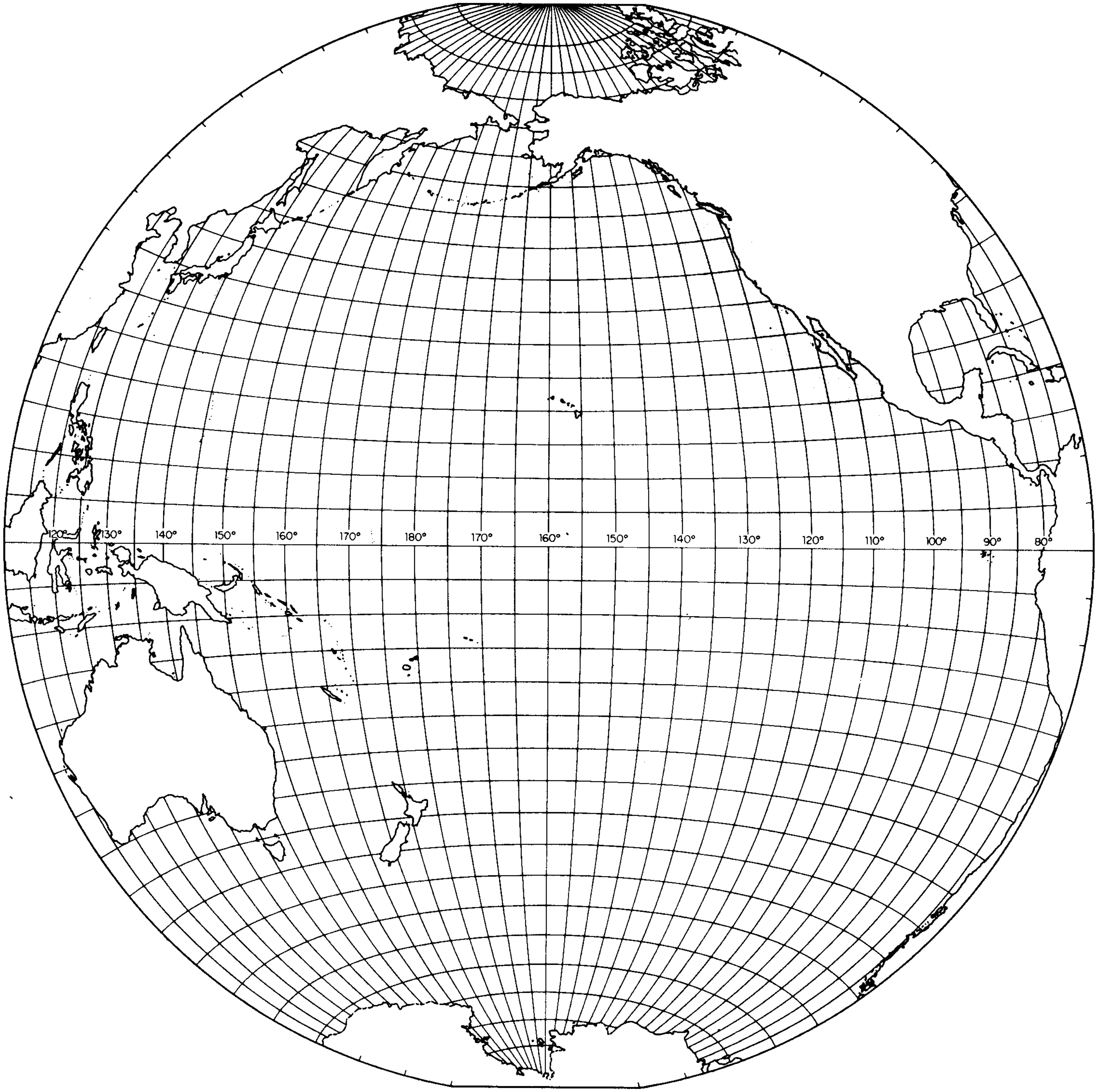
STATE OF CALIFORNIA
MARINE RESEARCH COMMITTEE



CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

REPORTS

VOLUME XVII

OCTOBER 1974

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STATE OF CALIFORNIA
DEPARTMENT OF FISH AND GAME
MARINE RESEARCH COMMITTEE

CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

Reports

VOLUME XVII
1 July 1971 to 30 June 1973

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 October 1974

STATE OF CALIFORNIA—RESOURCES AGENCY RONALD REAGAN, *Governor*

DEPARTMENT OF FISH AND GAME
MARINE RESEARCH COMMITTEE

28 January 1975

The Honorable Edmund G. Brown Jr.
Governor of the State of California
Sacramento, California

Dear Governor Brown:

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

The report consists of four sections. The first contains a review of the administrative and research activities during the period 1 July 1971 to 30 June 1973, a description of the fisheries, and a list of publications arising from the programs.

The second section consists of papers presented at two symposia, "Large scale aperiodic fluctuations in the Pacific Ocean" and "New challenges to accepted dogmas about productivity in the sea," held in November 1971. Participants in the symposia included key members of the scientific community who provided new insight to some fundamental oceanographic problems.

The third section consists of papers presented at a symposium, "Oceanography and fisheries of Baja California waters," held in November 1972, which brought together members of the scientific communities and governmental agencies of California and Mexico. This symposium demonstrated the spirit prevailing in the informal cooperative research programs that have been initiated between CalCOFI agencies, Instituto Nacional de Pesca of Mexico, and the Instituto de Investigaciones Oceanologicas, Universidad Autonoma de Baja California.

The fourth section consists of scientific contributions which are either a direct result of CalCOFI research programs or represent research directly pertinent to the living marine resources of California.

Respectfully submitted,

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

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Part I

REVIEW OF ACTIVITIES

1 July 1971 to 30 June 1973

REPORT OF THE CALCOFI COMMITTEE

Over the 25 years of its existence, the CalCOFI program has undergone considerable evolution. This evolution has emerged from the advancing perception of the nature of broad populations of pelagic creatures and the nature of large-scale events in the ocean and atmosphere that strongly influence the relative abundance and distribution of these oceanic inhabitants. Thus CalCOFI investigations not only initiated inquiries into vital current aspects of ocean climatology, but into recent past changes of climate and populations, into the creatures of the deep sea floor, into food webs and trophic interrelationships, into better measures of plankton biomass, and into a host of other aspects of the oceanic environment. The great majority of these inquiries has demonstrated fundamental value not only in understanding the living resources of the California Current, but in many other scientific areas such as climatology and studies of pollution, and in broader geographical areas. Indeed, CalCOFI has set the philosophy, approaches, and methodology for similar inquiries around the world. It has set a firm base for the re-establishment of a major pelagic fishery in the California Current.

Clearly further enlargement and evolution of the program are necessary, and these are being considered at this time.

One important development in the program during the last two years has been the inclusion of the Instituto Nacional de Pesca (INP) of Mexico in the cooperative planning of CalCOFI cruises in the ocean off Baja California and the Gulf of California. In the fall of 1971 the beginning steps were taken between the Subdirector of INP, the Co-Director of the Mexico/FAO Project of Fisheries Research and Development, and members of the CalCOFI committee. At that meeting it was agreed:

1. To schedule research cruises in Baja California waters in time and area coverage in such a way as to complement each other's efforts.
2. To use comparable methods and equipment in making observations and collections at sea.
3. To share all data and collections obtained during these joint operations.

Profitable discussions have continued between the groups since that time. CalCOFI agencies have supplied INP with help in developing the techniques to use CalCOFI-type equipment, by putting personnel on their ships and receiving INP personnel aboard CalCOFI ships.

The Southwest Fisheries Center invited two biologists from INP for training in identifying fish eggs and larvae of species of interest to CalCOFI in samples collected by all cooperating ships and shared between appropriate agencies.

There has been increased participation of the Escuela Superior de Ciencias Marinas of the Universidad Autónoma de Baja California in Ensenada in cooperative research with the CalCOFI agencies in the California Current and the Gulf of California. Also many of these students are gaining experience by participation in our cruises.

The need for this cooperation was succinctly expressed by Philip M. Roedel in 1968 and at the 1972 CalCOFI Conference, as follows:

> "Because the eastern Pacific fishery resources and interests, particularly those of Southern California and the west coast of the Baja California peninsula, are in such large degree the same, there is the very evident need for cooperation between the United States and Mexico in fishery matters if their common resources are to be properly husbanded."

Several of the papers in this volume of the CalCOFI Reports are based wholly or partly on data cooperatively obtained in 1972 by INP and CalCOFI.

Herbert W. Frey, John D. Isaacs, Brian J. Rothschild, and Marston C. Sargent

AGENCY REPORTS

CALIFORNIA ACADEMY OF SCIENCES

July 1, 1971, to June 30, 1972

During the fiscal year 1971–72 studies have been concentrated on the food of the Pacific hake, *Merluccius productis*, and of the squid, *Loligo opalescens*. On the basis of discussion at the meeting of the Marine Research Committee at the California Academy of Sciences on 2 September 1971 (Minutes, p. 9), the Academy agreed to include study of the food of the Pacific saury, *Cololabis saira*, insofar as these fish become available to us.

Material has been obtained from various sources, including the California Department of Fish and Game, the Northwest Fisheries Center of the National Marine Fisheries Service (Seattle), and from commercial fishermen. All stomachs have been examined by Anatole S. Loukashkin.

Hake. To the date of this report, 447 stomachs of hake have been examined. Juvenile fish from southern California appear to feed largely on copepods and copepod larvae. Larger fish from the same area ranging from 13 cm. to 21.5 cm. in total length, collected in subsurface water at night, were found to be feeding almost exclusively on euphausiids; other crustaceans were present in insignificant numbers. Two stomachs in this group contained juvenile hake. In two hake, 52.5 cm. long, from Monterey Bay, the stomachs were filled with juvenile rockfish, *Sebastodes jordani*.

A collection of hake from Port Susan, Puget Sound, Washington, proved interesting if somewhat baffling. Of a total of 333 specimens, mostly ranging in size from 25 to 42 cm., only three contained food in the stomach, and fifteen contained food in the mouth. The food thus found included shrimps *Sergestes similis* and *Cragon* sp., the euphausiid *Thysanoessa spinifera*, a hyperion amphipod, and unidentified Crustacea and crustacean parts. In addition, the three stomachs containing food, all contained juvenile hake. The specimens in this size range were sexually mature, and the sex ratio consisted of 214 males to 109 females. Of the smaller fish (12, ranging from 8.5 cm. to 14.5 cm.), ten could not be sexed. None contained any food either in stomach or mouth.

Two hypotheses were developed to explain this relative (indeed nearly complete) absence of food in this sample of fish: (1) hake may not ordinarily feed during the breeding season (such abstinence is common in various species of fish, and also in squid); (2) the expansion of gases in the swimbladder of hake brought up from depths of from 46 to 52 fathoms might have forced out any food contained in the stomach (in at least half of these specimens the swimbladder had been ruptured).

We discussed this with Dr. Dayton L. Alverson, Director of the Northwest Fisheries Center, who favored the first hypothesis. He stated that hake taken in offshore areas from equal or greater depths contained various quantities of food in the stomach, expansion of the swimbladder notwithstanding. The finding of juvenile hake in three stomachs of the fish here investigated indicates that if hake fed freely during the spawning season, they would devour their own eggs and young.

Saury. Fifty-four specimens of saury collected offshore in Washington coastal waters on Aug. 18, 1971 were sent to us, frozen. The fish ranged from 27.5 cm. to 35.5 cm. and were nearing spawning condition. There were 17 males and 37 females. Four stomachs contained no food. All the others contained food in various amounts, from full capacity to less than one-eighth capacity. The food consisted of well macerated remains of crustaceans, mainly adult and larval euphausiids.

Squid. The study of the food of squid is somewhat frustrating. The commercial catch is chiefly taken when squid are on the spawning grounds. This varies up and down the coast, being earlier in the south and later in the Puget Sound region; it is possibly correlated with temperature, and may vary from year to year in the same locality. In Monterey Bay the season is in general from April to June or July. Specimens may be obtained in any month, but with more difficulty. (The latest and best information is in Calif. Dept. of Fish and Game, Fish Bulletin 131, by W. Gordon Fields.)

In several hundred specimens obtained from commercial fishermen, most stomachs were empty, especially those of females, which are known not to eat at spawning time (this could also be more or less true of males). A further complication is that squid feed intermittently, not continually, and digestion is very rapid.

In stomachs containing food we found crustaceans, especially sergestid shrimps and euphausiids, and various small fishes. Identification is difficult because squid do not swallow their food whole, but bite it up into small pieces. Several writers have reported that squid are cannibalistic, eating smaller specimens of their own or other species of squid. This is doubtless true, although we have not observed it. Lack of appetite during spawning would thus be a factor in conserving the species. Considerably more study needs to be made of the squid and its role in the food chain.

We wish to thank our various collaborators, especially Dr. Dayton C. Alverson, and Messrs. Kenneth Waldron and Steven Hughes, of the Northwest Fisheries Center, National Marine Fisheries Service, and James Hardwick of the California Department of Fish and Game.

R. C. Miller

CALIFORNIA ACADEMY OF SCIENCES

July 1, 1972, to June 30, 1973

During 1972–73 investigations have centered on food habits of the Pacific hake, *Merluccius productus*, and the market squid, *Loligo opalescens*, with attention directed also to other species of commercial interest as they came to hand.

Hake. 467 specimens were taken in Monterey Bay, at Point Sur, off Avalon, and around Point George, in October 1972 and April, May, June, and August 1973. Slightly more than 10 per cent of the stomachs were empty. Dominating food items found in the stomachs were crustaceans; euphausiids, *Thysanoessa spinifera* and *Euphausia pacifica*, ocean shrimp, *Pandalus jordani*, and sergestid shrimp, *Sergestis similis*. Fishes contained in the stomachs were identified as follows: whitebait smelt, eulachon, night smelt, juvenile hake, lantern fish, anchovy, and juvenile rock fish not yet identified. Occurrence of fish in the stomachs did not exceed 9 per cent. In three stomachs from Point Sur young market squids were found. Also 95 hake were collected during a cruise of the research vessel SCOFIELD in June 1973 in Monterey Bay; these were quick-frozen and the stomach contents will be analyzed in fiscal year 1973/74.

Squid. Samples were obtained in July 1972 and May 1973, all from Monterey Bay, totaling 349 specimens. July squids had only empty stomachs, while May specimens contained food, however in insignificant quantities. Among food items there were remains of small crustaceans, possibly euphausiids and sergestids; fish remains occupied second place, and the rest of the stomachs contained an indeterminate semi-fluid (jelly-like) substance.

Anchovy. 827 stomachs were collected in May and June in Monterey Bay, predominantly of larger fish (up to 185 mm. S.L.). Almost all the stomachs were green in color, thus indicating that much of the food contained in them is phytoplankton. Detailed examination of the stomachs will be made in the fiscal year 1973/74.

Saury. On July 13, 1972, a sample of 54 fish in frozen condition was received from Mr. Steven Hughes, who collected them in August 1971 in coastal waters of Washington. All stomachs contained well macerated remains of crustaceans, mainly young and adult euphausiids.

From May 23 through June 8, 1973, Mr. Loukashkin took part in a cruise of the research vessel ALASKA of the California Department of Fish and Game. He collected a good series of stomachs for food habit study, including 72 hake, 318 market squid, 827 anchovy, 11 herring, 13 young sand dabs, 10 topsmelt and 14 California pompano.

The following persons extended their cooperation in providing material for our study. Messrs. Doyle E. Gates, Herbert Frey, Kenneth F. Mais, James Hardwick, Jerome D. Spratt, and Miss Nancy E. Nelson, all of the California Department of Fish and Game, and Mr. Steven Hughes of the Northwest Fisheries Center, National Marine Fisheries Service, to whom our thanks are due.

Robert C. Miller.

CALIFORNIA DEPARTMENT OF FISH AND GAME PELAGIC FISH PROGRAM

July 1, 1971, to June 30, 1972

Research within the Pelagic Fish Program is devoted chiefly toward gaining greater knowledge and understanding of the pelagic wet-fish resources of the California Current System upon which to base recommendations for management of these resources. The Pelagic Fish Program consists of four discipline oriented projects: (i) Fishery Research and Monitoring, (ii) Biological Studies, (iii) Sea Survey. and (iv) Sea Survey Data Analysis.

Fishery Research and Monitoring

Activities of the wet-fish fleet were monitored on a routine basis by means of catch sampling and log-interviews aimed at determining age composition of landings, areas of catch, and amount of fish effort expended by the fleet. A review of the pelagic wet-fisheries for the year is reported elsewhere in this volume.

Biological Studies

Emphasis was placed on developing and initiating a jack mackerel and Pacific mackerel tagging program. Early in the program, fish to be tagged were caught by hook and line from our research vessels, but with the cooperation of the skippers and crews of the San Pedro purse seine fleet, techniques were developed which enabled us to tag large numbers of mackerel during commercial fishing operations. By the end of the fiscal year, 5,519 jack mackerel and 1,047 Pacific mackerel had been tagged and released at various points along the coast, at offshore banks and islands off southern California, and off Baja California from Cedros Island to Magdalena Bay. Early tag returns (59 jack mackerel and 17 Pacific mackerel) demonstrated limited local movements.

Collection of specimens was begun for anchovy, jack mackerel, and Pacific mackerel fecundity studies. Information to be gained from these studies may be used to refine estimates of fish populations based on ichthyoplankton surveys.

A 2 year investigation of the Pacific herring resources in Tomales Bay was completed during the year, and studies concerning market squid were initiated.

Sea Survey

Nine cruises were conducted during the year including a cooperative CalCOFI egg and larva survey. Routine anchovy surveys using acoustic and midwater trawl gear were made during September and April off southern California and during June off central California. Anchovy school size and behavior studies were carried out in southern California waters during November and March. Exploratory cruises for Pacific sauries and large old jack mackerel were made off central and southern California in December and May. A sardine and Pacific mackerel survey was conducted in central Baja California and southern California waters during August.

The anchovy fall survey off southern California found schools widely distributed over the entire area. Schools were most numerous, but small, seaward of San Clemente and Santa Catalina Islands, with densities based on sonar detections ranging from 10 to 35 schools per square mile. Extremely good commercial concentrations were located in Santa Monica Bay where schools estimated to contain 100 to 300 tons of fish were found in densities averaging 24 schools per square mile. The estimated number of anchovy schools for the southern California region was approximately 135,000 which is slightly above the mean of all surveys in this region.

The spring anchovy survey off southern California indicated the anchovy population had shifted south and southwest of San Pedro since fall and was located more offshore and southward. Schools were much smaller and more numerous than previously. Sonar school densities ranged up to 42 schools per square mile and averaged 13. An estimated total of 207,892 schools, the highest estimate produced from sonar operation thus far, was in the entire region. School sizes were small (less than 10 tons) with only one area off Ensenada, Mexico, containing fishable size schools. Availability in California waters was extremely low.

The June survey in central California waters again confirmed the minor importance of this region as anchovy habitat. Estimates based on sonar produced a total of only 12,696 anchovy schools which is approximately 6% of the April estimate for southern California waters. Most schools were located between Morro Bay and Point Conception where densities ranged from 1.1 to 7.6 schools per square mile. The only other anchovy concentrations were located in Monterey Bay where good commercial size schools were found near Santa Cruz.

Schooling behavior and school size studies in late fall demonstrated anchovy schools at this time of year are much larger in horizontal extent than vertical. Most schools studied were 40 to 90 meters in horizontal dimensions and only 8 to 12 meters thick. Visual observations from underwater ports and expanded echograms from a precision depth recorder indicated fish in these schools were highly dispersed. Estimates of density were difficult to ascertain with any degree of accuracy, but there did not appear to be more than 100 fish per cubic meter. Although most schools were located within 7 fathoms of the surface, none was visible from aircraft, and observation from a surface vessel was possible only when a school was directly beneath it. Schools at this time of year could be approached closely by surface vessel without causing alarm or flight. Availability for purse seining was good.

A similar cruise conducted in March found schools with much smaller horizontal dimensions but with approximately the same compaction or density. A wild evasive behavior was characteristic of all schools studied. Much difficulty was experienced in approaching close enough for observation. The few schools observed through underwater ports contained less than 3 tons biomass and were always in full flight away from the vessel. Availability was very poor. A routine anchovy survey in April also found this behavior prevalent with extremely poor commercial availability throughout southern California waters.

In the middle of June, schooling behavior suddenly changed with the formation of very dense surface schools. Aircraft observers reported thousands of dense schools from Dana Point to Gaviota. A one day coordinated survey in the San Pedro Channel involving ALASKA and our marine patrol aircraft found hundreds of small dense anchovy schools on or near the surface. An 11 mile sonar transect produced a record density of 88 schools per square mile. Visual observations and acoustic signal strength measurements from sonar and echo sounder indicated anchovy schools were much denser and more compact than at other times of the year. These schools persisted through the remainder of June and into July. Commercial availability was excellent, but the reduction season had closed one month earlier.

The sardine-Pacific mackerel survey was conducted using a night light and blanket net. Sardines were taken on 16% of the stations located off central and northern Baja California. The 1971 year class was represented in only one sample. No sardines were captured or located in southern California waters. Pacific mackerel were taken on 6% of the stations off Mexico and 4.7% of those in southern California waters. These station success rates are indicative of continued low population levels in both regions.

The exploratory offshore surveys for saury and large adult jack mackerel were unfruitful. Only minor quantities of sauries and no jack mackerel were located; however, severe weather conditions precluded any meaningful surveys of offshore waters.

The disparity between sonar and echo sounder school detection rates has been resolved. Gross overestimation of school numbers from echo sounding was due to a very large difference between horizontal school dimensions and the echo sounder's search beam width in the upper layers. The varying behavior of near surface schools in avoiding the vessel's path also severely biased echo sounder detections. Echo sounding will be continued for determining school sizes, schooling depths, school thickness, and species identification. School number estimates from echo sounder surveys made prior to acquisition of sonar have been adjusted by applying a correction factor which was computed from data obtained when both sonar and echo sounder were used simultaneously.

Target strength measurements of anchovy schools detected by sonar and echo sounder indicate school density or compaction, rather than school biomass, is the dominant factor affecting target strength.

Work was started early in 1972 to publish the results of the first 5½ years of sea survey work. Data Report Number 21 covering sea surveys conducted during 1971 was published early in 1972.

Sea Survey Data Analysis

The systems analysis study of the Pelagic Fish Program was continued during Fiscal Year 1971–72. A task statement was written and a data inventory for sardines, Pacific mackerel, and jack mackerel was completed.

Modeling and simulation studies of the Pacific mackerel population were undertaken and its growth potential calculated. The likelihood of population increase falls drastically with even modest harvesting. This work culminated in the formulation of a Pacific mackerel management bill (Senate Bill 865) which was passed by both houses at year's end.

Considerable time was spent determining age composition of jack mackerel landings during the 1947–48 through 1956–57 seasons. Several papers were prepared and submitted for publication. These papers included an estimate of the annual mortality of the northern anchovy, delineation of the maturation and growth of Pacific mackerel, and major purse-seine gear changes of the San Pedro wetfish fleet.

Charles Haugen

CALIFORNIA DEPARTMENT OF FISH AND GAME PELAGIC FISH PROGRAM

July 1, 1972, to June 30, 1973

Sea Survey

A total of eight cruises was conducted during the year. Routine acoustic surveys for anchovy resource assessment were made off central California during September and June and off southern California-northern Baja California during November, March, and May. Exploration for Pacific hake and Pacific saury was conducted in conjunction with the September anchovy survey in northern California waters. One survey for assessment of Pacific sardine and Pacific mackerel populations was made during the fall in northern Baja California and southern California waters using a night-light and blanket net. An experimental acoustic cruise was conducted off southern California during February to develop methods of measuring anchovy school biomass acoustically. A CalCOFI egg and larva survey was conducted during July as a cooperative venture with National Marine Fisheries Service, Scripps Institution of Oceanography, and the Institutio Nacional de Pesca, Mexico.

Three acoustic surveys off southern California-northern Baja California indicated the highest anchovy population level since present sonar mapping techniques were initiated in 1969. Estimates of school numbers for these surveys were: fall 158,000, late winter 343,000, and spring 210,000. These estimates exceed the mean for all previous years which is 135,000. Estimates of population biomass were made by calculating school volumes and applying our best estimate of packing density to obtain tonnage. Minimum estimates of anchovy biomass for the three surveys range from 1.0 to 1.7 million tons. The true population size is very likely considerably larger than these estimates.

All surveys found anchovies distributed more to the south than usual. The late winter cruise found the southeastward spawning migration, that occurs at this time, had extended much deeper into waters off northern Baja California than previously observed. Approximately 66% of the population was located in waters off Mexico during late February and early March. The fall and spring surveys also found the population center located south of its normal position for these seasons.

Availability and vulnerability to harvest by purse seining was inversely related to the number and surface area of schools. The winter survey found the largest number of schools ever detected by sonar. Schools consisted of thin layers of relatively large surface area but very low packing density. These schools were very widely distributed 10 to 100 miles offshore with most fish in waters off northern Baja California. Purse seine fishing at this time was extremely poor.

The spring survey over exactly the same region 6 weeks later found 39% fewer schools and a 66% reduction in total school surface area. Packing density appeared much increased as evidenced by much more distinct sonargrams and higher echo levels. Visual observations from underwater viewing ports and the vessel's bridge also indicated denser schools. The population center had shifted northwestward out of waters off Mexico into the southern portion of southern California waters. The commercial purse seine fleet at this time made record catches.

Results of central California surveys during August and the following June indicated extreme fluctuations of anchovy abundance. The cruise in August found more fish than at any time in the past with an estimated 16,000 schools in the region. During the latter survey in June, sonar detection results were so sparse and negative that no schools could be identified as anchovy. No one anchovy was taken by trawl during the survey. The only signs of fish were the visual sighting of several schools of "pinhead" anchovies of the 1973 year class. During a squid survey several weeks earlier, schools of adult anchovies were observed close to shore in Monterey Bay.

Incidental acoustic search during a sardine-mackerel survey in central and southern Baja California waters detected the largest concentration of anchovies found to date in this region. This concentration was distributed over an area 55 miles long and at least 10 miles wide between Cedros Island and Punta Baja. Numerous large schools were located 25 to 35 miles offshore at depths of 100 to 135 fathoms where bottom depths ranged from 100 to 900 fathoms. These fish were of the southern subpopulation as evidenced by their age and length composition. At least 200,000 tons were present in this area.

Pacific sardines and Pacific mackerel were surveyed by a single cruise using a blanket net and night-light off the northern half of Baja California and southern California. Very low population levels of adults and poor 1972 year class recruitment were indicated by the occurrence of these species on only two of 71 night-light stations. No young of the year were taken or observed. Sardines were found only in Baja California waters.

A survey off northern and central California during August found Pacific sauries from Monterey northward. Commercial concentrations of large fish were located by sonar and searchlight near Point Reyes and Point Arena.

Intensive acoustic survey effort inshore along the northern California coast failed to locate identifiable schools of Pacific hake. Apparently hake do not form extensive schools in this region such as occur off Oregon and Washington or they school too close to the bottom for detection by echo sounder.

Sea Survey Data Analysis

A paper on the maturation and growth of Pacific mackerel was published. Analysis of data reveals spawning can occur from March through October, but is most common from April through August. During this April through August period, 22.5%, 65.5%, 75.1%, 84.7%, 84.2%, and 87.5% of the female fish were mature or maturing for Age Groups I, II, III, IV, V, and VI+ respectively.

During 1972 and early 1973, several different methods of determining Pacific mackerel population size were investigated as mechanisms for estimating the spawning population size of Pacific mackerel stocks north of Punta Eugenia, Baja California. The estimate of Pacific mackerel spawning population size obtained by a tagging procedure was 5,480 tons. Three additional methods were used to estimate spawning biomass. These estimates were 4,730 tons, 6,210 tons, and 6,970 tons.

Examination of past Pacific mackerel data and estimated parameters has raised serious doubts about the reliability of these estimates.

Analysis of the early years of the jack mackerel cannery fishery has shown an almost 7 to 1 variability in year class strengths has occurred in the past.

Kenneth F. Mais
Eric Knaggs

HOPKINS MARINE STATION

July 1, 1971, to June 30, 1972

The Hopkins Marine Station of Stanford University, at Pacific Grove, California, conducts studies on the environment and organisms of the coastal waters off central California. Under the program, the Station monitors the marine environment and phytoplankton of Monterey Bay, and is involved in studies of pelagic food chains and their relationships to the biological oceanography of Monterey Bay.

The standard series of hydrographic surveys, as outlined in CalCOFI Reports XV (September 1971), has been continued, on 32 approximately bi-weekly cruises. Data collected on these cruises (see CalCOFI Annual Reports of Monterey Bay Hydrographic Data) form the base for biological oceanographic investigations conducted concurrently.

With the completion of studies on the entry and transfer of DDT residues in pelagic food chains, investigations on trace metal relationships in a pelagic marine system were commenced during 1971–72.

Surface water samples collected from Monterey Bay and on a transect between Hawaii and Monterey were analyzed for Cd, Cu, Mn, Pb, and Zn. Mixed phytoplankton and zooplankton samples collected from Monterey Bay during this same period were analyzed for Na, Mg, Ca, K, Sr, Si (phytoplankton), Ba, Al, Zn, Fe, Cu, Mn, Ni, Ti, Ag, Cd, and Pb. Samples of the northern anchovy, *Engraulis mordax*, were also collected in Monterey Bay, dissected into specific tissues, and analyzed for Pb, Cd, Ag, Ni, Mn, Cu, Fe, Zn, Al, and Ba. In addition, each of the above samples was analyzed for total mercury.

Methods and Materials

Sample preparation and analysis presented several problems. In comparing wet digestion, Muffle furnace, and low temperature ashing (LTA) techniques, results indicate that there is no one single sample preparation method for analyzing all elements. Hg analysis must be done using wet digestion techniques followed by flameless atomic absorption, since both LTA and Muffle furnace perparation give rise to sample losses. The use of LTA appears to cause the "loss" of some iron, while lower zinc values are obtained using the Muffle furnace (450°C).

The large quantities of silica contained in phytoplankton tests amount to approximately 80% of the total dry weight and remain as the major part of the ash, and experiments using hydrofluoric acid to dissolve the silica indicate some interferences with analytical procedure may exist for some elements (e.g. Cd) if this silica is not removed. Excess salt, extremely difficult to remove from phytoplankton and zooplankton samples, can cause "matrix" or interference effects in the analysis of samples. Analysis of anchovy and some zooplankton species presents problems due to high lipid content, with some evidence that lead is lost in the lipid phase of wet digestion.

Samples were analyzed by conventional atomic absorption spectrometry. Each of the above samples was also analyzed for total mercury by flameless atomic absorption spectrometry. Results from plankton samples sent to Battelle Northwest for analysis by an alternate method (neutron activation) were in agreement with the results obtained by Hopkins Marine Station.

Results

Phytoplankton samples were separated into acid soluble and silica fractions prior to analysis. The acid soluble fraction (i.e. elements associated with the organic material plus adsorbed elements) contained large amounts of Na, K, Mg, Ca and Si ($>$1000 μg/g dry wt.), intermediate amounts of Sr, Ba, Fe and Al ($>$25 μg/g dry wt.), and low concentrations of the remaining elements (i.e., $<$25 μg/g dry wt.). Titanium usually was not detected in this fraction. In the silica fraction, Na, K, and Mg were found to have the highest concentrations, followed by Al, Ca, Fe and Sr. The lowest levels found in this fraction were for the elements Cu (9 μg/g dry wt.) and Zn (5 μg/ dry wt.) with Ba, Mn and Cd detected only occasionally.

For nearshore surface waters, levels of Cu, Mn and Zn were usually higher than offshore levels (Hawaiian transect) especially during periods of strong upwelling. Cd and Pb concentrations were almost always an order of magnitude higher inshore. The effects of phytoplankton uptake on the concentrations of Cu, Mn, Pb, and Zn in nearshore surface waters were minimal, even during periods of extreme productivity. However, Cd levels were found to decrease during peak periods of productivity. Generally, metal levels in nearshore surface waters appear to be more dependent on hydrological fluctuations than on biological factors. Elemental concentrations in phytoplankton were low compared to the findings of other workers, and the annual variations observed here also seem to be dependent on hydrological as well as biological factors.

Analyses of surface plankton collected in the central Pacific indicate that the open ocean surface plankton contain mercury levels approximately two times greater than their Monterey Bay counterparts, while levels in the zooplankton vary insignificantly. Between the phytoplankton and the zooplankton, there is no significant difference in concentration on a wet weight basis, although on a dry weight basis the phytoplankton appear to have a higher mercury content.

Anchovies from five age classes were examined, but no correlation between total mercury content and age was observed. The mean mercury level in different tissues was as follows: muscle, 40; gills, 28; gonads, 15; liver, 91; and skin, 9 ppb wet weight. On this basis, the muscle tissue appears to be considerably higher than plankton levels; however, if the average wet weight Hg content of the muscle tissue is expressed on a dry weight basis, a value of 130 ppb is obtained (statistically indistinguishable from associated plankton samples). For comparative purposes, it is recommended that mercury values be expressed on a dry weight basis.

George A. Knauer

HOPKINS MARINE STATION

July 1, 1972, to June 30, 1973

The Hopkins Marine Station of Stanford University, at Pacific Grove, California, conducts studies on the environment and organisms of the coastal waters off central California. Under the program, the Station monitors the marine environment and phytoplankton of Monterey Bay, and is involved in studies of pelagic food chains and their relationships to the biological oceanography of Monterey Bay.

The standard series of hydrographic surveys (as outlined in CalCOFI Reports 15, September 1971), has been continued, on 24 approximately biweekly cruises. Data collected on these cruises (see Annual Reports, CalCOFI Hydrographic Data) provide the base for concurrent biological oceanographic investigations. During 1972–73, an investigation of trace metal relationships in a pelagic marine system was completed, and a study of seasonal changes in the size characteristics of food particles supporting Monterey Bay food chains was commenced.

Results

Phytoplankton concentration factors (relative to sea water) were found to be highest for Pb, Fe, Si, Cd, Al, and Ti, while relatively low values were obtained for Ba, Zn, Cu, Mn, Ni, and Ag. Except for K, Sr, and Ba, the alkaline earth metals were not concentrated relative to sea water.

Levels of the metals Pb, Cd, Ag, Ni, Mn, Cu, Fe, Zn, Al and Ba were also compared in phytoplankton, zooplankton and anchovy samples in order to determine existing relationships in this simple food chain. In general, concentrations of biologically active metals were relatively constant in all three trophic levels. For nonbiologically active metals (e.g. Cd, Ni, Pb) little evidence for food chain amplification was found, as would be expected in an unpolluted area under equilibrium conditions. On a daily basis, even during periods of high productivity, the removal of metals by phytoplankton was low compared with the findings of other workers, and the annual variations observed were dependent on hydrographical as well as biological factors.

George A. Knauer

MARINE LIFE RESEARCH GROUP SCRIPPS INSTITUTION OF OCEANOGRAPHY

July 1, 1971, to June 30, 1973

Originally called the California Cooperative Sardine Research Program, CalCOFI and the Marine Life Research Group (MLR) were conceived over twenty-five years ago as an inquiry into explaining the decrease or disappearance of the sardine which had previously supported an immense fishery. It soon became apparent that the answer to this question would not ensue from a hopeful poking about into the sardine, but, rather, from a large-scale study of the major pelagic inhabitants of the California Current system and the changes in their environment, which has thus been the mission of CalCOFI and MLR.

In addition to these studies of the organisms and conditions of the California Current, the MLR program has extended its inquiries in time—the varved sediments; in depth—the benthic work; in space—the North Pacific Study; and in penetration—the inhabitants of the sea and their interactions. Some components of these are described below.

Varved Sediments

Anaerobic and varved sediments accumulating under productive coastal waters preserve information in considerable detail on the ocean and terrestrial environment.

Investigation of this type of sediment in the Santa Barbara Basin, California, and the Soledad Basin, Baja California, continue to support the original conjecture that herein lie serial pages of climatologic, oceanographic and marine biological history, recording critical events and trends in post-pleistocene and contemporary times. Particularly important to the further development of this record into the past have been pertinent scientific observations on those portions of the sediments deposited in the last century-and-a-half.

The continued investigations by Andrew Soutar, John D. Isaacs, and others, have revealed that such sediments constitute a unique framework for the critical evaluation of geochronological methods and geochemical sequences (including man's effects). These sediments display a response related to records of seasonal rainfall that can characterize fluctuations and trends of precipitation in recent millennia. There are also evidences of interrelationships between pelagic fish and records of fluctuations in their abundance over past centuries, which are supported by recent studies of these fish.

From the record of varved sediments of southern California and southern Baja California, the sardine question has been substantially penetrated by the discovery that the sardine apparently has only occasionally been a conspicuous component of the pelagic population of the California Current. Rather, for the last several thousand years the pelagic fish populations have been dominated by the hake and northern anchovy, species presently in great abundance, and while these species also fluctuate in abundance, the fluctuations are small compared with variations of the sardine.

The conditions responsible for such fluctuations are not yet clear, but it *is* clear that they are related to changing oceanographic and marine biological conditions and that those are initiated by events far from the California coast, probably by those in the western North Pacific and possibly by events in the equatorial Pacific. This realization has stimulated inquiries into large-scale air-sea interaction in the North Pacific, some of whch is discussed below.

The varved sediment studies have placed the pelagic fish of the California Current system in perspective. It appears that these studies constitute not only an entree that greatly enhances our understanding of fishes and their associates but one that will continue to yield an increasing inventory of integrated understanding of past events—an understanding of growing importance in the broad guidance of man's activities in recognition of the range of natural changes to which he must accommodate, and in the secular effects and guidance of his activities.

North Pacific Study

Late in 1972 the North Pacific Study directed by John D. Isaacs, was reorganized under collaborative sponsorship of the Office of Naval Research and the National Science Foundation (office of IDOE), was renamed the North Pacific Experiment (NORPAX) and transferred to Scripps' Ocean Research Division under the direction of Charles S. Cox. The following are reports of research carried out before the change in organization.

Study was continued on large-scale air-sea interactions over the North Pacific Ocean. Two research projects were completed by Tim P. Barnett in collaboration with Warren B. White. One offered a rudimentary theory of ocean-atmosphere coupling and indicated that the spatial distribution of heat flux off the east coast of Asia exerted a strong control over the weather of the North Pacific Ocean. The other project offered a qualitative explanation of the coupling mechanisms and interactions between the major ocean-atmosphere fields in the North Pacific Basin. Dr. Barnett completed, in collaboration with numerous other authors, an extensive monograph on the Joint North Sea Wave Project (JONSWAP). The principal result indicated that nonlinear wave-wave interactions are responsible for a major portion of wave growth. A brief summary of JONSWAP results was presented to the Offshore Technology Conference.

Dr. White has completed work on a seasonal thermocline model, wherein the depth of the mixed layer and the interfacial mixing are specified from surface observations of wind stress and vertical heat flux.

Jerome Namias has continued his research relating to large-scale and long-term interactions between atmosphere and ocean. Among other things it was determined that a major change in winter wind, weather and ocean surface temperature patterns took place between the roughly decadal periods 1948–57 and 1958–70. Clear evidence of the change shows up in temperature anomalies over the United States where in the earlier decade it was unseasonably cold in the west and warm in the east, but the reverse in the latter decade. It was demonstrated that these changes were associated with equally remarkable changes in North Pacific sea-surface temperatures and upper air wind patterns. The evidence suggests that the anomalous weather pattern over the United States was generated by air-sea interactions over the North Pacific involving complex feed-back systems whose understanding should ultimately make possible forecasting of climatic and oceanographic regimes.

