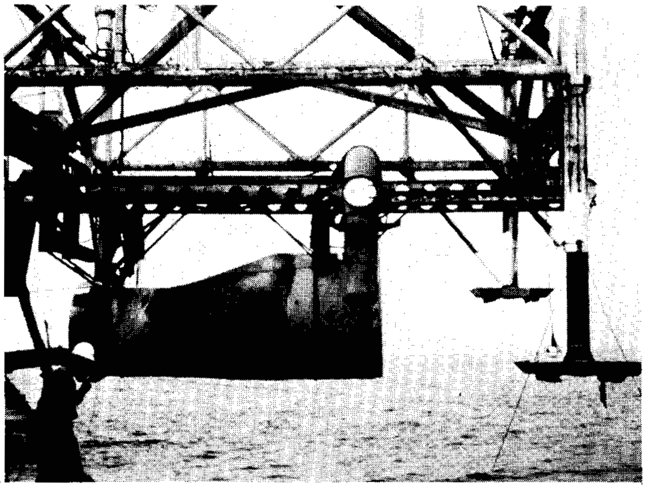

FIGURE 4. Discharge port being installed.

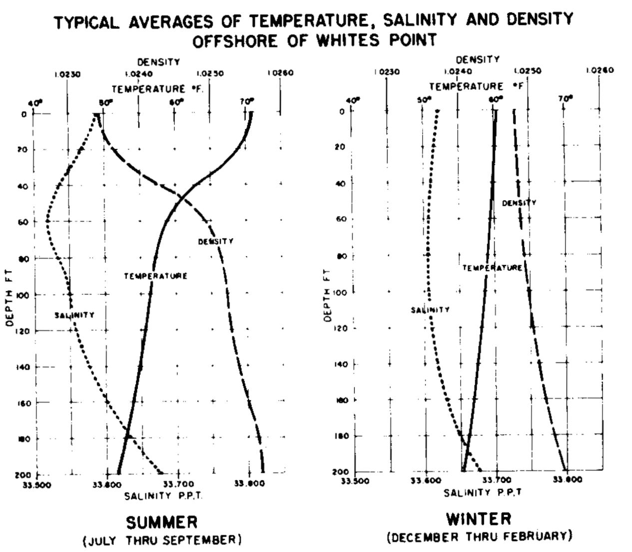


FIGURE 5. Typical averages of temperature, salinity and density, offshore of Whites Point.

most DDT was transmitted through the atmosphere and through fields where it was used in agriculture. Even analyses of other wastewaters indicated DDT levels were very low.

As a result of the findings of recent times we have analyzed now for DDT in our system and we have found it and have already succeeded in controlling at least 80% of it. We are seeking the other sources so that we can control them also. There are certainly other industrial waste materials of concern within our system since we take ⅔ of the industrial waste of Los Angeles County. We have a community with practically every kind of industry and with many kinds of wastes. We know very little about the specifics of some of these wastes or their influence upon the environment. We need to have scientists determine what materials in the waste are detrimental to the environment so that we may either control them at the source, which we have the capability of doing and prevent them getting in, or, if they cannot be handled that

JOINT WATER POLLUTION CONTROL PLANT EFFLUENT HEAVY METAL CONCENTRATIONS

| CONSTITUENT | TOTAL (mg/l) | SOLUBLE (mg/l) |
|---|---|---|
| CADMIUM | 0.170 | 0.025 |
| CHROMIUM | 1.173 | 0.013 |
| COPPER | 0.898 | 0.040 |
| NICKEL | 0.218 | 0.116 |
| ZINC | 2.640 | 0.102 |
| LEAD | 0.320 | 0.001 |
| MERCURY* | 0.006 | — |

ALL DATA ARE AVERAGES OF MONTHLY SAMPLES FROM APRIL THRU OCTOBER 1970

*A SINGLE SAMPLE

FIGURE 6. Joint water pollution control plant effluent heavy metal concentrations.

way, treat them. But first we have to know what it is that is environmentally important. This is where we have to rely on you to a large degree, although we are also in the process of doing some work on our own and through the Southern California Coastal Water Research Project. We hope to find out what some of the negative effects of wastewater are on the environment.

I would like to emphasize that wastewater is not a single thing. It has many, many things in it and not everything in it is bad. In fact, there are some that believe, and I share this belief, that particularly the nutrient component of wastewater may provide a source of nutrient which would be essential to increasing the productivity of the ocean's desirable forms. We need to know more about how to utilize this potential for improved productivity and, again, this is an important area which we need your help on. I think if you were to decide you wanted to run a farm in the ocean, so to speak, and many people in your field have spoken of this, one of the first things that you would find you needed was a source of fertilizer or nutrient and there is probably no more economical or available source than wastewater. I think we need to be careful not to eliminate that source before we find out how to use it for our benefit.

*Question:* Regarding the DDT flap. The last data I saw was that you had cut your output about ½—400–200 pounds per day.

*Dryden:* I would speculate it had been higher to begin with. I would say we are down in the vicinity of 100–200 lbs. per day now and we may have been, at one time, on the order of 600–800 lbs. per day. The problem is we began setting up for the DDT tests in the summer of 1969. We didn't even get our instrumentation set up to begin running anything until late last year and didn't begin to get any reliable data until spring and we can only speculate as to what had

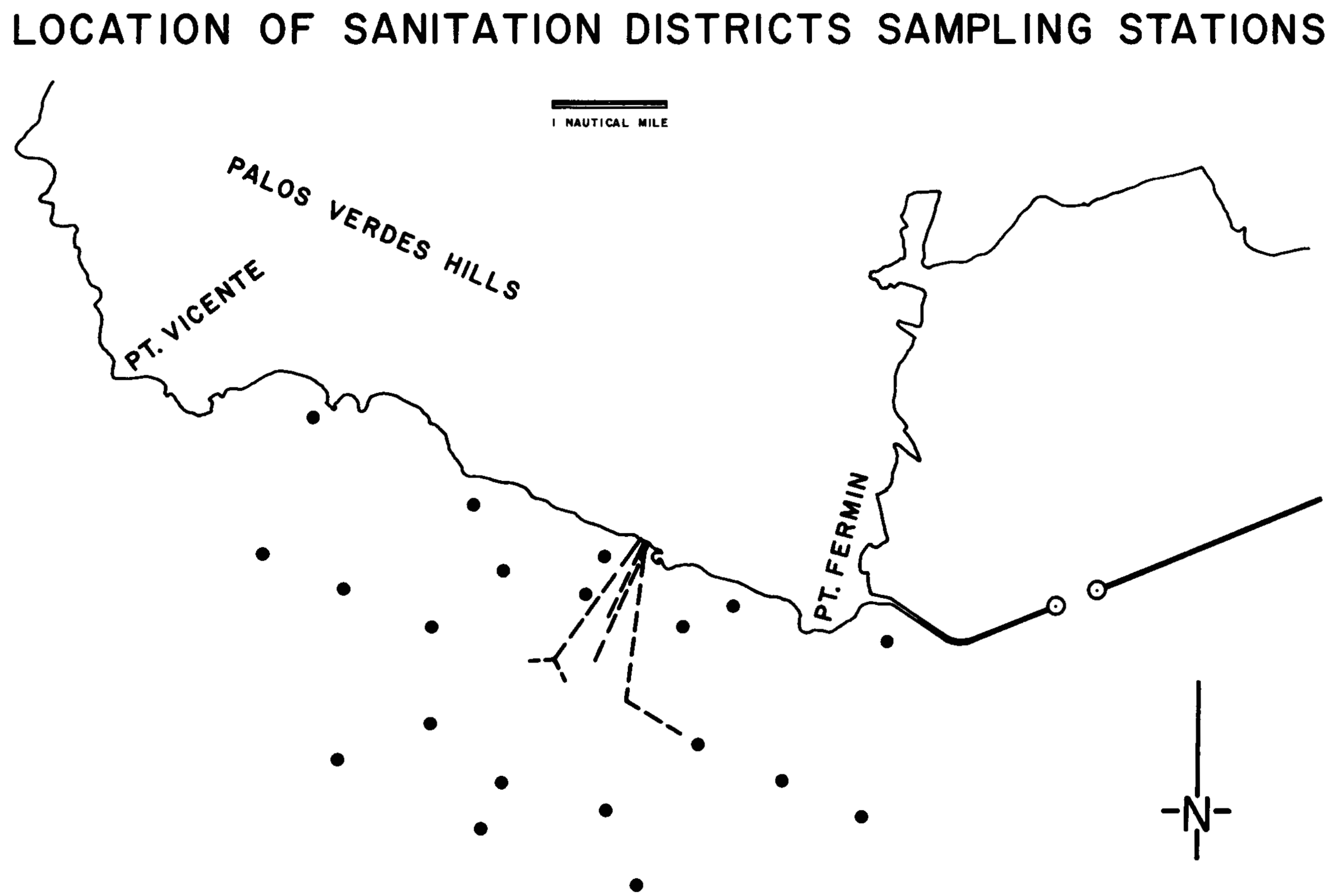


FIGURE 7. Location of sanitation districts sampling stations.

FIGURE 8. SEA-S-DEE

OFFSHORE MONITORING
WEEKLY

DISSOLVED OXYGEN

GREASE

TEMPERATURE

TRANSPARENCY (SECCHI DISK)

COLIFORM (MPN)

FIGURE 9. Offshore monitoring—weekly.

OFFSHORE MONITORING
MONTHLY

DEPTH PROFILES OF:
DISSOLVED OXYGEN
TEMPERATURE
GREASE
PERCENT TRANSMISSION OF LIGHT (TURBIDITY)

FIGURE 10. Offshore monitoring—monthly.

OFFSHORE MONITORING
SEMI-ANNUALLY

BOTTOM TRAWL
SCUBA DIVING STATIONS: MACROBENTHOS COUNT
BLUE LIGHT ENERGY
BOTTOM SEDIMENTS:
PERCENT ORGANICS BY NITROGEN ANALYSIS (SHIPEK SAMPLER)
BIOMASS (SHIPEK SAMPLER)
PHOTOGRAPHS OF CORES

FIGURE 11. Offshore monitoring—semi-annually.

been happening before that time. Then between March and April when we found that we had at least one major source in Montrose Chemical, we began to work with them because they seemed to represent at least 80% of all that we had. They have cut down close to nothing as near as we can tell. Now we seem to have that under control and we are working very hard within the entire system in a sleuthing project to find out what other sources there may be. All we can say so far is, there seems to be no single large source. We seem to have a number of small sources which add up to maybe 100–200# per day.

*Question:* Do you think this is merely part of the consumption process of the population or is it close to an industrial discharge?

*Dryden:* It is speculating to answer because we haven't much to go on. You will find that the largest concentrations of pesticides are in the larger industrial areas, but that practically covers the whole southern part of the county. When you get up into strictly residential areas, the concentrations drop down to fairly low values which probably represent the amount contained in foods.

*Question:* Doesn't Hyperion have lower values of DDT than the Districts?

*Dryden:* That is right. The Hyperion system has much less industry and much lower values of DDT.

*Question:* Maybe there are some spot sources that you haven't tracked down yet.

*Dryden:* We feel there may be several hundred spot sources. By the way, this is why I asked the question earlier today concerning records of DDT production and distribution. If only there were some record of DDT from the time it is produced to where it goes next, like we do in the drug industry, then it would be easier to trace. Right now there is no one you can go to and ask who uses it, who handles it, who processes it. You can't find out until you get to agricultural uses and that is not our problem. We are trying to look at both ends; we are checking on who uses it and also trying to sample within the sewerage system. You know we have hundreds and hundreds of miles of sewers and our analytical capability is still only about 4 or 5 samples a day. It's a tough job.

*Question:* Do you have any samples taken from previous years?

*Dryden:* No, we really don't have.

*Question:* Did you know the City of San Francisco is planning to incorporate a waste discharge ordinance? Does your district have such plans?

*Dryden:* First, our district presently has a policy which permits us to control industry but we work through the cities now and we have 71 cities and they have ordinances. Many of them aren't the same as our policy and some have different wrinkles, but we work through their enforcement power. We are now in the process of writing an ordinance for ourselves with the objective of having more direct control than we have had in the past.

*Question:* What was the concentration of phenol in your effluent?

*Dryden:* About 6 ppm.

*Question:* There is lots of evidence in the literature documenting phenol to tainted fish flesh right now.

*Dryden:* In what concentrations?

*Question:* About 0.1 ppm.

*Dryden:* Well, you see by the time the effluent starts rising in the ocean it is diluted well below that.

*Question:* Do you take the coliform count before the effluent is discharged or at the point of discharge?

*Dryden:* We take coliform counts before the effluent goes into the ocean and we take coliform counts in the surface waters and along the shoreline in accordance with the Water Quality Control Board's requirements, but we do not remove coliforms in our treatment process. The test of whether or not you need to remove coliforms is whether or not they are reaching the shore or surface waters where there would be human contact because coliforms are only an indicator of whether or not you could transmit disease. If there is no one to transmit it to then there is no problem. We meet bathing water standards along the shoreline by the method of operation which keeps the field submerged and by keeping the field submerged we do not have to then remove the coliforms. However, when the water column is mixed, as by a storm in the wintertime, then we do need to continue to meet those requirements and, if necessary, chlorinate to kill the coliforms to the point that we continue to meet the requirements.

*Question:* How high does the coliform count get at the point of discharge?

*Dryden:* I think is probably runs about 70 million per 100 ml.

*Question:* What I am interested in is protecting the scuba or skindiver that might be out beyond the bathing area.

*Dryden:* We have probably sent more scuba divers out there than anyone else to check our outfalls for us and we haven't had any problem yet.

*Question:* What evidence have you that organics you are putting out are beneficial to the environment?

*Dryden:* Wheeler North told me once that work with kelp indicated that waste discharges increased the growth rate of kelp. The relationship between waste discharges and kelp is apparently by way of the urchin population. When that relationship is tied down, I trust we will have the ability to find a suitable solution.

*Question:* What makes you think the nutrients of waste discharges can help increase productivity? Is there any data on it?

*Dryden:* I would like to point out that there may be, if you will, a type of proof coming up. What you need to tie this thing down is a tracer and one of the potential tracers may be DDT. If we really show that DDT from waste discharges is getting into fish then we have an excellent tracer, which shows that the organic or other material in waste discharges is probably being utilized in a food chain, because the DDT appears to be tied closely with particulate and organic matter.

*Question:* Would it be feasible to have a separate sewer system for industrial waste?

*Dryden:* The question is what do you do with it? If something should not get into the sewer system, then it should be treated at the industrial site where it is concentrated before it goes into the sewer; that would be our approach. We do convey certain industrial wastes around a water reclamation plant so that it doesn't have to go there but that is because you don't want that particular material in that plant. If we don't want it in the system at all then it has to be treated at the source.

*Question:* How much water goes into water reuse and what is it used for?

*Dryden:* The Sanitation Districts' plant at Whittier Narrows has about 14 MGD of capacity; the water is spread for groundwater basin recharge. In the Pomona area, we have about a 10 MGD plant and some of the water there is recharged and some of it is used for irrigation purposes. There are other plants with limited irrigation uses; probably the biggest potential use is still for groundwater basin recharge.

*Calif. Mar. Res. Comm., CalCOFI Rept.*, 16: 51–53, 1972

# SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT

GEORGE HLAVKA
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Good morning gentlemen. I would like to spend a few minutes talking about the Southern California Coastal Water Research Project, especially for the benefit of any of you who may not have heard of this organization, which is fairly new and may not be too well known among people like yourselves, but should be.

The project represents a rather unique attempt by government at the local level to tackle the problems of pollution and protection of our environment. The emphasis, of course, is on the condition of the ocean. I would like to start by describing how the project originated and what its purposes are. How I ramble from that point on depends on the looks on your faces.

First of all, as you know, there is one Federal Government, plus 50 State Governments, and about 40,000 local governments in the United States. In our individual communities, most of us are beset with a multiplicity of governments operating to regulate us, to tax us, and so on. The problems of the environment are involved in many of these different government agencies. In particular we all reside in sanitation districts, which are governmental entities responsible for collecting, processing, and disposing of domestic and industrial wastes.

In California, the coastal areas are characterized by extremely high total waste flows. In Southern California this waste flow, one billion gallons a day, requires rather large collection, treatment, and disposal systems, utilizing ocean outfalls as the ultimate disposal site for the wastewater. This is in contrast to the practice in inland areas where lakes and rivers are utilized and the ultimate disposal is in a body of water that does not have the size or assimilative capacity of the ocean. Southern California generally utilizes primary sewage treatment (first stage treatment) on its outflows as opposed to the secondary or tertiary treatment recommended where the disposal is to bodies of fresh water. In the area from Ventura to San Diego there are 5 major agencies responsible for this large flow to the ocean: the cities of San Diego and Los Angeles, the county of Ventura and the major sanitation districts of Orange and Los Angeles Counties. The five agencies took a very interesting and unique step about a year or two ago. They decided to get together and do something about the problem of ocean pollution on an area-wide scale. This was the beginning of the Southern California Coastal Water Research Project (SCCWRP), which is sponsored by these 5 agencies of local government.

The method used under state law was a joint powers agreement, which enables a group of agencies to take some duty or function for which they have responsibility and turn it over to a new government organization. So SCCWRP is a new government agency charged with the limited responsibility of research on the effects of treated wastewaters on the ocean environment. There is concern about the effects on the ocean environment of wastewaters and there is insufficient knowledge on how to design most effectively the corresponding collection and disposal systems. There is a desire to minimize adverse effects on the environment and maximize beneficial effects. The limited experience which the agencies felt that they had in ocean ecology led them to form a project that would achieve two general objectives:

1. A more thorough understanding of the ecology of the ocean waters to help agencies that are responsible for the regulation of wastewater dischargers.
2. Evaluate criteria for ocean disposal and sewage treatment and suggest guidelines for the acceptance or rejection of contaminants as inputs to these systems.

The Regional Water Quality Control Boards, the State Water Resources Control Board, and the Federal agencies that are involved would all be affected by the second objective.

The project was formed by agencies which might be called polluters, even though their responsibility is to accept, treat, and dispose of waste of many kinds from others in some safe and hygienic fashion. To avoid results ordained beforehand, the agencies set the project up to be an *independent* agency. Five commissioners were appointed to be responsible to the public for the project. The Commissioners then turned to the task of forming a team which was as technically qualified as possible to take on this enormous task of understanding the ocean environment sufficiently well to derive better rules for the safe disposal of wastewaters.

The Commission named five eminent experts as a Consulting Board: John Isaacs, Scripps Institution of Oceanography; John Ryther, Woods Hole Oceanographic Institute; Donald Pritchard, Chesapeake Bay Institute; Erman Pearson, University of California; and Richard K. C. Lee, University of Hawaii. These men represent a technological spectrum ranging from physical and chemical oceanography and marine biology to public health and sanitary engineering. About six months after the official formation of the project, the Consulting Board and the commissioners arrived at a decision as to a project manager, who is before you today. During the other six months that have gone by since the project was formed, I have devoted my efforts to organizing the project tasks and staffing. At the present time we have four specialists involved in the project, three of whom are here today. I would like very much for you to get to know who they are, so I am going to ask them to stand. Irwin Haydock, would you stand, please. Dr. Haydock is our biologist—he is a graduate of the University of California system and has worked in fisheries research at BCF and with the California Dept. of Fish and Game. Dr. James Jones is our physical oceanographer and a graduate of Scripps. He was with Bendix Marine Advisors and has a number of years of experience in physical oceanography. Dave Young, our chemical oceanographer, is also from Scripps. The fourth member, not present today, is Chen Young, a sanitary engineer from the University of California at Berkeley.

Well, what are we going to try to do in this project? In general, most of the items discussed at this excellent conference are of interest to us. They are all involved in one way or another with ocean pollution. One of our basic problems is to try to identify priorities. We have approximately $1 million which has been pledged by the five sponsors. We have about two years left and want to do the best job with the first million dollars and accomplish as much of the original objectives as we possibly can. On the other hand, the early advice of the five consultants was to adopt a very fundamentally oriented approach. Thus, for example, it was not necessarily best to make extensive measurements in the general vicinity of ocean outfalls and to seek conclusions about what these might be in the future. It was pointed out that identifying the effects of wastewaters on the ocean environment was an extremely difficult task because the ocean environment is not itself well enough defined to facilitate a good assessment of manmade effects. Hence it was decided early to try for a research program that began with a study of natural processes and phenomena in the coastal waters of Southern California. We are interested in physical oceanography, marine chemistry, marine biology and the various mixing processes that occur naturally. Many technical topics having nothing to do with wastewaters have been identified as areas to study before the general effects of man on the ocean can be properly assessed. Only afterwards can one hope to establish the past and present effects of wastewaters of various types.

Frankly, we are having a very difficult time trying to decide what to do in a short period of time—the two years that we have—that will be of early benefit to the design of wastewater treatment and discharge systems and to help the regulatory agencies. The result of our struggle with these decisions should be a formal research plan to guide the program for the remainder of its term—and perhaps to serve as a model for subsequent programs.

We are also attempting to get certain kinds of research work funded as well—for example, extensions of the work of people such as Jim Galloway who spoke to you yesterday about analysis of the sediments around ocean outfalls. Typically when we find someone doing relevant work with, say, four or five metals, the project would propose to fund the expansion of the analysis to at least two dozen constituents. If we discover someone making an interesting study of the effects of wastewaters on the biota, we might help by enabling him to get samples from a wider geographic area, particularly the entire Southern California area, and also to get the best instrumentation and technicians in order to optimize his results. The researchers that we would be working with would publish their own findings with their own conclusions.

One of our tasks, then, is to take the work of many people, whether we have assisted them or not, and synthesize it to form a more comprehensive picture of Southern California coastal water ecology. In general, we are attempting to assess the condition of the ocean and we are immediately faced with the fact that the California Current and other ocean current flows are the sources of many of the constituents of the waters of the Southern California Bight. Thus we are also interested in, and may contribute to, certain research on the California Current or even larger systems.

I hope I have given a general idea of the functions and responsibilities of the Project. If you are interested, there are some copies available of a booklet which contains a more comprehensive description of the project. Otherwise, I would like to open the floor to questions. One of our functions is to get inputs from the general community and in particular from specialists like yourselves who are very deeply involved in the problems.

*Question:* Do you intend to initiate research in addition to finding people that are already working. Do you plan to sit down and find out what needs to be done?

*Hlavka:* Yes sir. I should have mentioned that the original plans assumed there would be a three phase program. Phase I is the assessment of the problem and the review of existing data, partly to determine what information is *not* available. Phase II is the gathering of new data. Some of the work will be initiated by the project and some of it will be a cooperative effort. Obviously the amount of work we can do with a four man professional staff is limited. We don't have laboratory facilities; hence there is a natural tendency to use the lab facilities and technical help of other programs, if possible. However, our organization is bound to grow and to some degree be more directly involved itself. Phase III is to be the analysis of the data and publishing of a final report.

*Powell:* I understand that you intend to coordinate published information in this field and make it available. Do you have a definite source for making this information available?

*Hlavka:* Yes, SCCWRP is a public agency. Information we obtain, or generate ourselves, will be available in general through our progress reports, which periodically summarize our findings. We will be happy to include concerned organizations or individuals on our progress report distribution list on request. We may also turn out reports on our assessment phase of the project.

*Powell:* Do you have any headquarters or source that people could be referred to, to get information about what has been published in your area of work. It is such scattered information.

*Hlavka:* Our headquarters are in Los Angeles. Scattered information is one of our very serious problems. It is a costly task to ascertain with some probability that certain necessary work has not, in fact, already been accomplished to some degree.

*Powell:* Could you use any of the money that you have to make reports available to people that want them and can't get them from an agency that has put out a limited number of copies of progress reports that are no longer available?

*Hlavka:* We don't intend to operate as a reproduction agency for reports from somebody else, but to the best of my knowledge (maybe the staff would contradict this) we have had no difficulty in getting access to information. Sometimes, of course, it has to be read in a library.

*Powell:* Libraries do have trouble getting it, this is why I am asking.

*Hlavka:* In some areas we have good connections for getting information, even if it is borrowing someone's personal copy. I suppose in certain circumstances we have no objection to reproducing a few copies.

*Question:* It seems to me that there is an awful lot to be done from the engineering point of view in terms of dispersal mechanism—to understand it better. I have tried to find someone doing something in that area.

*Hlavka:* We are very interested in that area and, as an example, Jim Jones and I were just talking yesterday about the possibility of taking the drift bottle data from many years of CalCOFI cruises and analyzing it to see what it tells us about water motions in surface layers, which is one of the important phenomena involved in that mixing that you are asking about. We would like to be able to tell the ocean outfall designer what the mixing process is and what he can count on in the way of assimilation by the ocean beyond the physical and biological—how much will it tolerate on the local level. This is one aspect of it, but the project also is concerned with the worldwide impact of pollution. James Galloway was saying yesterday that there was a certain fraction of discharged contaminants that did not show up in the sediments he has measured. Obviously they go somewhere else, and they may have a very wide distribution. So we are interested in the general oceanic changes due to pollutants as well as the local ones, but that all involves an understanding of the mixing processes within the ocean waters themselves.

*Question:* Do you anticipate that your agency will be funded beyond the original three year period?

*Hlavka:* Yes. In fact, the joint powers specified that it was anticipated that federal and other sources of funding would be sought, even during the term of the joint powers agreements, to magnify the effort that could be brought to bear. We would like very much to write a good solid proposal to the Federal Water Quality Administration, for example, but in trying to write a good document, trying to explain what the project is and what the plan is, we have to go well into this assessment phase that I spoke about earlier. Without the assessment having been completed, we cannot have good assurance that we have outlined the best research program. However, I expect that we will be making application for outside funding to at least two or more agencies including FWQA.

*Question:* Have you inquired through EPA whether your program might be related to theirs?

*Hlavka:* Oh definitely. Individuals in FWQA, which is a part of EPA—in fact *the* present EPA people in the water pollution and water quality fields, plus the State Water Resources Control Board and also the Regional Water Quality Control Boards in the Southern California area, were consulted about the formation of this project right from the beginning. They made very constructive suggestions that were incorporated in the format of the joint powers agreement and in the organization of the project itself. They are aware of SCCWRP and are getting reports of progress regularly.

Part III

# SCIENTIFIC CONTRIBUTIONS

*Calif. Mar. Res. Comm., CalCOFI Rept.*, 16: 57–65, 1972

# NEAR-SHORE CIRCULATION IN THE CALIFORNIA CURRENT

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A great many of you are very familiar with the major current along the California Coast. What we wish to do today is to review the currents closer to the coast, since they are equally pertinent to the problem of pollution along the coast.

Figure 1 is a 16-year mean chart of the surface currents (relative to geostrophic flow) along the California coast in winter (January). The normal offshore flow all during the year is towards the southeast. In the wintertime the Davidson Current nearshore moves northward opposite to the current farther offshore. This northward flow in winter is attributed to the seasonal change in the wind patterns across California, Oregon and Washington. The winter winds are primarily from the south in the coastal area northward from San Francisco.

*Question:* Can you tell us what the speeds are that correspond to the California Current?

*Schwartzlose:* The average speed of the general California Current is about ¼ to ½ knot (12.5–25 cm/sec). Direct measurements, using drogues, which we have made off Monterey, southern California and northern Baja California, indicate that speeds up to a knot (50 cm/sec) can obtain for short periods of time. Primarily they are in the range of .4–.6 knot (20–30 cm/sec). It appears that the general current is not straight, but includes loops and eddies with a general southeast drift at about ¼ knot (12.5 cm/sec).

Figure 2 is the mean January geostrophic flow at 200 meters. The northward current or undercurrent is slightly wider than at the surface. This undercurrent persists throughout the year flowing northward at these depths along the coast. There have been some direct measurements of this current by Wooster and Jones using current meters in the area off Cape Colnett in northern Baja California, and various measurements with drogues have been made by Schwartzlose, Reid, Jennings, and Brown.

Figure 3 is the January 1964 flow charts. The difference from the mean charts (Figs. 1 and 2) is not very great, though more detail can be seen in Fig. 3. The Davidson Current and the eddy system in southern California are well developed. At 200 meters we see the undercurrent moving northward along the coast.

*Question:* What is the speed of undercurrents?

*Schwartzlose:* Very low, .1–.2 knot (5–10 cm/sec) according to the drogue measurements, but at least one series of direct current measurements by Wooster and Jones has shown speeds as high as half at knot (25 cm/sec) in a narrow layer.

Figure 4 shows drift-bottle results for December 1969. The Davidson Current was very well developed. There was water moving out of southern California northward along the coast. One drift bottle went to Alaska. The minimum speed of some of the December 1969 drift bottles that moved northward in the Davidson Current was about .3 knot (15 cm/sec).

We have records from other drift bottles in other years during the winter that indicated minimum speeds in the Davidson Current of .6 knot (30 cm/sec) for long periods of time, up to 2 to 3 months. This Davidson Current is usually a very strong current compared to the offshore California Current and it extends to the Gulf of Alaska. In January 1958 a large number of drift bottles from central California were recovered off northern Oregon, Washington and British Columbia; this was due to a very strong development of the Davidson Current.

The Davidson Current is usually between 40 and 50 miles wide, and in the northern area the overlying wind is from the south. In December of 1969 one of the returned bottles had been released 80 miles from shore; it is rare to see any returns from that distance. Our other drift-bottle charts show that the Davidson Current is the narrowest at its southern end off Point Conception, and it slowly widens northward. Pearcy's Figure 2 that we saw the other day showing the plume of the Columbia River going northward in the wintertime is a very good indication of the same type of information that the drift bottles show, and at that location the plume appeared, as you recall, to be something like 50–60 miles wide.

Another interesting feature seen from the drift-bottle returns is that usually we receive few returns from Baja California because of the small, scattered population. The returns are from farther south in winter than in summer.

Figure 5 is presented to show that the interpretation of the drift-bottle data is at times not clear. Note that from the January 19 release of bottles just north of Point Conception one bottle went northward and one bottle landed well south, near San Diego. There is, of course, some diffusion or spreading of the bottles as they drift. If the release location is near the boundary of the southward-flowing portion of the California Current, a few of the bottles may spread into that current.

In the spring of the year, primarily in April, sometimes in May, the winds off northern California turn southward again and the northward flow of the California Current ceases (Figure 6). The storm centers are farther north than in winter. The current all along the coast is usually moving southward, including the area through the Channel Islands. In April the water flows right through the southern California borderland, and the normal gyre that exists the remainder of the year in the southern California borderland is not found.

Figure 7 presents the 15-year mean geostrophic flow for July. The Davidson Current, of course, is not present, but we do find the gyre off southern California. This is the period of time when the California Current is the strongest due to the northwest winds.

In figure 8, the mean July geostrophic flow at 200 m shows the undercurrent along the coast flowing very slowly northward from southern Baja California through northern California. The width of this northward undercurrent appears to be 40 to 50 miles.

Figure 9 shows the percent of drift-bottle recoveries from releases at various distances offshore. As can be seen, the recovery from 15 miles inward is very good off southern California, whereas it is poor off Baja California, possibly because there are not so many people on the beaches. Many of the recoveries from 70 to 90 miles off southern California are from the currents that form the gyre within the southern California bight.

The drift bottles that are dropped within 3–5 miles of the beach usually go ashore very quickly, not far from the point where they have been released. There are problems in interpretation of the returns, since there is no way of knowing how long the bottles may have lain on the beach before recovery or how many beaches they have been on.

Some direct drogue measurements were made earlier in the CalCOFI Program from the Catalina Channel to west of the north end of San Clemente Island. These data suggest the presence of a number of small gyres (Figure 10).

We have a little more data from a current meter that was placed about 6 miles west of Scripps for 15 days. It was about 25 feet below the surface. The data showed a current moving northward about half of the time, then shifting rapidly within a few hours and moving southward. These nearshore currents were primarily between $\frac{1}{4}$ knot (12.5 cm/sec) and $\frac{1}{2}$ knot (25 cm/sec). They were persistent for more than a week in one direction and then reversed themselves.

There have been a number of studies of currents around sewer outfalls, but usually these are only for several days, not for long periods of time.

*Question:* How much water leaves the southern California bight? Is there internal circulation?

*Schwartzlose:* I do not know. There is internal circulation within the bight, but there is mixing with new water coming in from the main stream of the California Current.

*Sargent:* Some act like ball bearings between the others. I think this problem is susceptible of a rough solution with a computer, but no one has been interested enough to get down and do it. The question was asked about the rate of escape, but no one has ever done it.

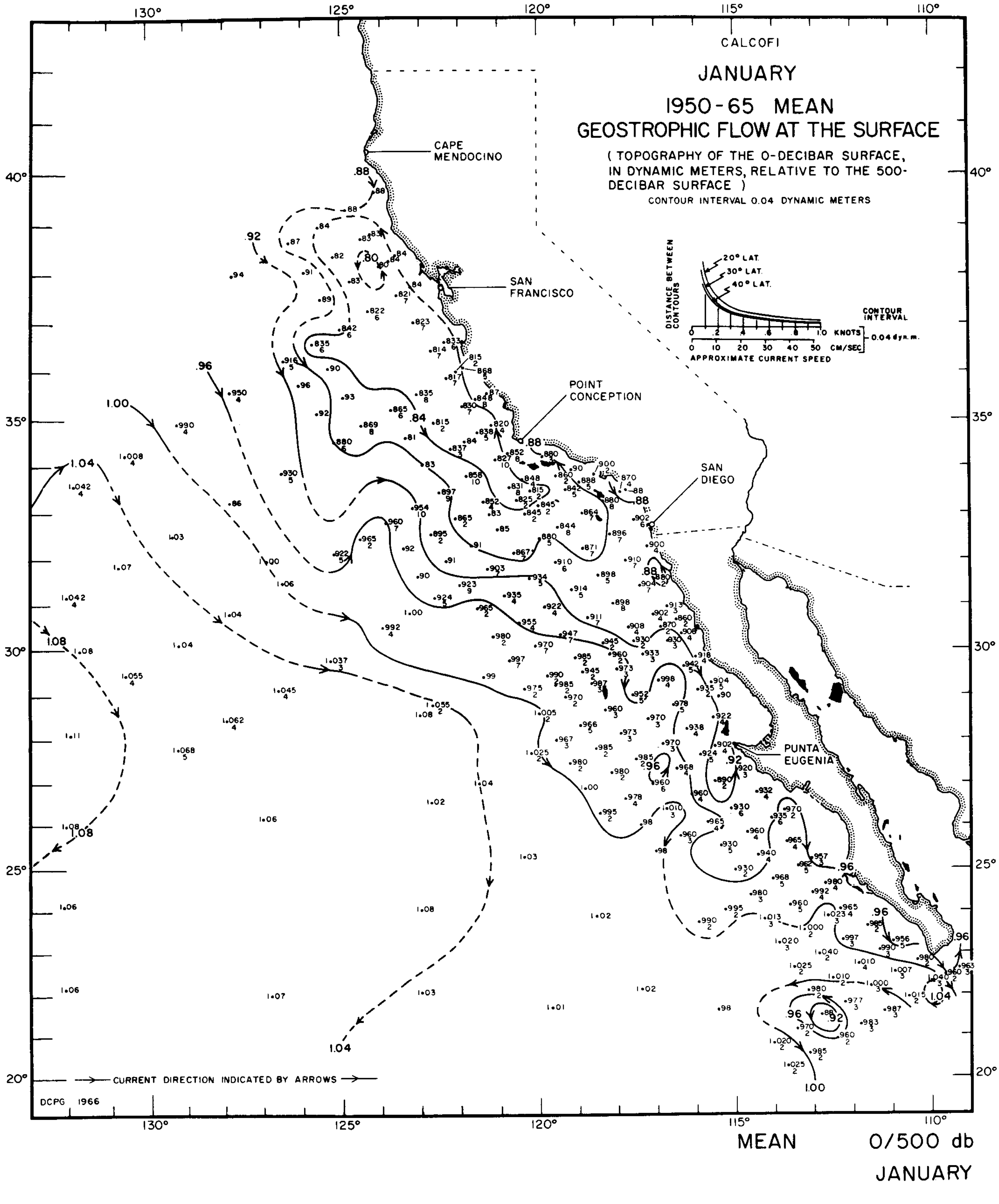


**FIGURE 1. Mean January geostrophic flow (1950–1965) (sea surface relative to the 500-decibar surface, in dynamic meters).**

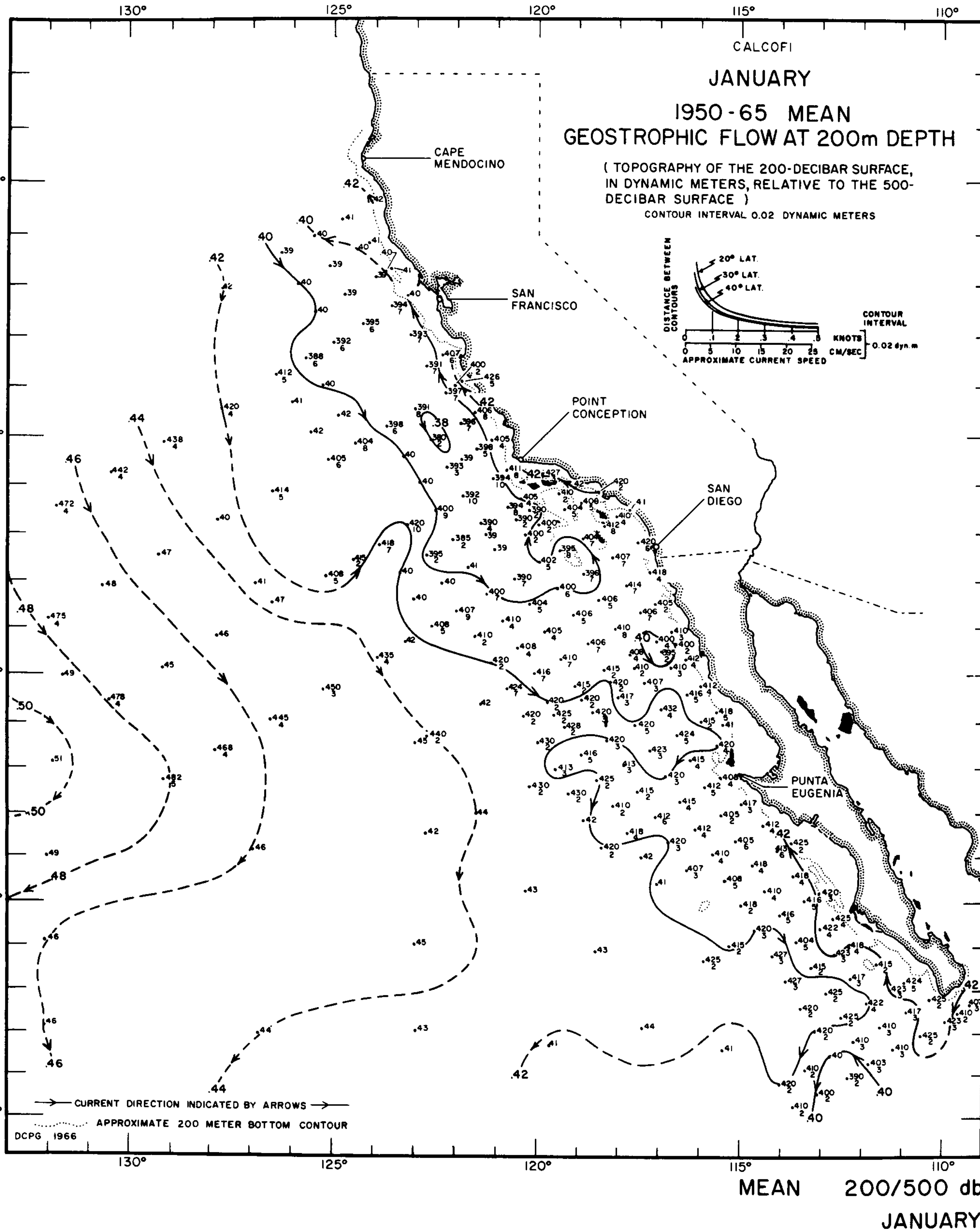


**FIGURE 2.** Mean January geostrophic flow (1950–1965) (200-decibar surface relative to the 500-decibar surface, in dynamic meters).

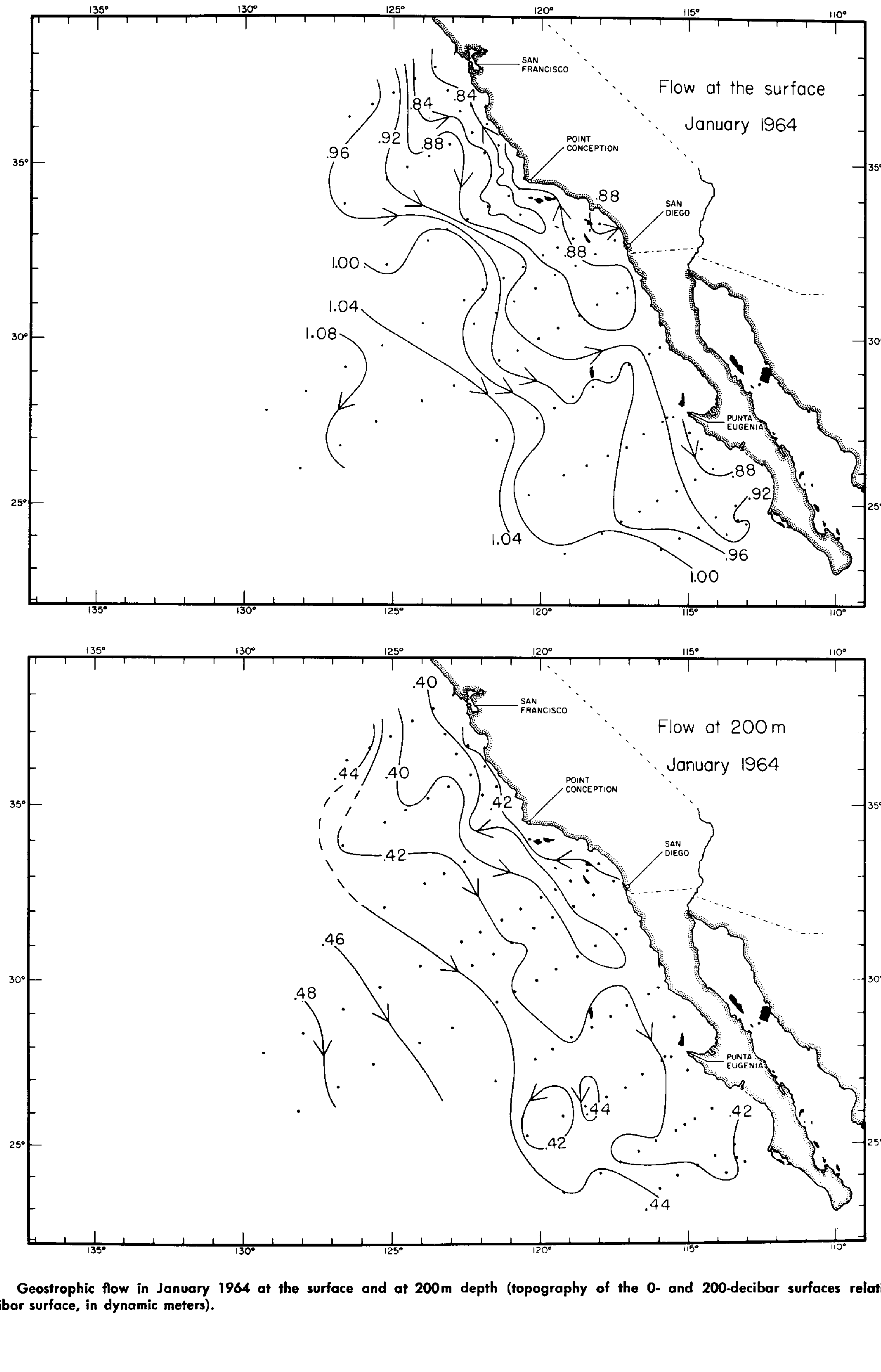


FIGURE 3. Geostrophic flow in January 1964 at the surface and at 200m depth (topography of the 0- and 200-decibar surfaces relative to the 500-decibar surface, in dynamic meters).

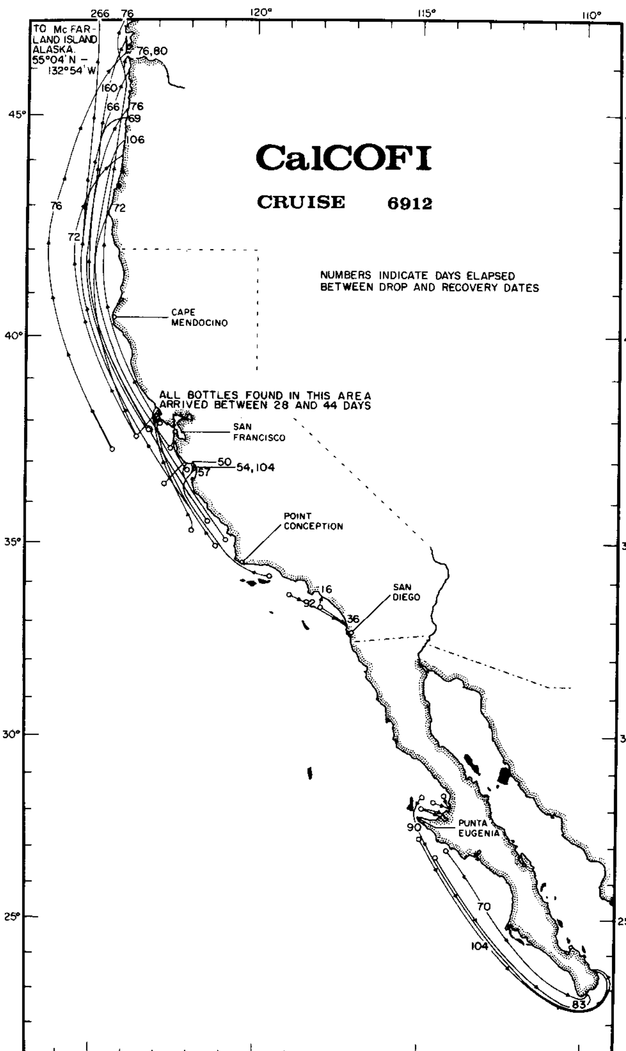


FIGURE 4. Drift-bottle returns for December 1969.

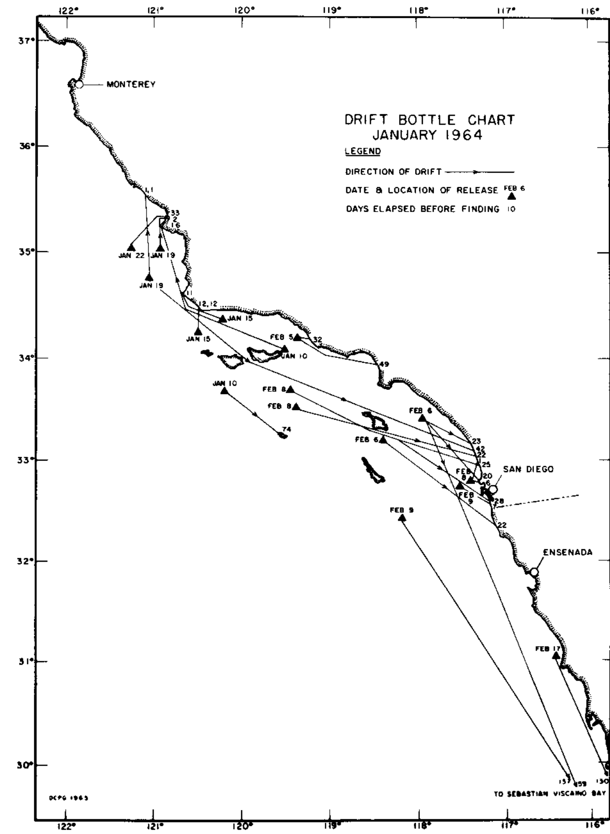


FIGURE 5. Drift-bottle returns for January 1964.

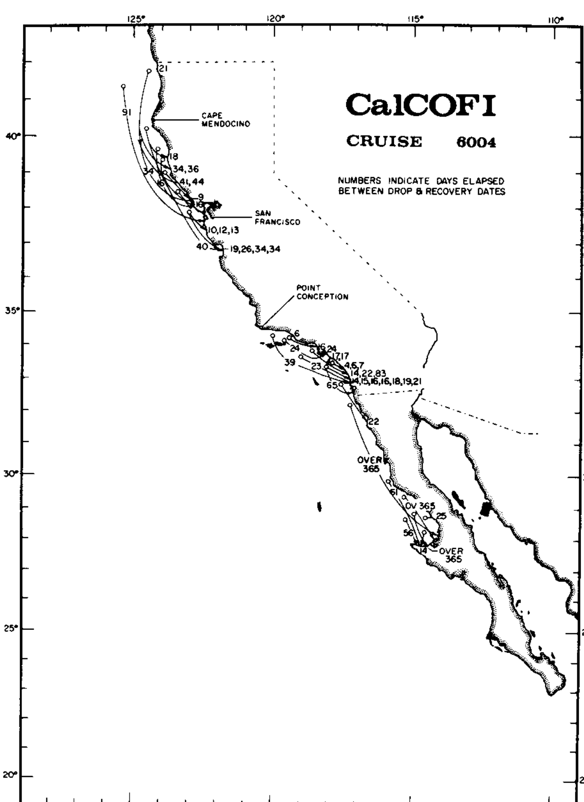


FIGURE 6. Drift-bottle returns for April 1960.

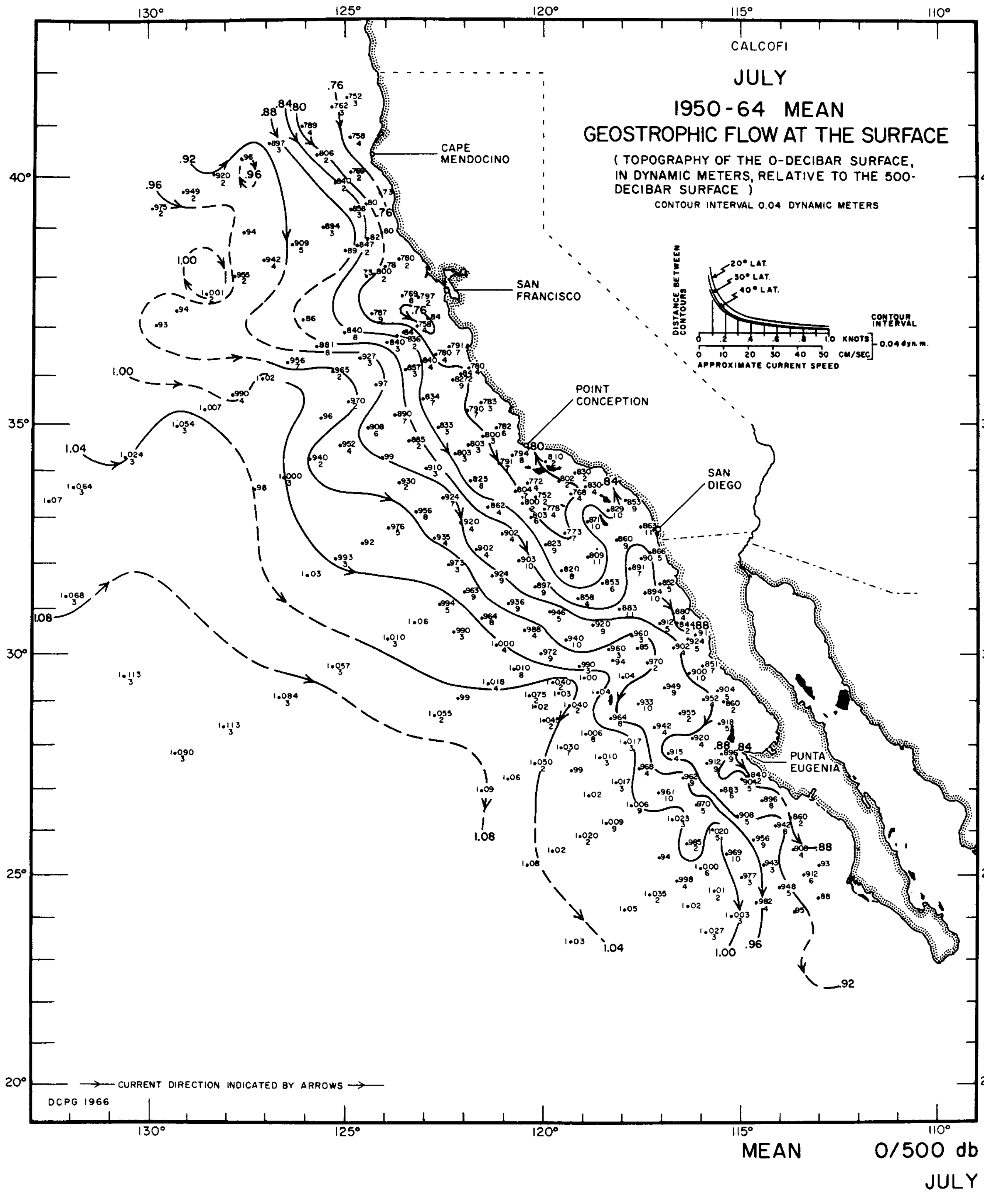


**FIGURE 7.** Mean July geostrophic flow (1950–1964) (sea surface relative to the 500-decibar surface, in dynamic meters).