In other studies by Dr. Namias, the time and space scales of atmospheric and surface temperature anomalies were investigated. When treated as statistical aggregates over a month or more, strong spatial coherence was found indicating that (1) there is large-scale coupling of atmospheric and sea surface system; (2) the dimensions of anomalies in either medium are of the order of one third of the North Pacific basin. Study was begun involving empirical techniques to specify and forecast air-sea changes of the order of a month or season. Preliminary results suggest that, because of differences in the time constants between air and sea, it may be possible to throw light on pertinent physical processes to be further explored and at the same time to develop some interim prediction methods.

The research of Joseph C. K. Huang has concentrated on a numerical dynamic model in simulation of the North Pacific Ocean. This model was developed for the study of air-sea interacting mechanisms in order to understand the physical nature of large-scale normal characteristics and anomalous changes in the North Pacific Ocean in response to the various seasonal meteorological conditions. The model is based on the governing hydrodynamic equations for fluid contained in a basin. The lateral configuration and bottom topography of the North Pacific Ocean are built into the model. Real oceanic and atmospheric field data are used as input constraints to the hydrodynamic system. The model provides insight into transient phenomena of the responding ocean when the boundary conditions are changed from one state to another. Different hypotheses concerning the large-scale ocean-atmosphere interacting processes will be tested in the model as a first step toward the understanding of the coupling phenomena. In addition, an atmospheric model is being developed. Ocean-atmospheric systems for the North Pacific Experiment will be coupled in the near future. More model study concerning ocean-atmosphere coupled processes responsible for large-scale oceanic and atmospheric fluctuations and teleconnections is being carried out next year.

Other research work by Dr. Huang, based on field data, includes a mesoscale pilot study for the heat budget in the atmosphere-ocean system within an area 200 km in diameter in the central North Pacific Ocean, which has just been completed. Based on long-time series of atmospheric and ocean field data monitored by a cluster of buoys moored in the mid-latitude, detailed subsurface heat content analyses on local heat conduction, horizontal and vertical heat advection and diffusion are carried out. Results confirm that the net heat transformation in the surface is mainly responsible for the local temperature change in the upper ocean but that the horizontal advection of heat is not negligibly small.

Twenty years of subsurface data in the eastern North Pacific Ocean have also been analyzed by Dr. Huang. From the long-term mean thermohaline structure in the California Current system, decadal oceanic patterns were identified thus verifying the recent decadal climatic regions observed by meteorologists. Detailed analysis based on the temperature and salinity data confirms the decadal variations of sea-level along the California coast.

Deep Benthic Investigations

An understanding of the benthic populations is most pertinent to a number of important long-term problems. These creatures are subject to the "fallout" of terminal material entering the sea from all terrestrial and atmospheric sources and from processes within the oceanic surface and midwaters.

Thus the degree to which inputs of many trace substances, metals, long-lived radioisotopes, and pollutants are brought into balance by deposition in the sediment is strongly influenced by the degree of uptake of these terminal materials by benthic organisms on the sea floor. These activities must then constitute a final vital term in the expression for the ultimate equilibrium value of trace materials introduced into the sea.

It appears that the populations of large active deep creatures are often dense extensions of commercially valuable species, caught in higher latitudes at shallower depths. Thus the extent of resources, known and unknown, may be much greater than previously estimated. In addition, depending on rates of migration, these populations constitute vectors by which terminal trace debris can be returned directly to the nearshore environment and to the food of man.

Such creatures, organized to discover and exploit large falls of food, can be unusually and extensively vulnerable to ill-advised acts of man. Thus the organisms killed in relatively small lethal areas created by disposal could selectively attract the active creatures from great areas in a sort of deep undersea La Brea charnel pit, with an attendant persistent wide-scale disruption of benthic life.

There is a great need for further work to understand with some thoroughness the nature, behavior and possible vulnerability of the life on the deep sea floor.

Photography. Under the direction of John D. Isaacs and Richard Schwartzlose, the development of the deep autonomous still and motion picture cameras by Meredith Sessions and Richard Shutts has made it possible to photograph and observe the nature and behavior of the active populations of the deep ocean floor. A stereo mode of operation has provided photographs of spectacular realism and greatly added to the veracity of measurements of size and distribution of the subjects.

A new "drifting camera" is being developed which will provide a tool whereby the densities and variations of many benthic populations can be quantitatively approached. This camera has had several successful trials at sea. The results from this system clearly show the advantage of an unbaited instrument drifting across the bottom with the current, taking pictures at preset distances, thus making it possible to assess the density of benthic fish and invertebrate populations more accurately and also provide a known photographic transect of the ocean bottom. With the present arrangement close estimates can be made of the speed of the current and the direction and dimensions of the track covered by the camera.

During 1972, MLR's primary effort centered around the cruise on the R/V THOMAS WASHINGTON to the Chile-Peru Trench. The cruise covered a latitudinal range of 21° between 35°S and 14°S. Still photographs and movies were taken both in shallow depths on the continental shelf and in the bottom of the Chile-Peru Trench where the deepest pictures are from 7864 m. Data were collected on the bottom of the trench, at the upper edge and on ledges noted on the precision depth recorder. Most of the pictures were taken near free-vehicle set lines and traps. Films show species of fish not taken by hook or trap.

Examination of the black and white film was started on board the vessel soon after cameras, fish traps and baited set lines were recovered. These revealed no fish at the bottom of the trench—only an abundance of amphipods which rapidly stripped the bait, and a few tube worms and holothurians. The deepest fish were taken at 4937 m on a bench on the eastern slope of the trench off Taltal, Chile. One large five rayed starfish was also seen at this depth. At a similar depth (4956 m) on the abyssal plain westward of this latter site, only amphipods and shrimp-like forms were captured by film and in the traps.

One film sequence shows the amphipods arriving at the bait within 15 minutes after the camera reached the bottom. In one hour there were great numbers in all sizes. Within about 12 hours the flesh on the fish bait was consumed leaving only the bones; the amphipods had disappeared almost entirely. In one of the photographs there are ten holothurians slowly creeping towards the remnants of the bait at the time the camera released from the bottom.

Unlike the deep fish concentrations that have been observed at other locations, the amphipods are able to devour the bait very quickly because of their ability to remove small pieces of flesh. Since each of the camera stations in the bottom of the trench show large numbers of amphipods arriving in a very short time after the camera reached the bottom, the biomass appears to be very large. A high biomass could be accounted for by the very large production of anchovettas near the surface causing a continual rain of detrital and fish remains to the bottom. The biomass on the floor of the Chile-Peru Trench probably is not representative of the other trench areas that do not lie under areas of high productivity.

Current measurements. During the 1972 cruise to the Chile-Peru Trench, five current records were recovered. Two of these were in the trench bottom 5 and 10 meters off the ocean floor. A preview of the data indicates that the direction was between 020° and 340° at a speed of 4 or 5 cm/sec. One record is eight days long, the other is one-and-a-half days. The eight-day record at the lip of the trench was quite variable in direction, probably due to large influence by the tide.

Ronald K. Lam has been examining existing data and gathering additional data in order to better understand the California Current. His major effort has been directed toward developing a taut-wire subsurface mooring capable of placing near-surface current meters with an accuracy of ± 10 meters in 4 km of water. To this end the existing SIO current meters were modified to withstand the strain of a taut-wire mooring. The timing devices used with SIO free-vehicle systems were adapted to two different releases; the first system utilizing the conventional release and squib linked to a mechanical-advantage mechanism while a later model uses the release electronics and an explosive bolt.

Test moorings were placed near San Diego and off Point Conception. The first test mooring verified the ability of the design to withstand launching stresses. Two free-vehicle, near-bottom, current meter records, totaling about three months duration, have been obtained off of Pt. Conception in 4 km water depth.

Dr. Lam has developed computer programs to calculate dynamic height and to plot any combination of temperature, depth and salinity in order to assist in examining existing and incoming data. This has been applied to some interesting hydrographic data series obtained in years past and also to the pertinent data obtained in the 1972 CalCOFI Cruises.

Techniques for least square mapping of hydrographic data are being applied to dynamic heights in the CalCOFI region in order to obtain a quantitative mapping of the heights and the associated error field.

Deep circulation. In other deep benthic research, a number of physical oceanographic studies have been in progress. Joseph L. Reid has completed an initial study of the contribution of the Norwegian-Greenland and Weddell seas to the bottom waters of the Indian and Pacific oceans. These bottom waters have temperature, salinity, and density characteristics that suggest origins from the extreme waters of the Norwegian-Greenland and Weddell seas. With R. J. Lynn, Dr. Reid has attempted to trace these waters along a stratum defined by a density parameter. From the Norwegian-Greenland Sea the cold and saline water is traced southward through the Denmark Strait, where vertical mixing raises both temperature and salinity to their maximum values in the central North Atlantic. From there the temperature and salinity decrease monotonically southward toward the Weddell Sea, partly by lateral mixing with the cold, low-salinity waters on this stratum where it lies near the sea surface in the Weddell Sea, and partly by vertical mixing with the underlying Antarctic bottom water. From the southern South Atlantic the high values of temperature and salinity (the stratum now lies close to a vertical maximum in salinity) extend eastward with the Antarctic Circumpolar Current into the Indian and Pacific oceans, with monotonically decreasing temperature and salinity as further vertical mixing erodes the maximum in salinity, until the salinity maximum is found at the bottom in the North Pacific Ocean.

The stratum thus defined terminates at abyssal depths in the northern Indian and Pacific oceans; since water must rise somewhere to balance the sinking in regions of bottom-water formation, there must be upward flow across the stratum elsewhere. The tremendous areal extent of the salinity maximum, however, suggests that the upward flow through the stratum must be minimal except in the North Indian and North Pacific oceans, where stability is shown to be very low at the depth of the stratum.

Biological Studies

Pelagic communities. Elizabeth Venrick and Lanna Cheng, with members of the Food Chain Research Group (FCRG) of the Institute of Marine Resources at Scripps, are participating in a program directed by John A. McGowan to describe, quantitatively, the community structure and food-chain relationships of the open ocean system near the axis of the North Pacific Central Gyre. Further, the group is working to define as rigorously as possible the physical-chemical variables of the habitat.

The group has carried out extensive studies of the California Current—an area of extremely complex and changeable structure and function. They have chosen the gyre as a much simpler area for a first attempt at a multidisciplined approach. The central gyres of the Pacific are particularly appropriate for these studies because, of open ocean areas, they best approximate closed systems—a fundamental condition for ecosystem analysis in its present development.

The group so far has made nine cruises to the North Central Gyre and three to the South Central Gyre. The South Gyre, which is in some ways an analog of the north was studied for comparative purposes. While these cruises were specifically designed to understand the community structure, about 50% of the work time was spent on hydrography.

The area selected lies between 27°N and 30°N, 155°W, and is the approximate biogeographic center of the eastern portion of the North Pacific Central Gyre. On each of the several 24-hour stations occupied on each cruise, replicate discrete depth profiles were taken of temperature, salinity, O_2, nutrients, chlorophyll, productivity, phytoplankton and microzooplankton, as well as replicate integrated samples of zooplankton, neuston and micronekton. Weather, sea state, scattering layer, bird and mammal observations are also done at these stations. *Each* of the samples and/or observations is done at almost exactly the same time of day, every day.

The data have established that during the summer months the relative proportions of abundances of macrozooplankton and mesopelagic micronekton species are less diverse and more stable than in the California Current. The rank order of species abundances is very similar both within replicates and between stations. However, although both the north and the south gyres have about the same species list and diversity, the rank order differs strongly between them.

The total biomass of zooplankton has remained fairly constant from summer to summer but the biomass of meso- and bathypelagic micronekton has varied significantly both in terms of numbers of individuals per species and the average size of individuals within species. The chlorophyll distribution shows a persistent and almost continuous maximum at about 110 m. This is *below* the traditionally defined euphotic zone but nevertheless it is functional, judging from *in situ* measures of productivity. The productivity peak is much shallower and there have been year-to-year significant differences in standing crops of chlorophyll associated with large-scale meteorological events. The changes in biomass of meso- and bathypelagic nekton are associated with variations in chlorophyll, however the zooplankton standing crops have remained relatively constant.

Phytoplankton. Dr. Venrick has conducted research in the seasonal and long-term fluctuations in the species composition of the first trophic level of the gyre. Working with members of FCRG, she is also investigating the productivity and nutrient dynamics of the upper 50 m where nitrogen is the limiting nutrient, and where there appears to be a very close balance between the nitrogen uptake by phytoplankton and the nitrogen regenerated by zooplankton excretion. Blooms of the diatom *Rhizosolenia* containing the endophytic N_2-fixing blue-green alga, *Richelia,* may be a significant source of nitrogen during the later summer. Additional studies underway by Dr. Venrick include small-scale fluctuations of phytoplankton abundances and their implications for sampling and the composition, formation, maintenance and dynamics of the deep chlorophyll-maximum layer which underlies the euphotic zone of the Central Pacific at a depth of 110–130 m.

Biology of the sea surface. Dr. Cheng is carrying out research on animals living at the air-sea interface, a highly specialized community in the marine environment (pleuston or surface neuston). The major organisms found in this layer include the Portuguese-man-of-war, *Physalia,* the by-the-wind-sailor, *Velella,* and other siphonofores, the purple snail, *Ianthina,* and eggs and larvae of several families of fish (Exocoetidae, Scomberesocidae, Myctophidae, Engraulidae, Mullidae, Carangidae, Soleidae, etc.). On the sea surface itself, only the "sea skaters" (marine insects in the genus *Halobates*) occur. Although some of these animals are well-known by name, very little is known about their biology, or their special adaptations to cope with changes in physical and chemical properties at the air-sea interface. Dr. Cheng has collected neuston samples from the North Pacific Gyre for studies of community structure and estimates of biomass. During two of the 1973 CalCOFI cruises neuston samples were collected specifically for community structure studies; they are currently being sorted to major animal groups.

Dr. Cheng is also studying some of the special adaptations of *Halobates* to its unique environment. These insects have a very efficient mechanical gill—the plastron—which enables them to breathe when accidentally submerged, for instance, during storms. In collaboration with Dr. Richard Lee, she has also investigated the lipids of these insects. They are able to store food in the form of triglycerides in much larger quantities than do their freshwater relatives, thereby enabling them to survive without food for two weeks.

Midwater and benthic fish. Tetsuo Matsui, in collaboration with Dr. Richard Rosenblatt, is studying the taxonomy and distribution of the midwater fish family Searsidae, and the life history of the rattails (or grenadiers), *Coryphaenoides acrolepis.*

Setline data on rattails collected during a cruise Feb. 28–March 2, 1973 seem to indicate that sexual segregation in the female-dominant area of the San Diego Trough breaks down during the spawning period (28 females to 20 males). Prior to this the records show the females dominating the catch over the flat part of the troughs and the males dominating the escarpment. Males were still dominant (22 males to 1 female) over the escarpment during that cruise. This seems to indicate a movement of males into the female territory during spawning. Plankton tows that sampled the entire water column from bottom to surface using 10-foot Isaacs-Kidd Midwater Trawls (505 mesh netting) and series of 1-meter opening-closing nets (333 mesh netting) failed to catch any larval rattails.

Study on the family Searsidae indicates that the distribution of the species is influenced by oxygen concentration. Those occurring in high O_2 waters have reduced gill filaments. The size of the gill filament correlates fairly well to the O_2 level. The five species of the Eastern Pacific have well-developed gill filaments and are in low O_2 water. Two of these have the longest gill filaments in the family and are in water of about 0.2 to 1 ml/l O_2.

Euphausiids. Edward Brinton and his associates have been working with problems in zoogeography, life histories, and comparative morphometry of euphausiid and sergestid crustaceans. A clearer definition has been gained of the mechanisms, both intrinsic and environmental, that act to maintain or conserve populations. Studies have been made of the dynamics of the environments of the California Current, the Indian Ocean, a transition zone in the tropical South Pacific, and more recently some Atlantic species and their habitats have been compared.

The importance of euphausiids in the economy of the sea stems partly from the fact that these crustaceans are omniverous feeders, consuming diatoms, zooplankton and detritus. In addition, they bulk second to the copepods as a stock of basic animal protein, if we exclude the larger protozoans from consideration. Euphausiids serve as fodder plankton, forming a part of the diets of many commercially important fishes, including both filtering and predaceous species. They are known as "krill"—the principal food of the baleen whales, particularly in northern and southern seas where euphausiid populations frequently form into great swarms at the surface. In tropical or subtropical oceanic waters such swarming has been rarely noted.

Much of the data now compiled has been applied to evaluating differences between the animals of distinguishable populations of the same or similar species. Thus insight has been gained into the genetic specificity of the taxonomic entities being dealt with, and the pathways along which morphological and geographical divergence may have occurred. Recognition and interpretation of levels of population specificity has provided the basis for meaningful systematic status, which reflects as much of phylogeny as possible. In this connection, there has been considerable revision of the genera *Euphausia* and *Sergestes.* In particular, David L. Judkins carried out research on taxonomy, morphometrics, and distribution of the penacidean Sergestidae, with emphasis on eight species of the *Sergestes edwardsi* species group. K. Gopalakrishnan conducted rearing, feeding and growth rate studies, and critical examination of morphological development of larvae and adolescents of *Nematoscelis* species. As a result of their research work, both Dr. Judkins (in 1972) and Dr. Gopalakrishnan (in 1973) received their PhD degrees at Scripps.

Dr. Brinton's research has included the population structure, reproductive capacity, growth and survival of two predominant California Current euphausiids, *Euphausia pacifica* and *Nematoscelis difficilis.* Recognition, sorting and description of larval development series, particularly of species in the genera *Thysanopoda* and *Bentheuphausia,* in addition to *Euphausia* and *Nematoscelis,* was carried out.

Margaret Knight identified a curiously ornate, relatively large and quite comon metanauplius, long a mystery to specialists in the plankton of the Indian Ocean and the Pacific, as a developmental stage of the euphausiid *Thysanopoda tricuspidata.* She has prepared detailed descriptions of the stages of this species, providing evidence for a different relationship of the species to others in the genus than had been assumed. Similarly, her work on larval development in *Euphausia* is yielding new evidence on intragenetic phylogeny.

Dr. Brinton has directed analyses of plankton samples and environmental data from two cruises (opposite seasons) he carried out along north-south transects of an equatorial-subtropical region of the mid South Pacific. These have provided three dimensional data on the structure of northern and southern plankton populations. Work is in progress to obtain as fine a definition as possible of the local zoogeography across this abrupt gradient from fertile to barren water.

The zoogeography of Indian Ocean euphausiids has been studied by Dr. Brinton extensively, the species have been mapped and research continues on processes that affect the distributions—seasonal variability in population structure (based on recognition and enumeration of early larval stages), comparisons with hydrographic data and resolution of taxonomic problems.

Copepods. Drs. Abraham Fleminger and Kuni Hulsemann have been examining a large assembly of epiplanktonic zooplankton samples representing all oceans and adjacent seas of the world lying between 60°N and 60°S latitudes to establish the number and geographical distribution of species comprising selected epipelagic genera of calanoid copepods. The results provide a relatively sharp view of speciation in each genus and the means to infer the modes of evolutionary history within each group. Studies of this nature are the basis for understanding the historical aspects of geographic dispersal, community organization and pathways of ecological evolution in the pelagic environment.

The results to date clearly indicate several biogeographical generalizations: (1) warm-water species that breed regularly up to mid latitudes tend to be circumglobal in distribution and probably maintain gene flow around South Africa; (2) warm-water species that breed regularly only in low latitudes are provincial and may have one or more tropical cognates in other oceans. The tropical (equatorial) copepods tend to be restricted to either (a) the Atlantic Ocean, (b) the Indian Ocean and western portion, or more, of the Pacific Ocean, or (c) the eastern tropical Pacific Ocean.

Taxonomic analyses have been refined by development and application of integumental organs as taxonomic characters. The arrangement, numbers and morphological types of organs provide diagnostic features applicable to regional populations, species, species groups, the genus and the family. The use of these newly developed characters and recognition of morphologically and geographically distinct populations among epipelagic copepods has led to the discovery of a number of new species formerly undistinguishable from previously described forms.

Biogeographic patterns in the coastal zone of the American continents and an evaluation of American species of *Labidocera* (Copepoda) were outlined. The results indicate that when closely related coastal zone species occupy overlapping ranges, the secondary sexual structures differ more or less according to whether overlap is more or less. No such differences are observed in the feeding appendages. Selection appears to have favored development of reproductive barriers, but not favored dependence on different food supplies.

A study concerned with the utilization of copepods by non-copepod predators was also undertaken to determine whether copepods are preyed upon selectively. Evidence indicating that copepods are being selected on the basis of body size was obtained from analyses of the stomach contents of sergestid shrimps and young gadiform fishes.

Appendicularians. Dr. Robert P. Fenaux of the zoological Station at Villefranche-sur-Mer, France, visited Dr. Fleminger's laboratory for several months early in 1973 to work on appendicularians from the California Current region.

Food Web Theory

It has long been apparent that neither the ecology of marine environments nor the scientific management of fisheries can adequately progress without a much more meaningful understanding of the interrelationships among organisms. For example, such criteria as maximum sustainable yield can be useful only as long as the relationships with the associates of the target species remain unaltered by natural or fisheries interactions. For example, the populations and recruitment of sardines, anchovy, hake, etc. probably cannot be considered independent for times longer than the generation period of the most rapidly developing species involved.

In a classical food web model, the major developmental stages of each species of consumer organisms are considered to occupy relatively well-defined positions within a small number of trophic steps. As the real ocean is better studied, the definition of these steps becomes increasingly complex and uncertain. Thus, Professor John D. Isaacs has been studying the implications of a different sort of food web model, in which the number of pathways of food material are so numerous and diverse that the web can be approached statistically and with much simpler concepts of trophic positions and interactions of organisms.

The approach seems to explain a number of persistent findings in which the biomass of populations of predators, detrital feeders and other consumer forms exceed the biomass of the populations of herbivores with which they seem to be in balance. The approach also appears to explain some anomalous results of trace element content of fishes.

If the model is shown to be generally applicable to pelagic marine food webs, a number of new insights may ensue, including a much simpler approach to multi-species population dynamics of fishes and invertebrates.

Deep Scattering Layers

The deep scattering layers (DSLs) are so called because the organisms that make up the layers scatter sound and are recorded on echo sounders as a continuous layer. The layers which have important scientific, fishery and military application have often been mistaken for bottom echoes—the "phantom bottom" in popular literature. One of the most characteristic activities of the DSL is the vertical migration of many of its components. Its close synchronization with sunrise and sunset suggests a daily light-instigated movement ranging as much as 2300 ft., although co-existing static layers are commonly observed in the world ocean. Other parameters, such as temperature, oxygen and chlorophyll concentration have also been associated with the diverse behavior of the layers.

Ever since their discovery in 1948 the DSLs have been subject to numerous scientific inquiries; but no comprehensive study has been conducted that describes the overall distribution of the DSLs of the Pacific Ocean and their relationships, if any, with the many physical, chemical and biological parameters. The massive literature most often deals with measurements at one location or a few transects obtained under different atmospheric and oceanic conditions, thus making any meaningful analysis such as seasonal variations very difficult. The change in composition of the layers throughout the ocean also makes analysis difficult.

During the past two years Sargun A. Tont has been studying the wealth of acoustic records that have been accumulating in a vault at SIO. Accompanying oceanographic information has been periodically reported in Scripps' data reports by various investigators, but up to now no complete survey has been done from all the records.

Mr. Tont has classified the layers with respect to their migratory behavior as well as with respect to the biotic regions which they occupy. The results have been plotted on a series of 27 maps by computer. The statistical analysis of the data is also nearing completion. It is hoped that the results of this study will not only give important clues as to the behavior of the layers but may also predict the distribution of the layers in regions where no acoustical data is available.

Additional research is also being done on the original idea proposed by John Isaacs earlier, and verified successfully in the California Current region by Isaacs, Tont, and Gerald Wick, that as a result of vertical migration, the organisms that constitute the DSLs are preferentially transported into the areas of high productivity.

As part of the same study, Mr. Tont headed a joint SIO-Oregon State University expedition to a site in the North Atlantic to determine the effect of the solar eclipse of 1972 on the DSL (Deep-Sea Research, 20: 769–711, 1973).

CalCOFI Atlases

The Marine Life Research Group's continuing contribution to the CalCOFI studies is the conduct and analysis of periodic oceanographic and marine biological surveys of the California Current system. These are presently carried out every three years. Data and results of the analyses are contained in the CalCOFI Atlas series now encompassing 19 volumes.

Four atlases were published during the past two years; three of them on distribution of organisms of the California Current—on mesopelagic fish larvae, on euphausids and on calanoid copepods. The fourth atlas, "Release and Recovery Records of Drift Bottles in the California Current Region 1955 through 1971" was compiled by Fred J. Crowe and Richard A. Schwartzlose from 17 years of data. In late 1954 MLR began using drift bottles to study seasonal variation in the inshore portion of the California Current. During the intervening years 148,384 drift bottles were released and 4,994 were recovered. The percentage of recovered drift bottles varied from zero for some months to as high as 23.0 percent. The northern-most return was from Montague Island, Alaska, the southern-most came from an area just north of Acapulco, Mexico, and the western-most return was from the island of Hawaii. One uncontrollable factor influencing the frequency of the drift bottle recoveries and interpretation of the results is the intensity of human traffic along the coastline. However, the results from drift bottle studies of inshore currents on the Pacific coast of British Columbia, Oregon, California and Baja California demonstrate their usefulness as indicators of the direction of surface flow. For example, few other data show as clearly the presence of the Davidson countercurrent during the late fall and winter months.

NATIONAL MARINE FISHERIES SERVICE SOUTHWEST FISHERIES CENTER LA JOLLA LABORATORY

July 1, 1971, to June 30, 1972

In July 1971, Dr. Robert M. White, Administrator of the U.S. Department of Commerce's newly-established National Oceanic and Atmospheric Administration, which includes the National Marine Fisheries Service (NMFS) as one of its major units, announced a major organizational change. One result of this reorganization, as it affected NMFS, was the establishment of five major fisheries research centers throughout the nation intended to bring about a more integrated scientific and technical direction of the fisheries research laboratory activities. For the Southwest area, Dr. White's plan established the Southwest Fisheries Center, consisting of laboratories in both La Jolla and Honolulu, with headquarters in La Jolla, California.

CalCOFI coordinated research continued to be a major and continuing element in the research program of the La Jolla Laboratory. The report which follows is not intended as a comprehensive account of Laboratory or Center activities but only of the work directly related to CalCOFI interests.

Most CalCOFI work at the SWFC is carried out by the Population Dynamics Investigations (one of three research groups at the La Jolla Laboratory) under Dr. Paul E. Smith. This Investigation seeks to obtain information upon which abundance estimates and management policy must be based for management of multispecies fisheries in the California Current. The identification and assessment of unexploited fisheries resources in the eastern Pacific by surveys of fish eggs and larvae, and the development of the technique and methodology of such surveys forms an important part of the work of this Investigation. It is also the working model for all NMFS Marine Resources, Monitoring, Assessment, and Prediction (MARMAP) Phase I studies, a national ichthyoplankton survey. Successful hydroacoustic techniques developed at the La Jolla Laboratory for counting and estimating the biomass of schools of pelagic clupeid fish while proceeding at full ship speed are another important facet of this research. The relationships among the many species of competing pelagic fish which inhabit the California Current are being studied, based on the body of data on the biology of the California Current and more especially on the population size (based on marine fish egg and larva sampling) of a number of commercial species in each of the last 20 years. In particular, the interrelations between the vast present populations of northern anchovies and the small remnant populations of Pacific sardines is being closely researched.

Sardine-Anchovy Interrelations

In an intensive study of the endangered northern subpopulation of the Pacific sardine, Drs. Smith and W. Lenarz obtained improved estimates of the effect of continued fishing on this subpopulation. Spawning season information from local bait fisheries, sea survey information obtained by the California Department of Fish and Game, CalCOFI egg, larva and sonar surveys, and Mexican fishery data were added to the data base on the sardine.

Reexamination of the CalCOFI data indicated that 1) the present northern population of sardines may now be smaller than 5,000 tons, and that 2) the anchovy population, in the period before the precipitous decline of the sardine population, may have been much larger than previously thought. The CalCOFI data do not appear to support the species replacement concept, nor the thesis that removal of anchovies will materially hasten recovery of sardines. Both the population model used by Dr. G. Murphy and a new stochastic model used by Dr. Lenarz indicate that periods of several decades are necessary for recovery of non-fished sardine stocks from the postulated levels.

Drs. Smith and Lenarz examined the historical trends in the size of the anchovy populations. Their estimates indicate that in the early 1950's, both anchovy and sardine were at a relatively low ebb (sardine about 0.5 million tons, anchovy about 0.7 million tons) and that while anchovies increased thereafter, sardines did not, but continued their decline. From these and other data, they concluded that 1) environmental events resulted in a significant reduction in the spawning success of both species with a subsequent reduction in biomass, and 2) that the population structure of sardines had been so altered by fishing mortality (number of year classes reduced) that it could not recover, while the anchovy population, not so altered, was able to recover and built back up to 5 or 6 million tons in about 15 years.

Drs. Smith and Lenarz simulated the population growth of sardines, given its mortality, growth, and fecundity rates under various conditions. The possible conclusions from the results of this simulation model are that an unfished northern population with a biomass of 2,000 tons has a 0.84 (out of 1.00) probability of recovery to 10,000 tons in a decade; a probability of 0.66 with an annual catch of 250 tons, a probability of 0.42 at 500 tons, and no measurable probability with catches of 1,000 tons or larger. A recovery to about 1.0 million tons (the 1944–45 level) has only an even chance (0.54) of happening within

25 years starting at 2,000 tons, assuming there is no fishing effort during that time.

In subsequent action, members of the California Marine Research Committee (MRC) at their meeting on February 8, 1972, passed a resolution recommending a moratorium on the northern stock of Pacific sardine. In its resolution MRC noted that although this stock was of great importance to the commercial and sport fish industries of California, the data provided by the CalCOFI scientists, including Drs. Lenarz and Smith, indicated that the northern stock of the Pacific sardine population was presently at an extremely low level.

Estimations of Anchovy Spawning Biomass

In an attempt to compare the spawning biomass of anchovy directly through an egg survey rather than using the analogous biomass figures from sardine and the larval census ratio of sardine to anchovy, the California Marine Research Committee is sponsoring work to sort anchovy eggs from the fine-mesh plankton net samples at the La Jolla laboratory. Results from the first complete cruise to be sorted indicate that the standard nylon (0.505 mm mesh) CalCOFI net is retaining 40% of the eggs retained by the 0.333 mm mesh nylon anchovy egg net.

Based on preliminary or non-standardized data, indications are that the proportion of eggs retained will vary seasonally from February through May. These data are consistent with the theory that one-third of the eggs are retained in winter and that eggs get smaller in summer to the extent that only 10% of the eggs are retained by the regular mesh. These proportions are based on the assumption that the 0.333 mesh holds all of the oblong 0.6 x 1.4 mm eggs.

CalCOFI-MARMAP Surveys

The national MARMAP program is designed to serve as a focal point for obtaining a standard and valid series of assessments of living marine resources which is responsive to national needs in a time of environmental crisis when it is important to understand the consequences of continuing use of the ocean. To this end, the basic research strategy of MARMAP involves field studies, with NMFS vessels as the primary platforms. Survey I in which the La Jolla Laboratory is a participant is an ichthyoplankton survey, emphasizing the collection of fish eggs and larvae. Although confined to the California Current area, the CalCOFI surveys are compatible with MARMAP objectives and much of the work in this area is conducted concurrently. An important initial step in Survey I involves design and development of new sampling techniques, including remote sensing gear for helping monitor resources, particularly the case of hydroacoustic assessment of pelagic fishes, and for calibrating direct capture methods.

Hydroacoustic Assessment Techniques

Fish school sonar mapping, a technique developed by the Population Dynamics Investigations, with the 5 million ton northern anchovy population as the principal object of research, is now routinely used in conjunction with CalCOFI and MARMAP surveys. With present techniques it is possible from a ship making 10–12 knots during 8 hours of daylight to count the schools in a continuous strip of ocean 2 miles (3200 m) wide and to measure the horizontal dimensions of schools within ± 2 m in a strip 250 m wide.

Biomass calibration schemes using commercial seiners on charter have already been planned; these calibration experiments will also provide data for the eventual capability of acoustic identification of fish schools. It is, therefore, feasible to automate the acoustic determination of the number of fish schools per unit area and the size distribution of fish schools although it is not feasible to develop refined biomass estimates or determine size distribution of gas bladder-containing fish without a miniature computer system. These devices will also be necessary to develop techniques for distinguishing northern anchovy from other schooling pelagic fish.

In collaboration with the Applied Physics and Information Sciences Department, University of California, San Diego (UCSD) and the Marine Biology Section of the Naval Underwater Research and Development Center (NUC), Dr. Smith, during a recent CalCOFI cruise, demonstrated a practical technique for underway analysis and display of resonant frequency from fish gas bladders in schooled fish. During the feasibility stage of the resonant frequency work, the power spectrum of the echo from the schooled fish was analyzed and displayed on an oscilloscope or plotted on an x-y recorder as power versus frequency. The present method can be adapted to any echo-sounding or echo-ranging recorder and plots a power spectrum of received frequencies at short time intervals. The presence of anchovies can be inferred from a spectral peak at their characteristic resonant frequency. Lower frequencies in the spectrum are characteristic of larger fish, and higher frequencies can pertain to the young of any of several schooling fish.

Calibration and Comparison of Sampling Gear

There is no known single net which will adequately collect all stages of fish from eggs through adults. Three basic net types have been proposed for use in the MARMAP studies which began in January 1972: a plankton net to collect eggs and larvae; a medium size trawl with about a 2 mm mesh to collect larger larvae and juveniles; a midwater trawl to collect adults. During a cruise of the research vessel, *David Starr Jordan*, off San Diego in December, work began on a comparison of the Blackburn 1.5 x 1.5 m net and the Isaacs-Kid MARMAP trawl. In January and February 1972, a cruise on JORDAN was made off Santa Barbara with four types of collecting gear, to study the problems of relating recent results to those obtained with gear used in past operations of CalCOFI, NORPAC, and ICNAF. Precise information from these net comparisons will not be available until the samples are sorted but some information on the conditions leading to the extrusion and escapement of fish larvae through the mesh is presently available in the series of MARMAP Technical Memos, issued by the La Jolla Laboratory. In general, the catches and the size frequency of anchovy and hake larvae are strongly dependent on towing speed of bongo nets with the rate of extrusion of the fusiform hake larva less affected by towing speed than is the rate of extrusion of the filiform anchovy larva.

CalCOFI History and Analysis

The analysis of the long-term CalCOFI record of pelagic fish spawning in the California Current is underway with work completed on the definition of spawning areas and seasons and a ''sampling effort stabilized'' estimate obtained of the mean abundance of larvae and eggs. The hake spawn only in the winter quarter with most hake spawning confined to south of San Francisco this year. The anchovy spawns in the winter and spring quarters, the jack mackerel and sardines spawn predominantly in the spring quarter with some spawning in the summer quarter. The Pacific mackerel spawn predominantly in the summer quarter.

Hake Spawning

The Pacific hake undertakes annual spawning migrations to the waters off California and Baja California. The fishery for hake is conducted by Soviet trawlers off Oregon, Washington, and British Columbia. Estimates of the current status of the stocks are now gathered by Soviet research vessels in cooperative ichthyoplankton surveys with the La Jolla Laboratory of the Southwest Fisheries Center and acoustic surveys with the Northwest Fisheries Center, Seattle. Conversion of the relative estimates of biomass to absolute estimates has led to disagreements on the size of the spawning population. Two of many reasons for this disagreement are 1) that more than one hake population is spawning off California and Baja California and these are indistinguishable in the larval stage, leading to overestimates of hake spawning stock in the fishable population, and 2) only a small portion of the spawning stock migrates to the Pacific Northwest fishing grounds, leading to underestimates of breeding stock size from adult surveys.

Cooperative Fisheries Research with the USSR

For the fourth consecutive year, the U.S.-U.S.S.R. cooperative study of the distribution of hake spawning stocks continued. For the first time in the history of these cooperative surveys, an exchange of scientists was carried out with J. Thrailkill and K. Bliss of the La Jolla Laboratory on the Soviet stern trawler ALBA and two Soviet scientists on the NMFS research vessel JORDAN.

Assignment of ALBA, operated by the Far Eastern Seas Fisheries Laboratory in Vladivostok, to the 1972 research program was made at the annual meeting of U.S. and Soviet scientists in Seattle, Washington, in November 1971, when both sides agreed on the necessity to continue studies on the life history, distribution, and abundance of the Pacific hake, which have been conducted cooperatively under the terms of the Bilateral Fisheries Agreement between the two countries since 1969. During this year's survey, ALBA worked the CalCOFI pattern from the California-Oregon border to San Francisco, using standard CalCOFI nets. Plankton samples taken on ALBA were divided at the La Jolla Laboratory with one-half taken aboard the Soviet vessel for return to the Vladivostok Laboratory, and the other half remained at La Jolla for sorting and study.

As a delegate to the annual U.S.-U.S.S.R. scientific meeting held at the NMFS Northwest Fisheries Center in Seattle in November, Dr. Smith presented data derived from the CalCOFI surveys showing the variation in hake spawning biomass as estimated from the larval census. The last large year class recruited to the hake fishery off Oregon, Washington, and British Columbia was spawned in 1962. Since variations in hake larva survival are reasonably small, variation in the juvenile survival may be the cause of recruitment failure. The same feature in the other large populations of this area, the Pacific sardine and northern anchovy has also been noted.

Cooperative Fisheries Research with Mexico

Twenty years of CalCOFI surveys and the current status of the work were reviewed at a meeting of fisheries scientists in Mexico City, November 29–December 1, to discuss cooperative investigations by CalCOFI and the Instituto Nacional de Pesca. The U.S. Group explored several lines of CalCOFI research which would be more effective if extended to lower latitudes off the Mexican coastline. In particular, the geographic separation of hake stocks has been in question for some years and the spawning biomass for all stocks is not a useful quantity for the management of specific stocks. Similarly, the Pacific mackerel, Pacific sardine, and northern anchovy are distributed widely in Mexican waters and the offshore area, and some populations are endemic. The results of the meetings included the establishment of several areas of joint research and the selection of people in both organizations to be principal contacts for the work. The cooperation entails studying the abundance and distribution of hake, mackerels, anchovy, sardine, red crab, and rockfish by egg and larva surveys, echo-sonic surveys, and exploratory fishing.

At a subsequent follow-up meeting in April, Dr. Smith reported on the results of a technical intercomparison of Mexican and U.S. data in a common area of the CalCOFI grid in preparation for joint CalCOFI and Instituto Nacional de Pesca (INP) work on continued assessment and monitoring of the pelagic fish resources off the Pacific coast of Baja California. The number and size distribution of anchovy larvae and hake larvae were the primary bases for intercomparing the cooperative work. Also compared were the number of anchovy eggs and the displacement volumes of the total catch of plankton. In all, 14 stations were used from three cruises in the south Baja inshore and offshore regions, constituting a zone of overlap of 23,000 square miles of survey area. Samples taken by the NMFS and the Mexican research vessel appear to be comparable with respect to the measures used.

Anchovy Growth Studies

To study the formation of annual and accessory rings on scales and otoliths of anchovies, a school of very young anchovies was raised under controlled conditions in the experimental aquarium at the La Jolla Laboratory. Each fish was injected with oxytetracycline to form a mark on the scales and otoliths which is visible under ultraviolet light. Since all the fish were injected on the same day, this oxytetracycline ring forms a basic data reference ring recognizable on the scales and otoliths removed from the anchovies at a later time.

Preliminary analysis of anchovies reared and held for 730 days indicates that a ring-like formation seems to be closely related to water temperature. The fish began to form a ring in early autumn when the water temperature fell and the second in early spring when the temperature began to climb.