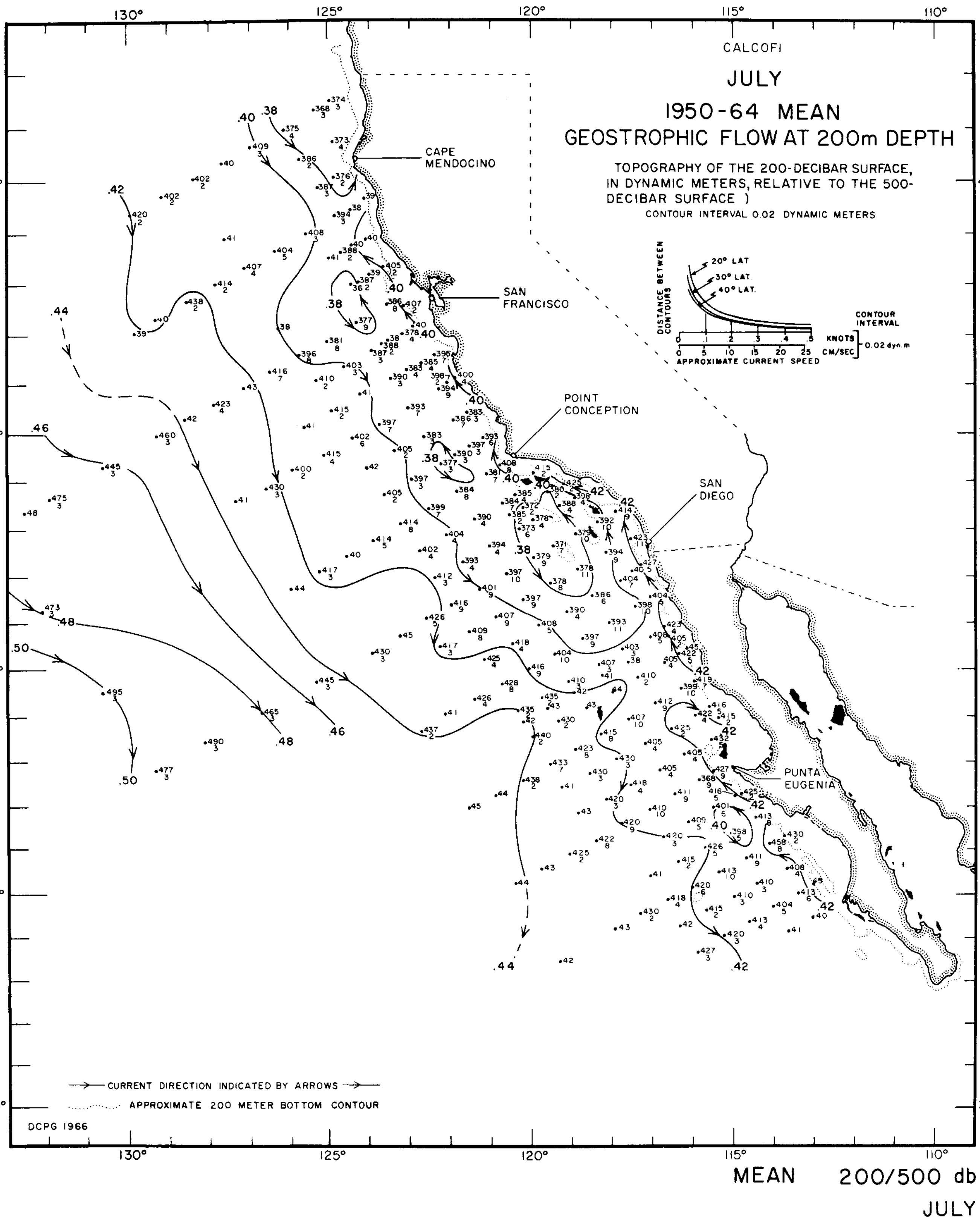


**FIGURE 8. Mean geostrophic flow (1950–1964) (200-decibar surface relative to the 500-decibar surface, in dynamic meters).**

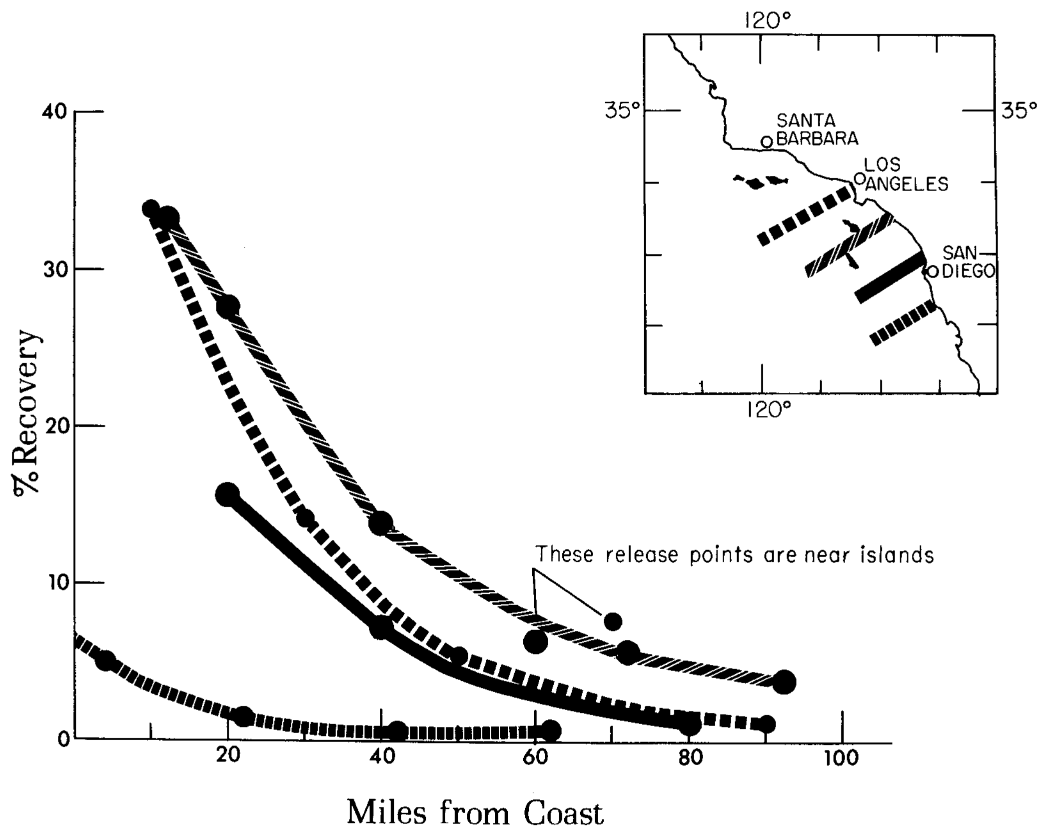


**FIGURE 9. Drift-bottle recoveries from releases at various distances offshore.**

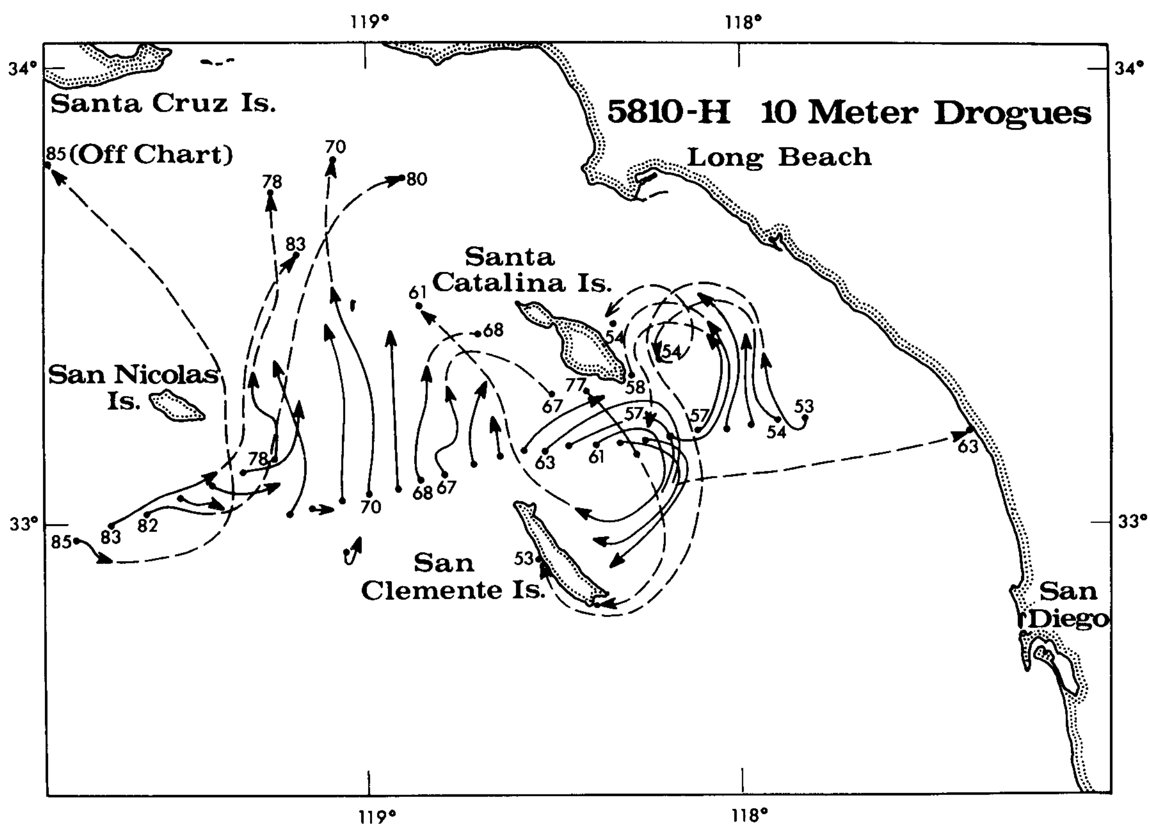


**FIGURE 10. Drogue measurements off southern California in October 1958.**

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# ZINC-65 AND DDT RESIDUES IN ALBACORE TUNA OFF OREGON IN 1969

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*and*

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## THE HYPOTHESIS

Albacore (*Thunnus alalunga*) is typically an oceanic tuna found far from continents. However, each summer a portion of the North Pacific population migrates into nearshore waters along the west coast of North America. Pearcy and Osterberg (1968) found that the zinc-65 radioactivity increased dramatically in albacore caught off Oregon and Washington during the summers of 1962–1966. This increase was attributed to the association of albacore with Columbia River water, a known source of radionuclides into these marine waters.

Manigold and Schulze (1969) reported DDT, DDE and DDD in Columbia River water during various seasons, 1966–1968. Sometimes levels of residues were 0.1 ppb (0.1 μg/l), which is similar to those reported in the Sacramento River which drains agricultural lands where pesticides are heavily used.

Therefore, if the Columbia River is a major mechanism for transport of DDT and its metabolites to the ocean, then DDT as well as $^{65}$Zn should increase with time while albacore inhabit nearshore waters off Oregon during the summer. Similar trophic pathways and uptake rates for DDT and $^{65}$Zn are implicit in this hypothesis.

## BACKGROUND

The Columbia River is the largest river on the Pacific coast of the Americas and the second largest in the United States. It discharges about 7,250 m$^3$ per second of fresh water into the Pacific Ocean at the headwaters of the California Current (Leopold, 1962). The Columbia is also unique because until 1971 it carried distinctive radionuclides from the Hanford nuclear reactors into the ocean.[1] Columbia River water was used as a primary coolant for the reactors and the intense neutron flux of the reactors induced radioactivity of trace elements in the water. Stable zinc-64, for example, added a neutron and became radioactive zinc-65. Most of the radionuclides in the coolant water had short physical half-lives and decayed to undetectable levels during the 370 mile trip to the ocean. Zinc-65 and chromium-51 (half lives of 245 and 28 days respectively) were the most common artifically induced radionuclides entering the Pacific Ocean (Osterberg, Pattullo and Pearcy, 1964; Gross, Barnes and Riel, 1965; Perkins, Nelson and Haushild, 1966; Osterberg, 1965).

The distribution of Columbia River water in the ocean varies with season and is dependent upon the direction of prevailing winds. During the summer, northerly winds predominate and Columbia River waters usually flow to the south or southwest as a "plume." The maximum discharge of the Columbia River usually occurs in June, and the plume can often be detected by low salinities far to the south of the mouth of the river (Barnes and Gross, 1966; Owen, 1968). With the onset of winter, the wind stress reverses and prevails from the south, resulting in northerly transport of Columbia River waters along the Washington coast. During this season the plume is not as obvious because of large runoff of coastal rivers (Barnes and Gross, 1966). Figures 1 and 2 illustrate the location of plume waters during the summer by salinity and the winter by chromium-51. The plume has been identified by chromium-51 and zinc-65 (Gross, Barnes and Riel, 1965; Osterberg, Cutshall and Cronin, 1965; Barnes and Gross, 1966), specific alkalinity (Park, 1966) and surface temperature (Owen, 1968; Pearcy and Mueller, 1970; Pearcy, in press).

Seasonal, geographic and bathymetric variations in the Zn-65 content of marine organisms off Oregon is correlated with the distribution of Columbia River waters at sea (Carey, Pearcy and Osterberg, 1966). Pearcy and Osterberg (1967) found seasonal maxima during the summer in Zn-65 of oceanic zooplankton and micronekton collected by midwater trawling in the upper 150 m off Oregon. These seasonal variations (see Figure 3) are believed to result from seasonal shifts in the location of plume.

Zinc-65 was ubiquitous in marine organisms radioanalyzed off Oregon (Osterberg, Pearcy and Curl, 1964; Carey, Pearcy and Osterberg, 1966). Of particular interest is the enhancement of Zn-65 in albacore tuna. Zinc-65 levels in albacore livers increased dramatically during the summer months off Oregon and Washington, whereas levels in albacore collected off

[1] When this paper was written (February 1971) all nuclear reactors at Hanford were shut down.

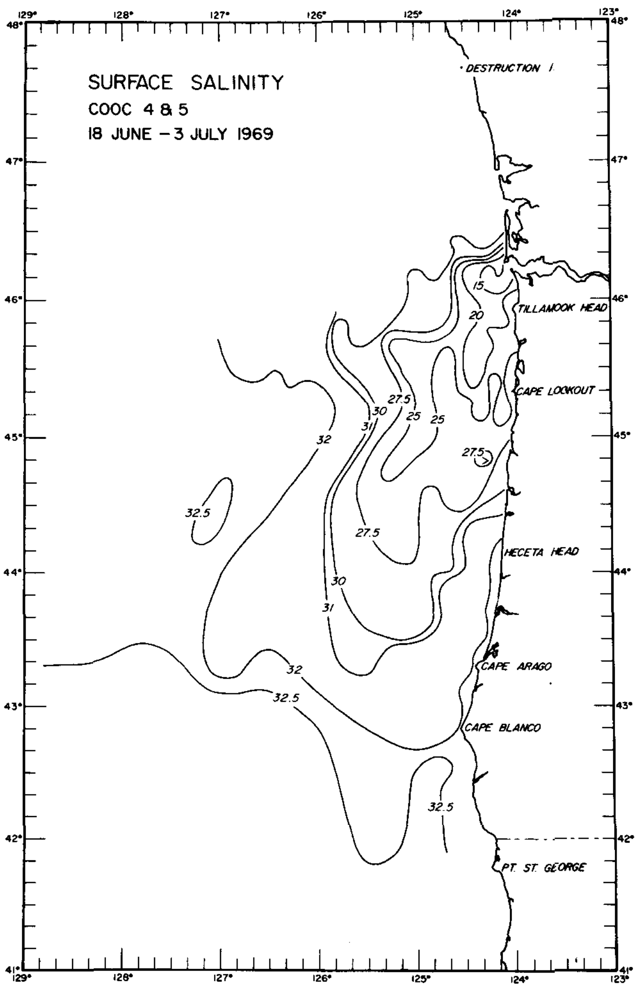


FIGURE 1. Pattern of Columbia River plume based on surface salinity, June 18–July 3, 1969.

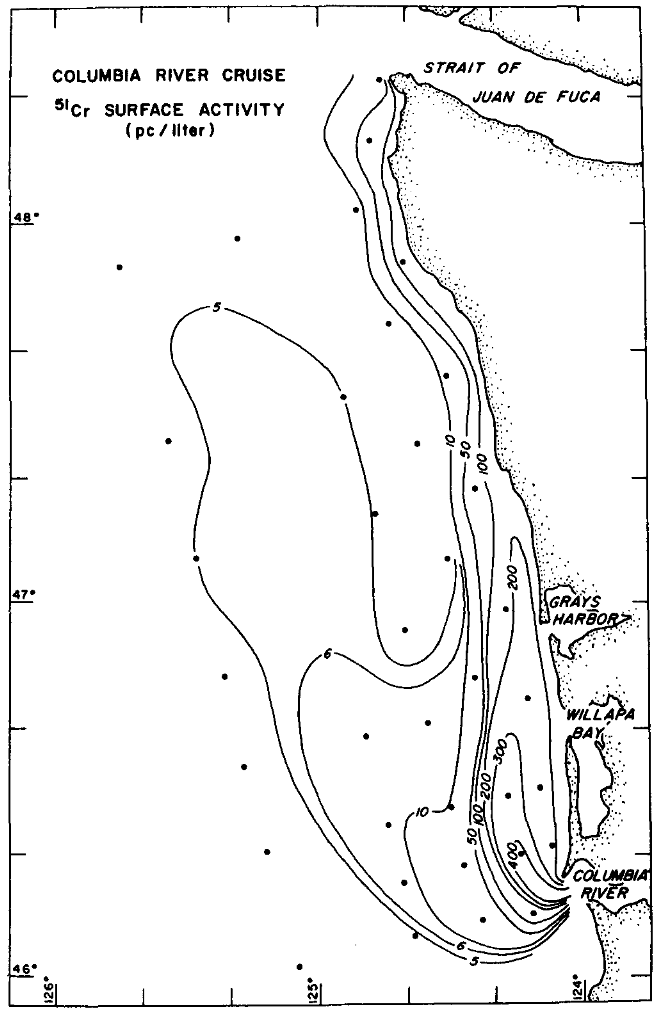


FIGURE 2. Pattern of Columbia River plume based on chromium-51 activity of surface water, February 1966 (from Frederick, 1967).

southern and Baja California were much lower and displayed no seasonal increase (Figure 4). This marked increase in Zn-65 levels off Oregon and Washington is attributable to albacore feeding on animals which have accumulated Zn-65 introduced into the ocean by the Columbia River. Albacore concentrations are also known to be located in the vicinity of plume waters, probably because plume waters are heated more rapidly than surrounding waters during the early summer (Owen, 1968; Pearcy, in press; Panshin, unpublished).

Because of the marked increase in Zn-65 in albacore after they migrated into Oregon waters and because of the DDT residues detected in Columbia River water (Manigold and Schulze, 1969), we examined albacore in 1969 for both radionuclides and pesticides.

## METHODS

Albacore (550–730 mm fork length) were collected off the Oregon coast during the summer of 1969 on jigs trolled from the R/V YAQUINA and CAYUSE or the fishboats SUNRISE and TYPHOON. Livers were either removed from the albacore at sea and frozen in plastic bags, or whole albacore were frozen and samples of livers and flesh obtained in the laboratory ashore. These samples were used for radioanalysis and pesticide analysis.

Procedures for radioanalysis were similar to those described by Pearcy and Osterberg (1968). Whole livers and samples of flesh were weighed, dried, ashed and packed in 15 cc counting tubes for radioanalysis in a 12.7 cm$^3$ sodium iodide (TI) crystal coupled to a 512 channel pulse-height analyzer. Counting time was 100 or 400 minutes.

The predominant gamma emitter was zinc-65. To permit calculation of specific activity of zinc-65, total concentration of zinc was determined by atomic absorption spectrometry (Perkin-Elmer model 303) on samples of ash digested in nitric and hydrochloric acids.

Liver samples for pesticide analysis were obtained from lateral lobes, the median lobe, or entire homogenized livers. Flesh samples were taken near the body cavity. The tissue sample was diced and a 7–20 gram subsample was blended in an Omni-mixer with 25 ml of acetone and 1 gram of anhydrous $Na_2SO_4$ per gram of sample. After filtering the mixture through a Buch-

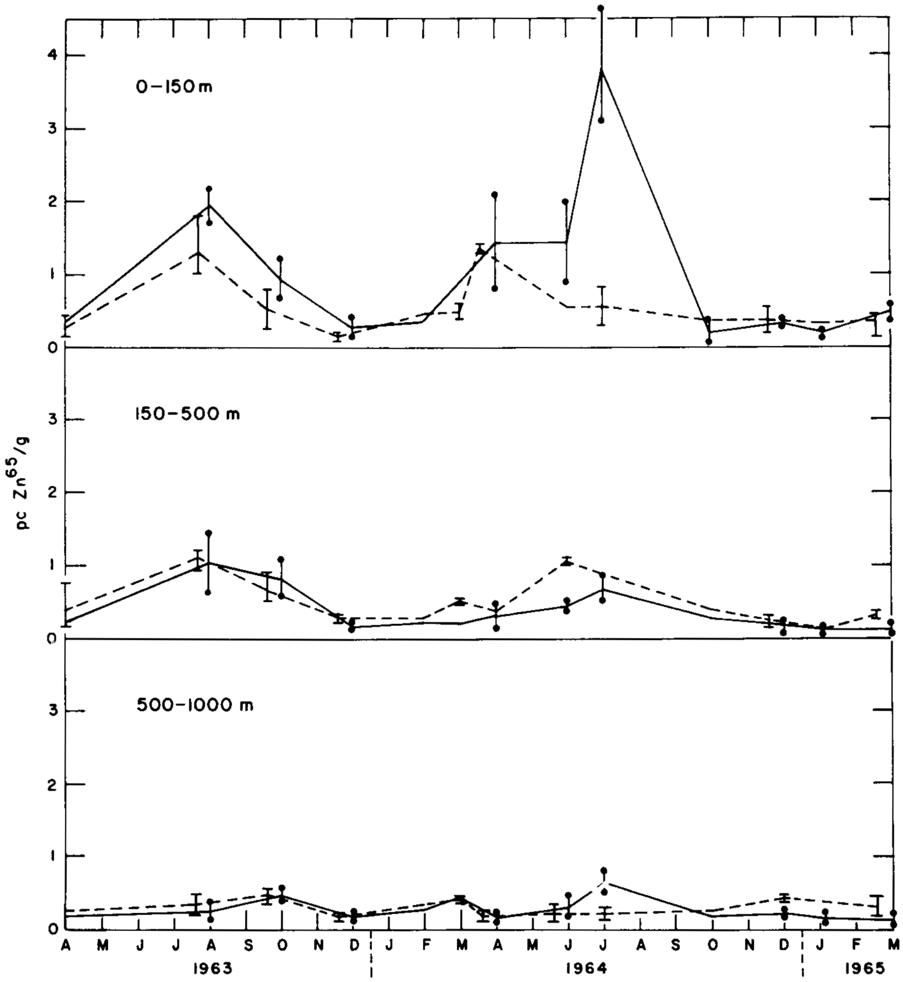


FIGURE 3. Zinc-65 radioactivity per gram wet weight from opening-closing midwater trawl samples from three depth intervals, 93 km off central Oregon coast, 1963–1965. Solid lines connect the average of nighttime collections, the dashed lines of daytime collections. Vertical lines show the range of values (from Pearcy and Osterberg, 1967).

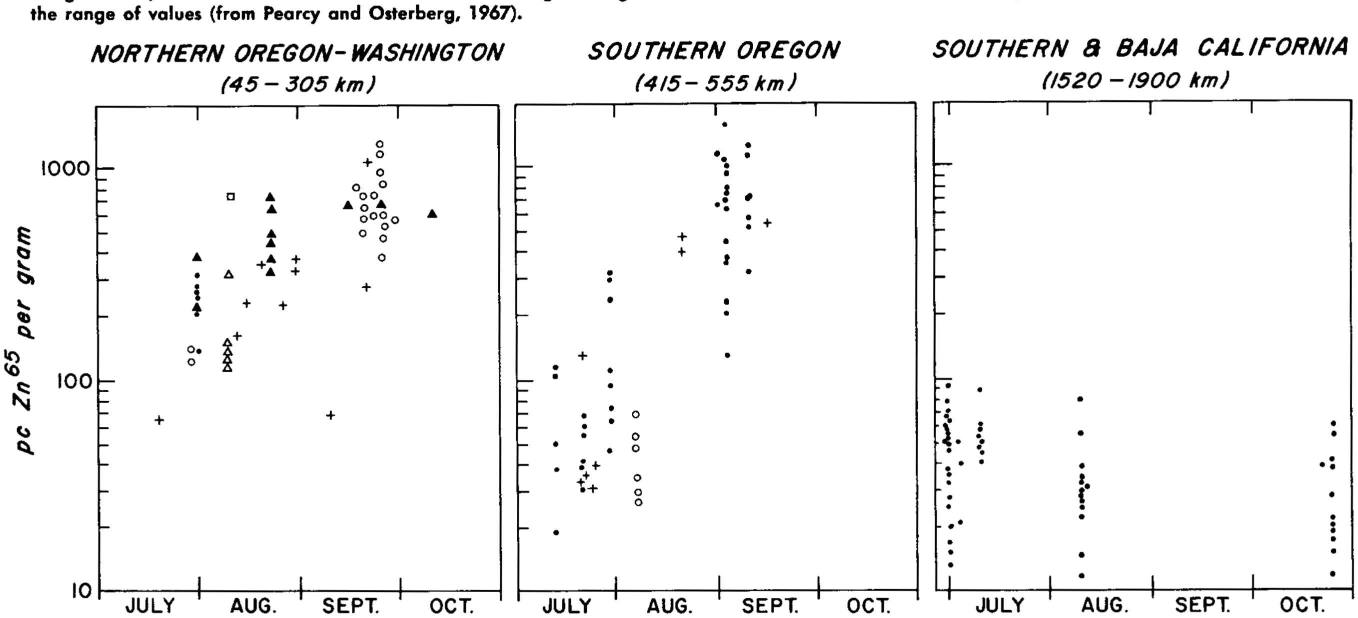


FIGURE 4. Zinc-65 per gram of albacore liver ash off the west coast of North America during the summer of 1962 (□), 1963 (+), 1964 (●), 1965 (▲ Oregon, △ Washington), and 1966 (○). The distances in kilometers indicate how far albacore captured in the three regions were from the mouth of the Columbia River (from Pearcy and Osterburg, 1968).

ner Funnel, the vacuum was reduced, the filter cake covered with acetone, and vacuum was reapplied. One part water per part acetone was added to the filtrate and pesticides were extracted with 50 ml of pentane in a separatory funnel. The pentane layer was collected and an additional one part water and 50 ml of pentane were added for a second extraction. The combined pentane fractions were evaporated to 5–10 ml and loaded on top of a Florisil adsorption column for further separation.

The Florisil column was prepared by adding 25 ml of hexane to a 16 mm i. d. glass column fitted with a Teflon stopcock. Ten grams of —200 mesh, 450°C oven dried Florisil were stirred into the column and washed down with hexane. Then $\frac{3}{4}$ inch of anhydrous $Na_2SO_4$ was added.

Pesticides were eluted from the column with: 1st cut, 60 ml of hexane; 2nd cut, 75 ml of 5% benzene hexane (this eluant contains p, p'-DDE, o, p'-DDT, p, p'-DDT); 3rd cut, 75 ml of 20% benzene-hexane (contains p, p'-TDE); 4th cut, 60 ml of 15% diethyl ether, 0.25% acetone, 85% hexane; 5th cut, 90 ml of the 15% diethyl ether, 0.25% acetone, 85% hexane mixture (contains dieldrin and endrin). After initial analysis showed that DDE could elute into the first cut on occasion, the hexane elution was omitted. The 4th and 5th cuts were not analyzed routinely because of poor lipid separation and absence of pesticides.

The column eluant was analyzed for pesticides by gas-liquid chromatography using electron capture and microcoulometric detectors with a sensitivity (0.1 mv peak height) of 0.01 and 1.0 nanograms of p, p'-DDE respectively. A 122 cm (4 ft) x 2 mm i. d. pyrex column (fluorosilicone polymer) was packed with a 2.4:1.0 mixed packing of 7% QF-1 and 7% DC-11 (methylsilicone polymer) on 100/120 mesh Chromosorb W high performance for analysis.

The conditions for the electron capture gas chromatograph were: 210°C inlet temperature, 180°C column temperature, 200°C detector temperature and column gas (nitrogen) flow rate of 40 ml/min. The retention time of p, p'-DDE was approximately 4 minutes. The sample solution was analyzed in duplicate by injecting 2–8 µl subsamples into the gas chromatograph with a 10 µl syringe, followed by injections of 2–8 µl subsamples of 0.01, 0.02 or 0.04 ng/µl standard solutions. The amount of standard was selected to give a peak within 20% of the sample pesticide peak. The second injection of sample solution was either $\frac{1}{2}$ or twice as large as the first injection. A third analysis was required if the peak heights were not within 8% on a comparable basis.

Because of the very low levels of pesticides present, special precautions were taken to avoid contamination. Technical acetone was refluxed with $KMnO_4$ (0.5 g/l) for 1 hour and distilled. N-pentane and n-hexane were refluxed over sodium wire overnight before distillation. The Florisil adsorbent required purification and was placed in a muffle furnace at 450°C for 15 hours. All glassware was isolated and cleaned with $K_2CrO_4$-

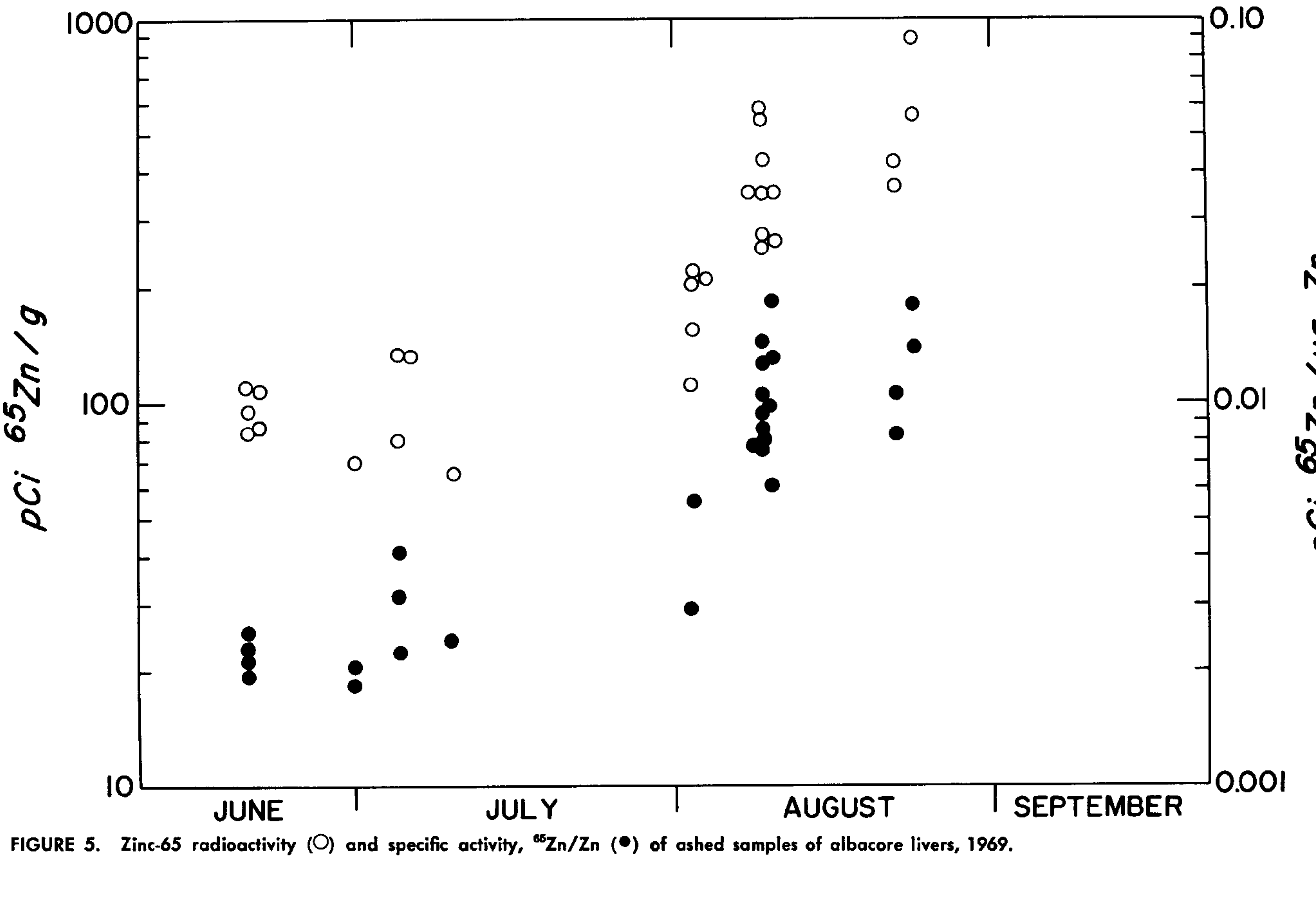


FIGURE 5. Zinc-65 radioactivity (○) and specific activity, $^{65}Zn/Zn$ (●) of ashed samples of albacore livers, 1969.

$H_2SO_4$ cleaning mixture and rinsed with water and acetone. The anhydrous $Na_2SO_4$ was washed with hexane before use and the water was purified by hexane extraction prior to use. The contamination of the glassware and reagents was determined prior to use by analyzing "solvent blanks", i.e. following the above procedure without addition of tissue.

Our procedure for the elution of the Florisil column was selected for analysis of low levels of chlorinated hydrocarbons. Other reported procedures resulted in interferences in the gas chromatographic analysis.

The presence of DDT was confirmed by microcoulometric detection of halide compounds and by base hydrolysis which converts o, p′ and p,p′-DDT to their respective DDE analogs. Base hydrolysis destroys TDE. Arochlors and samples containing 0.001 ppm or more of any of the DDT analogs could be detected by this procedure.

The presence of other chlorinated compounds, particularly the polychlorinated biphenyls (PCB's) was also investigated by microcoulometry after base hydrolysis of DDT. The PCB compounds are stable under the conditions used. PCB compounds were not found in our albacore samples above our detection level of 0.03 [2] ppm.

## RESULTS

Gamma-ray spectra revealed Zn-65 as the prominent artificial radioisotope present in albacore livers. Cesium-137, manganese-54 and cobalt-60 were also present. Figure 5 shows that the Zn-65 radioactivity per gram and the specific activity of Zn-65 of albacore livers increased greatly during the summer of 1969, thus reaffirming trends observed in previous years by Pearcy and Osterberg (1968). Slopes of linear regression lines fitted by least squares to both the untransformed and logarithms of radioactivity values are highly significant ($P < 0.01$, $n = 28$).

Our analyses of DDT residues in albacore liver and flesh tissue are summarized in Table 1. The levels of all metabolites were low. p, p′-DDE was the most prominent residue. It was found in concentrations up to a maximum of 0.16 ppm and was present above blank values in all 41 samples analyzed. Chromatographic peaks attributable to p, p′-DDT; o, p′-DDT and p, p′-TDE were usually present. Although levels of these residues were lower than p, p′-DDE, most values were significantly above blank values. Low values of o, p′-DDT and p, p′-DDT may be influenced by PCB's. No dieldrin was detected above blank levels of 0.003 ppm. The average values for all DDT residues combined were 0.05 for liver (range 0.003–0.22) and 0.07 for flesh (range 0.004–0.22).

To our dismay, we discovered that liver tissue was not uniform in regard to DDE storage. Both lateral and median lobes from each of four fish were analyzed and the lateral lobes on the average contained about seven times more DDE than the long median lobes. Because of this large difference, we had to consider separately each type of liver sample.

The values for DDE and DDT in whole albacore livers and median lobes are plotted in Figure 6 to show any trends that occurred with time during the summer of 1969. Concentrations of DDE and DDT were highly variable (note the log scale). No pronounced changes in the average pesticide level are evident during the summer. The slope of regression lines fitted by least squares to the untransformed pesticide values are not significant ($P > 0.5$) for either DDE or DDT in the median lobes ($n = 19$), whole livers ($n = 7$), or in flesh ($n = 11$, not shown in Fig. 6).

Thus Zn-65 was significantly enhanced while albacore resided in coastal waters off Oregon during the summer of 1969, but DDT residues did not undergo a similar increase. The lack of positive correlations between Zn-65 and DDT or DDE further indicated the independence of these pollutants. Correlation coefficients were not significant ($P > 0.05$) among Zn-65 and p, p′-DDE, Zn-65 and p, p′-DDT, and Zn-65 specific activity and DDT. The correlation between specific activity and DDE, however, was significant ($P = 0.05$). These correlations were based on twelve comparisons of livers from individual albacore.

[2] Since this paper was written, some extracts of whole livers have been reanalyzed for PCB's by an improved method. Values ranged from 0.02 to 0.03 ppm using 1260 formulation as a standard. Since many of the samples were collected in plastic bags and possibly contaminated with PCB's, these values must be suspect.

TABLE 1

**DDT residues, parts per million, on a wet weight basis in albacore collected off Oregon, 1969. (B = equivalent to blank value)**

ppm

| | p, p′-DDE | | | o, p′-DDT | | | p, p′-TDE | | | p, p′-DDT | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | $\bar{x}$ | Range | n | $\bar{x}$ | Range | n | $\bar{x}$ | Range | n | $\bar{x}$ | Range |
| Whole livers | 7 | 0.025 | 0.01–0.05 | 4 | 0.005 | B–0.01 | 4 | 0.007 | 0.004–0.01 | 6 | 0.012 | 0.001–0.03 |
| Median lobe | 19 | 0.023 | 0.001–0.14 | 9 | 0.009 | B–0.026 | 9 | 0.004 | 0.004–0.016 | 14 | 0.011 | B–0.04 |
| Lateral lobes | 4 | 0.09 | 0.022 0.16 | -- | --- | --- | -- | --- | --- | -- | --- | --- |
| Flesh | 11 | 0.035 | 0.003–0.14 | 7 | 0.012 | B–0.028 | -- | --- | --- | 11 | 0.02 | 0.001–0.04 |
| Blank values (per 5 gm samples) | 4 | 0.0002 | 0.0003–0.0028 | 4 | 0.0006 | 0.0002–0.001 | 4 | <0.0004 | --- | 4 | 0.0008 | 0.0003–0.003 |
| Percent recoveries | 4 | 93.7 | 90–113 | 3 | 96.3 | 94–98 | 4 | 88.3 | 83–94 | 4 | 90.3 | 86–93 |

## DISCUSSION

Our results indicate small amounts of DDT residues in albacore tuna and no significant increase in levels during their sojourn in Oregon waters in 1969, even though Zn-65 levels increased drastically as a result of their association with the Columbia River plume. Seasonal variations in the DDT residues of other fishes have been reported (Kelso *et al.*, 1970; Smith and Cole, 1971), indicating that rapid uptake of DDT is possible. Our hypothesis that the Columbia River is a major source of DDT for the ocean off Oregon is therefore rejected.

The average values for total DDT residues in albacore were very similar to those reported by Risebrough (1969) for skipjack tuna (*Euthunnus pelamis*) off Hawaii and the Galapagos Islands. Thus we have no evidence that freshwater drainage into coastal waters is a major source for DDT contamination in albacore. Our results provide additional support for aerial transport as an important mechanism for transfer of chlorinated hydrocarbons into the oceans.

The lack of correlation between freshwater drainage from agricultural lands and DDT in marine fishes has been reported by Risebrough *et al.* (1967) and Risebrough (1969). They found that northern anchovy in San Francisco Bay contained less DDT

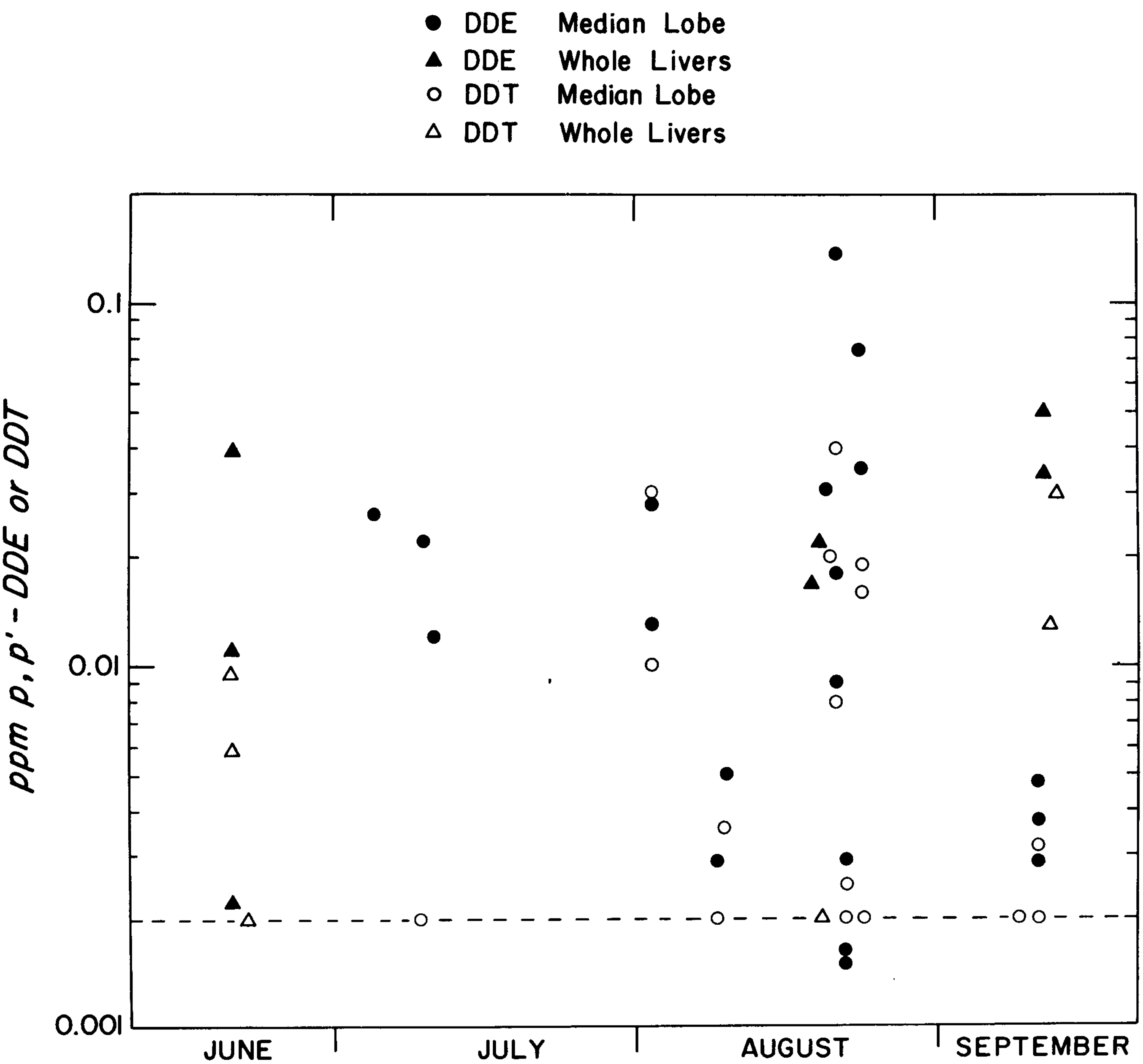


FIGURE 6. DDT residues and samples of albacore livers, 1969. The dashed line at 0.002 ppm represents twice our blank values for p, p'-DDT; any values recorded less than this are located on this line.

residues that those off southern California. Cox (this volume) found little evidence for elevated DDT residues in waters around the Columbia River plume. Aerial fallout and global atmospheric transport of DDT is further evidenced by DDT residues in airborne dust transported by the Atlantic trade winds (Risebrough *et al.*, 1968), by DDT residues in rainwater, even from the agriculturally remote Shetland Islands (Tarrant and Tatton, 1968), by the occurrence of pesticides in Antarctic birds and mammals (Tatton and Ruzick, 1967), in seals and porpoises in Scotland and Canada far from sites of application (Holden and Marsden, 1967), in the Bermuda petrel (Wurster and Wingate, 1968), other shearwaters and other pelagic birds (Risebrough *et al.*, 1967), and in sperm whales (Wolman and Wilson, 1970).

The ocean distribution of some radionuclides that were produced by nuclear explosions and transported by world-wide atmospheric circulation also indicate less accumulation of fallout in coastal waters. Pearcy and Osterberg (1968) found that manganese-54 levels decreased with time in albacore caught during the summer off Oregon. This trend suggested higher uptake of this fallout radionuclide in oceanic than in nearshore waters, a conclusion that was supported by the higher amounts of Mn-54 found in oceanic than coastal zooplankton. Pillai, Smith and Folsom (1964) and Folsom and Young (1965) found higher concentrations of other fallout radionuclides offshore than inshore. Thus fallout of some pollutants, including DDT, into oceanic regions far from the area of initial dispersal may actually be higher than into coastal seas.

Some conclusions of the recent Report of the Study of Critical Environmental Problems (SCEP, 1971, pp. 133, 135) provide an ideal ending for this paper but hopefully not an epitaph for the oceans. They concluded that " . . . DDT and its residues are most probably distributed throughout the marine biosphere . . . " and "the atmosphere appears to be the major route for transfer of DDT residues into the oceans, . . . and ultimate accumulation site of DDT and its residues".

## ACKNOWLEDGMENTS

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# EVIDENCE FOR EUTROPHICATION IN THE SEA NEAR SOUTHERN CALIFORNIA COASTAL SEWAGE OUTFALLS—JULY; 1970[1]

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## INTRODUCTION

Much of the year surface waters off southern California are depleted of plant nutrients, especially nitrogen, with nitrate undetectable at the surface and ammonium concentrations less than 1 μM (cf. Strickland, ed., 1970, and earlier references cited therein). More recently Ryther and Dunstan (1971) reported nitrogen to be limiting for phytoplankton growth also in waters off Long Island. In local waters natural enrichment takes place periodically, especially in spring and summer, by the upwelling of nutrient-rich water when marked increases in the concentration of nitrate, phosphate, and silicate are seen. A detailed study carried out April through September, 1967, off La Jolla, California, provided comparative data on crop size and nutrient concentrations in both quiescent and upwelling periods (Strickland, ed., 1970). The physical oceanography of upwelling has been reviewed recently (Smith, 1968) and the importance of the processes for local phytoplankton production has been recognized for many years (Moberg, 1928). Nutrient enrichment during upwelling tends to increase the size of the phytoplankton crop in local waters. In some cases, especially offshore, diatoms are the principal components of the resulting blooms (Sverdrup & Allen, 1939; Sargent & Walker, 1948) whereas dinoflagellates often form blooms (red tides) within a few miles of shore (Allen, 1946; Holmes et al., 1967). At present we are unable to predict whether dinoflagellates or diatoms will increase in response to nutrient enrichment nearshore (Strickland, ed., 1970) and further research on the character and mechanisms of species succession is needed.

Enrichment of surface waters results also from sewage disposal off southern California in outfalls serving Ventura, Los Angeles, Orange and San Diego counties. At present we lack sufficient data to compare the nutrient contributions from upwelling and sewage disposal to local surface waters. Very preliminary and approximate estimates suggest that natural upwelling may exceed sewage by an order of magnitude as a source of nitrogen for phytoplankton growth over a year. Fairly accurate estimates of the nitrogen input from sewage can be made but determining the contribution from upwelling would be very costly of ship time and no doubt variable from year to year.

Upwelling provides nitrogen as nitrate while sewage would be expected to supply ammonium as the principle form of nitrogen. Phytoplankton appear to utilize both forms equally well although their chemical composition, especially C/N and C/chlorophyll *a* ratios, may vary with the nitrogen source used for growth (Eppley *et al.*, 1971). Since upwelling is seasonal and intermittent a survey of the region during a quiescent period (no upwelling) would be expected to show the outfall areas as points of nutrient-rich water, with high phytoplankton crops, against a low nutrient, low crop background. This was the case, in part, in July 1–15, 1970, for coastal waters between Los Angeles and San Diego: phytoplankton crops were high only at the outfalls but nutrient concentrations were low everywhere.

Grigg and Kiwala (1970) and Turner, Ebert and Given (1968) provide maps of the White Point and Point Loma outfall areas, respectively, and report studies on benthic organisms.

## METHODOLOGY

### 1. *Station Locations*

Station locations are depicted in Figure 1. Stations 1, 6, and 10 are located in Scripps Canyon; Stations 12 and 18 at the Point Loma outfall; and Station 19 at the Whites Point outfall.

### 2. *Collection of Water Samples*

Water samples were taken with a 50 liter polyvinylchloride sampler and/or an 8 liter Van Dorn sampler for nutrients, dissolved and particulate organic constituents, and for primary productivity measurement; and with a continuous profiling pump for chlorophyll *a* determinations.

### 3. *Euphotic Zone Depth*

The depth of the euphotic zone was taken as three times the Secchi disc depth.

### 4. *Chlorophyll a in micrograms per liter (μg/l)*

Extracts in 90% acetone from filters were measured on a Turner fluorometer standardized against a Beckman spectrophotometer using pure cultures of marine algae and the SCOR-UNESCO equations for evaluating spectrophotometrically, the amount of chlorophyll in an extract.

Continuous depth profiles were made with a modified Turner fluorometer (Lorenzen, 1966); the same fluorometer as was used for extracts but with a flow-through cell replacement. Four sensitivities could be obtained by changing the size of the illuminated area. This was managed automatically by a servomotor which changes the opening or "door" according to the fluorescence recorded. Thus if, with the widest opening (door 1), the output exceeded 95 units the mecha-

[1] Supported by the U.S. Atomic Energy Commission, Contract No. AT(11-1) GEN 10, P.A. 20, California Cooperative Oceanic Fisheries Investigations, and the U.S. Federal Water Quality Administration, Contract 16010 EHC. Ship time supported by National Science Foundation, *Alpha Helix* Eastern Pacific Program, 1970.

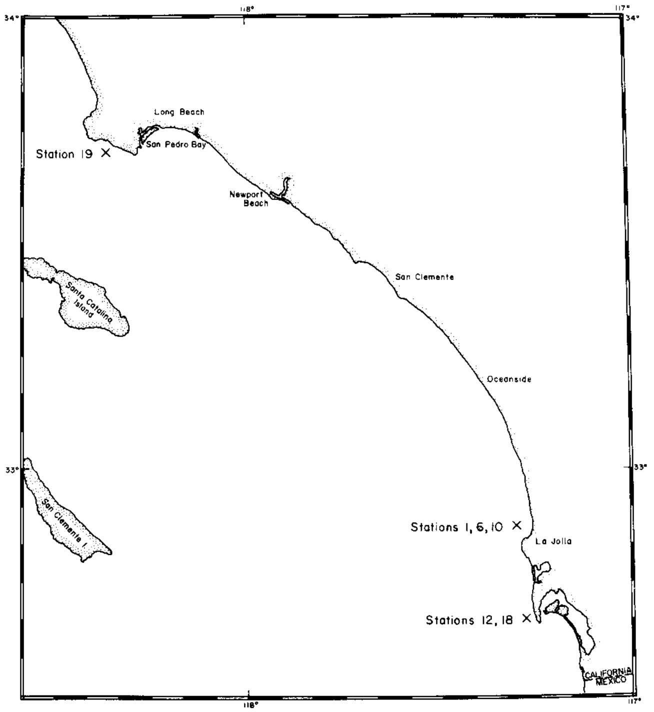


**FIGURE 1. Location of stations.**

nism automatically moved the next door, with less area, into position and so on through a total of four doors. If the fluorescence output signal decreased below 20 units the door was again changed, this time to the next largest opening. Factors to convert all door readings to the reading to be expected on door 1 were determined experimentally. Since the amount of fluorescence per weight of chlorophyll varied, to an extent and for reasons yet unknown, this ratio was determined for at least two depths (usually four or five) when making profiles and several times a day when charting surface properties.

### 5. *Phaeophytin a (µg/l)*

This was calculated from fluorometer readings taken before and after acidification of acetone extracts. When calculating a chlorophyll factor for the *in vivo* fluorometer the total pigment (chlorophyll *a* plus phaeophytin *a* was used (see above).

### 6. *Surface and Submarine Irradiance*

A photometer consisting of a selenium photocell with green filter was used to measure submarine irradiance as percent of that seen by an identical photocell on deck.

Incoming radiation as langlies/day was measured by a bimetallic actinograph (Kahl Scientific Instrument Corporation; El Cajon, Calif.) calibrated against an Eppley pyranometer and kept ashore at the Scripps Institution.

### 7. *Primary Production as milligrams of carbon per cubic meter per day or grams of carbon per square meter per day (mg C/m³/day, g C/m²/day)*

Samples were taken at depths corresponding to sunlight irradiances of 87, 43, 20, 7, 4, and 1% of surface irradiance. (These depths were chosen to match the transmission of neutral density filters in the deck incubators.) The light depths for sampling were based on three-times the Secchi disc depth as the 1% light level and the further assumption of a constant attenuation coefficient with depth.

The water samples were passed through 183 micron (µ) netting and placed in 300-ml glass-stoppered bottles. Radiocarbonate solution (5 or 20 microcuries in one ml) was added with rinsing, the contents of the bottles mixed and the bottles placed in incubators on deck in unobstructed sunlight. The incubators provided cooling water at sea surface temperatures.

Samples were incubated for 24 hours. They were then passed through 0.45-µ membrane filters and the filters were dried immediately in a vacuum desiccator over silica gel.

Finally, the radiocarbon of the filtered particulate matter was assayed with a scintillation counter and the counts were corrected for counter efficiency, background radiation and coincidence effects. Carbon assimilation was calculated as mg $C/m^3$/day. These values were integrated over depth to express production as g $C/m^2$/day.

### 8. *Adenosine triphosphate in nanograms per liter (ng/l)*

Water samples were first filtered through a 183-µ nylon net to remove any large particulate matter or zooplankton. Volumes of sample between 0.1 and 1.0 liter depending on phytoplankton population density were then filtered through 25-mm micro-fine glass fiber filters (Reeve Angel 984h). As soon as the filtration was completed the filters were immersed in boiling Tris buffer at 100°C as rapidly as possible to inactivate all enzymes. The concentration of ATP in the extracts was determined by the bioluminescent reaction utilizing firefly luciferin-luciferase (Holm-Hansen and Booth, 1966).

### 9. *Particular Organic Carbon and Nitrogen (µg/l)*

Water samples were first filtered through a 183-µ nylon net. Volumes of sample between 0.3 and 1.0 liter were then filtered through combusted 25-mm glass fiber filters (Whatman GF/C). Carbon was determined by infrared absorption on the $CO_2$ liberated during wet oxidation of the samples (Holm-Hansen *et al.*, 1967) and organic nitrogen was determined by a colorimetric method with ninhydrin-hydrindantin (Holm-Hansen, 1968).

### 10. *Inorganic Nutrients in microgram-atoms per liter (µg-at/l)*

$PO_4^{3-}$, $SiO_3^{2-}$, $NO_3^{1-}$ and $NH_3$ were determined with the autoanalyzer as described in Strickland and Parsons (1968) with the exception that the ammonia method was modified by using citrate to prevent precipitation (unpublished MS).

### 11. *Dissolved Organic Nutrients (mg/l, µg-at/l, ng/l)*

Dissolved organic carbon, nitrogen and phosphorus, and vitamins $B_{12}$, $B_1$ (thiamine) and biotin were determined by methods given in Strickland and Parsons (1968).

## RESULTS

### *Measures of the Phytoplankton Crop*

Depth profiles of chlorophyll *a* (discrete sample points) and chlorophyll fluorescence (continuous traces) are shown for two stations off La Jolla (6 and 10) and for the Pt. Loma (Sta. 18) and Whites Pt. (Sta. 19) outfalls (Fig. 2). Values integrated over the depth of the euphotic zone are given in Table 1. Integrated values for the outfall stations approach the highest values observed in the 1967 study during upwelling (81 and 106 mg chl. $a/m^2$ at two stations) and mark the outfall areas as highly productive of phytoplankton.

Depth profiles of ATP, particulate organic carbon and particulate organic nitrogen (Figs. 3, 4, 5) also suggest high crops at the outfall stations (Sta. 12, 18 and 19). Organic carbon and nitrogen measurements will include a detrital component, but ATP is restricted almost entirely to living organisms (Holm-Hansen and Booth, 1966). That the ATP values represent primarily phytoplankton is suggested by the similarity of ATP/chlorophyll *a* ratios at the outfall stations to values observed in phytoplankton cultures (Holm-Hansen, 1970) in which bacteria, ciliates and other heterotrophic organisms are not present.

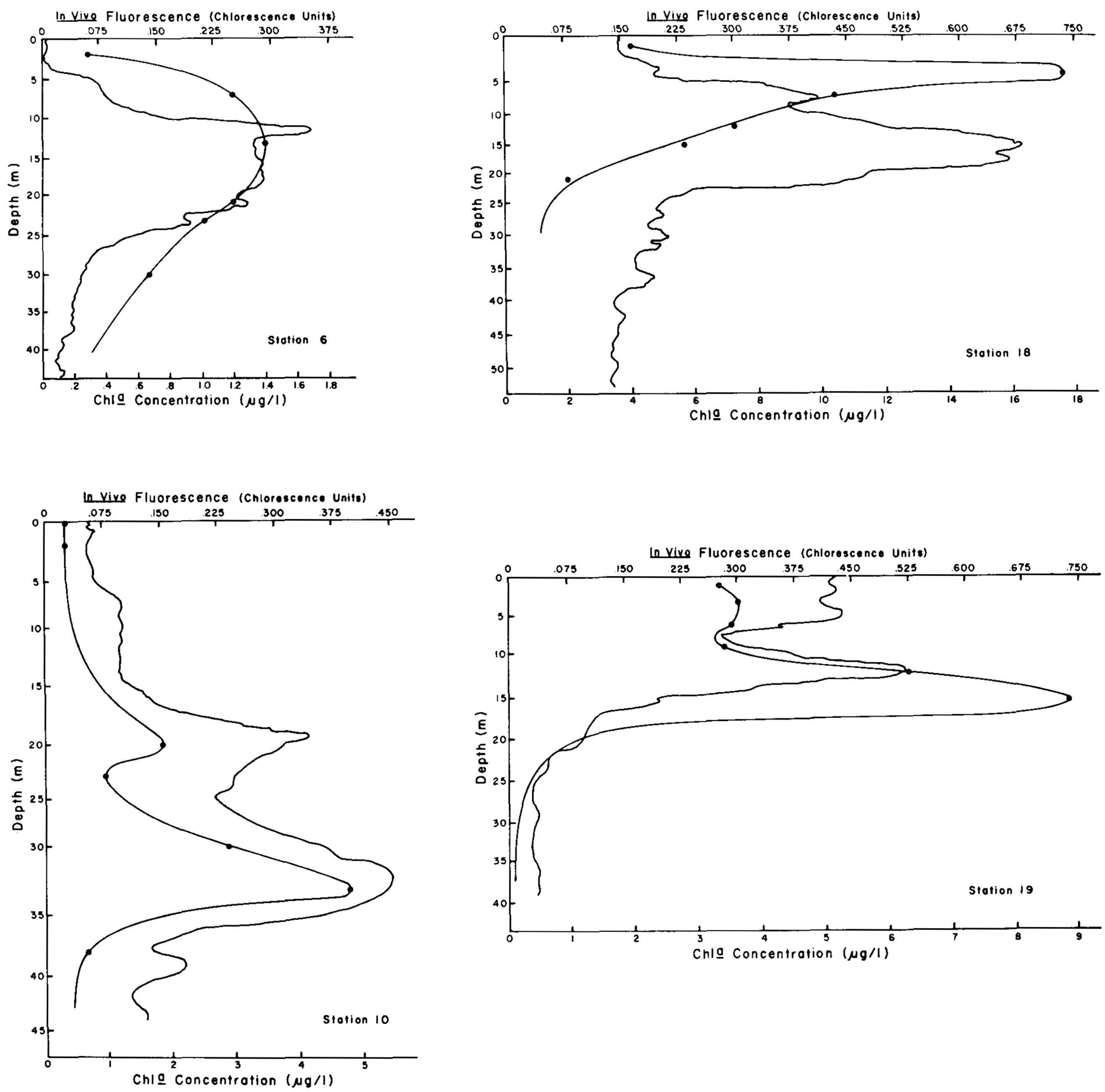


**FIGURE 2. Concentrations of chlorophyll *a* in waters from Stations 6 and 10 (non-outfall) and 18 and 19 (outfall). Smooth line with points determined from discrete samples. "Chlorescence" units for continuous profiles are relative chlorophyll concentration.**

### *Phytoplankton Photosynthesis*

The outfall stations showed much higher primary productivity than at stations off La Jolla (Fig. 6). Daily production integrated over the euphotic zone (Table 1) was 1.8 and 2.6 gram C/m$^2$/day at the outfalls, values typical of rich upwelling regions such as the Peru Current and two to three times higher than seasonal averages off La Jolla (1.0 and 1.1 g C/m$^2$/day at two stations).

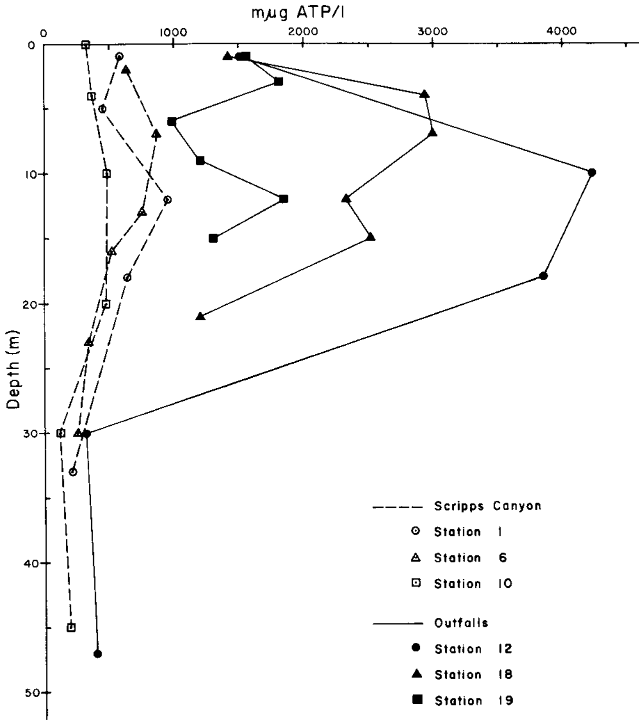


**FIGURE 3. Concentrations of ATP (adenosine triphosphate) in waters from Stations 1, 6, and 10 (non-outfall) and 12, 18 and 19 (outfall).**

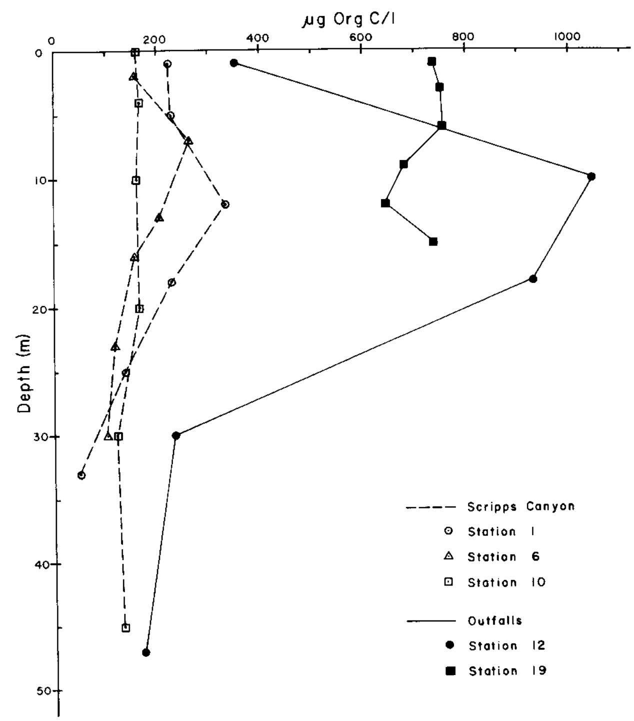


**FIGURE 4. Concentrations of particulate organic carbon in waters from Stations 1, 6, and 10 (non-outfall) and 12 and 19 (outfall).**

The specific growth rates (μ) of the crops, expressed as doublings of carbon per day, were calculated using 250 times the ATP concentration (Holm-Hansen, 1970) as a measure of the phytoplankton crop as carbon (P) and 24-hour measurements of photosynthetic rate as a measure of the daily carbon increase of the crop (ΔP)

$$\mu = \frac{1}{\text{days}} \log_2 \left[ \frac{P + \Delta P}{P} \right] \qquad (1)$$

Rates were relatively low and similar at all stations (Table 1), implying no inhibition of phytoplankton

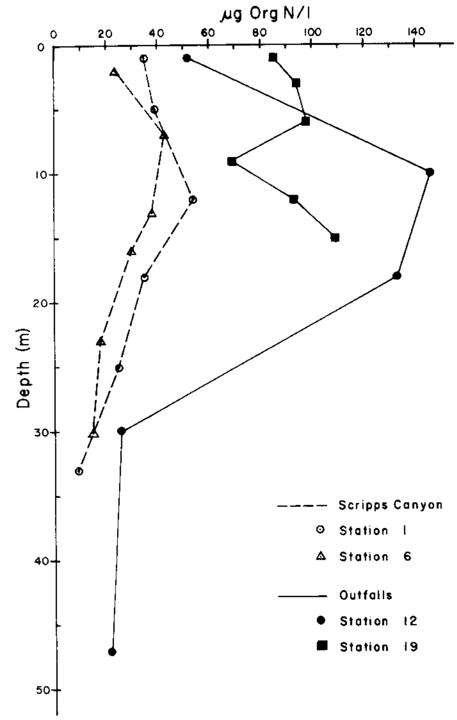


**FIGURE 5. Concentrations of particulate organic nitrogen in waters from Stations 1 and 6 (non-outfall) and 12 and 19 (outfall).**

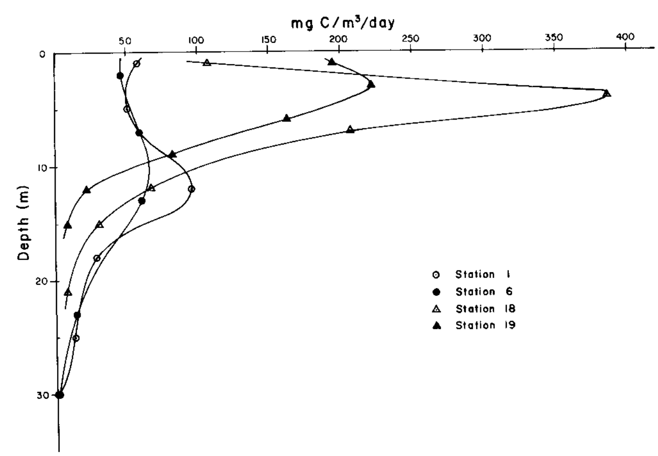


**FIGURE 6. Primary production in waters from Stations 1 and 6 (non-outfall) and 12 and 19 (outfall).**

TABLE 1

**Comparison of phytoplankton crop and primary production, integrated over the depth of the euphotic zone, for stations near Scripps Canyon, the Pt. Loma (San Diego) and Whites Point (Los Angeles) sewage outfalls.**

| | Station | | | | | |
|---|---|---|---|---|---|---|
| | Pt. Loma | | White Pt. | Scripps Canyon | | |
| | 12 | 18 | 19 | 1 | 6 | 10 |
| Phytoplankton carbon ($g/m^2$) (as 250 × ATP) | 14.9 | 12.1 | 5.9 | 8.4 | 4.4 | 3.6 |
| Chlorophyll *a* ($mg/m^2$) | – | 163 | 83 | 40 | 30 | 29 |
| Primary production (g $C/m^2$/day) | – | 2.64 | 1.76 | 1.37 | 1.10 | 0.36 |
| Specific growth rate (doublings/day) | – | 0.28 | 0.37 | 0.26 | 0.32 | 0.13 |
| Depth of euphotic zone (m) | 18 | 21 | 16.5 | 33 | 33 | 46 |

growth at the outfall stations. Because of the uncertainties in estimating both standing stock and production, these rates must be regarded as tentative, but nevertheless they provide a basis for intercomparison. Similar rates were indicated from nitrogen assimilation at these stations (McCarthy, 1971). Thomas (1970) reported a 3- to 5-day doubling time for phytoplankton of the nutrient-poor surface waters of the eastern tropical Pacific Ocean. The specific growth rate of phytoplankton in upwelled water off Peru was higher (0.6–0.8 doublings/day when integrated over the euphotic zone). Off Peru nitrate nitrogen was 10–20 micromolar (μM) and we propose that the lower rates measured off southern California are due to nitrogen limitation, as reported for oligotrophic waters of the eastern tropical Pacific Ocean (Thomas and Owen, 1971).

### *Concentration of Nutrients*

Depth profiles of phosphate and silicate (Fig. 7), nitrate and ammonium (Fig. 8) show little difference between outfall stations and other coastal stations in spite of the sewage enrichment.

Nitrate, ammonium, and urea (McCarthy, 1971) were low in the euphotic zone at all stations and ammonium and urea were important sources of nitrogen for plant growth, as shown by the rates of assimilation of $^{15}N$-labelled compounds (McCarthy, 1971).

Water at the outfall stations contained higher concentrations of silicate, relative to phosphate and nitrate, then elsewhere. This is best seen by plotting a graph of phosphate vs silicate or nitrate vs silicate (see, for example, Strickland, Solórzano and Eppley, 1970). Graphs of nitrate vs silicate for water off La Jolla, California, show a similar high silicate/nitrate ratio at an inshore station (approximately 1 km from the beach) but not for stations farther offshore. The higher inshore silicate/nitrate ratio could not be attributed to lack of diatoms in the phytoplankton (Strickland, ed., 1970) but seems to be characteristic of nearshore water.

### *Dissolved Organic Constituents of the Seawater*

Dissolved organic carbon (DOC) and dissolved organic phosphorus (DOP) (Table 2) and dissolved organic nitrogen (DON, Fig. 8) did not show significant differences between outfall and other stations. At the Whites Pt. outfall (Sta. 19) the vertical distributions of DOC, DON and DOP were remarkably

TABLE 2

**Dissolved organic carbon (DOC) and phosphorus (DOP) at Stations 1 and 6 (non-outfall) and Stations 18 and 19 (outfalls).**

| | Depth (m) | DOC (mg/l) | DOP (μg-at/l) |
|---|---|---|---|
| Station 1 | 1 | 1.12 | 0.48 |
| | 5 | 0.66 | 0.59 |
| | 12 | 0.90 | 0.33 |
| | 18 | 0.98 | 0.63 |
| | 25 | 1.38 | 0.63 |
| | 33 | 0.63 | 0.77 |
| Station 6 | 2 | 1.42 | 0.89 |
| | 7 | 1.25 | 1.49 |
| | 13 | 0.86 | 1.11 |
| | 16 | 0.91 | 0.86 |
| | 23 | 0.85 | 0.88 |
| | 30 | 0.39 | 1.19 |
| Station 18 | 1 | 1.40 | 0.47 |
| | 4 | 1.23 | 0.59 |
| | 7 | 1.61 | 0.57 |
| | 12 | 2.30 | 0.61 |
| | 15 | 1.10 | 0.38 |
| | 21 | – | 0.40 |
| | 30 | 1.34 | 0.15 |
| | 40 | 0.75 | 0.08 |
| | 55 | 1.00 | 0.12 |
| Station 19 | 1 | 1.26 | 0.35 |
| | 3 | 1.50 | 0.47 |
| | 6 | 1.26 | 0.59 |
| | 9 | 1.22 | 0.74 |
| | 12 | 1.12 | 0.50 |
| | 15 | 1.22 | 0.65 |
| | 30 | 1.12 | 0.23 |
| | 50 | 1.46 | – |
| | 80 | 1.05 | 0.33 |

uniform even though there were considerable gradients in the inorganic nutrients. This situation suggests rapid bacterial oxidation of the dissolved organic fraction at this station.

Dissolved vitamin $B_{12}$ profiles likewise showed no marked differences between outfall and other stations (Fig. 9). Biotin concentration was elevated at the Whites Pt. outfall, but not at the Pt. Loma outfall (Fig. 9). Vitamin $B_1$ (thiamine) showed little difference between stations (Table 3).

## DISCUSSION

The timing of this work in July, 1970, was propitious for showing the eutrophication around southern California sewage outfalls where phytoplankton crops and primary production exceed typical levels off this coast and approach values characteristic of upwelling periods.

Surprisingly, to us, concentrations of nutrients (except silicate) and dissolved organic materials were not

TABLE 3
**Dissolved vitamin $B_1$ (thiamine) in waters from Stations 1 and 6 (non-outfall) and Stations 18 and 19 (outfalls).**

| Station | Depth (m) | Vitamin $B_1$ (ng/l) |
|---|---|---|
| 1 | 1 | 26 |
| | 5 | 20 |
| | 12 | 5 |
| | 18 | 12 |
| | 25 | 10 |
| | 33 | 18 |
| 6 | 2 | 36 |
| | 7 | 8 |
| | 13 | 40 |
| | 16 | 12 |
| | 23 | 11 |
| | 30 | 13 |
| 18 | 1 | 16 |
| | 4 | 20 |
| | 7 | 16 |
| | 12 | 8 |
| | 15 | 5 |
| | 21 | 5 |
| | 30 | 11 |
| | 40 | 5 |
| | 55 | 10 |
| 19 | 1 | 11 |
| | 3 | 16 |
| | 6 | 5 |
| | 9 | 10 |
| | 12 | 10 |
| | 15 | 6 |
| | 30 | 30 |
| | 50 | 11 |
| | 80 | 26 |

elevated in samples taken at the outfall stations even when bottle casts were taken directly over outfalls (noted on the ships fathometer). This would seem to imply that the hydraulic diffusers were effective in diluting the wastes prior to emission and/or that the phytoplankton growth was sufficiently vigorous to deplete the waters of excess nutrients.

If a value for inorganic nitrogen (nitrate and ammonium) of 2 millimolar (mM) is taken for sewage (Weibul, 1969), with a 200-fold dilution with sea water prior to emission, the final nitrogen concentration would be about 10 μM. This concentration of nitrogen would produce a phytoplankton crop equivalent to about 10 μg/l of chlorophyll *a*, using conversion factors found in this laboratory. Maximum observed chlorophyll *a* concentrations were 10 to 17 μg/l at the two outfall stations, in reasonable agreement with the hypothesis that the phytoplankton crop was assimilating the inorganic nitrogen of the effluent as fast as it was released. Such calculations can only provide a rough guide to reality because of advection and the unknown nature of the local food chain (see, for example, Smith, 1969).

Nutrient (nitrate and phosphate) concentrations found in this study were much lower than in eutrophic estuaries of the eastern coast of the United States (Ketchum, 1969; Carpenter, Pritchard and Whaley, 1969; Ryther and Dunstan, 1971) and fall within the range of values observed elsewhere along the southern California coast (Strickland, ed., 1970). Chlorophyll *a* and phosphate concentrations resemble those from Long Island Sound rather than polluted estuaries (see Fig. 4, in Ketchum, 1969).

Particulate nitrogen and carbon were high at the outfall stations primarily as constituents of the phytoplankton crop. The fate of these large crops was not studied and their contents of toxicants (heavy metals, pesticides) are unknown. Recently fish caught near Los Angeles have been impounded by the authorities because of excess DDT content (San Diego Union, 1 Jan., 1971) and this underscores the need for studies of pelagic and benthic food chains in relation to such poisons.

The calculation of phytoplankton specific growth rate requires some explanation, particularly in respect to methods used to estimate the phytoplankton standing stock as carbon. In the past phytoplankton carbon was computed from laborious cell counts and measures of cell volume (Reid, Fuglister and Jordan, 1970). In this study the carbon of the living cells was computed as 250 times the ATP content of the samples. The conversion factor, 250, is based upon laboratory cultures of bacteria (Hamilton and Holm-Hansen, 1967) and phytoplankton (Holm-Hansen, 1970). The two methods were compared with good agreement for several stations (Holm-Hansen, 1969). The ATP measured, of course, includes that contained in all living cells and is not unique to phytoplankton. And one wonders if the quantity and proportion of heterotrophic organisms may not differ among the stations. The ratio (250 × ATP/chlorophyll *a*) tended to be low at the sewage outfall stations and similar to values observed in natural phytoplankton cultures aboard ship (Eppley *et al.*, 1971). Higher values of the ratio were observed at the Scripps Canyon stations and may reflect a greater contribution of heterotrophs or higher carbon/chlorophyll *a* ratios in phytoplankton resulting from higher mean irradiance, nutritional status, or species composition of the phytoplankton community.

Specific growth rates so computed were as high, or higher, at the outfall stations than off Scripps Canyon. No toxic effects of sewage effluent on phytoplankton growth were noted. Rather, if one considers that the crops at outfall stations were high, and that specific growth rates could well be a crop density-dependent function (Sutcliffe, Sheldon and Prakash, 1970) then the sewage-enriched waters could be regarded as stimulatory with respect to phytoplankton growth rate, as would be expected from the nutrient enrichment.

In the absence of measurements over the seasons it cannot be assumed that our measurements of the phytoplankton crop and growth rate represent a steady-state. Advective processes, variation in the quantity and quality of wastes discharged, and periodic upwelling would complicate mathematical modeling but efforts in this direction would be interesting and perhaps useful (Dugdale and Whitledge, 1970). On the other hand, the outfalls provide appealing sites for study, especially in respect to tracing food chain pathways of pesticides, heavy metals, and other toxicants or when large phytoplankton crops facilitate evaluation of shipboard analytical methods.

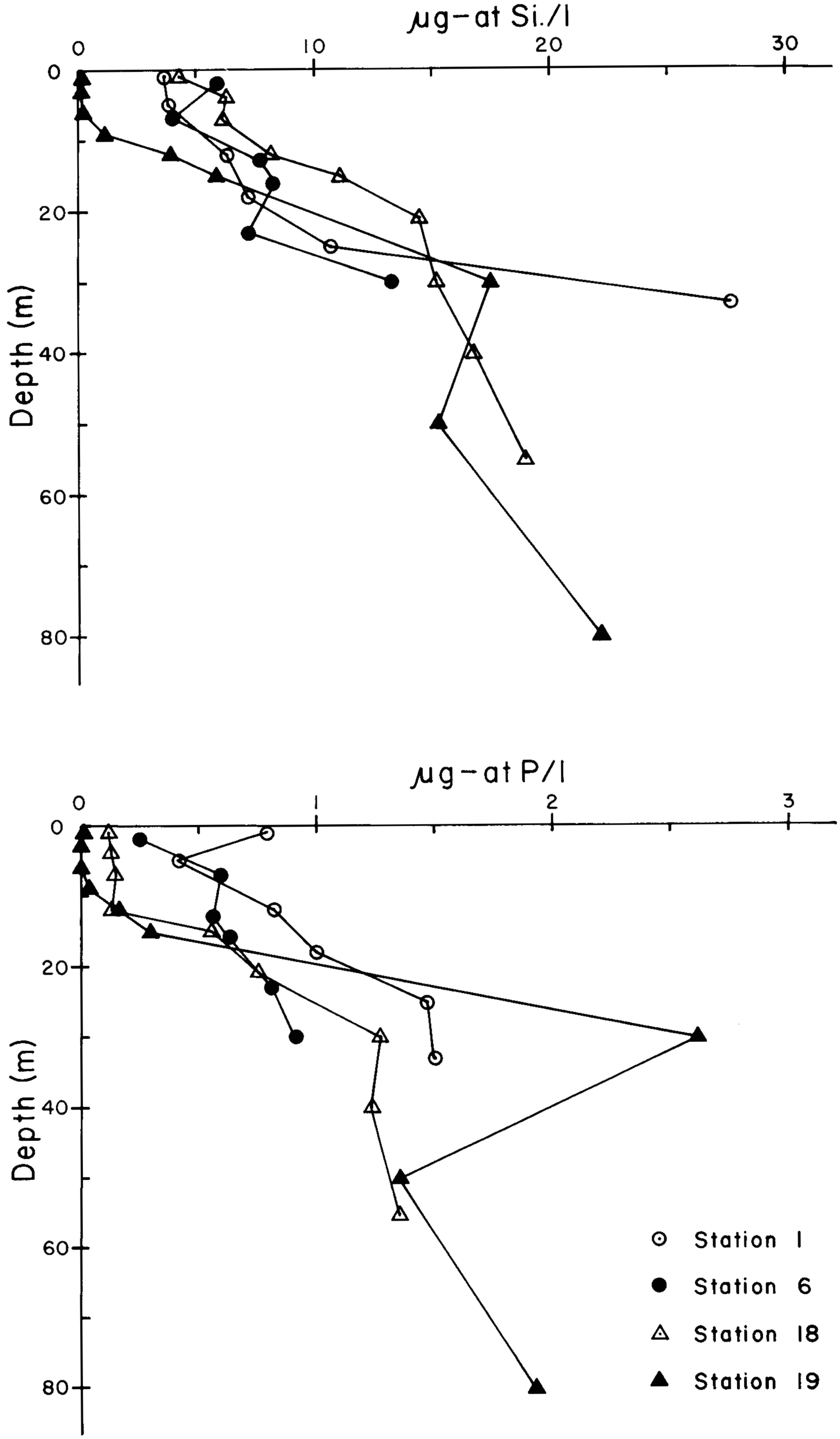


FIGURE 7. Concentrations of silicate and phosphorus in waters from Stations 1 and 6 (non-outfall) and 18 and 19 (outfall).

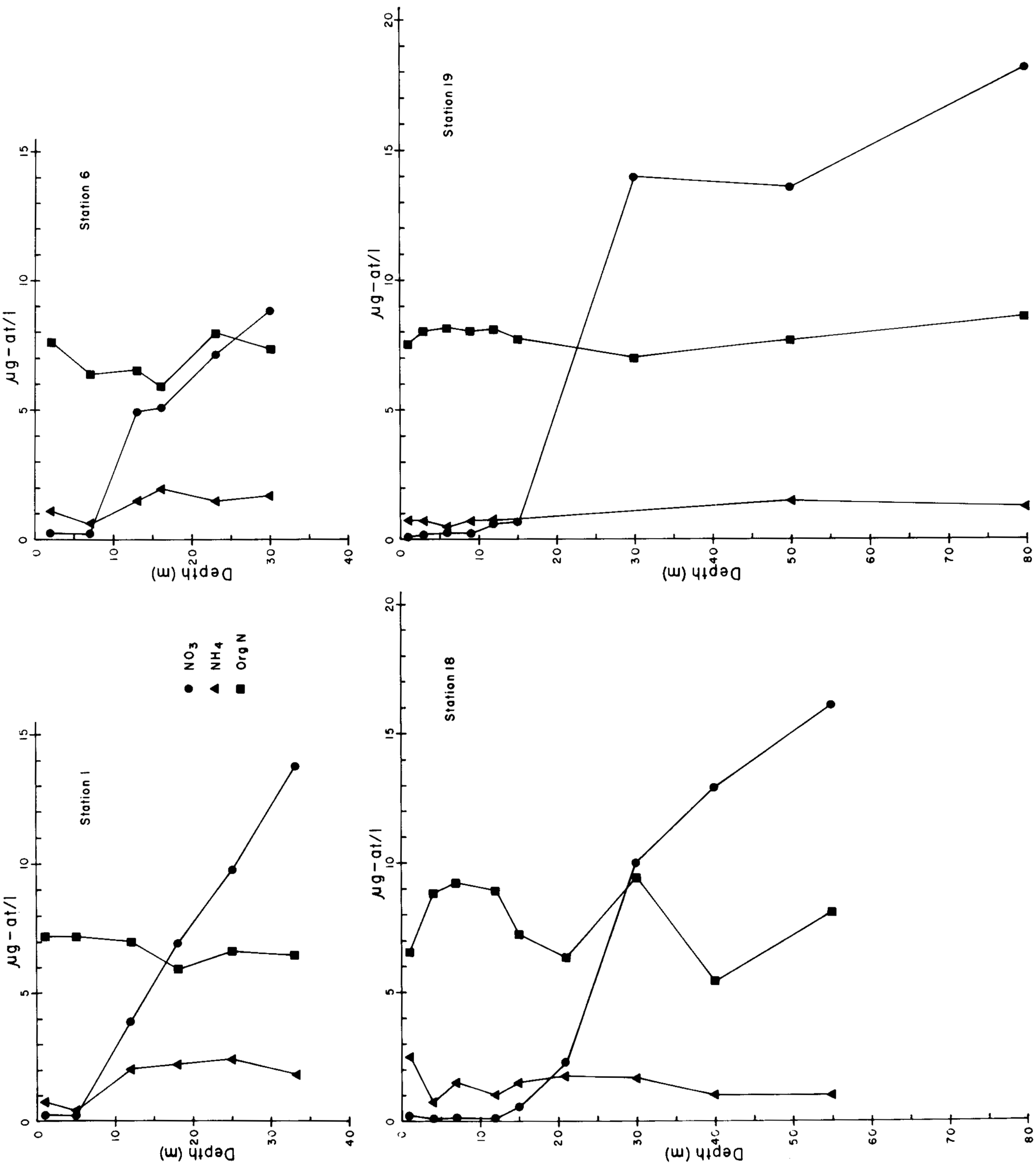


FIGURE 8. Concentrations of $NH_3$-N, $NO_3^-$-N, and dissolved organic nitrogen in waters from Stations 1 and 6 (non-outfall) and 18 and 19 (outfall).

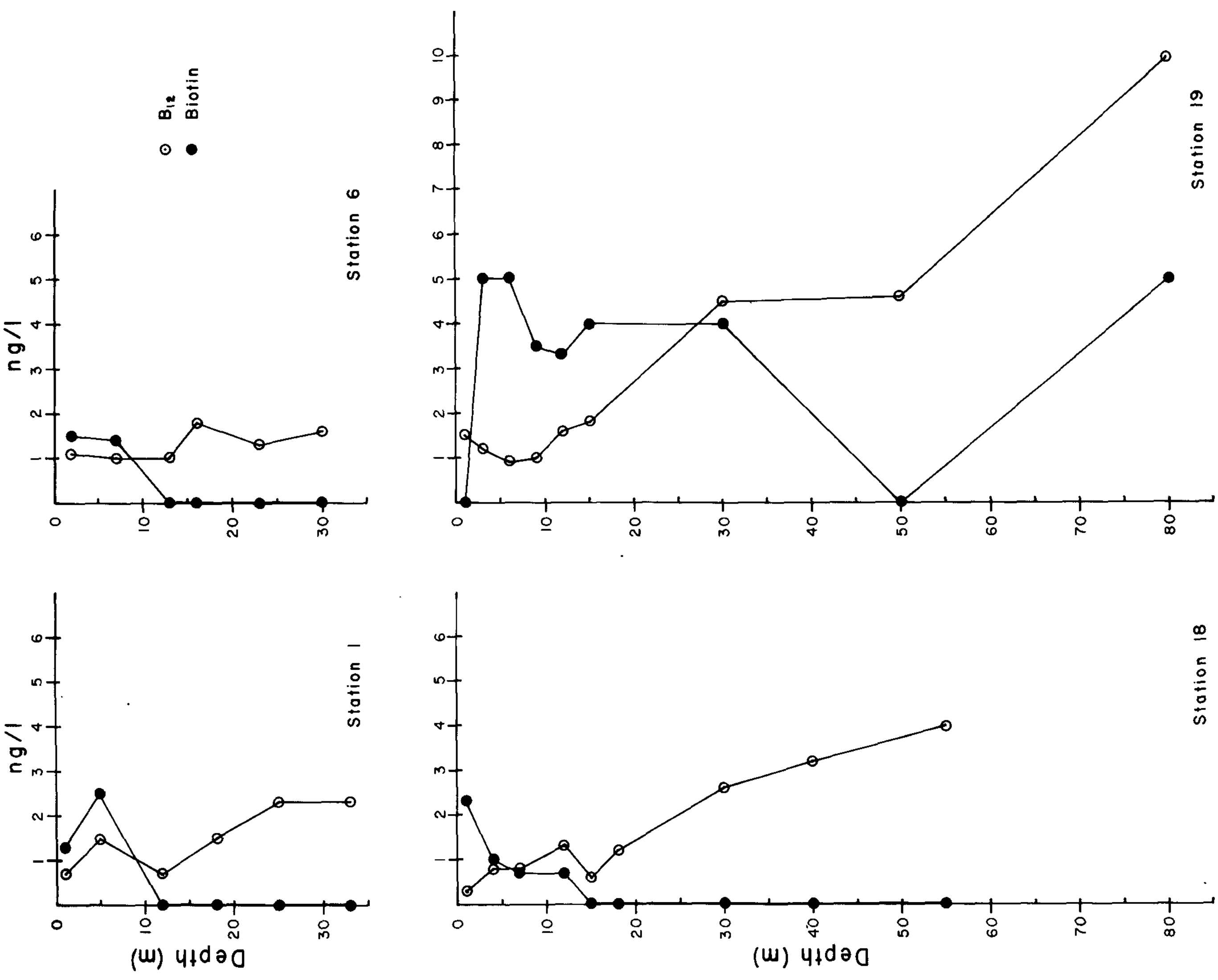


FIGURE 9. Concentrations of dissolved vitamin $B_{12}$ and biotin in waters from Stations 1 and 6 (non-outfall) and 18 and 19 (outfall).

## SUMMARY

Eutrophication of seawater at the Point Loma and Whites Point sewage outfalls off southern California has been demonstrated by measurments of primary productivity two to three times the normal seasonal averages along the coast. Associated with this enhanced phytoplankton production were high concentrations of chlorophyll *a,* ATP, and particulate organic carbon and nitrogen. These parameters provide evidence for high phytoplankton standing stock. However, there were no appreciable differences in the nutrients or dissolved organic constitutents between outfall areas and the normal coastal background. This latter condition suggests rapid uptake of nutrients and/or effective dispersal from the outfall origins.

## ACKNOWLEDGMENTS

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# SOME ASPECTS OF POLLUTION IN SAN DIEGO COUNTY LAGOONS

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## INTRODUCTION

Water is considered polluted if it is not suitable for its intended use, whether that be a water supply, propagation of fish and wildlife, or recreation. Water pollution thus covers a diversity of events, such as oil spills, pesticide accumulation, heavy metal contamination and sewage discharge. Since the most serious pollutant in the lagoons of San Diego County appears to be sewage effluent, we shall confine ourselves to this topic.

Almost all of the coastal lagoons in San Diego County have a history of use as sewage disposals. Most of the effluent now entering the lagoons is secondarily treated, that is, the solids have been removed, and most of the organic matter has been oxidized. However, even after secondary treatment, the effluent still contains large quantities of nitrogen and phosphorus. The effluent adds a large nutrient load to the naturally nutrient-rich lagoon water, and results in a stimulation of excessive plant growth. Phytoplankton in some lagoons may be so prolific that the water turns pea green; other lagoons become covered with rafts of filamentous algae (*Enteromorpha spp.*). Following an algal bloom, the decomposition of plant material may result in the lowering of dissolved oxygen to such low concentrations that fish and other aquatic organisms can no longer survive; the death of these organisms further adds to the organic load and the oxygen deficiency. Other undesirable effects of this eutrophication process include the accumulation of sludge from the partially decomposed organic matter, the development of foul odors, and a lowering of the esthetic and recreational values of the lagoons.

Some of the features of this eutrophication process in the San Diego County lagoons have previously been described by Bradshaw (1968), Carpelan (1964, 1969), Gannon (1967), the California Department of Fish and Game (1951) and the California Department of Public Health (1951). The primary purpose of our study was to measure several chemical indicators of eutrophication (specifically, inorganic nitrogen and phosphorus) in lagoons receiving different amounts of nutrient-rich effluent, and to compare these nutrient levels with the background values of non-polluted lagoons in the same area. We also attempted to estimate the impact of sewage effluent disposal via the lagoons on the nutrient levels of the adjacent coastal waters. Our data was collected between August 22 and October 17, 1970; we have also drawn on the data of Gannon (1967), and on the records of the San Diego County Regional Water Quality Control Board. Our preliminary analyses are based on limited data, but we hope that the broad trends shown by them will spark more detailed and exacting studies in the future.

### *Description of the Lagoons*

The distribution of the coastal lagoons in San Diego County is shown in Figure 1. These partially landlocked water bodies have resulted from the drowning of river mouths and the subsequent development of protective sand bars, a process thought to have begun approximately one million years b.p. Evidence from Indian kitchen middens indicates that all of these lagoons supported rich marine faunas from approximately 9,000 to 800 years ago (Miller, 1966).

Some aspects of the recent ecology and geology of these lagoons have been studied by Carpelan (1964, 1969), Miller (1966), Gannon (1967), Bradshaw (1968), Ford (1968), Damon (1969), Fairbanks (1969), and Mudie (1970). The most important factor affecting the lagoon ecosystems appears to be the size of the tidal prism, which is the volume of water exchanged by the tide. If the tidal prism is reduced below a critical volume (due to obstruction of the entrance channel, or to decrease of river inflow or lagoon volume), long-shore transported sand fills in the lagoon mouth, and tidal exchange ceases until the entrance barrier is breached by river flooding or by artificial means. If the lagoon remains closed for an extended period of time, the ecosystem changes from one characteristic of protected inshore ocean water to one dominated by brackish water (when the volume of fresh water inflow is high) or by hypersaline water (when the fresh water inflow is small).

The tidal prism of a lagoon is determined by the surface area, the height of the sill at the lagoon entrance, and the tidal range. Large lagoons (tidal prism $> 1 \times 10^7$ cu.ft.) generally remain open to the ocean (Inman and Frautschy, 1965), and, in Southern California, where river flows are relatively small, the salinity of the water in these open lagoons is similar to that of the ocean 33.5‰. At the other extreme, small lagoons normally remain closed and are connected with the ocean only during times of severe winter flooding. Fresh water predominates in these lagoons, the salinity generally being less than 5 parts per thousand (‰). Lagoons with tidal prisms in the "critical range" (defined empirically here as $1 \times 10^7$ to $1 \times 10^5$ cu.ft.) tend to remain open only a few months of the year but can be kept open artificially by annual small-scale dredging of the entrance channel. The salinity of the water in these variable lagoons is subject to great seasonal variation, the maximum range being approximately 10 to 65‰.

The pertinent characteristics of the San Diego County lagoons are summarized in Table 1. San Diego Bay, Mission Bay and Agua Hedionda Lagoon are open lagoons which support a high diversity of inshore marine fish and invertebrates, and a phytoplankton flora dominated by marine diatoms. Sewage effluent discharge rates in these lagoons are presently relatively low, the effluent constituting raw sewage contributed directly from watercraft. Up until 1962, however, large volumes of raw and primary sewage were discharged into San Diego Bay (1962 discharge rate was approximately $60 \times 10^6$ gals/day). Buena Vista is a closed lagoon with a limited brackish water fauna and flora. Prior to 1966, approximately $2 \times 10^6$ gals/day of secondary sewage effluent were discharged into this lagoon. In recent years, however, this discharge has stopped and at present only a small volume of irrigation runoff enters the lagoon from Buena Vista Creek.

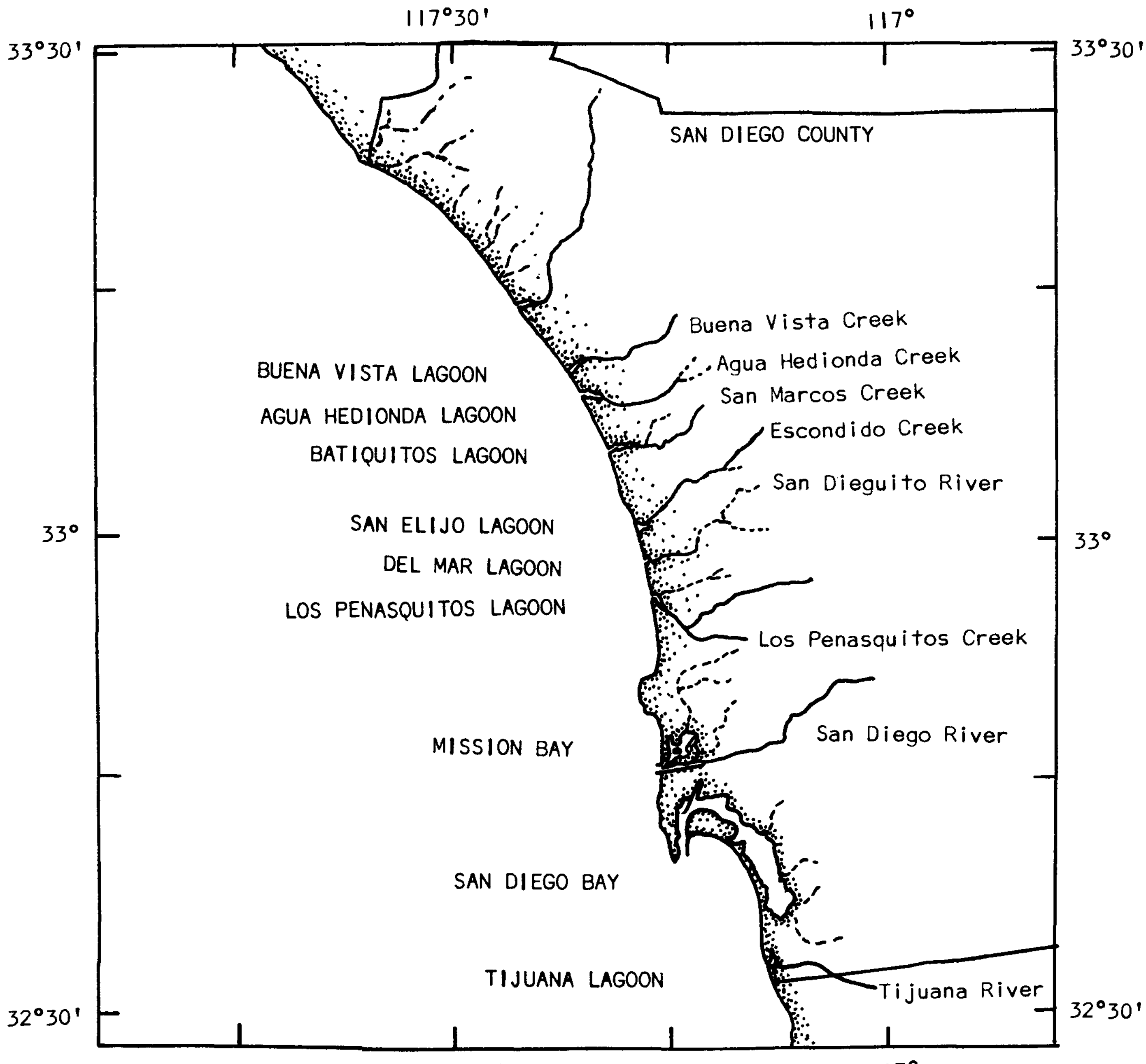


FIGURE 1. Distribution of the San Diego County lagoons sampled in this study.

Los Penasquitos, San Elijo, Batiquitos and Del Mar lagoons are variable lagoons. Prior to the inflow of significant volumes of sewage effluent (commencing between 1955 and 1960), these lagoons probably supported a limited euryhaline biota, with brackish water elements appearing temporarily during periods of fresh water accumulation. The biology of these variable lagoons has undoubtedly been altered by their history of secondary effluent discharge. At present, sewage enters the Los Penasquitos and Del Mar lagoons in ditches from treatment plants located within one mile of the lagoons. In contrast, the sewage entering San Elijo Lagoon originates as effluent discharged into the Escondido Creek approximately eleven miles upstream. The effluent entering Batiquitos Lagoon now comprises a relatively small volume of irrigation runoff and overflow from a sewage effluent storage dam. However, extensive sludge beds still exist in the lagoon from an earlier period of greater sewage discharge. Most of these polluted lagoons presently support an impoverished aquatic fauna comprising a few species of fish and large populations of Tubificidae, chironomids and ostracods. The phytoplankton is usually dominated by unicellular or colonial green algae, several species of which commonly number well over 100,000 cells/ml during bloom periods. Los Penasquitos Lagoon forms an exception to this general picture. This lagoon has been periodically opened by artificial means since 1966; tidal flushing for approximately nine months of each year has subsequently allowed the establishment of a moderately diverse marine biota.

### *Methods of Nutrient Analysis*

Surface water samples were collected in 100 ml polyethylene bottles and were frozen within one to four hours after collection. Analyses for ammonia, nitrite, nitrate and orthophosphate on unfiltered samples were carried out with a Technicon AutoAnalyzer, using a modification of the techniques of Strickland and Parsons (1968), as described by Bradshaw and Spanis (1971).

### *Results of Nutrient Analyses*

The horizontal distribution of nutrients in Mission Bay (Figure 2) and in San Elijo Lagoon (Figure 3) illustrate typical late-summer nutrient profiles of an unpolluted and heavily polluted lagoon, respectively.

Mission Bay is a tidally-flushed lagoon receiving an insignificant sewage input, and thus can be considered as representing the background nutrient levels of an open lagoon. The phosphate levels were generally low (0.3–1.2 μg-at P/l), although occasional higher values (up to 6 μg-at P/l were found. Nitrate and nitrite levels were also uniformly low (< 2.5 μg-at N/l). In contrast, ammonia values were relatively high and variable, with a total range of 17–720 μg-at N/l. The two extremely high ammonia values appear atypical and comparable values were found in no other lagoons.

Figures 3 and 4 show the distribution of nutrients in San Elijo Lagoon and in Escondido Creek below the entry point of the sewage effluent. This lagoon is open for only one to two months of each year following winter flooding. Between these major openings, the lagoon is usually closed except for sporadic short-term artificial openings (2–7 days duration).

Approximately $3 \times 10^6$ gals/day of secondary sewage effluent enters the creek from the City of Escondido, 14 miles inland; roughly two-thirds of this reaches the lagoon 11 miles downstream. Above the sewage outlet, the inorganic nutrient levels of the creek were low ($NO_3$-N, $NO_2$-N and $PO_4$-P values were < 1.5 μg-at/l; $NH_3$-N was 8 μg-at/l). The sewage entry was marked by a moderate increase in ammonia (25 μg-at N/l) and a dramatic rise in phosphate (700 μg-at P/l). The first 3.5 miles downstream from the sewage outlet were characterized by a decrease of approximately 50% in phosphate, and a relatively moderate increase in inorganic nitrogen levels. Between 3.5 and 5 miles downstream, however, ammonia and nitrite levels soared rapidly, reaching peak values of 8000 and 150 μg-at N/l, respectively. Phosphate and nitrate levels also increased to lesser peaks in this region.

The creek below this area is inaccessible for sampling, but the nutrient values at stations 10 and 11 miles downstream indicated a marked decrease in ammonia and nitrite, a lowering of phosphate, and a rise in nitrate along this stretch. Approximately 12 miles downstream from the sewage outlet, the creek enters the shallow upper reaches of San Elijo Lagoon. Within the lagoon, ammonia and nitrite levels remained

**TABLE 1**
**Summary of Lagoon Characteristics**

| | Type of Lagoon | Effluent Discharge Rate (cu. ft. $\times 10^3$/day) | Type of Effluent | Lagoon Volume at MHHW (cu. ft. $\times 10^6$) | Tidal Prism (cu. ft. $\times 10^6$) | Salinity Range °/°° | Nutrient Concentration Factor[3] |
|---|---|---|---|---|---|---|---|
| Mission Bay | Open | <0.134 | Untreated | 1,260 | 456 | 32–35 | $0.147 \times 10^{-6}$ |
| Agua Hedionda | Open | <0.134 | Untreated | 81 | 30 | 32–35 | $2.23 \times 10^{-6}$ |
| San Diego Bay | Open | 33.4 | Untreated | 15,000 | 3,000 | 32–35 | $5.63 \times 10^{-6}$ |
| Los Peñasquitos | Variable[1] | 133.7 | Secondary | 2.8 | 0.7 | 15–40 | $9.55 \times 10^{-2}$ |
| Buena Vista | Closed | 0.669 | Irrigation | 28.7 | 0[2] | 2–5 | $0.64 \times 10^{-2}$ |
| Batiquitos | Variable | 3.1 | Secondary & irrigation | 17.4 | 0.3[2] | 4–27 | $4.6 \times 10^{-2}$ |
| San Elijo | Variable | 267.4 | Secondary | 69.9 | 0.6[2] | 2–14 | $91.5 \times 10^{-2}$ |
| Del Mar | Variable | 26.7 | Secondary | 5.5 | 0.2[2] | 5–55 | 1.27 |

[1] Normally kept open artificially and thus treated as open lagoon for calculation of nutrient concentration factor.
[2] Normally closed and thus tidal prism is effectively zero.
[3] Patio of concentration of pollutant in lagoon to concentration of pollutant in sewage (see text for details).

uniformly low. However, nitrate reached a maximum peak of 325 µg-at N/l near the creek entrance, and phosphate increased to a minor peak of 200 µg-at P/l in the upper reaches of the lagoon. In contrast, at the lagoon entrance, all nutrient levels were low (< 5 µg-at/l), suggesting that the broad shallow lagoon acts as an effective nutrient filter.

In order to compare the nutrient levels of the various types of lagoons in a meaningful way, it was necessary to relate the effluent discharge rate for each lagoon to the physical factors (tidal prism, lagoon volume etc.) of each lagoon. A highly simplified mathematical model of lagoon effluent dilution was constructed (see Appendix for details) and from this model, the ratio of pollutant concentration in a lagoon ($C_L$) to pollutant concentration in the effluent ($C_E$) was calculated. We have called this ratio the "nutrient concentration factor."

For open lagoons, a steady state condition between effluent influx and tidal removal was assumed, and the nutrient concentration factor was calculated from the

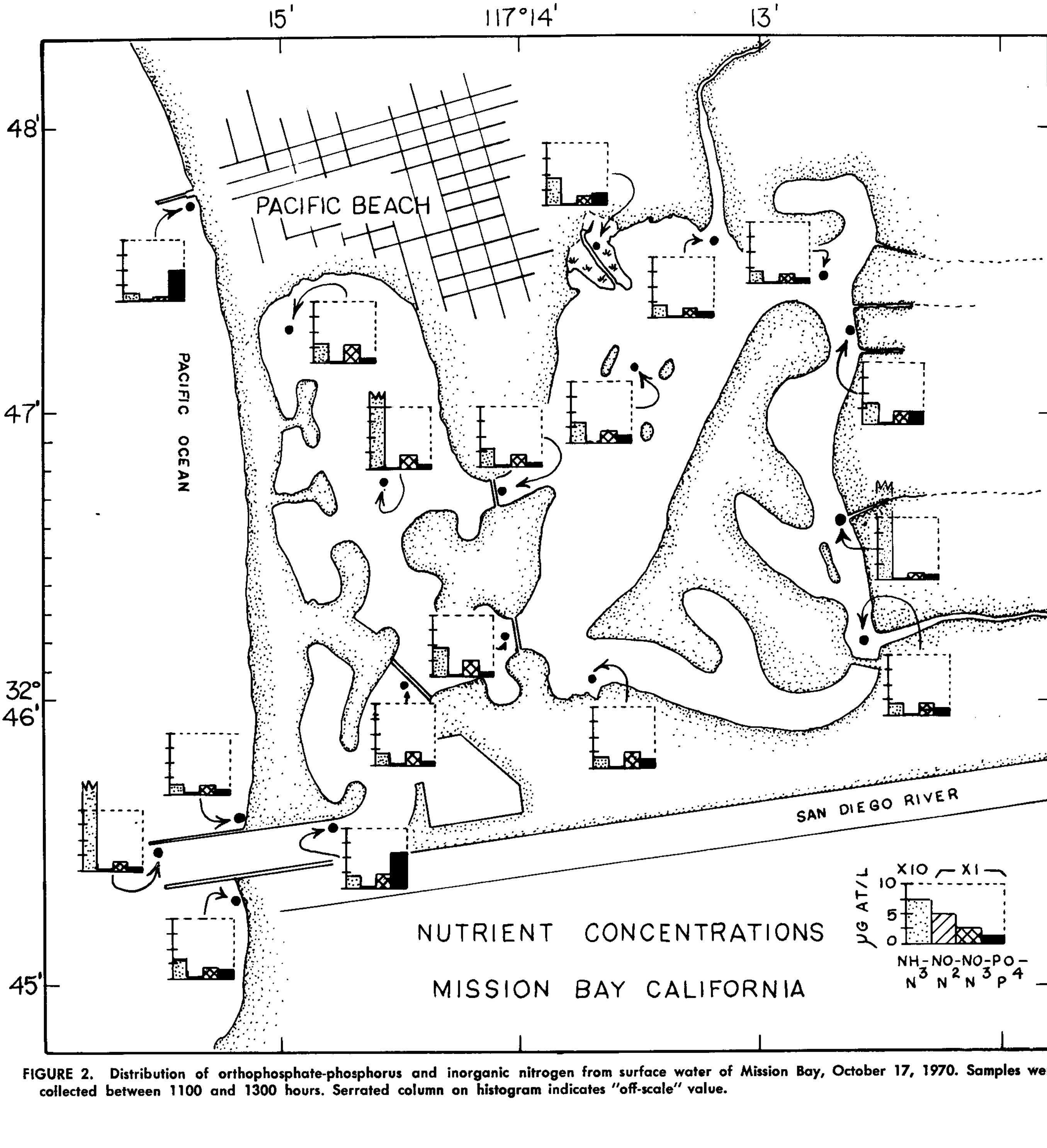


**FIGURE 2.** Distribution of orthophosphate-phosphorus and inorganic nitrogen from surface water of Mission Bay, October 17, 1970. Samples were collected between 1100 and 1300 hours. Serrated column on histogram indicates "off-scale" value.

equation $\frac{C_L}{C_E} = \frac{R_E}{2T}$, where $R_E$ is the rate of effluent discharge and T is the tidal prism. For a closed lagoon, the assumption was made that flood water flushes the lagoon of accumulated nutrients once a year, and that the concentration of pollutant in the lagoon water at the time of closing was very small relative to that in the incoming effluent. The nutrient concentration factor was then calculated as $\frac{C_L}{C_E} = \frac{R_E \times N}{V_L}$, where N is the number of days after closing, and $V_L$ is the volume of the lagoon. It was assumed that evaporation from the closed lagoon was balanced by effluent inflow, an assumption that is supported by casual observations.

The mean value and range of phosphate for each San Diego County lagoon and for the nearshore coastal water is shown in Figure 5. A positive correlation is apparent between the mean phosphate values and the nutrient concentration factor. The phosphate levels of those open lagoons which have relatively large tidal prisms and volumes are clustered around a

TABLE 2

**Summary of Nitrite and Nitrate Data**

| Lagoons | Number of stations | $NO_2$-N (µg-at/l) | $NO_3$-N (µg-at/l) |
|---|---|---|---|
| Mission Bay | 11 | 0.10– 0.22, $\bar{X}$ = 0.15 | 1.4– 2.9, $\bar{X}$ = 1.9 |
| Agua Hedionda | 6 | 0.05– 0.07, $\bar{X}$ = 0.05 | 0.5–31.0, $\bar{X}$ = 0.7 |
| San Diego Bay | 12 | 0.10– 0.50, $\bar{X}$ = 0.21 | 0.7– 2.0, $\bar{X}$ = 1.5 |
| Los Peñasquitos | 5 | 0.07– 1.40, $\bar{X}$ = 0.30 | 0.2–21.5, $\bar{X}$ = 2.5 |
| Buena Vista | 5 | 0.05– 0.10, $\bar{X}$ = 0.05 | 0.5– 0.6, $\bar{X}$ = 0.5 |
| Batiquitos | 5 | 0.10–10.0 , $\bar{X}$ = 2.8 | 0.6–26.0, $\bar{X}$ = 1.3 |
| San Elijo | 6 | 0.01– 0.05, $\bar{X}$ = 0.03 | 0.1–1.0(–325), $\bar{X}$ = 0.36 |
| Del Mar | 3 | 0.70– 0.85, $\bar{X}$ = 0.80 | 0.7– 1.7, $\bar{X}$ = 1.2 |
| *Beaches* | 13 | 0.05– 0.30, $\bar{X}$ = 0.15 | 0.5– 2.2, $\bar{X}$ = 1.0 |

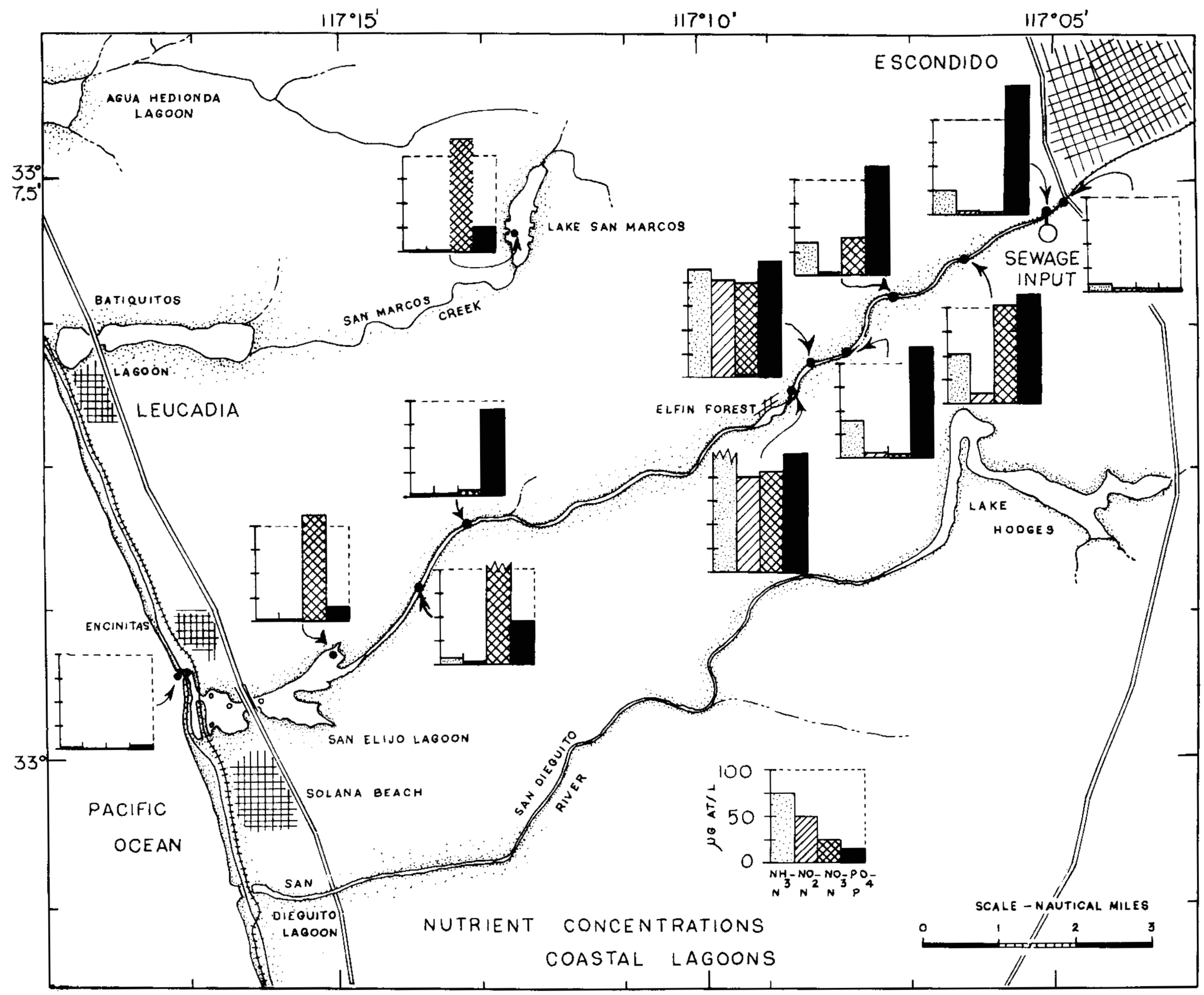


**FIGURE 3. Distribution of orthophosphate-phosphorus and inorganic nitrogen from surface water of San Elijo Lagoon and Escondido Creek, August 23, 1970. Samples were collected between 1530 and 1900 hours. Serrated column on histogram indicates "off-scale" value.**

mean value of 1 μg-at P/l. These values are similar to those found in the nearshore ocean water just off the local beaches. In contrast, the mean value for Los Penasquitos, an open lagoon with a small tidal prism, and relatively large effluent discharge rate, is approximately forty times greater than the mean of the other open lagoons. The mean phosphate values for the closed lagoons show a general increase with increasing nutrient concentration factor.