In these anchovies the number of rings formed on the scales increased with age. At 1 year, 65% of the fish had only one ring, while 35% of these fish had two. At 2 years, the second ring was present in all fish, while at least 50% of these also had three rings, and 25% had four rings.

Systematics and Life Histories of Larval Marine Fish

Under Dr. E. Ahlstrom, work is in progress to continue the description of early life history stages of fishes of the California Current (CalCOFI) region and adjacent areas and to identify and enumerate ichthyoplankton (fish larvae and juveniles) from wider ranging survey cruises in the eastern Pacific, such as EASTROPAC and NORPAC, as a means of evaluating the kinds of fishes, their relative abundance, spawning season, and distribution in relation to oceanographic features such as water masses. In addition, Dr. Ahlstrom and his staff provide training in larval fish taxonomy for NMFS personnel, foreign scientists supported by FAO or UNESCO, and students.

During the past year Dr. Ahlstrom completed a manuscript dealing with the kinds and abundances of fish larvae taken on the second multi-vessel EASTROPAC cruise, and with the annual cycle of reproduction in tropical waters based on six bi-monthly coverages of a portion of the EASTROPAC area between February 1967 and January 1968. Larvae of all of the more abundant fishes were taken on each of the coverages of the pattern and for most species the range in relative abundance during the annual cycle was three times or less.

In collaboration with Dr. Moser, Dr. Ahlstrom completed a paper dealing with the development of the lanternfish, *Scopelopsis multipunctatus*, with a discussion of its phylogenetic position in the family Myctophidae. The value of larval characters in showing relationships among genera of myctophids was pointed up by them in their paper (Moser and Ahlstrom, 1970) dealing with 11 genera of myctophids having narrow-eyed larvae; the present paper on *Scopelopsis* utilizes larval characters to clarify some relationships among myctophid genera with round-eyed larvae.

Dr. Moser also completed a manuscript dealing with the development of the rockfish *Sebastes macdonaldi* and considerable work on the development of two species of channel rockfishes, genus *Sebastolobus*.

In August 1971, Dr. Ahlstrom taught a 4 week course at the La Jolla Laboratory on identification of fish larvae to a group of 15, mostly NMFS personnel from all parts of the country. During the course approximately 240 life history series were studied, representing 107 families of fishes. The larval fish collection assembled for course study has been kept as a unit to facilitate future programs of this kind.

Larval Fish Ecology

The Behavior-Physiology Investigations, under Dr. R. Lasker, seek to obtain information on the physiological and behavioral responses of larval and adult marine fishes to their environment, fundamental to the study of the dynamics of fish populations at the La Jolla Laboratory.

An understanding of the processes of mortality which determine the survival or lack of survival of larval fish is of fundamental importance in fishery biology; therefore, a comprehensive study of larval fish survival is a major study at the La Jolla Laboratory. Both natural and contaminated environmental situations are considered and the effects of contamination of the pelagic ecosystem on the viability of larval fish is an important consideration of this Investigation.

Based on the availability of artificially reared anchovy eggs and larvae, studies during the past 2 years have now resulted in a quantified description of the development and nature of larval feeding behavior and mechanisms, and of larval energy budgets during the first few weeks of life.

Among the important studies completed during the past year was a series of experiments on predation by euphausiid shrimps on anchovy larvae. This study is a continuation of earlier studies which showed that a variety of zooplankters eat significant numbers of fish larvae. More than 350 experiments were run with *Euphausia pacifica,* the most abundant euphausiid found in the California Current. This animal migrates to the surface nightly and feeds where anchovy larvae are most abundant. The results indicate that feeding on early larvae by juvenile euphausiids was unaffected by animal size, the addition of another prey, imposed starvation, molting, or the length of time the euphausiids were in captivity. In all of these experiments, the euphausiids ate a median number of five larvae per day, plus *Artemia* nauplii.

If larval anchovy could find and remain in areas of high food concentration, their survival would be greatly enhanced. The object of recent studies was to determine how the characteristics of food distribution affect the ability of larval anchovy to find food.

One of the principal techniques used in these experiments was the creation of a patchy food distribution in rearing containers. *Gymnodinium splendens,* a dinoflagellate, was selected as the food because it is an adequate diet for anchovy larvae and because when added to containers in high concentration it will naturally form patches that can be easily identified and that persist for 2 weeks or longer. Results of these experiments indicated that 1-day-old yolk-sac anchovy larvae aggregate in patches of *Gymnodinium*. These experiments prove that a precocious development of food-searching abilities exists in yolk-sac larvae before they begin to feed. This mechanism could be of considerable adaptive advantage to first feeding larvae (age 3 days) because they have exceptionally high food requirements at this stage in their larval life.

A study describing the swimming and feeding behavior of laboratory reared larval anchovy, *Engraulis mordax*, during the first 30 days of larval life was completed. Calculations of larval swimming, descriptions of feeding sequences and feeding success, measurements of the extent of the reactive perceptive field for prey were combined to estimate the volume of water searched per larva per hour. This estimate and others were used to calculate the density of food required by larvae to meet metabolic requirements. These calculations indicated that anchovy larvae just after yolk absorption require up to 37 times the food density required by older larvae. Thus, just after yolk absorption, anchovy larvae are more vulnerable to death from starvation than at any other time during the larval stage. This research has important implications for an eventual model for estimation of survival of larval anchovy in the sea.

Work began at the La Jolla Laboratory in February, on a project sponsored by the California Marine Research Committee to develop microencapsulated particles as food for fish larvae. When perfected, the encapsulation techniques offer the possibility of incorporating a wide variety of nutritive materials into a stable particle diet. In progress thus far, particles coated with gelatin or gum arabic have been produced in the laboratory with diameters as small as 130 microns which are eaten by first feeding anchovy larvae. Particles up to 350 microns have been made and are ingested by correspondingly larger larvae.

A new technique has been developed whereby extremely small particles less than 50 microns in diameter are bound together with gelatin, alginates, or albumen to produce particles of any desired size. The most nutritious core material for the particles has been shown to be a commercial fish food. Anchovy larvae have a growth rate on this diet equivalent to that obtained with wild plankton as food, for at least a month. Other species of fish larvae which have accepted, digested and grown on these microencapsulated particles include the croaker and the Pacific mackerel.

To test particle feeding, special rearing containers were designed and built with automatic feeders. Anchovy larvae can be observed in these containers for at least 1 month and growth rates measured.

Work is underway to spawn sardines through hormone treatment with the objective of producing sardine larvae on demand for experimental studies of competition between anchovies and sardine larvae. Many of the sardines from the southern subpopulation that were brought to the laboratory in October 1971, now have enlarged gonads. The fish have grown from 150 to nearly 180 mm and the eggs in some of the more mature females have grown from less than 0.2 mm to nearly 0.77 mm.

In May 1972, a few sardine larvae were obtained that appeared normal. The larvae were active and lived for about 4 days in the absence of food. Present information suggests that the quality of larvae is related to the size of the eggs in the parent fish before hormone application. It appears that the eggs must have an initial diameter of at least 650 microns before the embryos can develop normally. The percentage of hatching eggs is still very low and more investigation is needed in this area.

Pollution in the Marine Ecosystem

Research also continued on the effect of DDT and other pesticides upon the pelagic fish resources off California. The CalCOFI has sampled plankton in the area off California and Baja California since before 1950. From these samples a collection of myctophid fish of the species *Stenobrachius leucopsarus* has been obtained which is being analyzed to determine the historical trend of DDT and its metabolites in the area off southern California.

Preliminary work indicates that the DDT residues in the myctophids increased from 1950 to 1970, and that in any given year, DDT tends to decrease with distance from Los Angeles. The data also show that DDT was more abundant than either of its two primary metabolites, DDE and DDT, in the early 1950's. Most of the DDT appears to metabolize slowly to DDD which is very persistent and builds up in the environment. Since the mid-1950's, DDE has been the most abundant of the three substances. Another change has taken place in the proportions of DDT and DDD since dumping of pesticide waste stopped in 1970. Before 1970, DDT was almost without exception more abundant than DDD. In the few myctophids taken in 1972, DDD was more abundant. In larger samples of other species of fish taken in 1970 before sewer releases stopped, DDT was more abundant; in samples taken $1\frac{1}{2}$ to 2 years later, DDD was more abundant.

Sufficient data on DDT and PCB contamination of zooplankton has been accumulated to permit the drawing of contour plots of the concentration of pollutants in the California Current region for the year 1969. The DDT distribution in zooplankton exhibits a hot spot in Santa Monica Bay off Los Angeles and generally decreases uniformly with distance from shore from 10^{-8} g per cubic meter of ocean, to one-tenth this value 200 miles offshore. The Santa Monica Bay level was 2×10^{-6} g DDT in plankton/m^3. The PCB distribution showed highest levels (between 0.5×10^{-6} and 1.5×10^{-6} g/m^3) at stations located 60–120 miles offshore. These regions include a large (200 x 80 mile) area extending from San Francisco to Point Conception and two areas 60 miles west of both Santa Monica and San Diego. With the exception of high values found in Vizcaino Bay, levels decreased with distance from San Francisco both north and south.

Analysis of chlorinated hydrocarbons (CHC) in Longhurst-Hardy Plankton Recorder records shows that zooplankton samples taken at different depths at the same station contain about the same CHC concentration in their lipids despite an order of magnitude change in zooplankton density. In addition, CHC concentration did not vary appreciably with species. These results imply that zooplankton can be used as probes for CHC concentration in the ocean as a whole. Analysis of whole water extracts and filtrates has shown that most of the California Current's burden of CHC is adsorbed on particulate material smaller than 0.5 micron or is in solution. Polychlorinated biphenyls (PCB), principal CHC contaminant, fall in the range 1 to 10 parts per trillion.

In an effort to determine the half life of DDT in sediments near White's Point sewer outfall near San Pedro, a concentration profile for DDT and metabolites was obtained from cores taken near the outfall. The concentration profiles for DDT resemble that of the heavy metals. Thus, other factors than biological degradation, such as mixing, varying sedimentation rates, etc., must determine the character of the profile. However, the half life of DDT in ocean sediments can be estimated at 1.5 ± 0.5 years.

Experiments are also in progress to study adverse effects of DDT incorporated in the food of marine teleosts. Schools of the northern anchovy, *Engraulis mordax,* and the gulf croaker, *Bairdiella icistia,* are being brought to spawing condition while receiving food contaminated with DDT. Fertilized eggs from these fish will be incubated and reared to determine the effect on the subsequent survival of the larvae of residues transmitted through the female to the yolk. Another group of gulf croakers is being subjected to periodic temperature shocks while receiving contaminated food to determine the effect of residue accumulations on the temperature tolerance of the fish.

Brian J. Rothschild

NATIONAL MARINE FISHERIES SERVICE SOUTHWEST FISHERIES CENTER LA JOLLA LABORATORY

July 1, 1972, to June 30, 1973

As one of the major fishery research centers in the National Marine Fisheries Service, an agency in the U.S. Department of Commerce' National Oceanic and Atmospheric Administration, the Southwest Fisheries Center, which consists of laboratories in Honolulu, Hawaii and La Jolla, California, is responsible for research and management studies for fisheries in the California Current, eastern tropical Pacific and central and western Pacific. Research at the Center's two laboratories is organized into multidisciplinary groups which study the tunas of the Atlantic and Pacific, whales, porpoise, and under the umbrella of the California Cooperative Oceanic Fisheries Investigations (CalCOFI), the fisheries of the California Current. The report which follows is not intended as a comprehensive account of Laboratory or Center activities but only of the research directly related to CalCOFI intrests. CalCOFI coordinated research continued to be an important element in the research program of the La Jolla Laboratory in Fiscal 1973, with most such work carried out by two of the three research groups at the Laboratory, the Population Dynamics Investigations, under Dr. Paul E. Smith, and the Behavior-Physiology Investigations, under Dr. Reuben Lasker.

To obtain the data to fulfill the Federal responsibility within CalCOFI, the Population Dynamics Investigation has among its objectives (1) application of new analytical techniques to population estimates of pelagic fish stocks, (2) improvement of techniques of sonar mapping for counting, (3) measuring and estimating tonnage of fish schools, (4) gathering of information upon which abundance estimates and policy must be based for management of multi-species fisheries in the California Current, (5) identification and assessment of unexploited fisheries resources in the eastern Pacific by surveys of fish eggs and larvae, and (6) development of the technique and methodology of such surveys. The relationships among the many species of competing pelagic fish which inhabit the California Current are being studied, based on the body of data on the biology of the California Current and more especially on the population size, based on marine fish egg and larvae sampling. The Population Dynamics Investigation is also the working model for all NMFS Marine Resources, Monitoring, Assessment and Prediction (MARMAP) Phase I studies, a national ichthyoplankton survey. Studies conducted by this investigation during the past fiscal year have included the following:

Direct Estimate of Anchovy Spawning Biomass

All estimates of anchovy, *Engraulis mordax,* biomass to date have been indirect, depending on the relative abundance of anchovy and sardine larvae and a knowledge of the sardine spawning biomass. Plankton sampling on CalCOFI cruises has historically been carried out chiefly with nets of 0.505 mm mesh, which do not fully retain anchovy eggs from which an estimate of spawning biomass can be made. In 1965, 1966, and 1969, a net of 0.333 mm mesh which fully retains anchovy eggs, was towed simultaneously with a net of 0.505-mm mesh to compare retention rates and obtain a factor which could be applied to the numbers collected by the larger mesh net. Thus far, all fine mesh samples from 1969 have been sorted, standardized, and compared to the regular mesh samples with which they were paired. Similarly, the 1966 samples have been sorted from four CalCOFI cruises. Still to be sorted are five cruises from 1966 and four cruises in 1965.

In 1969, the fine mesh nylon net retained 2.46 times as many anchovy eggs as did the regular mesh nylon net, on the average. For the fine mesh nylon net the average number of eggs per 10 m^2 in 1969 was 4,700, with 95% confidence limits of 3,700–5,900. The 0.505-mm net towed with it averaged 1,900 eggs per m^2 with 95% limits of 1,500–2,400. With the samples sorted thus far in 1966, the mean number caught by the fine mesh net is 7,600 eggs per 10 m^2 with 95% limits of

5,400–11,000. The silk mesh net towed with it averaged a catch of 1,800 eggs per unit area, with 95% limits of 1,300–2,600.

In addition to the sample frequency distribution, results from each region and each quarter in 1969 were evaluated for the comparison of regional census estimates of absolute egg abundance. It is particularly apparent from the data that retention of eggs is greater in the winter than in the summer. When the examination of 1966 data is complete, a greater sense of the regularity of the seasonal changes will be obtained. At this point, however, it appears that the ratios in winter and spring were more different in 1969 than they were in 1966. Preliminary estimates of the biomass of anchovy in 1969 indicate a somewhat higher spawning biomass than the same calculation using the anchovy census data and the sardine analogy. Future calculations will incorporate an estimate of hatching time at the temperature in the upper mixed layer. The California Marine Research Committee is sponsoring the work to sort anchovy eggs from fine mesh plankton net samples at the La Jolla Laboratory.

To improve the efficiency of future sampling surveys, a study was completed by Dr. Smith which relates the number of samples of anchovy larvae per unit area and time and the standard deviation of the mean of the log number of larvae per sample. From this summary of 10 years of anchovy data it would appear that little is to be gained by collecting more than 20 samples of anchovy larvae per space-time stratum.

Estimates of Northern Sardine Biomass

A California Senate bill has been introduced to prohibit the taking or possession of sardines, *Sardinops sagax caeruleus,* for any purpose, except sardines taken incidentally with other fish, until the spawning population of the northern stock of sardines has reached 20,000 tons, at which time, under California Fish and Game (CF&G) permit, 1,000 tons may be taken with increases as the spawning stock increases. A similar bill dealing with the Pacific mackerel, *Scomber japonicus,* was passed by the California Legislature last year and is now law.

This legislation had its beginnings in a statement made 2 years ago to the CalCOFI Committee by Drs. W. Lenarz and P. Smith. Prompted by the fact that the 1965 moratorium on sardines was not having the desired effect, Drs. Lenarz and Smith made a study of the effect of small catches on the existing small stock and on the probability of recovery of sardine stocks to commercial levels. These data indicated that the recovery of the northern subpopulation was, in part, still controlled by man. If a decision were made to stop using the remaining stock, the result within a decade could be a flourishing bait stock of 10,000 tons of sardines (odds in favor 5:1), at which time a bait level of harvest of 1,000 tons would have little or no effect on the chances for the population to rise to a level at which sardine canning would be important within 25 years.

The probability statements and estimates of biomass for the northern sardine subpopulation worked out by Drs. Lenarz and Smith were subsequently embodied in a recommendation by the Marine Research Committee to the CF&G. [Senate Bill No. 192 embodying the recommendation was passed and became law September 21, 1973. Ed.]

Effect of Mesh Size on Retention of Plankton

There has been general agreement that the catch of zooplankton should increase with towing speed of nets if all other factors remain the same. However, it has also been observed that nets towed too fast damage and lose some organisms through the mesh. These concepts, while generally demonstrable, have not been sufficiently precise to make decisions regarding optimum towing speed. The analysis of mortality in wholly planktonic species and species with planktonic stages, and the analysis of feeding depends on a more careful deployment of differing mesh sizes so that comparable samples can be taken of widely differing sizes of plankton. In February 1971, the La Jolla Laboratory made 102 simultaneous tows with bongo nets of four different mesh sizes; the tests were based on the larvae of northern anchovy and Pacific hake, *Merluccius productus.* Analysis of the data from the bongo tests indicates that the catches and the size frequency of anchovy and hake larvae are strongly dependent on the towing speed. About 40% of hake and anchovy larvae retained at 1.5 knots are extruded through the 0.505 mesh at 4.5 knots. About 30% of the rest of the plankton is extruded at that speed as well. The quantity of plankton retained by the bongo nets is an inverse linear function of the cross-sectional area of the individual mesh apertures. This relationship is similar to the one between clogging rate and mesh size.

A 6 ft. Isaacs-Kidd Midwater Trawl has been designed and tested for sampling the large planktonic and smaller swimming organisms in the marine community, with northern anchovy juveniles and large larvae as the particular target species. Early trials with oblique tows to 200 meters at 4 knots towing speed filtered 14,000 cubic meters of water. Many more larger larvae were captured than in the normal CalCOFI tows or bongo tows which filter 300 to 650 cubic meters of water at 1.5 to 2 knots. Mesh specifications for the IKMT included provision for five times as much mesh aperture as mouth opening. Samples have been collected over the entire northeast Pacific during 1972 and the net has been used in a series with mesh of varying sizes from 0.167 to 4 mm.

Hydroacoustic Assessment Techniques

Through the use of sonar mapping techniques developed by the Population Dynamics Investigation, the capability now exists for estimating biomass, availability and vulnerability to gear for schooled fish, particularly anchovy in the upper mixed layer of the California Current. The rapidity with which acoustic surveys can be made at full ship's speed, and analyzed and reported (an area in which the La Jolla Laboratory has made significant R&D advances) permits effective within-season estimates of the fluctuations in species of fish population in the California Current; these estimates supplement and augment fishery resource information derived from the traditional egg and larva surveys. This useful research tool has great potential for further development to other than clupeoid species and to other areas.

Further studies, carried out in cooperation with scientists in the Applied Physics and Information Sciences Department at the University of California, San Diego, and the La Jolla Laboratory in the application of underwater acoustics to the identification of pelagic fish schools were carried out during the July 1972 cruise of the SWFC's research vessel, DAVID STARR JORDAN. Two areas were investigated. The first, an assessment of MK-80 explosives as acoustic sources for swimbladder resonance studies revealed tht the MK-80 source has a greater source level than the seal control bombs used in previous work but is unsuitable for resonance studies. One difficulty lies in the number of large bubbles resulting from an MK-80 explosion. The slow rise and subsequent collapse of these bubbles cause numerous unacceptable bubble pulses in the pressure history as a function of time.

The second area investigated was the doppler signature for a number of unidentified pelagic fish schools. Data were acquired with ½ and 1 second CW pulses at 30 kHz. These signals were transmitted by the Simrad system under computer control. A computer-assisted data analysis and acquisition system was used to process the echoes from about 30 targets. Doppler analysis of transmitted and echo frequencies allowed continuous estimates of gross school movements of fish school targets more than 500 meters from the JORDAN. Swimming speeds of 0.1 to 2 meters per second (0.2 to 4 knots) were measured. The scales of motion typical of individual fish and parts of individual fish have been evaluated for use as identification clues.

Sound Velocity Atlas

In connection with hydroacoustics research, a sound velocity atlas has been produced from oceanographic stations. This atlas contains the summarized statistical result of 12,000 observations; the data are available by year, by oceanographic regions of 15,000 square miles, and by month, and include depths to 300 meters. This atlas will be used for planning fishery research cruises using sonar and will permit the prediction of effective sonar range for detection of fish schools. The atlas will also be used to specify the number of thermal profiles that will have to be taken to improve sonar range analysis. It will thus be possible to reduce the number of sound velocity profiles needed for definition of sonar effective range. This atlas is a joint effort of NMFS, National Oceanographic Data Center and the Fleet Numerical Weather Central in Monterey, California. A similar atlas is being produced from bathythermographs taken by these groups since 1939.

Hake Spawning Biomass

In 1972, fishery research groups from the University of California, California Department of Fish and Game, NMFS, TINRO (Pacific Research Institute of Marine Fisheries and Oceanography, Vladivostok, U.S.S.R.) and the Instituto National de Pesca (INP), Mexico, conducted a survey of hake spawning from the Oregon-California border, 42°N to Mazatlán, Mexico, 23°N, and offshore for approximately 250 miles. The survey was intended to cover the presently known extent of hake spawning during the height of the spawning season.

Preliminary analysis of samples taken by the U.S.S.R., Mexico, and the U.S. on this cooperative survey indicates the spawning biomass is an estimated 1.4 million metric tons—the lowest level since the Soviet fishery on hake began in 1965. This is lower than the 1966, 1968, 1969, and 1970 estimates of 4.5, 3.8, 2.5, and 4.2 million metric tons of spawning biomass. The previous high estimate of hake spawning biomass was 7.2 million metric tons in 1957 and the previous low was 0.57 million metric tons in 1959, before any significant fishery had begun.

The Soviet hake catch is primarily in the nearshore region off British Columbia, Washington and Oregon during the spring and summer feeding migrations of hake to the north. In 1972, the winter spawning area was between Monterey Bay, central California, and Cape San Lazaro, Baja California, Mexico, and at least 200 miles offshore. Soviet catches of the Pacific hake have been 128.3, 170.6, 102.7, 125.1, 167.2, and 140.0 thousand metric tons between 1966 and 1971. No major year classes have appeared in the fishery since the 1962 year class.

Hake Subpopulations

The taxonomic status of *Merluccius* species is a matter of current research at the La Jolla Laboratory where the study was started to ascertain if the Oregon and Washington hake are a stock distinct from those that remain off California and Baja California after spawning, or are merely a migrating segment of the CalCOFI stock. Meristic, morphometric, and biochemical comparisons of fish are made from the tip of Baja California to Washington. The spawning biomass of the migratory population being fished off Oregon, Washington, and British Columbia may be mixed in part with local races or subpopulations of non-migratory hake. So far, five stocks have been identified: 1) the large, migratory stock of *M. productus,* 2) the Puget Sound stock, 3) the "red dwarf" stock off southern Baja California, 4) the "Gulf giant" stock in the upper part of the Gulf of California, and 5) the species, *Merluccius angustimanus,* in the Gulf along the mainland coast of Mexico extending southward to Cape Corrientes. Collections of adults are not yet adequate to delineate migration routes, feeding areas, and spawning areas of the southern stocks.

One test of the importance of these separate stocks to the estimation of the spawning biomass of the migrating portion of this group is the correlation of the spawning in regions adjacent to and removed from each other. Dr. Smith has made calculations which indicate that the spawning over much of the CalCOFI area is due to one major migratory stock and that the smaller peripheral stocks can be disregarded for the time being. The "dwarf red" might account for a sizeable proportion of the spawning south of Point Eugenia and if separated would make the spawning biomass of 1965 and 1954 lower.

All of the trawl-caught hake from south of Viscaino Bay to the tip of Baja California have been small, less than 300 mm standard length. These "dwarf" hake have a slower growth rate and mature at a smaller size than *M. productus* or *M. angustimanus*. They are more similar to *M. angustimanus* than *M. productus* in the number of gill rakers on the upper and lower limb of the first gill arch, number of anal fin rays, number of second dorsal rays; are intermediate in head length; and have fewer vertebrae than *M. productus*.

Cooperative Fisheries Research with U.S.S.R.

In December 1972, representatives of the U.S. and U.S.S.R. at their annual scientific meeting held under terms of the bilateral fishing agreement in force since 1966 between the two countries, agreed to conduct a cooperative ichthyoplankton cruise in the spawning grounds of the Pacific hake between 23° and 36° latitude, to assess the 1973 spawning biomass. The Soviet research vessel, KAMENSKOYE, was dispatched from Vladivostok to work with NMFS representatives in a cooperative survey but the late arrival of the vessel on the spawning grounds forced a change in plans from an ichthyoplankton survey to a midwater sampling and acoustics cruise. On March 26, the Soviet research vessel began the cooperative leg of the cruise, with a NMFS biologist from the NMFS Northwest Fisheries Center, Seattle, aboard as the official U.S. observer. The KAMENSKOYE worked from San Francisco south to Baja California collecting hake with a midwater trawl for subpopulation studies being conducted at the La Jolla Laboratory. In all, 56 trawls were taken with three types of trawls; 81 species were taken in the trawls with the northern anchovy, red crabs, hake, Dover sole, and plainfin midshipman, *Porichthys notatus,* the top five in that order.

This is the fifth consecutive year of NMFS cooperative cruises with the Soviets off the Pacific Coast. The scientific leader on the KAMENSKOYE, which carries a crew of 80, was Dr. Yuri Yermakov of TINRO, Vladivostok; Dr. Yermakov also served as scientific leader on the first Soviet research vessel, PROFESSOR DERYUGIN, to work cooperatively in this area in 1969.

As a member of the U.S. delegation to the 10 day meeting (November 26–December 5, 1972) of Soviet and U.S. fisheries scientists in Moscow, Dr. P. Smith presented information on the status of the hake resource based on analyses of data from the 1972 cooperative surveys with CF&G, University of California, TINRO (U.S.S.R.), and the INP (Mexico). Preliminary results of these surveys indicated a decrease in larval hake abundance; this was interpreted as being proportional to the spawning biomass of the hake. Based in part on these data, the group recommended that the level of hake fishing should be watched carefully until a better rate of population renewal is achieved.

Part of the agenda was devoted to joint discussions of the anchovy resource off California and Mexico which, in recent years, has caught the attention of the Soviet fishing fleet. According to Dr. Smith's assessment of the situation, the Soviets could begin an anchovy fishery in 1973 with very little change in overall fleet strategy.

Larval Fish Distribution, Development and Taxonomy

Since 1949, the La Jolla Laboratory has placed great emphasis on surveys of fish eggs and larvae which have been carried out as part of the CalCOFI investigations of the California Current region. The laboratory has accumulated an outstanding collection of fish eggs, larvae, and juvenile fishes from the eastern Pacific and a great body of information on their taxonomy, embryology, morphology, zoogeography, and ecology. Under Dr. E. Ahlstrom, work has continued to utilize this fund of knowledge on larval fish taxonomy and development to supply information on much of the fish biomass—on fishes of present or potential commercial importance and also on fishes whose primary importance is as links in the oceanic food web. In particular, Dr. Ahlstrom is concerned with (a) establishing life history series of pelagic marine fishes of the eastern Pacific, particularly the California Current region, (b) determining distribution and abundance of the eggs and larvae of marine fishes in relation to oceanographic features such as temperature and water masses, (c) training NMFS personnel in identification of fish eggs and larvae, and (d) reviewing scientific contributions dealing with fish eggs and larvae.

During the past fiscal year, Dr. Ahlstrom conducted an intensive 6 week training course at the La Jolla Laboratory on the identification of pelagic marine fish eggs and larvae, from July 10 to August 18. Seventeen persons participated in the course, mostly NMFS personnel, but including two FAO-sponsored Mexican scientists and three persons from universities working on Sea Grant or MARMAP contracts. In all, about 300 life history series were studied representing 125 fish families. Emphasis was placed on life history series from families of commercial importance—clupeids, gadids, scombrids, scorpaenids, and flatfishes. Through the cooperation of other service laboratories, both Atlantic and Pacific species in these families were represented in the study series. Five days of the course were spent in supervised identifications of fish larvae from complete samples obtained on survey cruises, in order that participants could put the knowledge gained from the course to immediate use.

Fish specimens obtained in midwater trawl hauls during cruises 7205 and 7210 of the DAVID STARR JORDAN have been identified. The area covered was between 20° and 32° N. latitude and between the coast and 145° W. longitude. Two types of midwater trawls were used—a modified 6 ft. Isaacs-Kidd trawl and a modified Mark II midwater trawl. Mr. John Butler of the Smithsonian Institution, stationed at La Jolla, cooperated with Dr. Ahlstrom in the identification of the larval fish in these samples. These collections contain important specimens for establishing larval series of offshore species, and also will be of value in establishing the community structure of fishes in the several major water masses of the eastern North Pacific.

A paper dealing with the distribution and relative abundance of fishes in the Gulf of California, based on ichthyoplankton surveys made in 1956, 1957, and 1972 has been completed by Dr. G. Moser. The Gulf fish fauna is made up of three basic elements: 1) tropical species identical to those occurring in the tropical eastern Pacific to the south of the Gulf including tunas, *Auxis*, *Bragmaceros*, scorpaenids, and various mesopelagic fishes, 2) temperate water species that occur both in the Gulf and in the outer coastal waters of Baja California such as the Pacific sardine, Pacific mackerel, hake, the bathylagid smelt, *Leuroglossus stilbius*, and the myctophid lanternfish, *Triphoturus mexicanus* (numerically the dominant group), and 3) a group of endemic species restricted to the Gulf. The pelagic fishes are less numerous in species than are comparable faunas in the adjacent Pacific. Subsequently, fish larvae from the only summer cruise among the seven Gulf cruises were identified and will be included in the manuscript to be published in CalCOFI Reports. This was by far the richest in number of specimens and number of species.

Rockfish Life History Studies

Dr. H. G. Moser continued his research on the scorpaenid fishes of the eastern Pacific. Papers are being prepared on developmental series of two species of *Sebastolobus* and on *Scorpaenodes xyris*. Dr. Moser is also working on a guide for identification of genera, and (in some genera) of species of larvae of the eastern Pacific scorpaenid fishes.

As an aid to taxonomic identification, Dr. Moser with the cooperation of David Kramer succeeded in rearing the green-spotted rockfish, *Sebastes chlorostictus*, for 4 weeks at 14°C on a diet of the rotifer, *Brachionus plicatilis*. The growth rate from yolk absorption and the beginning of feeding at this temperature and with this diet was very slow, only 1.0–1.5 mm in 28 days. Rearing was not attempted at temperatures above 14°C since these were found to be lethal to rockfish larvae during yolk absorption.

It appears from this work (as well as some unpublished work on other species) that rockfish are poor subjects for experimental studies because of their slow growth. One of the goals of this experiment has been achieved, however, even during the short-term period of rearing. The early stages of pigment patterns in some commercial and sportfish species is now known and their larvae can be accurately identified in the CalCOFI fish collections. These include the following commercial and sportfish species: *S. paucispinis*, the boccacio, *S. goodei*, the chilipepper, *S. rosenblatti*, the green-blotched rockfish, and *S. eos*, the pink rockfish.

Phytoplankton Ecology

Measurements of phytoplankton dynamics, conducted in the southern and northern parts of the CalCOFI pattern in 1969, and in the southern part in 1972, have been computer processed, edited and mapped in preliminary form. The basic data consist of ^{14}C uptake measurements at seven depths extending to the bottom of the euphotic zone as determined by use of the Secchi disc and of plant pigment measurements at 10 to 12 depths extending to 150 to 250 m. Ancillary data, to be used in the analysis and synthesis of the basic information, include direct measurements of incident solar radiation, water column structure, and nutrient measurements. Manuscripts describing various aspects of temporal and spatial variations of plant production and standing stocks and contributing factors have been or will be started with the close of the field program of CalCOFI phytoplankton measurements. The description of fodder dynamics is considered important for understanding and subsequent predictions of fishery dynamics.

Chaetognath Distribution in Relation to Hydrographic Conditions

Dr. A. Alvarino has completed a draft of a paper on the chaetognath *Sagitta scrippsae* and the California Current, based on the analyses of the three-dimensional day and night distribution of this species off California and Baja California. *S. scrippsae* is a planktonic indicator of the northern flow of water off California and the regional, seasonal, and diurnal changes in the vertical distribution of this species were analyzed in relation to hydrographic conditions and population characteristics. The highest concentration of specimens during both day and night hauls for all seasons was at the northward extent of the survey region—near San Francisco; specimens were less abundant or absent at the southward extent off Punta Eugenia, Baja California. The population of *S. scrippsae* declined from September to May; the highest population density was reached during the August–September period.

Breeding does not appear to be restricted to any particular season. *S. scrippsae* up to 25 or 30 mm (Stage I of maturity) occurred throughout the year off California; this size group constituted about 90% of the total population. In general, a greater number of older and larger specimens appeared in the night hauls than during the day for the same location and depth. Small specimens, 6 mm, were found during August at the most northerly stations surveyed, suggesting that the presence of recently hatched individuals indicated the greatest flow of northern waters off California during that month.

Southern California Water Research Project Uses CalCOFI Plankton Data

A 3 year report of the Southern California Water Research Project (SCCWRP) was published in March 1973 entitled, "The ecology of the southern California Bight: Implications for Water Quality Management." A section of this report, 9.2.2, "Santa Monica Bay Plankton Study, 1957–1970," described the collection of plankton data in the Santa Monica Bay area which was made to determine if the Hyperion waste water discharges affected plankton productivity or species composition. During this period waste water discharge was increased and the system was changed from a 1 mile outfall at 14–18 meters deep to a 5 mile outfall at a depth of 60 meters.

Data from CalCOFI plankton biomass studies taken during CalCOFI cruises and reports by the La Jolla Laboratory were used for comparisons of plankton biomass before and after the changes in the system. The same trends were apparent in both sets of data suggesting strongly that the environmental factors affecting plankton abundance in Santa Monica Bay are the same as those affecting abundance throughout southern California waters. Also of interest is the fact that plankton production dropped off after the system was changed indicating that the formerly well-mixed and available nutrients from the shallow outfall were made less available to surface plankton from the deep outfall except by vertical diffusion or advection or by excretions of animals that migrated into the region.

Larval Fish Investigations in the Laboratory

Under Dr. R. Lasker, the Behavior-Physiology Investigations group at the La Jolla Laboratory is involved in identifying the features of the oceanic environment which affect the survival of young fish, and eventually the prediction of abundance of catchable sizes. Because the year class strength of fishes is mainly determined in the larval stages of life, the study of the physiology and behavior of fish eggs and larvae is an important part of the research. Concentrating on the larvae of the northern anchovy, the most abundant fish in the California Current area, studies by this group in the last few years have progressed rapidly and routine techniques have been developed for spawning on demand adult anchovy in the laboratory to obtain supplies of viable eggs and young larvae for experimentation. Further, experimental techniques and standard diets for rearing these young larvae through their first weeks of life have been developed. Based upon these techniques the studies have now resulted in a quanitified description of the development and nature of larval anchovy feeding behavior and mechanisms, and of their energy budget during their first few weeks of life.

During the past year, Dr. Lasker and his colleagues have made advances in several important areas. The spawning techniques used so successfully on the anchovy were extended to the Pacific mackerel to provide NMFS scientists with a readily available source of scombrid larvae. Pacific mackerel in the laboratory have responded well to a temperature of approximately 19°C and a diet of anchovies and nearly all of the mackerel developed their gonads after only a few months in captivity. Sexual development appeared to have progressed equally well under imposed day lengths of 4, 8, or 16 hours or under ambient daylight conditions. Some spawning has, in fact, occurred under all these conditions but has been very sparse for the indoor pools with the imposed photoperiods. Spawning has occurred about three times a week in the outdoor pool with an average of about 800 viable eggs filtered from the tank per spawning. Some of the resultant larvae have been reared for over two weeks and have metamorphosed.

For the first time work is in progress at the La Jolla Laboratory to spawn an anadromous fish using the facilities of the experimental seawater aquarium. Biologists of the California Fish and Game's Inland Fisheries Branch and personnel in the Behavior-Physiology Investigation have combined their efforts to bring striped bass, *Morone saxatilis,* to spawning condition and to rear the resultant larvae.

Adult fish were brought to La Jolla from Sacramento where they were caught and held in fresh water. The captive bass quickly adapted to sea water in the laboratory and soon began to consume chopped squid and anchovies in amounts up to 3.7% of their body weight per day. The fish are presently being maintained under different photoperiods to induce gonad maturation. Striped bass eggs were also received from the Elk Grove Hatchery near Sacramento and studies begun to determine salinity tolerance of striped bass larvae. Survival of yolk sac larvae was somewhat better when they were acclimated just after hatching, instead of as yolk sac larvae hatched from acclimated eggs. Survival of larvae was as high as 98% in 20% sea water as compared to 35% survival in fresh water.

Under a grant to Dr. Lasker from the Marine Research Committee of California, attempts were made to develop a synthetic food for fish larvae so that researchers will be free of dependence on natural larval fish food sources. The ability to compound larval fish diets from defined food stuffs will also permit research to be conducted on the specific nutritional requirements of fish larvae. Dr. Douglas Conklin, Resident NOAA Research Associate and Mr. R. Mindlin, SIO Staff Research Associate, were able to produce a suitable custom diet from readily available sources using 11 high protein ingredients bound with chitosan. Growth and survival of anchovy larvae on this diet were superior to all previous artificial diets made from commercial fish foods, although growth is markedly slower compared with natural foods. The main obstacle in rearing these animals on microencapsulated particles is the putrefaction that occurs when the particles settle to the bottom.

Working with post yolk-sac anchovy larvae, Dr. J. Hunter has completed work describing how the search pattern of the larva is modified by the density and distribution of food. The results of his study indicate that search patterns for food are non-random and appear to be adapted to a contagious food distribution, and that larval anchovy have the ability to find food concentrations while still in the yolk-sac stage. These results may explain why no critical period of increased mortality of anchovy larvae is observed in the laboratory at the onset of feeding and why laboratory estimates of food density required for larval anchovy are consistently above the average found in the sea.

Chemical Pollutants in the Biota of the California Current

Supported, in part, by Sea Grant funding from the University of California, San Diego, the principal objective of pollution research at the La Jolla Laboratory has been to survey historical trends of DDT and related chemicals in the California Current from CalCOFI plankton samples collected and stored for over two decades. Most of the DDT in the ocean environment off southern California originated from a point source rather than from widespread agricultural activities. This point source was the Los Angeles County sewer system that empties into the ocean off Palos Verdes, and the DDT came from a large manufacturer of the pesticide who released manufacturing wastes into the sewer system from about 1950 until 1970. The historical buildup of DDT in the ocean off southern California was traced through analyses of specimens of the myctophid fish, *Stenobrachius leucopsarus*, taken on CalCOFI cruises from 1950 until the present. Results indicated that the DDT gradually built up in the species over the 20 year period. DDT concentrations were much higher in fish taken near the point source of contamination and declined away from the source. Also, DDT was the dominant pesticide during the early fifties, but DDE becomes more dominant after the mid-50's indicating a metabolic breakdown of DDT in the ecosystem of the Los Angeles Bight.