Figure 6 summarizes our data for ammonia levels in the lagoons and nearshore waters. The mean values show a much higher degree of scatter than those of phosphorus and we could find no obvious correlation with effluent dilution or effluent volume.

The means and ranges of nitrite and nitrate are shown in Table 2. It is evident that, with the exception of one station in San Elijo (where nitrate = 325 μg-at N/l), the nitrate and nitrite values were generally low in both polluted and unpolluted waters, and showed no marked correlation with effluent discharges.

## DISCUSSION

On the basis of the results of our preliminary study, we tentatively suggest that two important generalizations can be made concerning the values of inorganic nutrients found in the lagoons of San Diego County. Firstly, orthophosphate appears to be a relatively good

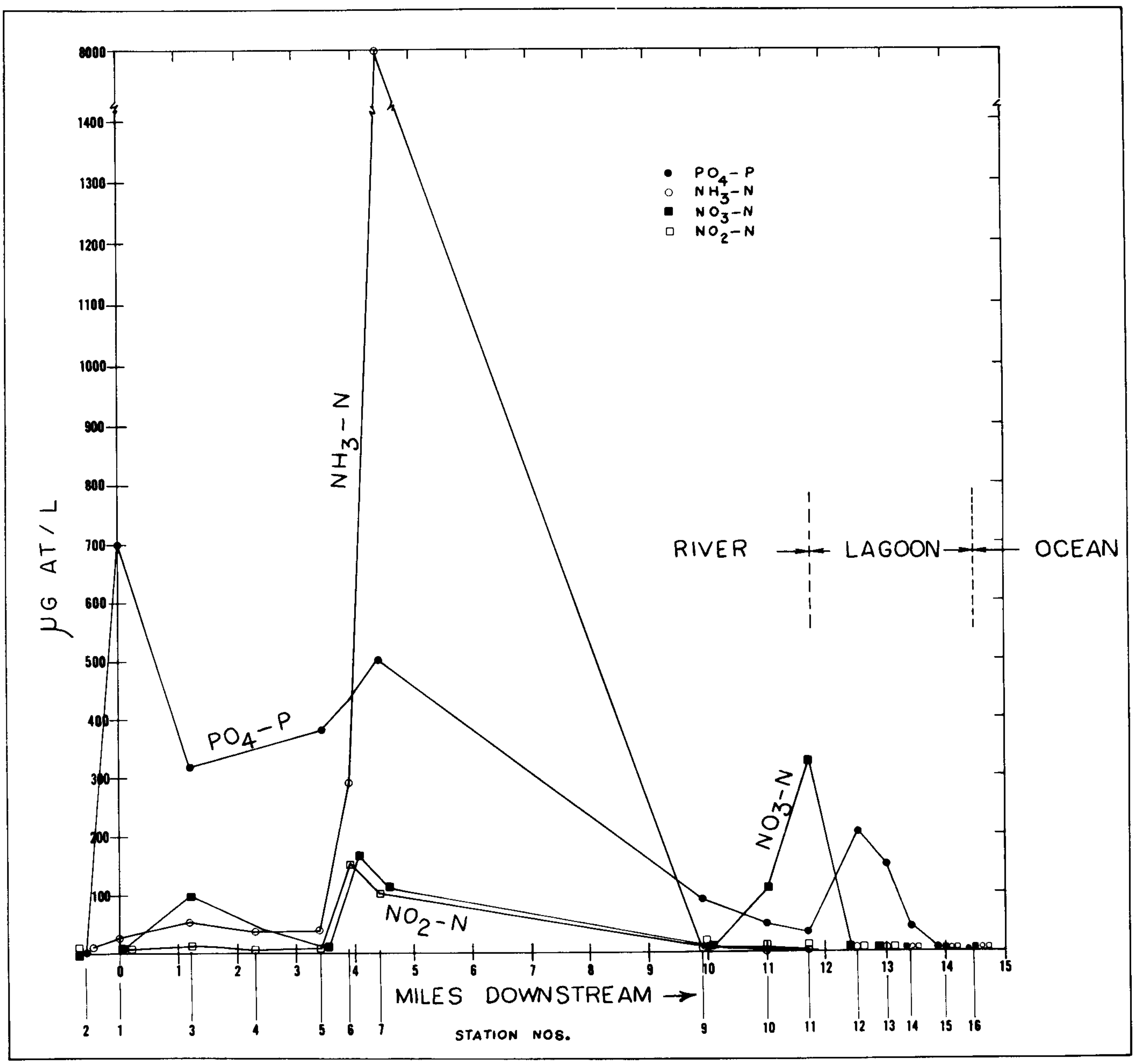


FIGURE 4. Distribution of data shown in Figure 3, plotted against distance downstream from point of effluent discharge.

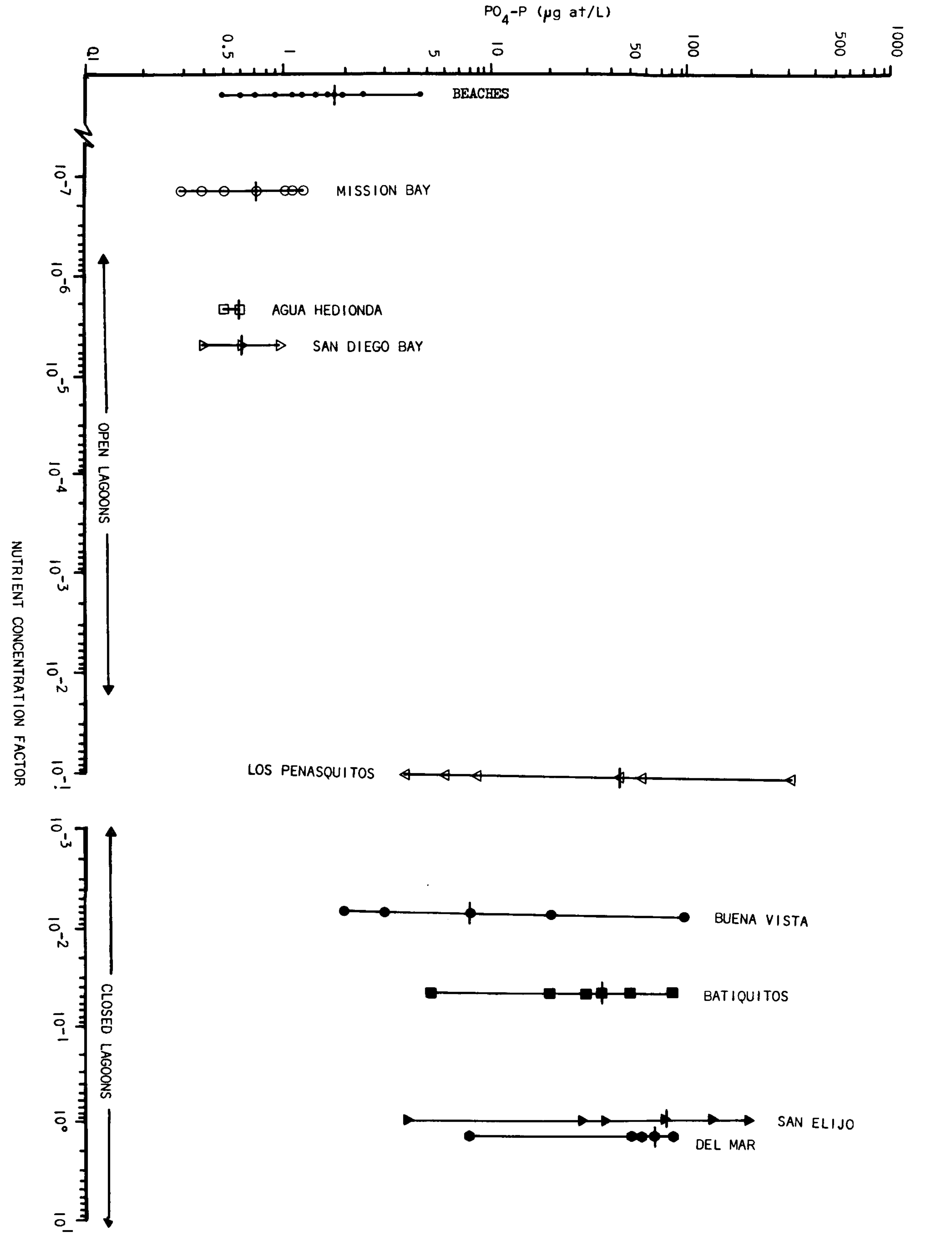


**FIGURE 5.** Summation of orthophosphate-phosphorus data from San Diego County lagoons and nearshore waters, Fall, 1970. Horizontal lines indicate mean values. Number of stations at each locality is shown in table 2.

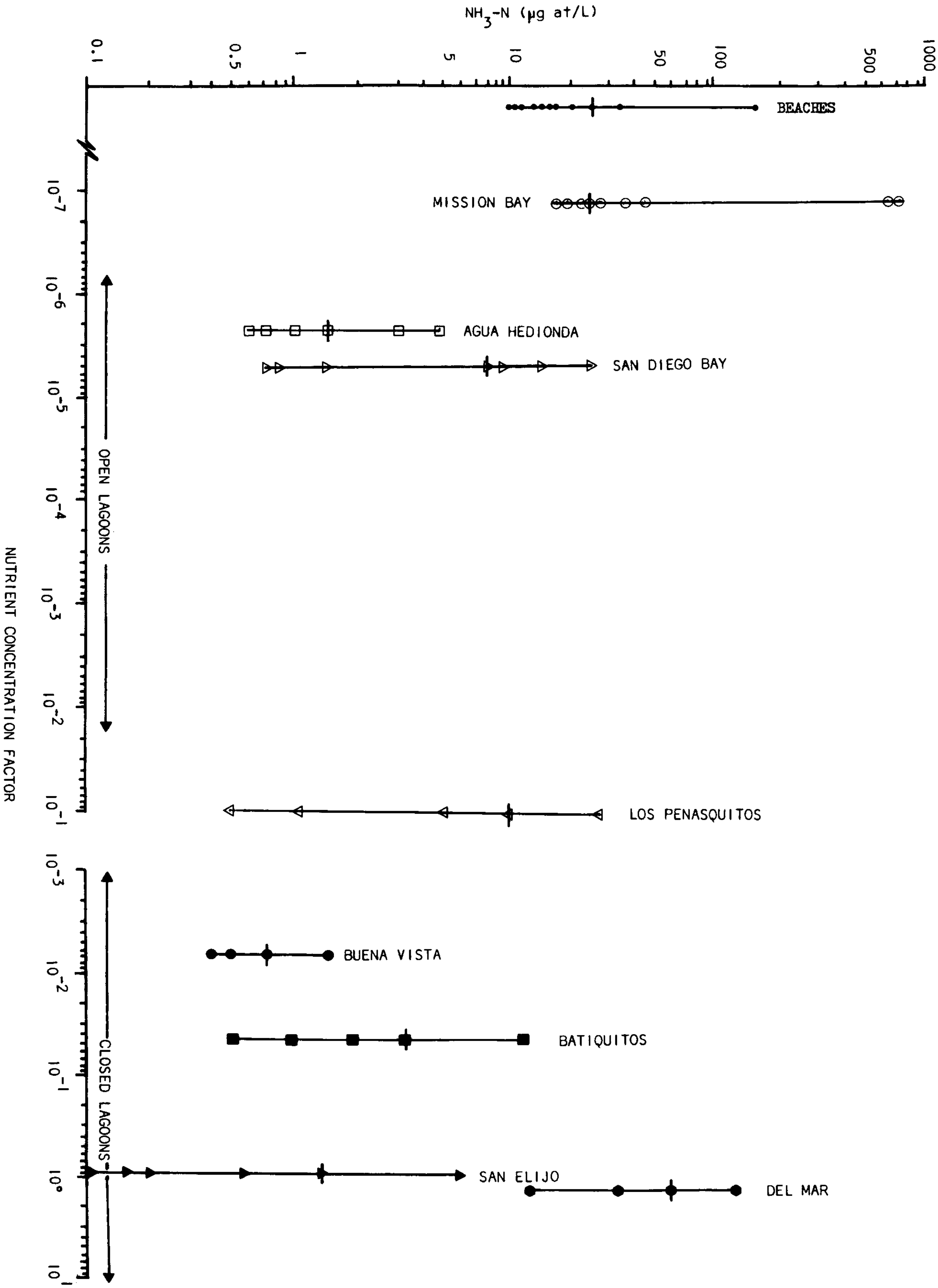


FIGURE 6. Summation of ammonia-nitrogen data from San Diego County lagoons and nearshore waters, Fall, 1970. Horizontal lines indicate mean values. Number of stations from each locality is shown in table 2.

indicator of nutrient enrichment in these coastal lagoons. This nutrient is relatively easy to measure and is far less subject to atmospheric contamination or loss than ammonia. In the lagoon ecosystems, orthophosphate appears to remain in excess of phytoplankton demands and thus seems less subject to sporadic depletion with algal blooms than does inorganic nitrogen. This observation is supported by the work of Ryther and Dunstan (1971) and Ketchum (1969) in the estuaries on the east coast of the United States. Although absorbed phosphate may be released from the lagoon muds when the overlying water is anaerobic (Mortimer, 1941), this is probably not an important factor in our shallow lagoon waters which are usually moderately or well oxygenated, and in which nighttime periods of oxygen depletion are usually brief (Carpelan 1969). To provide a complete picture of the phosphate budget in the lagoon ecosystem, it would be necessary to measure dissolved organic and particulate phosphate in addition to orthophosphate, both in the water and in the sediments. However, our data suggests that inorganic phosphate measurements of the water alone can serve as a useful estimate of excess nutrient loading.

In contrast to inorganic phosphorus, the various forms of inorganic nitrogen measured by us did not show a clear-cut relationship to sewage effluent volume or dilution during the time of study. The uniformly low nitrate and nitrite levels suggest that these ions are limiting nutrients and are rapidly depleted by phytoplankton. A similar conclusion for the coastal waters of the United States east coast was reported by Ryther and Dunstan (1971). We have some evidence that a dramatic inorganic nitrogen depletion may occur within a distance of a few thousand feet when the effluent enters a shallow, sluggish-moving stretch of lagoon or creek water. For example, in San Elijo, nitrate fell from a maximum value of 325 to 1 μg-at N/l between stations 11 and 12; in the Del Mar Lagoon, nitrate dropped from 200 to 4.4 μg-at N/l within a distance of approximately 1000 feet of the broad shallow creek that conveys the effluent from the sewage oxidation pond to the lagoon. In general ammonia levels also showed a rapid decrease downstream of the effluent entry point, but sporadic high

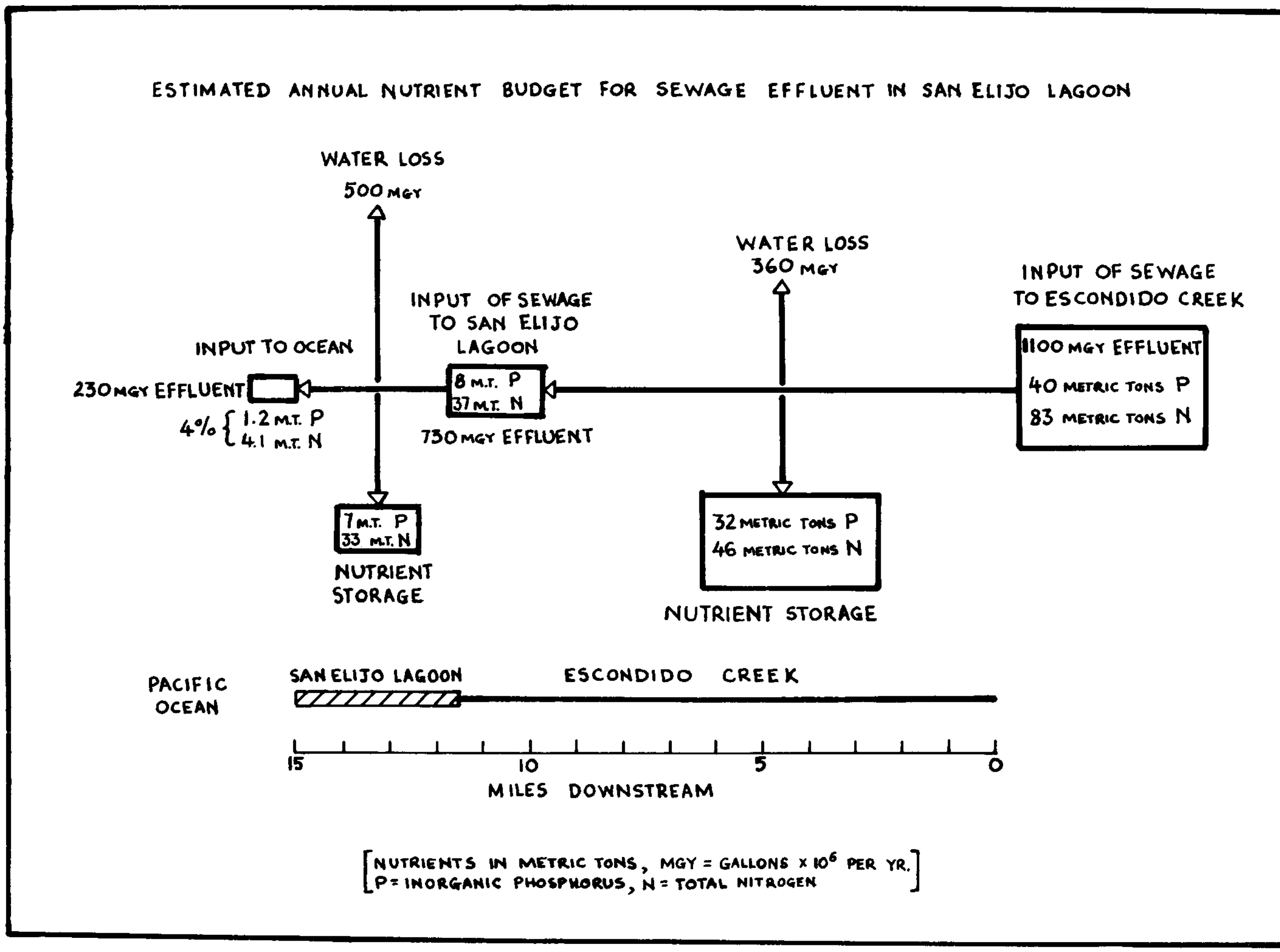


**FIGURE 7.** Estimated annual budget for sewage nutrients in Escondido Creek and San Elijo Lagoon.

values in both the polluted lagoons and the relatively unpolluted nearshore and open lagoon waters suggest that the factors governing ammonia uptake and regeneration are highly complicated.

The second generalization that we wish to make is that the broad, shallow lagoons in North San Diego County act as nutrient filters and thus normally prevent all but a fraction of the original effluent nutrient load from reaching the nearshore waters. Using data from Gannon (1967) and the WQCB records for Escondido Creek from 1964 to 1970, we have calculated a rough annual nutrient budget for orthophosphate-phosphorus and total nitrogen for San Elijo Lagoon (Figure 7).

Using an average daily effluent discharge rate of $3 \times 10^6$ gallons, a mean total nitrogen value of 20 mg N/l and a mean inorganic $PO_4$ concentration of 29 mg $PO_4$/1, we estimated an annual nutrient input into Escondido Creek of 83 metric tons of nitrogen and 40 metric tons of inorganic phosphorus. Approximately 10 miles downstream, one mile before the creek enters the lagoon, the average N and $PO_4$ concentrations were 13.8 and 8.9 mg/l, respectively, indicating that approximately 80% of the phosphate and 56% of the nitrogen were removed in the creek. (The creek flow at this station is approximately two-thirds that at the point of effluent entry.)

Although there is considerable horizontal and seasonal variation in nutrient levels within the lagoon, a reasonable average nutrient value would be 4.0 mg/l $PO_4$ and 4.8 mg/l N. This means that approximately 80% of the phosphorus and 90% of the nitrogen entering the lagoon from the creek is trapped in the four mile stretch of shallow lagoon channels and mudflats. Using an annual evaporation rate for the lagoon of $500 \times 10^6$ gallons (based on data from Lake Hodges, ten miles from the lagoon), and a creek inflow rate of $730 \times 10^6$ gallons/year, we estimate that 230 $\times 10^6$ gallons of effluent finally enter the ocean each year. This would contribute an annual load of approximately 1.2 metric tons of inorganic phosphorus and 4.1 metric tons of nitrogen, a mere $\pm$ 4% of the original sewage load. Compared with an estimated daily discharge rate of 90 metric tons of nitrogen and 30 metric tons of phosphorus into the New York bight (Ryther and Dunstan, 1971), this appears to be an insignificant contribution to the nearshore waters.

In conclusion, it can be stated that the present rates of effluent discharge in the lagoons of San Diego County make little impact on the nearshore ocean water. However, the trapping of nutrients within the lagoons has an obviously deleterious effect on the estuarine biota, which is compounded in the variable lagoons by the stresses imposed by great salinity fluctuations.

## APPENDIX

We extend our sincere thanks to Tanya M. Atwater, John D. Mudie, John M. Parks and Walter R. Schmitt, all of Scripps Institution of Oceanography, for their elucidation of the mathematics of effluent dilution.

The "nutrient concentration factor" used in this report was derived in the following way:

$C_L$, $C_E$ and $C_T$ are the concentrations of a pollutant in lagoon, effluent and tidal prism. $V_L$ is the volume of water in the lagoon. $R_E$, 2T and $R_e$ are the daily rates of water added or removed from the lagoon by effluent, tide and evaporation.

The amount of pollutant at time t will be

$$(C_LV_L)_t = (C_LV_L)_{t_1} + \int_{t_1}^{t}(C_ER_E + 2C_TT)dt - \int_{t_1}^{t} C_L(2T + R_E - R_e)dt$$

where it is assumed that the only additions to the lagoon are by the effluent and the tides, and the only removal is by outflow at the lagoon entrance and evaporation. Mixing is assumed to be perfect so that all water in the lagoon and flowing out of the lagoon has a concentration of $C_L$.

*Steady State Situation.* Tides are assumed to remove as much pollutant as is being added by the effluent, so that the amount of pollutant in the lagoon is constant, i.e. $(C_LV_L)_t = (C_LV_L)_{t_1}$.

Thus $\int_{t_1}^{t} C_ER_Edt + \int_{t_1}^{t} 2C_TTdt = \int_{t_1}^{t} C_L(2T + R_E - R_e)dt$, and differentiating with respect to t gives $C_ER_E + 2C_TT = C_L(2T + R_E - R_e)$. Assuming that the concentration in the incoming tide, $C_T$, is small compared to $C_L$, and that the rate of effluent addition, $R_E$, and evaporation rate, $R_e$, are small compared to the tidal prism, T,

then $C_ER_E = C_L2T$, and $\frac{C_L}{C_E} = \frac{R_E}{2T}$.

This is the pollutant concentration ratio used to calculate the "nutrient concentration factor" for open lagoons.

*Non-steady State Situation.* Here the lagoon mouth closes at time $t_1$ and thereafter all pollutant added by the effluent remains in the lagoon. There is no tidal prism, i.e. T = 0. Evaporation is assumed to balance water added by effluent, i.e. $R_E = R_e$, and the concentration of pollutant in the lagoon when the mouth closes is assumed to be small, so that $(C_L)_{t_1} = 0$.

Thus $(C_LV_L)_t = \int_{t_1}^{t} C_ER_E\, dt$.

and at time t = N days after $t_1$, then $C_LV_L = C_ER_EN$,

and $\frac{C_1}{C_E} = \frac{R_EN}{V_L}$.

This is the pollutant concentration ratio used to calculate the "nutrient concentration factor" for closed lagoons, taking N = 240 for San Elijo, and N = 263 for the other closed lagoons.

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# LIPIDS IN THE MARINE ENVIRONMENT

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## INTRODUCTION

Lipid utilization in the marine environment has been the subject of investigation in our laboratory. We have studied the composition and metabolism of lipids in members of a planktonic marine food chain: diatoms, copepods, and anchovies and sardines. We have discovered polyunsaturated hydrocarbons in diatoms and other marine algae and large amounts of wax esters, a reserve fuel for many copepods, were recognized during the course of our work (Lee *et al.*, 1970 a, 1970 b). A wax ester is a fatty acid esterified to a long chain alcohol, while a triglyceride is composed of fatty acids esterified to glycerol. Triglycerides, which are the normal reserve lipid in most animals, are used only for short term fuel needs in the copepods. The wax esters are used for long term fuel needs, and a special wax ester lipase is used for the mobilization of wax esters. Starvation experiments with bathypelagic copepods and seasonal studies of the lipid composition of Arctic copepods have demonstrated the important role of wax esters as reserve fuels during starvation and nutritional stress. The copepod, *Calanus helgolandicus,* was cultured on a known concentration of phytoplankton (expressed as μg carbon per liter) in the laboratory (Paffenhöfer, 1970), and the results of lipid determinations were compared with values from field-collected copepods. We have also measured the lipid changes during the life cycle of *Calanus helgolandicus* and *Euchaeta japonica*. Studies on the food of sardines and anchovies have shown that the major food was copepods (Hand and Berner, 1959; DeCiechomski, 1967; Haushi, 1967; Baxter, 1967; Nakamura and Wilson, 1970). We were concerned with the metabolism of wax esters and the transport of lipids in the blood of these fish.

Besides our findings on "natural" marine lipids, we have also included in this report our preliminary results on the uptake and discharge of petroleum hydrocarbons by marine invertebrates.

## METHODS

### *Field Collections*

Copepods from several depth intervals were collected using bongo nets of .333 mm mesh and a 3-m Isaacs-Kidd midwater trawl, on two cruises of the R/V MELVILLE about 450 km off the coast of southern California (31°N, 119°W). The live copepods were sorted as to stage or sex and taxonomic group aboard the ship, and lipid extraction was carried out as described below. Specimens of *Euchaeta japonica* were collected in Indian Arm Inlet near Vancouver, British Columbia. Copepods from the Arctic station T-3, were frozen and kindly sent to us by the Arctic Research Program of the University of Southern California. The sardines and anchovies were obtained from bait barges in San Diego, California.

### *Copepod Rearing*

The method used for rearing *Calanus helgolandicus* has been described by Paffenhöfer (1970), while the rearing of *Euchaeta japonica* was described by Lewis and Ramnarine (1969).

### *Lipid Analysis*

The lipids from algae, copepods, and fish were extracted in chloroform-methanol (2:1 v/v) and dried under nitrogen. The lipid was weighed, and for those experimental groups from which more than 6 mg were available, the lipid was fractionated on a silicic acid column, eluting the different lipid classes with solvents of increasing polarity as described by Nevenzel *et al.* (1965), and then each fraction was weighed. The procedure for analyzing the different lipid fractions (hydrocarbons, wax esters, triglycerides, free fatty acids, sterols, and phospholipids) by gas-chromatography is given in the paper by Lee *et al.* (1971b). When less than 6 mg of total lipid was available, the lipids were separated by thin-layer chromatography, and the amount of different types of lipid was determined spectrophotometrically by the procedure of Armenta (1964) using acid dichromate digestion and measurement at 250 mμ.

### *Petroleum Uptake*

Mineral oil, 1, 2, 3, 4, -tetrahydronaphthalene and $^{14}$C-heptadecene were used as hydrocarbon substrates. Approximately 2 gm of diatomaceous earth (Celite) were added to a 100 ml beaker containing 75 ml of sea water. The mixture was sonicated for several minutes, and the sonicated oil and water mixture was added to a 10 liter aquarium containing the mussel, *Mytilus californianus*. Some experiments were performed without sonication so that an oil slick was formed on the surface of the water. Mussels were taken out at various times, extracted with chloroform: methanol (2:1 v/v), and the lipid was fractionated using a silicic acid column in order to obtain the hydrocarbon fraction. The hydrocarbon fraction was weighed and analyzed by gas-liquid chromatography. For the $^{14}$C-heptadecene experiments the mussel extraction mixture was assayed by counting in a liquid scintillation counter.

## RESULTS

### 1. Algae

Since diatoms and dinoflagellates were used as food for rearing *C. helgolandicus,* we carried out extensive analysis of diatom and dinoflagellate lipids (Lee *et al.,* 1970c, 1971a). No wax esters were detected in these marine algae, but a unique lipid of most marine algae was identified as a 21:6 hydrocarbon (21 carbon atoms and 6 double bonds). This hydrocarbon occurs in diatoms, dinoflagellates, brown algae, euglenids, a few marine green algae, and cryptophytes (Table 1). *C. helgolandicus* adults showed no trace of this 21:6 hydrocarbon, so that excretion or metabolism of this hydrocarbon must occur. On the other hand, *Euchaeta japonica* and *Rhincalanus nasutus* did contain the hydrocarbon, probably by storing it from their algal or small zooplankton food. Blumer *et al.* (1970a) recently reported the occurrence of the 21:6 hydrocarbon in *Rhincalanus* and described its distribution in marine phytoplankton. The extent to which the 21:6 hydrocarbon occurs in higher members of the food chain needs further investigation.

TABLE 1

**The Percent Lipid and Hydrocarbon in Algae**

| Organism | Lipid (Percent of dry weight) | Hydro-carbon (Percent of lipid) | 21:6 Hydro-carbon (percent of total hydro-carbon) |
|---|---|---|---|
| Green Algae—Chlorophyta | | | |
| *Platymonas* sp. | 6.6 | 7.8 | 82 |
| *Dunaliella tertiolecta* | ---- | -- | absent |
| Euglenids—Euglenophyta | | | |
| *Euglena gracilis* | 10.1 | 5.2 | 1 |
| *Eutreptia viridis* | 18.8 | 4.2 | 12 |
| Dinoflagellates—Pyrrhophyta | | | |
| *Gymnodinium splendens* | 16.2 | 0.4 | 80 |
| *Exuviaella cassubica* | 5.2 | 3.7 | 20 |
| *Peridinium sociale* | 16.2 | 0.9 | 80 |
| Cryptomonads—Cryptophyta | | | |
| *Crytomonas ovata* | 18.3 | 12.3 | 20 |
| *Rhodomonas lens* | 16.8 | 11.7 | 45 |
| Diatoms—Bacillariophyta | | | |
| *Chaetoceros curvisetus* | 9.1 | 13.2 | 90 |
| *Cylindrotheca fusiformis* | 11.8 | 3.7 | 90 |
| *Skeletonema costatum* | 9.2 | 15.0 | 90 |
| Golden Algae—Chrysophyta | | | |
| *Isochrysis galbana* | 26.0 | 4.6 | 90 |
| *Prymnesium parvum* | 4.2 | 7.6 | 80 |
| Brown Algae—Phaeophyta | | | |
| *Ectocarpus* sp. | 8.7 | 7.6 | 85 |
| *Laminaria* sp. | -- | 5.8 | 30 |

### 2. Copepods

There are some major differences between the nature of lipids in terrestrial and marine organisms. In most terrestrial animals, triglycerides serve as the only type of storage lipid. In starvation experiments with marine calanoid copepods, we found that triglycerides are only used for short-term fuel needs (Table 2 and 3), and that wax esters are the major metabolic reserve fuel. Also, in contrast to the saturated wax esters of terrestrial plants and animals, the copepod wax esters have appreciable amounts of polyunsaturated acids, and copepods living near the sea surface contain polyunsaturated alcohols (Tables 4 and 5). Wax esters of terrestrial organisms may provide structural or protective properties, whereas the waxes of marine copepods are utilized for metabolism and buoyancy regulation.

TABLE 2

**Starvation Experiment with Females of the Bathypelagic Copepod *Gaussia Princeps***

The copepods were placed in the dark in plastic containers with about 10 liters of sea water previously cooled to 5°C and passed through 35 μ mesh nylon netting. Values are expressed as weight percent of total lipid.

| Lipid Type | Hours of Starvation | | |
|---|---|---|---|
| | 0 | 80 | 120 |
| Hydrocarbons | 1 | 1 | 2 |
| Wax esters* | 49 | 64 | 61 |
| Triglycerides | 18 | 9 | 2 |
| Polar lipids† | 15 | 10 | 23 |
| Phospholipids | 17 | 16 | 22 |
| Total lipid (percent of body dry weight) | 26 | 22 | 23 |

* Includes a trace of sterol esters.
† Includes sterols, free fatty acids, free alcohols, and pigments.

TABLE 3

**Starvation Experiment with Females of the Copepod *Euchaeta Japonica* Collected at Indian Arm Inlet, British Columbia in Net Hauls from 200m**

The copepods were kept in seawater at 10°C. Values are expressed as weight percent of total lipid.

| Lipid Type | Hours of Starvation | |
|---|---|---|
| | 0 | 168 |
| Hydrocarbons | 2 | 2 |
| Wax esters* | 54 | 68 |
| Triglycerides | 18 | 2 |
| Polar lipids† | 12 | 4 |
| Phospholipids | 14 | 20 |
| Total Lipid (percent of body dry weight) | 41 | 39 |

* Includes a trace of sterol esters.
† Includes sterols, free fatty acids, free alcohols, and pigments.

A study of the changes of lipid composition during the life cycle of *Calanus helgolandicus* and *Euchaeta japonica* has indicated some important differences between these two copepods. In *C. helgolandicus* the eggs, the nauplii, and copepodite-I do not contain wax esters, but an increasing amount of lipid and proportion of wax ester occurred from copepodite-III to copepodite-V (Table 6). *E. japonica* showed sizeable amounts of wax esters in the eggs and also in the first naupliar stage, but a decreasing amount of lipid and wax esters was found in the remaining naupliar stages and in the first copepodite stage. An increase in lipid and proportion of wax was found from copepodite-III to V (Table 7). The largest quantity of lipid and wax esters was obtained in the copepodite-V of all species of copepods examined (Table 6 and 7, and unpublished work.)

Two cruises aboard the R/V MELVILLE enabled us to collect copepods from various depths down to 2500 m. Preliminary results are shown in Table 8. The deep-water copepods (below 750 m) appeared to have a higher proportion of wax ester content (expressed as a per cent of the total lipid) than did the near-surface copepods. The copepods collected at 2000 m showed no significant differences in total lipid or wax ester content from copepods collected at 1000 m. Why the bathypelagic copepods should have a higher lipid and wax ester content is an intriguing question. The high lipid content appears to function as a reserve fuel during long periods of nutritional stress, but the reason for the replacement of triglyceride by wax esters in copepods as the depth of the habitat increases or the temperature decreases is not easily answered. We have evidence that there is a slower rate of utilization of wax esters relative to triglycerides. Analysis of zooplankters other than copepods and micronekton captured in mid-water trawls taken to 2500 m also showed the presence of appreciable amounts of wax esters (Table 9).

At higher latitudes, such as the Arctic or the North Pacific off British Columbia, we have noted that the near-surface copepods (upper 200 m) have both high lipid and wax ester content. In Table 10 we report the seasonal change in lipid composition of two Arctic copepods, *Calanus hyperboreus* and *Metridia longa,* which were obtained at monthly intervals (November, 1969 to October, 1970) from the Arctic Island T-3. The storage of lipid occurred during the months of July, August, September, and October, which is correlated with the phytoplankton blooms in this area (English, 1961: Grainger, 1959: Marshall, 1958). During the dark winter months, these lipid reserves serve as fuels as indicated by the gradual decrease in lipid content (Table 10). *Calanus hyperboreus* has been shown by Mullin (1963) to be mainly herbivorous; the lipid reserve allows this animal to survive during the remaining 7 months of phytoplankton paucity. The females in June, which contain 30% lipid may be from a different generation than the females in July which contain 73% lipid. The females produce eggs in January and February (Conover, 1965) and would presumably not live much longer.

**TABLE 4**

**Fatty Acid Composition of Wax Esters from Several Species of Calanoid Copepods**

Values are weight % as methyl esters.

| Fatty Acid* | Species of Copepod | | | | |
|---|---|---|---|---|---|
| | *Rhincalanus nasutus* | *Gaussia princeps* | *Calanus hyperboreus* | *Calanus helgolandicus* | *Gaetanus brevicornis* |
| 12:0 | t | -- | t | -- | t |
| 12:1 | t | -- | -- | -- | t |
| 13:0 | -- | -- | -- | -- | t |
| 14:0 | 1.4 | 0.3 | 4.3 | 11.8 | 0.4 |
| 14:1 | 0.4 | -- | 0.5 | -- | 0.7 |
| 15:0 | -- | 0.2 | -- | -- | -- |
| 15:1 | -- | -- | -- | -- | t |
| 16:0 | 2.9 | 0.8 | 2.6 | 29.0 | 0.5 |
| 16:1 | 38.9 | 8.8 | 27.9 | 13.2 | 12.7 |
| 16:2 | t | t | -- | -- | 0.5 |
| 16:3 | 2.7 | -- | 1.3 | t | -- |
| 17:0 | -- | t | t | -- | -- |
| 17:1 | t | 2.6 | -- | 0.6 | -- |
| 18:0 | t | 0.3 | -- | 4.3 | 2.5 |
| 18:1 | 32.4 | 70.5 | 5.4 | 12.1 | 63.7 |
| 18:2 | 5.9 | 1.7 | 2.2 | 3.6 | 0.5 |
| 18:3 | 3.2 | 0.5 | -- | -- | -- |
| 20:0 | t | 1.8 | -- | -- | t |
| 20:1 | -- | 5.6 | 14.4 | 7.3 | 4.7 |
| 20:2 | 0.3 | -- | t | 5.1 | -- |
| 20:3 | -- | -- | -- | 0.6 | -- |
| 20:4 | 2.3 | 0.2 | 13.7 | 7.6 | -- |
| 20:5 | 9.2 | 5.8 | 23.1 | 2.0 | 11.3 |
| 22:0 | -- | -- | -- | -- | -- |
| 22:1 | -- | -- | 1.1 | -- | -- |
| 22:2 | t | 0.8 | -- | -- | 0.5 |
| 22:6 | -- | -- | 3.2 | 2.1 | 1.9 |

* Chain length: number of double bonds.

**TABLE 5**

**Long Chain Alcohol Composition of Wax Esters from Several Species of Copepods**

Values are weight % as trifluoroacetate esters.

| Alcohol* | Species of Copepod | | | | |
|---|---|---|---|---|---|
| | *Rhincalanus nasutus* | *Gaussia princeps* | *Calanus hyperboreus* | *Calanus helgolandicus* | *Gaetanus brevicornis* |
| 12:0 | t | t | t | -- | t |
| 12:1 | t | -- | -- | -- | -- |
| 14:0 | 18.8 | 7.6 | 5.5 | 1.5 | 6.7 |
| 14:1 | t | t | -- | -- | 4.6 |
| 15:0 | -- | 1.5 | t | -- | t |
| 15:1 | -- | t | t | -- | 0.1 |
| 16:0 | 52.1 | 54.9 | 61.7 | 13.0 | 44.5 |
| 16:1 | 0.7 | t | 9.6 | 1.0 | 1.0 |
| 16:2 | -- | -- | -- | -- | -- |
| 16:3 | -- | -- | -- | -- | -- |
| 17:0 | -- | -- | -- | -- | -- |
| 17:1 | -- | 3.0 | 0.8 | 1.2 | 5.2 |
| 18:0 | 15.7 | 1.2 | 0.1 | 0.8 | 1.7 |
| 18:1 | -- | 11.6 | 2.2 | 3.8 | 11.3 |
| 18:2 | -- | 0.5 | t | 0.2 | 4.3 |
| 18:3 | 3.0 | -- | -- | -- | -- |
| 20:0 | 0.9 | -- | -- | -- | t |
| 20:1 | t | 4.9 | 14.3 | 18.4 | 5.1 |
| 20:2 | 5.4 | -- | -- | -- | -- |
| 20:3 | -- | -- | -- | -- | -- |
| 20:4 | 0.3 | -- | -- | 40.9 | -- |
| 20:5 | 1.4 | -- | -- | -- | -- |
| 21:0 | -- | -- | 0.3 | -- | -- |
| 22:0 | 0.2 | -- | -- | -- | -- |
| 22:1 | 0.3 | 11.5 | 5.1 | -- | 5.2 |
| 22:2 | 0.5 | -- | -- | -- | -- |
| 22:3 | -- | -- | -- | 8.4 | -- |
| 22:4 | 0.4 | -- | -- | -- | -- |
| 22:6 | -- | -- | -- | 8.1 | -- |
| 23:1 | -- | -- | -- | -- | 2.2 |
| 24:1 | 0.4 | 3.3 | 0.1 | -- | 7.9 |
| 24:5 | -- | -- | -- | 1.7 | -- |

* Chain length: number of double bonds.

### 3. *Fish*

The manner in which the copepod wax esters are digested by sardines and anchovies was the subject of our investigation into the alteration of the lipid composition of prey by predators in a marine food chain. The first operation involves hydrolytic cleavage of the wax ester catalyzed by a wax ester lipase. The wax ester lipase activity was highest in the pyloric caecum of the anchovy. Liver, red muscle, and white muscle wax ester lipase was much less active. Wax ester lipase releases long chain alcohols, but an analysis of both sardine and anchovy blood showed an absence of long chain alcohols. The long chain alcohols may be oxidized to the corresponding fatty acids before being released into the blood. Analysis of serum lipoproteins of sardine blood (Table 11) showed large amounts of cholesterol esters.

### 4. *Uptake of Petroleum Hydrocarbons by Marine Invertebrates*

Blumer's *et al.* (1970b) recent study of oysters after an oil spill in Buzzards Bay, Massachusetts, indicated that oysters were able to take up petroleum hydrocarbons. We were interested in doing laboratory studies concerned with the uptake and discharge of petroleum hydrocarbons by various marine invertebrates. We used the mussel, *Mytilus californianus*, for our work, since it is a filter feeder easily obtained in our area. Purified paraffinic mineral oil was used in our experiments. It contained no aromatic compounds, and consisted only of straight chain, branched chain, and cycloparaffins. Uptake of a suspension of mineral oil in sea water was rapid during the first 24 hours, but no further increase was observed after 10 days of exposure to mineral oil (Table 12). Sonication of the mineral oil with Celite (diatomaceous earth) in the sea water did not increase uptake rate, nor did it increase the total amount of uptake in 48 hr. Discharge of the mineral oil was rapid and 99% of the mineral oil was discharged in 4 days after exposure to 7 liters of oil-free sea water. After exposure to oil-free sea water for 120 hr, the residual mineral oil could still be detected by gas chromatography of the hydrocarbon fraction from the mussel. Approximately 1% of the lipid of *M. californianus* is hydrocarbon. The identification of these natural hydrocarbons has not been completed, but a branched $C_{19}$, $C_{20}$, and $C_{21}$ were important natural hydrocarbons. The mineral oil hydrocarbons were quite different from natural mussel hydrocarbons, and higher boiling point components

TABLE 6

**The Changes in Wax Esters and Other Lipids During the Life Cycle of *Calanus Helgolandicus***

Fertile female *Calanus helgolandicus* were collected offshore and fed a large concentration (600μg C/liter) of *Thalassiosira fluviatilis* which caused the females to deposit their eggs. Approximately 1000 eggs were collected and placed in filtered sea water to remove diatoms and 200 eggs were allowed to become naupliar 1. Thus 200 naupliar 1 and 800 eggs were extracted for lipid analysis. Another batch of eggs was used to obtain the different copepodid stages which were fed on a mixture of *Lauderia borealis* and *Gymnodinium*.

| Stage | Lipid (percent of dry weight) | Wax Ester (percent of total lipid) | Triglyceride (percent of total lipid) |
|---|---|---|---|
| Eggs | -- | absent | 60 |
| Naupliar I | -- | absent | 15 |
| Copepodid I | -- | absent | 12 |
| Copepodid III (early) | -- | 1 | 5 |
| Copepodid III (late) | -- | 10 | 2 |
| Copepodid IV (early) | -- | 16 | 6 |
| Copepodid IV (late) | -- | 22 | 5 |
| Copepodid V | -- | 50 | 3 |
| Adult | 28 | 41 | 12 |

TABLE 7

**The Changes in Wax Esters and Other Lipids During the Life Cycle of *Euchaeta Japonica***

Females with egg-sacs were collected in vertical net hauls (0–200m) at Indian Arm Inlet near Vancouver in September, 1971. The egg-sacs were removed from the females and placed in filtered sea water. Naupliar stages 2–4 were reared in the filtered sea water. Naupliar stages 5 to copepodid II were raised in the laboratory by feeding a mixture of *Dunaliella tertolecta* and *Phaeodactylum tricornutum* (Lewis and Ramnarine, 1968). Lipid extraction and analysis were performed as described in *Methods*.

| Stage | Lipid (percent of dry weight) | Wax Ester (percent of total lipid) | Triclyceride (percent of total lipid) |
|---|---|---|---|
| eggs | 64.4 | 58 | 19 |
| eggs (late stage) | 59.1 | 50 | 17 |
| Naupliar 2 | 43.8 | 61 | 17 |
| Naupliar 3 | 30.8 | 56 | 5 |
| Naupliar 4 | 25.0 | 20 | 3 |
| Naupliar 5 | 21.2 | 15 | 1 |
| Naupliar 6 | 17.1 | 12 | 0 |
| Copepodid I | 14.2 | 9 | 0 |
| Copepodid I (field-collected) | 23.6 | 29 | 0 |
| Copepodid II | 11.6 | 12 | 0 |
| Copepodid IV (field-collected) | 31.2 | 40 | 3 |
| Copepodid V (field-collected) | 50.1 | 81 | 2 |
| Adult (field-collected) | 41.3 | 54 | 18 |

TABLE 8

**Lipid Composition of Calanoid Copepods from Various Depth Intervals Collected During Two Cruises of the R/V *Melville***

| Species | Lipid per individual (mg) | Percent lipid of dry weight | Percent triglyceride of total lipid | Percent wax ester of total lipid |
|---|---|---|---|---|
| Sample depth interval: 1–10 m | | | | |
| *Candacia* sp. | 0.02 | 9 | 11 | 1 |
| *Euchirella* sp. | 0.14 | 19 | 37 | absent |
| *Undeuchaeta* sp. | 0.16 | 21 | 30 | 1 |
| *Calanus gracilis* | 0.08 | 26 | 17 | 21 |
| *Rhincalanus nasutus* | 0.12 | 48 | 9 | 69 |
| Sample depth interval: 0–250 m | | | | |
| *Scottocalanus persecans* | 0.11 | 8 | 22 | absent |
| *Gaidius* sp. | 0.05 | 12 | 18 | 2 |
| *Pleuromamma xiphias* | 0.03 | 16 | 31 | 3 |
| *Gaetanus* sp. | ---- | 29 | 2 | 36 |
| *Eucalanus bungii* | 0.08 | 31 | 42 | 1 |
| Sample depth interval: 325–625 m | | | | |
| *Metridia princeps* | 0.10 | 12 | 4 | 41 |
| *Gaetanus unicornis* | 0.20 | 16 | 26 | 5 |
| *Undeuchaeta* sp. | 0.11 | 18 | 38 | 14 |
| *Pleuromamma* sp. | 0.08 | 19 | 32 | 2 |
| *Disseta* sp. | 0.44 | 29 | 4 | 51 |
| *Euchirella galeata* | 0.06 | 43 | 20 | absent |
| *Disseta maxima* | 1.30 | 45 | 10 | 67 |
| *Paraeuchaeta* sp. | 0.65 | 46 | 2 | 68 |
| *Euaugaptilus* sp. | 0.30 | 50 | 2 | 59 |
| Sample depth interval: 625–750 m | | | | |
| *Metridia* sp. | 0.30 | 24 | 5 | 72 |
| *Disseta* sp. | 0.20 | 27 | 4 | 69 |
| *Lucicutia bicornuta* | 0.14 | 31 | 12 | 63 |
| Sample depth interval: 750–1600 m | | | | |
| *Bathycalanus* sp. | 31.1 | 59 | 11 | 77 |
| *Heterorhabdus* sp. | 0.11 | 62 | 1 | 82 |
| Sample depth interval: 1300–2500 m | | | | |
| *Lucicutia* sp. | 0.07 | 15 | 1 | 50 |
| *Gaetanus* sp. | ---- | 47 | 4 | 62 |

of mineral oil make it easy to identify in the mussel.

Uptake and discharge rates of $^{14}C$-heptadecene by the mussel were similar to that of mineral oil (Table 13). The aromatic hydrocarbon, 1, 2, 3, 4-tetrahydronaphthalene, killed the mussels at very low concentrations, but uptake at one hundred parts per million was shown by gas chromatography of the aromatic fraction.

TABLE 9

**Various Zooplankton and Micronekton Taken in a 3-m Isaacs-Kidd Midwater Trawl from 0–2500 m**

Lipid extraction and analysis was performed as described above.

| Taxonomic group | Lipid (Percent of dry weight) | Triglycerides (Percent of total lipid) | Wax ester (Percent of total lipid) |
|---|---|---|---|
| Alciopidae sp. (Polychaeta) | 55 | 11 | 76 |
| Gammaridae (Amphipod) | 57 | 13 | 73 |
| Chaetognatha sp. A | 13 | 22 | 18 |
| Chaetognatha sp. B | 40 | 11 | 71 |
| Oegopsidae sp. (Cephalopoda) | 23 | 6 | 27 |
| *Gennadas* sp. (Mysidacea) | 21 | 35 | 10 |
| *Gnathophausia* sp. (Mysidacea) | 42 | 12 | 69 |
| *Argyropelecus* sp. (Hatchet fish) | -- | 7 | 22 |
| *Stomias atriventer* | -- | 32 | 9 |
| *Cyclothone* sp. | 22 | 16 | 53 |

TABLE 10

**Arctic Copepods**

| Date of Collection | Depth (meters) | Lipid (percent of dry weight) | Triglyceride (percent of total lipid) | Wax ester (percent of total lipid) |
|---|---|---|---|---|
| Species—*Calanus hyperboreus* (female) | | | | |
| Nov 18 | 0–500m | 62.0 | 2 | 92 |
| Feb 27 | 0–100m | 46.5 | 1 | 67 |
| March 17 | 0–100 | 46.7 | 2 | 70 |
| April 18 | 0–100 | 41.6 | 1 | 61 |
| June 6 | 300–400 | 37.8 | absent | 52 |
| June 6 | 50–150 | 30.4 | absent | 46 |
| July 8 | 300–400 | 63.2 | 2 | 79 |
| July 8 | 50–150 | 76.6 | 2 | 93 |
| Aug 14 | 300–400 | 72.3 | 6 | 88 |
| Aug 14 | 50–150 | 66.2 | 4 | 88 |
| Sept 9 | 50–150 | 62.1 | 2 | 93 |
| Oct 8 | 50–150 | 63.7 | 3 | 91 |
| Species—*Metridia longa* (female) | | | | |
| Nov 18 | 0–500 | 56.9 | 2 | 81 |
| Feb 27 | 0–100 | 52.9 | 9 | 76 |
| March 27 | 410–500 | 59.1 | 2 | 75 |
| April 18 | 0–100 | 31.2 | absent | 36 |
| June 6 | 300–400 | 37.2 | 1 | 29 |
| June 6 | 50–150 | 30.4 | absent | 24 |
| July 8 | 300–400 | 63.2 | 3 | 59 |
| July 8 | 50–150 | 76.6 | 4 | 92 |
| Aug 14 | 300–400 | 72.3 | 6 | 90 |
| Aug 14 | 50–150 | 56.2 | 7 | 82 |
| Sept 9 | 50–150 | 52.1 | 9 | 72 |
| Oct 8 | 50–150 | 53.7 | 6 | 70 |
| Oct 8 | 300–400 | 57.3 | 10 | 76 |
| Species—*Calanus finmarchicus* (copepodite V) | | | | |
| Nov 7 | 0–500 | 52.4 | 1 | 62 |
| Species—*Calanus finmarchicus* (female) | | | | |
| Nov 7 | 0–500 | 50.4 | 9 | 51 |
| Species—*Euchaeta* sp. (copepodite V) | | | | |
| Nov 7 | 0–500 | 30.8 | 5 | 46 |

## DISCUSSION

### 1. Copepods

The studies of many workers, including our own, have emphasized the importance of lipid to marine zooplankton. Our early work was done on *Calanus helgolandicus* cultured at various concentrations of food (Lee *et al.*, 1970a, 1971b). A linear relationship was noted between the amount of food and the per

TABLE 11

**Lipoproteins of Sardine Blood**

Blood was taken from sardines and serum lipoproteins were fractionated into three density classes by the method of preparative ultracentrifugation. These density classes are very low density lipoproteins, VLDL (less than 1.006gm/cc); low density lipoproteins, LDL (1.006–1.063 gm/cc); and high density lipoproteins, HDL (1.063–121 gm/cc). The lipid of each of these density classes was fractionated into the different lipid classes (hydrocarbons, sterol esters, triglycerides, polar lipids, and phospholipids) by silicic acid column chromatography.

| Lipid Type | Lipoprotein Class | | |
|---|---|---|---|
| | VLDL | LDL | HDL |
| Hydrocarbons | trace | trace | trace |
| Sterol Esters | 16 | 16 | 20 |
| Triglycerides | 31 | 31 | 10 |
| Polar lipids* | 15 | 15 | 15 |
| Phospholipids | 35 | 35 | 55 |

* Includes sterols, free fatty acids, and pigments.

TABLE 12

**Uptake of Mineral Oil by the Mussel, *Mytilus Californianus***

The mussels were placed in a 7 liter aquarium and a mineral oil "slick" was formed by adding approximately 1 gram of oil. Mussels were taken out after various times of exposure and the procedure for analysis is given in *Methods*.

| Time of Exposure (days) | mg of hydrocarbon/gm of mussel | percent of hydrocarbon (percent of lipid) |
|---|---|---|
| 0 | 0.5 | 3 |
| 2 | 5.9 | 30 |
| 4 | 6.1 | 36 |
| 10 | 4.8 | -- |

TABLE 13

**Uptake and Discharge of $^{14}C$-Heptadecene by the Mussel, *Mytilus Californianus***

Mussels were placed in a 500 ml beaker filled with sea-water containing $^{14}C$-heptadecene (approximately $2 \times 10^6$ cpm), which was dispersed by sonication. Mussels were removed at various times and analysis performed as described in *Methods*.

| Hours | Cpm/gm of wet tissue |
|---|---|
| 3 | 45 x $10^2$ |
| 5 | 180 |
| 24 | 1135 |
| Transferred to radioactive-free sea water after 24 hours exposure to $^{14}C$-heptadecene. | |
| 20 | 20 |
| 48 | 80 |

cent lipid of the body dry weight. The number of carbon atoms in the wax esters of *C. helgolandicus* decreased with a decrease in the concentration of food, which indicated that the proportion of saturated wax esters probably increased at low food concentrations. Much of our recent work has been concerned with calanoid copepods, many of which contained large quantities of wax esters as reserve lipids. Wax esters were shown to be metabolized after triglyceride utilization was completed; wax esters are therefore probably the more lasting sources of reserve energy.

Littlepage (1964), Raymont *et al.*, (1969), and Orr (1934) have reported seasonal changes in the biochemical composition of zooplankters including euphausiids, copepods, and other crustaceans. Our seasonal study of lipid from Arctic copepods has indicated that the wax esters are slowly consumed during the long winter months. The copepodite stages (C-I to C-V) of wax ester-containing adult copepods have wax esters, but the eggs and naupliar stages of these same copepods may or may not have wax esters. The C-V contains the largest amount of wax esters of any stage in the life history (Tables 6 and 7), and the C-V is the stage which allows the copepod to "over-winter" or to withstand other times of food scarcity.

A study of the lipids of copepods from various depths (0 to 2500 m) has indicated that copepods from the depths below about 750 m invariably contain large amounts of wax esters and lipid, while copepods nearer the surface (0 to 250 m) contain less lipid and often do not contain appreciable amounts of wax esters.

### 2. Food Chains

An examination of food chains at shallow and great depths allows some interesting observations. A study of a near surface food chain consisting of phytoplankton—*C. helgolandicus*—anchovy and sardine, has shown the presence and often predominance of wax esters in the copepod, *C. helgolandicus,* but complete absence of wax esters in the phytoplankton and anchovies and sardines. Thus, wax ester lipases are probably essential enzymes in copepod-eating fish. The fatty acid composition of the wax esters of *C. helgolandicus* has been shown to closely resemble the fatty acid composition of the species of phytoplankton used as food (Lee *et al.*, 1971b) and therefore synthesis of wax ester is supplied by acids in the diet. A study of sub-tropical copepods indicated that many of the copepods in the upper 200 m have very low levels of both lipid and wax esters. On the other hand, a study of bathypelagic food chains indicates that perhaps all members of these food chains contain sizeable amounts of wax esters, since an examination of all specimens taken below 1000 m showed appreciable amounts of wax esters (Tables 8 and 9). The work of Nevenzel (1969, 1970) and our present studies reveal the importance of wax esters in the deep-water fish belonging to the families Myctophidae, Latimeridae, Gempylidae, Gonostomatidae, and Stomatidae. Copepods were observed in the stomachs of deep-water myctophids, gonostomatids, and stomatids by Gordin *et al* (unpublished data), so that wax esters in the copepods may go into the fish without modification to serve as fuel reserves.

Many of the copepods and fish obtained in deep midwater trawls are large relative to forms living in shallower water. Abyssal copepods have well-developed raptorial feeding apparatus, and the fish have developed a carnivorous mode of feeding adapted to infrequent encounters with other large individuals (Hardy, 1958). If most deep-living organisms do in fact feed infrequently at very low concentrations of prey, it would be of survival value for the predator to have: 1) an efficient digestive system, 2) a low metabolic rate, and 3) a large reserve of energy to sustain metabolic needs related to their environment. It therefore appears intuitively reasonable that near-surface omnivorous copepods living in subtropical or tropical regions do not need large energy reserves in the form of lipids, and that deep-living groups must store large energy reserves.

In the case of near-surface copepods from boreal and polar regions, much of the annual primary production occurs in short blooms during a few spring or summer months (McAllister *et al.*, 1960). Herbivores must feed and store this energy in preparation for winter months of relatively lower production and food abundance. When the supply of food is inhomogeneously distributed in time and is relatively abundant for only short periods, it should be an advantage for an organism to have a metabolism similar to that of the deep-living carnivores described above. One would expect that the deep-living organisms of high latitudes also follow the metabolic pattern of carnivores in deep water at lower latitudes.

### 3. Hydrocarbons

An important natural hydrocarbon of marine phytoplankton is the polyunsaturated 21:6 hydrocarbon. This hydrocarbon is not generally found at higher levels of the food chain although a few copepods, such as *Rhincalanus nasutus* and *Euchaeta japonica,* can store the 21:6 hydrocarbon (Blumer *et al.*, 1970a and the present work). Pristane is generally found in members of a food chain along with a series of straight chain compounds from $C_{15}$ to $C_{36}$ (Clark and Blumer, 1967; Lee *et al.*, 1971a).

A study of the distribution of "natural" hydrocarbon is important for any study of petroleum hydrocarbon uptake. Since marine life contains significant amounts of "natural" hydrocarbon, biosynthesis and metabolism of hydrocarbons occurs in these systems. Studies with *Mytilus californianus* demonstrated that filter feeding mussels can rapidly take up petroleum hydrocarbons (Tables 12 and 13). Discharge of the petroleum hydrocarbons is also rapid, but a low level of the petroleum hydrocarbons will remain for an unknown length of time. We have recently begun studies on the uptake of petroleum hydrocarbon by zooplankton, so that questions concerning the effects of oil spillage on a marine food chain can perhaps be answered.

## SUMMARY

1. Wax esters are a major lipid of bathypelagic copepods and copepods from all depths in polar and temperate waters. Starvation experiments with copepods demonstrated that triglycerides serve for short-term fuel needs, while wax esters have a secondary reserve function.

2. In members of the shallow-water marine food chain, phytoplankton—copepods—anchovies and sardines, only the copepods contained wax esters, so that active synthesis of wax esters from phytoplankton lipid occurred. Sardines and anchovies contained an active wax ester lipase in their pyloric caecum, for the hydrolysis of wax esters from their copepod food.

3. All members of bathypelagic food chains contained high amounts of lipid and wax esters. Deep-living copepods in tropical and subtropical regions were found to contain a higher amount of lipid (as per cent of dry weight) and a higher content of wax esters (as per cent of lipid) than did copepods from more shallow waters. Upper water (upper 250 m) copepods contained polyunsaturated alcohols in their wax esters, while saturated and monounsaturated alcohols were found in the wax esters of bathypelagic species.

4. Seasonal studies of Arctic copepods (*Calanus hyperboreus* and *Metridia longa*) demonstrated that a large buildup of lipid in the form of wax esters occurred in the phytoplankton-rich summer months (July through October) followed by slow utilization of the wax esters during the dark winter months.

5. A study of "natural" hydrocarbons in marine algae showed the presence of large amounts ($\frac{1}{10}$% of the lipid) of a polyunsaturated hydrocarbon, 21:6 (21 carbons and 6 double bonds). This and similar hydrocarbons are good markers for "natural" hydrocarbons because they are absent from petroleum hydrocarbon. Preliminary results with the mussel, *Mytilus californianus,* indicated that petroleum hydrocarbons (mineral oil) are rapidly taken up by these filter feeders without apparent toxic effects. Discharge of the petroleum hydrocarbons was rapid when the mussels were placed in oil-free sea water. The aromatic hydrocarbon, 1, 2, 3, 4-tetrahydronaphthalene, shows toxic effects on mussels at low concentrations (10 parts per million) and like compounds may have future detrimental effects on the marine environment.

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# PESTICIDE RESEARCH AT THE FISHERY-OCEANOGRAPHY CENTER

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Chemicals that are used today differ strikingly from those used before World War II. Pesticides in use then, with a few exceptions like lead arsenate and paris green, were not persistent. They consisted of organics that were found in nature, for example pyrethrins, nicotine sulfate, or rotenone. Compared to the post war use of pesticides they were not used in great quantities.

Within 20 years of the end of World War II there were 8,000 manufacturing firms in the U. S. mixing about 500 chemical compounds into more than 60,000 formulations registered for use as pesticides. The U. S. chemical industry was producing about 800 million pounds of pesticides a year and several pesticides had achieved almost universal distribution in the environment.

The first of a large group of synthetic chlorinated hydrocarbon chemicals, DDT, became available for public use in 1945 and has since become the best known and most widely used of post-war pesticides. It is also the most persistent and widespread of these chemicals.

Late in 1969, the then U.S. Bureau of Commercial Fisheries initiated a survey of chlorinated hydrocarbon pesticide residues in marine fishes found in the coastal waters of the U.S. The Fishery-Oceanography Center in La Jolla was assigned the task of collecting fish samples off southern California and Baja California. For this survey only fish livers were analyzed. Liver is easily sampled and it tends to concentrate the residues, therefore, it was felt that this organ would be a good indicator of the degree of pesticide contamination among fishes in any area.

In January 1970, samples of various species of fish were taken along the Baja California coast plus a few samples from Cortes Bank, which is about 100 miles offshore from San Diego, and one sample from Farnsworth Bank, which is on the west side of Catalina Island. In May, additional samples were taken at Cortes Bank, Farnsworth Bank, Santa Monica Bay, and along the coast between San Diego and Oceanside (Fig. 1; sample #1 taken off Manzanillo, Mexico, and sample #37 taken off Cape Mendocino, California, not shown). All of these samples were sent to the National Marine Fisheries Service (NMFS) Pesticide Laboratory in Gulf Breeze, Florida, for analysis. The samples showed that residues of DDT and its metabolites in fish livers increased from very low values in the south to very high values in Santa Monica Bay (Table 1). Off southern Baja California, DDT residues averaged about 140 parts per billion (ppb) for 9 samples, which included a total of 170 fish. Values for the 9 samples ranged from 38–430 ppb. In the Sebastian Viscaino Bay area, central Baja California, 3 samples totaling 29 fish averaged 1.2 parts per million (ppm) and ranged from 0.23–2.1 ppm. Fifteen samples, totaling 179 fish taken along the coast between San Diego and Oceanside at Cortes Bank and at Farnsworth Bank, averaged 13 ppm and ranged from 0.94 for ocean whitefish at Cortes Bank to 30 ppm for rockfish, *Sebastodes rosaceous* taken at Cortes Bank. In Santa Monica Bay, 8 samples, 65 fish, averaged 370 ppm and ranged from 63 ppm for Dover sole to over 1,000 ppm for one species of rockfish, *Sebastodes constellatus*.

Later the fillets of some of these fish were sent to the NMFS Laboratory in Seattle, for analyses. Analyses of the fillets (Table 2) showed that for 7 samples, Farnsworth Bank, San Diego, and Oceanside, in which total pesticide residues in the liver averaged from 7.3–18 ppm, the values for fillets ranged from 0.23–0.78 ppm. In five samples from Santa Monica Bay in which the liver residues ranged from 63–1,030 ppm, fillets ranged from 12–57 ppm. In the above 12 liver samples DDE averaged 87%, (82–96%) of the total pesticide residues, DDD 6% and DDT 7%. In 8

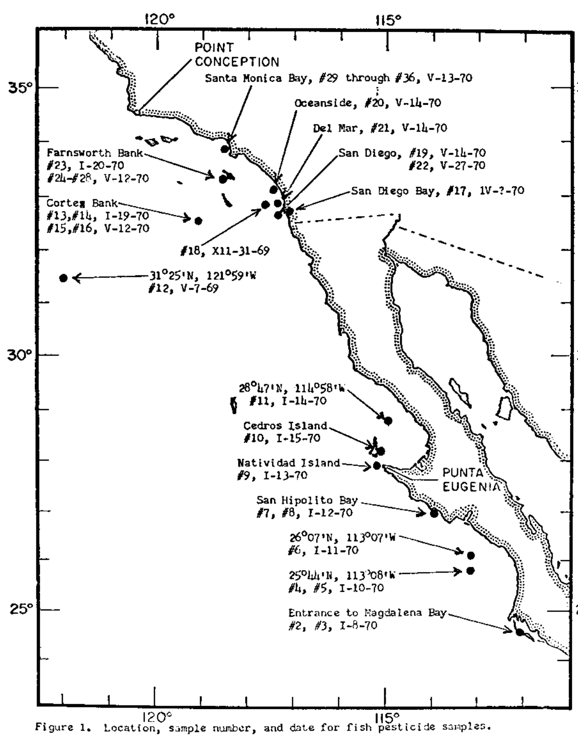


**FIGURE 1. Location, sample number, and date for fish pesticide samples.**

of the fillet samples, excluding the 4 containing less than 0.3 ppm total of residue, DDE averaged 87% (81–95%), DDD 5%, DDT 8%. One sample of fat from the body cavity of a Santa Monica Bay *S. constellatus* contained 2,600 ppm of DDT and its metabolites, of which 85% was DDE, 7% DDD and 8% DDT.

These extremely high residues in fish from the Santa Monica Bay area apparently resulted from the large amounts of pesticides discharged into the ocean at Whites Point by the sewers of the County Sanitation Districts of Los Angeles County (Carry and Redner, 1970). In March 1970, an estimated 800 pounds of DDT was being dumped into this sewer system each day. Investigators from the County Sanitation Districts determined that the source of most of this pesticide was the Montrose Chemical Company of Torrance, California. This company is the sole manufacturer of DDT in the United States, and reportedly produced two-thirds of the world's supply. On March 30, 1970, samples of sewage taken by County Sanitation District personnel upstream from the Montrose Chemical Company's sewer connection contained 34 ppb of DDT in a flow of 25.3 million gallons per day or 7.2 pounds of DDT per day. Samples taken downstream contained 2950 ppb in a flow of 26.6 MGD or 654 pounds of DDT per day. The situation has since been corrected. In April 1970, the company began hauling by truck what was termed a "caustic liquor waste" to landfills for disposal.

In contrast to the roughly estimated 146 tons of DDT per year that were being dumped into the Los Angeles County sewer system, it has been estimated that the Mississippi River contributes about 10 tons of pesticides a year to the Gulf of Mexico, and that the easterly tradewinds transport an estimated one-half ton of DDT across the north Atlantic annually (Butler, 1969).

**TABLE 1**

**Residues of DDT and its metabolites, DDD and DDE, in the livers of fish taken off the Pacific Coast of the United States and Mexico (1969–1970)**

| Sample Number | Species | Number of Fish in Sample | Residues in parts per million | | | |
|---|---|---|---|---|---|---|
| | | | DDE | DDD | DDT | Total |
| | SOUTH OF POINT EUGENIA | | | | | |
| 1 | Yellowfin tuna (*Thunnus albacares*) | 11 | .047 | .091 | .026 | .164 |
| 2 | San bass (*Paralabrax nebulifer*) | 10 | .038 | -- | -- | .038 |
| 3 | Ocean whitefish (*Caulolatilus princeps*) | 10 | .22 | -- | -- | .22 |
| 4 | Pacific mackerel (*Scomber japonicus*) | 19 | .040 | -- | .009 | .049 |
| 5 | Bonito (*Sarda chiliensis*) | 10 | .050 | .012 | .038 | .100 |
| 6 | Hake (*Merluccius productus*) | 90 | .36 | .018 | .048 | .426 |
| 7 | Sand bass (*Paralabrax nebulifer*) | 10 | .15 | -- | -- | .15 |
| 8 | Ocean whitefish (*Caulolatilus princeps*) | 10 | .088 | -- | -- | .088 |
| | SEBASTIAN VISCAINO BAY | | | | | |
| 9 | Bonito (*Sarda chiliensis*) | 6 | 1.1 | .054 | .13 | 1.284 |
| 10 | Ocean whitefish (*Caulolatilus princeps*) | 10 | .14 | .031 | .056 | .227 |
| 11 | Lizzardfish (*Synodus sp.*) | 13 | 1.6 | .18 | .35 | 2.13 |
| | CORTEZ BANK AREA | | | | | |
| 12 | Jack mackerel (*Trachurus symmetricus*) | 2 | .092 | .019 | -- | .111 |
| 13 | Ocean whitefish (*Caulolatilus princeps*) | 2 | .78 | .060 | .099 | .939 |
| 14 | Treefish (*Sebastodes serricepts*) | 10 | 1.6 | .080 | .16 | 1.84 |
| 15 | Rosy rockfish (*Sebastodes rosaceus*) | 7 | 27. | 1.2 | 1.6 | 29.8 |
| 16 | Olive rockfish (*Sebastodes serranoides*) | 5 | 21. | 1.0 | 2.6 | 24.6 |
| | SOUTHERN CALIFORNIA COAST | | | | | |
| 17 | Sardine (*Sardinops caeruleus*) | 32 | .96 | -- | -- | .96 |
| 18 | Hake (*Merluccius productus*) | 52 | 4.5 | .71 | 1.4 | 6.61 |
| 19 | English sole (*Parophrys vetulus*) | 14 | 12. | 1.1 | .83 | 13.93 |
| 20 | White croaker (*Genyonemus lineatus*) | 16 | 16. | .28 | .35 | 16.63 |
| 21 | Ling cod (*Ophiodon elongatus*) | 1 | 15. | .90 | 1.9 | 17.80 |
| 22 | Jack mackerel (*Trachurus symmetricus*) | 10 | 2.5 | .16 | .41 | 3.07 |
| | FARNSWORTH BANK (STA. CATALINA IS.) | | | | | |
| 23 | Rockfish (*Sebastodes* sps.) | 11 | 21. | 1.4 | .23 | 22.63 |
| 24 | Sculpin (*Scorpaena guttata*) | 10 | 7.0 | .55 | .58 | 8.13 |
| 25 | Blue rockfish (*Sebastodes mystinus*) | 5 | 9.4 | .79 | 1.3 | 11.49 |
| 26 | Rosy rockfish (*Sebastodes rosaceus*) | 16 | 8.5 | .54 | 1.0 | 10.04 |
| 27 | Treefish (*Sebastodes serriceps*) | 7 | 6.4 | .31 | .56 | 7.27 |
| 28 | Starry rockfish (*Sebastodes constellatus*) | 13 | 16. | .71 | 1.4 | 18.11 |
| | SANTA MONICA BAY | | | | | |
| 29 | Bocaccio (*Sebastodes paucispinis*) | 9 | 510. | 33. | 48. | 591. |
| 30 | Sablefish (*Anoplopoma fimbria*) | 10 | 90. | 6.0 | 7.1 | 103.1 |
| 31 | Vermilion rockfish (*Sebastodes miniatus*) | 10 | 141. | 9.0 | 12. | 162. |
| 32 | Starry rockfish (*Sebastodes constellatus*) | 5 | 900. | 56. | 70. | 1026. |
| 33 | Dover sole (*Microstomus pacificus*) | 13 | 54. | 4.1 | 4.9 | 63. |
| 34 | Spiny dogfish (*Squalus acanthias*) | 5 | 200. | 15. | 13. | 228. |
| 35 | Spiny dogfish (Large female with embryos) | 1 | 406. | 24. | 43. | 473. |
| 36 | Spiny dogfish (embryos from #35) | 12 | 300. | 20. | 32. | 352. |
| | CAPE MENDOCINO AREA (RUSSIAN TRAWLER) | | | | | |
| 37 | Hake (*Merluccius productus*) | 13 | 1.4 | .29 | .43 | 2.12 |

Our own program in pesticide research at the Fishery-Oceanography Center has just started, so we do not have any results of our own to present at this point. We expect our research to be along two main lines: 1) the effect of pesticides on the reproductive metabolism of fish and the survival of eggs and larvae, and 2) an investigation of residues in plankton, current and historical, using the extensive collections of the California Cooperative Oceanic Fisheries Investigations (CalCOFI).

With respect to the reproductive metabolism of fish, it has been demonstrated that DDT in fish eggs can cause heavy mortality among the fry. Concentrations on the order of 3 ppm caused mortality in lake trout fry (Burdick *et al.*, 1964). In a few of the samples of fish collected in our original survey, we found females that were nearly ripe. One sample of *Sebastodes rosaceous* that contained 10 ppm DDT and metabolites in the liver had 3.6 ppm in the ovaries. One sample of *Sebastodes serriceps* contained 7.3 ppm in the liver and 4.3 ppm in the ovaries. More than 80% of the total was DDE rather than DDT in both samples, and DDE appears to be less toxic than DDT.

The rockfish taken in Santa Monica Bay that had very high pesticide residues in the liver were species that spawn earlier in the year and had no ovarian development at the time of capture.

It is possible that some fish in California coastal waters contain such high residues of pesticide that they cannot reproduce effectively. We are going to explore this problem in the laboratory.

We are also designing experiments to describe the uptake by various tissues of adult marine fish under chronic sub-lethal exposure to pesticides.

In the plankton project, we are still experimenting with analyzing material preserved in formalin and trying to determine if we should concentrate our efforts on only certain constituents of the plankton samples. Samples of plankton have been collected regularly each year by vessels of CalCOFI agencies since 1949. Most of these samples have been sorted into fish eggs and larvae, and to a lesser degree some of the other constituents have been removed. This means that the formalin has been changed one or more times for each sample and possibly some of the pesticide residue may have been discarded with the old formalin. We are presently investigating some of the possible problems associated with using such preserved material.

There are also extensive collections of small fishes taken by dip netting and plankton net over the past 20 years on the CalCOFI cruises that might be valuable in determining the historical trend of pesticide accumulation in the ocean off California.

We have run a series of frozen plankton samples that were collected earlier this year. These were taken along CalCOFI line 87, which starts in Santa Monica Bay and runs to the southwest. We took samples out to about 400 miles along this line. Pesticide residues were higher for the two inshore stations and tended to decrease offshore except for one high value in the shallows off San Nicolas Island. Only the San Nicolas Island station and the two inshore stations contained DDE in excess of 1 part per million dry weight. Two-thirds of the samples contained only traces or no detectable DDD, and the same held true for three-fourths of the samples with respect to DDT. At these low pesticide levels there is great difficulty in interpreting the chromatograms owing to the large number of other small peaks, most of which may be polychlorinated biphenyls.

All of the samples had prominent peaks at the retention time of DDMU, a metabolite of DDT, but the PCB's also have peaks at that point. In fact the peak can be obtained by soaking some plastics in hexane, and can be introduced into samples as a processing, preservation or experimental artifact, although it appears to occur "naturally" in many samples.

The constituents of the plankton samples were primarily crustaceans, ctenophores, and salps. Most of

**TABLE 2**

**DDT residues in the flesh of fish from Southern California**

| Sample Number | Species | Length (mm) | Oil (percent) | Moisture (percent) | Residues in fillets (Parts per million) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | DDE | DDD | DDT | Total |
| | CORTEZ BANK | | | | | | | |
| None | *Sebastodes* sp. | no data | 0.9 | 80.0 | .123 | -- | -- | .123 |
| | FARNSWORTH BANK | | | | | | | |
| 24 | *Scorpaena guttata* | 194–262 | 0.9 | 77.8 | .258 | -- | trace | .258 |
| 25 | *Sebastodes mystinus* | 166–219 | 1.8 | 79.6 | .436 | trace | .058 | .494 |
| 26 | *Sebastodes rosaceus* | 137–180 | 0.7 | 80.0 | .283 | trace | trace | .283 |
| 27 | *Sebastodes serriceps* | 139–215 | 0.9 | 80.8 | .229 | -- | -- | .229 |
| 28 | *Sebastodes constellatus* | 142–194 | 0.9 | 80.2 | .283 | -- | -- | .283 |
| | SOUTHERN CALIFORNIA COAST | | | | | | | |
| 19 | *Parophrys vetulus* | 160–269 | 0.8 | 82.0 | .653 | .051 | .077 | .781 |
| 20 | *Genyonemus lineatus* | 181–255 | 0.7 | 79.0 | .583 | trace | .029 | .612 |
| | SANTA MONICA BAY | | | | | | | |
| 29 | *Sebastodes paucispinis* | 226–670 | 1.4 | 78.5 | 9.38 | 1.02 | 1.24 | 11.6 |
| 30 | *Anoplopoma fimbria* | 390–460 | 6.0 | 78.9 | 19.02 | 2.36 | 2.05 | 23.4 |
| 31 | *Sebastodes miniatus* | 205–304 | 2.2 | 79.1 | 14.9 | trace | 1.25 | 16.0 |
| 32 | *Sebastodes constellatus* | 165–248 | 1.8 | 76.4 | 50.5 | 3.14 | 3.64 | 57.2 |
| 33 | *Microstomus pacificus* | 180–205 | 3.6 | 79.9 | 11.55 | 0.82 | 0.93 | 13.3 |

the larger jellies were discarded before the samples were frozen. Inclusion of fish larvae or small fishes in the sample increased the pesticide residues noticeably. Myctophids weighing 0.3–0.5 g contained more than 100 times (on a dry weight basis) as much pesticide residue as the plankton samples from which they were removed. At the present stage of our plankton investigations, it appears that the best plankton constituents upon which to base a study of the historical trend in pesticide accumulation may be the myctophid fishes that have been taken in the plankton nets and by dipnetting on CalCOFI cruises since 1949.

*Question:* What kind of errors do you get in your DDT measurements or your other constituents of these in the high pressure stations? How extensively do you separate these?

*MacGregor:* We are getting pretty good separation with things like DDE.

*Question:* PCB's don't interfere?

*MacGregor:* They interfere, yes, especially when everything is there in very small quantities. We have a lot of interference with DDT.

*Question:* Have you done any mass spectrometry work?

*MacGregor:* No, but Dr. McClure is working—trying to use thin layer chromatography in conjunction with this and see if we can separate them out that way.

*Question:* Using one column or two?

*MacGregor:* Just one now.

*Question:* What concentrations are necessary in the fish flesh of DDT before you become concerned?

*MacGregor:* U.S. Food and Drug says 5 ppm.

*Question:* Has anyone worked the same species of fish from north of Pt. Conception?

*MacGregor:* We got one sample of hake from a Russian trawler that was sort of low.

*Question: Pearcy*—I am curious to know if this is a hot spot? You have the data from there south. How about north?

*MacGregor:* I think it is, around Los Angeles. How far north do you want to go? I know they got salmon off Alaska that they couldn't detect any residues in.

*Question: McGowan*—One sample of 20–30 fish and within that sample of fish DDT concentration varied by a factor of 10? On individuals?

*MacGregor:* We don't run individuals. Each sample was the same species. We would take all the livers in those species and blend them together.

*Question:* But you gave a range of numbers.

*MacGregor:* That was for different samples and different species of fish. Generally pelagic fish seem to be low as far as livers are concerned. Bottomfish tend to be higher.

*Question: McGowan*—Do you know if there is much variability among individuals within the species?

*MacGregor:* Not if you get them all from the same location. We had two samples of Pacific mackerel from the same school and it was just about the same.

*Question:* In samples of fish flesh, you said that DDE, or at least the residue, was from 12–57 ppm in the tissue. How is this information used from a consumer's standpoint? Obviously they shouldn't be consumed if they have that high concentration.

*MacGregor:* We didn't.

*Question: Fitch*—Most of the rockfish you are working on range in age with maturity up to 20 years or more, the ones that you mentioned anyway, and if this is accumulative you are bound to get great differences in individuals depending on the age of the individual.

*MacGregor:* If we take a simplistic view of this, what we think happens is—of course, each fish doesn't take in DDT, it is taking in a combination of different things, but DDT apparently breaks down to DDE, which is sort of an end point and that is stored in the fatty tissue and DDT also breaks down to DDD, which in turn breaks down to DDMU and eventually is excreted. So it apparently goes two ways—stores one and not the other.

*Question: Schmitt*—Are you passing out this information to FDA?

*MacGregor:* Actually FDA are just interested in stuff that goes into Interstate Commerce. They are sampling fish all along the coast themselves.

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# DDT IN MARINE PLANKTON AND FISH IN THE CALIFORNIA CURRENT

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DDT residues have entered all compartments of the world ecosystem due to their mobility, environmental stability, and their affinity for biological materials (Risebrough, *et al.,* 1968; Risebrough, 1969). Due to estuarine, air, and sewage transport of these contaminants to the oceans and their subsequent fixation into organisms and sedimenting particles, one would expect an eventual net transfer and accumulation of these materials in oceanic ecosystems (Wurster, 1969).

DDT residues, especially the compound p, p′-DDE, must have remarkable resistance to physical and biological degradation because of their abundance in the environment (Risebrough, *et al.,* 1970). A measure of the persistence of these compounds in the environment is the half life, or the time required for half of the originally present DDT to disappear. These estimates range from 10 to 15 years in the soil of forests and agricultural plots (Edwards, 1966; Nash and Woolson, 1967). "Disappearance" in this context does not necessarily imply degradation to non-toxic derivatives of DDT; movement of the DDT from the site of application must be considered. DDT is highly mobile when it is in contact with water (Bowman, *et al.,* 1964). This facilitated evaporation has been referred to as "codistillation." Recent estimates (Lloyd-Jones, 1971) indicate that half of the DDT applied to crops may eventually evaporate; a specific rate of $3 \times 10^{-3}$g cm$^{-2}$ hr$^{-1}$ at 20°C has been calculated.

Because of latent vaporization of the DDT residues from the site of application, as well as other causes of movement, such half life estimates are likely to be minima. An additional cause of global dispersal of DDT residues is atmospheric transport of DDT which becomes dispersed during aerial application. Hindin (1970) in a careful study of an agricultural study plot, estimated that 35% of released DDT never reached crop height. In an earlier study of forest soil, Woodwell (1961) indicated that over half of the released DDT did not actually reach the ground.

Latent movements of DDT residues from sites of application also occur via movement of particles with adsorbed DDT in run-off water (Peterle, 1970), and wind-borne dust (Cohen and Pinkerton, 1966). DDT residues in rainwater are present in quite high concentrations (Tarrant and Tatton, 1968), indicating that rain will remove much of the burden of DDT residues from the atmosphere, where it is present as aerosol and adsorbate on dust.

These processes require a certain amount of time to effect a transfer of DDT residues from terrestrial areas to the ocean. Evidence gathered from a series of DDT residue analyses of net phytoplankton samples collected in Monterey Bay, California from 1955 to 1969 (Cox, 1970a) suggests an approximately threefold increase in DDT residue concentrations. Considering the minimum environmental half life estimates of ten to fifteen years and the latency factor inherent in the transport of DDT residues to the ocean, it is not surprising that DDT residues in these phytoplankton samples increased despite a twofold decrease in domestic usage over the period 1959 to 1969.

Smith, *et al.* (1970) analyzed available data on DDT concentrations in river systems, dust and rainwater, and concluded that atmospheric transport was the greatest factor contributing to DDT residues in the surface mixed layer of the world's oceans. Their calculations of river input yielded a maximum annual input of $3.8 \times 10^3$ metric tons, and it was felt that even this figure was probably too high. Rainwater DDT residue concentrations and annual rainfall statistics yielded a value of $2.4 \times 10^4$ metric tons, almost an order of magnitude greater than the maximum estimate for runoff water.

An alternative procedure for calculation of DDT input to the ocean is to combine estimates of DDT residue concentrations in dust collected over the ocean and figures for sedimentation rates of the dust. Risebrough, *et al.,* (1968, thus computed the input to the Atlantic Ocean between the equator and 30° N at 0.6 metric tons annually and compared this to an estimated input of 1.9 metric tons per year from the San Joaquin River drainage. Goldberg and Griffin (1970) made further measurements of DDT residue concentrations in dust over the Bay of Bengal and found concentrations of 7.3 to $135 \times 10^{-8}$g with a mean of $32 \times 10^{-8}$g DDT residues/g of dust (compared to $4.1 \times 10^{-8}$g DDT residues/g of dust collected at Barbados). They calculated an input of six metric tons annually. These estimates of pesticides in dust are minimal estimates because of the inability of the dust traps to collect small particles, *ca.* 1μ and less, which may constitute the majority of the adsorptive interface present in airborne particulate material (Delany, *et al.,* 1967).

The foregoing discussion has emphasized exogenous measures of DDT residue inputs. Another way to assess this input is to measure DDT residues in the organic particulate material of the ocean.

Prevailing levels of DDT residues in phytoplankton material collected by a net in Monterey Bay are about $3 \times 10^{-5}$g DDT residues/g carbon (Cox, 1970a).

Using estimates of standing crop density given by Mullin and Brooks (1970), and Holm-Hansen (1969), the total DDT content of an area of about 100 km by 600 km extending from San Diego to Monterey Bay, California (hereafter referred to as the described area) was estimated at about 1–10 metric tons. The larger figure is more likely because of negative bias in standing crop estimations and because the DDT concentration value quoted above is a minimum value since it was determined for very high standing crop densities.

Extractions of whole seawater from a number of transects through the described area yielded DDT residue concentrations of whole seawater in this area of about $5 \times 10^{-6} g/m^3$, accounting for the extraction efficiency of the procedure. Assuming a depth of 50 m in the mixed layer of the described area, a total of 15 metric tons is yielded as an estimate of the DDT residues present. Much of the material included in the net tow material described above was excluded from these raw water extractions (chain-forming diatoms, larger detritus, *etc.*), so it is not unreasonable to lump this amount with the one reported above for an estimate of *ca.* 25 metric tons existing at one time in the phytoplankton, detritus, and water of the surface waters of the described area.

Fish, primarily the northern anchovy *Engraulis mordax,* account for about 3 metric tons in the described area, assuming a mean concentration of one part per million DDT residues and the values for fish tonnage of the area quoted by Baxter (1967). Estimates of zooplankton standing crop (Lasker, 1970) used with an assumed concentration of 0.25 parts per million yield another 3 metric tons. This brings the total estimate to 31 metric tons of DDT residues for the area.

In the southern California area especially, input of DDT residues from sewage effluent is considerable. In May, 1970, estimates of the input of the sewage outfall at Whites Point in Los Angeles amounted to 146 metric tons per year, authough it dropped to 36.5 metric tons after partial control of the manufacturing disposal of DDT into the sewage system. Clearly this input is of sufficient magnitude to account for a large share of the DDT residues estimated to be present in the surface waters of the described area. However, it is not known what fraction of this effluent is effectively transported to and dispersed in the water above the pycnocline (the outfall at Whites Point is below the pycnocline).

Risebrough, *et al.* (1968) estimated that the dust samples collected at the Scripps pier in La Jolla, California contained $10^3$ times more pesticide than the Barbados samples, despite the prevailing landward winds, and attributed this high concentration to ". . . an unknown admixture of air from neighboring agricultural area." They estimated a mean concentration of $1.8 \times 10^{-5}$g total pesticides/g of dust. DDT residues represent the principal component of this figure; if the same sedimentation rates apply to the described area as to the tropical Atlantic, the estimated input must be at least 0.7 metric tons annually. This amount is a minimum estimate since particulate fallout in the described area is most likely greater than that over the tropical Atlantic: moreover, the aforementioned negative bias in the collection techniques suggests the actual value is higher. Thus atmospheric fallout must be a quantitatively important factor for DDT residue input in the described area, along with runoff and sewage. Spatial patterns in DDT analyses of whole seawater collected on transects inside and outside of the described area are discussed in further detail by Cox (1971a).

Not accounting for runoff, the estimate of 31 metric tons of DDT in the described area may be attributed to inputs from sewage and airborne particles. A more accurate assessment of the magnitudes of the annual inputs from each of the three mentioned sources would allow computation of a turnover rate in the surface waters of the described area. Of equal importance is the description of the processes involved in the movement of these residues into and through pelagic food chains.

Fig. 1 schematically depicts the sources of DDT residues in the coastal environment and outlines some of the distributional possibilities once the residues have entered seawater. Before attempting to discuss the various transfer steps and the consequences of this schematic model, it is necessary to establish a few basic points:

(1) DDT residues entering the ocean via any of the indicated sources is mostly sorbed to the particulate material carried with the influx (Freed, 1970; Peterle, 1970).

(2) This binding is reversible, so when contact of the particle is made with biological material of high lipid content, there is a chance that the associated DDT residues will pass into the fatty material, in which it is highly soluble. In Fig. 1, we may consider material "soluble" if it is available for uptake by organisms.

(3) Once DDT has entered the lipid phase of a biological system, it is likely to remain chemically stable (Risebrough, *et al.*, 1970) and to stay there. Once it is in lipid, its movements are bound to be influenced almost entirely by phase equilibria rather than adsorption equilibria. For example, loss of DDT can be mediated by phase partitioning of DDT in the blood of an organism into the lipids of undigested remains of material in the digestive tract. This can be inferred from the data of Macek, *et al.* (1970) for freshwater fish.

(4) Sorption of DDT residues to particulate material changes in intensity with the nature of the substratum, so that interchange between the physical system and the biological one may be due to a difference in the adsorption energy coefficients of the two substrata (Weber and Gould, 1966).

The first step in entry to the food chain is uptake by organic particulate material. Initial studies of this step showed that phytoplankton cells had great concentrating capacity (Cox, 1970b), but the generality of the partition coefficients, as they were expressed, became dubious because it appeared in the analyses of the net tow material that the density of cells or particles did not greatly affect the amount of DDT residues taken up per unit volume of water (Cox, 1970a). The observation admitted two distinct possibilities: (1) a phase partition mechanism determined uptake, and in each instance the nearly total amount of available residues ("dissolved") were taken up in the lipids of the phytoplankton and other particles, or (2) uptake was determined by adsorption equilibria, but the concentrations were such that the liquid-solid adsorption equilibrium was still on the linear part of the curve (where there are still many available adsorption sites on the substratum), where almost all of the DDT is adsorbed. The only way to distinguish between these possibilities is to attempt to saturate the system. If phase partitioning is the case, it would take more "available" DDT to saturate the system, since DDT is soluble in lipids by as much as 50% by weight (*e.g.* in corn oil). Later experiments (Cox, 1971a) showed that, in the presence of abundant, available $^{14}$C-DDT, algal cells took up a constant amount per cell. This supports the adsorption hypothesis for *Dunaliella salina*, the species tested. In diatoms, the situation might be different because of the large oil inclusions often found in the cells.

Zooplankton (including various larval forms of fish) are likely to obtain some of their body residues of DDT by direct uptake from water. Cox (1971b) describes the results of uptake studies with a common euphausiid shrimp of the California coastal waters. The results are consistent with a two step uptake process: adsorption, then diffusion into lipid. It appeared that most of the DDT taken up during short term experiments would be lost when the ambient concentration was lowered, suggesting an easily reversible adsorption equilibrium. Direct uptake from water may be more important for the smaller zooplankton.

Uptake from food was shown to be an adequate explanation for the natural levels of DDT residues in the study organism. Uptake can be explained by bulk assimilation of lipids; loss of DDT in body is probably due to the process described in item (3) above, or to release of gametes (Cox, 1971c).

Fish in most environments probably do not acquire much of their body's DDT residues by uptake from water (Macek and Korn, 1970; Macek, 1970). Originally, it was assumed that uptake via gill surfaces was the principal mechanism by which fish acquired DDT residues (Holden, 1966). This is a reasonable explanation in instances of areas receiving direct or heavy indirect input of DDT (Edwards, 1970). One observation which has been made about fish in freshwater or marine environments is that DDT residues continue to accumulate with age (Reinert, 1970; Macek and Korn, 1970; Cox, 1970c). A study of DDT residues in *Engraulis mordax*, an important planktotrophic fish of the described area, suggests some of the basic mechanisms expected to control the acquisition and loss of DDT residues by fish (Cox, 1971c).

An examination of Fig. 1 leads to the idea that DDT residues, once they have entered the biological system, will eventually be transferred away from the

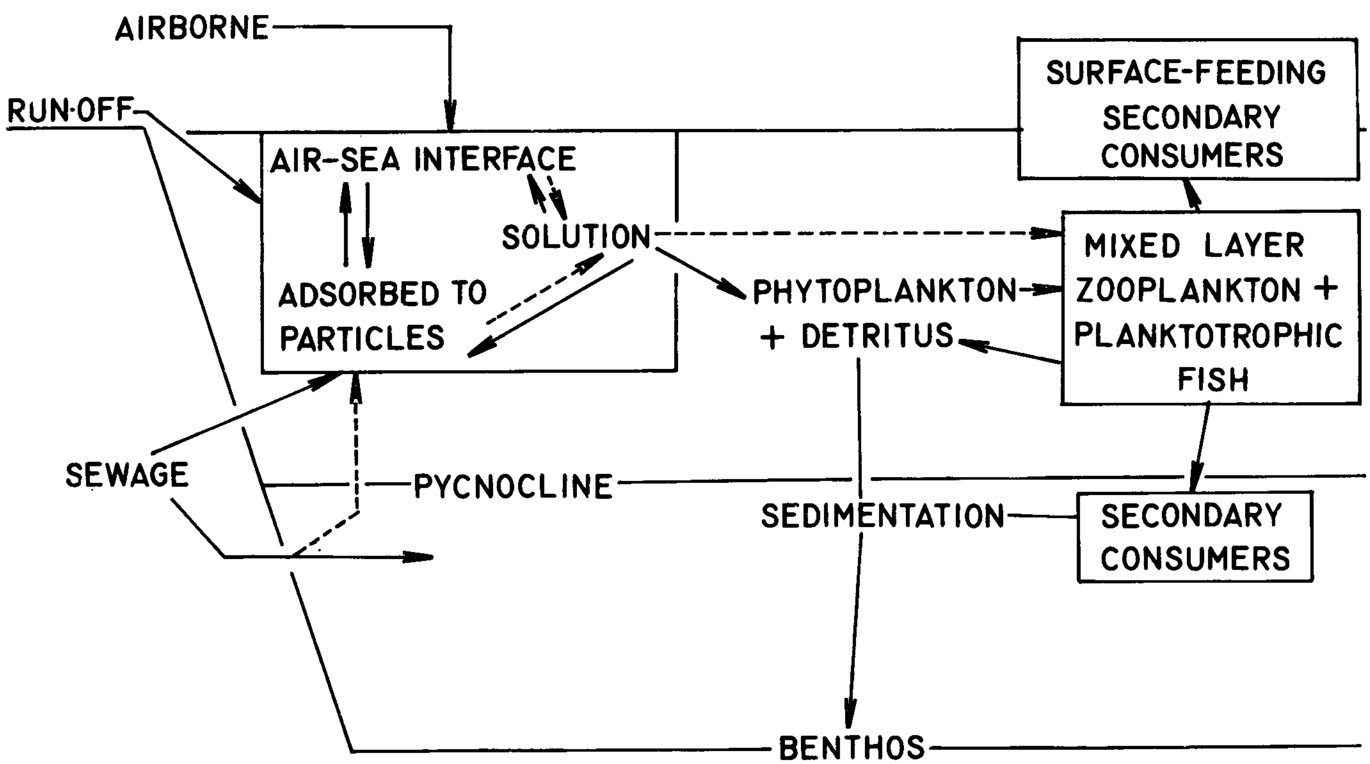


FIGURE 1. Flow chart depicting the fate and distribution of DDT residues in a populated coastal environment.

first compartment of planktotrophic fish and surface dwelling zooplankton by three routes: (1) by being eaten by avian, mammalian, or piscine predators, all of which will remain in association with surface layers, (2) by the sedimentation of detritus produced by this compartment, (3) or through consumption by vertically migrating predators from mid-depths. Some algal cells themselves will fall out of the surface layers. Although many possibilities exist for trophic re-

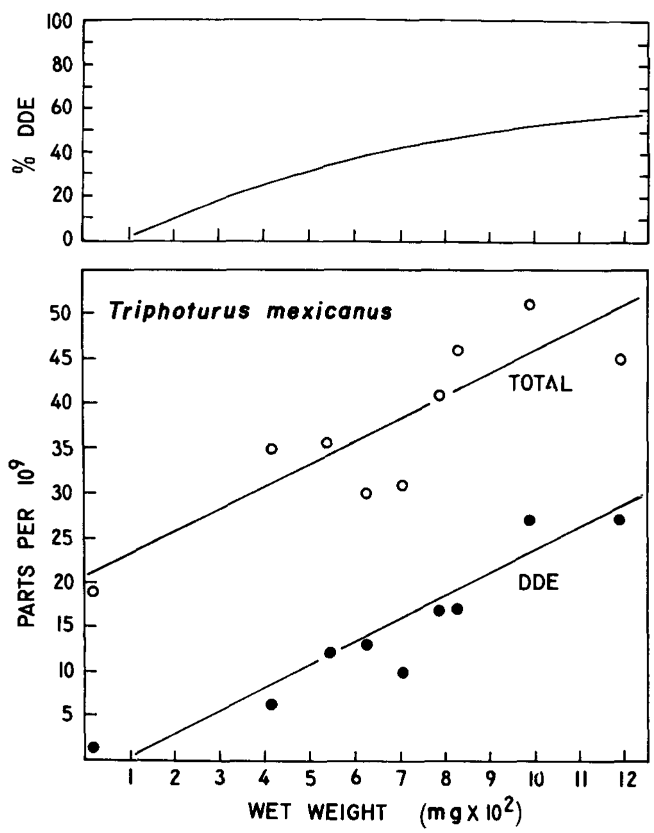


FIGURE 2. DDT residue concentration as a function of wet weight in the fish *Triphoturus mexicanus*, from the Gulf of California (Cox, 1970c). Upper curve is derived by measuring the differences between the regression lines in the lower plot.

cycling of DDT residues in the surface layers, ultimately the bulk of these residues will be transported away by highly mobile, surface feeding predators, or will sink to the benthos after death. Decay of the surface feeding predators will ultimately lead to some sedimentation of their DDT residues. On this basis, a net transport of DDT to oceanic sediments can be predicted.

One of the consequences of the incorporation of DDT into animal lipid is that it is relatively stable there and will tend to remain in association with lipid according to the mechanism stated in item (3) in a previous paragraph. As DDT stays in contact with biological materials, the amount which is converted to DDE apparently increases. Fig. 2 shows a DDE accumulation function derived from the analysis of *Triphoturus mexicanus* (Cox, 1970c). Risebrough, *et al.* (1970) postulated that the high DDE concentrations in oceanic predators reflected the residence time in biological materials occasioned by the multiple trophic transfers leading to consumption by high order predators.

On this basis, one would expect DDE to be accumulating in the benthos, since it is the final compartment of the system, and since its DDT residues may be expected to have resided in pelagic biological systems for a certain time before sedimentation.

Since the trophic relationships, the distribution and sedimentation rates of organic particulate material, and the actual biomass content of pelagic ecosystems are still imperfectly understood, we cannot expect a greater level of understanding of the distribution and movement of DDT residues in this system. The foregoing discussion has dealt with findings which allow use of our present knowledge of pelagic ecosystems for prediction of these distributions and movements. The examples studied, however, are far from being representative of the whole pelagic ecosystem and much more investigation is required. DDT and its metabolites are the most ubiquitous man-made substances known; while we still do not understand the complete range of their toxic effects, they are worthy of our continued attention on the basis of their global abundance alone.

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# HEAVY METALS IN COASTAL SEDIMENTS

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I would like to start by giving an historical perspective of pollution:

"In Kohln, a town of monks and bones,
and pavements fanged with murderous stones,
"And rags, and hags, and hideous wenches,
I counted two and 70 stenches,
"All well defined and separate stinks!
Ye nymphs that reign o'er sewers and sinks,
"The River Rhine it is well known,
Doth wash your city of Cologne,
"But tell me, nymphs, what power Divine,
Shall henceforth wash the River Rhine?"
Samuel T. Coleridge (1772–1834)

A couple of years ago when I became interested in environmental research, I was reading the literature and found that very few studies were being done to study the problem from a geochemical perspective. Most of the studies were piecemeal and studied only part of the problem. Therefore, as a step toward solving that, I started investigating the alteration of the natural geochemical cycle of copper, zinc, cadmium and lead.

I will be talking today about Los Angeles County Sanitation District's waste-water outfall. This outfall has a daily discharge of 370 million gallons (1.4 billion liters) of primary treated sewage. The concentration of particulate matter is about 325 ppm. The total concentrations of these four metals in the effluent and their annual rates of discharge from the outfall are shown below.

| | *Total Concentrates* | *Discharge Rate Grams/yr* |
|---|---|---|
| Zn | 1.2 ppm. | $7 \times 10^8$ |
| Cu | 0.5 | $3 \times 10^8$ |
| Cd | 0.08 | $4 \times 10^7$ |
| Pb | 0.17 | $9 \times 10^7$ |

The concentrations of these metals in this effluent are 5–100 times above normal river concentrations.

Figure 1 is a map of the Los Angeles County outfall system showing the location of the two outfall pipes and the depth of water in fathoms. The sediment cores with which I worked (twenty-two gravity cores, fifteen centimeters long) were graciously taken for me by the Sanitation District of Los Angeles County at the positions shown on the map. The top surface centimeter of each core was analyzed for lead, copper, zinc and cadmium by atomic absorption spectrophotometry.

Figure 2 is a contour map of zinc concentrations in the surface sediment. The concentration measured at 5,000 feet away from the outfall was 1900 ppm and as far away as 5 miles from the outfall the zinc concentration was between 50 and 100 ppm. In other words at 5 miles distance from the outfall you begin to approach natural concentrations (see below). One obvious fact from this data is that the sewage outfall is severely affecting the sediments. I also have contours like this for cadmium and copper, but to keep the talk short, people can see me later, if they wish to see them.

Figure 3 is a graph showing zinc concentration in surface sediments vs. distance from the outfall.

Figure 4 is a detailed study of one core taken 5,000 feet away from the outfall. Samples were taken every other centimeter in the core (core 22 cm. long) and analyzed for cadmium, copper, zinc and lead. The line at the bottom of the graph is what I call the *natural unpolluted concentration* in coastal sediment. For the present I have defined this quantity on the basis of the lowest concentration of each metal that I have found in the deepest sample of any core. The values so obtained are: zinc 70 ppm; copper 20; cadmium 1.5; lead 20.0. The vertical axis is variable, such that it is normalized to the natural concentration line for the different elements.

There are a number of ways that this data can be explained. One could conjecture that the top 10 cm. were deposited after the main sewer outfall of Los Angeles County was put in use in 1957. That assumption results in a sedimentation rate of 0.6 cm. per year. Or one can say that there is a mixing/stirring mechanism that accounts for this profile and, therefore, the time variable above will be distorted. Or you could say that above a depth of 10 cm. in the core the sediments became reducing and began concentrating the metals at some time in their history.

We are in the process of doing absolute age determination with the cores, so that we can better define the process going on.

The real function of this sediment study is to discover where the metals are going once they enter the ocean. The studies so far strongly suggest that some go into sediments, but I don't have a concrete idea of how much because I have no independent measure of the rate of sedimentation.

But what happens once it is in the sediments? Are the metals easily mobilized? Is there biological uptake? In an effort to find how tightly bound these elements are in the sediment, I did a fractional dissolution of one sediment sample that was taken 5,000 feet away from the outfall and at 2 cm. from the top of the core. Table 1 shows the results of this work. One of the important things shown by this data is that large amounts of copper and lead are strongly bound, possibly in an organic complex. For all of these elements, but most for copper and lead, if the sediment around the outfall becomes oxidizing, then the organic matter will be oxidized and these elements will perhaps be mobiblized and escape into the sea water. Again, very preliminary and a lot of work has to be done.

The only reason I gave this paper was to talk to some people about the biological uptake. If anyone knows about the uptake of transition metals from the sediment-water interface, then I would enjoy talking to you afterwards.

TABLE 1

**Los Angeles County**

| Fraction | Reagent | Percent of metal removed | | | | Percent sediment dissolved |
|---|---|---|---|---|---|---|
| | | Zn | Cu | Cd | Pb | |
| I | Boiling water | 0.4 | 0.3 | 1.1 | 0.5 | 8.2 |
| II | 1:10 acetic acid | 49.0 | 0.08 | 50.2 | 17.9 | 6.7 |
| III | 1:5 acetic acid | 22.7 | 1.2 | 24.5 | 8.9 | 2.5 |
| IV | 1:2 acetic acid | 10.5 | 0.5 | 10.7 | 7.6 | 2.3 |
| V | Acetic acid | 3.3 | 0.7 | 2.7 | 4.0 | 4.0 |
| VI | 1:10 nitric acid | 11.7 | 82.3 | 7.6 | 40.7 | 17.5 |
| VII | 1:5 nitric acid | 1.4 | 10.7 | 0.9 | 12.8 | 4.1 |
| VIII | Nitric acid | 0.4 | 2.2 | 0.7 | 2.2 | 1.5 |
| IX | 1:1 perchloric acid | 0.4 | 1.9 | 0.7 | 3.1 | 4.4 |
| X | Perchloric acid | 0.3 | 0.2 | 0.7 | 2.2 | 1.0 |
| XI | Hydrofluoric acid | 0.4 | 0.4 | 0.3 | 0.2 | 47.8 |

*Question:* .6 cm. per year?

*Galloway:* That is what could be said.

*Question:* You were correlating this with the data when the effluent started going into the ocean. Was that 10–12 years ago?

*Galloway:* 1957, 13 years ago. Or it could be 1945 when the Los Angeles population started to increase rapidly.

*Lasker:* What kind of organisms do you find around that outfall?

*Galloway:* I've found only red worms and shrimp in my cores. But there are pictures of fish trying to swim into the outfall pipe presumably because the waste water is so rich in nutrient and organic matter.

*Question:* What happens if you treat these samples with sea water? I would think there might be some ion exchange going on.

*Galloway:* True, but these sediments have been in contact with sea water for a long time.

*Question:* You might get fresh sea water flowing over these at all times.

*Galloway:* I don't know. You can have 0.3 billion gallons of waste water per day coming out there.

*Question:* You also have California Current water.

*Galloway:* Yes, but California Current at depth here really doesn't have that much umph. This is a real tidal surge area here.

*Question:* Is the composition of the sediment different in here—size, distribution, etc.?

*Galloway:* Yes.

*Question:* Have you done a similar study on an area not affected by an outfall? Because your organic content could go up or down for natural reasons.

*Galloway:* No, but I would say that the best place to study background level is right in that area, at depth in the sediment column.

*Question:* Did you measure mercury?

*Galloway:* No. I tried measuring mercury by neutron activation, but you have to do some chemistry after radiation and I haven't had the time to go back. That is in the works.