In January and May, 1970, samples of fish were collected off southern California as part of a NMFS survey of chlorinated hydrocarbon pesticides in marine fishes. Additional samples were taken in the Los Angeles area in 1971 and 1972 to determine changes since dumping was stopped. The results of this investigation showed that contamination of the California Current with DDT was due mainly to industrial dumping into the Los Angeles sewer system. When dumping ceased, changes in the proportions of DDT to its metabolites occurred.

Research was also conducted to determine the pathways (aerosols, outfalls, ships) whereby polychlorinated biphenyls enter the California Current and are accumulated by fishes. Three hundred twenty-one zooplankton samples taken throughout the California Current in 1969 were analyzed for PCBs and DDT. PCBs averaged 33 ppm in hexane-extracted lipid while the DDTs averaged 2.5 ppm. PCBs in zooplankton taken inshore were usually lower than in those offshore in all the samples combined.

PCB concentrations in zooplankton during the fall of 1969 were highest in areas west and southwest of metropolitan and industrial areas and the average values for these months over the whole sampling area was twice as high as levels during the rest of the year when offshore winds are less frequent.

Onshore sea breezes contribute a flux of about 0.2 $g/km^2/day$ of DDTs and dieldrin and appear to be a contribution from hot inland agricultural areas whose DDTs are borne aloft by thermals. In February 1972, fallout of PCBs from the atmosphere on La Jolla averaged 0.4 $g/km^2/day$. La Jolla is in the lee of Los Angeles much of the year and a simple model of transport based on Los Angeles as a source correlates well with the measured flux data. The model predicts that 35 metric tons of PCBs will be generated per year in aerosol form by the Los Angeles metropolitan area. San Diego's source strength was calculated to be 7 metric tons per year.

PCBs in sea water samples taken off California and Baja California averaged 5 parts per trillion; therefore the coastal water extending from San Francisco to Vizcaino Bay and 250 km offshore to a depth of 200 m contained about 500 metric tons of PCB in 1969. Sewers and runoff seem to contribute no more than 15 metric tons per year. Fallout therefore seems to be the major PCB contributor to the ocean.

Experimental studies have been made with the Gulf croaker, *Bairdiella icistia,* and the northern anchovy, *Engraulis mordax,* to examine the effects of DDT accumulated from food on some aspects of reproduction. Dr. C. O'Connell found that larval mortality tends to be associated with the level of DDT accumulated in the eggs while they are developing in the female parent. This tentative result suggests that larval survival is adversely affected if the parent stock is under chronic exposure to relatively high levels of dietary DDT.

Transfer of PCBs in Laboratory-Reared Food Chain

Dr. E. Scura, Scripps Institution of Oceanography, SIO postgraduate appointee supported in part by the National Science Foundation (IDOE), and fishery Biologist G. Theilacker, are studying the accumulation and transfer of PCBs in a laboratory-reared algae → rotifer → anchovy food chain. These experiments are designed to study the biological transfer of PCBs at levels known to exist in organisms of the California Current.

Large, 20 liter cultures of the green flagellate, *Dunaliella,* and the dinoflagellate, *Gymnodinium splendens,* were monitored at 5 day intervals to determine the accumulation of PCBs during exponential growth. Rotifers, *Brachionus plicatilis,* maintained in 2 liter *Dunaliella* cultures are also being tested for PCB residues every 5 days. Anchovy larvae, reared on the dinoflagellate-rotifer diet were sampled every fifth day for 20 days. The results indicate that *Dunaliella* concentrate DDT from the sea water about 10,000×. There is also a biological magnification of about 3 times between each step in the food chain—*Dunaliella* contain about 0.3 ppm Arochlor 1254, the rotifers about 1 ppm and anchovy larvae 2 to 4 ppm.

—Brian J. Rothschild

REVIEW OF THE PELAGIC WET-FISHERIES FOR 1971 AND 1972

Total wet-fish landings for 1971 dropped almost a third from the previous years high catch (Table 1). A decrease in success of the anchovy reduction fishery was responsible for this drop. Economic and sociological problems combined with poor availability during part of the year resulted in anchovy reduction landings of 43,632 tons. Jack mackerel landings in 1971 totaled 29,941 tons, the highest since 1965, and squid landings were also up substantially from previous years. Sardine, Pacific mackerel, and herring landings remained at very low levels.

TABLE 1

Landings of Pelagic Wet-Fishes in California in Tons; 1962–1971

Year	Sardine	Anchovy	Pacific Mackerel	Jack Mackerel	Herring	Squid	Total
1962	7,682	1,382	24,289	44,990	653	4,684	83,680
1963	3,566	2,285	20,121	47,721	315	5,780	79,788
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
1971	149	44,853	78	29,941	120	15,759	90,900

Pacific Sardine

Legislation passed in 1969 remained in effect through 1971 and the first half of 1972. The law allows 250 tons per year to be taken for dead bait, with a maximum landing of 3 tons per boat per calendar day. An incidental catch of 15% is permitted in mixed loads. There were 149 tons reported landed in 1971.

Northern Anchovy

The 1971–72 anchovy reduction season opened with no changes in seasons, quotas, or closed areas. There were 37 boats which had a total carrying capacity of over 3,000 tons that took out permits for the season. Landings in central California totaled 986 tons, while 52,440 tons were landed in southern California (Table 2). A number of factors were responsible for the decrease in catch from the previous 2 seasons. The 1971–72 season opened August 15 in the north and September 15 in the south, but the San Pedro fleet remained idle until October 8 due to a price dispute. Some boats began fishing at that time, but it was not until October 18 that the dispute was settled and the fleet began fishing in earnest. Fishermen received $21.00 per ton of anchovies.

TABLE 2

Anchovy Landings for Reduction in the Southern and Northern Permit Areas 1965–66 through 1971–72

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
1971–1972§	52,440	986	53,426

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.

The completion of new reduction facilities enabled the fleet to land record daily (1,990 tons) and weekly (8,070 tons) catches during October. Near the end of that month the anchovy price dropped and the fleet put more emphasis on other species. In November a daily landing limit of 1,200 tons was imposed by the industry on the fleet due to a water quality problem in Fish Harbor. These factors plus an excellent showing of jack mackerel greatly restricted the anchovy reduction fishery at San Pedro. In January the price was again negotiated and modest landings were made during January and February. The Fish and Game Commission voted not to restrict fishing during February this year. Landings were low in March, April, and may. The season closed may 15 with a total of 53,426 tons of anchovies landed for reduction. About one third of the southern California catch was landed at Port Hueneme.

TABLE 3

Commercial Landings and Reported Live Bait Catch of Anchovies in Tons; 1962–1971

Year	Reduction	Other Commercial	Live Bait	Total
1962	0	1,382	6,167	7,549
1963	0	2,285	4,442	6,727
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	93,805	2,438	6,105	102,348
1971	43,632	1,221	3,825	48,678

Reported live bait catch was down in 1971, (Table 3), but this does not imply there was a scarcity of anchovies. Anchovies were readily available for live bait throughout 1971 and early 1972 except for the usual spring scarcity in the Santa Monica-Oxnard area.

Jack Mackerel

The 1971 landings of jack mackerel were the highest since 1965. Good availability as well as anchovy reduction fishery problems contributed towards the increased catch. Most fish were taken at Cortez Bank and Santa Catalina Island; however, San Clemente Island and the Horseshoe Kelp area also contributed. Fishermen received $80 per ton for jack mackerel during 1971. Fish 1 and 2 years old dominated the fishery.

Fishing was fairly good the first 3 months of 1972, but dropped off in late spring. Landings improved in June. Over 8,000 tons were landed the first half of 1972, compared to 12,613 for this period the previous year.

Pacific Mackerel

Pacific mackerel landings for 1971 were a very low 78 tons. A moratorium was in effect all year and appeared to be quite successful. Meanwhile, the sport catch increased to more than 200,000 fish for 1971. Sampling data indicate that over 90% of the population consists of 1970 year class fish.

Squid

Squid landings of 15,759 tons in 1971 were the second highest in the history of the California fishery, the highest landings being in 1946. Fluctuations in catch are primarily a result of canners' demand. Squid landings for the first half of 1972 were about 25% behind 1971 landings for the same period. Most were caught at Monterey.

Herring

Herring landings remained at a low level. A commercial fishery for herring eggs on seaweed has been established for several years in the San Francisco area. Another potential fishery utilizes roe of spawning herring for the production of "Kazanoko", a Japanese delicacy. Though the herring resource is relatively small, it is not presently utilized to its full extent.

Ralph H. Norberg

REVIEW OF THE PELAGIC WET-FISHERIES FOR 1972

Total wet-fish landings in California for 1971 were down appreciably from 1970. During 1971 a total of 90,897 tons of wet-fish was landed compared to the 133,101 tons landed in 1970 (Table 1).

The 1971 jack mackerel catch of 29,941 tons was the best since 1965. Most of the mackerel was caught at Cortes Bank and around Catalina Island. Jack mackerel also were taken from San Clemente Island, Santa Barbara Island, and from inshore waters along the southern California coast.

Squid landings jumped to 15,756 tons in 1971. It was only in 1946 that more squid were delivered to California ports. Over 60% of the catch was landed at Monterey, while most of the remaining catch was landed at Port Hueneme and San Pedro.

TABLE 1

Landings of Pelagic Wet-Fishes in California in Tons; 1963–1972

Year	Sardine	Anchovy	Pacific Mack-erel	Jack Mack-erel	Herring	Squid	Total
1963	3,566	2,285	20,121	47,721	315	5,780	79,788
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
1971	149	44,853	78	29,941	120	15,756	90,897
1972*	186	69,101	54	25,559	63	10,081	105,044

* Preliminary figures.

The anchovy catch was less than half that of the previous year. Only 44,853 tons of anchovies were landed in California ports compared to over 96,000 tons landed in 1970.

Pacific mackerel landings continued to drop as did landings of Pacific sardines. The catch of both species was restricted by state law. A moratorium on Pacific mackerel prohibited all commercial landings except for an incidental catch of 18%. The sardine fishery was limited to a 250 ton quota for dead bait and each boat fishing sardines was allowed only one 3 ton delivery each day. Landings of 78 tons of Pacific mackerel and 149 tons of Pacific sardines were reported during 1971.

For 1972 the total wet-fish landings were slightly higher than those of 1971. Jack mackerel and squid landings of 25,559 tons and 10,081 tons were below those of the previous year, but anchovy landings were up nearly 25,000 tons. The reported sardine catch of 186 tons was somewhat higher than the 1971 catch, but did not reach the 250 ton quota. The fishery continued to be under the same restrictions as in 1971. Under a continuing moratorium, Pacific mackerel landings again dropped. Only 54 tons were landed in mixed loads with other species, usually jack mackerel.

During 1971, a total of 29 large purse seiners and 9 small seiners (under 60 ft.) fished in California waters. There was only one seiner based at Monterey and two fishing out of Port Hueneme. The remaining 35 seiners fished from San Pedro. Several of the seiners were larger boats with capacities of 150–200 tons. These seiners were attracted to the anchovy fishery during the fall of 1971. They also fished briefly for anchovies during the fall of 1972. One new steel hulled seiner, especially built for the San Pedro fishery, joined the fleet during 1972. Nineteen lampara boats fished along the coast.

Northern Anchovy

Landings for the 1971–72 anchovy reduction season totaled 53,426 tons (Table 2). A quota of 110,000 tons was in force during the season. In the southern permit area 52,440 tons were landed at Terminal Island and Port Hueneme, while 986 tons of anchovies were reduced at Moss Landing in the northern area.

The first anchovies of the season were landed at Moss Landing in August, but the northern season was shortened when the only processing plant closed in October. In the south, anchovy fishing was delayed a month from the September 15 opening by a price dispute. Following a settlement, the San Pedro fleet had excellent success landing nearly 7,000 tons of anchovies in 1 week. However, a water quality problem required curtailing the processors reduction capacities forcing daily landing limits on the boats. Fishermen continued to have reasonable success until early March when the fish scattered and never schooled again throughout the rest of the season.

TABLE 2

Anchovy Landings for Reduction in the Southern and Northern Permit Areas in Tons; 1965–1966 to 1972–1973 Seasons

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
1971–1972	52,440*	986	53,426
1972–1973	75,142*	377	75,519

* Of these landings, 388 tons were reported as being caught in the northern zone in 1971–72, and 1,975 tons in 1972–73.

Fishermen received $19.50 to $21.00 per ton for their anchovies. The price was based on a sliding scale reflecting the world fish meal market which remained relatively low throughout the season.

The 1972–73 anchovy season, the eighth reduction season, also was under a 110,000 ton quota; 100,000 tons for the southern permit area and 10,000 tons for the northern area. As in the pervious year, the anchovy season started slowly until mid-October when fishermen switched their attention from other species and started to earnestly fish for anchovies. Due to a rising fish meal market, the price paid to fishermen started at $24.00 per ton in October and rose to $26.00 per ton by the end of November. There were few landings after mid-December due to poor weather, very poor availability of anchovies, and fleet effort on other species. Then at the beginning of April, anchovies began to school into dense spots. This behavior and a new price of $47.50 per ton brought total fleet effort to the anchovy fishery and over 40,000 tons were landed for reduction in the last 6 weeks of the season.

At season's end, fishermen had delivered 75,142 tons of anchovies to southern area ports, but only 377 tons had been landed at Moss Landing.

Eugene Fleming

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Part II

SYMPOSIA

A. LARGE SCALE APERIODIC FLUCTUATIONS IN THE PACIFIC OCEAN

Edited by Marston C. Sargent
Goleta, California
November 8–10, 1971

A POSSIBLE EXPLANATION OF ANOMALOUS EVENTS OBSERVED IN THE OCEAN/ATMOSPHERE SYSTEM OF THE NORTH PACIFIC 1955–1960

W. B. WHITE and T. P. BARNETT
Scripps Institution of Oceanography University of California, San Diego

1.0 *Introduction*

In 1958, the CalCOFI Conference conducted a symposium on the anomalous oceanographic and meteorological events that occurred during 1957–58 in the eastern North Pacific Ocean. During that time period the sea surface temperature over much of the eastern North Pacific was abnormally high and the wind systems were associated with unusual pressure patterns during the winter months. The physical models that were formulated to explain the evolution of these observed anomalous events were of such a nature that Isaacs and Sette (1960) were prompted to remark that no dynamical theory then in existence could account for the observed sequence of events. That statement was certainly true then because scientists before the symposium, except for J. Namias (1960) and a few others, did not interpret the 1957–58 anomalous events as adjustments of an *ocean/atmosphere coupled system.*

The consensus that the ocean and atmospheric anomalies were somehow intimately coupled was perhaps the most important result to come out of the 1958 CalCOFI Symposium. It was also realized how little effort was being expended to investigate the large-scale, air-sea interaction problem. In response to this latter point, Professor John D. Isaacs in 1965 initiated the North Pacific Study at Scripps Institution of Oceanography. The purpose of this study was to investigate large-scale, air-sea interaction over the North Pacific.

Since the inception of the North Pacific Study, a large amount of historical data and more recent deep-moored buoy data has been collected. From this body of data Namias (e.g., 1969) and others have begun to describe the mechanics of large-scale ocean/atmosphere coupling in the mid-latitude North Pacific. Working independently, Bjerknes (1966a,b, 1969) has made notable contributions to the study of large-scale ocean/atmosphere interactions in the equatorial Pacific Ocean. More recently, White and Barnett (1972) analyzed oceanic and atmospheric data contained in the North Pacific Study data bank for the decade of the 1950's, and from this developed a theory describing the physics of one type of large-scale, mid-latitude feedback mechanism (a servomechanism) which may have initiated widespread anomalous conditions over the Pacific.

The present undertaking combines the ideas of Namias, Bjerknes, and White and Barnett into a coherent discussion on the possible evolution of these anomalous events. The ocean/atmosphere interaction mechanisms important to the sequence of the anomalous events observed during this period formed a cycle, wherein the geographical distribution of heat flux from the ocean to the atmosphere maintained a stable balance with the oceanic transport and with the atmospheric pressure systems. In outline, the sequence of events was as follows: an unusually large zonal westerly wind stress in 1955 induced an anomalous distribution of heat flux from ocean to atmosphere along the subarctic frontal zone off the east coast of Asia in the fall and winter of 1955–56. This, in turn, caused a large perturbation of the westerly wind regime. The perturbation profoundly affected the ocean/atmosphere heat flux distribution in both the central regions of the mid-latitude North Pacific and the tropical regions for the next few years. Stability factors inherent in the Pacific-wide ocean/atmosphere system brought conditions back to their initial state in 1960.

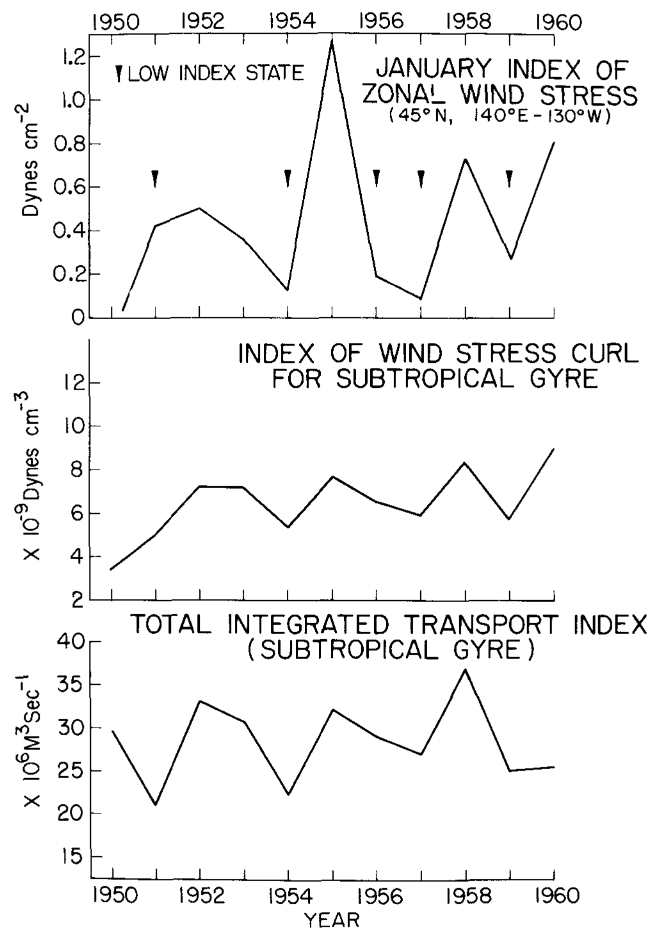

Figure 1. Time history of ocean/atmosphere indices of motion in the North Pacific for the decade 1950–60 (Fofonoff, 1960; Fofonoff and Dobson, 1963). Upper panel: January index of zonal wind stress at 45°N, averaged between 140°E and 130°W. Middle panel: Annual index of wind stress curl for subtropical gyre averaged from 140°E to 130°W between latitudes 20° and 30°N. Lower panel: Annual index of total integrated transport for subtropical gyre calculated near 160°E.

2.0 *The Initial State, 1955–1956*

The variations of three fundamental descriptors of the ocean and atmosphere during this period are shown in Figure 1. These graphs have been computed from the work of Fofonoff (1960) and Fofonoff and Dobson (1963). Beginning in January, 1955, the westerly wind stress index had a very large value, the largest of the decade. In association with this was a peak in the index of wind stress curl for the subtropical gyre. According to Sverdrup's (1947) theory, the large wind stress curl in 1955 and 1956 was the reason for the consistently higher transport in the subtropical gyre in those same years (shown in the lower panel of Figure 1). This high value of transport would be expected to have significantly affected the characteristics of the subarctic frontal zone off the east coast of Asia. The subarctic frontal zone is the zone of contact between the Oyashio and Kuroshio western boundary currents, the latter of which completes the western part of the subtropical gyre. As the Sverdrup transport of the subtropical gyre increased in 1955 and 1956, the subarctic frontal zone off the east coast of Asia extended farther north than at any other time in the decade, as observed in the upper panel of Figure 2 by the meridional position of both the 60°F isotherm and the Kuroshio extension. At the same time the meridional temperature gradient increased (lower panel of Figure 2) thus maintaining the necessary geostrophic balance.

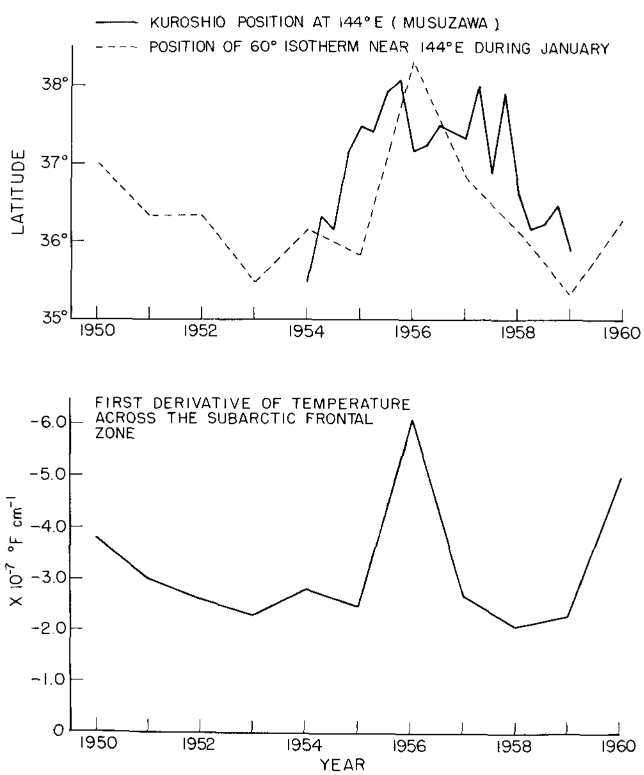

Figure 2. Time history of subarctic frontal zone characteristics for the decade of 1950–1960. Upper panel: Latitude of Kuroshio extension at 144°E (Masuzawa, 1960) and position of 60°F isotherm near 144°E. Lower panel: Index of first derivative of sea surface temperature across the subarctic frontal zone
$\left(\frac{\partial T}{\partial y} \approx \frac{T_{50°F} - T_{60°F}}{\Delta y}\right)$ **from 150°–170°E.**

Both Rossby (1939) and Namias (1959) have discussed how quasi-stationary long waves in the upper-level westerly wind system respond to the large amounts of heat given up to the atmosphere at the subarctic frontal zone. The matter has been expressed quantitatively by Fisher (1958) who showed that the increase with time in upper-level (700 mb) cyclonic vorticity is proportional to the Laplacian of the upward surface heat flux ($\nabla^2 Q$). The distribution of the sum of latent and sensible heat transfer (Q) over the North Pacific (upper panel in Figure 3), is such that the subarctic frontal zone possesses the maximum $\nabla^2 Q$ intensity found in the North Pacific during the winter season. The substantial intensity of $\nabla^2 Q$ at the subarctic frontal zone would be expected to increase significantly the cyclonic vorticity of the upper-level westerly wind system which, in turn, affects the amplitude and wave length of the quasi-stationary long waves.

Sensible and latent heat flux data (kindly provided by Dr. N. Clark, National Marine Fisheries Service, La Jolla) were used to calculate $\nabla^2 Q$ in the vicinity of the subarctic frontal zone (lower panel in Figure 4) from 1950 to 1957 (the extent of the data). These data show that in the winters of 1955–56 and 1956–57, the subarctic frontal zone was characterized by intensities of $\nabla^2 Q$ that were over *twice* those occurring in any of the five preceding years. The large intensity of $\nabla^2 Q$ was associated with large absolute values of the second meridional derivative of sea surface temperature, $|\partial^2 T/\partial y^2|$, across the subarctic frontal zone (upper panel in Figure 4). This relationship suggests that the large intensity of $\nabla^2 Q$, that induced cyclogenesis in the upper-level westerly wind system was principally due to the sea surface temperature distribution, which has previously been related to the intensification of the wind-generated transport in the subtropical gyre during 1955 and 1956.

The injection of cyclonic vorticity into the upper-level westerly wind system induced by the anomalously large $\nabla^2 Q$ in 1956, according to White and Barnett (1972) caused the formation of an amplified, quasi-stationary, long wave (right hand panels in Figure 5). This amplified long wave was, in turn, associated at sea level with a split Aleutian low pressure system. This is to be compared with the low amplitude long wave at 700 mb found in 1955 (left hand panels of Figure 5). The transition from high (1955) to low (1956) index situation observed in the upper panel of Figure 1 may be attributed to the formation of this amplified long wave in response to the increased cyclogenesis at the subarctic frontal zone.

3.0 *The Sequence of Anomalous Events, 1956–1958*

The main source of cyclogenesis that initially induced the amplified long wave in 1956 comes from the subarctic frontal zone. The continued large $\nabla^2 Q$ in 1957 is responsible for the recurrence of the amplified long wave in 1957 and the continuation of the low index state of the ocean/atmosphere system. However, the anomalous atmospheric conditions in 1956 produced dramatic changes in the heat flux at other strategic locations around the North Pacific that promoted other anomalous conditions. The principal locations for these centers of influence were the central mid-latitude North Pacific and the tropical and equatorial Pacific.

3.1 *Anomalous Events in the Central North Pacific*

The ocean/atmosphere system in the central North Pacific during 1956–1958 has been described by Namias (1959, 1960) who found evidence indicating that the anomalous atmospheric circulation which began in 1956 developed anomalous sea surface temperatures in an area centered near 40°N, 180°. The resulting abnormal surface temperature gradients and unusual heat flux from ocean to atmosphere, according to Namias, promoted increased cyclogenesis in the overlying air masses that influenced the position and strength of the amplified long wave through 1956–57. However, in light of the work of White and Barnett (1972) the principal effect of this influence in 1957 seems to have been to position the ridge of the long wave farther to the east of its 1956 position. Using arguments based on planetary long wave dynamics and anomalous Ekman drift, Namias (1959) showed that the local ocean/atmosphere feedback system would result in a slow migration of the coupled area of anomalous sea surface temperatures and atmospheric long wave system eastward across the North Pacific exactly as was observed (see Figure 6) from 1956 to 1957.

By the winter of 1957–58 the values of $\nabla^2 Q$ at the subarctic frontal zone were small (as indicated by the low values of $|\partial^2 T/\partial y^2|$ in Figure 4). This resulted in the reduced amplitude of the planetary long wave and the return to a high index year (Figure 1). Furthermore, the large area of anomalous temperatures in the central North Pacific had diminished in both intensity and size and now occupied an area east of 140°W (see Figure 6). This movement seems to have been the result of southward displacement of the westerly wind regime that brought unusually warm air into this region. To understand the southward shift in the westerly wind regime, we must turn attention to events near the equator.

3.2 *Anomalous Events in the Tropical and Equatorial North Pacific*

The meridional displacements experienced by the atmospheric pressure field over the central North Pacific in the winter of 1955–56, and to a lesser

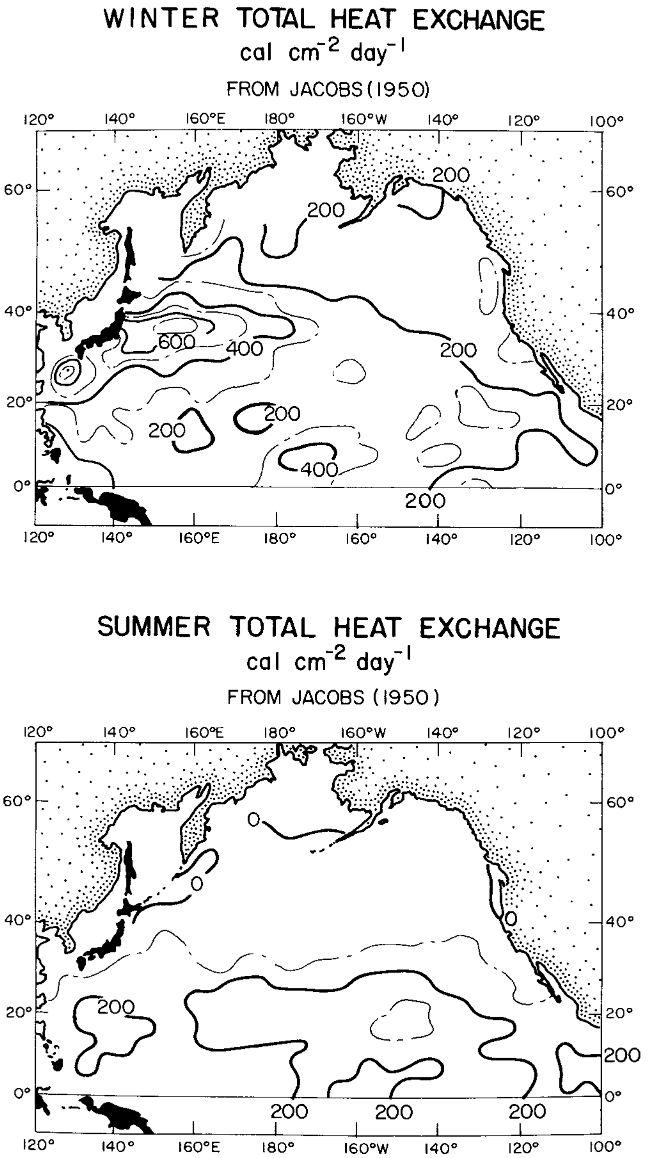

Figure 3. Mean geographical distribution of the sensible and latent heat exchange between the ocean and atmosphere in summer and winter for the North Pacific (Jacobs, 1950). Positive values indicate heat gain by the atmosphere.

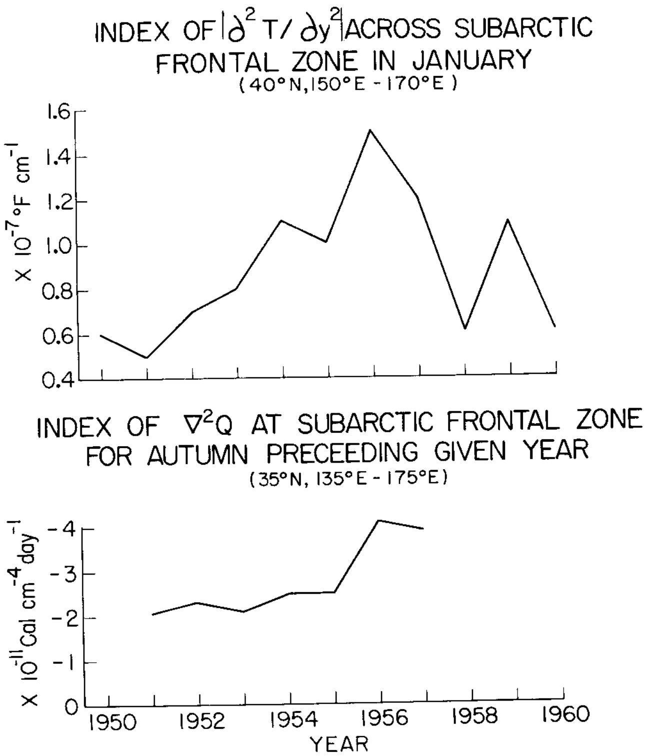

Figure 4. Upper panel: Index of the second meridional derivative of sea surface temperature at the subarctic frontal zone for January at 40°N, 150°–170°E. Lower panel: Index of the Laplacian of autumn heat flux ($\nabla^2 Q$) near the subarctic frontal zone averaged between 135° and 175°E (Q values courtesy of Dr. N. Clark, National Marine Fisheries Service La Jolla).

extent in the winter of 1956–57, were mirrored in the tropical pressure patterns north of the equator. This may be seen by comparing the second panel of Figure 7 with Figure 1, where the *zonal* indices of northeast trade wind stress and westerly wind stress are seen to have fluctuated in unison.

The drop in the zonal northeast trade wind stress in 1956 should have resulted in the reduction of the fluxes of sensible and latent heat from the underlying waters to the atmosphere (Namias, 1972; Bjerknes, 1966b). Under such conditions the surface temperature under the northeast trade wind should have increased. The data of Bjerknes (1966b) and Allison *et al* (1971) indicate that east of 180° this warming was small but marginally significant. West of 180°, the surface temperature stayed about the same. However in general over the entire period the surface temperature fluctuations of the eastern and western portions of the equatorial ocean were *out* of phase with each other.

The surface cooling in the western tropical Pacific from 1956–58 (Figure 8, lower panel) was due to the fact that as the northeast trade wind increased in strength, and the fact that its mean direction rotated counterclockwise (upper panel of Figure 7). The index of the southward component of the mean northeast trade winds in the western tropical Pacific Ocean increased from a minimum in January 1956 to a maximum in January 1957. This indicates an unusual flow into the tropics of cool, dry air from the north. The increased rate of heat flux from sea to air due to the large air-sea temperature difference enhanced that which would have already accompanied the higher zonal wind speed.

The lowering of the sea surface temperature over the west tropical and equatorial North Pacific resulted in reduced thermal convection in the atmosphere and a corresponding reduction in the rainfall, as reported by Quinn and Burt (1970) and Allison *et al* (1971). Furthermore, a reduction in the rainfall in the western equatorial Pacific would be expected to lower the amount of latent heat energy available to both the Pacific Hadley Cell and the Pacific zonal equatorial Walker Cell. Since this geographic area provides most of the energy for both of these atmospheric circulation features (Flohn, 1971; Krishnamurti, 1970) one would expect them to weaken beginning in 1956 and extending through 1957. The zonal pressure gradient along the equator, the driving force for the Walker Cell, did indeed decrease, eventually reversing itself (Rowntree, 1972). In the absence of any hard evidence, we have to assume that the Hadley Cell in the Pacific also decreased. This weakening of the Hadley Cell and Walker Cell beginning during the late winter of 1955–56 were followed by a weakening of the southeast trade wind (lower panel of Figure 7).

An inverse relation between the strength of the southeast trade wind and the sea surface temperature in the equatorial region has been demonstrated (Hires and Montgomery, 1971). However an increase in sea surface temperature was observed in 1956–58 along the equator at both Canton and Christmas islands (Figure 8). This relation was explained physically by Bjerknes (1966b) as due to reduction of both (a) wind-induced equatorial upwelling and (b) advection of cold water from upwelling areas off Peru. Part of

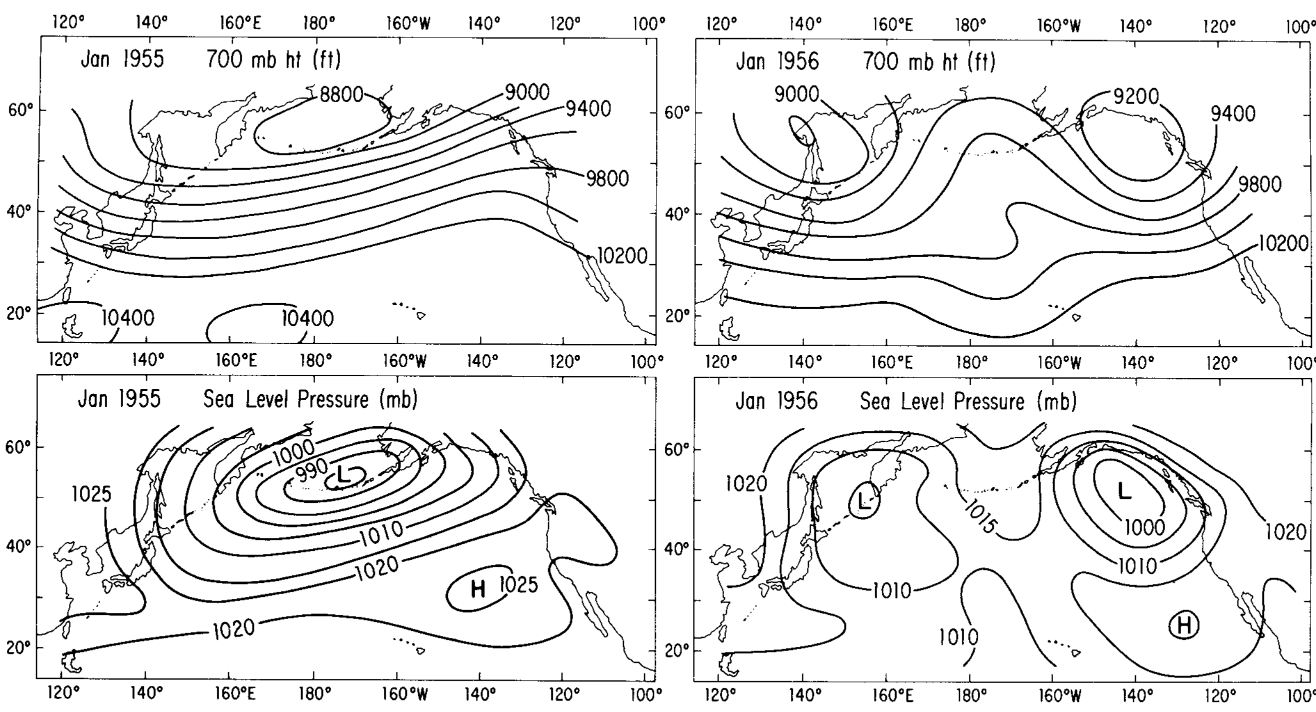

Figure 5. Circulation patterns characterizing the westerly wind system during January 1955 and 1956 at sea level and at a height of 700 millibars (National Weather Service). In each case the isopleths approximate streamlines of the air flow.

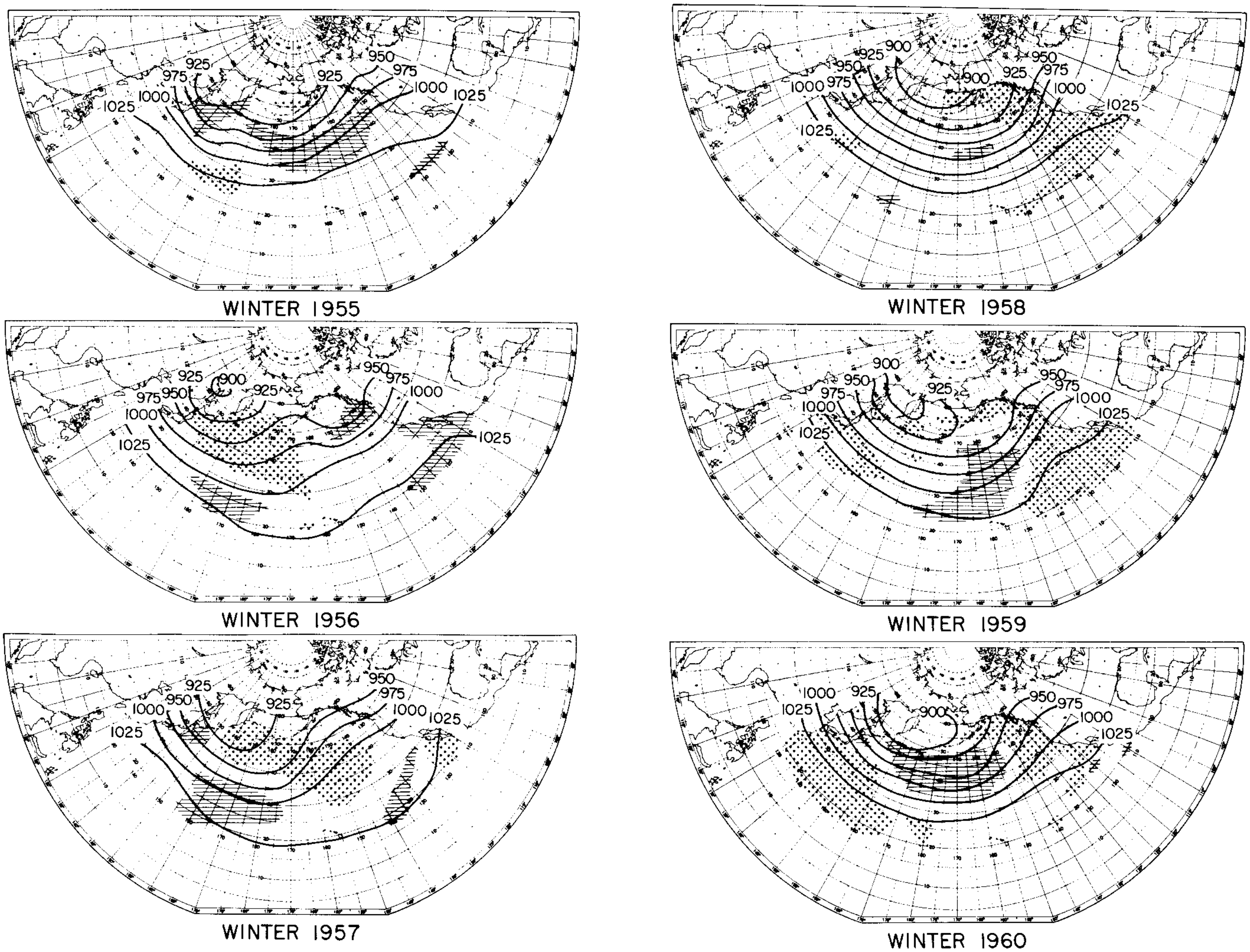

Figure 6. January sea surface temperature anomalies (base period 1947–66) superimposed upon 700 mb contours. Stippled areas are more than 1°F above 20-year mean and hatched areas are more than 1°F below.

the equatorial warming may also be attributed to the fact that in the winter of 1957–1958 the winds in the vicinity of the equator developed a westerly component (Figure 9). This component will induce *convergence* of Ekman drift at the equator as opposed to the divergence caused by an easterly component.