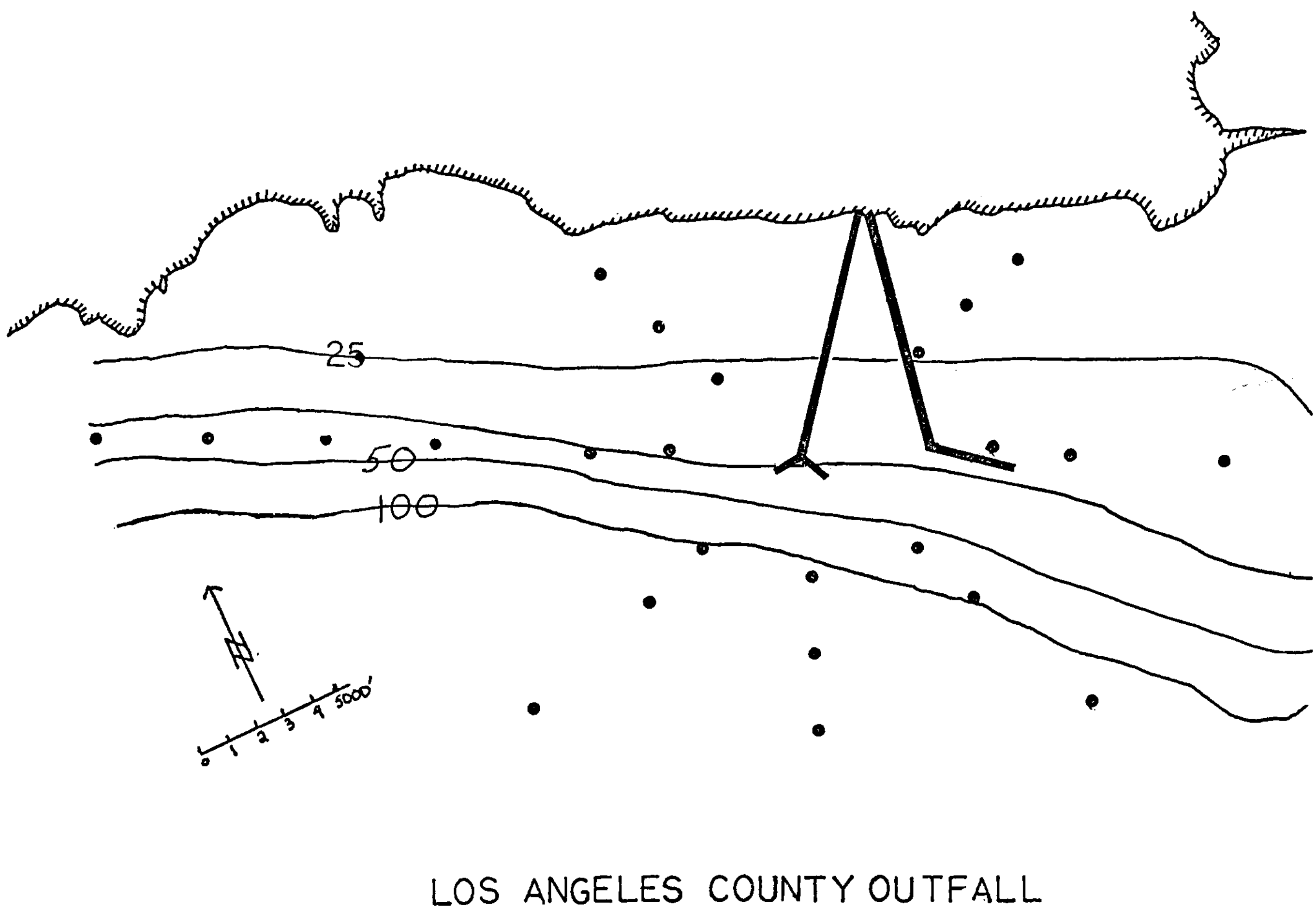


**FIGURE 1. Sediment core stations near Los Angeles County outfalls. Depths in fathoms.**

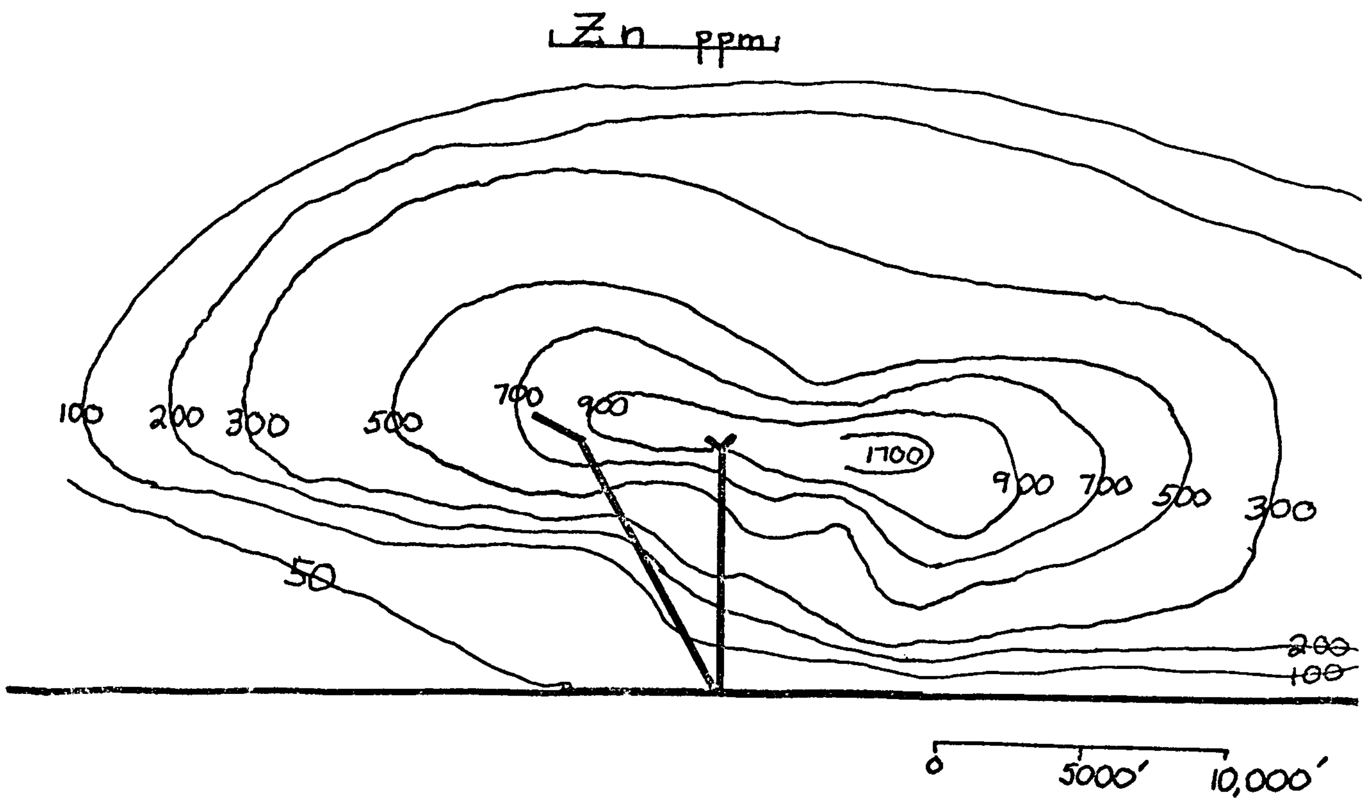


FIGURE 2. Generalized distribution of concentration of zinc in parts per million in surface sediments near Los Angeles County outfalls.

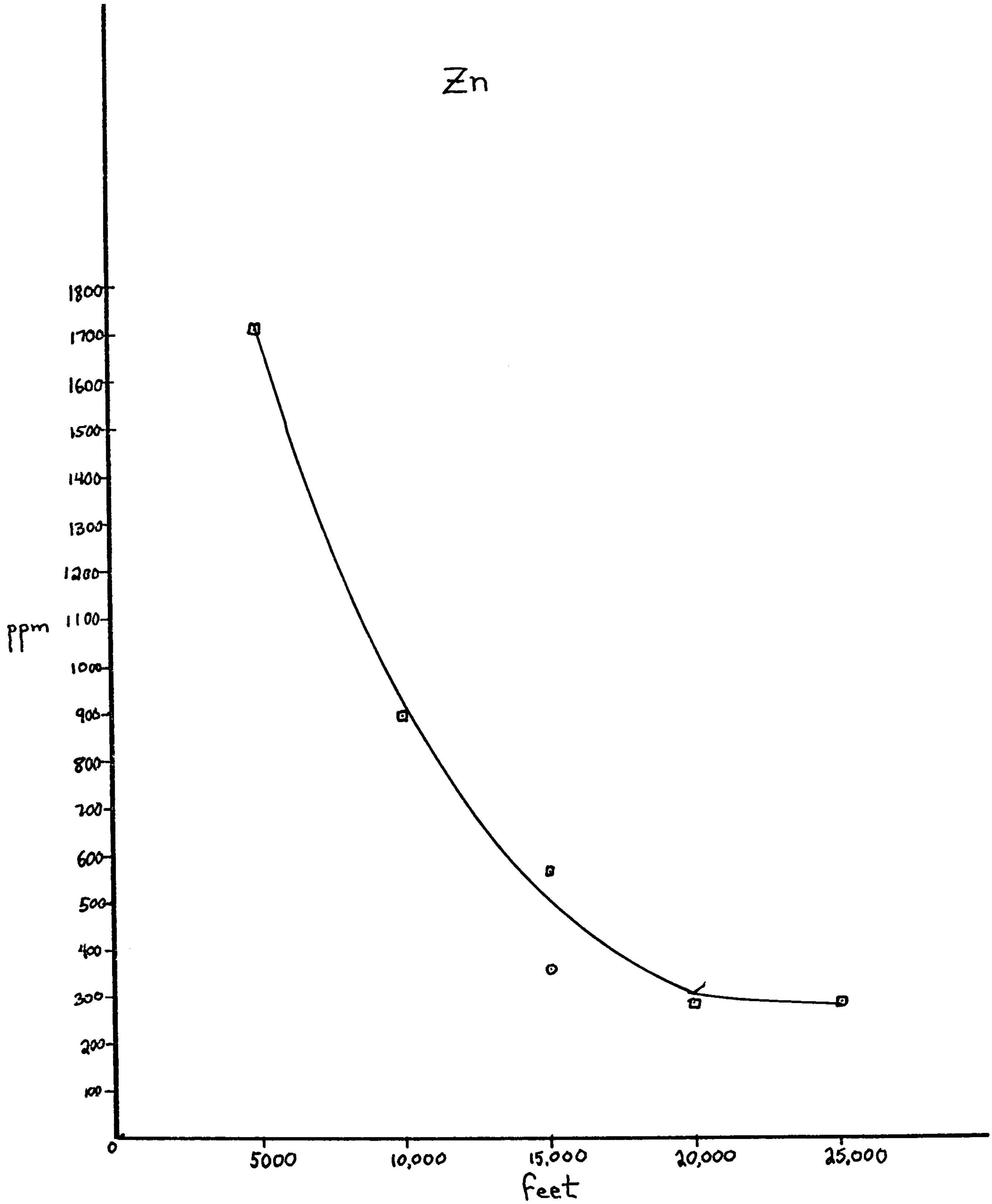


FIGURE 3. Relation of concentration of zinc in surface sediments to distance from outfalls. Concentration in parts per million. Horizontal distance in feet.

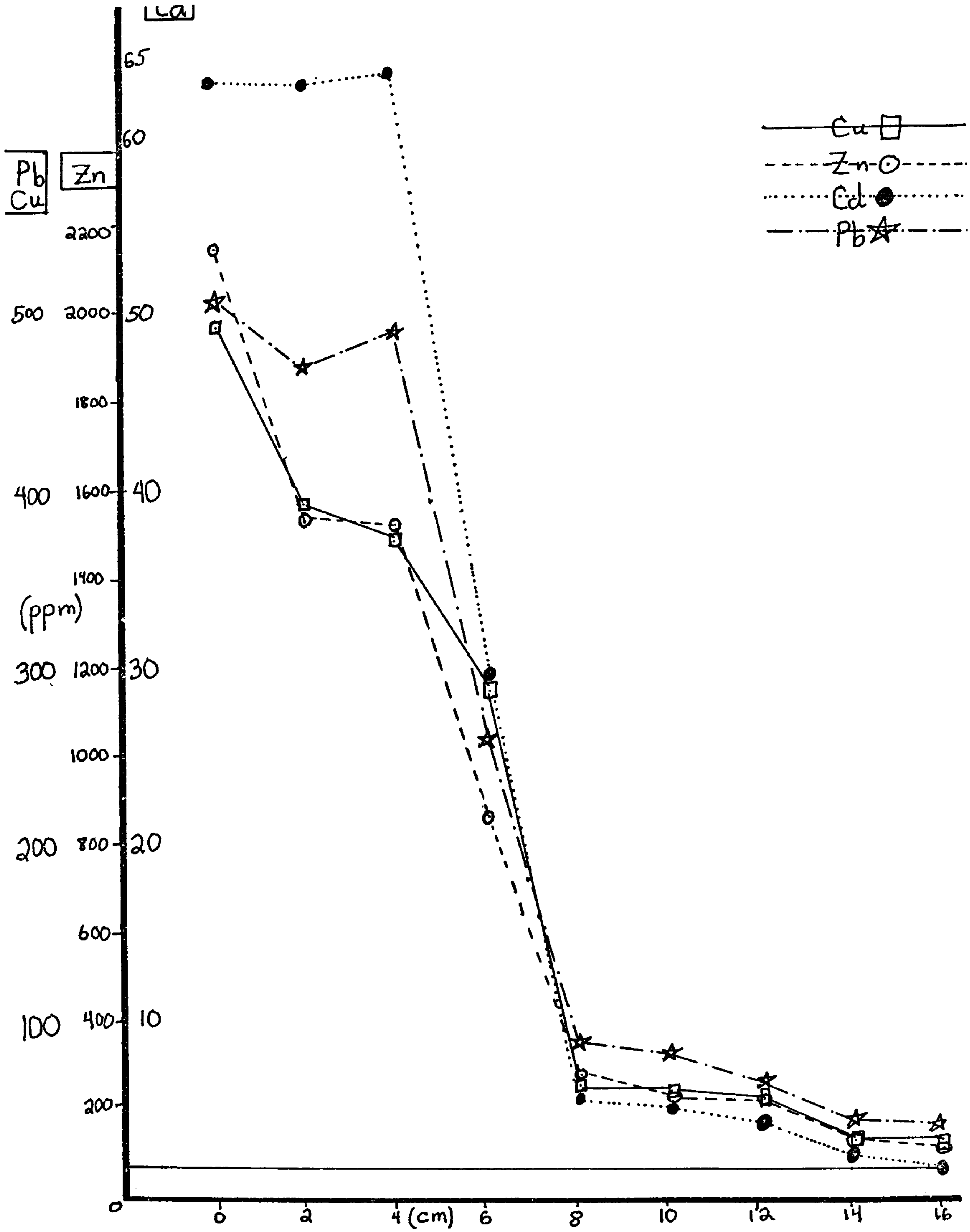


FIGURE 4. Relation of concentration of copper, zinc, cadmium and lead in a sediment core to depth below the sediment-water interface. Concentrations in parts per million are shown in the scales on the left. Depth in centimeters.

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# BIOLOGICAL CHANGES IN LOS ANGELES HARBOR FOLLOWING POLLUTION ABATEMENT

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## INTRODUCTION

Los Angeles-Long Beach harbors are an example of a highly industrial body of water which has been modified by construction (Figure 1). Industrial wastes of various types, of which oil refinery wastes constitute the single most important kind, are emptied primarily in the inner harbor areas. Domestic sewage is discharged throughout the region but only the wastes from the Terminal Island sewage treatment plant discharge any large quantity of effluents. Storm drains are located throughout the harbor area. Los Angeles and Long Beach harbors are one harbor oceanographically; the distinction is political, with the administration under two separate city harbor departments. Originally the area was a marshland with meandering channels. The Los Angeles River flowed into the inner harbor near Consolidated Slip (Figure 1). The river was diverted to its present course in 1923. Development of the harbor area began in 1850 and has proceeded to this day (McQuat, 1951; Anon., 1952; Reish, 1959).

The history of pollution in the harbor area has been outlined in the accounts by Anon., 1952; Larson, 1956; Reish, 1959. Biological studies concerned with pollution in the Los Angeles-Long Beach Harbors include these accounts: benthic studies (Anon., 1952; Reish, 1955, 1957a, 1957b, 1959, 1960, 1963, 1964b), fouling organisms (Barnard, 1958; Crippen and Reish, 1969; Reish, 1961a), experimental studies (Reish and Barnard, 1960; Reish, 1961b), and wood-boring organisms (Menzies, Mohr, and Wakeman, 1963). Oil refinery wastes constitute the single most important industrial waste discharged into the harbor. A peak of 16.5 m.g.d. of oil refinery wastes was emptied into Dominguez Channel in 1968. The effect of these wastes on the benthic fauna has been recorded in Reish (1959) and on fouling organisms in Crippen and Reish (1969). Essentially the harbor floor in the area affected by this discharge was devoid of animal life (Figure 2, Table 1). Only a few fouling organisms were observed over a period of years at station LA50; these consisted of blue-green algae, tubificid oligochaetes and rat-tail maggots. Five species of polychaetes, with *Capitella capitata* dominating, were present on boat docks at station LA 54 along with the green alga *Enteromorpha crinita*, chironomid larva, and tubificid oligochaetes. These biological conditions have been similar since I began studying this area in 1950. Elsewhere, the benthos of Los Angeles-Long Beach Harbors was divided into five zones on the basis of the association of polychaete species: a healthy zone characterized by *Tharyx parvus*, *Nereis procera*, and *Cossura candida*; semi-healthy zone I, characterized by *Polydora (Carazzia) paucibranchiata* and *Dorvillea articulata*; semi-healthy zone II, characterized by *Cirriformia luxuriosa*; a polluted zone characterized by *Capitella capitata*; a very polluted zone devoid of macroscopic life (Reish, 1959).

TABLE 1

**Number of Species Collected from Boat Docks and Harbor Floor**

| Station Number | Docks | Benthos | |
|---|---|---|---|
| | October 1970 | November 1954[1] | October 1970 |
| LA51 | 13 | 0 | 10 |
| 50 | 15 | 0 | 4 |
| 49 | 16 | 0 | 6 |
| 54 | 18 | 0 | 11 |
| 26 | 27 | 15 | -- |
| 7 | 37 | 11 | -- |

[1] Data from Reish, 1959b.

### *Pollution Abatement in the Consolidated Slip-East Basin Region*

On February 21, 1968, the California Regional Water Quality Control Board, Los Angeles Region, issued an order prohibiting the discharge of oil refinery wastes into the Dominguez Channel. Following this directive, the 18 major companies involved either ceased emptying their wastes into the channel or eliminated the oxygen-depleting fraction of their discharge. The last company to comply with this order did so on September 25, 1970. The average daily volume discharged into this region is now 4 m.g.d. and consists largely of cooling waters or wastes from which the oxygen-depleting portion has been removed. The estimated costs for this clean-up were over 20 million dollars.

Since the termination of collections on January 8, 1968, as reported by Crippen and Reish (1969), I have visited the Consolidated Slip-East Basin region in May 1968 and April 1970. The conditions on the boat floats were identical to the earlier studies. However, during the summer of 1970, I received various reports that biological conditions in this region were changing. I visited the area on October 30, 1970, and saw marked changes in the biological conditions. This report, therefore, constitutes the observations made on that date.

## MATERIALS AND METHODS

The biological characteristics were observed at six stations in Los Angeles Harbor on October 30, 1970. These stations (Figure 1) were selected with reference to an increasing distance from the source of oil refinery discharge. The exact location of these stations has been described previously (Reish, 1959; Crippen and Reish, 1969). Biological materials (= fouling organisms) were removed from floating boat docks and placed in pans for field identification; some smaller species were identified later in the laboratory. Subtidal benthic samples were taken at the four inner stations with a size one Hayward orange peel bucket, and the material was washed through a screen with a mesh opening of 0.7 mm. The material retained on the screen was preserved with formalin and brought to the laboratory for identification. Subsurface water samples were taken for dissolved oxygen measurements according to the Winkler method.

## DATA

*Dissolved oxygen.* The present dissolved oxygen concentration at all stations is recorded in Table 2 together with some previously published data. It can be seen that the concentration of oxygen has increased markedly in the inner harbor area following pollution abatement.

*Fouling organisms.* The number of species encountered on the boat docks at the six stations is recorded in the second column of Table 1. It can be seen from these data that the number of species encountered increases from a low of 13 at LA51 to a high of 37 at LA7. For the most part, species present at LA51 were present at the other stations. The bay mussel,

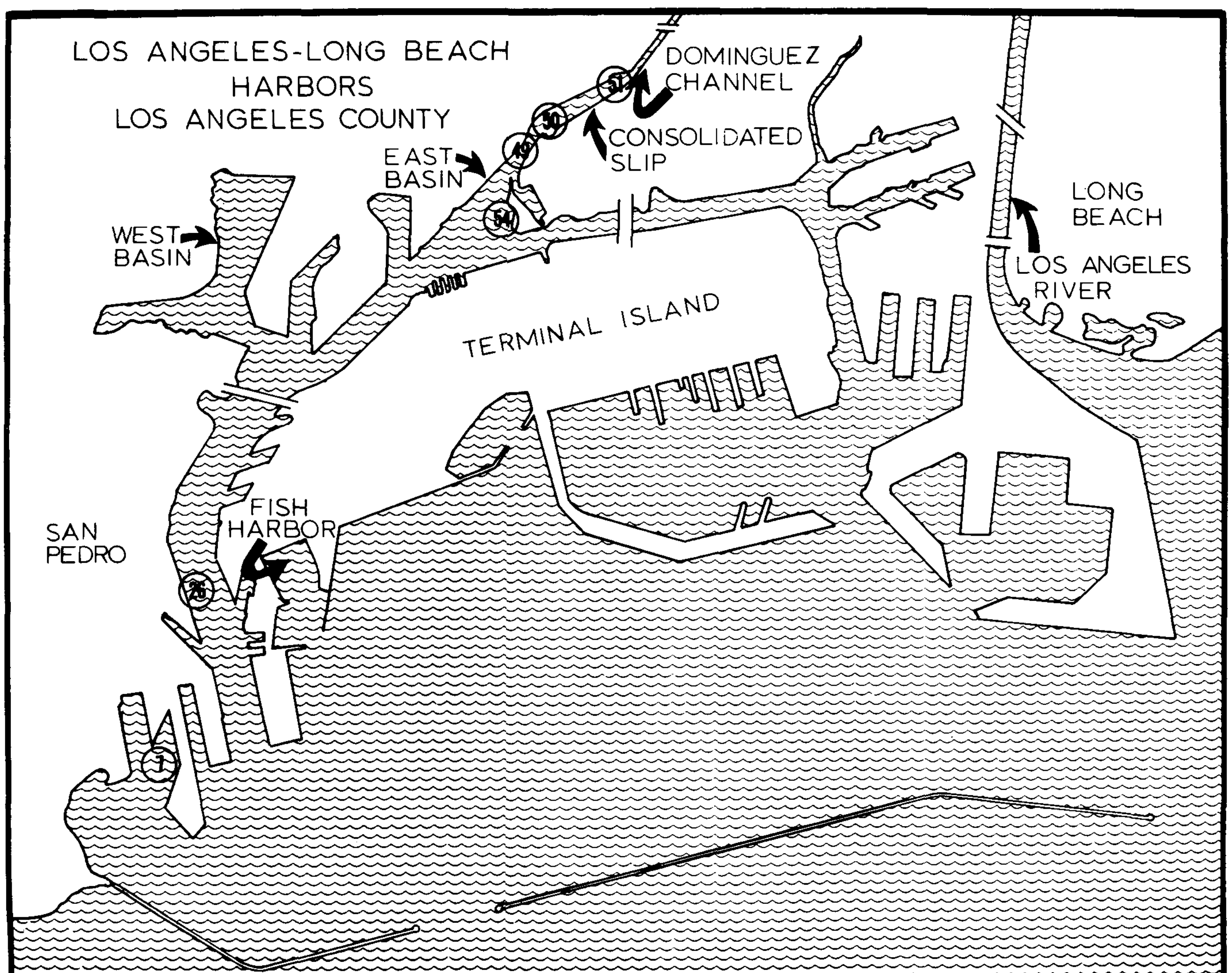


**FIGURE 1. Map of Los Angeles-Long Beach Harbors, California, showing station locations and other features mentioned in the text.**

*Mytilus edulis*, was present at all stations, but it was not considered a dominant member of the present community except at the three outer stations (LA54, 26, 7). The green alga *Enteromorpha crinita* and the polychaete *Hydroides pacificus* were dominant species at LA51, 50, 49 and 54. The wood-boring isopod *Limnoria tripunctata* was observed burrowing into wood at LA50 and 54.

*Benthic organisms.* The number of species encountered in the benthos at the four stations in the Consolidated Slip-East Basin region is given in the third and fourth columns of Table 1. With the exception of LA51, the number of species increased as one proceeded away from the previous source of waste discharge. The polychaete *Dorvillea articulata*, characteristic of semi-healthy zone I, was the most prevalent animal taken along with the pelecypods *Chione undatellum* and *Hiatella arctica.* The polychaete *Capitella capitata*, the characteristic animal of the polluted zone, was the dominant animal at the remaining three stations. The substrate at these four stations was black and possessed a sulfide odor.

TABLE 2
**The Dissolved Oxygen Concentration (in mg/l) at Selected Stations in Los Angeles Harbor 1954–1970**

| Station | November[1] 1954 | October[2] 1966 | October[2] 1967 | October 1970 |
|---|---|---|---|---|
| LA51 | 0.0 | -- | -- | 3.8 |
| 50 | 0.0 | 0.4 | 0.2 | 4.4 |
| 49 | 0.5 | -- | -- | 4.4 |
| 54 | 1.0 | -- | 0.9 | 5.2 |
| 26 | 2.3 | 2.4 | 1.7 | -- |
| 7 | 3.7 | 4.5 | 2.7 | -- |

[1] Data from Reish, 1959.
[2] Data from Crippen and Reish, 1969.

## DISCUSSION

Comparisons of the data for fouling organisms for October 1970 with those of 1966–67 indicate striking changes in the community structure. The blue-green algae-oligochaete and the *Enteromorpha crinita*-oligochaete associations, which occurred previously at the stations with little or no dissolved oxygen, were no longer present. The *Mytilus edulis* community, with some additional commonly encountered species, apparently is developing at all stations. It is, however, progressing in degrees. The alga *Enteromorpha crinita* is the prominent species at the inner stations and *Ulva lobata* at LA26 and LA7. The large population of *Hydroides pacificus* ( = *H. norvegica*) may be the result of warmer water temperatures or the absence of competition for space on floating logs (Reish, 1961a; 1964a). *Limnoria tripunctata* has now moved into regions of the harbor where it has been absent (Menzies, *et al.,* 1963).

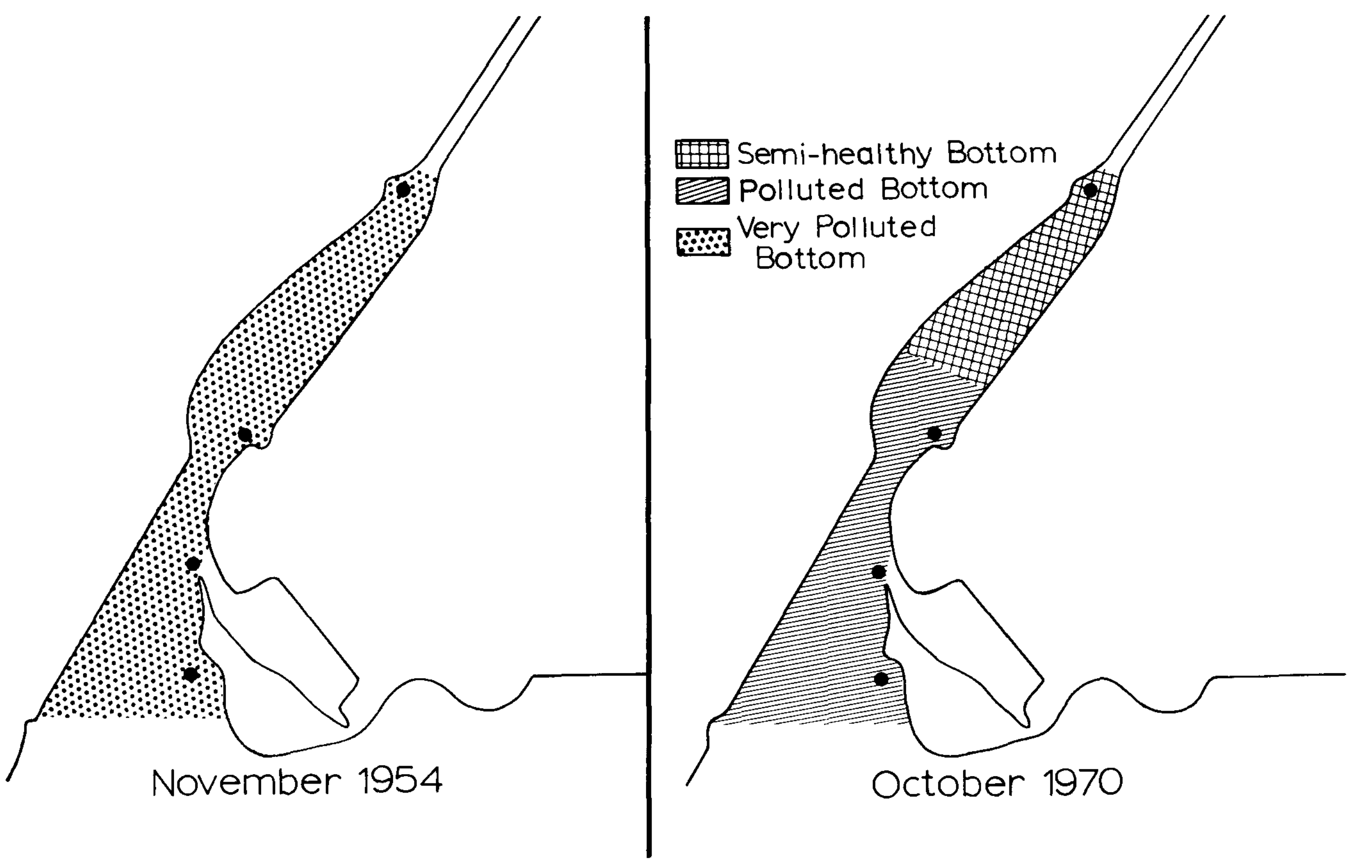


**FIGURE 2. Summary of distribution of bottom conditions in the Consolidated Slip-East Basin region of Los Angeles Harbor in November 1954 and October 1970.**

Comparisons of the findings for the benthos in 1954 with 1970 (Table 1) are equally striking. Except for the period of one year following dredging activity in 1953 (Reish, 1957b), no macroscopic life was present in this region. All animals collected in 1970 were present in either the main channel or outer harbor area in 1954. The organisms at these four stations have representatives of the polluted zone (*Capitella capitata*), the semi-healthy zone I (*Dorvillea articulata* and *Polydor paucibranchiata*) and semi-healthy zone 2 (*Cirriformia luxuriosa*) (Reish, 1959). It is of interest that no dominant species from the healthy zone was present. It appears from these data that station LA51 has progressed further towards cleaner conditions than either LA50 or 49 and perhaps 54 (Figure 2).

I think that some possible biological predictions may be appropriately stated herein. Initially, with the termination of the oil refinery discharge, water quality improved and dissolved oxygen appeared. Since many of the local species of marine organisms, especially bay and harbor representatives, have either extended reproductive periods or reproduce throughout the year (Reish, 1961b), larvae were able to settle rapidly. Successful settlement and growth of a greater diversity of organisms occurred more rapidly on the boat floats than the benthos because of the lack of the accumulative wastes characteristic of the bottom. Since *Mytilus edulis* reproduces during the winter months in nearby Alamitos Bay (Moore and Reish, 1969) with settlement of larvae extending into the spring months (Reish, 1964a), apparently sufficient water quality improvement had occurred by the end of spring 1970. It seems logical to assume that *M. edulis* will become the dominant organisms on the boat docks in 1971.

Speculation concerning the benthos is more difficult, especially with regard to estimating recovery time. Several variables will influence this rate of recovery. The affected sediments extend to at least a depth of 20 cm; the time required for the oxidative processes to change these sediments is unknown. Dominguez Channel also serves as a flood control channel, and the amount of run-off from rain may influence this rate of recovery. Finally, the role played by the early inhabitants in assisting this oxidative process is unknown. It is also difficult to predict the final community structure at these benthic stations. *Capitella capitata* is the normal dominating organism in similar upper reaches of Alamitos Bay (Stone and Reish, 1965). It is doubtful that the healthy zone from the outer harbor will extend this far; however, it is quite possible that this zone may extend up to the level of LA26 or farther since this abatement.

## ACKNOWLEDGMENTS

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# SANTA BARBARA OIL SPILL—INTERTIDAL AND SUBTIDAL SURVEYS

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On January 28, 1969, Union Oil Platform-A, which is 6½ miles south of Santa Barbara, California, ruptured. By February 3, a large oil slick had surrounded Anacapa Island and was encircling the eastern end of Santa Cruz Island.

During February 5–13, California Department of Fish and Game marine biologist-divers and warden-divers established 14 transects around the islands: Anacapa, 4 and Santa Cruz, 10. The transects extended from the high tide line into depths which did not exceed 50 feet (Figure 1). Visual observations were made as to the presence or absence of oil and its apparent effect upon the marine life. Table 1 summarizes our observations. Subsamples, scrapings, or counts within a measured quadrat, were taken in areas inundated by oil.

In general, during our February 1969 survey, the various animal and plant assemblages observed appeared normal. However, some plants and animals in the intertidal area, from the splash zone to just below low tide, were coated with varying amounts of oil. Oil was observed on the surface canopy of many of the kelp (*Macrocystis*) beds, but most of this oil could be easily shaken off. During the storm, the kelp beds were cleaned by the rough waters. The surf grass, *Phyllospadix torreyi*, at Anacapa Island was heavily coated with oil when the initial survey was made on February 5. By February 14, the plants were free of oil. Subtidal plants and animals appeared untouched by the oil. Oil slicks were observed in slight to moderate amounts around both islands, particularly on both sides of the middle of Anacapa Island. These slicks of coalesced oil droplets formed dense patches up to ¼ inch in thickness which extended seaward from the shore for several hundred feet. Beached oil adhered to the intertidal rocks and driftwood in patches several hundred feet long. These patches were up to 20 feet wide, and were in lumps

FIGURE 1. ISLAND INSHORE DIVING SURVEY TRANSECTS

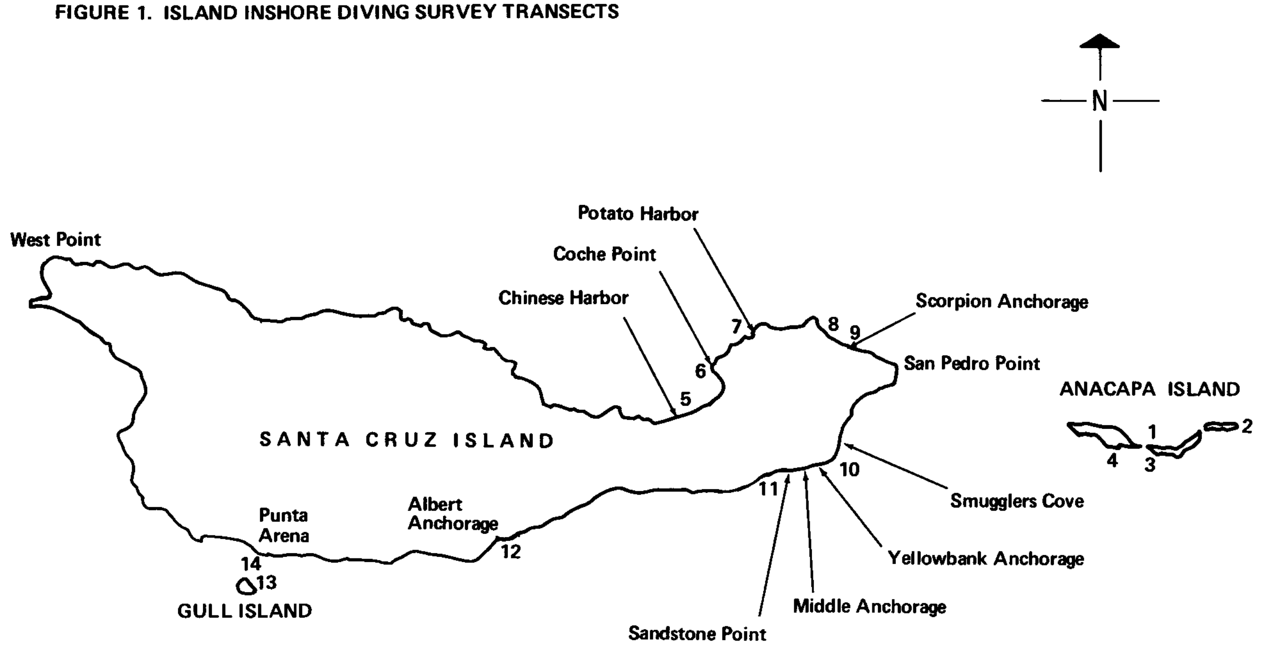


FIGURE 1. Island Inshore Diving Survey Transects.

up to ½ inch thick. The patches were commonest on the north side of the middle of Anacapa Island and on Santa Cruz Island at Punta Arena, Yellowbank Anchorage, Smugglers Cove, and Scorpian Anchorage. At Santa Cruz Island, major concentrations of floating oil were observed in the kelp canopy at Scorpion Anchorage and in the nearshore waters between Sandstone Point and Middle Anchorage. Topsmelt, *Atherinops affinis,* would swim up under the coalesced floating oil and investigate its lower surface. Several dead birds were observed in the kelp canopy at Scorpion Anchorage and three dead surf scoters were observed on the beach. About 35 California sea lions, *Zalophus californicus,* coated with oil, but in no apparent distress, were observed at Sandstone Point. Another group, about 300, observed in the vicinity of Coche Point, had no evidence of oil on them. The black abalone, *Haliotis cracherodii;* gooseneck barnacles, *Pollicipes polynerus;* and numerous other intertidal animals as well as the algae, *Hesperophycus harveyanus*, *Pelvetia fastigiata,* and surf grass, *P. torreyi* were heavily coated with oil at Punta Arena. On the north shore of Anacapa Island, numerous oil droplets were suspended in the water column from shore seaward about 100 feet. These droplets appeared to be adhering to organic detritus, wood chips and grass, which had washed into the sea during the recent rains. Although visible in the surge zone throughout

TABLE 1

**Diver Observations and Collections at Anacapa Island**

| Species | Number |
|---|---|
| Algae | 33 |
| Invertebrates | 62 |
| Vertebrates (marine fishes) | 19 |
| Marine mammals | 2 |

**Diver Observations and Collections at Santa Cruz Island**

| Species | Number |
|---|---|
| Algae | 48 |
| Invertebrates | 100 |
| Vertebrates (marine fishes) | 35 |
| Birds | 3 |
| Marine mammals | 1 |

the water column, these droplets did not adhere to the substrate or the plants and animals.

On April 9 and 10, 1969, we resurveyed the transects previously established in February. The plants and animals appeared normal, except that there was some question as to the healthy condition of the surf grass at Anacapa Island (Transect I) and one alga at the Punta Arena Transect. The surf grass at Transect I, which had been heavily coated with oil on February 5 and appeared clean on February 14, had turned yellow at its base. Normally, the entire

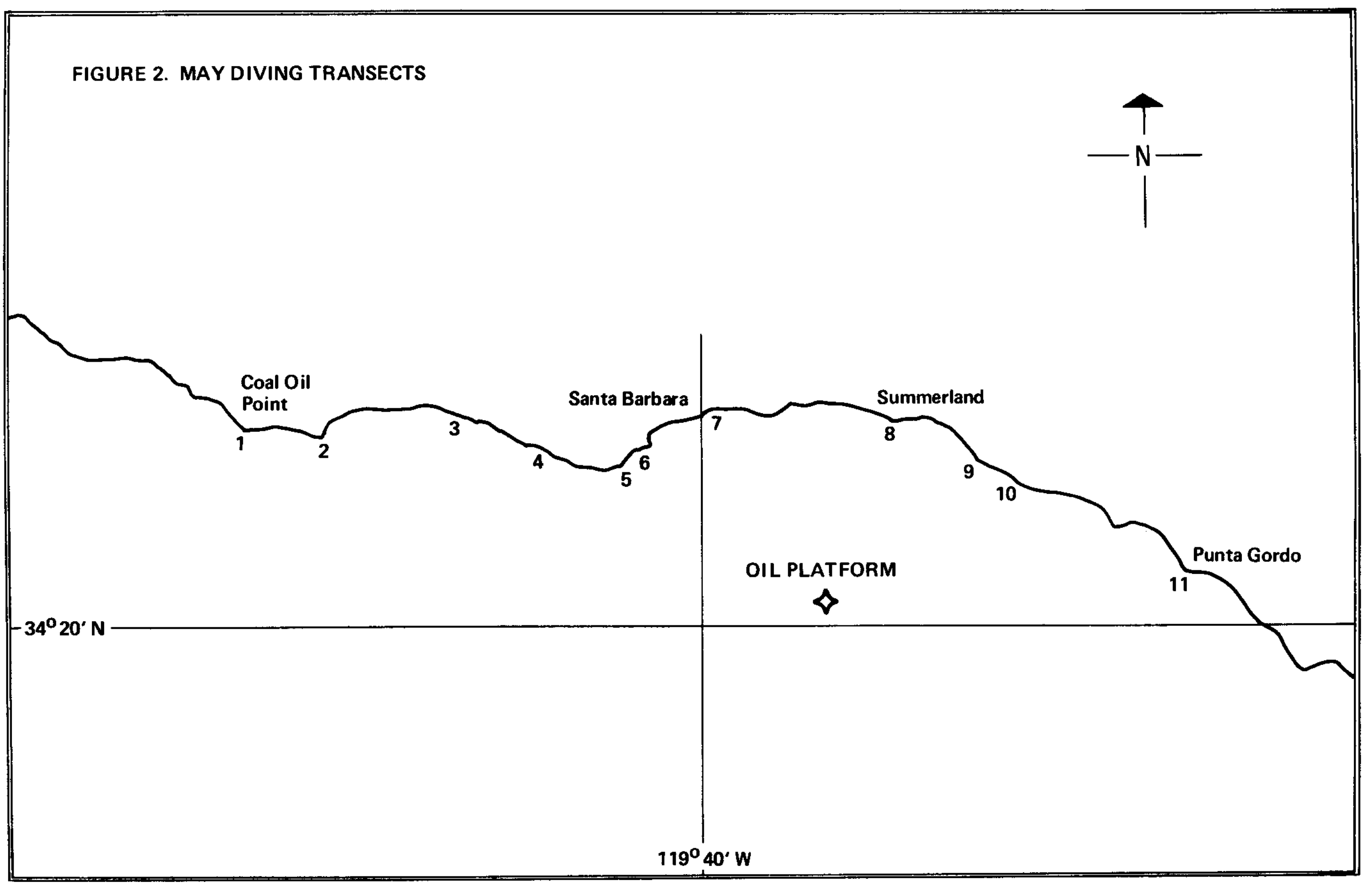


FIGURE 2. May Diving Transects.

plant is green. The alga *H. harveyanus* at Punta Arena, which was heavily coated with oil on February 13, was apparently absent. The only concentration of floating oil observed was on the north side of the middle of Anacapa Island. Again the plants and animals observed appeared to be free from the oil. The oil on the shells of mollusks in the intertidal areas had hardened by the time we made our August 1969 survey; nevertheless, the animals were still healthy. While oil had hardened on some of the rocks, invertebrates in the area were in good condition and appeared unharmed by the oil on their habitat. At Punta Arena the alga *H. harveyanus*, which was heavily coated with oil on February 13, 1969, and nearly absent on April 10, was again observed in near normal quantities. On August 6, numerous young plants (one to two inches long) were recorded at this station. Apparently only the adult plants had been adversely affected by the oil slick coating in this area. With the oil nearly dissipated, the exposed rock was again acceptable habitat for this alga. The only oil noted at either island was in small patches which had adhered to the rock surfaces above the high tide line, or on material buried by 3 to 4 cm of cobble on the beaches.

The fourth, and final survey around the islands, was conducted during February 1970. The alga, *H. harveyanus* at Punta Area had attained lengths of 4 to 5 inches. The only oil noted was at the same locations as during the August 1969 survey.

During each diving survey, the California spiny lobster, *Panulirus interruptus*, was observed at a number of stations. All appeared to be healthy. Commercial lobster fishermen in the area reported that when a trap was brought to the surface the oil floating on the water would adhere to a trapped lobster's shell and kill the lobster. From diving observations, it appears that as long as the lobsters were not covered by the oil film, they suffered no ill effects. Since lobsters occur below the intertidal zone, the lobster resource exhibited no known damage as a result of the oil leak.

No deleterious effects due to oil, on invertebrates in the subtidal areas along the mainland, were observed on 11 transects in our May 1969 survey (Figure 2). Oil was encountered on several of the beaches, on the water surface at several locations, and on the bottom at Coal Oil Point.

Several factors contributed to keeping the loss of marine life to a minimum: the oil flowing from the blowout was of such a gravity that it floated on the water's surface; the use of dispersants, detergents, or other chemicals was prohibited in State waters; and as a result of the January floods the beaches and inshore waters had great quantities of flotsam and jetsam on them which helped to absorb the oil.

## SUMMARY

There was some initial damage to certain algae and a surf grass on the Channel Islands, but later surveys revealed that these plants had recovered. The invertebrates generally appeared to have remained healthy and viable. Our surveys indicated that all the fish observed were free from oil, and showed no signs of starvation due to oil on the plants and animals in their food chain.

Speciation diversity appeared to have remained the same as before the oil leak. During our diving survey, we found no indication that there had been any modification in the number of species present.

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# A SURVEY OF THE BENTHOS OFF SANTA BARBARA FOLLOWING THE JANUARY 1969 OIL SPILL

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Los Angeles, California

The shelf off Santa Barbara is rather extensive and forms a large embayment open to the west. It is cut from the remainder of the southern California Borderland by the row of Channel Islands to the south and east. The deepest part of this bay, the Santa Barbara Basin is somewhat to the south of the middle of the bay, so that the shelf areas off Santa Barbara are considerably wider than the shelf of the Channel Islands. It is on this wide portion of the shelf that the oil drilling off Santa Barbara has been taking place. Platform A, which started leaking during the last days of January 1969, is roughly in the middle of the widest portion of the shelf.

A large-scale benthic survey was done off the southern California coast by the Allan Hancock Foundation during the years 1956–1960. (Allan Hancock Foundation, 1965) This survey, which was financed through the State of California, concentrated on mapping the different kinds of environments found along the coast. During this survey some very high values of standing crop of macroinvertebrates were reported from the Palos Verdes shelf off Los Angeles and from the shelf off Santa Barbara; up to 2,800 grams per square meter were present off Palos Verdes and better than 2,300 grams per square meter off Santa Barbara. These values are among the highest measured in the marine environment.

The present study, referred to below as the Pollution Study (Allan Hancock Foundation 1971) was patterned as much as possible on the State Survey to facilitate comparisons. We used a different, large grab than was used during the State Survey, but the

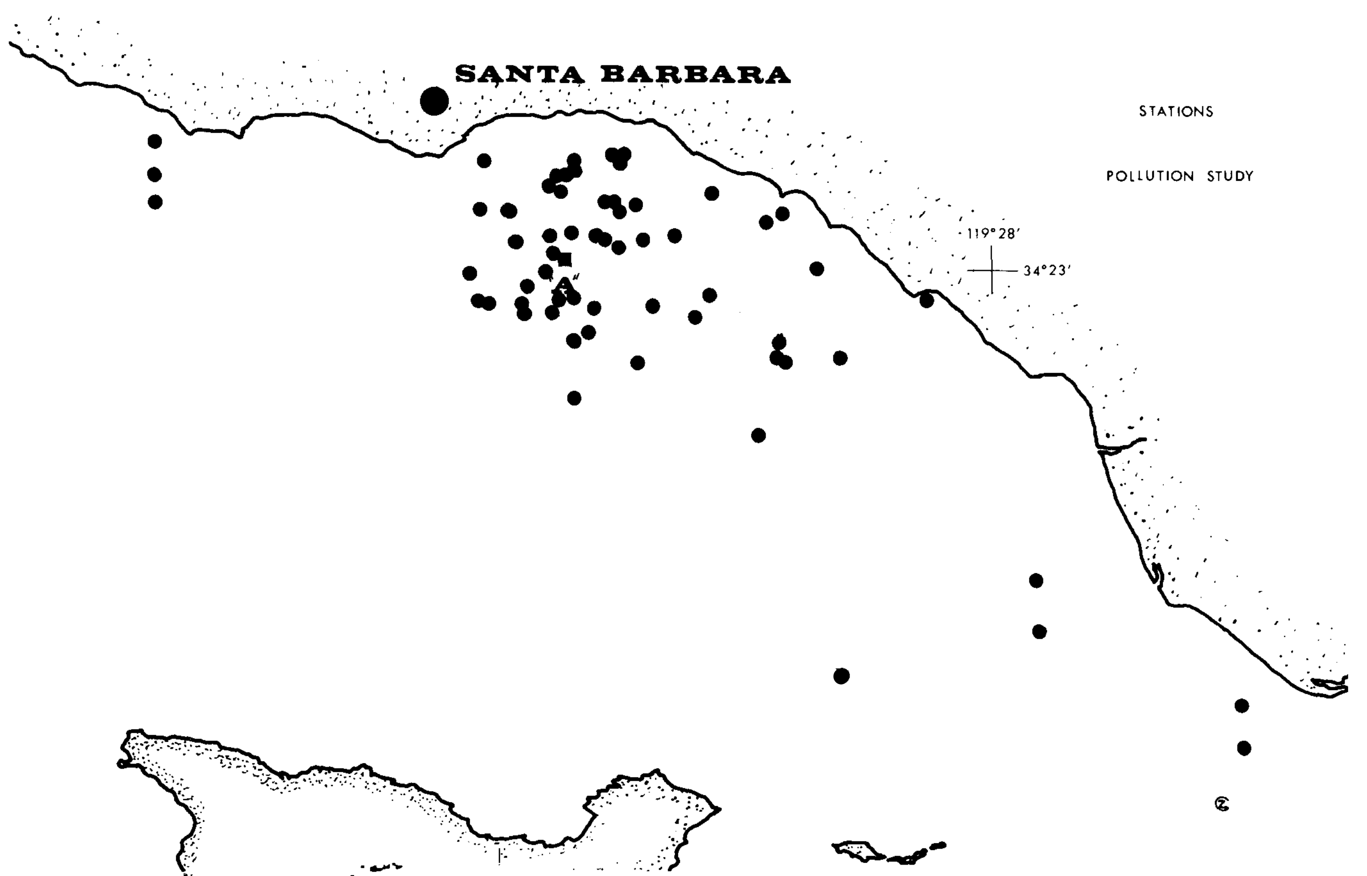



FIGURE 1. Stations, Pollution Study.

screening was done through screens of the same mesh-size and the lab-procedures were the same as much as possible.

It should be pointed out that neither study has been completed; both surveys were done only as far as the time and money permitted. During the State Survey at least some samples from all areas of the coast were as completely analyzed as possible; we had considerably shorter time to our disposal and had to analyze the samples as they came in. All samples in both surveys were analyzed for standing crop of macroinvertebrates. During both studies emphasis was placed on analyzing those groups that made up the largest fraction of the standing crop. In most samples analyzed, the groups actually identified is somewhere between 50 and 75% of the total standing crop.

The stations were taken in a pre-determined pattern (Fig. 1). In early March 1969 we took a series of samples scattered over the whole shelf area to see if we could identify any large-scale immediate effects of the oil spill. In May and June we repeat-sampled selected areas where the densest concentration of standing crop had been reported during the State Survey. Finally, in October, 1969 we re-sampled the whole area as much as possible. The areal distribution of samples during the Pollution Survey was approximately the same as during the State Survey in the same area, even if the number of samples was considerably higher during the latter study. As an example can be mentioned that during the State Survey we re-sampled the same area four times a year in an attempt to demonstrate temporal variations in the fauna; such an approach was impossible during the Pollution Study.

Perhaps the most striking differences between the results of the State Survey and those of the Pollution Study are in the records of standing crop. Figure 2 shows the standing crop in 1956–60. The population is described by contours, where points of similar standing crop have been connected to show the distribution of standing crop in the bottom. This method of showing standing crop has been criticized since it connects areas that have little or nothing to do with each other biologically, except that a similar amount of living macroinvertebrates is present in all areas connected. Nevertheless, the method gives a striking picture of what has been taking place off Santa Barbara in the ten years separating the two surveys (Figure 3). In general, the base-level of standing crop is similar in both surveys; it may have been re-

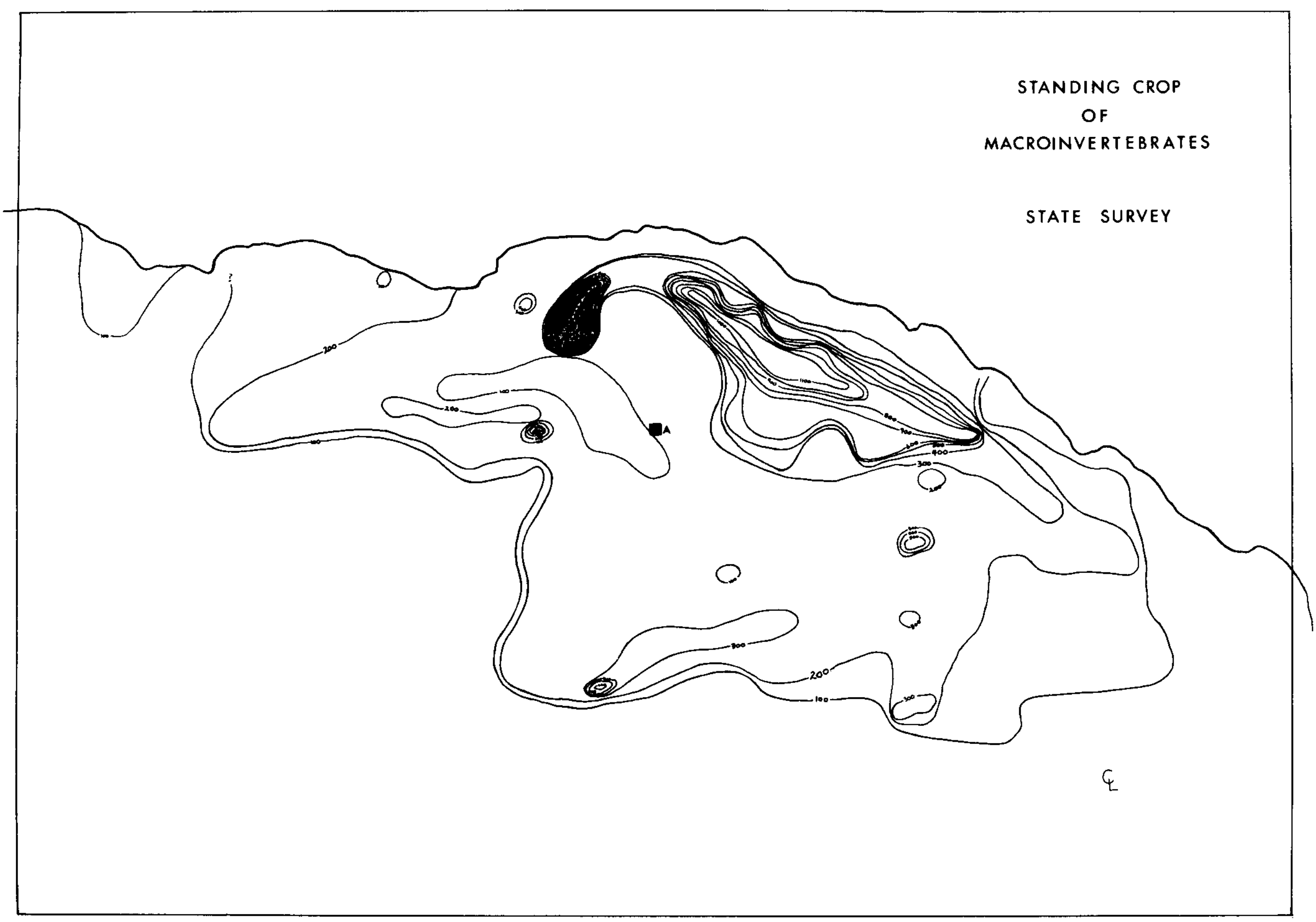
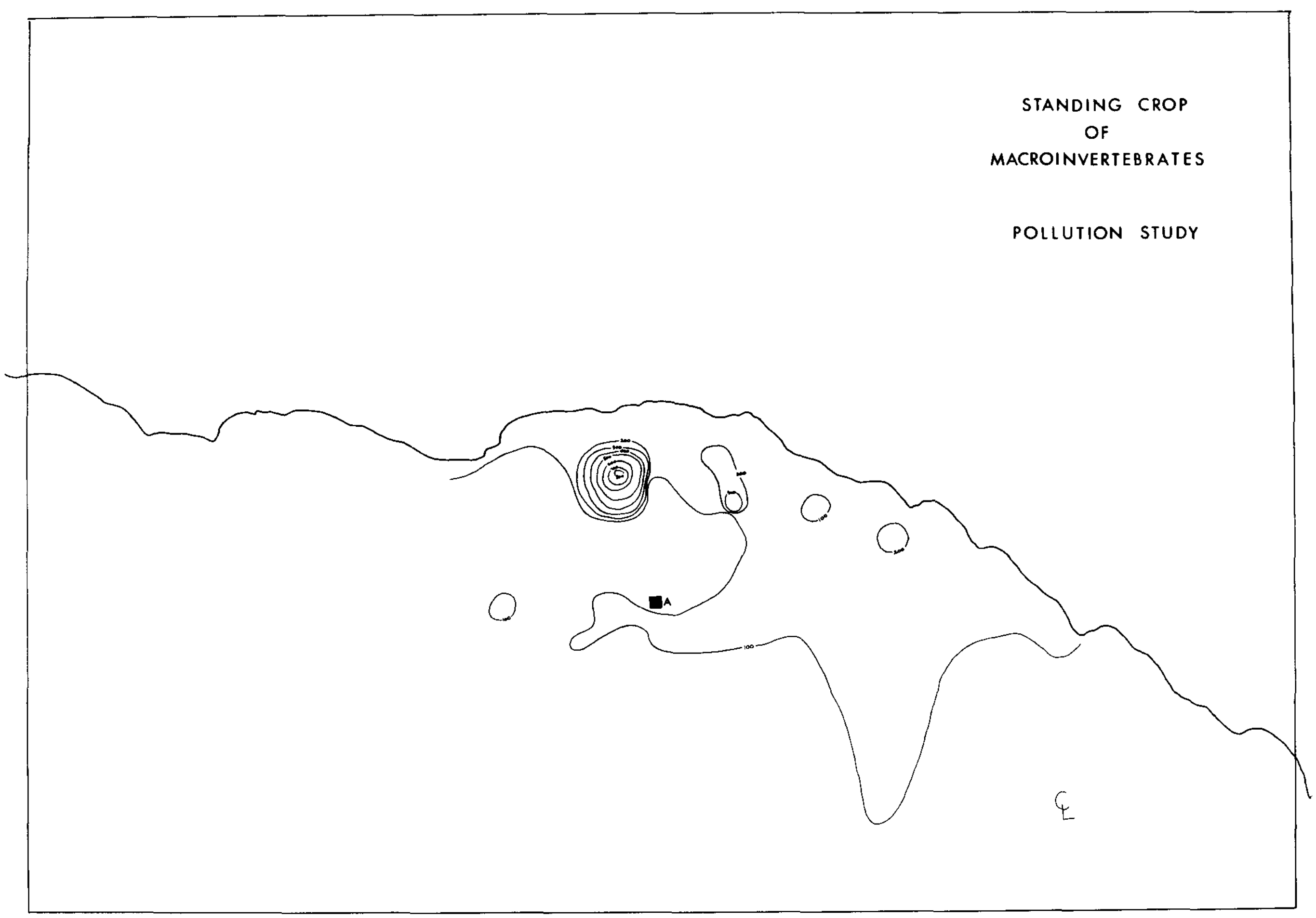



**FIGURE 2. Standing crop of macroinvertebrates, State Survey.**

duced slightly in some areas, but this may be due to natural fluctuations in the bottoms. Generally, the values of standing crop over most parts of the shelf off Santa Barbara appear to be near 100 grams per square meter. Inshore of Platform A was found a very large patch with high values of standing crop; the peak values reported in the State Survey were near 2,300 grams per square meter. During the Pollution Study we found no value higher than 800 grams per square meter in the same area. Most of the repeat-sampling, both during the State Survey and the Pollution Study was done in this general area, so both sets of data are considered equally valid. Even more striking is the absence of the very dense areas stretching from Santa Barbara to Carpinteria as an eastwards extension of the major peak in biomass. This large area has dropped severely in standing crop in the ten years separating the two surveys.

This whole high-density area is essentially made up of a single species, the echiuroid worm *Listriolobus pelodes* Fisher. It was primarily thought that there had been a mass extinction of the worm in some areas, but the geographical distribution of *L. pelodes* in both surveys (Figs. 4–5) does not seem to have changed between the two surveys. The species is still present in roughly the same area it occupied ten–fifteen years ago, but has been drastically reduced in numbers in the intervening years. It should be remarked that in general communities that are dominated totally by one species tend to be rather unstable ecologically and the drop in numbers of *L. pelodes* in these beds may thus be a highly significant event in the biology of the sea-bed off Santa Barbara. Furthermore, these beds are, as far as known, the only beds formed by *L. pelodes* throughout its range, which presently is considered to be from Monterey to Isla Cedros in Mexico. Barnard and Hartman (1959) indicated that the presence of the beds off Santa Barbara might be due to the sedimentation pattern in the area and that the species is highly dependent on suitable sediment conditions. The biology of *L. pelodes* is otherwise unknown; McGinitie and McGinitie (1949) reported no luck in maintaining these animals alive in aquaria. Some specimens were maintained for nearly three weeks under highly abnormal conditions at the Santa Catalina Marine Biological Laboratory during the summer of 1969 and intensive studies of the biology of this animal are now being planned.

Other changes that have taken place in the ten years that separate the State Survey from the Pollution



Study include certain changes in the faunal composition, especially among the polychaetous annelids and the mollusks. The echinoderm fauna appears to be the same as it was ten years ago, both in terms of species composition and in numbers of specimens. Some of the apparent species replacements may be due to taxonomic difficulties, but in a number of instances the specimens taken in the two surveys were compared directly and found to differ.

We tried to analyze the factors that may have caused the observed changes in the benthos. During 1969 there was very heavy flooding in the area, with a corresponding high influx of terrestrially derived sediments. Hartman (1960) reported a local extinction of the marine fauna in the vicinity of the Ventura River following a flood in April, 1958; the numbers of *Listriolobus* in the beds off Santa Barbara, appear, however to have been unaffected by this flood. The floods in 1969 were considerably larger than those in 1958, so the factor cannot be excluded based on this prior example of flood effect in the same general area. Because of the general increase in human population in Santa Barbara and Ventura Counties, there has been an increased flow of sewage over the area. No matter how well sewage is treated, an increased flow is going to mean an increased load on the sea bottom. This factor cannot be excluded, but cannot, on the other hand, be indicted as responsible until we know the biology of the animals living in the area considerably better than we do today. If *L. pelodes* is in fact dependent on the exact composition of the sediments, the drilling for oil in the beds may in itself be enough to upset the balance in these ecologically precariously balanced beds. Finally, the oil spill cannot be excluded as a factor either. We found in October 1969 a small *L. pelodes* sitting in the middle of an inch-thick layer of oil only some 150 yards from Platform A; this may indicate that the effects of the crude oil are less than originally anticipated, but again, the long-term effects of large quantities of oil on the bottom cannot be assessed.

There are also possibilities that what we have seen in terms of numbers of specimens of *L. pelodes* may be due to natural fluctuations in the population, but this appears presently rather unlikely. Any of the factors mentioned may, singly or jointly, be responsible for the drop in standing crop of *L. pelodes* and the change of species of polychaetes and mullusks seen in the area, but at the present nothing can be said about this, since the biology of the different species remains unknown.

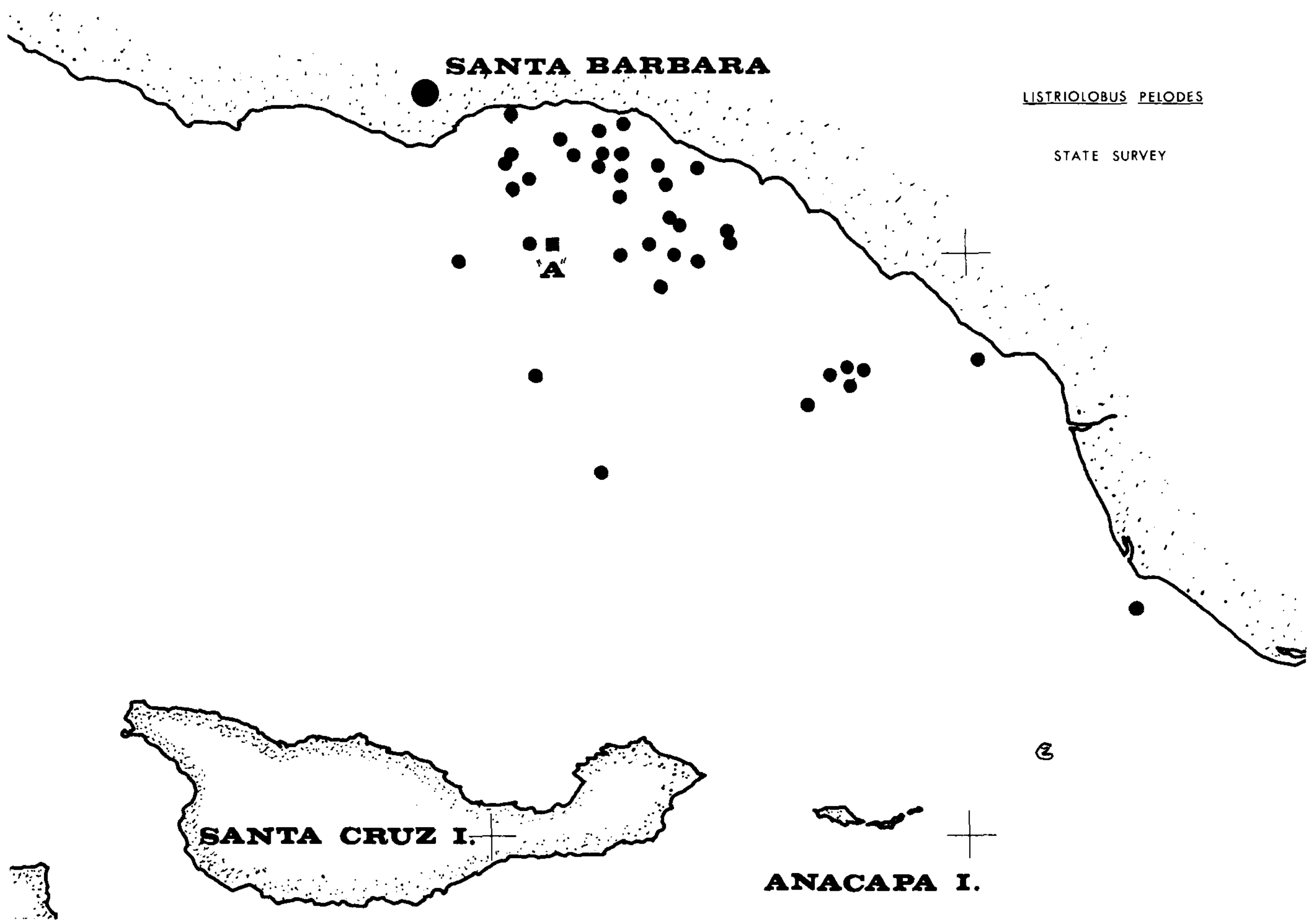



**FIGURE 4.** *Listriolobus pelodes,* State Survey.

The methodology used in the study may also have influenced our results. The survey method, using large grabs, counting the numbers of species present and their standing crop may be too insensitive to show the effects of pollution until it is too late. The brittle-star *Amphiodia urtica* is considered an indicator species for sandy bottoms in southern California and is common also elsewhere; in fact, it is so common just because it is rather insensitive to environmental changes as indicated by the range of conditions which it can be found in. To use such a species as an indicator of pollution, as we in fact did by using the survey method, will obviously underestimate the total effects of the pollutant in question. Smaller animals, such as small crustaceans, polychaetes and foraminiferans, may be more sensitive to environmental changes and may thus be better indicators of what is happening in the sea beds.

What is needed is at any rate a thorough, complete reworking of all the materials collected during the State Survey and the Pollution Survey so that we may get a comparatively firm base from which we can evaluate the kinds of studies that will be needed for each type of pollutant we pour into the area. I would furthermore recommend, that since we do not know what is happening in the area, we should be very careful not to upset the area further than has been done so far, provided of course that the changes we have observed are not due to natural fluctuations. It would be a shame if we should lose the *Listriolobus* beds off Santa Barbara, since they represent a unique natural resource. Since this environment is so precariously balanced, with nearly all the energy following through a single species, we may expect completely changed conditions in the sea bottom if this species should become extinct.

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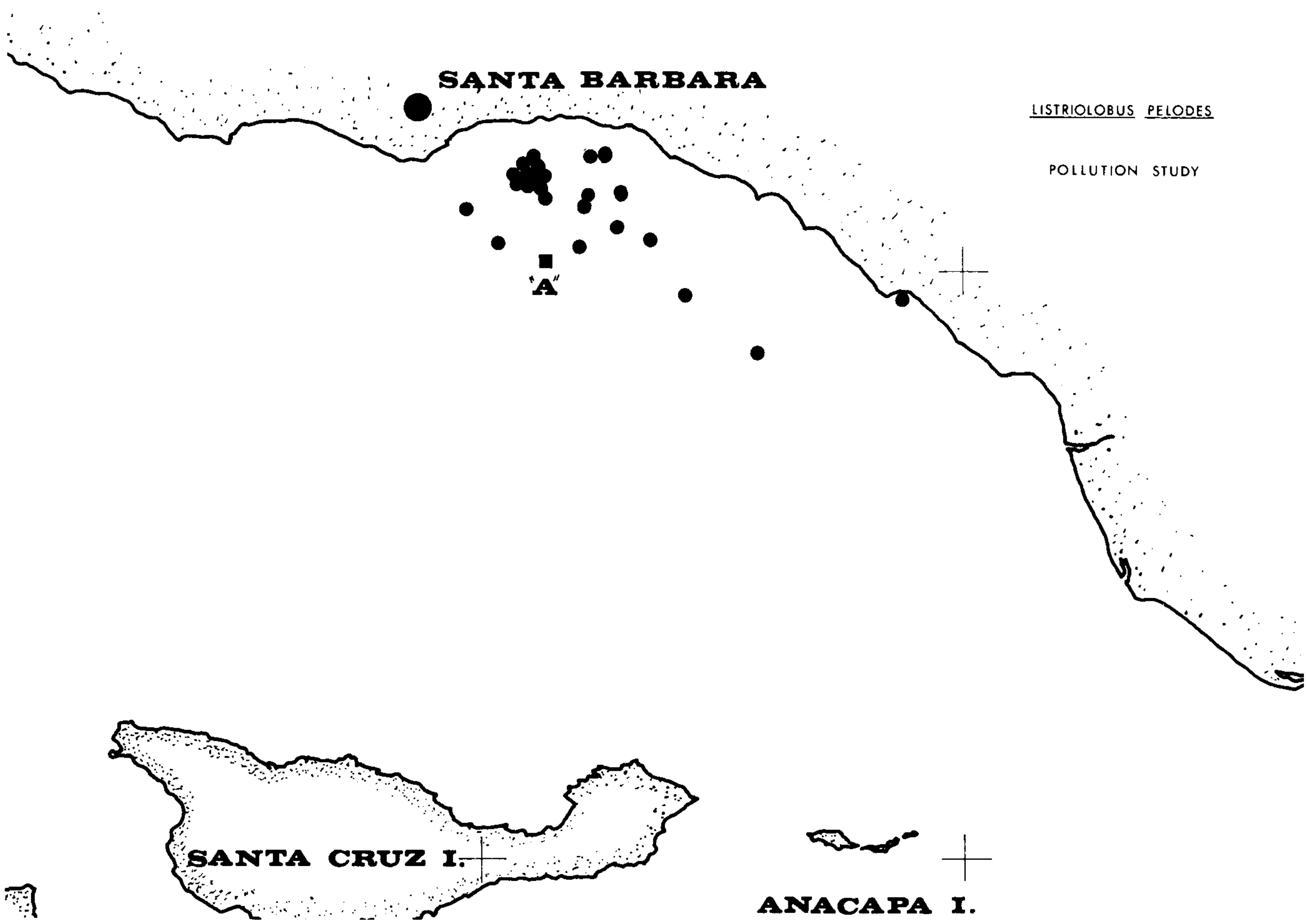


FIGURE 5. *Listriolobus pelodes*, Pollution Study.

*Calif. Mar. Res. Comm., CalCOFI Rept.*, 16: 130–149, 1972

# THE SANTA BARBARA OIL SPILLS IN PERSPECTIVE

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## INTRODUCTION

Two oil spills during 1969 in the Santa Barbara Channel affected an area undergoing major adaptive changes. These changes most probably occurred in response to air and sea water composition that has been steadily altered by human activities since the turn of the century. The first spill (January–April, 1969) loosed 11,290–112,900 metric tons [1] of crude oil from the sea floor near Union Oil Company's Platform A (Allen, 1969). The second spill (December 21, 1969) occurred from a break in an underwater pipeline serving Platform A, and an estimated 60 metric tons were released. Oil from the first spill affected approximately 100 miles of coastline (Fig. 1) and persisted in scattered patches for several months. In December, oil from the second spill was most conspicuous on Carpinteria State Beach (Plate 1A) and Hobson County Park and behaved differently from the crude oil of the first spill in that it remained frothy and fluid during its stay (about 1 month) in the intertidal, readily coating wet and dry surfaces alike. Crude oil is soft and glossy, quickly forming a shiny "skin" on exposure to air, then dulling and hardening after a day or two of weathering.

In the intertidal environment that is the subject of this paper, the effects of both spills were mediated by the time of year when the oil came ashore: winter months lack harsh summer insolation but do inflict large doses of fresh water (possible bleaching of algae due to rain is shown in Plate 1B) and mechanical disturbance from sand movements and storm surf (Plate 2B) on the beaches, leaving relatively fewer organisms to be affected.

Crude oil is a regular feature of the Channel environment, a consequence of variably active seeps that dot the floor of the Channel (Kolpack, 1971). Some seeps are nearly intertidal and fairly active, as at Coal Oil Point. Other seep areas are a mile or more offshore (Carpinteria) and of uncertain activity. Distance from shore is important as one of the factors governing the type of seep product (tarry gobs, iridescent slicks) affecting inshore populations. Measurements (Kolpack, 1971) of water around seeps show that some of the oil actually dissolves in the water column, but most of the oil separates according to specific gravity, fractions with the heavier asphaltic components sinking to form "tar mounds" and lighter components floating as thin slicks. Thin, iridescent slicks are largely dissipated by evaporation if they remain at sea for days; winds, currents and insolation make the presence of such slicks intertidally erratic and rare. If slicks reach shore (they usually do at Coal Oil Point), they are thoroughly worked across intertidal populations by surf. Gobs of tarry material from seeps adhere more readily to warm, dry surfaces than to cool, wet ones and thus stick selectively in the upper intertidal, especially during low tides combined with sunny weather.

There are some major differences between the Santa Barbara spills of 1969 and the *Tampico Maru* accident in Baja California during early spring of 1957 (North, Neushul and Clendenning, 1965; North, 1967). The *Tampico Maru* ran aground at the mouth of a small cove, releasing highly toxic dark diesel (8,000 metric tons) into a confined area, producing an immediate and spectacular kill of marine life. In contrast, the Santa Barbara incident resulted in the release of crude oil about seven miles offshore, producing slicks that remained at sea for several days. These either sank under the influence of tremendous amounts of sediment present from storm runoff or were driven onto beaches by wind and currents. This delay at sea allowed a natural product (crude oil) to lose many of its toxic volatile components through evaporation prior to its arrival on shore. An investigation made soon after the spill by Anderson, *et al.*[2] for the Western Oil and Gas Association reported few immediate deleterious effects on marine organisms of the mainland and Channel Islands.

The difference in consequences of spills according to the degree of refinement of the petroleum product involved is further illustrated by the release of 38,647 metric tons of #2 diesel fuel oil when the barge *Florida* ran ashore off west Falmouth in Buzzard's Bay, Massachusetts (Hampson and Sanders, 1969); a drastic kill of fish, worms, crustaceans and molluscs occurred rapidly, even before the application of detergents. Blumer and co-workers (1970) have pointed out that even though slicks may be sunk and/or dispersed to remove them from view, petroleum products persist in marine food chains. Thus immediate and spectacular kills from refined products that are relatively more toxic than crude oil (the difference in toxicity was pointed out by Clendenning in 1964) may be followed by subtle, long-term effects.

In comparing the Santa Barbara spills with another spill of crude oil, it is necessary to point out that cleanup methods may affect the health of marine

[1] One metric ton = 6.9 barrels, 1 barrel = 42 gallons (60° F, sp. gr. of 0.917 for California crude oil).

[2] Anderson, E. K., L. G. Jones, C. T. Mitchell and W. J. North, "Preliminary report on the ecological effects of the Santa Barbara oil spill."

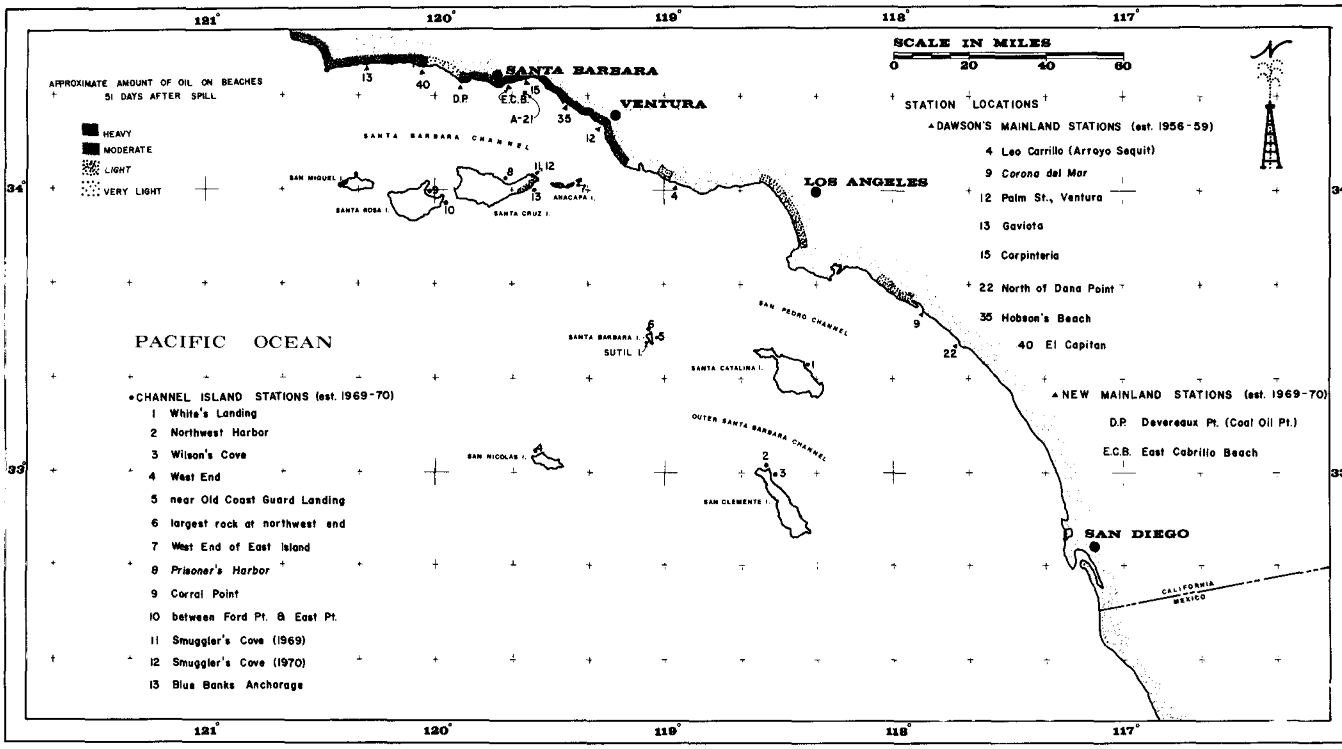


FIGURE 1. California from Point Conception south to Mexico. Locations of study beaches and extent of distribution of crude oil 55 days after the onset of the January 1969 spill (Allen, 1969) are shown. Smallest diameter stipples on coastline do not represent oil cover.

organisms. When the *Torrey Canyon* ran aground on the Seven Stones Reef, 15 miles from Cornwall, England (March 1967) 119,000 metric tons of crude oil escaped. This volume is comparable to that released during the Santa Barbara spills and the accident occurred twice as far from shore. Slicks from the *Torrey Canyon* thus had some time at sea to lose toxic volatile fractions, but cleanup operations involved extensive use of detergents and dispersants on and near shore, thus causing much of the mortality (Smith, 1968). As a result of observations that detergents, dispersants (some are kerosene-based) and their chemical kin were more toxic to marine organisms than crude oil, the spills from Platform A were handled in a different fashion than those from the English disaster. No dispersants were applied inside the one mile limit except when oil penetrated the Santa Barbara Harbor (Gaines, in press). Beaches were cleaned by broadcasting chopped straw over oiled areas (Plate 2A), then scooping the resultant gummy mess into trucks that hauled it away to be burned. During and immediately after the January 1969 spill a study made by marine biologists at the University of California at Santa Barbara (Foster, Neushul and Zingmark, 1969) did not report massive kills of intertidal organisms.

In summary, it is necessary to separate changes due to the Santa Barbara oil spills from the effect(s) of naturally-occurring oil, from seasonal changes, from responses to special events (such as record rainfall) during 1969, and from long-term effects of chronically altered air and water chemistry. These distinctions may be in part accomplished by careful selection of study sites so they span areas inside and outside the influence of the spills and represent combinations of factors affecting intertidal areas.

## METHODS

Ten rocky intertidal stations were surveyed monthly from May, 1969 to June, 1970. Eight of these stations were identical with areas surveyed by Yale Dawson in 1956–59 and two were stations established since the first survey. Ranging from Gaviota State Beach, approximately 30 miles north of Santa Barbara, to Dana Point 60 miles south of Los Angeles (Fig. 1), these stations were:

Gaviota State Beach (Dawson Station 13)
El Capitan State Beach (Dawson Station 40)
Coal Oil Point or Devereaux Point (Neushul, New Series 1: est. 1967)
East Cabrillo Beach (Nicholson-Cimberg Station 1: est. 1969)
Carpinteria State Beach (Dawson Station 15)
Hobson County Park (Dawson Station 35)
Palm Street, Ventura (Dawson Station 12)
Leo Carrillo State Beach (Dawson Station 4)
Corona del Mar (Dawson Station 9)
1 mile north of Dana Point (Dawson Station 22)

Line intercepts were chosen as the sampling method for this investigation. There are some problems with linear samples: they may miss rare organisms or those with extremely patchy distribution, but this can be overcome by carefully exploring the beach and listing all categories of organisms desired, then comparing this list with the list from the line intercept. This was done for each sample. A line intercept does not guarantee a sample of the complete range of tidal levels at which a particular organism dwells, but does yield a contiguous sample. The rapidity with which a line intercept may be completed (2–3 hours) over a long distance (200 to 500 feet) is a major point in favor of a method used where a site is steadily flooded by the incoming tide. Data were taken so that a quantitative estimate of density and percent occurrence of organisms along the populated length of the station line could be obtained. Finally, the surveys of Dawson and Neushul employed line survey methods comparable to the one used in the present study.

The details of the line intercept have been set forth (Nicholson and Cimber, 1971). Briefly, records were made of the substratum and organisms that intersected the tape at three inch intervals along the entire station line. The shore base point was always the end of the station line. Except when the stations were surveyed at night with the aid of miner's lamps, color transparencies were taken to record the visual aspect of the station area. All data are filed in the Herbarium of the Allan Hancock Foundation (Marine Plants).

Selection of stations to be surveyed was accomplished with the purpose of establishing field controls for the wide variety of factors operating in the field (Tables 1 and 2). Unfortunately, the Southern California mainland has no areas where human interference can be conclusively shown to be absent, thus making it necessary to turn to the Channel Islands for relatively undisturbed controls. For this purpose, 13 stations were established and distributed among all of the islands except for San Miguel Island. Two cruises during the fall of 1969 and one during spring 1970 were made in the Channel Islands and SCUBA divers collected representative samples of marine organisms from depths of 0′ to 10′, 10′ to 20′ and 20′ to 30′ in the station area. Dredging was used in water of 80′ to 120′ depth. No calculations of percent occurrence were made on the basis of the Channel Islands data: comparisons were based on presence or absence of intertidal-shallow subtidal species during appropriate months.

All data were compared on an equal taxonomic basis.

**TABLE 1**

**Major Waste Discharges to Coastal Waters of San Diego, Los Angeles and Ventura Counties**

| Discharger and/or Location of Discharge | Date of Initial Discharge | Type of Discharge | Volume, mgd, (1970) | Outfall Length (ft.) | Terminus depth (ft.) |
|---|---|---|---|---|---|
| San Diego | 1963 | Primary Effluent | 80 | 11,430 | 220 |
| In addition, there are three power plants discharging a total of 597 mgd into San Diego Bay, with an average △ T of 12.1°F. | | | | | |
| San Elijo | 1966 | Primary Effluent | 1.1 | 3,700 | 52 |
| Encina (Joint Plant) | 1965 | Primary Effluent | 4.5 | 5,300 | 100 |
| Encina (Power Plant) | 1954 | Cooling Water | 345 | At Beach | |
| San Onofre Power Plant | 1968 | Cooling Water | 506 | 2,600 | 13 |
| San Clemente | 1947 | Secondary Effluent | 1.8 | 700 | 12 |
| Dana Point | 1959 | Primary Effluent | 0.8 | 4,000 | 35 |
| South Laguna | 1955 | Secondary Effluent | 1.8 | 1,700 | 55 |
| Laguna Beach | 1958 | Primary Effluent | 2.0 | 3,000 | 80 |
| County Sanitation Districts of Los Angeles County | 1937 | Industrial and Domestic | 380.0 | 5,000 | 110 |
| | 1937 | ---------- | ---------- | 6,500 | 165 |
| Palos Verdes Peninsula | 1937 | Primary Effluent | ---------- | 8,500 | 215 |
| | 1937 | ---------- | ---------- | 11,900 | 195 |
| City of Los Angeles, Santa Monica Bay | 1959 | Industrial and Domestic, mostly Primary Effluent; some Secondary | 335.0 | effluent 26,400 | 200 |
| | 1957 | | | sludge 36,960 | 330 |
| City of Oxnard, Ormond Beach | 1950 | Industrial and Domestic | 30.0 | 6,000 | 52 |
| | | Primary Effluent | ---------- | -- | ------ |
| City of Port Hueneme, Ormond Beach | 1955 | Industrial and Domestic | 2.0 | 5,200 | 60 |
| | | Primary Effluent | ---------- | ---- | ------ |
| City of San Buenaventura, Ventura | 1938 | Industrial and Domestic | 1.8 | 2,500 | 30 |
| | | Primary Effluent | ---------- | ---- | ------ |
| City of Avalon, Santa Catalina Island | about 1930 | Raw sewage | Winter 0.14<br>Summer 0.44 | 400 | 125 |
| Southern California Edison Co. El Segundo Generating Station, El Segundo | 1953 | Cooling | 460.8 cooling | 2,600 | 20 |
| | | Sewage | 0.0045 sewage | | |
| Redondo Beach Generating Station, Redondo Beach | 1948 | Cooling | 1134.7 | 2,000 | 20 |
| Ormond Beach Generating Station, Ormond Beach | 1971 proposed | Cooling | 640.0 | 1,800 | 20 |
| Mandalay Generating Station, Oxnard | 1958 * | Cooling | 253.4 | Discharge to Beach | ------ |
| City of Los Angeles Department of Water and Power | | | | | |
| Scattergood Steam Plant, El Segundo | 1958 | Cooling | 518.8 | 1,250 | 15 |
| Mobil Oil Company, Sea Cliff | 1968 * | Oil Brines, Tanker Ballast | 11.9 | 3,100 | 30 |
| Continental Oil Co., Pitas Point | 1967 * | Treated Seawater, Oil Brine | 0.273 | 500 | 12 |
| Standard Oil Co. of California, El Segundo | 1951 * | Cooling, API water | 72.0 | 400 | 15 |
| Atlantic Richfield Co., Rincon Island | 1962 * | Oil Brine | 0.26 | Rincon Island | Surface |
| Chancellor-Western Oil and Development Co., Rincon | 1963 * | Oil Brine | 0.30 | nearshore | 10 |
| Phillips Petroleum Co., Punta Gorda | 1967 * | Oil Brine | 0.63 | 500 | 20 |
| Standard Oil Co. of California, McGrath Beach | 1961 * | Oil Brine | 0.14 | nearshore | 4.0 |

* Year in which requirements were prescribed.

Compiled March 1971.

**TABLE 2**

**Summary of Factors Affecting Mainland Stations**

| Factor | Station | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Gaviota | El Capitan | Coal Oil Pt. | East Cabrillo | Carpinteria | Hobson | Palm St., Ventura | Leo Carrillo | Corona del Mar | North of Dana Pt. |
| Jan. 1969 oil spill (Allen, 1969) | Moderate amounts | Moderate amounts | Moderate amounts | Heavy amounts | Heavy amounts | Heavy amounts | Moderate amounts | None | None | None |
| Dec. 1969 oil spill | -- | -- | -- | -- | Moderate amounts | Moderate amounts | -- | -- | -- | -- |
| Natural oil seeps | Nearby | Nearby | Near shore active | -- | About 1 mile offshore active | -- | -- | -- | -- | -- |
| Substratum | Large rocks | Large rocks | Shelf and sand | Metal groin | Shelf and sand | Rocks | Rocks | Rocks | Shelf | Rocks |
| Sand movement | Little | Little | Moderate | Little | Moderate | Moderate | Heavy, station covered 69–70 | Heavy, station covered 2 months | Moderate | Moderate |
| Usage | Public camping | Public camping | Public collecting, surfing | Public swimming | Public collecting, camping | Public clamming, camping | Public surfing | Public camping, surfing | Public collecting, swimming | Private surfing, swimming |
| Industrial effluents | -- | -- | -- | -- | -- | -- | Possible large amounts | Possible large amounts | Possibly affected by Newport Harbor water | -- |
| Agricultural effluents | -- | -- | -- | -- | Possible moderate amounts | -- | Possible moderate amounts | -- | -- | -- |
| Nearest sewage outfall | See Table 1 | | | | | | | | | |
| Fresh water | Small creek | Small creek | -- | -- | Nearby creeks, town flooded winter, 1969 | -- | Heavy, Ventura River | Heavy, large creek | -- | -- |

**TABLE 3**

**Occurrence of Oil on the Ten Rocky Intertidal Mainland Stations**

| Date | Stations | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Gaviota | El Capitan | Coal Oil Point | East Cabrillo | Carpinteria | Hobson's | Palm St., Ventura | Leo Carrillo | Corona del Mar | North of Dana Point |
| 5/69 | -- | -- | -- | 413 | -- | 34 | -- | -- | -- | -- |
| 6/69 | 42 | 0 | 24 | 380 | 1 | 8 | -- | -- | -- | -- |
| 7/69 | 40 | 16 | 49 | 479 | 75 | 30 | 0 | 0 | 8 | 0 |
| 8/69 | 0 | 0 | 88 | 230 | 0 | 0 | -- | 0 | 22 | 0 |
| 9/69 | 1 | 0 | 35 | 384 | 0 | 0 | -- | 0 | 11 | 0 |
| 10/69 | 20 | 30 | 96 | 177 | 5 | 0 | 0 | 0 | 21 | 0 |
| 11/69 | 38 | 12 | 41 | -- | -- | 0 | -- | 0 | -- | 0 |
| 12/69 | 23 | -- | 195 | 308 | 106[2] | 670[2] | -- | 0 | -- | -- |
| 1/70 | -- | 0 | 8 | 251 | 1 | 291[2] | -- | 0 | 2 | 0 |
| 2/70 | 13 | 36 | 59 | 254 | 48 | 6 | -- | 0 | 6 | 0 |
| 3/70 | 7 | 18 | 44 | 208 | 114 | 1 | -- | 0 | 4 | 0 |
| 4/70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 5/70 | 27 | 9 | 43 | 92 | 1 | 0 | -- | 0 | 11 | 0 |
| 6/70 | 63 | 4 | 28 | 156 | 0 | 0 | -- | 0 | 24 | 0 |
| Total | 274 | 125 | 710 | 3332[1] | 351 | 1040 | 0 | 0 | 109 | 0 |
| Average | 25 | 11 | 59 | 277 | 32 | 80 | 0 | 0 | 12 | 0 |

Note: Table indicates number of times oil was observed at three-inch intervals along transect; dashes (--) indicate no oil data available.
[1] This represents the crude oil (persistent, weathered) deposited primarily during the January, 1969 spill; counted repeatedly.
[2] Oil (treated) deposited during the December 1969 spill.

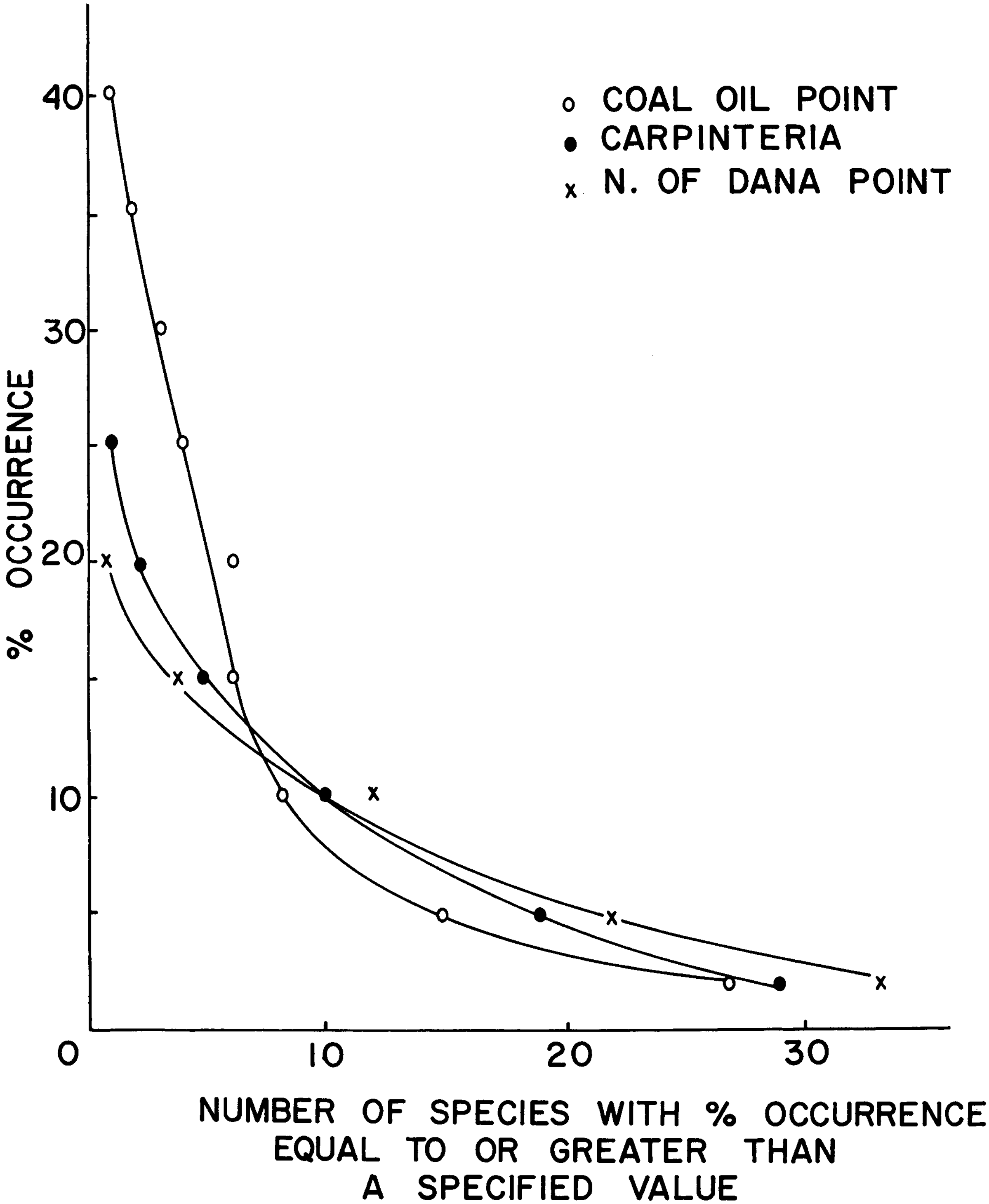


FIGURE 2. Distribution of percent occurrence among marine plant and selected animal species at three beaches with a substratum of stable rock. Crude oil from seeps is nearly continuous at Coal Oil Point, erratic and rare at Carpinteria and not known to occur at the beach one mile north of Dana Point (Salt Creek Road). (Coal Oil Point receives 50 to 70 barrels per day from the seeps (Allen, *et al.*, 1970).)

## OBSERVATIONS

Crude oil from the first spill (January 1969; Fig. 1) persisted as hard asphaltic patches in the upper intertidal for at least 7 months, whereas oil from the second spill (December 1959) had been treated with agents that left it fluid and frothy, possibly accounting for the relatively rapid (about 1 month; see Table 3) disappearance of this oil from intertidal rocks. For reasons involving the probability of long-term repercussions, it is probably not safe to assume that no damage (or minimal damage) occurs, regardless of treatment or refinement of oil, even if it is present for only a short time.

Distribution of oil among the 10 beaches studied is shown in Table 3. At a given beach, oil adhered more readily to relatively warm, dry surfaces in the upper intertidal (Plate 6B) and stuck rarely and more reversibly in the cooler, wetter lower intertidal.

Coal Oil Point was the only beach under study where iridescent oil films were continuously present at times other than during the spills. Both the number of plant species and distribution of abundance within the species is noticeably different at Coal Oil Point if

**TABLE 4**

**Percent Occurrence of Selected Marine Invertebrates at Three Stations During the Period from June 1969 through June 1970**

| Invertebrate / Date | Coal Oil Point | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6/69 | 7/69 | 8/69 | 9/69 | 10/69 | 11/69 | 12/69 | 1/70 | 2/70 | 3/70 | 5/70 | 6/70 |
| *Acanthina* | † | † | -- | † | † | -- | -- | † | † | † | † | † |
| *Acmaea* | † | 2 | -- | † | † | † | -- | † | -- | † | † | † |
| *Anthopleura* | 41 | 11 | 8 | 25 | 38 | 25 | 26 | 37 | 30 | 33 | 37 | 45 |
| *Balanus* | † | † | -- | † | -- | † | † | † | -- | † | † | † |
| *Chthalamus* | 3 | † | † | † | † | † | † | † | -- | † | † | † |
| *Pollicipes* | † | † | -- | -- | -- | -- | -- | -- | † | † | † | † |
| *Tetraclita* | -- | † | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *Littorina* | -- | † | -- | † | -- | -- | -- | 2 | † | 2 | -- | -- |
| *Mytilus* | -- | 2 | -- | 4 | 3 | 4 | 4 | 5 | 3 | 5 | 2 | 5 |
| *Pachygrapsis* | * | * | * | * | * | * | * | * | * | * | * | * |
| *Pagurus* | † | 2 | 2 | † | 2 | † | † | † | 3 | † | † | † |
| *Pisaster* | -- | -- | -- | † | -- | † | -- | -- | -- | -- | -- | -- |
| *Tegula* | † | † | -- | 2 | † | -- | † | † | † | † | † | -- |

**TABLE 4—Continued**

| Invertebrate / Date | Carpinteria | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6/69 | 7/69 | 7/69 | 8/69 | 9/69 | 10/69 | 12/69 | 1/70 | 2/70 | 3/70 | 5/70 | 6/70 |
| *Acanthina* | † | † | † | † | † | † | † | † | † | † | 2 | † |
| *Acmaea* | 2 | 3 | 4 | 3 | 3 | 3 | † | † | † | † | † | † |
| *Anthopleura* | 24 | 26 | 29 | 32 | 26 | 13 | 15 | 34 | 14 | 33 | 22 | 18 |
| *Balanus* | 6 | 7 | 4 | 4 | 2 | 2 | † | † | † | † | † | 3 |
| *Chthalamus* | 11 | 14 | 11 | 10 | 6 | 7 | 5 | 6 | 5 | 7 | 4 | 7 |
| *Pollicipes* | 3 | 4 | 6 | 2 | 3 | 3 | † | 2 | † | 2 | † | 2 |
| *Tetraclita* | -- | † | -- | -- | † | -- | † | -- | † | -- | -- | -- |
| *Littorina* | -- | † | -- | † | † | † | -- | † | -- | -- | -- | † |
| *Mytilus* | 13 | 15 | 14 | 14 | 16 | 9 | 9 | 8 | 8 | 8 | 5 | 7 |
| *Pachygrapsis* | * | * | * | * | * | * | * | * | * | * | * | * |
| *Pagurus* | † | † | † | † | † | † | -- | 2 | † | † | -- | † |
| *Pisaster* | -- | † | -- | -- | † | -- | -- | -- | -- | -- | -- | † |
| *Tegula* | † | † | † | 2 | 3 | 3 | 2 | 5 | 2 | 6 | 4 | 2 |

**TABLE 4—Continued**

| Invertebrate / Date | Beach 1 Mile North of Dana Point | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7/69 | 8/69 | 8/69 | 9/69 | 10/69 | 11/69 | 1/70 | 2/70 | 3/70 | 5/70 | 6/70 |
| *Acanthina* | † | 2 | -- | † | -- | -- | -- | 2 | -- | † | † |
| *Acmaea* | 12 | 5 | 4 | 6 | † | † | 3 | 8 | † | 3 | 3 |
| *Anthopleura* | 8 | 7 | 5 | 10 | 2 | 2 | 6 | -- | 7 | 2 | 5 |
| *Balanus* | 9 | 6 | 4 | † | † | † | 2 | † | -- | -- | -- |
| *Chthalamus* | 45 | 32 | 29 | 10 | 33 | 33 | 26 | 27 | 34 | 51 | 31 |
| *Pollicipes* | 2 | † | -- | -- | † | † | -- | † | † | -- | -- |
| *Tetraclita* | † | † | 4 | † | -- | -- | † | -- | † | † | -- |
| *Littorina* | 5 | 2 | † | † | -- | -- | -- | † | -- | † | -- |
| *Mytilus* | 5 | † | † | † | † | † | † | † | 2 | 2 | † |
| *Pachygrapsis* | * | * | * | * | * | * | * | * | * | * | * |
| *Pagurus* | † | 3 | 5 | 4 | 7 | 2 | 8 | 5 | 5 | 3 | 2 |
| *Pisaster* | † | -- | -- | † | † | -- | † | † | † | † | † |
| *Tegula* | 2 | 3 | 2 | 2 | 14 | 4 | 7 | 5 | † | 4 | 5 |

† = less than 2% occurrence.
* = observed but not recorded on the station line

**TABLE 5**

**Percent Occurrence of Selected Marine Algae at Coal Oil Point During 1969 and 1970**

| Organism | Date | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6/69 | 7/69 | 8/69 | 9/69 | 10/69 | 11/69 | 12/69 | 1/70 | 2/70 | 3/70 | 5/70 | 6/70 |
| *Phyllospadix* spp. | 5 | 17 | 38 | 8 | 4 | 8 | 2 | 2 | 5 | 4 | 13 | 13 |
| *Bryopsis hypnoides* | -- | -- | -- | * | -- | -- | -- | -- | -- | -- | -- | -- |
| *Chaetomorpha aerea* | -- | -- | -- | -- | -- | -- | -- | -- | -- | * | -- | -- |
| *Enteromorpha* spp. | 13 | -- | † | 4 | † | 3 | 16 | 24 | 13 | 23 | 6 | 4 |
| *Ulva* spp. | 11 | 6 | 25 | 14 | 12 | 17 | 8 | 8 | 18 | 19 | 18 | 8 |
| *Ectocarpus* spp. | -- | † | † | -- | -- | -- | * | -- | -- | -- | -- | -- |
| *Egregia laevigata* | -- | † | † | † | * | † | -- | -- | † | † | † | 2 |
| *Endarachne binghamiae* | -- | -- | -- | -- | -- | † | † | † | † | † | -- | -- |
| *Pelvetia fastigiata* | -- | -- | -- | -- | † | -- | -- | -- | -- | -- | 2 | -- |
| *Ralfsia* spp. | -- | -- | -- | -- | -- | † | 2 | † | † | 2 | † | † |
| *Scytosiphon lomentaria* | -- | † | -- | -- | -- | -- | † | † | † | † | -- | -- |
| *Agardhiella tenera* | 2 | † | -- | -- | -- | -- | -- | -- | -- | -- | † | † |
| *Anisocladella pacifica* | -- | -- | -- | -- | -- | -- | -- | -- | † | -- | -- | -- |
| *Bangia fuscopurpurea* | -- | -- | -- | -- | -- | -- | † | * | -- | -- | -- | * |
| *Bossiella* spp. | -- | -- | -- | † | † | -- | -- | † | -- | -- | -- | -- |
| *Microcladia coulteri* | -- | -- | -- | -- | -- | -- | -- | -- | -- | † | -- | † |
| *Centroceras clavulatum* | -- | -- | -- | * | * | * | * | -- | -- | -- | * | * |
| *Ceramium* spp. | 13 | 13 | 24 | 7 | 13 | 4 | † | 4 | 5 | 7 | 10 | 5 |
| *Chondria nidifica* | -- | -- | -- | * | -- | -- | -- | -- | * | * | -- | † |
| *C. pacifica* | -- | -- | -- | * | * | * | * | -- | -- | * | -- | -- |
| *Corallina vancouveriensis* | † | 2 | † | 3 | 8 | 13 | 13 | 8 | 5 | 8 | † | 3 |
| *Cryptopleura* spp. | † | -- | † | † | -- | † | -- | -- | -- | † | † | † |
| *Gastroclonium coulteri* | -- | † | -- | -- | 6 | † | -- | -- | -- | -- | † | † |
| *Gelidium coulteri* | • | -- | † | † | † | † | 3 | † | † | † | † | -- |
| *G. crinale* | -- | -- | -- | -- | -- | * | -- | -- | -- | * | -- | -- |
| *G. purpurascens* | † | -- | -- | -- | * | -- | -- | -- | * | -- | -- | -- |
| *Gigartina canaliculata* | 11 | 5 | 4 | 9 | 8 | 5 | 3 | 5 | 7 | 3 | 7 | 8 |
| *G. leptprhyncos* | 3 | † | † | -- | † | † | † | † | † | 2 | 6 | † |
| *G. spinosa-armata* complex | -- | † | -- | † | -- | -- | -- | -- | -- | -- | -- | -- |
| *Gracilariopsis* spp. | • | † | 4 | † | * | 8 | 6 | † | 2 | 3 | * | † |
| *Gymnogongrus* spp. | -- | -- | -- | -- | † | -- | -- | † | -- | -- | -- | -- |
| *Iridaea* spp. | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | † |
| *Laurencia* spp. | -- | -- | -- | -- | † | -- | -- | † | -- | -- | -- | -- |
| *L. pacifica* | † | -- | † | † | † | 3 | -- | † | † | † | † | † |
| *Lithothamnion* spp. | -- | 2 | -- | -- | † | -- | † | † | -- | * | -- | -- |
| *Lithothrix aspergillum* | -- | -- | -- | * | -- | -- | * | † | -- | -- | -- | -- |
| *Melobesia mediocris* | -- | 7 | -- | 7 | 3 | 3 | † | † | † | -- | -- | -- |
| *Plocamium coccineum* v. *pacificum* | -- | † | -- | * | -- | * | -- | -- | * | * | † | † |
| *Polysiphonia* spp. | • | -- | -- | * | -- | 4 | 6 | † | 5 | 3 | † | † |
| *Porphyra perforata* and *P. thuretii* | † | -- | † | † | -- | -- | -- | † | † | † | 2 | † |
| *Pterosiphonia* spp. | * | -- | -- | * | * | * | † | † | * | † | † | † |
| *Rhodoglossum affine* | -- | -- | † | -- | † | -- | -- | -- | -- | -- | -- | -- |
| *R. americanum* | -- | -- | -- | -- | -- | † | -- | -- | -- | -- | -- | -- |
| *Rhodymenia* spp. | -- | -- | -- | -- | -- | -- | -- | -- | -- | † | † | -- |
| *Smithora naiadum* | 5 | 12 | 34 | † | -- | † | * | † | -- | -- | -- | 10 |
| *Spermothamnion snyderae* | -- | 7 | -- | -- | * | * | * | -- | -- | -- | -- | -- |
| *Stenogramme interrupta* | -- | -- | -- | -- | -- | -- | -- | † | -- | -- | -- | -- |
| Diatoms | -- | -- | -- | -- | -- | * | * | -- | -- | † | † | -- |

† = less than 2% occurrence.
* = observed but not recorded on the station line.

these statistics are used to compare it to other beaches (Fig. 2; Tables 4–7). Coal Oil Point was compared with Carpinteria State Beach and the beach 1 mile north of Dana Point because all three areas have similar (but not identical) species composition and physical substratum (principally stable rock reef, moderately open coast). In brief, Coal Oil Point has fewer species than the other two beaches, but some of them are highly abundant (Fig. 2). Plate 3B shows the visual aspect of this beach, covered in large part with patches composed of a single species (*Anthopleura* and *Phyllospadix* are most conspicuous in the photograph).

Representative oil damage to the upper intertidal is shown in Plate 3A. Barnacles (*Balanus*) tall enough to project beyond the crust of oil survived; shorter

TABLE 6

**Percent Occurrence of Selected Marine Algae at Carpinteria State Beach During 1969 and 1970**

| Organism | Date | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6/69 | 7/69 | 7/69 | 8/69 | 9/69 | 10/69 | 12/69 | 1/70 | 2/70 | 3/70 | 5/70 | 6/70 |
| *Phyllospadix* spp. | 11 | 8 | 6 | 3 | 9 | 4 | 9 | 6 | 10 | 8 | 10 | 7 |
| *Enteromorpha* spp. | 3 | 7 | † | † | 5 | 5 | 5 | 8 | 3 | 3 | † | 3 |
| *Ulva* spp. | 19 | 25 | 18 | 10 | 17 | 8 | 7 | 13 | 22 | 32 | 36 | 48 |
| *Cystoseira osmundacea* | -- | -- | -- | -- | -- | -- | -- | -- | -- | † | -- | -- |
| *Egregia laevigata* | 3 | † | † | † | 2 | † | † | † | † | † | 3 | 5 |
| *Endarachne binghamiae* | -- | -- | -- | -- | -- | -- | -- | † | † | † | -- | -- |
| *Laminaria sinclairii* | † | -- | † | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *Macrocystis pyrifera* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | † | -- |
| *Pachydictyon coriaceum* | -- | -- | -- | -- | -- | -- | -- | -- | -- | * | -- | -- |
| *Ralfsia* spp. | † | -- | † | † | † | † | † | † | † | † | † | † |
| *Scytosiphon lomentaria* | † | -- | -- | † | -- | -- | -- | -- | -- | -- | -- | -- |
| *Agardhiella tenera* | -- | -- | -- | -- | -- | -- | -- | -- | † | † | 4 | 2 |
| *Bangia fuscopurpurea* | -- | -- | -- | -- | -- | -- | -- | 2 | † | † | -- | * |
| *Bossiella* spp. | † | † | -- | † | † | † | † | † | † | † | † | † |
| *Botryoglossum farlowianum* | -- | -- | -- | -- | -- | -- | -- | † | -- | -- | * | -- |
| *Centroceras clavulatum* | -- | * | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *Ceramium* spp. | -- | 4 | 3 | 3 | 5 | 3 | † | 6 | 4 | 8 | 12 | 6 |
| *Chondria nidifica* | -- | * | -- | -- | * | * | * | * | -- | * | * | * |
| *C. pacifica* | -- | • | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *Corallina officinalis* v. *chilensis* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *C. vancouveriensis* | † | 2 | † | 2 | 4 | 8 | 8 | 15 | 5 | 10 | 3 | 3 |
| *Cryptopleura* spp. | -- | 2 | † | † | 3 | † | † | † | 2 | † | † | † |
| *Gastroclonium coulteri* | 2 | -- | † | -- | 9 | -- | -- | -- | † | † | -- | † |
| *Gelidium coulteri* | 4 | 5 | -- | 2 | 2 | † | † | 2 | 2 | 4 | 10 | 9 |
| *G. crinale* | -- | * | -- | * | * | -- | -- | -- | -- | -- | -- | -- |
| *G. purpurascens* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | * |
| *G. robustum* | -- | -- | -- | * | -- | -- | -- | -- | -- | -- | -- | -- |
| *Gigartina canaliculata* | 10 | 17 | 11 | 9 | 12 | 7 | 10 | 9 | 7 | 10 | 9 | 14 |
| *G. harveyana* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | * | † |
| *G. leptorhynchos* | -- | † | † | -- | * | * | † | † | † | 2 | 2 | 2 |
| *G. spinosa-armata* complex | † | † | † | -- | † | † | † | † | † | † | † | -- |
| *Gracilaria* spp. | -- | -- | -- | 2 | -- | -- | -- | -- | -- | -- | -- | -- |
| *Gracilariopsis* spp. | -- | 2 | 3 | 2 | † | 10 | 3 | 4 | 2 | 5 | 4 | 2 |
| *Grateloupia* spp. | -- | -- | -- | † | -- | -- | -- | -- | -- | -- | -- | -- |
| *Gymnogongrus* spp. | -- | -- | -- | -- | -- | -- | -- | † | † | † | -- | -- |
| *Iridaea* spp. | -- | -- | -- | -- | -- | -- | -- | -- | -- | * | -- | -- |
| *Laurencia* spp. | -- | -- | -- | -- | † | † | † | † | -- | -- | * | † |
| *Lithothamnion* spp. | -- | -- | † | † | † | † | † | -- | † | † | -- | * |
| *Melobesia mediocris* | -- | -- | † | † | † | 2 | † | 2 | * | -- | -- | * |
| *Microcladia coulteri* | -- | -- | -- | -- | -- | -- | -- | -- | -- | † | † | † |
| *Nienburgia andersoniana* | -- | -- | -- | -- | -- | -- | -- | -- | -- | * | * | -- |
| *Plocamium coccineum* v. *pacificum* | -- | • | † | † | * | * | * | * | -- | * | * | † |
| *Polysiphonia* spp. | -- | • | -- | -- | † | 4 | 6 | 6 | † | 7 | * | 6 |
| *Porphyra perforata* and *P. thuretii* | 3 | -- | † | † | † | -- | † | † | 2 | 3 | † | † |
| *Prionitis* spp. | -- | -- | -- | -- | -- | -- | -- | -- | † | -- | -- | -- |
| *Pterocladia pyramidale* | -- | -- | -- | -- | -- | 4 | -- | -- | † | -- | -- | -- |
| *Pterosiphonia baileyi* | -- | -- | -- | * | -- | † | -- | -- | -- | -- | -- | -- |
| *P. dendroidea* | -- | -- | -- | -- | -- | † | * | † | * | -- | † | † |
| *Rhodoglossum affine* | -- | † | -- | -- | -- | -- | -- | † | † | † | † | † |
| *R. americanum* | -- | -- | -- | -- | -- | † | -- | † | -- | † | -- | -- |
| *Rhodymenia* spp. | -- | -- | -- | -- | -- | * | -- | -- | -- | * | -- | † |
| *Smithora naiadum* | 6 | 7 | 6 | 3 | 7 | † | 2 | 2 | † | 7 | 8 | 8 |
| *Spermothamnion snyderae* | -- | -- | † | † | -- | -- | * | -- | -- | -- | -- | -- |
| Diatoms | -- | -- | -- | -- | † | -- | • | -- | 8 | † | -- | -- |

† = less than 2% occurrence.
* = observed but not recorded on the station line.