The important result of the equatorial warming in the eastern and central Pacific beginning in early 1956 is that it eventually shifted the oceanic thermal equator (associated with the atmospheric intertropical convergence zone) to the south, closer to the geographical equator, during the winter of 1957–58 (Figure 10). In addition, the principal source of heat for the atmosphere located in the western equatorial Pacific Ocean in 1956 had spread eastward in 1958 so that the Hadley Cell was able to receive energy from a band of ocean extending almost entirely across the Pacific.

The fact that the thermal equator coincided with the geographic equator indicates that in 1958 the Hadley Cell axis must have shifted south in correspondence with the intertropical convergence zone. This contention is born out in Figure 9. The data are from Canton Island which was near the middle of the zone during 1958. In this position one would expect maximum convection above Canton, but little horizontal motion. This is exactly what the data show. The alternative explanation of the data in terms of *no* Hadley circulation during 1958 seems quite unlikely.

The result of the major movements by the equatorial atmospheric systems led to a subsequent shift south of the mid-latitude upper-level westerly winds. Such a shift in the winter of 1958 has indeed been observed and documented by Namias (1959). This southerly shift accounts for the positive surface temperature anomalies off the coast of north America in 1958–59 mentioned in the beginning.

4.0 *Stability Factors in the System, 1959–1960*

Observations from many sources indicate that the trend in the sequence of anomalous ocean/atmosphere events of 1955–57 began to reverse itself in late 1958 and early 1959, returning by 1960 to a state not unlike that in 1955. In this section we offer a hypothesis to explain this stability in the ocean/atmosphere system. Since the anomalous activity over the entire North Pacific emanated from the equatorial region in 1958 this hypothesis centers on the inherent stability in the equatorial ocean/atmosphere interaction mechanisms.

4.1 *The Equatorial System*

On the basis of Bjerknes' (1966a,b) description of the equatorial ocean/atmosphere system, it can be shown how equatorial processes act to return a perturbed ocean/atmosphere system to its initial state. These processes may be thought to constitute a stable servomechanism (our term) involving a triple interaction between sea surface temperature (governed principally by wind-induced equatorial upwelling), the heat given up to the Hadley Cell circulation, and the resulting strength of the trade winds. Physically the excess evaporation from an anomalously warm tropical ocean increases the release of latent heat in the atmosphere (via rainfall) and increases thermal convection in the Hadley Cell which intensifies trade wind stress. The latter intensification increases equatorial upwelling and thus cools the equatorial sea surface. The resulting reduced sensible heat transfer weakens convective action in the Hadley Cell and lessens trade wind stress. In the presence of weakened equatorial upwelling local solar heating begins the cycle again. If one considers these processes occurring simultaneously then a steady state equilibrium can be established. When an external perturbation disturbs this equilibrium, the above mentioned processes will act to restore the system to its initial state.

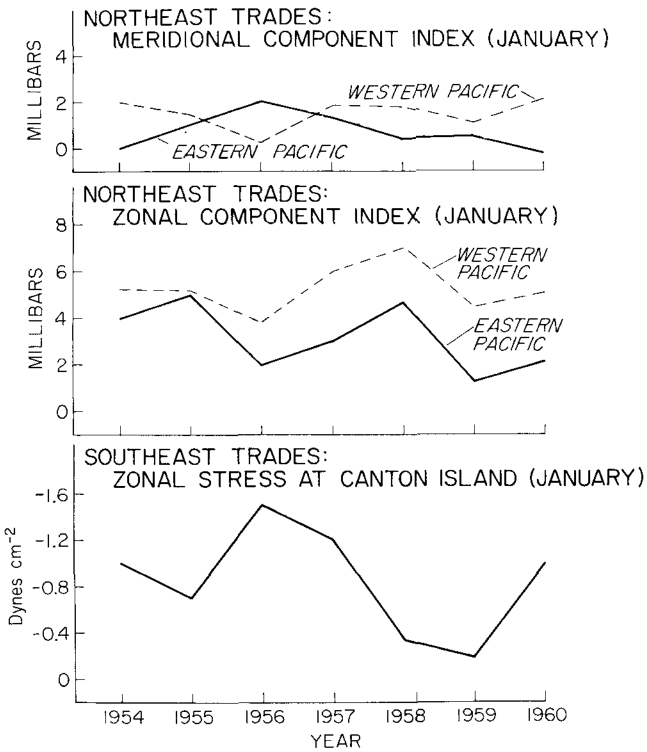

Figure 7. Trade wind indices for January. Upper panel: Meridional component of northeast Trades estimated from pressure difference between 155° and 165°W at 15°N in the eastern Pacific, and from pressure difference between Wake Island (19°17'N, 166°34'E) and Legaspi (13°8'N, 123°44'E) in the western Pacific. Middle panel: Zonal component of northeast Trades estimated from pressure difference between 10° and 20°N at 165°W in the eastern Pacific, and from pressure difference between Wake Island and Tarawa Island (1°21'N, 172°56'E) in the western Pacific. The western Pacific data for both panels came from Bjerknes (1966b). Lower panel: Zonal stress for southeast Trades as measured at Canton Island (2°48'S, 171°43'W) (Data from GEOTAPE courtesy of W. Munk).

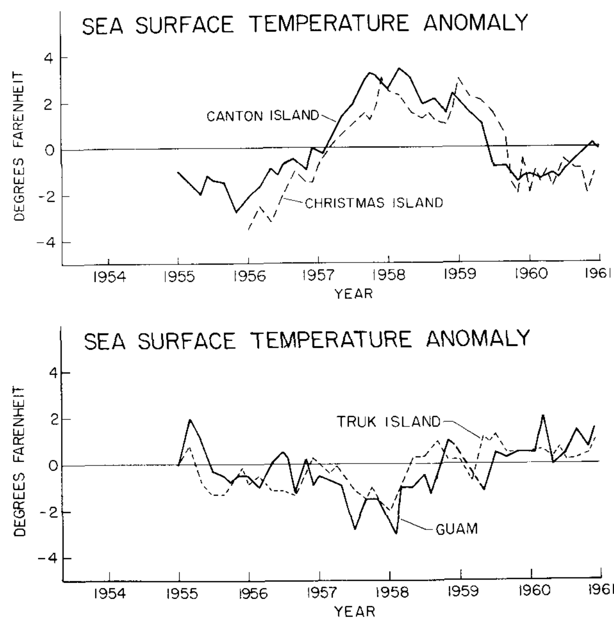

Figure 8. Sea surface temperature anomaly for Christmas (1°59'N, 157°22'W) and Canton (2°46'S, 171°43'W) islands in the eastern and central Pacific, and for Truk (7°28'N, 151°51'E) and Guam (13°34'N, 144°55'E) islands in the western Pacific (from Bjerknes, 1966b).

The stability of the equatorial ocean/atmosphere system began to reverse the trend of anomalous events in late 1958 and 1959. This is demonstrated by the following observations. In 1958 the positive surface temperature anomaly along the equator in the eastern and central Pacific was directly correlated with high equatorial rainfall at the remarkable level of 0.93 (Allison *et al*, 1971) and low values of the southeast trade wind stress (Hires and Montgomery, 1971). This rainfall was not confined to the western equatorial region, but occurred in a broad belt across much of the eastern and central equatorial Pacific (Doberitz *et al*, 1967). Hence, the energy provided to the atmosphere through the conversion of latent heat would be expected to be released also in a broad belt across much of the equatorial Pacific. In view of this, one would further expect rather marked increases of velocity in both the trade winds and westerly winds from the winter of 1957–58 through 1959. Figures 1 and 7 show that the westerly wind stress and northeast trade wind stress did, in fact, increase rather

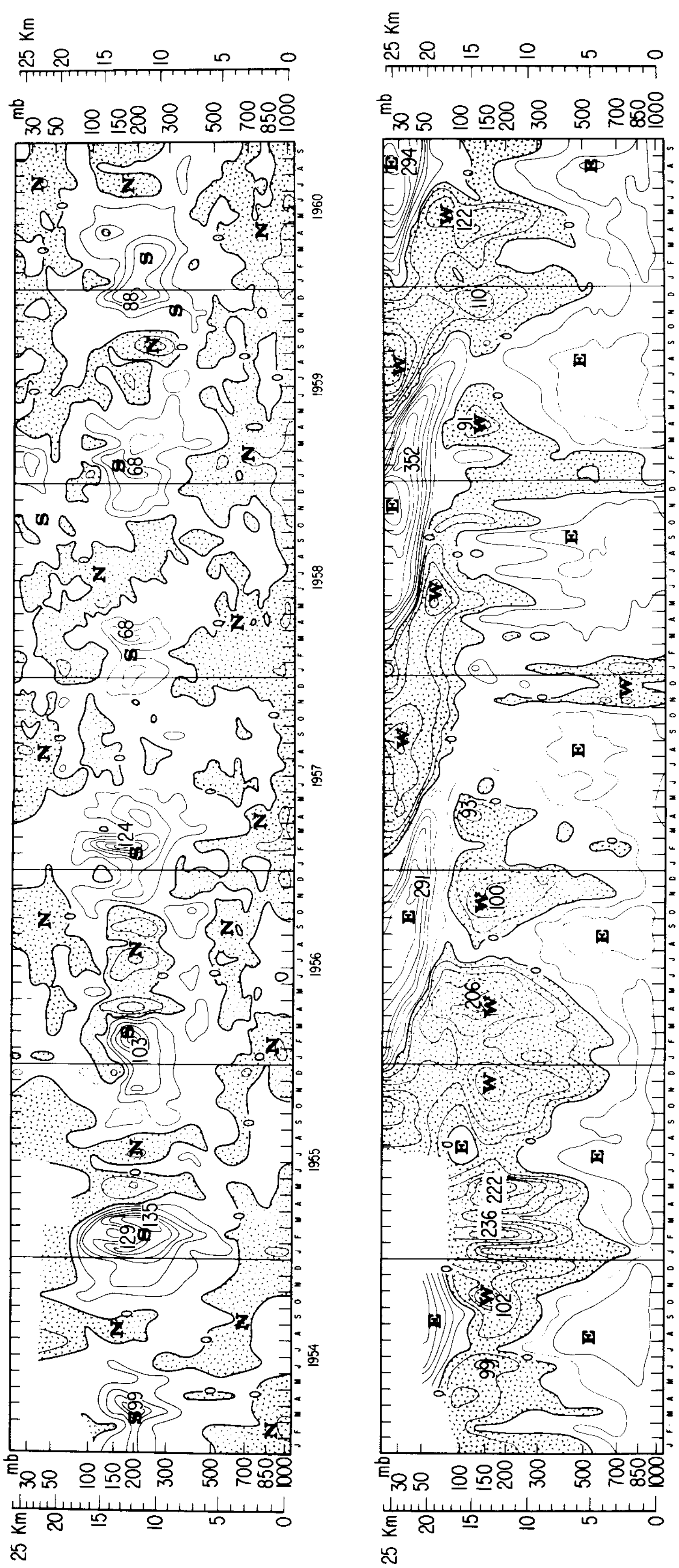

Figure 9. Upper air data from Canton Island. Upper panel: North-south component of monthly averaged 1200 GMT wind velocity. The stippled areas denote northward (N) flow and the contour interval is 20 decimeters/sec. Lower panel: East-west component of monthly averaged wind velocity. The stippled areas denote westward (W) flow and the contour interval is 40 decimeters/sec. The data for this illustration were generously supplied by Dr. D. Henning, Inst. Meteorology, Univ. Bonn.

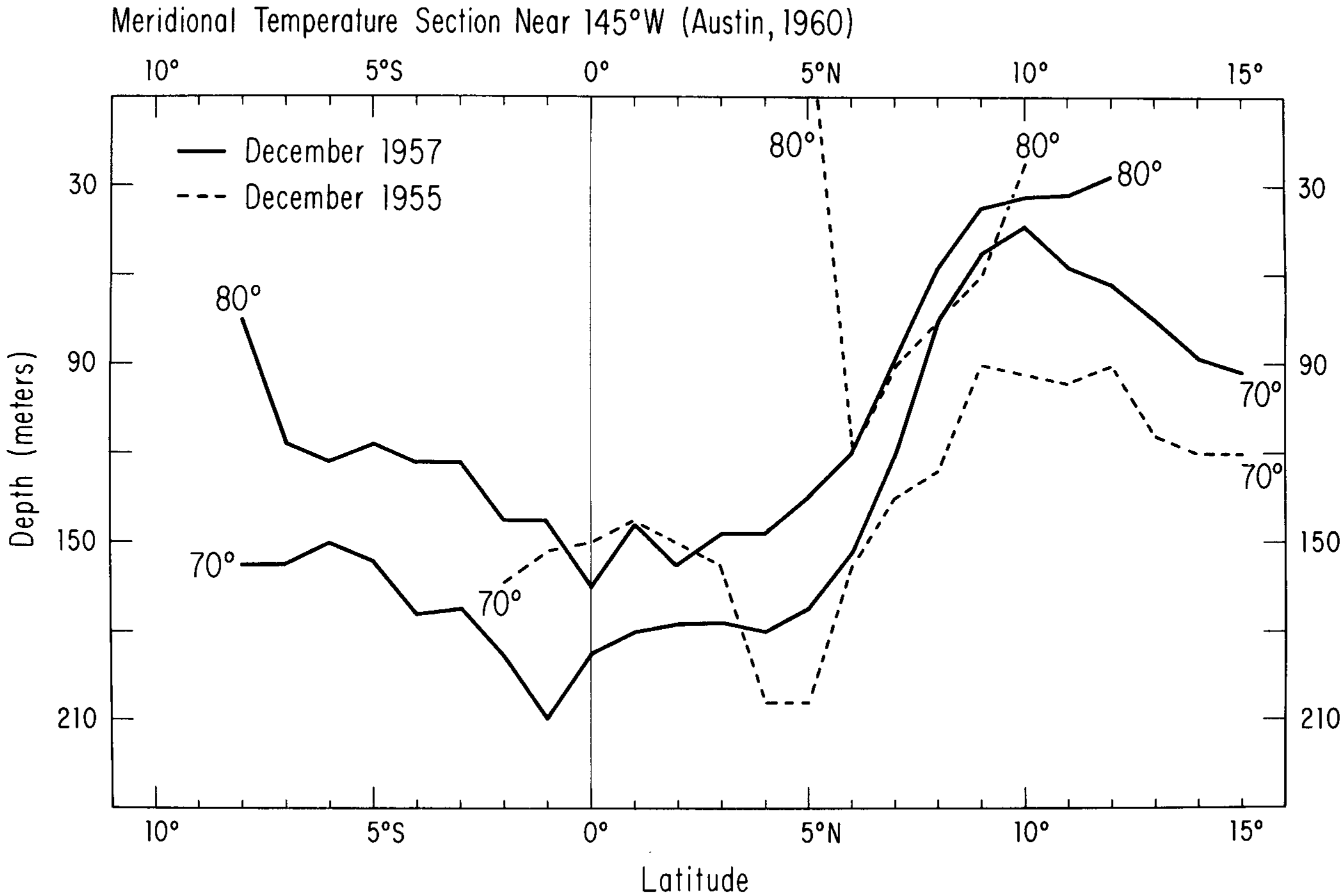

Figure 10. Meridional temperature section near 145°W for December of 1955 and 1957. Note the southward shift in the thermal equator, as well as the apparent major alterations of the equatorial current systems. Data for this Figure is from Austin (1960).

dramatically during these years. However, the southeast trade wind stress as observed at the equator (Canton Island) did not exhibit a similar behavior. This occurred because as Figures 9 and 10 indicate, the thermal equator (and the associated intertropical convergence zone) was coincident with the geographic equator. Under such a situation one would expect little trade wind activity over the equator, an area normally dominated by the southeast trade wind regime.

The southern shift in the Hadley Cell circulation in 1957–58 indicates that the center of the southeast trade wind regime was displaced to the south. Nevertheless, the strengthening of the trade winds away from the equator had the effect of increasing the oceanic transport of the Peru current and the upwelling off the west coast of South America. By mid-1958 a resulting drop in sea surface temperature was observed along the coast of South America (Allison *et al,* 1971; Bjerknes, 1966b). The area of decreased sea surface temperatures spread from the west coast of South America to a longitude of 180° in about 6 to 9 months (Allison *et al,* 1971). The partial reduction in sea surface temperatures along the equator during late 1958 allowed the intertropical convergence zone to shift gradually north into its normal position near 7° N. This shift apparently spread from east to west in correspondence with the surface temperature changes. The shift brought the southeast trade wind regime again to the equator where the normal surface temperatures were reestablished by the winter of 1960 (Figure 8).

4.2 *The Mid-latitude System*

During the time that the equatorial anomalies were going through one cycle from 1955–1960, the mid-latitude region went through two cycles; high index states were found in 1955, 1958, and again in 1960. The 1955 and 1960 high index years were in phase with the "normal" state of the equatorial system, where the Walker Cell was well developed and the intertropical convergence zone in the central and eastern equatorial ocean was positioned between 5° and 10°N. However, the 1958 high index was out of phase with the normal equatorial systems and the mid-latitude anomaly pattern in 1958–1960 was somewhat different from that in 1956–1958.

During the winter of 1958, the westerly winds had a high stress index, but were shifted south about five degrees of latitude from their normal position in association with a similar shift in the Hadley Cell over the central and eastern equatorial ocean. A positive sea surface temperature anomaly was located off the west coast of North America, as a result of anomalously *warm* air being advected over this region. In the following winter of 1958–59, the Laplacian of the heat flux at the subarctic frontal zone rose again, but less so than in 1955–56. This resulted in an amplification of the upper level long wave in the westerly wind system and the development of the split Aleutian low. These circulation patterns characterized the low index state in both the westerly wind and northeast trade wind systems.

Also during the winter of 1958–59 the stability of the equatorial ocean/atmosphere servomechanism was sufficient to restore the initial state in the equatorial Pacific. The fact that the mid-latitude and equatorial air-sea interaction mechanisms were still out of phase, plus the overriding control exerted by the central and eastern equatorial Pacific on mid-latitude conditions resulted in disappearance of the mid-latitude anomaly in late 1959.

By the winter of 1959–60 conditions in the North Pacific had generally returned to those of 1955. The wind stress index for both the westerlies and trade winds (Figure 1) were high as in 1955. The distribution of temperature anomalies (Figure 6) over the mid-latitude North Pacific was similar to that in 1955. Furthermore, the equatorial sea surface temperatures (Figure 8) returned to values that were found in 1955.

5.0 *Concluding Remarks*

An attempt has been made to combine data and theory to heuristically explain the unusual events that occurred in the North Pacific during the latter half of the 1950's. Our basic role has been to *integrate* the ideas of previous authors (particularly Namias and Bjerknes), old and new oceanographic and meteorological data, and additional theoretical results into a physical framework that can explain the interaction of the major ocean/atmosphere systems over the North Pacific.

We hold no illusion that our explanations are complete or entirely correct. However, this seems to be one of the first attempts to relate data and theory on the scale with which we have been concerned. If our primitive efforts encourage additional discussion, research and more sophisticated explanations, then our major goal in writing this paper will be realized.

ACKNOWLEDGMENTS

We gladly acknowledge stimulating discussion on the general subject of this paper with J. Namias and J. Bjerknes.

Our thanks to Ted Walker for developing much of the data and many of the illustrations used in this paper. The figures were ably drafted by Kieko Akutagawa and Fred Crowe and the (numerous) draft manuscripts typed patiently by Grace Cottrell, Christine Harris and Doreene Brown.

This work was supported by the Office of Naval Research contract N000-14-69-A-0200-6006. Much of the data for this study came from the data banks of the North Pacific Study. GEOTAPE data was made available by W. Munk.

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THE NORTH PACIFIC'S ROLE AS A WORLD WEATHER FACTORY

(Abstract)

JEROME NAMIAS

Extended Forecast Division, National Weather Service, NOAA and Scripps Institution of Oceanography, La Jolla, California

This talk attempted to describe some concepts associated with large-scale atmosphere and ocean interactions over the North Pacific and their effect on weather and climate anomalies there and elsewhere. It was pointed out that monthly and seasonal averages of both sea surface temperature (SST) and atmospheric pressure patterns over the North Pacific usually have dominant size scales of $\frac{1}{3}$ to $\frac{1}{2}$ the width of the North Pacific. The temporal coherence for SST patterns is appreciably greater than for atmospheric pressure patterns; sea surface temperature (SST) patterns may retain their integrity for a couple of years, compared with a month or two for pressure patterns. In both atmosphere and ocean this coherence is due primarily to persistent recurrence. It appears in the atmosphere as geographically fixed repetitive cyclone and anticyclone tracks and as recurrent long (Rossby) wave positioning. The integrated effect of these recurrences on the ocean engenders characteristic SST patterns since heat exchange and advection are closely coupled to air mass characteristics. When SST patterns are correlated at lag and stratified by initial month it is found that anomalous SST patterns generated in winter or spring often recur in the following year and even two years later. It is postulated that these SST patterns are representative of the relatively deep cold-season mixed layer, are masked by the shallow summer warming, and reappear during the fall and winter storms. Patterns generated in summer are much less likely to recur at these time lags because of their shallowness.

As an example of the foregoing concepts, the mean fluctuations in SST and atmospheric flow patterns were described for the two approximately decadal periods 1948–57 and 1958–69. These were exceptionally coherent regimes separated by an abrupt change. The abrupt change and the coherence during the two periods characterized not only the SST and the North Pacific air circulation patterns, but such remote elements as the temperature and snowfall at Atlanta, Georgia and, indeed, the entire Eastern United States. For example, in Atlanta the winters of the 1958–69 period averaged 5° F higher than those of the 1948–57 period. This difference was attributed to downstream influence from the disturbed westerlies in the North Pacific.

An attempt was made to investigate the great upheaval in pattern which occurred mainly in 1957–58. The data show that a slowly progressive planetary trough in the upper westerlies over the North Pacific during this period resulted in extensive and substantial heat losses from the sea to the air. These heat losses were primarily due to the extraction of latent and sensible heat by polar air masses and to the advection of cold water masses from more northerly latitudes. A plot of one year lag correlations of seasonal SST patterns for the entire period suggests that at least a year of consistent alteration is necessary to demolish a preexisting regime.

Finally it was shown that the height of sea level along the coast of Southern California responded to changes in wind stress so that winter heights were almost 6 cm higher in the 1958–69 period than in the 1948–57 period. A detailed account of the above information has been published (see references).

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PHYSICAL OCEANOGRAPHY OF COASTAL UPWELLING: PRESENT KNOWLEDGE—FUTURE PLANS (ABSTRACT)

ROBERT L. SMITH
Oregon State University
Corvallis, Oregon
and
J. J. O'BRIEN
Florida State University
Tallahassee, Florida

Recording current meters and thermographs have been moored on the continental shelf off Oregon during the upwelling seasons from 1965 to 1969. These measurements have been supplemented by extensive hydrographic measurements and, more recently, airborne infrared thermometry. In 1969 mesoscale studies were made off Peru and off Oregon in coordination with biological and chemical oceanographers. A descriptive synthesis from these several studies provides us with a conceptual model of coastal upwelling. To validate, improve, and quantify our knowledge, a coastal upwelling experiment (CUE) is planned.

CUE-1 is a mesoscale physical oceanographic field experiment to be executed during the summer of 1972 off Newport, Oregon. Three ships, approximately 50 current meters, an NCAR Queen Air aircraft, various buoys, drogues, and current profilers will be deployed to determine the time and space scales of coastal upwelling in a one-degree latitude-longitude square on the Oregon coastal shelf. CUE is designed in close coordination with numerical models and is viewed as a first step toward attaining the capability to predict the complex integrated processes (both biological and physical) in upwelling ecosystems. CUE involves cooperation among scientists from eight universities, NOAA, NCAR, IATTC, and private industry.

Part II

SYMPOSIA

B. NEW CHALLENGES TO ACCEPTED DOGMAS ABOUT PRODUCTIVITY IN THE SEA

Edited by Marston C. Sargent

Goleta, California

November 8–10, 1971

REVIEW AND CRITIQUE OF PRIMARY PRODUCTIVITY MEASUREMENTS[1]

OSMUND HOLM-HANSEN
Institute of Marine Resources
University of California, San Diego
La Jolla, California 92037

Presented at CalCOFI Annual Conference November, 1971

Introduction

This paper is concerned primarily with the methodology employed in primary productivity measurements and the interpretation of productivity data. I shall also discuss briefly the magnitude of productivity values throughout the world's oceans, without any attempt to give any comprehensive review of the literature.

There are many different methods which may be used to estimate the rate of photosynthesis by phytoplankton. Since ^{14}C became available after the second world war, it has largely replaced most of the classical methods for estimating primary production. Many of the classical methods are still of value in certain types of environmental studies, but this report will discuss in detail only the methodology based on radiocarbon measurements.

Measurement of Photosynthesis

In studies of primary productivity the chief objective usually is to obtain quantitative data on the direct input of reduced carbon into the base of the food chain. The best approach therefore is to measure the reduction of CO_2 directly, although it is possible to estimate this rate of primary production by indirect methods as outlined below.

a) *pH.* During photosynthesis under favorable environmental conditions, the rate of CO_2 uptake may be 10 to 20 times the normal rate of respiratory CO_2 release. As the uptake of CO_2 (or any of the other species of inorganic carbon) will affect the hydrogen ion concentration, it is possible to estimate the rate of CO_2 uptake by measurement of the pH of the surrounding medium. This method is not very useful in the marine environment as the large reservoir of inorganic carbon (25–30 mg inorganic C/liter) makes the method relatively insensitive.

b) *Oxygen.* Before the advent of the radiocarbon method (Steemann Nielsen, 1952), most estimates of primary production were made by measurement of the amount of oxygen released in bottled samples. The drawbacks of this method have been discussed (Strickland, 1960), the main one being that the method lacks the sensitivity required to be used in open-ocean studies.

c) *Nutrient Uptake.* By measurement of the uptake of essential inorganic nutrients (e.g. nitrogen substrates and phosphate), coupled with assumptions regarding the carbon/nitgrogen or carbon/phosphorus rations in the phytoplankton cells, it is possible to estimate the rate of CO_2 reduction. This method cannot be very precise because of the relatively large variations in ratios of elements in cellular material, but it has been used to advantage in estimating large-scale productivity of water masses.

d) *Chlorophyll.* The basis for estimating productivity from chlorophyll measurments is that assimilation values (the rate of CO_2 reduction per unit chlorophyll per unit time) are quite similar for phytoplankton in most parts of the oceans. With our better understanding of the effects of temperature (Eppley, 1972), light, and nutrients on the rate of photosynthesis, it is possible to estimate productivity even in those environments where conditions are not optimum for photosynthesis.

Lorenzen (1970) has demonstrated that there is reasonably good agreement between surface chlorophyll values and integrated productivity values for the entire euphotic zone. This promise of estimating primary production from surface chlorophyll measurements has recently led to the development of remote sensing devices which analyze the spectral signature of upwelled light from the upper portion of the euphotic zone. Arveson has discussed a convenient sensor which can operate from light aircraft, while NASA has developed the Scanning Imaging Spectroradiometer which operates from planes at high altitudes (>35,000 ft.) or from satellites. These remote sensors are likely to be of great help in temporal surveys of productivity on a worldwide basis.

e) *Measurement of Biomass.* In laboratory cultures it is feasible to estimate photosynthetic rates by measurement of various cell constituents such as carbon, nitrogen, pigments, ATP, etc. This is not practical for most field investigations, however, because of the large amounts of organic detrital material relative to phytoplankton biomass and also because of the low concentrations of phytoplankton, coupled with generation times ranging from one-half to many days.

f) *Uptake of Radiocarbon.* Although the estimation of primary productivity by assimilation of ^{14}C-labeled bicarbonate (Steemann Nielsen, 1952) seems relatively simple and direct, there are some difficulties in the methodology which should be considered.

i) *Treatment of sample.* The conditions during preparation of the water sample and the conditions at which the samples are incubated are very important. The importance of wall effects and of composition and orientation of the bottles during incubation have been described by many workers, but the most drastic effects may be caused by changes in temperature and light intensity. The use of on-deck incubators to stimulate conditions in the water column suffers from many drawbacks. A much safer and more realistic approach is to use *in situ* techniques whenever possible. It is very important that care is taken to minimize physiological shocks, especially light, during sampling and preparation of the bottles. This is particularly true when working with populations sampled from dim light or from deep in the water column

[1] Supported by the United States Atomic Energy Commission, Contract No. AT(11-1)GEN 10, P.A. 20.

(Goldman *et al.,* 1963). A satisfactory way to minimize such effects is to do all sample preparation at night, and to incubate the samples *in situ* from dawn to sunset.

ii) *Filtration.* The amount of cellular material retained by the filter will depend upon the characteristics of the filter and the extent of cellular damage or lysis caused by physical stress during filtration. There are a variety of different filters in common use for productivity work, but most investigators use membrane filters of various types or glass fiber filters. The use of micro-fine glass fiber filters (Reeve Angel 984H) or Whatman GF/C fiber filters offers some advantages over membrane filters in regard to speed of filtration and ease of handling. The mean retention characteristic of these filters is less than 1.0 μ, so there is little or no danger of losing significant amounts of nannoplankton (Sheldon, 1972; Holm-Hansen, in preparation). The pressure at which the sample is filtered is important, as too great a differential pressure may result in cell lysis and loss of cellular material. Arthur and Rigler (1967) have reported significant losses of ^{14}C-labeled material which they attribute to such a lysis during filtration. This interpretation, however, does not agree with other data, which show a linear response between amount of sample filtered and amount of cellular material recovered such as chlorophyll or ATP (Sutcliffe *et al.,* in preparation). Nalewajko and Lean (1972) have suggested that the loss of material as reported by Arthur and Rigler may be due to retention of soluble materials by membrane filters.

iii) *Treatment of filter.* After filtration of the sample, one wants to eliminate all inorganic carbon from the filter without causing any loss of labeled organic matter. Steemann Nielsen suggested fuming of the filter with HCl fumes, a practice which was adopted by many investigators. Some manuals on measurement of primary productivity, however, state that it is not necessary to fume the filter (Vollenweider, 1969; Strickland and Parsons, 1968). Some oceanographers, in fact, state that filters should not be fumed as such a treatment can cause significant losses of labeled organic material. In our own work, not only have we not found any such losses of organic material by fuming, but we have demonstrated the necessity to fume the filter (Williams *et al.,* 1972). I usually fume the filter for a few minutes before placing it in a 5.0 disposable plastic scintillation vial, and then drying it in a desiccator with silica gel. Other investigators also use some alkali in the desiccator to help remove the CO_2. Ward and Nakanishi (1971) have recently claimed, however, that drying of the filter causes losses up to 30% of the total fixed radiocarbon. On the basis of our knowledge of the assimulation routes of carbon via photosynthesis, such losses seem very unlikely to me. There are enough conflicting reports in the literature, though, that some controlled experiments are essential before we can have faith in the correctness of any one procedure.

iv) *Counting of* ^{14}C. Most investigators have used Geiger-Mueller tubes for counting of the incorporated radiocarbon. Not only is the efficiency of GM tubes relatively low (usually less than 20%), but there are serious problems connected with self absorption and geometry. Scintillation counting is far more efficient (up to about 95%) and simpler, does not suffer from the above problems, and can also be used with wet filters if an appropriate fluor is used. Ward and Nakanishi (1971) have recently compared the results of counting samples by both these methods.

v) *Respiratory losses.* The ^{14}C technique as commonly used measures the increase with time of ^{14}C in the particulate fraction:

$$^{14}CO_2 + H_2O \underset{k_2}{\overset{k_1}{\rightleftharpoons}} (^{14}CH_2O)_{\text{Particulate}} + (\text{Org-}^{14}C)_{\text{Soluble}} + O_2\uparrow$$

Respiration is continuing concomitantly with photosynthesis, however, so that some of the ^{14}C-photosynthate will be respired back to CO_2 and H_2O (rate k_2 above). This correction should be incorporated into the calculations for primary productivity, but the conventional ^{14}C technique does not yield any information to use for making this correction. The amount of heterotrophic ^{14}C fixation in dark bottles is not relevant to this question.

A further complication is caused by different pools of cellular metabolites within cells. During a 4–12 hour incubation with ^{14}C-bicarbonate, the specific activity of respiratory substrates may differ in the various organelles of the cell. It is extremely difficult, therefore, to estimate the amount of labeled carbon which has been lost through respiration during the incubation period, even if one had an accurate determination of the total rate of respiration.

vi) *Excretion of soluble organic compounds.* Laboratory and field data indicate that the amount of soluble ^{14}C-labeled organic material which is excreted by phytoplankton ranges from a few percent to 40% of the total amount of carbon which is reduced. Most studies on primary productivity ignore this soluble fraction, but it should be considered as it represents an input into the ecosystem of energy-rich material that can be used for heterotrophic growth processes. This soluble fraction is more difficult to measure than the particulate fraction, and there are many papers in the literature which must be viewed with caution due to the analytical techniques used. One of the problems in these studies involves the purity of the ^{14}C-bicarbonate solutions used during the incubation period. Any labeled organic contaminants in the preparation (which apparently are quite common) will be interpreted as "excreted carbon." We minimize this danger by exposing our sodium bicarbonate solutions to UV irradiation, which oxidizes all the organic material. To determine the amount of labeled organic materials in the filtrate after the incubation period, we first eliminate all inorganic carbon by acidifying and purging with nitrogen, after which we combust all organic material to CO_2, which we transfer to hyamine solution and count by scintillation counting techniques (Williams *et al.,* 1972).

It should also be noted that Nalewajko and Lean (1972) have demonstrated retention of dissolved organic material by membrane filters.

vii) *Isotope effects.* There is an abundant literature on the biological discrimination between ^{12}C and ^{14}C (Strickland, 1960) which indicates a discrimination value of about 6%. The resulting error will usually be insignificant relative to other sources of error in the determination of primary productivity.

Productivity Profiles

I want to point out three interesting problems concerning the distribution and activity of phytoplankton cells in regard to productivity measurements.

a) Nearly all studies on primary productivity deal only with the "euphotic zone," the bottom of which is arbitrarily defined as that depth at which the light intensity is 1% of surface illumination. There is sufficient data in the literature (Kiefer *et al.*, 1972; Venrick *et al.*, 1973; Anderson, 1969) to indicate that healthy phytoplankton populations are found at depths much greater than this 1% light level and that they do show a net reduction of CO_2. Further evidence for this view is the fact that one can grow many algae in the laboratory at light intensities considerably less than 1% of average surface illumination. Halldal (1968) has also shown a net oxygen production with symbiotic algae when exposed to light intensities of about 1×10^{-5} that of sunlight. On the basis of work such as the above, I think our interests in photobiology in natural waters should extend to at least 500 m. Concomitant with such studies, it is important to improve on the light-measuring devices available for field work, and to measure energy in terms of light quanta and wavelength, and not in terms of photometric units which are related to sensitivity of the human retina.

b) Although most productivity studies are concerned with particulate carbon, one should also consider the energy content of the cellular material. The only photochemical reactions of photosynthesis involve the formation of reducing substances (NADH and NADPH) and ATP, which are used in dark reactions to reduce CO_2 and to drive most of the energy-requiring synthetic reactions. Photosynthesis is thought to be a two-step photochemical process, photosystem II serving to produce electrons from water with the evolution of oxygen, and photosystem I which is involved with formation of reducing power and high-energy phosphate bonds (Rabinowitch and Govindjee, 1969). Photosystems I and II can be experimentally isolated and may also be physiologically independent in certain cells. During cyclic photophosphorylation by photosystem I ATP is formed from ADP and inorganic phosphate. This ATP may then be used as an energy source for the cells, or it may be used to "upgrade" the caloric content of the reduced carbon. I do not know of any field studies designed to test this suggestion, but it is possible that such photophosphorylation reactions may be involved in sustaining life in deep-water populations.

c) Photoinhibition of photosynthesis is very commonly invoked to explain the relatively low concentrations of phytoplankton in surface waters, as compared to higher biomasses at greater depths. The basis for this suggestion lies in data from laboratory work demonstrating that there is inhibition of photosynthesis beyond a certain light level. This physiological response to high light intensities, however, is very dependent upon many physical and biological factors. The point at which high light intensities become inhibiting is not characteristic of any particular species, but depends upon the conditions of the experiment and the immediate history of the cells.

Although one can not dismiss the possibility of photoinhibition of photosynthesis in surface waters, it is likely that the distribution of chlorophyll is a function of nutrient concentrations and temperature, as well as of light intensity. There is a considerable amount of field data to indicate that chlorophyll concentrations can often be related to the concentration of inorganic nutrients, particularly nitrate. In Lake Tahoe, for instance, the chlorophyll maximum is at about 100 m, which also corresponds to the depth where nitrate concentration starts to increase with increasing depth, but the low light levels below 100 m apparently then become limiting for phytoplankton growth. In nutrient-rich waters, on the other hand, phytoplankton biomass often is highest at the surface and decreases with depth, indicating that at least some phytoplankton populations are not being seriously inhibited by high light intensities.

If productivity data are expressed as micrograms of carbon fixed by a microgram of chlorophyll-a per hour for samples from the surface down to the depth where the light intensity equals the saturating intensity for photosynthesis there is generally no indication of photoinhibition in the surface waters. Assimilation numbers commonly are either fairly uniform throughout the upper portion of the water column or they increase slightly toward the surface.

The reduced phytoplankton biomass in surface waters may also reflect greater grazing pressures at these levels. Most of the total biomass estimates based on measurements of ATP instead of chlorophyll indicate greatest biomass in surface waters. One interpretation of these data is that this increase in biomass in surface waters reflects increased populations of heterotrophic cells. We do not have enough data at present to know if this suggestion is correct.

Although I am suggesting that photoinhibition of photosynthesis may not be very important in the ocean, I certainly do visualize that high light intensities may have pronounced effects on phytoplankton fine structure and function, as well as on distribution of organelles. Dale Kiefer, in our laboratories, is studying the fluorescence characteristics of phytoplankton as related to cell structure, CO_2 reduction, light scattering, and light absorbtion under varying light intensities. I am hopeful that such studies, in conjunction with further field observations, will clarify this nebulous area of physiological effects of high light intensities.

World-Wide Productivity Data

I had intended to give a quick review and discussion of productivity on a global scale, but I think that would require more time than is available today. Instead I will refer to the excellent article by Ryther

(1969) in which he estimates the productivity in the major marine provinces (Table 1). Although it is difficult to estimate the yearly production because year-round data generally are not available for most oceanic stations, the data in Table 1 most likely convey a realistic appraisal of primary production.

TABLE 1

Primary productivity in the major ocean province (data from Ryther, 1969)

Province	Percentage of Ocean	g C/m²/yr	mg C/m²/day	Total Productivity (10^9 tons C/yr)
Open ocean	90	50	140	16.3
Coastal	9.9	100	280	3.6
Upwelling	0.1	300	820	0.1

Strickland (1960) has also compiled many references concerning primary productivity in the world's oceans. The figures of Ryther agree quite well with most reports in the literature. Thus, Zeitschel (1969) has reported an average value of 382 mg C/m^2/day for the Gulf of California, Menzel and Ryther (1960) reports a value of 72 g C/m^2/year for the Sargasso Sea, Jitts (1969) shows about 48 g C/m^2/year for the Indian Ocean, and El-Sayed (1970), on the basis of extensive, multiyear programs, shows figures of 100 to 500 mg C/m^2/day for the Antarctic Ocean. The one major oceanic area for which we have very little data is the Arctic Ocean. On the basis of available data from T-3 Ice Island which indicates about 5 to 10 mg C/m^2/day (for only 6–8 weeks, however), Hopkins (1969) has suggested that primary productivity can not sustain the zooplankton respiratory requirements. It is obvious that we need more information from the Arctic Ocean.

ACKNOWLEDGMENT

This research was supported by the United States Atomic Energy Commission, Contract No. AT(11-1) GEN 10, P.A. 20.

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EVIDENCE FOR AND IMPLICATIONS OF STOCHASTIC FOOD CHAINS

(Abstract)

JOHN D. ISAACS
Institute of Marine Sciences
University of California, San Diego
La Jolla, California 92037

The several species of fish living in the Gulf of California have been shown to possess quite different concentrations of cesium (and cesium in respect to potassium) than the same species of fish living in the Salton Sea. The Salton Sea fish display simple trophic steps of concentration, whereas those in the Gulf all show about the same levels. These differences are reasonably well explained by simplified trophic models of the two environments. The concentration factor found in the known and describable *food chain* of the Salton Sea, applied to a model of an assumed unstructured *food web* in the Gulf, leads to reasonable results. This suggests that study of the concentrations in marine organisms of such natural trace substances as cesium may lead to an understanding of the trophic position of the organisms, and hence constitute "pollutant analogues" that may yield a better understanding of the existing or potential distribution of pollutants in marine organisms.

This report has been published in an amplified form as:

Isaacs, John D. 1972. Unstructured marine food webs and "pollutant analogues". Fishery Bulletin U.S. *70* (3): 1053–1059

Part III

SYMPOSIUM

OCEANOGRAPHY AND FISHERIES OF BAJA CALIFORNIA WATERS

Edited by Marston C. Sargent
Yosemite Park, California
November 12–15, 1972

THE CALIFORNIAS AND SOME FISHES OF COMMON CONCERN

PHILIP M. ROEDEL, Director
National Marine Fisheries Service
National Oceanic and Atomspheric Administration
Washington, D.C. [1]

It was 5 years ago at Lake Arrowhead that I had the privilege of opening a CalCOFI Symposium that represented a significant departure from practices of the past. Today, I have a similar privilege, for this symposium represents an equally sharp break, one that can have, and I hope will have, far-reaching consequences as far as the fishes and the fisheries of the California Current are concerned.

At Lake Arrowhead in 1967, CalCOFI was seeking communication and rapport with the lay public in the State of California that was for a variety of reasons interested in fisheries and fishery-related problems. We the scientists hoped that by taking a new approach, and by inviting as participants people from a variety of callings, we could contribute to understanding, help explain the point of view of the scientist to the layman, perhaps help ease the tension and establish a channel between those two protagonists so frequently at loggerheads, the commercial man and the recreationist.

The purpose of that symposium was to consider:

"The living resources of the California Current System; their fluctuating magnitude, distribution, and susceptibility to use for the benefit of the State of California."

We asked these questions:

"What are the resources and what is the state of our knowledge?

"What are the legal, economic, sociological and technological problems impeding their best use? How can these be resolved?" (Messersmith, 1969).

Whether or not the symposium reached its stated and implied objectives is arguable, but there is no question but that it represented a significant step forward for fisheries. Surely, conflicts between user groups remain with us. The scientist too often still has difficulty translating his findings into English (or Spanish) for the benefit of those who pay the freight and must use these findings for diverse reasons. Yet the fact that we are prepared to make another significant departure from the past convinces me that CalCOFI has indeed served well, that the body of knowledge embodied in the report of that symposium and those that followed it have paved the way so that we are now able to do what would have been impossible in 1967.

We are today concerning ourselves not just with the people of California and the fisheries adjacent to their coast—the original frame of reference of the Marine Research Committee (MRC) and CalCOFI—but with the people and fisheries of Baja California regionally and the Republic of Mexico as a whole. This is not only right and proper, it is long overdue. One has only to look at the distributional charts of the key species of Baja and Alta California to see that this is true, and it comes as anything but news to this group or to anyone else associated with fisheries research, management, or utilization in this part of the world.

In 1967, we were prepared only to look inwardly, and with good reason, the internal pressures being what they were. Now CalCOFI has come to the point where it can look at resources as a whole and invites and requires, for scientific success, bilateral accord and cooperation between the appropriate governmental functions of the United States and Mexico. This has actually begun in the last year.

I said we were then prepared only to look inwardly. This is really not quite true—we know we had ultimately to look outward but it was a matter of one step at a time. However, only one of the speakers made specific mention of the key importance of Mexico. Robert Vile (1969), representing the Ocean Fish Protective Association, said,

"Another area which looms large on the horizon is our relationship with Mexico. Strong cooperation between our government and that of Mexico must be worked out, since so many of our sport fish migrate between California and Mexican waters. As both commercial and sport fishing expand in Mexico, this will become another steadily rising source of pressure on the *same* resource."

I doubt that he, or any of the rest of us, thought that only 5 years later CalCOFI would be taking so broad a look that its proceedings would require a bilingual approach and simultaneous translation.

In a literal sense, CalCOFI is concerned with a limited array of species, those enumerated in California law as subject to a special tax. However, the research organizations represented in CalCOFI have a much broader concern, and CalCOFI research itself has covered a wide spectrum in its attempts to understand the dynamics of the living resources of the California Current System.

The CalCOFI Committee envisioned CalCOFI's role in these terms in its report for 1963–1966 (Ahlstrom et al 1966):

"Clearly the direction of research that CalCOFI recommends is far from a singleminded inquiry into the anchovy. We believe that we would be serving neither science nor the state were we to to adopt the anchovy fishery as a single object of study. Rather we are recommending an adequate continuing and defensible study of the anchovy and sardine and an expansion of the broad studies of the pelagic environment, which have paid off so handsomely. In this we believe that we are choosing a multilane highway into the future, which not only coincides with the scientific objectives, but serves the statutory objectives of the State and the MRC, in manifold ways."

[1] Present address: Office of Marine Resources, National Ocean and Atmospheric Administration, Rockville, Md.

Figure 1

Figure 1. Map of California by Hondius, 1631, Amsterdam. Courtesy Huntington Library, San Marino, California.

A broad view is, I believe, the only acceptable one. Because of its long and successful history, I hope that CalCOFI can play the lead in meeting demands of the future so far as fisheries of the Californias are concerned. It will, no doubt, require some change in its present terms of reference and some means of close official collaboration with Mexico's fisheries research organizations if it is to do so.

Let me turn to specifics.

I want to confine myself geographically to the States of California and Baja California and the territory of Baja California Sur—essentially the "Californie Isle" depicted by Hondius in 1631 (Figure 1). Parenthetically, one wonders what sort of a group would be gathered here today if Hondius had been right.

I particularly want to consider the coastal stocks found most abundantly from Point Conception to Cabo San Lucas. These species of common concern to Mexico and the United States are pretty much restricted distributionally to the waters adjacent to our two nations. Those that reach Canada do so as strays or in a couple of cases as northern fringe populations. I am not going to discuss essentially nonmigratory species that are found in the territorial waters of both nations (e.g., kelp bass and abalone). Nor am I going to consider the highly migratory high seas fishes that are certainly of great importance to Mexico and the United States, but which do not fit my definition. These are, of course, the tropical and temperate tunas and the billfishes.

What I am concerned with are certain of the "Marine Research Committee species" (those subject to a special California landing tax), particularly the Pacific sardine, Pacific mackerel, and northern anchovy; and another group outside the CalCOFI purview in the sense that they are not subject to the special tax. They are, in fact of particular—not sole, I hasten to add—concern to southern California sportsmen.

The group includes for my purposes the barracuda, bonito, white seabass, and yellowtail, though some others of lesser significance or unknown migratory habits must not be overlooked—ocean whitefish, sheepshead, and various other sciaenids for instance.

What I am sorting out, quite obviously, are those species which (1) meet the criteria for coastal stocks as defined in the United States' position for the Law of the Sea Conference; (2) migrate along the Pacific coast between Mexico and the United States; but (3) do not range as far as Canada in substantial numbers except as relatively discrete populations. In other words, key fishes the rational long-range management of which depends on bilateral action. That is why my laundry list does not include such obvious candidates as the jack mackerel and hake. The first may not meet criterion (1) and neither may meet criterion (3). There is nothing unique about this approach—I had occasion to put it this way in 1968:

"The living marine resources off the coasts of the States of California and Baja California and the Territory of Baja California Sur are many and varied. In the aggregate they represent a huge stock which is being utilized only in part at the present time. While some of these resources are found only in one country or the other, many of them occur both in Mexico and the United States and others have far broader ranges. Such species as northern anchovy, Pacific mackerel, sardine, barracuda, yellowtail, bonito and white seabass are now the object of fisheries in both nations. . .

"Future prospects are for increased fishery utilization by Mexico, the United States and others. What can and should be done to afford maximum protection to the legitimate interests of the Californias?

"Because the eastern Pacific fishery resources and interests, particularly those of Southern California and the west coast of the Baja California Peninsula, are in such a large degree the same, there is the very evident need for cooperation between the United States and Mexico in fishery matters if their common resources are to be properly husbanded." (Roedel, 1968a).

I am suggesting that now is the time to take scientific stock, to expand our base of scientific knowledge where necessary, to act jointly in so doing, and if possible to use CalCOFI as a vehicle. I am suggesting that sooner or later some sort of an arrangement is going to have to be worked out between Mexico and the United States with respect to the conservation of this group of fishes.

You may say this is looking a long way down the road. Perhaps so but I think we have to. Scientifically sound expended programs mounted now on some cooperative base agreed to by our governments will only, with luck, provide the data necessary for management by the time the need for it is with us. Regardless of how the law of the Sea Conference turns out, regardless of whether conservation action is unilateral, bilateral, or multilateral, some sort of controls will almost surely be necessary beyond those we have now. And there are those who say the day may already be past.

The first thing we have to find out is how much we know. This is too often overlooked. Faced with a new challenge, some of us charge madly off in all directions, busily reinventing the wheel.

We know quite a great deal about the "non-MRC" California fishes and more than some people might think about those from Baja California.

For example, in pre-CalCOFI, pre-World War II days, the State of California conducted many research cruises particularly along the west coast of Baja California, but also into the Gulf of California. These cruises were made by the California State Fisheries Laboratory (CSFL) under terms of permits issued by the Government of Mexico. Extensive cruises by CSFL research vessels began in 1931, but as early as 1917, the launch "IMP" spent 3 days at the Coronado Islands trawling for young fish, with what success the surviving record does not tell us (Roedel, 1968b).

Though the Government of Mexico had no laboratory in Baja California during the 1930's, it did offer fine cooperation to the State researchers, issuing the necessary permits, expediting port procedures, and providing great hospitality at what were then isolated outposts south of Ensenada. The Mexican fishing industry was equally cooperative during the sardine and mackerel tagging programs, installing and maintaining electromagnets for tag recovery at the Ensenada plants.

The tagging programs first demonstrated that these were in fact common stocks, that the Mexican and American plant operators were drawing from a common source at least in southern California and northern Baja California. Pacific mackerel migration patterns, for example, showed some intermingling from central Baja California to central California. The sardine studies demonstrated the same interdependence.

In the post-World War II era, the CalCOFI program come into being and with it the blossoming of that fundamental tool for fishery-independent population estimates, the egg and larva survey.

The results of this survey reiterated for some species and established for others the joint Mexico-United States nature of so many of these key resources. The distribution of spawning stocks of anchovies and sardines both above and below the international boundary is an example.

There were other studies of particular species, some conducted under university auspices, some under Federal, some under State, still others under various combinations. We learned much, for example, of the life history and migrations of yellowtail and barracuda through State-operated partially federally-financed (Dingell-Johnson) projects (Baxter et al, 1960, Pinkas, 1966). These studies required the full support of the Mexican Government and a great deal of help from both sport and commercial sources in California for their success.

Now we are conducting integrated research with Mexico's fishery research laboratories in the standard CalCOFI framework. And currently scientists from California and Mexico are cooperating informally in a tagging program. I hope that these efforts not only continue but expand and strengthen. Both our nations have too much at stake to do otherwise.

On the United States' side, we are taking major steps to expand our research base, with particular respect to the so-called migratory marine game fishes, especially barracuda, bonito, white seabass, and yellowtail. We are taking inventory of what we know and identifying that which we do not so that a sound and practical research program can be mounted. This work involves both the Federal Government and the State, and a joint document defining the "state of the art" and recommending a course of action is due soon after the first of the year (1973).

We are concerned to a large degree with stocks common to both nations and with what we see as the ultimate need for our two governments to work jointly for resource conservation if these stocks are to be maintained. We hope that Mexico will join with us in this augmented effort.

It is all well and good to preach augmented research and it is a relatively easy concept to sell. The question is where does it lead? We have a tendency to study things to death and to expect all the answers before any use is made of the data in a managerial sense. However, in this day and age you cannot postpone decisions until the last bit of information is in. In this connection, it is now becoming quite fashionable to quote John Gulland (1971), which I shall now do:

> "It is obviously a fallacy to think that scientists given time, and perhaps also money, can produce the complete answer to management problems, e.g., specify the precise value of the maximum sustained yield from a particular stock of fish, and also the exact levels of fishing, and of population abundance required to produce it. The inability of scientists to produce such complete and exact analyses has resulted (sometimes deliberately) in a delay in the introduction of management measures . . . The obverse of this fallacy is that a complete scientific understanding is necessary for effective management."

Gulland's point is extremely well taken for we have had a very definite tendency in the past to postpone action until it was too late, simply because those of us with managerial responsibilities felt we could not act until the scientist felt he had all the answers. We need look no further than the collapses of the Pacific sardine and the Pacific mackerel fisheries in California for prime examples. In these cases, management actually lagged far behind science which transmitted the warning (albeit with data far less than complete) far in advance of the fact. I hope I make it clear that I certainly do not propose an expanded research program as a delaying action. Rather, I look upon it as necessary to provide us at least part of what we need to know before the hour of decision arrives.

I remarked earlier that there was nothing really new in what I have discussed so far as expanded research goes. That is equally true of international cooperation for management. Many of us forget, if indeed we ever knew, that Mexico and the United States entered into a convention including an international fisheries commission in 1926. The need for it was based chiefly on prevention of smuggling and on general concern for the barracuda resource and its economic future, but it was abrogated in 1927 before it had a chance to produce. The point is, such a treaty did exist.

The California Division of Fish and Game continued the barracuda research, started by the Commission, which culminated in a publication on barracuda life history and its fishery by Lionel Walford (1932), who was himself a Commission scientist during its brief existence.

We now have the bilateral agreement with respect to the contiguous fisheries zone which expires next January 1, 1973. One thing that the negotiations leading to the bilateral did was to emphasize the interest in Baja California of United States anglers. Those in the Federal Government who were concerned in the negotiations were quite aware of the importance of Baja California to commercial interests, but were less appreciative of its importance to sport fishermen.

It came out quite clearly that not only do we have a common resource on both sides of the border, but that sportsmen from north of it are likely as not to fish to the south so long as they can within the framework of Mexican law. Finally, "both delegations recognized the increasing need for joint cooperative efforts directed toward research on and conservation of the many living marine resources of common concern." An annex to the formal report called for "the two nations to exchange information and develop coordinated programs of research and management with special respect to anchovies, sardines, and hake." (Roedel and Frey, 1968).

Another organization exists which has at times interested itself in fisheries matters. I am speaking of the Commission of the Californias, that rather unique body made up of delegates from the State of California, the State of Baja California, and the Territory of Baja California Sur. This Commission can perhaps play an increased and significant role in developing and coordinating plans for research and when and if necessary management of these stocks.

I am not prepared to recommend a course of action for management at this point in time. For one thing, we need to know better where we are in terms of knowledge and as I mentioned earlier, we will not have an evaluation completed until early 1973. The Law of the Sea Conference may well change many of the rules of the international game and it might be good counsel to await development there before taking further action here. The action when it comes may take any one of several forms. One which obviously comes to mind is a formal bilateral treaty between our two nations. Other less formal steps are possible. My purpose now is to get people thinking about the problem both from the points of view of science, of management, and of politics.

I have not mentioned until now the obvious impact of joint international management upon the prerogatives presently exercised by the State of California. They are, however, apparent. Given an international arrangement, the State would lose its present authority to manage these stocks except to the degree that it could influence any international commission that might be established. This is a factor that State authorities must weigh in the balance.

So far as CalCOFI is concerned, I want to say once again that I feel it can and should play a significant role in any research program expanded to include migratory marine game fish of common concern. CalCOFI has a long and honorable past. I hope its future is even longer and more honorable, that its frame of reference is broadened, and that the scientists of the Republic of Mexico join in as full partners.

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INSTITUTE OF OCEANOLOGICAL INVESTIGATIONS WORK PROGRAM 1972–1973

Oc. KATSUO NISHIKAWA K., *Director*
Unidad de Ciencias Marinas
Instituto de Investigaciones Oceanologicas
Apartado Postal No. 453
Ensenada, Baja California

In Mexico investigation of the seas which border the Republic is relatively recent. Great efforts by universities and the Mexican Government led to the creation of elementary or basic groups in teaching and research related to our marine resources. At present the following array of existing centers of teaching and/or research have been established (See Figure 1).

Governmental Agencies

1. National Institute of Fisheries, under the Secretary of Industry and Commerce.
2. Directorate of Aquaculture and General Directorate of Uses of Water and Prevention of Contamination under the Secretary of Hydraulic Resources.

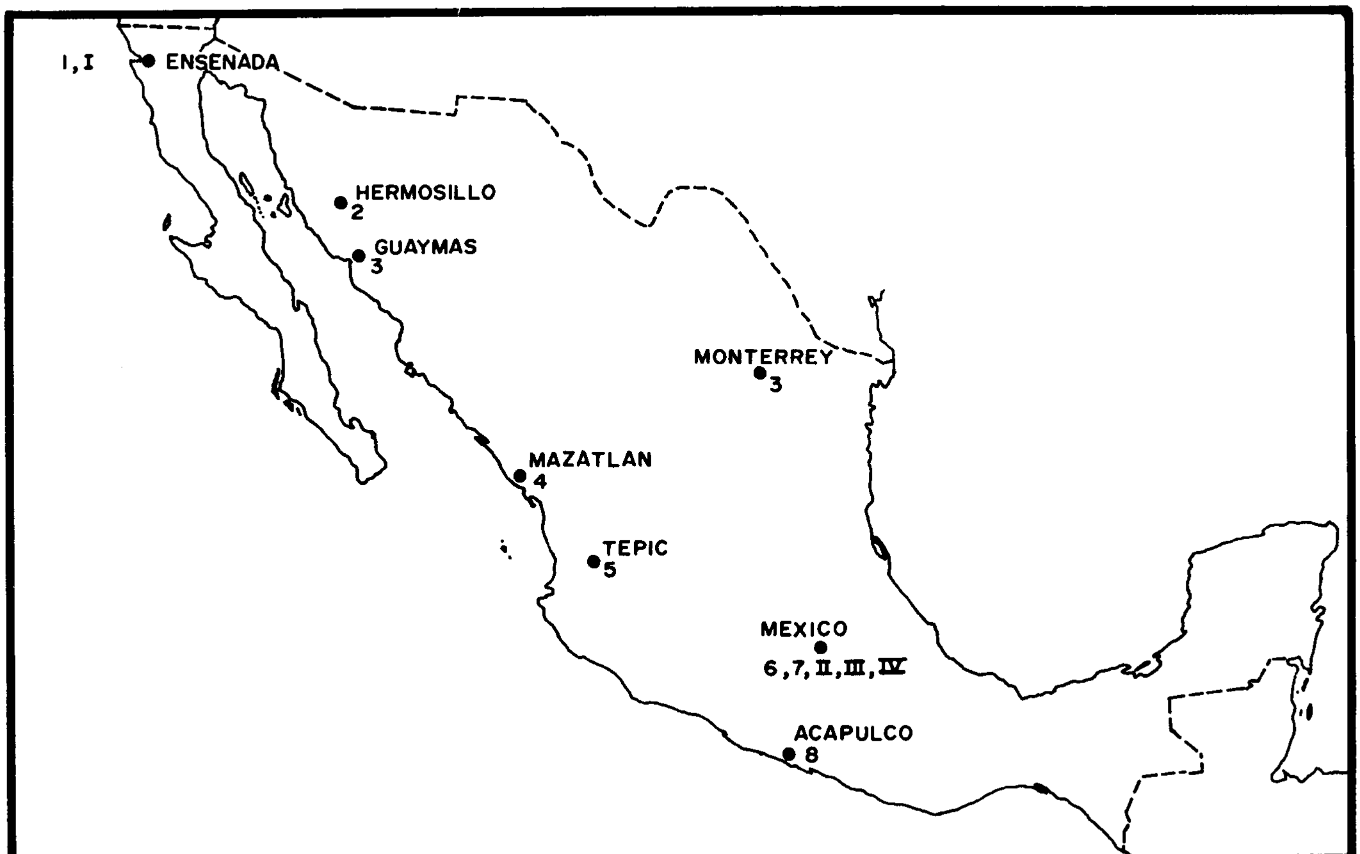

Figure 1. Map of the Mexican Republic, showing location of the principal centers of teaching and research in the Marine Sciences.

Figure 1. Map of the Mexican Republic, showing location of the principal centers of teaching and research in the marine sciences.

UNIVERSITIES

1. Inst. of Oceanological Inv. (IIO). School of Marine Sciences.
2. Center of Scientific & Technological Inv. Univ. of Sonora.
3. Technological Inst. of Higher Studies of Monterrey (ITESM).
4. School of Marine Biol. Univ. of Sinaloa.
5. School of Oceanography, University of Nayarit.
6. School of Biological ScNal. Polytechnic Inst.
7. Inst. of Geophysics, Inst. of Biol. Inst. of Geol. and Inst. of Geography, Nal. Univ. of Mexico (UNAM).
8. Marine Ecology School (1973). Univ. of Guerrero.

GOVERNMENTAL AGENCIES

I. Center of Scientific Inv. and Higher Education of Baja Cfa. (CONACyT-UABC-UNAM).
II. Nat. Inst. of Fisheries Undersec. of Industry and Commerce.
III. Directorate of Aquaculture and General Directorate of Uses of Water and Prevention of Contamination under the Sec. of Hydraulic Resources.
IV. Gen. Directorate of Maritime Works & Gen. Directorate of Oceanography & Maritime Aids to Navigation under the Sec. of the Navy.

3. General Directorate of Maritime Works and General Directorate of Oceanography and Maritime Aids to Navigation under the Secretary of the Navy.
4. Center of Scientific Investigations and Higher Education of Baja California. National Council of Science and Technology (CONACyT-UABC-UNAM).

Universities

1. Institute of Oceanological Investigations (IIO). School of Marine Sciences. Autonomous University of Baja California (UA BC).
2. Institute of Geophysics, Institute of Biology, Institute of Geology and Institute of Geography. Autonomous National University of Mexico (UN AM).
3. School of Biological Sciences. National Polytechnic Institute.
4. Technological Institute of Higher Studies of Monterrey (ITESM).
5. School of Oceanography, Autonomous University of Nayarit. Recently renamed Superior School of Fisheries Engineering (Feb. 1973).
6. School of Marine Biology, University of Sinaloa.
7. Center of Scientific and Technological Investigations, University of Sonora.
8. School of Marine Ecology, University of Guerrero.

Nevertheless, in spite of this proliferation of centers in recent years, economic and material resources are scarce; therefore, research is going through a transition from poorly oriented short term and intermittent studies not leading to significant conclusions, to major projects with specific purposes, which take a long time to bring to completion.

This condition probably is owing to a lack of appreciation by those who direct the destinies of Mexico, including the scientists themselves, of the full magnitude of the relevance and importance of proper understanding and management of our marine resources. Judging by events at the national level in the last five years, the situation just described will be remedied in the next five years.

Meanwhile, the different groups which form the oceanographic structure of Mexico have been effecting a program of preparation and investigation which, although in part simple, is a firm and necessary step toward resolving our most immediate oceanographic problems.

In particular, this is the case in the institution of which I am a part: the Marine Science Unit of the Autonomous University of Baja California, in Ensenada. Within this Unit, the Institute of Oceanology has now established a program of basic preparation in coordination with the School of Marine Sciences.
This program has several aspects such as:

a) Training investigators.
b) Acquiring documents.
c) Research on selected problems.
d) Obtaining funds.
e) Obtaining equipment and supplies.

Training investigators is without doubt the most difficult and time consuming task, a slow process of preparation and selection of competent people on whom within four years we believe we can rely as the basic group of investigators meeting our requirements. This will ocur thanks to the opportunities which the Government now offers through the National Council of Science and Technology.

Acquiring documents, that is, forming in Ensenada *a specialized center of oceanographic* information on the seas adjoining Baja California, is vitally important because the efficient utilization of the marine resources in the waters off our coasts depends largely on our understanding of the resources and of the application of technology. Even the developent of this technology will depend on the quantity and quality of the existing scientific and technical knowledge, and its availability and accessibility for efficient use.

Therefore, the objectives which this center of information seeks should be:

1. To identify the information required for teaching, research and industry; in marine sciences, atmospheric sciences, earth sciences, and applied sciences.
2. To satisfy and encourage a growing demand for information from the permanent users in the areas mentioned.
3. To provide reference, loan, and copying services.

However, for this to become a reality, it is necessary to obtain the close collaboration of the scientists of the whole world. For this purpose we have considered undertaking several projects, the most important being organizing *an international symposium on the oceanology of the seas adjoining Baja California* which in accord with what has been said already, will have the following objectives:

a) To accomplish the most complete synthesis of what has been learned up to now about the seas adjoining the peninsula of Baja California.
b) To identify the most urgent problems which demand immediate attention, and those problems which can be resolved only by long term programs.
c) To create the necessary bases for carrying out multi-institutional collaborative programs.
d) To lay the foundations necessary for a series of symposia to be held every year or two.

This would give an opportunity for an annual or biennial review of the advances accomplished, and for reorientation of work according to the experience being obtained.

The international symposium we plan to celebrate is expected to take place in late 1974. Meanwhile, obtaining funds and therefore equipment and supplies is being accomplished with direct assistance from the Government, as in the case of the research vessel, BENITO JUÁREZ, given by the President of the Republic and on the way to being built, or in the case of contracts for work on specific problems such as those we already have.

Research Projects

In the upper Gulf of California we now have two studies under way. One of them is *Contamination of the mouth of the Colorado River by insecticides,* in its second stage on the general ecology of the zone. The other is *Hydrography of the upper Gulf of California.* The objectives being pursued in these two studies are:

1. To recognize the mechanisms by which contaminants penetrate the marine ecosystem (trophic chain and transport).
2. To evaluate the hazard presented by the brackish effluent waters from the geothermal electric plant at Cerro Prieto.
3. To obtain data series of the ambient conditions in the northern part of the Gulf of California and the brackish water lagoons of the Colorado delta.
4. Effects of tides and tidal flats on the physical and chemical characteristics of the waters of the upper Gulf.
5. The submarine topography of the upper Gulf.
6. The commercial fishing grounds, betweeen 31° north latitude and the frontier with the United States of America.

On the Pacific slope basically we are carrying out two projects, one of them on *Contamination of the coast between Ensenada and the frontier by heavy oils.* In the first stage, we are limiting the area to the littoral zone and the sea bed. At the same time, observations are made on ecological effects. The other project is a long term program related to mariculture; in this project we are attempting to develop a pilot plan for oyster culture in Bahía de San Quintín in order to later create in that area a center of mariculture, which when operating will be able to finance itself and to extend cultivation to the whole peninsula of Baja California.

In this program, even though the oyster is the base of the project, experimentation will include all those marine species of commercial importance and susceptible to cultivation.

In conjunction with the studies previously pointed out, there is one more on the *Effects of tropical storms on the Pacific coast of Mexico.* In this program we are attempting to evaluate the damage caused on the coast by tropical disturbances, in order to be able to suggest types and characteristics of works to be constructed, and in addition to contribute to the beginning of a maritime system of protection against chubascos.

NOTAS SOBRE EL CRUCERO DEL ALEJANDRO DE HUMBOLDT EN LA PARTE NORTE DEL GOLFO DE CALIFORNIA, DURANTE SEPTIEMBRE DE 1971

JOSÉ MA. ROBLES PACHECO
y
RICHARD A. SCHWARTZLOSE

SUMARIO

Los datos muestran calentamiento de aguas poco profundas próximas a las costas del norte de Baja California, Sonora y cerca de la boca del Río Colorado.

En la parte central más profunda del norte del Golfo, el agua es más fría, probablemente debido a la mezcla de agua fría del fondo o quizás a surgencias.

Al norte de Ángel de la Guarda, parece existir una turbulencia desde la superficie, extendiéndose casi hasta el fondo.

INTRODUCCIÓN

Del 18 al 26 de septiembre de 1971 se llevó a cabo el Crucero AH/71/10 en la parte norte del Golfo de California, desde Isla Tiburón a la Boca del Río Colorado. Se efectuaron mediciones de temperatura, salinidad y oxígeno disuelto en una densa red de estaciones, aproximadamente 10 millas aparte una de otra.

El principal propósito de este crucero, fue obtener información utilizable de las condiciones ambientales en la parte norte del Golfo de California, región que como todo el Golfo, ha sido muy poco estudiada, no obstante la importancia que tiene tanto desde el punto de vista oceanográfico, como biológico. Este crucero representa además, el primer intento serio de investigación oceanográfica, que fue patrocinado totalmente por el Instituto Nacional de Pesca y el Programa México/PNUD/FAO.

La medición de temperatura se hizo con termómetros reversibles acoplados a botellas Nansen, la salinidad fue determinada por salinómetro inductivo y los análisis de oxígeno disuelto se hicieron mediante la técnica de Winkler (macro), en muestras de agua extraidas de las botellas Nansen. Estas fueron espaciadas a profundidades tipo ("estándar") de 0 a 500 metros, según lo permitiera la profundidad del fondo.

Estas notas tienen por objeto dar a conocer algunos rasgos principales sobre la distribución horizontal y vertical de la temperatura, salinidad y oxígeno disuelto en el área y período de estudio. Fundamentalmente, la distribución de esas características a 10, 50 y 100 metros de profundidad y en tres perfiles verticales considerados representativos de la parte norte, central y sur del área de estudio.

RED DE ESTACIONES

Se ocuparon 89 estaciones que se muestran en la Figura 1, en la cual también se indican las líneas que corresponden a los tres perfiles verticales de temperatura, salinidad y oxígeno: norte, central y sur.

TEMPERATURA, SALINIDAD Y OXÍGENO DISUELTO A 10 METROS DE PROFUNDIDAD

Se observa una variación de norte a sur de 30.4°C a 27.6°C. Los valores más altos próximos a 30°C, se encuentran en aguas someras cerca de la boca del Río Colorado y en Bahías de ambos litorales. En la parte central del Golfo, entre Cabo Tepoca e Isla San Luis, aparece un núcleo de 28°C. Las temperaturas más bajas se localizan al norte de Isla Tiburón (Figura 2).

La salinidad varía de 36.6‰ frente a San Felipe, B.C., a 35.4‰ cerca de Isla Tiburón. Las aguas costeras de la parte norte se caracterizan por valores de la salinidad mayores de 36.0‰. La parte central y sur presenta valores de 35.8 a 35.4‰. Frente a la boca del Río Concepción en la costa de Sonora, se observaron valores tan bajos como 35.4‰ (Figura 3).

En gran parte del área de estudio se observaron concentraciones de oxígeno con valores muy cercanos a 5.0 ml/L, principalmente a lo largo de las costas de Sonora, en la parte central y cerca de las Islas Ángel de la Guarda y Tiburón. Las concentraciones más bajas (4.2 ml/L) se presentan en la parte norte, frente a San Felipe, B.C. (Figura 4).

TEMPERATURA, SALINIDAD Y OXÍGENO DISUELTO A 50 METROS DE PROFUNDIDAD

De norte a sur el rango de la temperatura a esta profundidad es de 27° a 23°C. En el centro del Golfo, entre Isla San Luis y Cabo Tepoca, aparece un núcleo de agua fría (19°C), probablemente relacionado con mezcla de agua del fondo o quizás con surgencias. Los valores más altos se localizan en aguas someras del norte y cerca de la costa (Figura 5).

La salinidad a esta profundidad varía de 35.1 a 35.6‰. Como se notó a la profundidad de 10 metros, en este caso también aparece el valor mínimo frente al Río Concepción en Sonora. Frente a Isla Ángel de la Guarda la salinidad es de 35.3‰, valor que también es aparente en la parte central del Golfo aumentando hacia el norte hasta 35.4‰. Los valores más altos se encuentran entre el extremo norte de Isla Ángel de la Guarda y la costa de Baja California y también entre Cabo Lobos y Cabo Tepoca en la costa de Sonora (Figura 6).

En la distribución del oxígeno disuelto, las concentraciones más altas (mayores que 4.0 ml/L) se encuentran entre Punta Final e Isla Ángel de la Guarda. Valores altos también se observaron frente a Cabo Tepoca y en la parte central del área de estudio. Las concentraciones más bajas (3.0 ml/L) aparecen frente a San Felipe al norte de Ángel de la Guarda y cerca de Isla Tiburón (Figura 7).

TEMPERATURA, SALINIDAD Y OXÍGENO DISUELTO A 100 METROS

Como se notó a las profundidades de 10 y 50 metros en este caso también aparece un mínimo de temperatura (15.0°C) en la parte central del Golfo, entre Isla San Luis y Cabo Tepoca. En esta área y a la misma profundidad de 100 metros se nota una penetración de agua más caliente, probablemente procedente de profundidades menores del extremo norte del Golfo y de las costas de Baja California y Sonora. Al norte de la Isla Ángel de la Guarda aparece una lengua de agua también más caliente que empuja hacia el norte. En el extremo sur el gradiente horizontal de la temperatura es menos brusco (Figura 8).

La salinidad en la mayor parte del área tiene valores muy cercanos a 35.2‰ (Figura 9). Solamente frente a Punta Final, sobre las costas de Baja California, se observan valores mayores (35.3‰). Al sur de esta localidad y entre las Islas Ángel de la Guarda y Tiburón aparecen los valores mínimos (34.9 y 35.0‰).

Con relación al oxígeno disuelto, las mayores concentraciones próximas a 3.0 ml/L aparecen al norte de Ángel de la Guarda y entre Isla San Luis, B.C. y Cabo Tepoca, Son. Concentraciones más bajas se observan al sur entre las Islas Tiburón y Ángel de la Guarda (Figura 10).

PERFILES VERTICALES EN LA REGIÓN NORTE

En esta región de aguas muy someras (30 metros), se observaron valores casi iguales desde la superficie hasta el fondo. La temperatura es mayor (34.6°C) en las costas de Sonora, donde la pendiente del fondo es menos brusca que en Baja California (Figura 11). La salinidad aumenta también hacia las costas, de 35.6‰ en las estaciones centrales a 36.20‰ en aguas próximas a Sonora, y a 36.80‰ frente a Baja California (Figura 12). El oxígeno disuelto aumenta progresivamente desde las costas de Baja California a las de Sonora con valores de 4.2 a 4.7 ml/L (Figura 13).

PERFILES VERTICALES EN LA REGIÓN CENTRAL

Como se vió en el caso anterior, en esta región también el agua superficial más caliente se presenta frente a las costas de Sonora, con una diferencia aproximada de un grado con las aguas costeras de Baja California. Después de los 30 metros de profundidad la temperatura del agua decrece desde 28°C, hasta el mínimo de 15°C a 140 metros (Figura 14).

La salinidad aumenta de 35.4 a 35.6‰, desde las estaciones centrales hacia ambas costas. A 150 metros de profundidad su valor es de 35.0‰ (Figura 15).

Las concentraciones de oxígeno más altas se encuentran en las estaciones centrales, disminuyendo hacia las costas desde 6.4 a 4.8 ml/L. Con la profundidad, la concentración disminuye hasta 2.4 ml/L a 150 metros (Figura 16).

PERFILES VERTICALES EN LA REGIÓN SUR

Casi a todo lo largo de esta sección, en la capa superficial de mezcla se observan valores comprendidos entre 28.3° y 28.6°C. Aparece en la figura el extremo norte del Canal de Salsipuedes, entre la Isla Ángel de la Guarda y la costa de Baja California. Las isotermas se extienden de costa a costa casi paralelamente, con valores de 28°C cerca de la superficie y 13.0°C a 300 metros, en el Canal de Salsipuedes (Figura 17).

En la capa superficial, la variación de la salinidad es de 35.4 a 35.8‰ con los valores más altos hacia las costas, principalmente en la de Baja California. En el Canal de Salsipuedes aparecen valores de 34.96, 34.84 y 34.90‰ a profundidades de 150, 200 y 300 metros respectivamente (Figura 18).

El agua superficial a lo largo de esta sección está caracterizada por concentraciones de oxígeno disuelto cercanas a 5.00 ml/L. En las aguas más profundas principalmente en el Canal de Salsipuedes, los valores de oxígeno son de 1.80 ml/L (Figura 19).

CONCLUSIONES

Los datos muestran calentamiento del agua en áreas poco profundas, próximas a las costas del norte de Baja California, Sonora y cerca de la Boca del Río Colorado.

En la parte central más profunda del norte del Golfo, el agua es más fría, probablemente debido a procesos de mezcla con agua del fondo o quizás a surgencias.

Al norte de Ángel de la Guarda, parece existir un remolino desde la superficie, extendiéndose casi hasta el fondo.

En general, aguas someras presentan alta salinidad y aguas profundas de la región central y sur del área de estudio presentan los valores más bajos de salinidad.

Frente a la desembocadura del Río Concepción, al sur de Puerto Peñasco, Son., se localizan aguas con salinidad relativamente baja, observable a diferentes profundidades.

Las concentraciones más altas de oxígeno disuelto aparecen en la parte central del norte del Golfo de California.

SUMMARY

The data show heating of the shallow waters close to the northern coasts of Baja California and Sonora, and near the mouth of the Colorado River.

In the deeper central part of the northern Gulf, the water is colder, probably as a result of mixing with the cold very deep water, or perhaps because of upwelling.

North of Ángel de la Guarda, turbulence appears to occur, reaching from the surface almost to the bottom.