TABLE 7

**Percent Occurrence of Selected Marine Algae at the Beach One Mile North of Dana Point During 1969 and 1970**

| Organism | Date | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7/69 | 8/69 | 8/69 | 9/69 | 10/69 | 11/69 | 1/70 | 2/70 | 3/70 | 5/70 | 6/70 |
| *Phyllospadix* spp. | † | -- | † | † | -- | -- | † | -- | † | † | † |
| *Enteromorpha* spp. | -- | 2 | 5 | -- | -- | -- | -- | -- | -- | -- | † |
| *Ulva* spp. | 2 | 17 | 13 | 4 | 8 | -- | † | 4 | 5 | 12 | 8 |
| *Coilodesme rigida* | • | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *Colpomenia sinuosa* | † | -- | -- | -- | † | -- | -- | -- | -- | 4 | † |
| *Dictyopteris zonarioides* | -- | -- | -- | -- | -- | -- | -- | -- | † | -- | -- |
| *Dictyota flabellata* | • | -- | -- | -- | -- | -- | -- | -- | -- | -- | † |
| *Ectocarpus* spp. | † | -- | -- | -- | 3 | -- | -- | -- | -- | -- | -- |
| *Eisenia arborea* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | † |
| *Egregia laevigata* | 2 | 2 | † | † | † | † | 2 | † | † | † | 7 |
| *Endarachne binghaniae* | † | -- | 4 | 2 | † | -- | † | -- | -- | † | † |
| *Hesperophycus harveyanus* | -- | -- | † | -- | -- | -- | -- | -- | -- | -- | -- |
| *Macrocystis pyrifera* | † | -- | † | -- | -- | -- | -- | -- | -- | -- | † |
| *Pachydictyon coriaceum* | • | -- | -- | -- | * | -- | * | * | * | † | † |
| *Pelvetia fastigiata* | 11 | 6 | 4 | 4 | 2 | 8 | 3 | 2 | 4 | 6 | 4 |
| *Petrospongium rugusom* | 2 | -- | † | -- | -- | -- | -- | -- | -- | -- | -- |
| *Ralfsia* spp. | † | -- | 5 | 3 | 7 | † | 8 | 4 | 3 | 3 | 4 |
| *Sargassum agardhianum* | -- | -- | -- | -- | * | -- | -- | -- | -- | -- | • |
| *Scytosiphon lomentaria* | -- | -- | -- | -- | -- | -- | -- | -- | -- | † | -- |
| *Zonaria farlowii* | • | -- | -- | -- | * | -- | * | -- | * | * | † |
| *Acrosorium uncinatum* | -- | -- | -- | * | -- | -- | -- | -- | -- | -- | -- |
| *Anisocladella pacifica* | -- | -- | -- | -- | -- | * | -- | -- | -- | -- | -- |
| *Bossiella* spp. | 4 | -- | 2 | -- | † | -- | -- | -- | -- | -- | † |
| *B. dichotoma* v. *gardneri* | -- | -- | -- | -- | -- | -- | † | -- | -- | -- | -- |
| *Centroceras clavulatum* | -- | -- | -- | * | -- | * | * | -- | -- | -- | -- |
| *Ceramium* spp. | † | -- | -- | † | -- | * | 7 | 6 | † | † | † |
| *Coeloseira compressa* | † | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *Corallina officinalis* v. *chilensis* | * | -- | -- | -- | -- | -- | -- | -- | * | * | -- |
| *C. vancouveriensis* | † | 5 | 6 | 7 | 18 | † | 8 | 4 | 5 | 3 | 5 |
| *Cryptopleura* spp. | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | * |
| *Endocladia muricata* | -- | -- | -- | * | -- | -- | -- | -- | -- | -- | -- |
| *Erythrocystis saccata* | † | † | † | † | † | -- | -- | -- | -- | -- | † |
| *Gastroclonium coulteri* | † | -- | -- | -- | -- | -- | -- | -- | † | † | -- |
| *Gelidium coulteri* | 4 | -- | -- | 2 | † | -- | 4 | 7 | 19 | 2 | † |
| *G. crinale* | • | * | * | * | * | * | * | * | * | * | * |
| *G. purpurascens* | -- | -- | -- | -- | * | * | * | -- | -- | * | * |
| *G. robustum* | -- | -- | -- | -- | * | -- | -- | -- | -- | -- | -- |
| *Gigartina canaliculata* | † | 2 | 6 | 10 | 5 | † | 12 | 11 | 14 | 3 | 3 |
| *G. leptorhynchos* | -- | * | -- | † | -- | -- | -- | † | † | † | † |
| *G. spinosa-armata* complex | -- | -- | -- | † | -- | -- | -- | -- | -- | -- | -- |
| *Gracilariopsis* spp. | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | † |
| *Grateloupia* spp. | † | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *Herposiphonia secunda* | * | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *Hildenbrandia* sp. | † | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *Jania natalensis* | * | -- | -- | -- | -- | -- | * | -- | -- | -- | -- |
| *Laurencia spectabilis* | * | -- | -- | -- | -- | * | * | -- | -- | * | † |
| *L. pacifica* | 2 | 7 | 9 | 10 | 9 | † | 4 | 2 | † | 2 | 8 |
| *Lithothamnion* spp. | -- | † | -- | -- | 2 | -- | 2 | † | † | -- | -- |
| *Lithothrix aspergillum* | † | -- | -- | -- | -- | -- | † | -- | -- | -- | † |
| *Melobesia mediocris* | † | -- | † | -- | -- | -- | † | -- | -- | -- | † |
| *Plocamium coccineum* v. *pacificum* | -- | -- | * | -- | -- | -- | † | -- | -- | † | † |
| *Polysiphonia* spp. | * | -- | -- | * | 5 | -- | † | -- | † | * | -- |
| *Porphyra perforata* and *P. thuretii* | * | 3 | -- | -- | -- | -- | 3 | † | 2 | † | -- |
| *Pterocladia pyramidale* | • | † | -- | † | 4 | † | 5 | 3 | * | † | 3 |
| *Pterosiphonia dendroidea* | -- | -- | -- | -- | -- | -- | † | -- | -- | -- | -- |
| *Rhodoglossum affine* | -- | -- | -- | -- | * | -- | -- | -- | -- | * | -- |
| *R. americanum* | * | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| *Smithora naiadum* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | † |
| Diatoms | 2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Grazed or Turf Algae | 10 | † | † | † | † | † | † | † | † | † | † |
| *Pterochondria woodii* | -- | -- | -- | † | -- | -- | -- | -- | -- | -- | -- |
| GATGOR[1] | 3 | 10 | 4 | -- | -- | -- | -- | -- | -- | -- | -- |

[1] GATGOR = Green Algae That Grow On Rocks: a term used to describe films of green algae consisting of unicellular forms and/or microscopic phases of macroscopic species.
† = less than 2% occurrence.
* = observed but not recorded on the station line.

species (*Chthalamus*) were smothered. Juvenile barnacles established themselves on weathered oil; they were lost when the asphalt layer finally crumbled away. Smothering in the upper intertidal was frequent but occurred in discontinuous patches.

Comparison of data from spring 1969 and 1970 is made in Table 8. There is a tendency for the beaches affected by the spills (Gaviota State Beach to Hobson County Park) to show an increase in plant species over spring of 1969. All beaches studied were subjected to flooding; exceptional cases are noted in Table 2. Hobson County Park was subjected to constant mechanical disruption by clammers.

Table 9 documents a decade-long downward trend in number of intertidal plant species. Factors affecting the study beaches during this time are qualitatively shown in Table 2 and more quantitatively in Table 1. The average decline in number of intertidal species of plants between 1956–59 and 1970 is 63%. Details of species recorded in 1956–59 but not recorded in 1969–70 may be found in an earlier paper (Nicholson and Cimberg, 1971; Tables 6 and 7). The latter tables show different constellations of species missing from each beach.

Winter and summer months are characterized by populations of different plant species and differing abundances of persistent species (Tables 5–7). An interesting feature of cobble beaches is that they usually show half the species in winter that they have in summer (Table 10); assuming that a sufficient variety of plants is present to show this type of change (Palm Street, Ventura is excluded on this basis: see Plate 4B). Large cobbles (1 to 2 feet in diameter) are radically shifted about by winter surf, mimicking the action of a ball mill.

Public use of beaches was found to be highly destructive of intertidal areas. Sightseeing in tidepools results in trampling of both plants and animals when they are especially vulnerable. In the case of upper intertidal seaweeds, these commonly dry out to the extent that they are brittle and fragile. Such plants are shattered by trampling. Clamming also results in considerable mechanical disturbance to a beach. At Hobson County Park each low tide was characterized by swarms of clammers (Plate 4A) who routinely took many limits apiece of the clam *Protothaca staminea*, failed to replace large rocks moved for digging (all to whom it was suggested that the beach would benefit by restoration of disturbed areas refused to make the effort), and who did not bury the clams they dug up but did not use. In May of 1970, nearly 80% of the station line was overturned by the activities of clammers. The devotion with which people will pursue free clams can be illustrated by the observation that clamming slackened only slightly during the time the intertidal was covered with oil in December 1969: at least 12 humans were observed with most of their clothes and bodies liberally smeared with oil, busily digging clams.

TABLE 8

**Number of Plant Species Reported on Spring Stations, 1969–70**

| Stations | 1969 | | 1970 | | Change between June 1969 and 1970 |
|---|---|---|---|---|---|
| | May | June | May | June | |
| Gaviota State Beach | -- | 23 | 10 | 18 | −5 |
| El Capitan State Beach | -- | 15 | 6 | 17 | +2 |
| Coal Oil Point (Devereaux Pt.) | -- | 19 | 24 | 26 | +7 |
| East Cabrillo Beach | 6 | 5 | 6 | 6 | +1 |
| Carpinteria State Beach | -- | 19 | 30 | 32 | +13 |
| Hobson County Park | 15 | 23 | 15 | 16 | −7 |
| Palm Street, Ventura | -- | 4 | -- | 4 | 0 |
| Leo Carrillo State Beach | -- | 22 | 19 | 16 | −6 |
| Corona del Mar | -- | 5 | 18 | 17 | +12 |
| *One mile north of Dana* Point | -- | 35 | 24 | 31 | −4 |

TABLE 9

**Number of Marine Plant Specimens Recorded on the Rocky Intertidal Mainland Stations During this Study Compared to Previous Investigations Conducted in Comparable Months (Fall-Winter)**

| Investigation and Year | Gaviota State Beach | El Capitan State Beach | Carpinteria State Beach | Hobson County Park | Palm St., Ventura | Leo Carrillo State Beach | Corona del Mar | One mile north of Dana Point |
|---|---|---|---|---|---|---|---|---|
| Dawson, 1959—Average 1956–1959 | 28 | 25 | 36 | 26 | 18 | 32 | 28 | 31 |
| Neushul, 1967 | 13 | 20 | 29 | 13 | 17 | 14 | -- | -- |
| Nicholson and Cimberg, 1969 to 1970 Average | 13 | 7 | 26 | 7 | 4 | 7 | 9 | 14 |
| Percent Decrease[1] Between 1956 and 1970 | 54 | 72 | 28 | 73 | 78 | 78 | 68 | 55 |

[1] Percent decrease = $\frac{\text{average ('56–'59)} - \text{average ('69–'70)}}{\text{average '56–'59}} \times 100$

Average Number of Species per Visit
Dawson 1956–59: 29 (8 stations)
Neushul 1967: 17 (6 stations)
Nicholson and Cimberg 1971: 11 (8 stations)

A heavy, persistent cover of sand may also dramatically reduce intertidal populations (Plates 5A, B, 6A), as happened at Leo Carillo State Beach in January and February of 1970. By February, the plants that had managed to survive longest (*Egregia menziesii* var. *laevigata* and *Macrocystis pyrifera*) had died back to stumps of stipes. By mid-March 1970, 15 young plant and one animal species were recorded on the uncovered portions of rocks. A similar sandfill with partial coverage of *Egregia* and *Macrocystis* was reported by Dawson in February 1958 (Dawson, 1965).

Preliminary surveys of the marine flora of the Southern California Channel Islands (Table 11) show an average number of species (36) obtained at single visits that is higher than the averages obtained during the mainland studies conducted between 1956 and 1970 (Table 9).

## DISCUSSION

### *General Features of Intertidal Algal Populations in Southern California*

The physical-chemical setting for marine organisms is established by circulation patterns of oceanic water, runoff from continental areas or other factors governing nutrient levels and the quality and quantity of light penetrating to various depths. Given sufficient time, species distribute themselves throughout a geographical area in patterns corresponding to the stresses (or lack of stresses) the environment dictates. Natural patterns need to be differentiated from disturbed patterns to avoid error in assigning presence or absence of species to conditions observed as a result of human activities. As an example, it is improper to attribute the absence of cold water and/or low light intensity adapted species to the presence of oil or sewage when the area in question is characterized by warm water and/or high light intensities.

If heavily populated industrial centers develop along a coastline, their use of coastal waters can affect previously-developed distribution patterns. The ways in which human activities affect marine populations can be arbitrarily divided into two categories based on duration of a condition(s): acute (short term effects) and chronic (long term effects). Arbitrariness of the above designations is evident if it is pointed out that a sufficient number of acute events can approach and/or equal a chronic state. An acute event may also produce subtle repercussions that outlast its initial phases.

One of the dominant features of the natural distribution of algae in Southern California is their coincidence with areas of predominantly cool or warm water. The northern and southern Channel Islands, two main current periods, and wind-governed periods of upwelling contribute to a complex circulation pattern.

Two currents dominate water conditions in California: the California and Davidson currents. Although the term current brings to mind the image of a river or of the Gulf Stream, these two currents on the West Coast are composed of a complex system of gyres and eddies that transports water north (Davidson Current) or south (California Current) at velocities usually between 0.25 and 0.5 knots. At the surface, the California Current governs circulation for most of the year. The Davidson Current stays submerged (200 m) until late fall and early winter when north winds weaken. Under these latter conditions it forms

TABLE 10

**Number of Species of Marine Plants Present During Winter and Early Summer**

| Location | December 1969 | June 1970 | All Year Total | Type of Rocky Substratum |
|---|---|---|---|---|
| Gaviota State Beach (Dawson Sta. 13) | 16 | 18 | 48 | stable rock reef |
| El Capitan State Beach (Dawson Sta. 40) | 8 | 17 | 34 | unstable: large cobbles (1′ + dia.) |
| Coal Oil Point (New Series 1) | 25 | 26 | 49 | stable rock reef |
| East Cabrillo Beach (Nicholson-Cimberg 1) | 7 | 6 | 18 | metal groin |
| Carpinteria State Beach (Dawson Sta. 15) | 25 | 31 | 54 | stable rock reef |
| Hobson County Park (Dawson Sta. 35) | 7 | 16 | 44 | unstable: large cobbles |
| Palm Street, Ventura (Dawson Sta. 12) | 10/69<br>4 | 7/70<br>4 | 4 | unstable: large cobbles |
| Leo Carrillo St. Beach (Dawson Sta. 4) | 13 | 16 | 41 | cobble and stable rock |
| Corona del Mar (Dawson Sta. 9) | 12 | 17 | 28 | stable rock reef |
| One mile north of Dana Point (Dawson Sta. 22) | 11/69<br>16 | 33 | 60 | cobble and stable rock |

TABLE 11

**Preliminary Sampling of the Marine Flora of the Southern California Channel Islands: Intertidal and Shallow Subtidal Areas**

| Station | Date | Number of Species |
|---|---|---|
| Santa Rosa Island | | |
| Corral Point | 12/69 | 31 |
| Between Ford Point and East Point | 12/69 | 24 |
| Santa Cruz Island | | |
| Prisoner's Harbor | 12/69 | 28 |
| Smuggler's Cove | 12/69 | 33 |
| Smuggler's Cove | 4/70 | 45 |
| Blue Banks Anchorage | 4/70 | 61 (14 fms: biological chain dredge) |
| Anacapa Islands | | |
| Southern exposure on East Island | 12/69 | 36 |
| Santa Barbara Island | | |
| Near Coast Guard Landing | 12/69 | 33 |
| San Nicholas Island | | |
| Northwest End | 12/69 | 41 |
| Santa Catalina Island | | |
| Isthmus Cove | 1969–70 | 68 |

Note: Unless otherwise specified, data were obtained by skin and SCUBA divers at single visits. The Channel Islands are not as well explored as the mainland, so that species lists are minimal. This investigation added roughly 10% more species to the state's marine flora: some of these species are as yet undescribed and some were well-known, but had not been reported from California.

at the surface close inshore, extending from the tip of Baja California as far north as Washington.

Water circulation is further complicated by upwelling in many areas under the influence of winds blowing parallel to the shore. California shares this circulation pattern with Peru, since both coastlines have ranges of mountains that deflect winds into paralleling the shore. In California, upwelling is particularly strong south of the two large land masses of Cape Mendocino and Point Conception. Presence of offshore islands also affects water circulation on the continental shelf (Fig. 3).

Two prominent features of the circulation in the Santa Barbara Channel are a large counterclockwise gyre in the northern part of the Channel and a smaller clockwise gyre in the southern end. These two features strongly affect the distribution of marine organisms on the Channel shores.

The southern gyre can distribute any floating debris or liquid wastes (at least 30 or more mgd, see Table 1) discharged into the sea at Ventura-Oxnard-Hueneme to areas south of these settlements. And longshore drift can move 600 cubic yards of sand a day (contaminated or clean) south past a given point on a beach in average weather.

The northern gyre distributes cold water from regions north of Point Conception along the mainland side of San Miguel Island, Santa Rosa Island and the northwestern end of Santa Cruz Island. During August, a time of warm water (see temperature data in Fig. 3), islands influenced by this gyre show an average of 4°C cooler surface temperatures than the mainland waters opposite them.

One surprising feature of the annual temperature variation in the Channel is that the coldest temperatures occur in May. During May, the California Current is strong, sweeping cold water from the North. In November and December, warmer water from Baja California moves along close as far as Point Conception (the effect of this water is less north of the large promontory), but the effect of warm water is tempered by upwelling of cooler waters during this time. Seasonal differences in temperature encountered north (15°C in August, 10–13°C in March) and south (16–20°C in August, 14–15°C in March) of the cape and different durations of the temperature variations result in major floral and faunal changes at this point.

Marine algae favoring cold or warm waters distribute themselves accordingly, with intermediate forms on the islands of Anacapa, Santa Barbara and the southeastern end of Santa Cruz Island. Transition from cold water species (or forms) characteristic of habitats north of Point Conception to species adapted to warmer waters is more gradual in the Channel Islands than on the mainland because cold water swept south by the northern gyre allows species characteristic of the northern California mainland to penetrate farther down the island chain. A number of species found in Baja California are found on the more southerly Channel Islands of Santa Catalina and San Clemente. The bulk of the Channel Islands algal species are shared with the mainland.

A skeleton outline of the relatively undisturbed distribution pattern of species that existed around the turn of the century can be documented from collections of W. A. Setchell and N. L. Gardner, and such

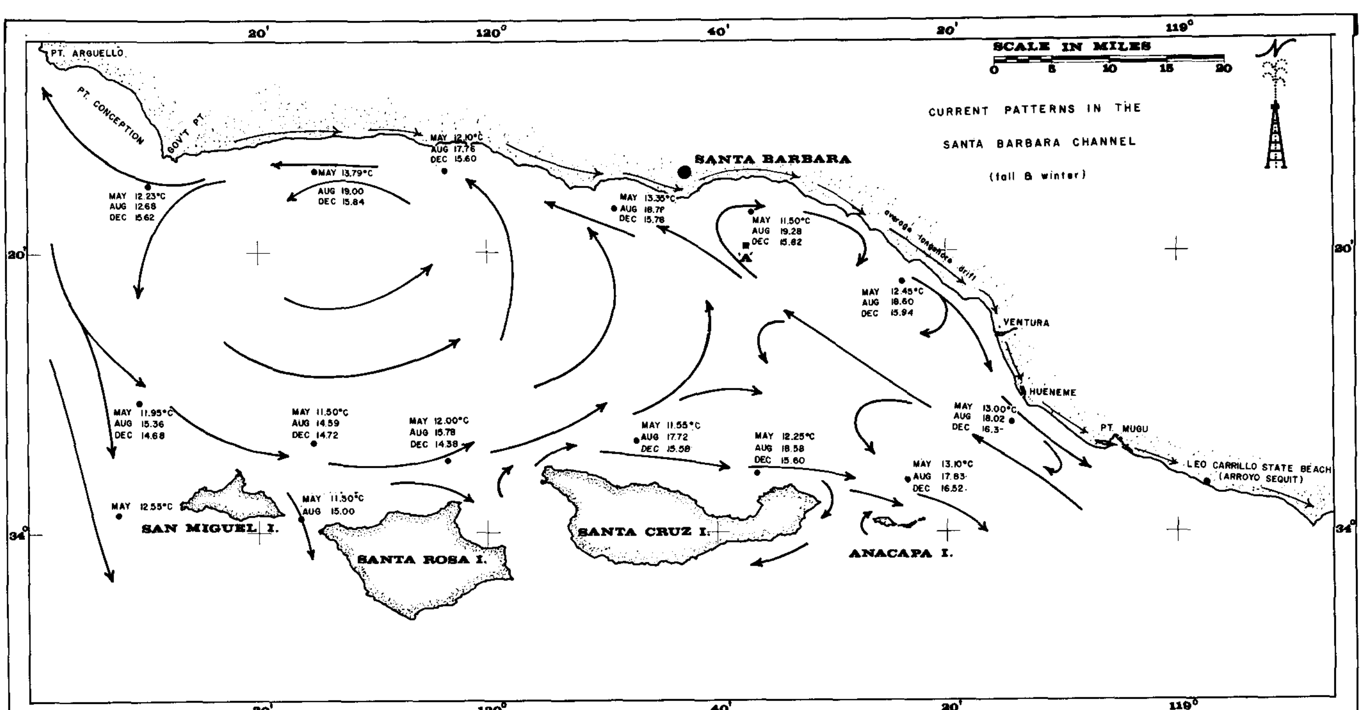


FIGURE 3. Fall and winter movements of surface waters in the Santa Barbara Channel. These were the currents prevailing at the time of both spills: note that the distribution of oil on the mainland and in the Channel Islands (Fig. 1) coincides with the pattern of flow. Temperature data are also shown (courtesy of Ronald Kolpack, Department of Geology, U.S.C.).

an outline is consistent with the circulation patterns of water briefly discussed above. Since the setting for the Southern California marine flora is composed of a variety of physical, chemical and geographical factors, it is not surprising that this variety is reflected in complex distribution patterns.

The diversity of the California flora at the turn of the century may now only be estimated, but Yale Dawson (1959) analyzed collections (intertidal and shallow subtidal) from the years 1895–1913 and felt that, as a conservative estimate, 60 conspicuous species made up the state's marine flora during a given season at a specific point on the coast. That this number is reasonable has been confirmed by findings at the stations surveyed in the Channel Islands by Nicholson and Cimberg (1971). The most thoroughly surveyed sites have minimum floras of 61 species (Blue Banks Anchorage, Santa Cruz Island) recorded from a single visit and 68 species (all year; Isthmus Cove, Santa Catalina Island). There have been 6 new records of macroscopic algae at Isthmus Cove added in the season following the 1969–1970 survey by USC, bringing the total to 74. The usual number of algal species at one visit in the Channel Islands varies between 28 and 45.

Island stations are here assumed to represent a relatively undisturbed condition, at least on the Pacific side of the islands which is freer than the mainland side from the influence of materials added to the water from mainland sources. The present island flora cannot be assumed to be identical with the hypothetical mainland flora of seven decades ago, but it can serve as a model baseline for comparison with Dawson's data gathered between 1956 and 1959. The major deviation in composition from mainland associations that the Channel Islands flora would be expected to show, would be a lack of dominance of species adapted to areas enriched by abundant natural runoff. In other words, the Channel Islands probably shared most species with the mainland, but the abundance of certain types was markedly different.

The intertidal plants in Southern California offer an example of populations responding to changing conditions. There has been a shift from waters unaffected by human-produced wastes to waters receiving nearly one billion gallons per day of assorted discharges (cooling effluents, industrial and municipal wastes, storm runoff from urban areas) from numerous ocean outfalls (Table 1). Dilution of these discharges is hindered by the restricted circulation between the mainland and the Channel Islands (Fig. 3 shows surface water movements in the Northern Channel). Wastes discharged into these gyres may be recirculated rather than efficiently diluted. In addition to changes in water chemistry, intertidal areas are now subject to photochemical smog (the water-soluble components of which dissolve on the wet surfaces of freshly exposed organisms, concentrating as exposure lengthens) the components of smog are thoroughly mixed into shallow water by waves on the ebb and flood tides. Because smog-borne heavy metals are not appreciably water soluble, they probably precipitate soon after their mixing into the water column and are likely to be found in the near shore sediments. A major exception to this route from atmosphere to sediment should be found in those areas where marine algae such as *Macrocystis* and diatoms secrete copious amounts of mucilages into the surrounding water, which are then capable of complexing heavy metals. In view of the continuous supply of heavy metals to the air and a ready mechanism for their introduction into the marine environment, their impact should be carefully investigated. This investigation was not able to concern itself specifically with the effects of smog components such as metals, but they are as important as the more readily observable effects of human usage of the beach areas. Mechanical disturbance arises from droves of sightseers, collectors, clammers, etc. (stampede effect). All of the above factors have, over the past eight decades, become increasingly chronic. During the period under consideration, there have occurred numerous incidents of acute exposure of marine populations to toxic materials intentionally or accidentally released. Thus the effects of acute incidents such as the Santa Barbara oil spills are superimposed on responses to chronic conditions and are influenced by antecedent events.

Changes (or dynamic equilibria) in the intertidal are most easily detected by monitoring populations of firmly attached organisms. Benthic seaweeds and sessile or sluggish animals attached to a rocky substratum allow repeatable sampling of the same populations over as long a time span as desired. It should be noted here that investigations in the rocky intertidal are affected by a number of factors related to regular exposure and inundation; the area available to sample is in a continual state of flux due to uneven tidal heights, shifting sand and rocks. There is also a continual change of species composition in the intertidal during the yearly cycle of seasons, making it imperative that samples from one year to the next be compared on the basis of similar months. Any comparative study must have baselines, without which detection of steady states or changes is impossible. In the case of the Southern California intertidal, the marine algae have been the only organisms for which a baseline exists.

There have been major changes in the number of species of intertidal plants at specific locations throughout most of Southern California. This conclusion is based on monitoring of 44 rocky beaches established as stations for checks on water quality in 1956–59 (Dawson, 1959), and resurveyed by Neushul (1967) and Nicholson and Cimberg (1971).

The dates and locations of these studies make it possible to draw three general conclusions regarding shifts in the composition of the intertidal flora. First, the change in number of species over the decade between 1959 and 1969 has been a decline amounting to an average value of 63% for the region between Point Conception and Dana Point. Second, the decline was well underway by 1967, (Table 9) at least in the Santa Barbara-Ventura region. Third, while the Santa Barbara spills of 1969 were responsible for specific destructive incidents, those oil spills cannot be the cause of the changes that occurred *before* them in time or *outside* their area of influence. The oil spills were responsible for kills of seabirds and losses of marine organisms in the upper intertidal when patches of their habitat were smothered. And, until the slicks were gone, they interfered with the settlement and establishment of marine populations on rocks. Effects of the sunken oil on deep water animals is not easy to assess (Fauchald, 1971), but the possibility exists that large areas of sediments were changed in texture and/or composition sufficiently to disturb their residents. Fauchald (1971) also reports a decrease in biomass of the echiuroid worm *Listriolobus pelodes* in the area ESE of Santa Barbara from a peak of 2,000 $g/m^2$ (surrounding areas varied between 1,100 and 1,800 $g/m^2$) in the state survey of 1959 to a present peak value of 800 $g/m^2$ (nearby areas show 8–180 $g/m^2$). This decline was not attributable to oil seep activity or to the oil spill, but it does fit a general picture of decline in many marine populations in Southern California. However, Hartman (1960) noted that there was a reduced fauna in oil seepage areas near Goleta (a short distance north of Santa Barbara).

### *Analysis and Interpretation of Data with Respect to the Presence of Oil and Other Influences on Intertidal Populations*

The brief list offered below, consisting of factors affecting health of intertidal populations, is intended to outline the complex situation from which single events (such as oil spills) must be untangled.

i) exposure of wet surface films to smog at low tide, with probable adsorption and/or absorption of heavy metal complexes (Pb is a logical possibility), acid-forming moieties and the like which concentrate as evaporation proceeds;
ii) mixing of smog into the first few feet of sea water by wave action, producing a local alteration in water chemistry;
iii) trampling, clamming, collecting;
iv) special events such as flooding, Santa Ana winds at low tide, storm surf, smothering by sand;
v) chronically altered water chemistry from municipal wastes, industrial wastes and storm runoff from urban areas;
vi) chronic presence of oil in the Santa Barbara Channel;
vii) selective adhesion of oil to warm, dry surfaces.

With the possible exception of chronic changes in water chemistry and chronic presence of oil throughout the floor of the Channel, all the above factors act more intensely in the upper rather than in the lower areas of the intertidal.

Viewed in long-range perspective, the Santa Barbara oil spills of 1969 are incidents of abuse to coastal waters that have been subject to chronic human interference for at least seven decades. The downward trend in variety of intertidal plants is a reflection of altered environmental parameters. At least for the upper intertidal, the tendency is now for the area to be inhabited by species that are aggressive annual colonizers: *Ulva, Enteromorpha,* diatom films and GATGOR (note at end of Table 7), instead of normal abundant cover of the slower growing *Endocladia* and the perennial rockweeds *Pelvetia* and *Hesperophycus.*

In the lower intertidal, *Egregia* is particularly abundant at Emma Wood State Beach (immediately north of Ventura), Point Fermin (near Port of Los Angeles) and White's Point (site of 380 mgd discharge of sewage and industrial wastes). Young *Egregia* sporophytes are abundant (spring and late winter) up to the 2.5 foot level in the latter two areas and mixed populations of juvenile and mature plants grow at least as deep as 35′ subtidally. Most of the adults occur from 0.5 tide level or lower: all sporophytes are thicker and more coriaceous than comparable plants around Santa Barbara, San Diego and the Channel Islands. *Egregia* is often found interspersed with *Macrocystis* (for example at Anacapa Island and Point Lobos in Northern California) under relatively undisturbed conditions, but it may be a successful competitor of *Macrocystis* under present conditions around Point Fermin and White's Point. Whether or not these small *Macrocystis* beds (remains of once vast kelp forests in the Los Angeles region) at these sites are suffering from encroachment of *Egregia* is a worthwhile topic for investigation.

Another good colonizer has made its appearance in Southern California: the large brown seaweed *Sargassum muticum.* This alga was introduced from Japan (probably on shells of young oysters) into the Puget Sound region about 1947 (Fensholt, 1955; Scagel, 1956) and worked its way southward into Oregon and Northern California. It first appeared in Southern California in spring 1971, where it was reported from Orange County, San Diego County and Santa Catalina Island. As this *Sargassum* establishes itself in the lower intertidal and shallow subtidal, its abundance is being monitored quantitatively. Whether *Sargassum muticum* represents a potential pest, an interesting addition to the Southern California marine flora or a commercial source of brown algal polysaccharides remains to be seen.

Vulnerability of simplified ecosystems to invasion and epidemics have been adequately discussed elsewhere (Hutchinson, 1959; Woodwell, 1970) and the warnings of these authors are pertinent to the situation that has developed in Southern California. Loss of huge areas of subtidal kelp forests (Limbaugh showed in 1955 that at least 125 species of fish associated themselves with the "living reef" of a kelp bed), persistence of rapid colonizers in the upper intertidal and the invasion of the lower intertidal-shallow subtidal by a large seaweed from Japan lead to the conclusion that a decade-long decline of 63% in variety of intertidal algae has not been a neutral event. Since marine plants are a basic source of food and shelter for animals, it is reasonable to suppose that a decline in variety and/or quality of food (not necessarily quantity) will have repercussions throughout marine food webs of the entire southern portion of the state. Shifts in predation pressures occurring as a result of altered food supply of local regions can expose distant relatively undisturbed sites to upsets. For instance, dwindling kelp beds yield fewer good fishing grounds for large mammals (man included), increasing frequency of catches in remaining submarine forests may reduce available food, interfering with migratory patterns of birds and mammals dependent on nearshore foraging.

What can be said concerning the effects of oil on intertidal plants in view of the complexity of the background against which they must be interpreted? The best field evidence for chronic influence of oil comes from comparison of populations at Coal Oil Point, Carpinteria State Beach and the beach one mile north of Dana Point (Fig. 2; Tables 4–7). Two observations are noteworthy: the plants present in largest numbers may be oil tolerant or oil evading, particularly in the upper intertidal (given the small solubility of crude oil fractions in sea water, and long exposures, there is greater opportunity for oil films to cling to warmed and dried organisms in the upper intertidal) and there are fewer species than at Carpinteria or near Dana Point. Lower intertidal plant species are the main contributors to variety at Coal Oil Point.

That Carpinteria State Beach is inshore of an oil seep area cannot be ignored, but other than during oil spill periods, slicks and their accompaniment of petroleum smell were not observed. Table 3 shows that occurrence of oil patches at Carpinteria is about half that at Coal Oil Point and its presence is sporadic. Carpinteria has slightly fewer but more abundant species than the beach near Dana Point, possibly reflecting the greater occurrence of oil at Carpinteria. Additionally, in spite of the presence of natural oil, exposure to two oil spills and flooding in the winter of 1969, Carpinteria may be a healthier beach (28% decline in algal variety over a decade) than the beach near Dana Point (55% decline for the same period) which is nearer large sources of discharged wastes. There are a number of ways in which populations may register damage; the percent occurrence data from Carpinteria and the Dana Point area raise the interesting possibility that species abundance decreases prior to loss of a species. In regard to the way in which the phrase "loss of a species" is used here, there is no intention of concluding that any of the missing species will never return to these sites: but it is noteworthy that their occurrence is sufficiently erratic and patchy for them to disappear for significant periods from their normal habitats.

In comparing the spring months of 1969 and 1970, there is an indication that the beaches affected by oil spills (Gaviota to Hobson) and runoff in 1969 recovered more variety of species than the four southern beaches also affected by runoff (Table 8). This conclusion implies simultaneous damage from oil and fresh water, which both produce dead and bleached algae (as at Catalina in January and December 1969–70 after the second oil spill: see Nicholson and Cimberg, 1971). Except in cases where oil is observed present long enough to smother or injure living tissue (as in the case of the smothered barnacles), it is extremely difficult to distinguish oil-killed from fresh water-killed specimens. In the vicinity of active oil seeps there is also the possibility that there will be traces of oil in tissues; simple presence of oil does not guarantee its origin from a spill.

Laboratory investigations do, however, show a potential for certain fractions of oil to interfere with photosynthesis (Clendenning, 1964). Even if this interference is slight, it may be sufficient to upset the delicate balance between photosynthesis and respiration, gradually producing a loss of vitality in vegetative and reproductive phases. The latter effects are best observed in detail in the laboratory, since slow or subtle changes in vitality are not easily observed quantitatively in the field.

### *Summary of Observations and Conclusions*

General or Long-term Trends:

1) There has been an average decline of 63% in variety of species of intertidal algae in Southern California (1956–1970).
2) The decline mentioned above was underway by 1967 at least in the Santa Barbara-Ventura region and continued in 1969–70 in the larger region between Point Conception and Dana Point.
3) Substantial losses in area of kelp forests, partial replacement of semi-permanent high intertidal species such as *Endocladia*, *Pelvetia*, *Hesperophycus* by algal films (GATGOR and diatoms), *Ulva* and *Enteromorpha* which are fast-growing annuals along with the invasion of lower intertidal-shallow subtidal areas by *Sargassum muticum* from Japan point to developing instability of associations of macroalgae.
4) It is suggested that altered air and water chemistry since the turn of the century combined with mechanical disruption of intertidal areas by public use have created an environment favoring the development of instability among marine algal populations.

Observed Effects of Crude Oil:

1) Barnacles that settled on weathered patches of oil were washed away when their substratum eroded away after further weathering.
2) Sessile organisms (algal films and barnacles) were smothered by discontinuous patches of oil.
3) Oil adhered selectively in the upper intertidal rather than in the lower intertidal due to greater length of exposure and consequent warming and drying of the former.
4) Chronic presence of oil (Coal Oil Point) in the intertidal produces a beach with fewer plant species, but those that can tolerate or evade the effects of crude oil are highly abundant.

PLATE 1A. Carpinteria State Beach at the time of the December 1969 spill, showing frothy oil on sand.

PLATE 1B. Bleached algae (white patches in foreground) at Carpinteria State Beach in late winter of 1969.

PLATE 2A. East Cabrillo Beach (Santa Barbara) in March 1969: cleanup operations employing chopped straw broadcast on crude oil.

PLATE 2B. East Cabrillo Beach Station Line: 7-foot section of metal groin smashed by storm surf in December 1969.

PLATE 3A. Oiled barnacles in the upper intertidal at Coal Oil Point.

PLATE 3B. Middle and lower intertidal at Coal Oil Point (near Goleta) showing large areas covered by the sea anemone *Anthopleura*. The dominant marine plants are *Phyllospadix, Ulva* and *Gigartina*.

PLATE 4A. Hobson County Park: improved facilities for camping completed in June 1969 attracted droves of clammers. Activity shown here is typical of each low tide—including low tides when the beach was covered by oil.

PLATE 4B. The beach at Palm Street, Ventura with green algal and diatom cover on exposed cobbles. Scene is west of Dawson's original station line, which was covered by sand in 1969–1970.

PLATE 5A. Leo Carrillo State Beach (Arroyo Sequit): onset of sandfill in winter 1969–1970. The kelps *Egregia* and *Macrocystis* protrude through the sand.

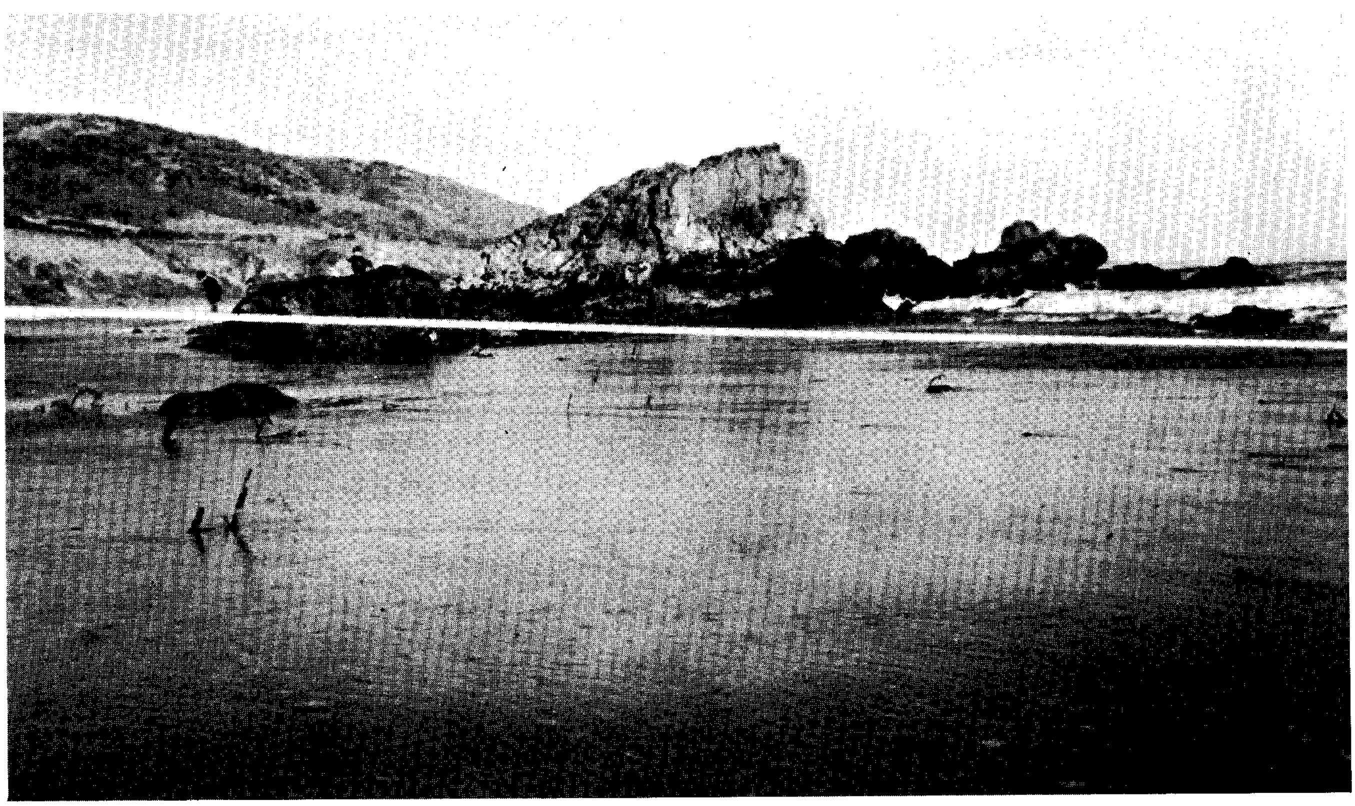

PLATE 5B. Leo Carrillo State Beach in February 1970: sandfill has smothered kelps, leaving behind scattered stumps of stipes.

PLATE 6A. Leo Carrillo State Beach in March 1970 after sand had been partially cut away, re-exposing rocks which were quickly repopulated.

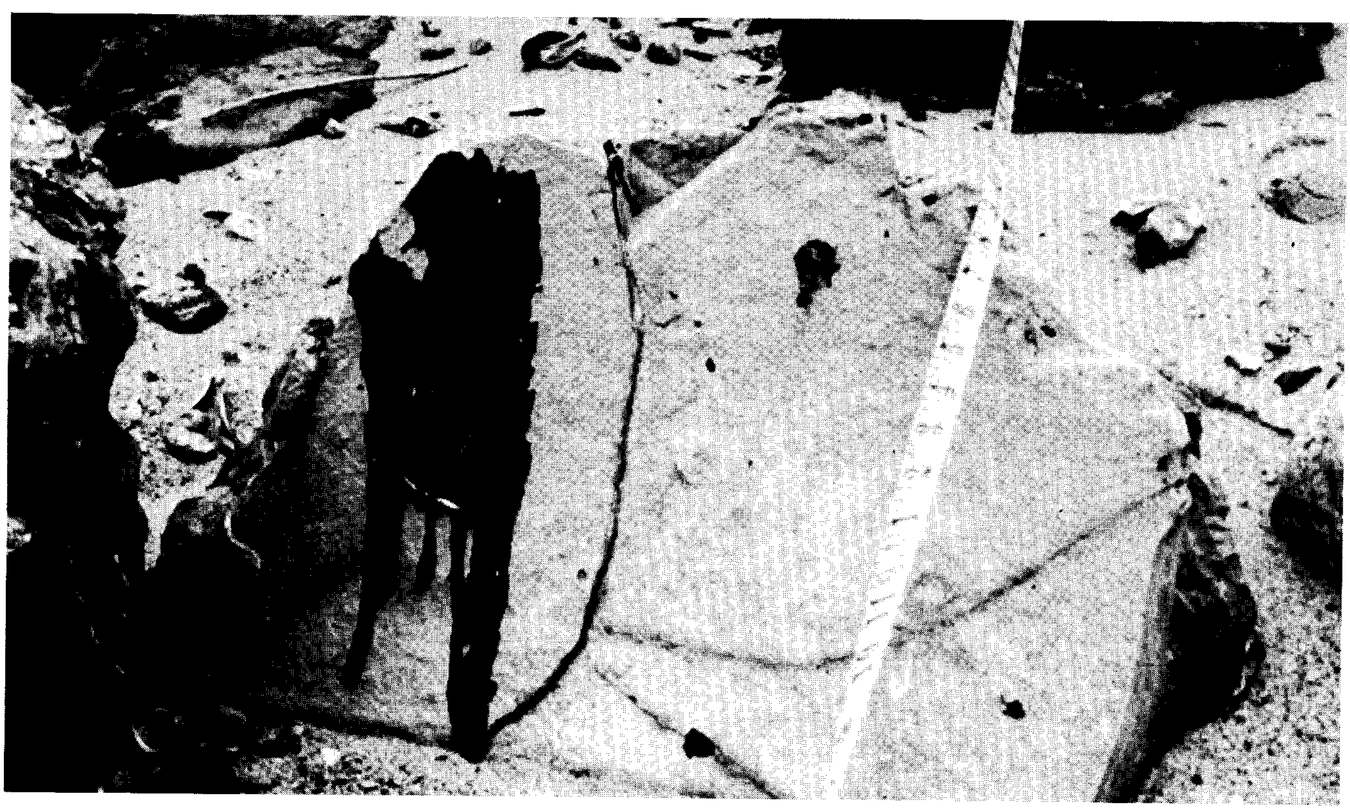

PLATE 6B. Corona del Mar: oil from an undetermined source on rocks in the upper intertidal. This beach is subject to heavy foot traffic and was the oiliest of the four southern beaches in this survey.

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# THE SANTA BARBARA OIL SPILL: DOSAGE OF CRUDE OIL ON SHORE AND INITIAL EFFECTS ON INTERTIDAL ORGANISMS

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## ABSTRACT

The quantity of oil which came ashore during the early stages of the Santa Barbara oil spill has been estimated from intertidal oil samples and aerial photographs. These methods indicate that 4,500 metric tons of crude oil was deposited on nearly 90 kilometers of coast by February 8, 1969, 11 days after the spill began. Dosages in the intertidal zone varied from 2.7 to 118.1 metric tons per kilometer. According to these estimates, the flow rate at the well was around 5,000 barrels (726 metric tons) per day. Oil continued to leak from the area at a reduced rate up to the time of this report, twenty months later. The discussion of dosage and distribution deals only with the initial pollution.

To determine the initial effects of the oil on intertidal organisms, 10 intertidal stations were surveyed from early February to June, 1969. The stations ranged in location from El Capitan State Beach north of Santa Barbara to Leo Carrillo State Beach near the Los Angeles County line. Based on pre-oil spill surveys at these same stations, the greatest negative biological change at a sample station after the spill was the loss of 16 plant species. However, losses in species were correlated in most cases with sand movement, and may have been related to the severe storms which occurred before and during the oil spill. Although gross species changes were not correlated with oil dosage, severe damage occurred in intertidal surf grass and barnacle populations as a result of the oil pollution. Potential long term biological effects of the continuing pollution are discussed.

A full account of methods and results has appeared in the following three publications, which are available as indicated. *Santa Barbara Oil Pollution, 1969.* A Study of the Biological Effects of the Oil Spill which occurred at Santa Barbara, California in 1969. Water Pollution Control Research Series 15080 DZR 11/70., published by Federal Water Quality Administration, Department of the Interior, October, 1970; Foster, Michael, A. C. Charters and M. Neushul. 1971. The Santa Barbara Oil Spill I. Initial Quantities and Distribution of Pollutant Crude Oil. *Environ. Pollut.*, *2*(2) :97–113 (available from authors) and Foster, Michael, M. Neushul and R. Zingman. 1971. The Santa Barbara Oil Spill II. Initial Effects on Intertidal and Kelp Bed Organisms. *Environ. Pollut.*, *2*(2) :115–134. (available from authors).

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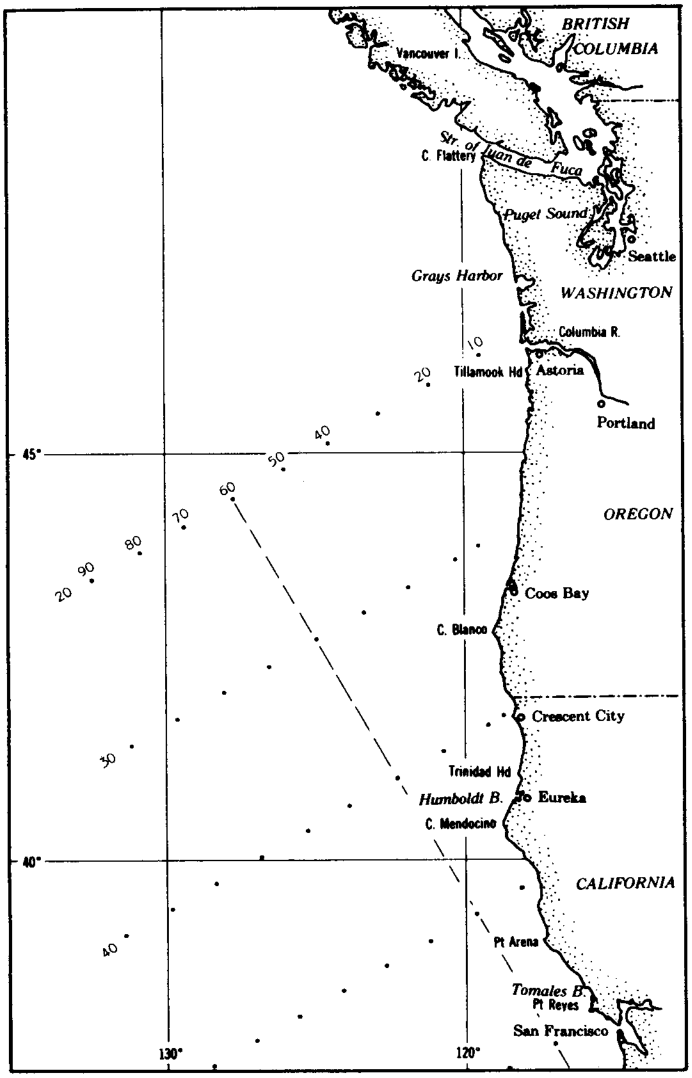


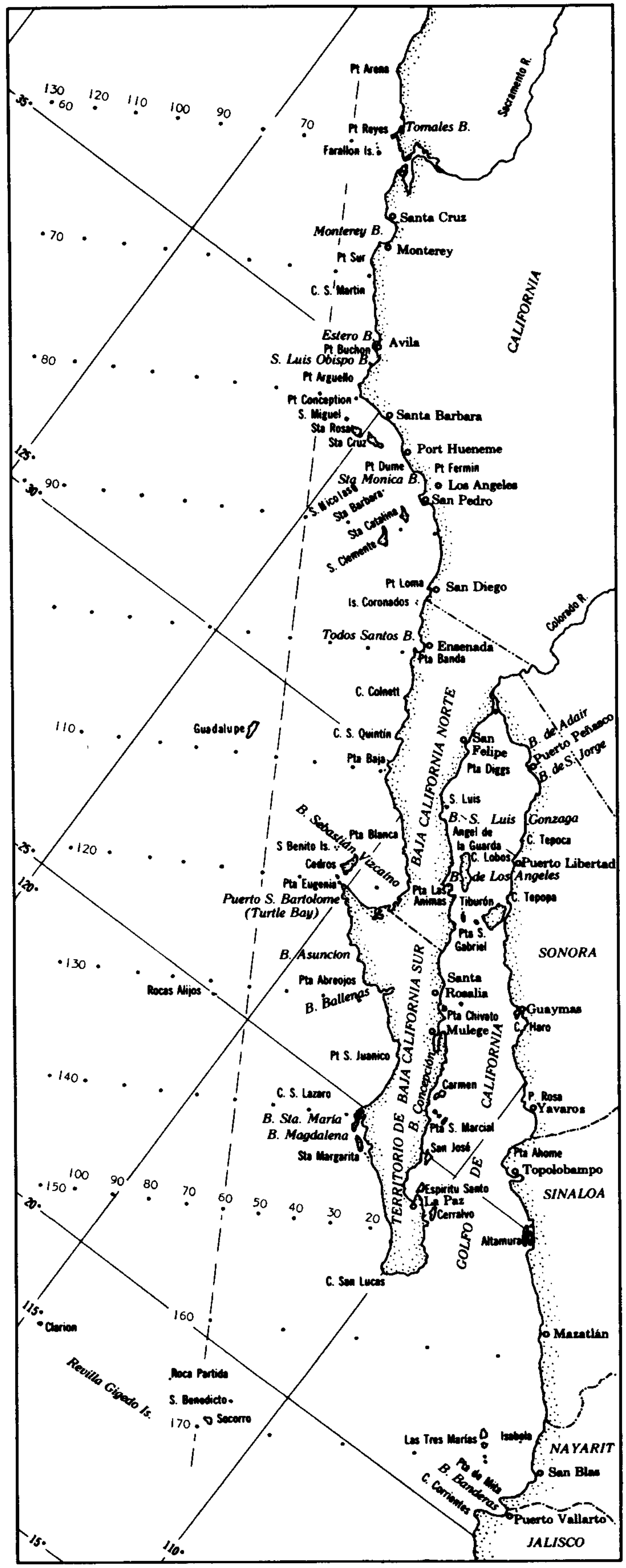


**These maps are designed to show essential details of the area most intensively studied by the California Cooperative Oceanic Fisheries Investigations. This is approximately the same area as is shown in color on the front cover. Geographical place names are those most commonly used in the various publications emerging from the research. The cardinal station lines extending southwestward from the coast are shown. They are 120 miles apart. Additional lines are utilized as needed and can be as closely spaced as 12 miles apart and still have individual numbers. The stations along the lines are numbered with respect to the station 60 line, the numbers increasing to the west and decreasing to the east. Most of them are 40 miles apart, and are numbered in groups of 10. This permits adding stations as close as 4 miles apart as needed. An example of the usual identification is 120.65. This station is on line 120, 20 nautical miles southwest of station 60.**

**The projection of the front cover is Lambert's Azimuthal Equal Area Projection. The detail maps are a Mercator projection. Art work by George Mattson, National Marine Fisheries Service.**

## CONTENTS