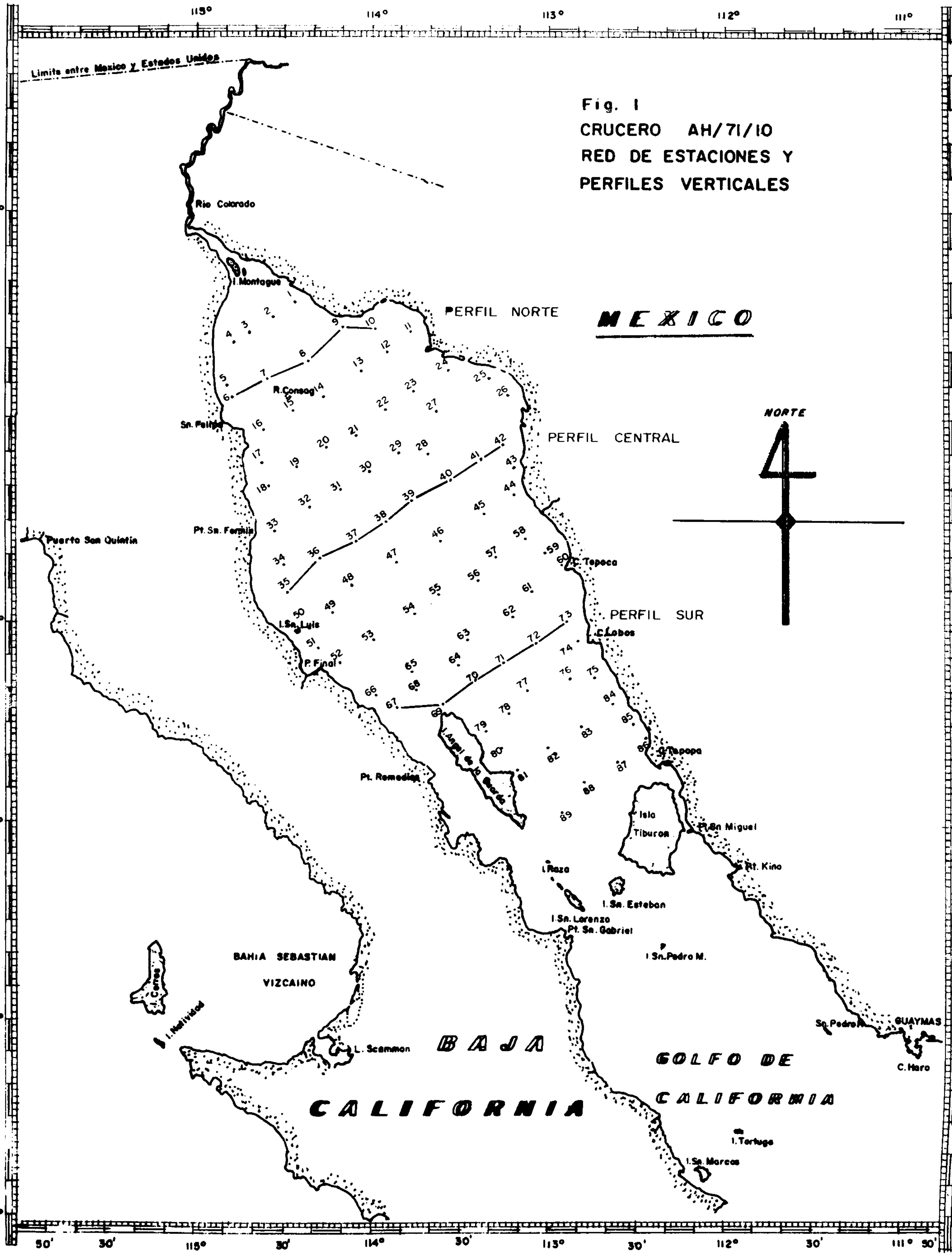

FIGURE 1. Positions of stations and vertical sections

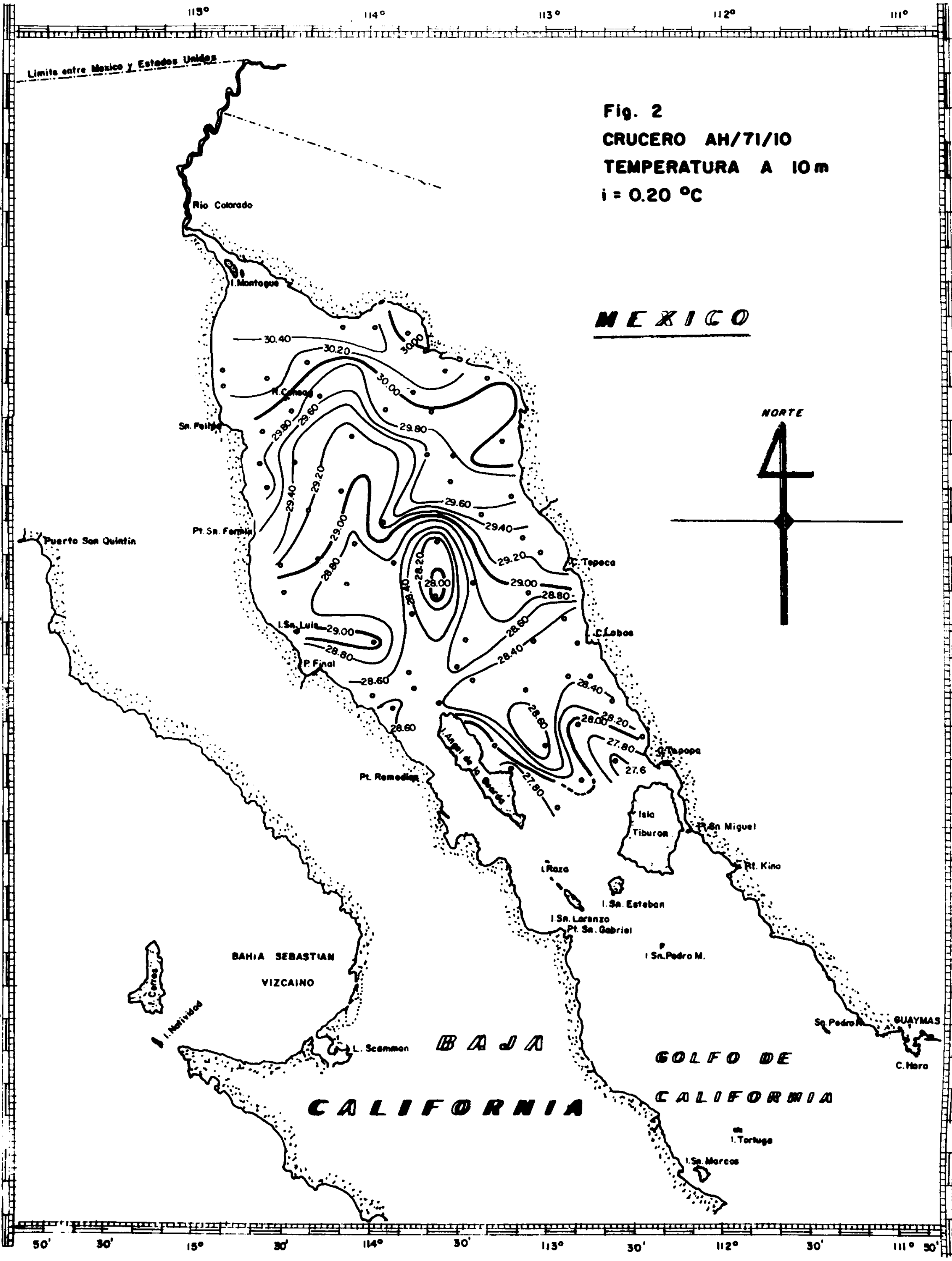

FIGURE 2. Temperature at 10 m. Contour interval 0.20° C

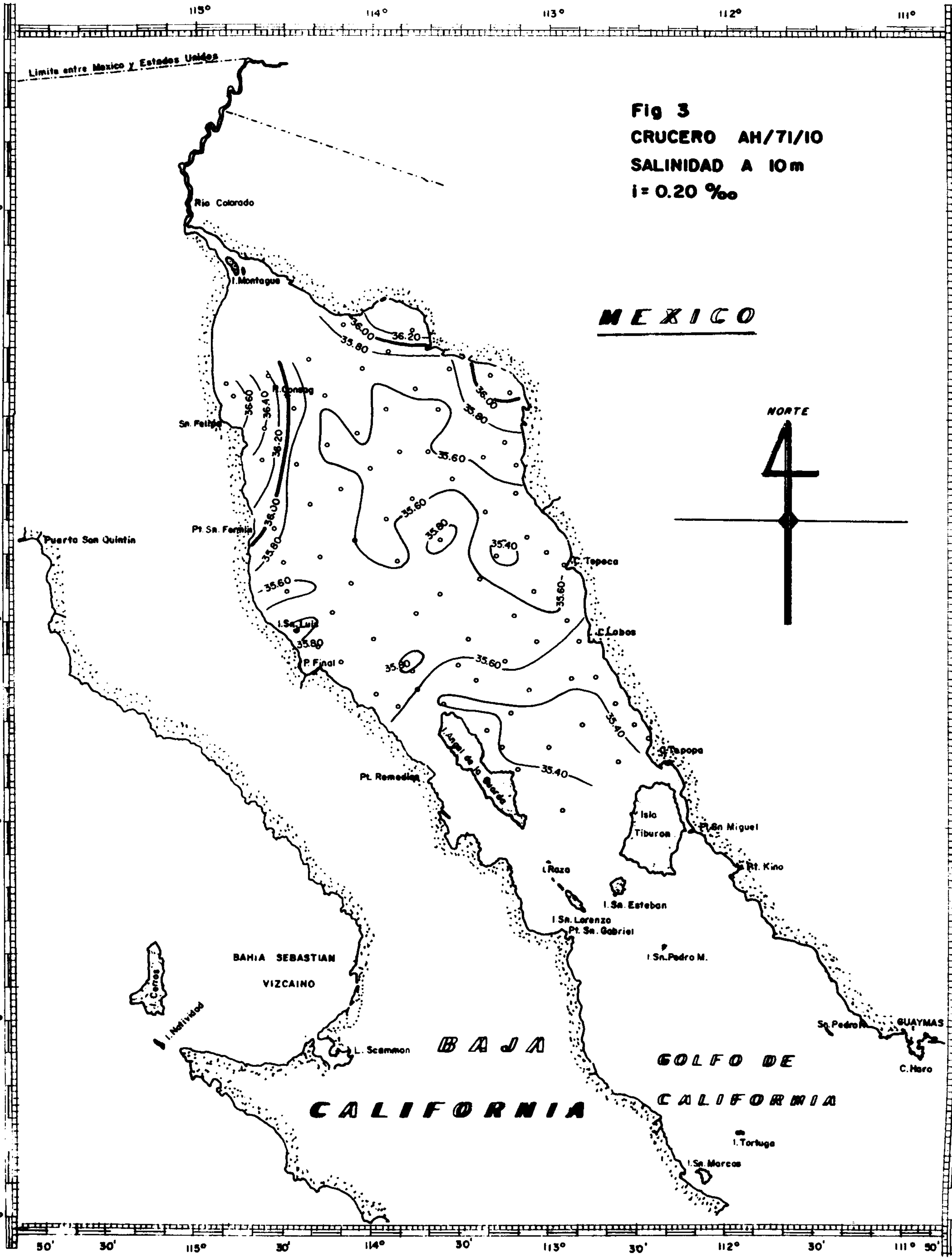

FIGURE 3. Salinity at 10 m. Contour interval 0.20‰

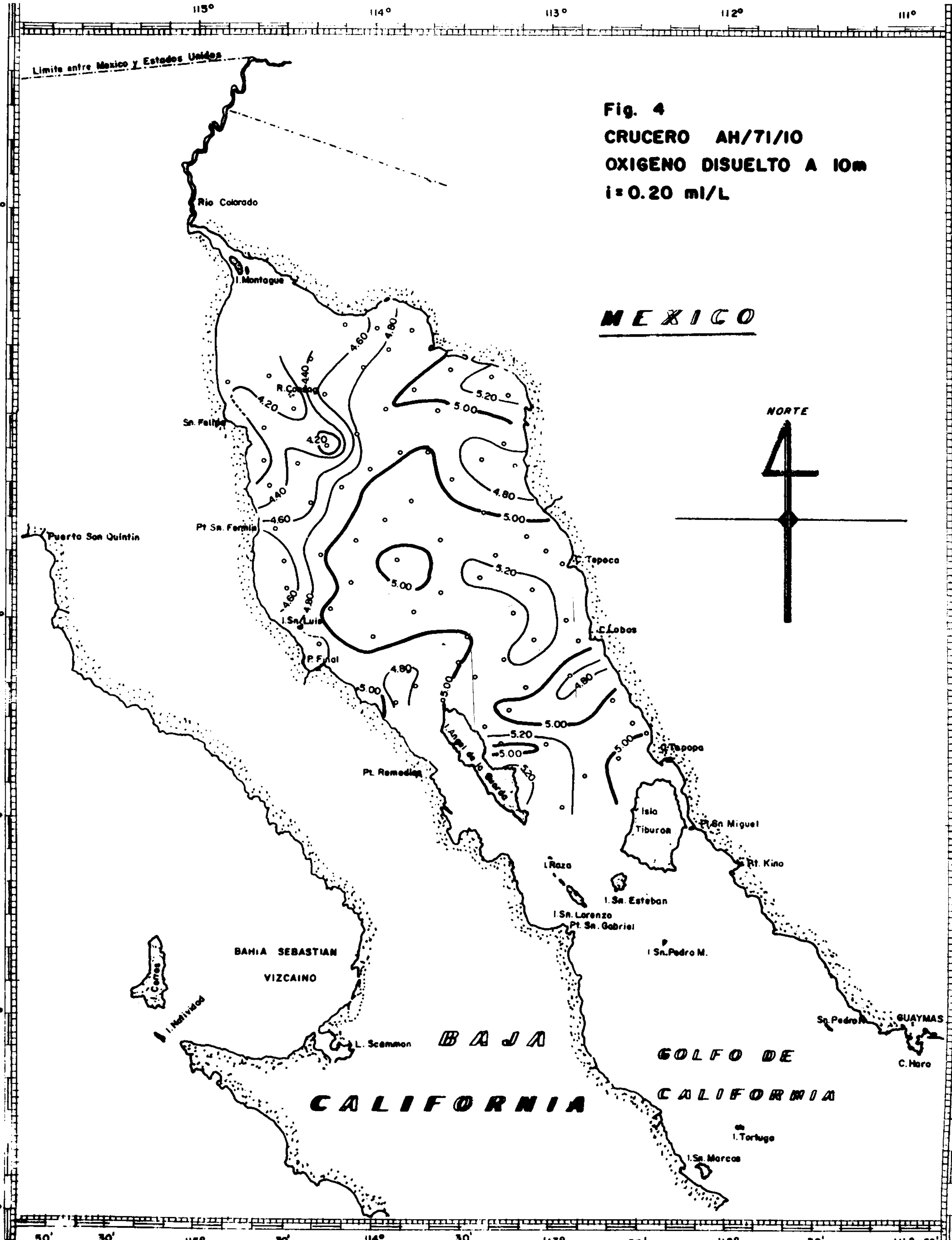

FIGURE 4. Dissolved oxygen at 10 m. Contour interval 0.20 ml/L

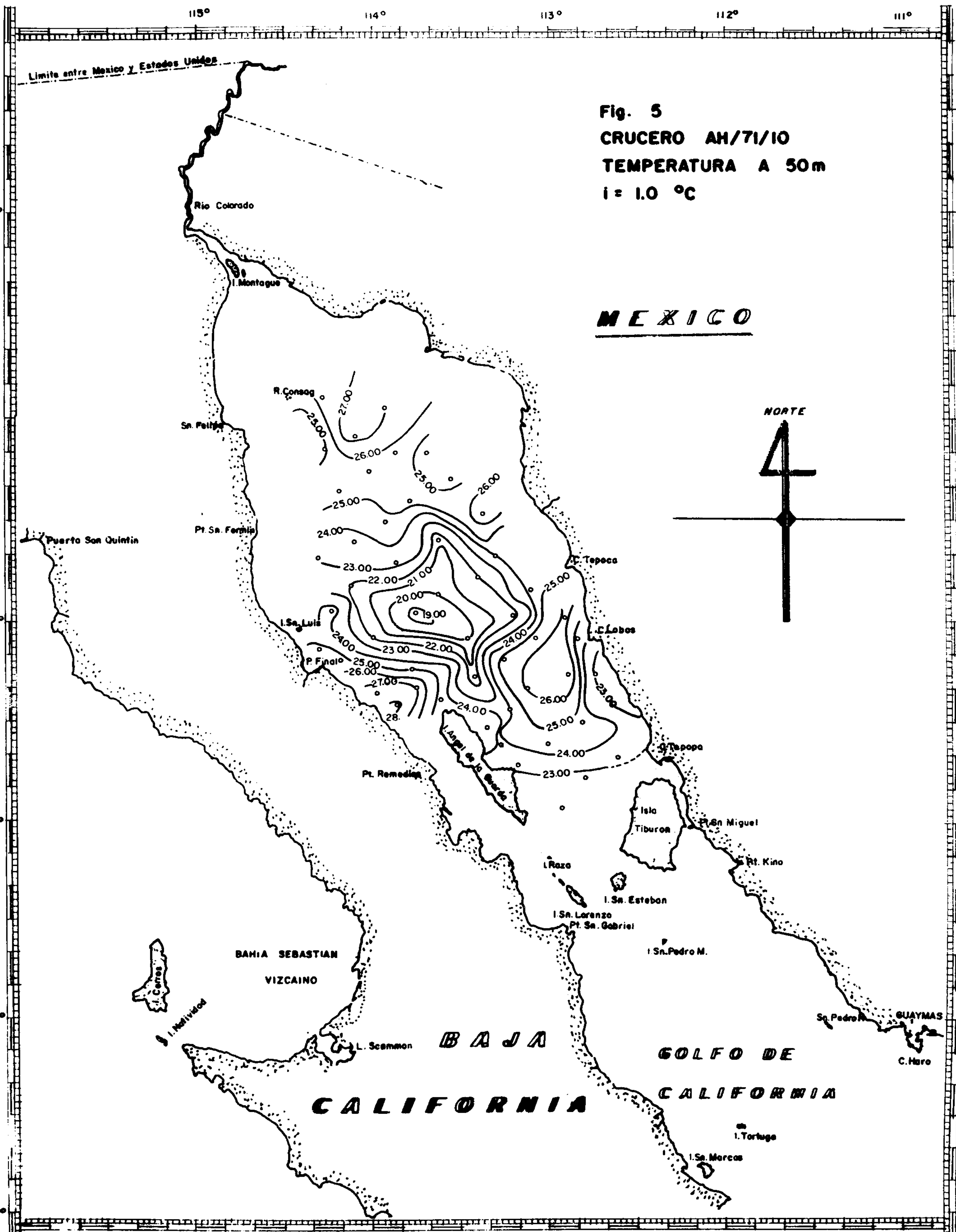

FIGURE 5. Temperature at 50 m. Contour interval 1.0° C

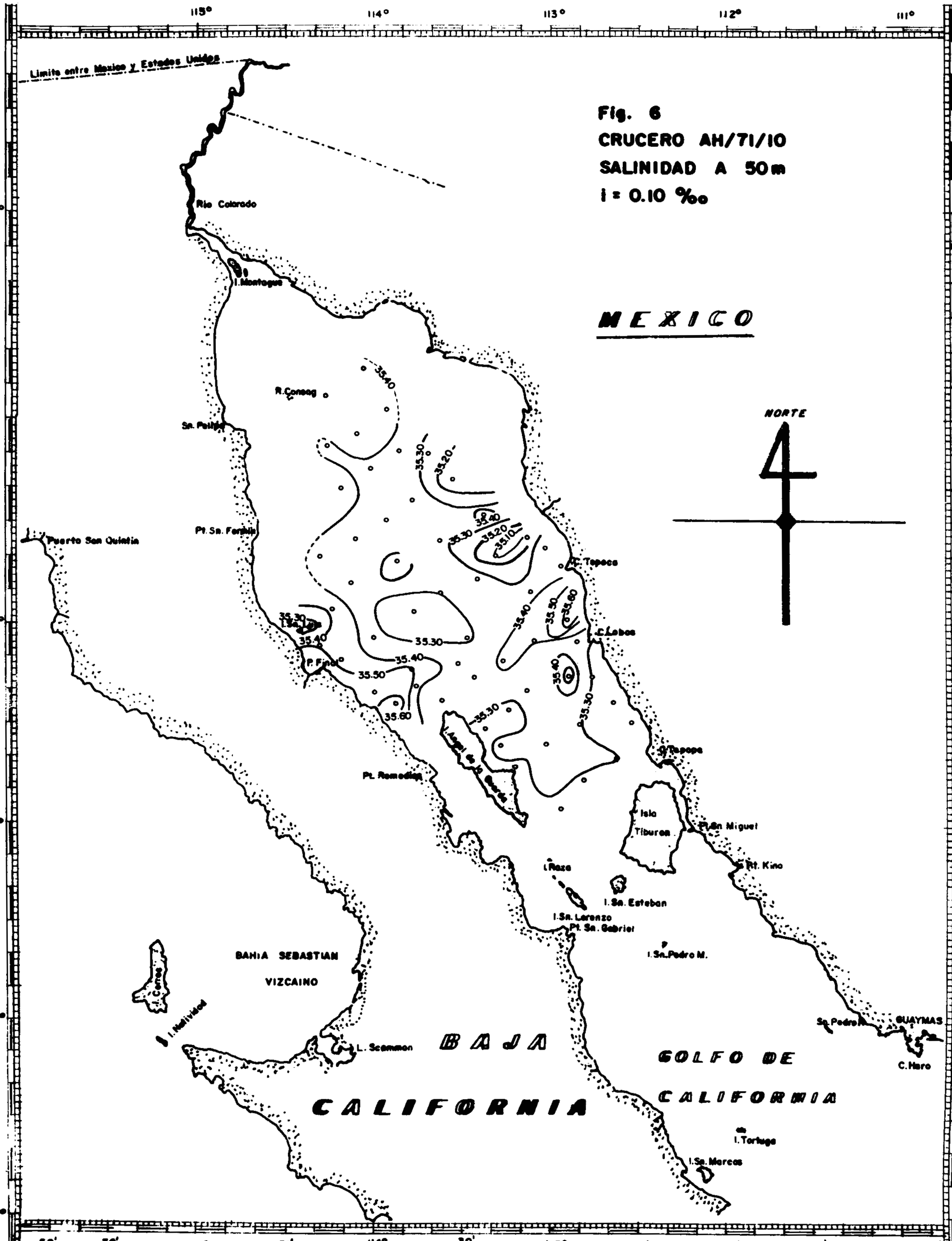

FIGURE 6. Salinity at 50 m. Contour interval 0.10‰

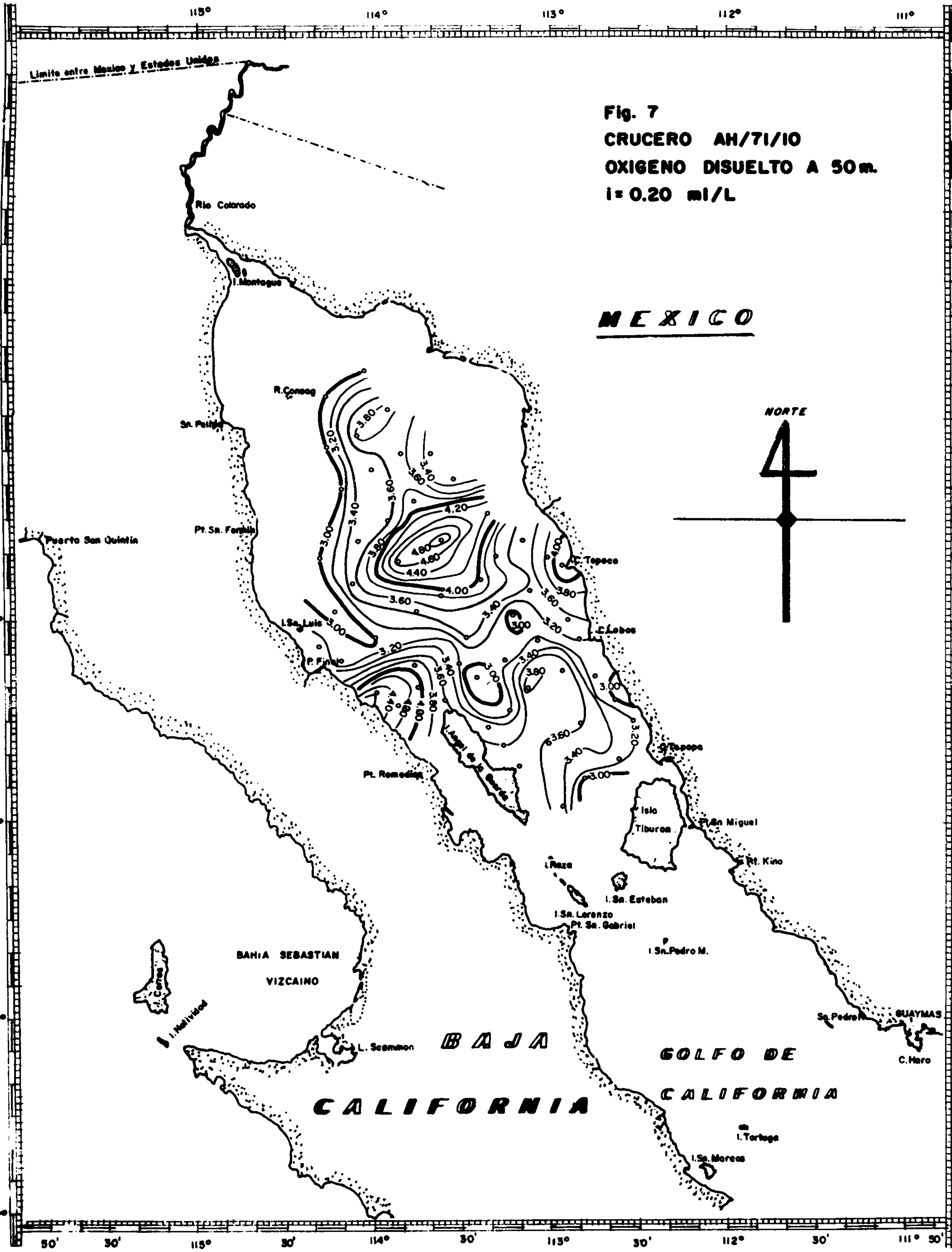

FIGURE 7. Dissolved oxygen at 50 m. Contour interval 0.20 ml/L

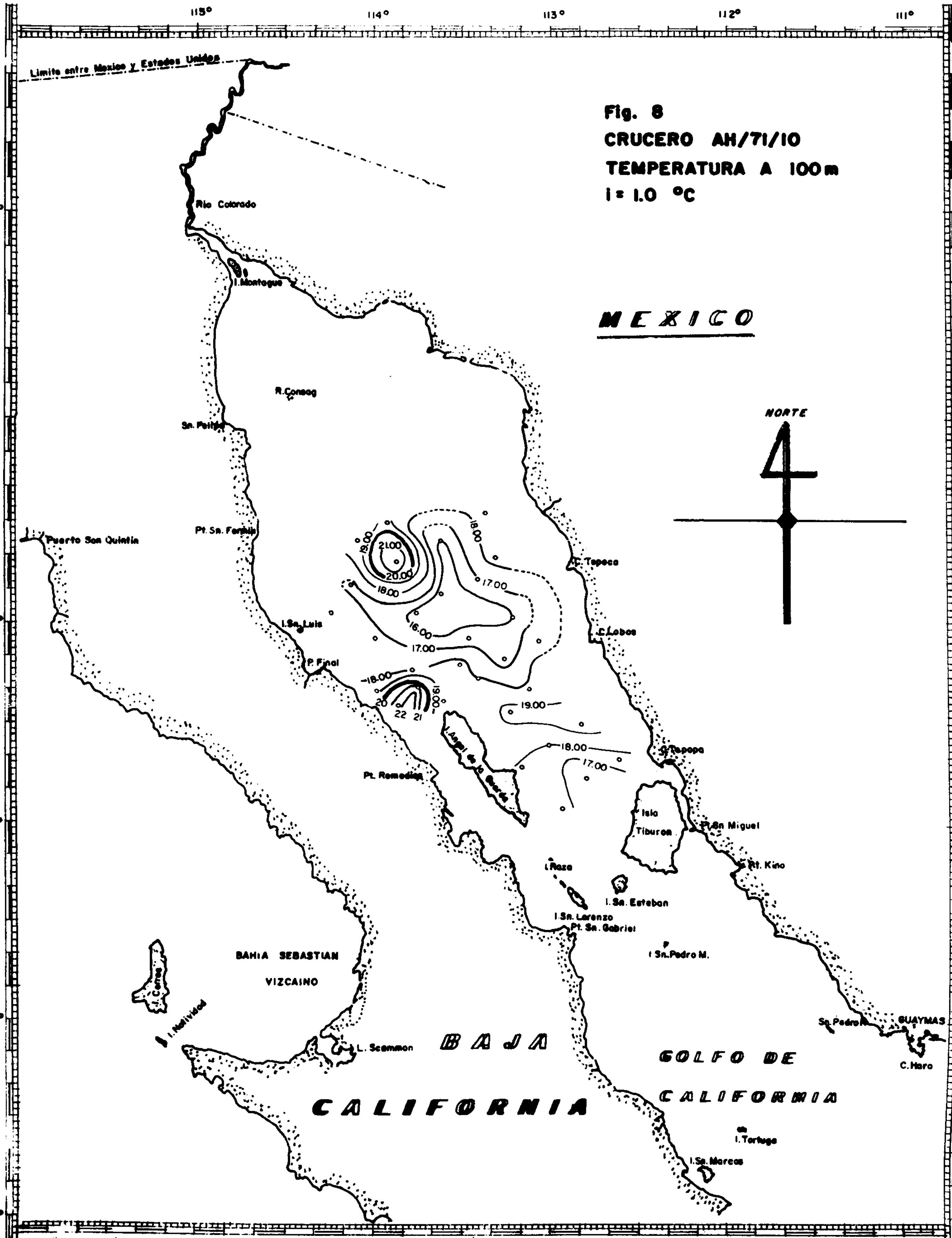

FIGURE 8. Temperature at 100 m. Contour interval 1.0° C

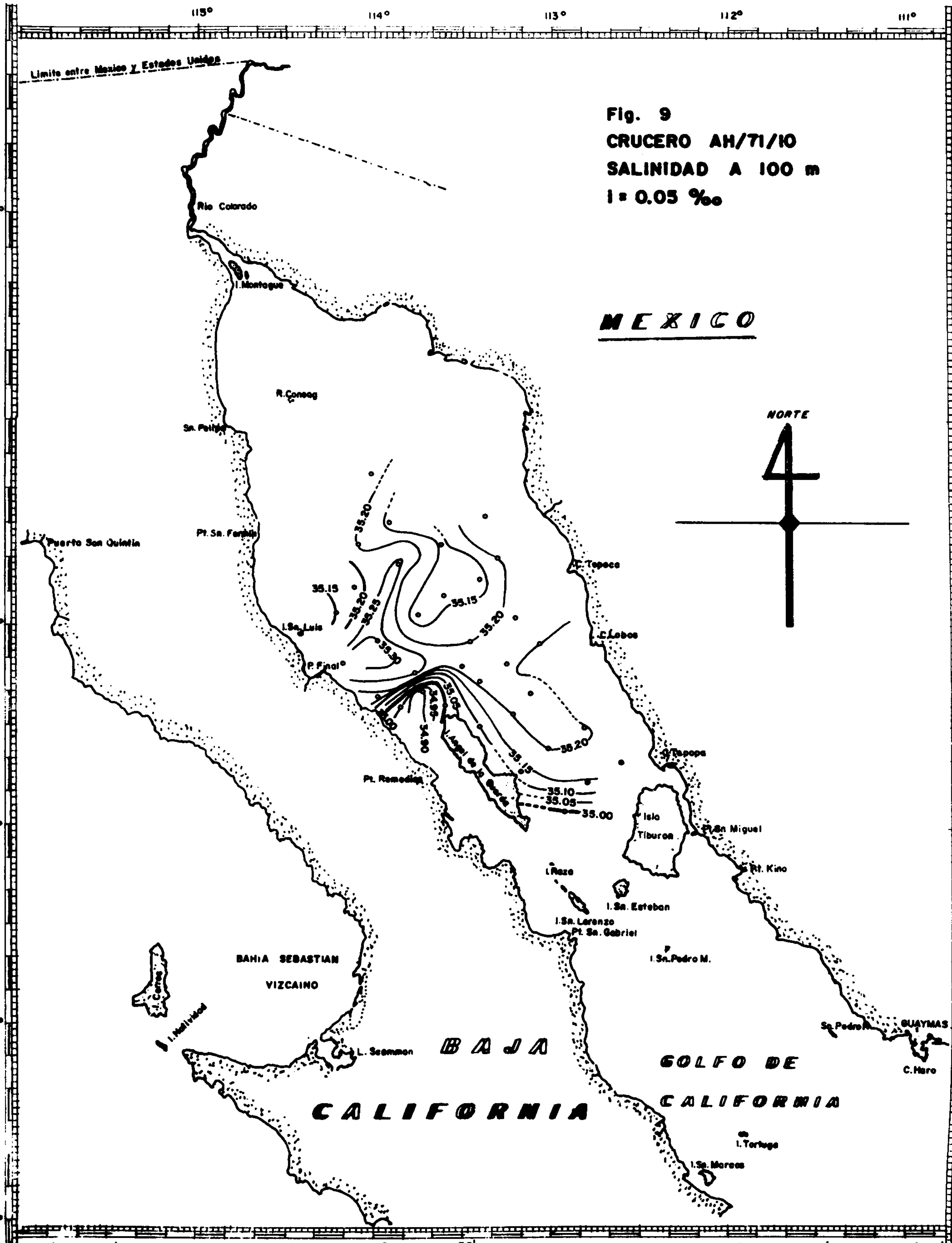

FIGURE 9. Salinity at 100 m. Contour interval 0.05‰

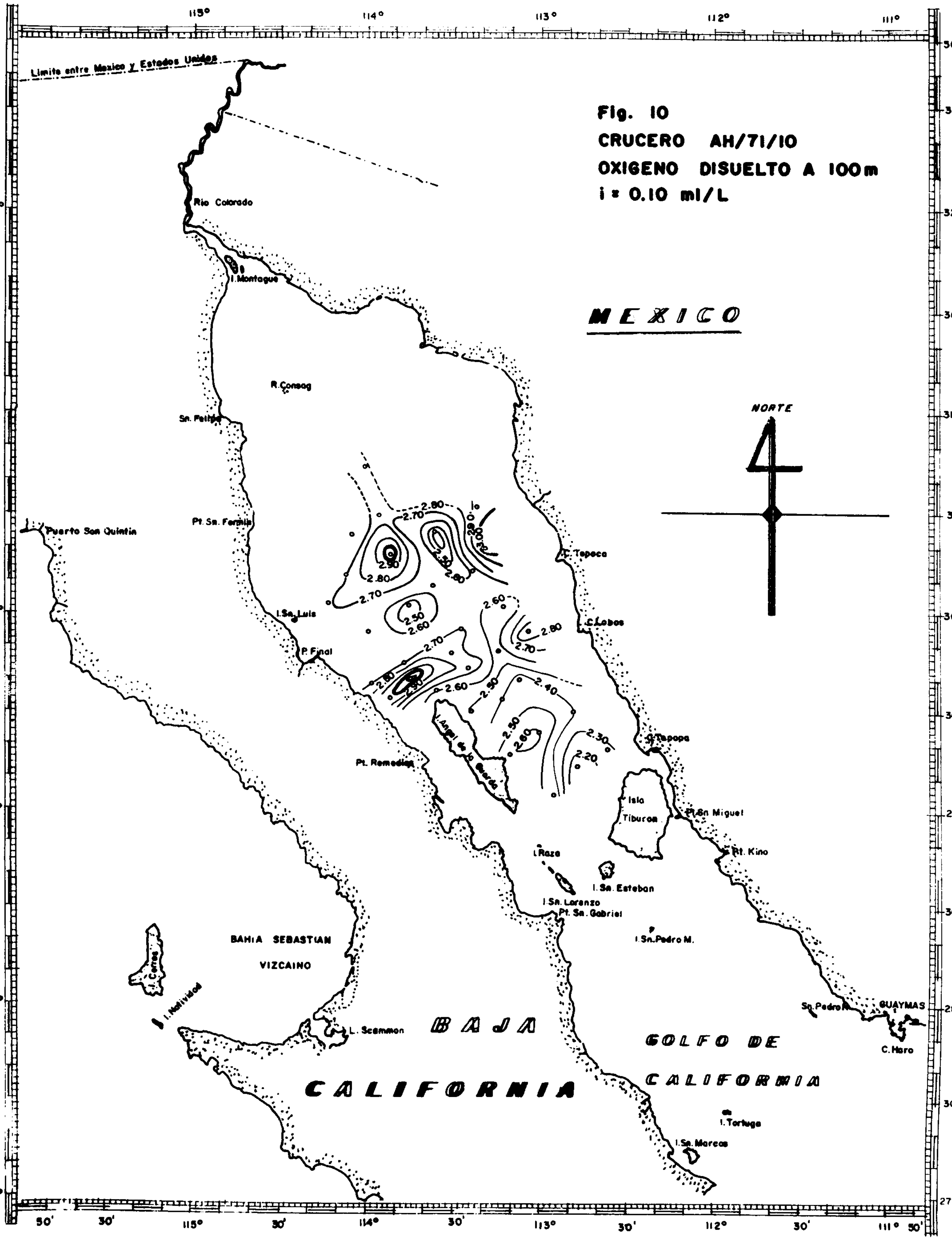

FIGURE 10. Dissolved oxygen at 100 m. Contour interval 0.10 ml/L

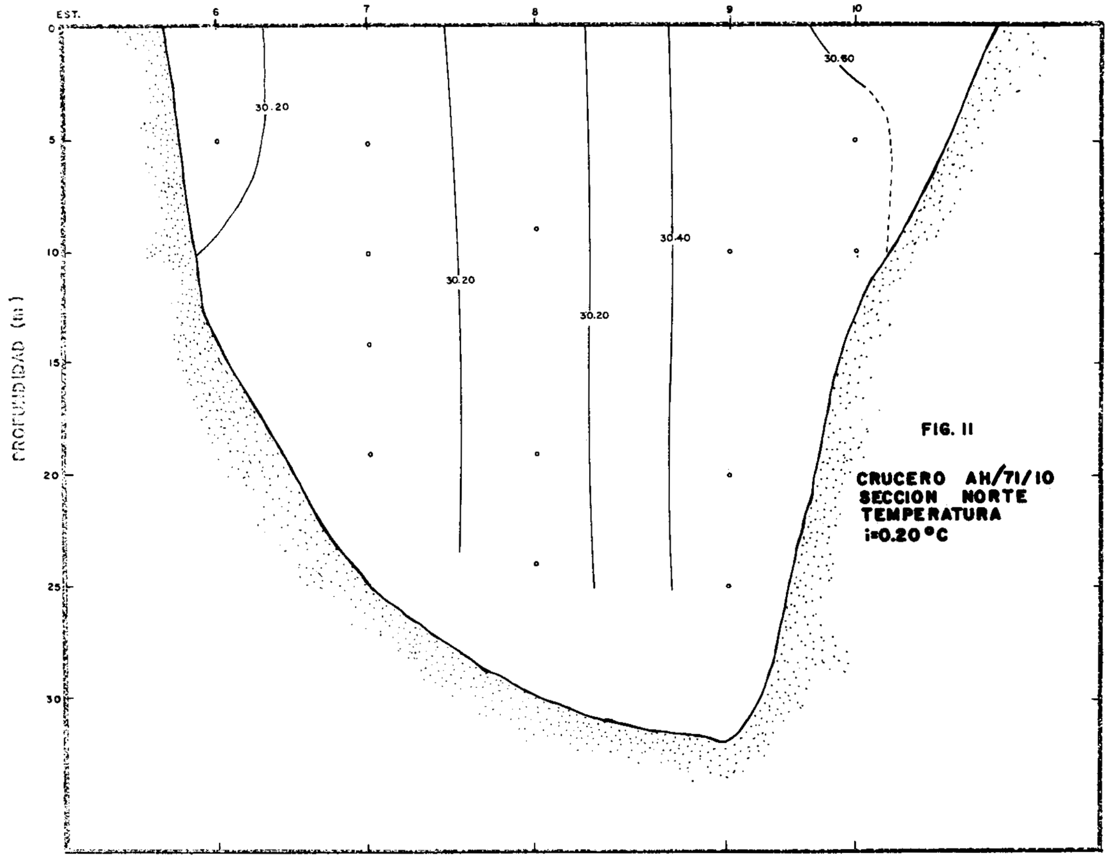

FIGURE 11. Vertical temperature distribution, northern section. Contour interval 0.20° C

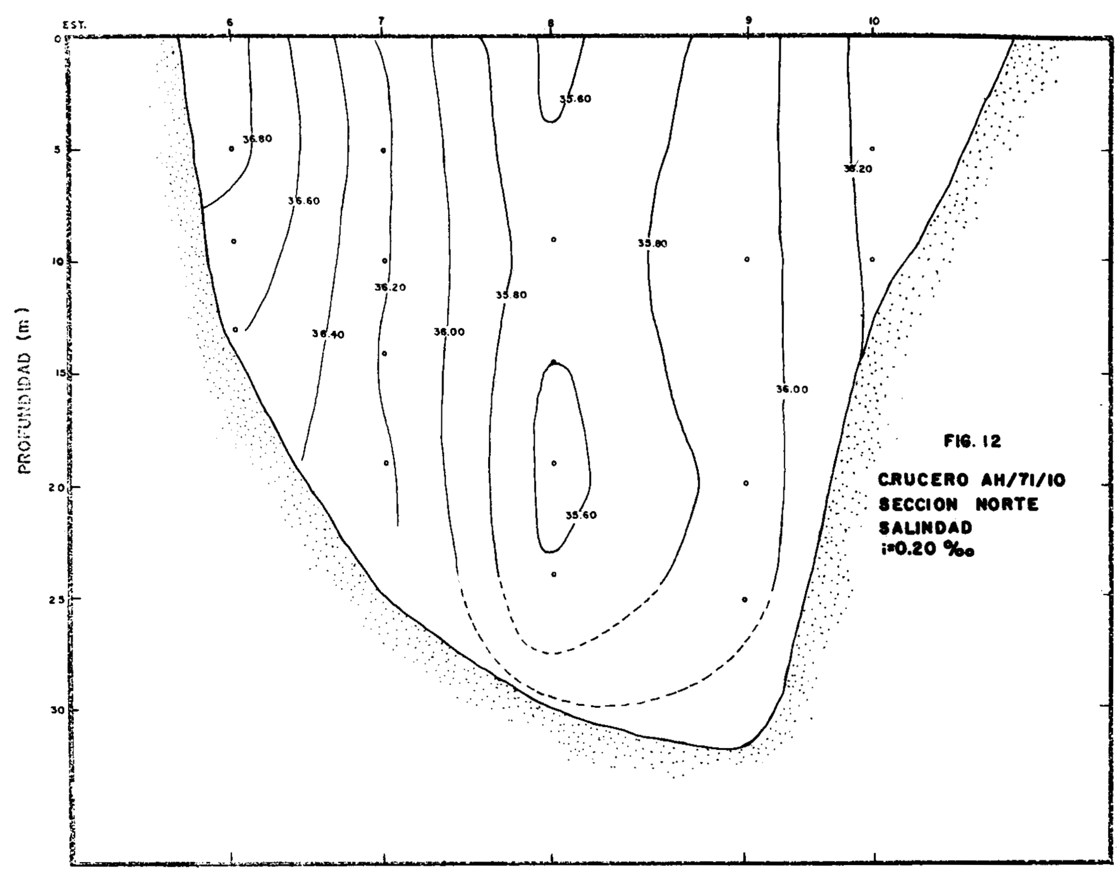

FIGURE 12. Vertical salinity distribution, northern section. Contour interval 0.20‰

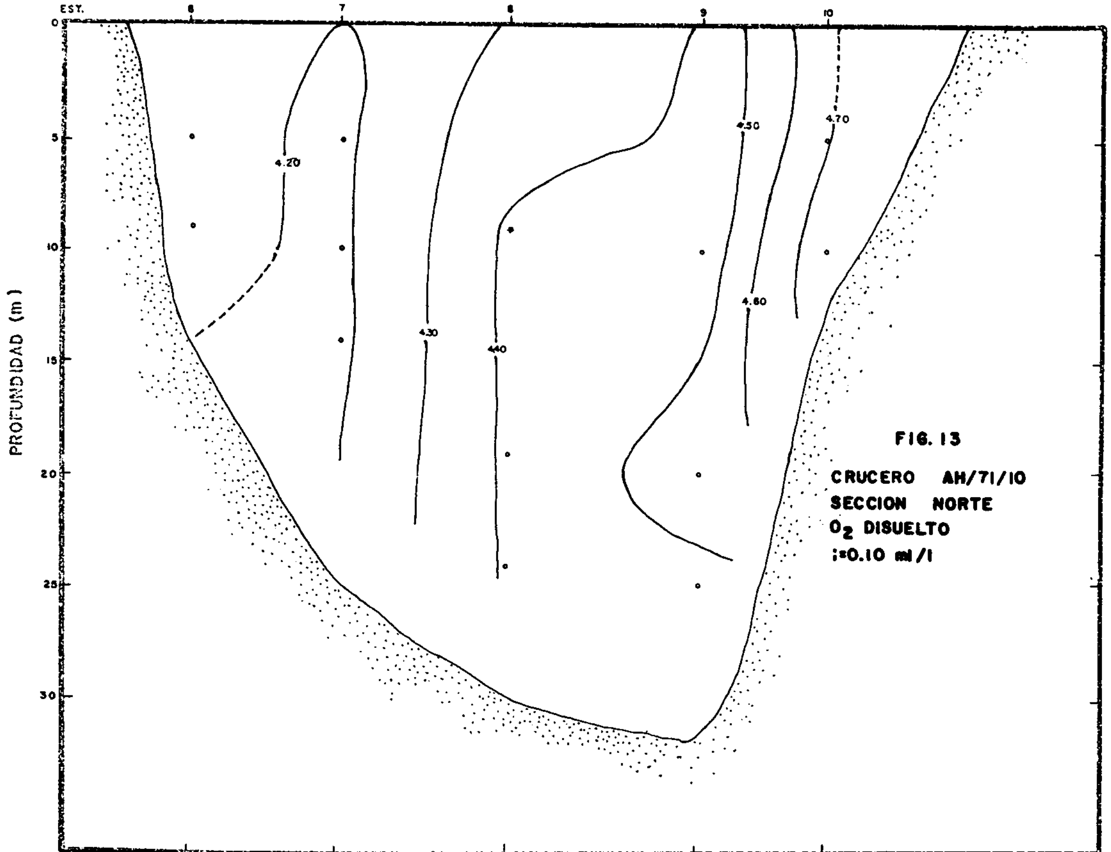

FIGURE 13. Vertical dissolved oxygen distribution, northern section. Contour interval 0.10 ml/L

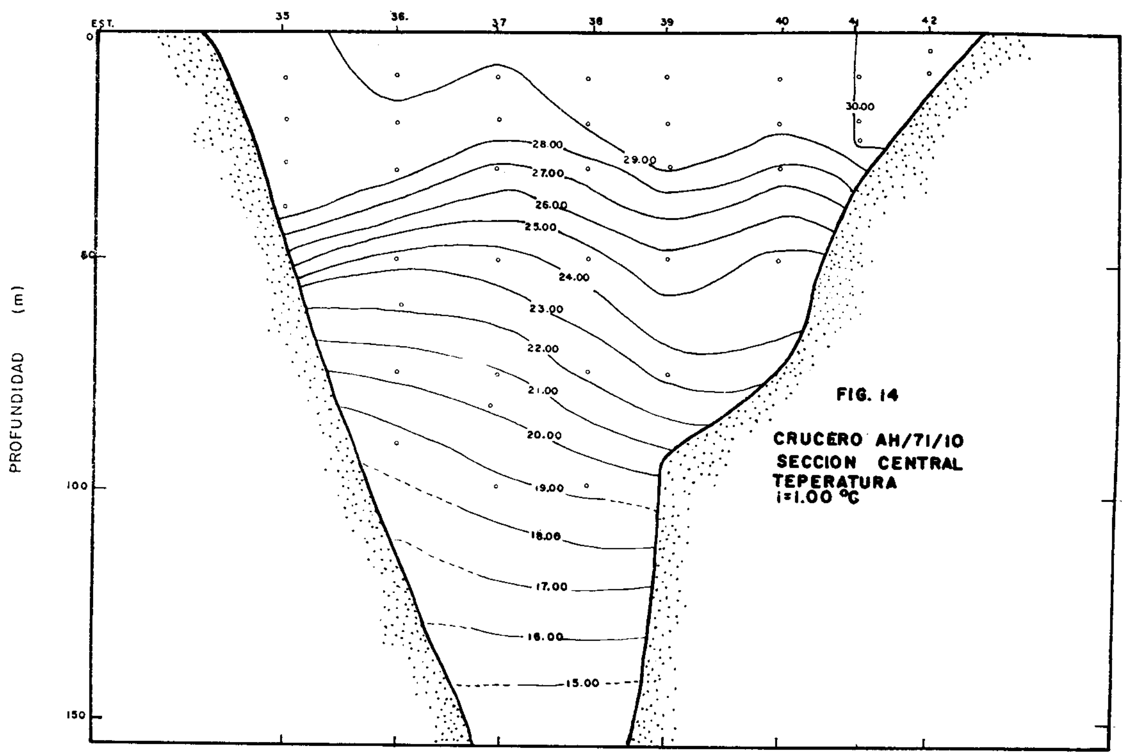

FIGURE 14. Vertical temperature distribution, central section. Contour interval 1.0° C

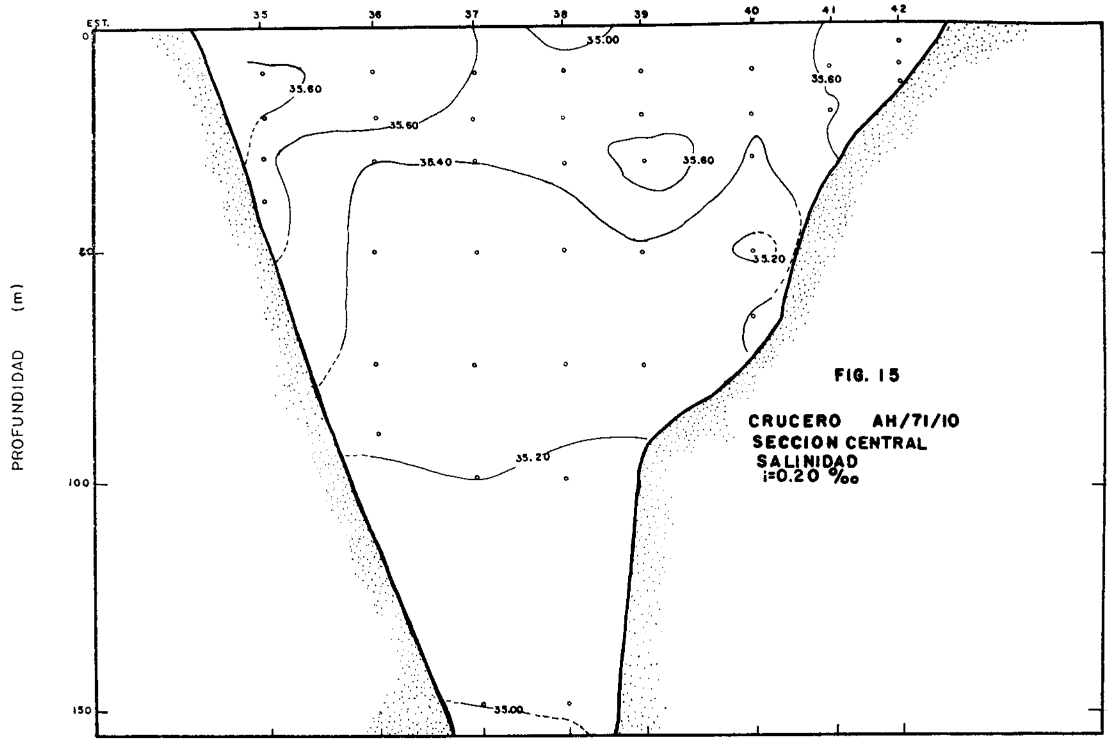

FIGURE 15. Vertical salinity distribution, central section. Contour interval 0.20‰

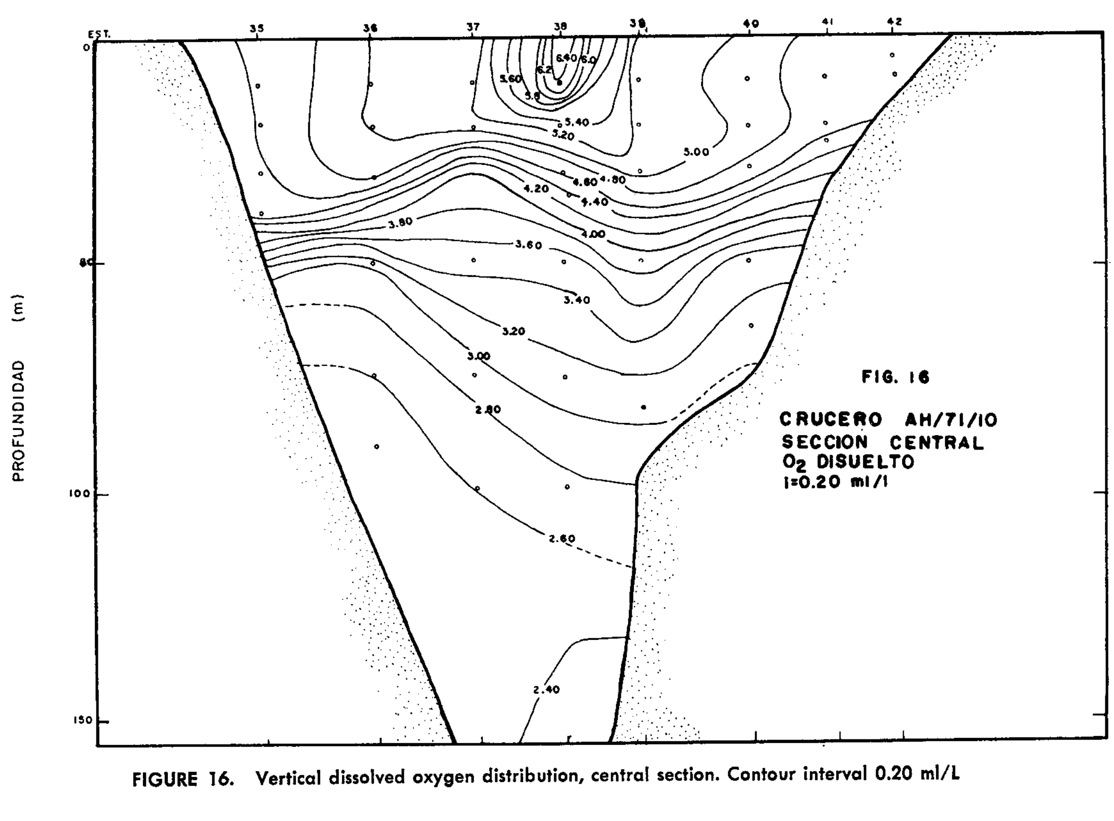

FIGURE 16. Vertical dissolved oxygen distribution, central section. Contour interval 0.20 ml/L

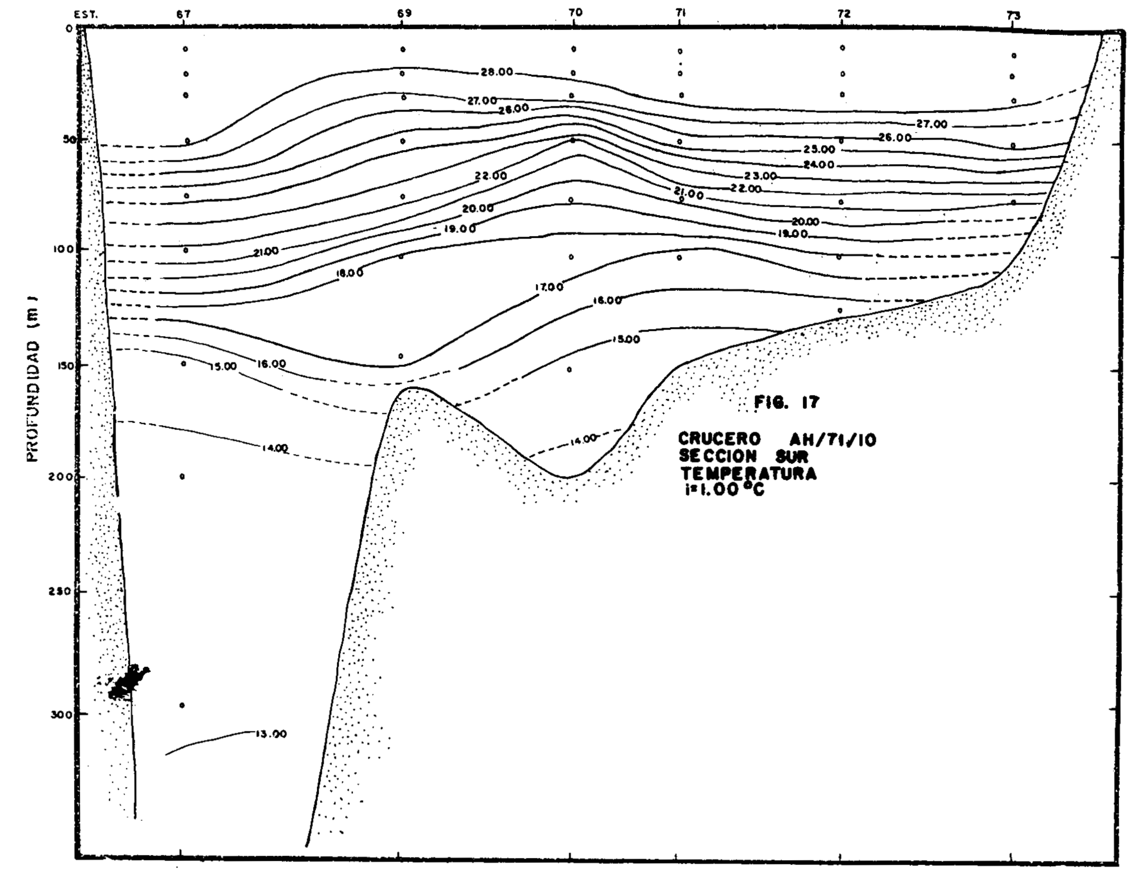

FIGURE 17. Vertical temperature distribution, southern section. Contour interval 1.0° C

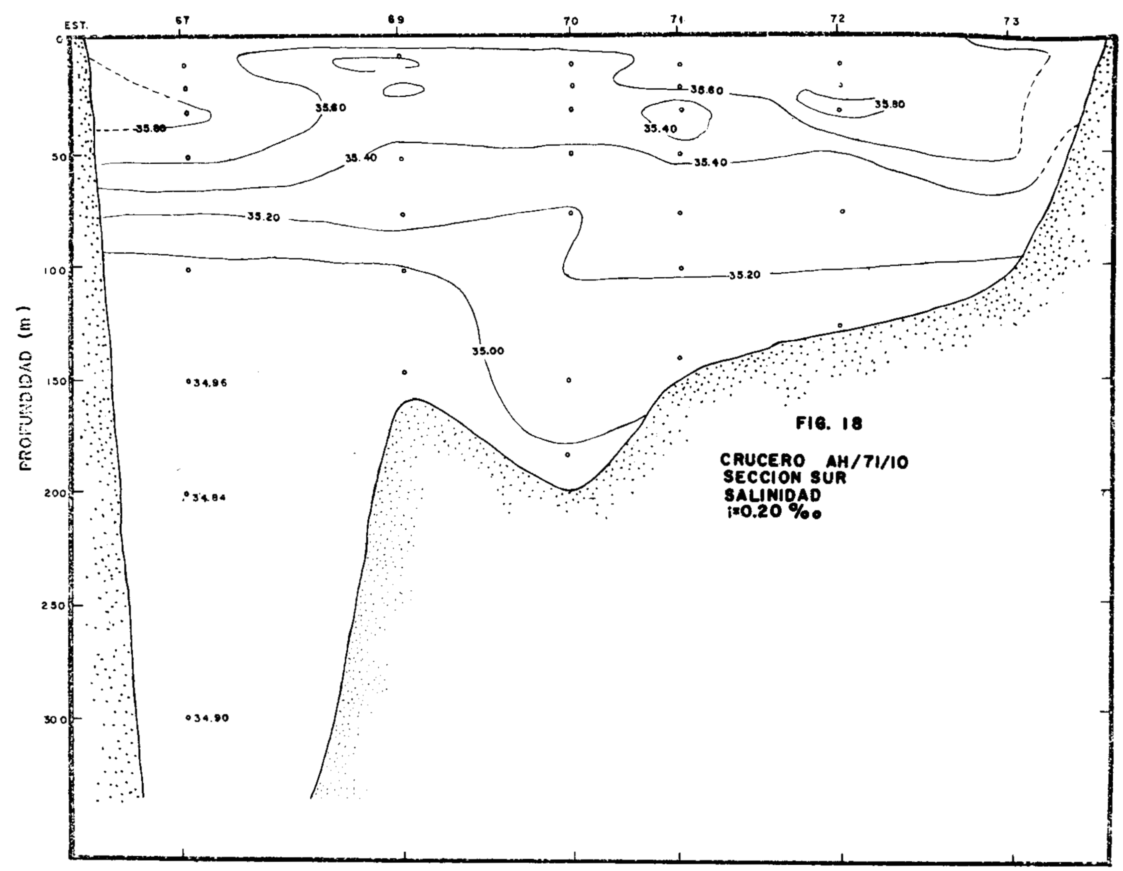

FIGURE 18. Vertical salinity distribution, southern section. Contour interval 0.20‰

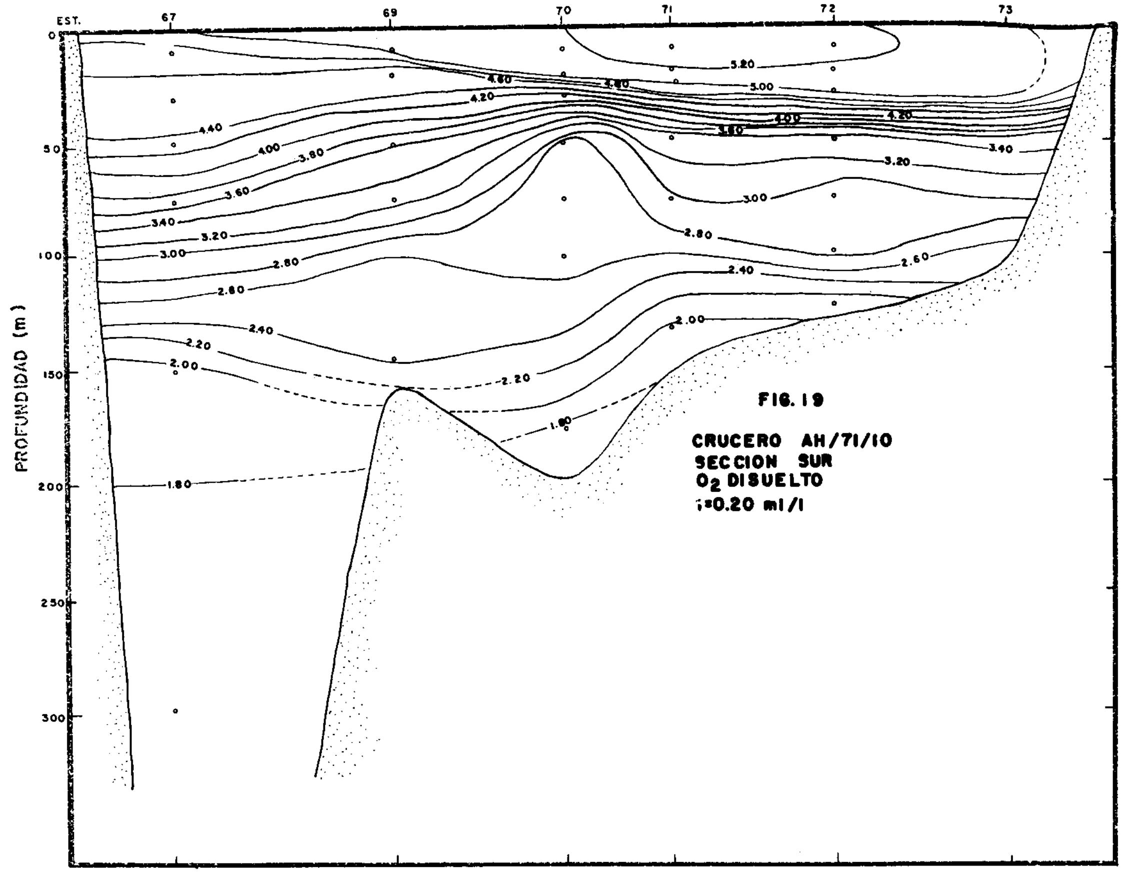

FIGURE 19. Vertical dissolved oxygen distribution, southern section. Contour interval 0.20 ml/L

CRUCEROS DEL JORDAN Y DEL HUMBOLDT EN ENERO Y FEBRERO DE 1972

RICHARD A. SCHWARTZLOSE

y

JOSÉ MA. ROBLES PACHECO

SUMARIO

El JORDAN realizó dos cruceros en enero y febrero de 1972, y el HUMBOLDT un crucero, frente a la costa oeste de Baja California.

Los datos de cada crucero fueron comparados entre sí y con los valores medios del Atlas de CalCOFI.

En la parte norte, la temperatura fue casi un grado centígrado más fría que la normal y en la parte sur fue casi un grado centígrado más caliente. Hubo alguna evidencia de surgencias a lo largo de la costa norte de Baja California.

INTRODUCCIÓN

En enero y febrero de 1972, se llevaron a cabo tres cruceros de CalCOFI frente a la Costa Occidental de Baja California por el JORDAN, el HUMBOLDT y JORDAN en ese orden. EL ALEJANDRO DE HUMBOLDT es uno de los barcos oceanográficos del INP. Está equipado para llevar a cabo el tipo normal de colecta de datos de CalCOFI, tales como mediciones oceanográficas, físicas y químicas y varios tipos de arrastre de plancton, además de arrastres de pesca de fondo y de media agua. Los datos colectados en los tres cruceros fueron del tipo estándar de CalCOFI. El principal propósito de estos cruceros estrechamente espaciados entre sí, fue colectar datos comparativos, casi coincidentes en tiempo para intercalibración y observar los cambios que están ocurriendo en los parámetros oceanográficos, la cantidad de desove de la merluza, anchoveta y sardina y el entrenamiento del personal en estos tres cruceros.

El primer crucero del JORDAN comprendió la zona de San Diego, Calif., a Cabo San Lázaro, B.C. Durante el crucero del HUMBOLDT se recorrió la zona comprendida de Punta Abreojos, B.C., a Mazatlán, Sin., y el segundo crucero del JORDAN, se desarrolló en toda la extensión de la costa oeste de Baja California, hasta Mazatlán, Sin.

TEMPERATURA A 10 METROS (Figuras 1–3)

Las gráficas muestran la distribución horizontal de la temperatura (°C) a 10 metros de profundidad para cada crucero (JORDAN-HUMBOLDT-JORDAN). El intervalo entre los contornos es de un grado centígrado. En el primer crucero del JORDAN se observa una diferencia de aproximadamente 7.0°C entre Ensenada y Cabo San Lázaro. Las gráficas de los siguientes cruceros del HUMBOLDT y del JORDAN muestran que estas condiciones no se alteran notoriamente durante el mes de febrero. Comparando estas dos últimas gráficas, tampoco se pueden notar diferencias significantes en la zona comprendida de Cabo San Lázaro a Mazatlán, Sin., entre los datos del HUMBOLDT y del JORDAN.

En relación con los valores medios de temperatura del Atlas CalCOFI, en la parte norte de Baja California se observan aguas aproximadamente 1°C más frías, mientras que en la parte sur aparecen aguas más calientes, también con una diferencia de 1°C. En la región costera comprendida desde Ensenada a El Rosario, B.C., se presentan aguas relativamente más frías, probablemente relacionadas con surgencias.

SALINIDAD A 10 METROS (Figuras 4–6)

Básicamente no hay diferencias de la salinidad entre los datos de los tres cruceros JORDAN-HUMBOLDT-JORDAN. Con respecto a los valores medios, se nota que en la parte norte de Baja California tampoco existen diferencias notorias, mientras que en la parte sur nuestros valores son ligeramente mayores, motivados por movimientos de agua de sur a norte.

CORRIENTES SUPERFICIALES (Figuras 7–9)

Los cálculos dinámicos muestran a la Corriente de California como un flujo de norte a sur paralelo a la costa, extendiéndose hasta el extremo sur de Baja California, donde aparecen algunos giros. Parece existir un flujo de agua del Golfo de California hacia el sur, a través de la boca del Golfo.

PROFUNDIDAD DE LA CAPA DE MEZCLA (Figura 10)

Los datos sobre profundidad de la capa de mezcla del crucero del HUMBOLDT, no pueden ser comparados con datos del Atlas CalCOFI por no existir suficiente información en este Atlas.

Un rasgo importante de esta gráfica es la presencia de una capa de mezcla de 30 m de espesor, aproximadamente a 200 millas náuticas frente a la costa del extremo sur de Baja California, donde debería esperarse un espesor de 70 metros en la capa de mezcla.

TEMPERATURA A 150 METROS (Figuras 11–13)

La distribución de la temperatura en los tres cruceros es muy semejante a la que se observa en el Atlas CalCOFI a la misma profundidad.

Comparando el crucero del HUMBOLDT con el segundo del JORDAN, aparecen en febrero dos lenguas de agua 1.0°C, más caliente que empuja hacia la costa en el sur de Baja California.

SALINIDAD A 150 METROS (Figuras 14–16)

La salinidad determinada en los tres cruceros, no muestra diferencias entre uno con otro, ni tampoco con los datos del Atlas de CalCOFI.

TEMPERATURA A 400 METROS (Figuras 17–19)

La temperatura de los cruceros de enero y febrero del JORDAN en la parte norte de Baja California es casi la misma; pero en el sur de Baja California, aproximadamente a 200 millas de la costa, aparece una saliente de agua aproximadamente 0.5°C más caliente en febrero, empujando hacia la costa, como también se notó en los datos observados a la profundidad de 150 metros.

SALINIDAD A 400 METROS (Figuras 20–22)

La salinidad a esta profundidad no muestra diferencias entre los tres cruceros, variando de 34.10‰ frente al extremo norte de Baja California a 34.60‰ en la parte sur. Como se observó en el caso de la temperatura, para la salinidad también aparecen en febrero (crucero del HUMBOLDT y segundo del JORDAN) dos lenguas de agua de 34.5 partes por mil entrando hacia la costa en el extremo sur de Baja California.

CONCLUSIONES

Los tres cruceros sólo presentaron condiciones muy poco diferentes a las típicas de la Corriente de California. Frente a la parte norte de Baja California, el agua es 1°C más fría mientras que en la parte sur, es 1°C más caliente que las condiciones medias de la Corriente de California.

Se observaron evidencias de surgencias cerca de la costa en el extremo norte de Baja California.

Las corrientes superficiales corresponden a los rasgos típicos de la Córriente de California, con algunos giros frente al extremo sur de la Península. A través de la boca del Golfo de California parece existir un flujo de agua hacia el sur.

Se considera que el trabajo cooperativo del Programa INP-CalCOFI, ha reunido información oceanográfica utilizable y que es conveniente para ambas Instituciones continuar con este tipo de trabajo.

SUMMARY

In January and February 1972 JORDAN executed two cruises off the west coast of Baja California and HUMBOLDT executed one cruise in the same area.

The data on these cruises were intercompared and compared with the average values in the *CalCOFI Atlas*.

In the northern part of the area the ten meter temperatures were almost one degree lower than the mean, and in the southern part almost one degree higher. There was evidence of upwelling along the coast of northern Baja California.

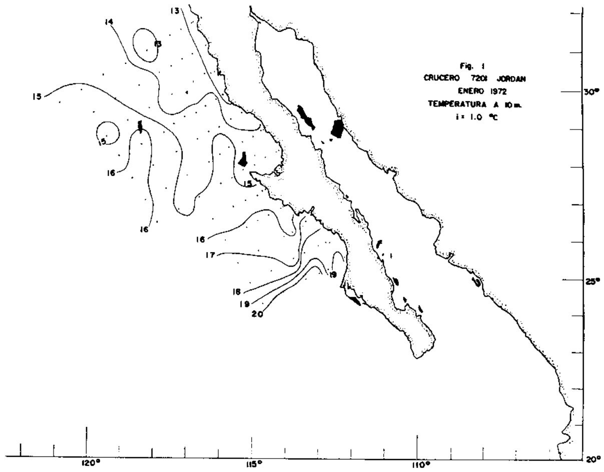

FIGURE 1. JORDAN, January Temperature at 10 m. Contour interval 1.0° C.

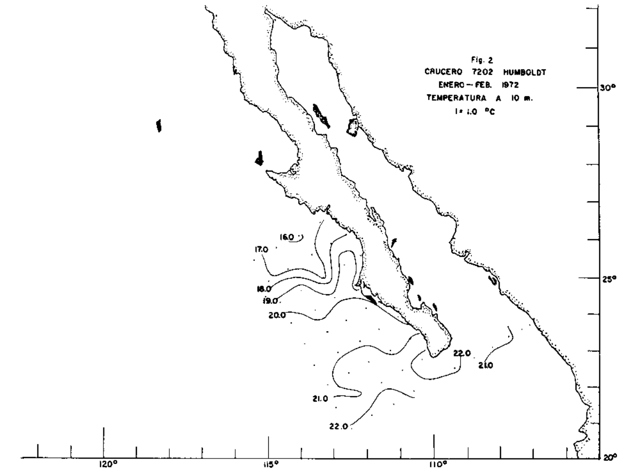

FIGURE 2. HUMBOLDT, Jan–Feb Temperature at 10 m. Contour interval 1.0° C.

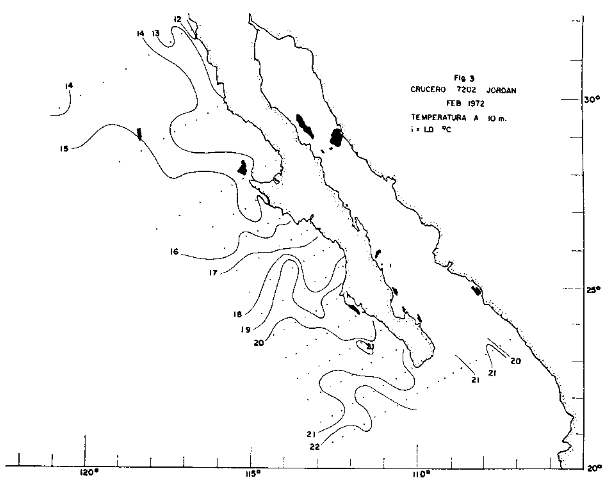

FIGURE 3. JORDAN, February Temperature at 10 m. Contour interval 1.0° C.

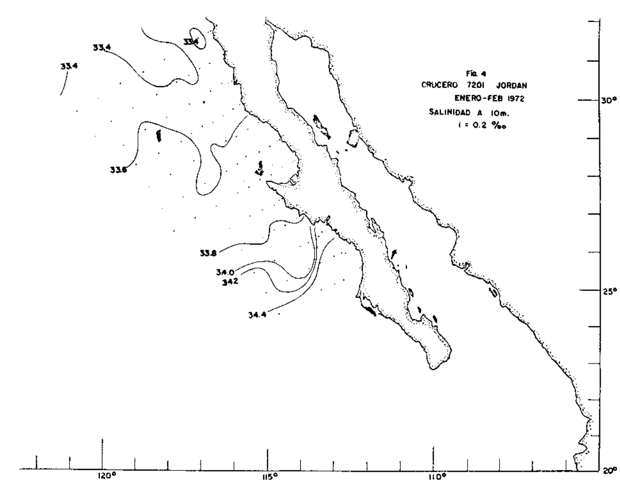

FIGURE 4. JORDAN, Jan–Feb Salinity 10 m. Contour interval 0.2‰.

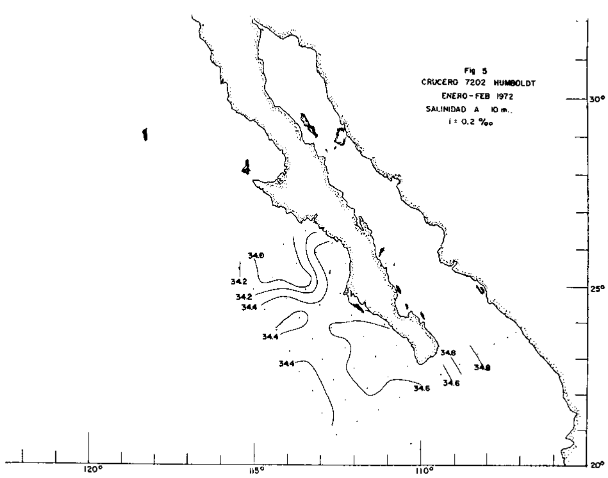

FIGURE 5. HUMBOLDT, Jan–Feb Salinity 10 m. Contour interval 0.2‰

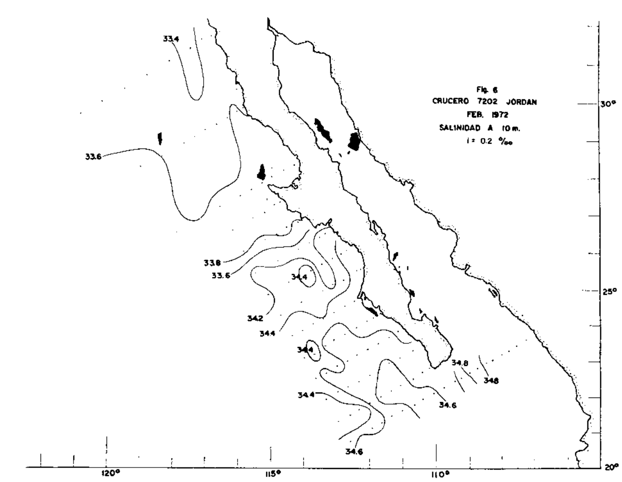

FIGURE 6. JORDAN, February Salinity 10 m. Geopotential topography. Contour interval 0.20‰.

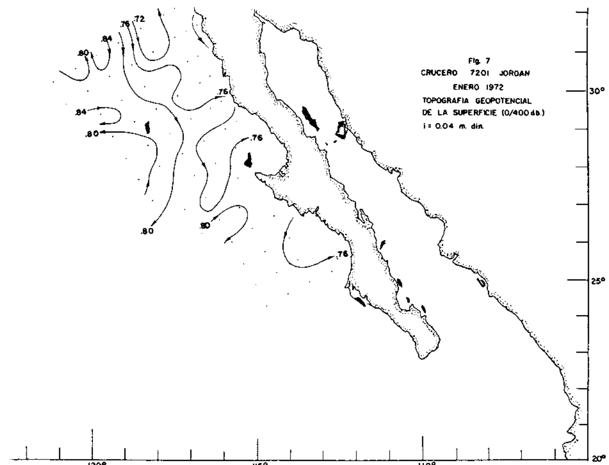

FIGURE 7. JORDAN, January 0/400 decibars, Geopotential topography. Contour interval 0.04 dyn. m.

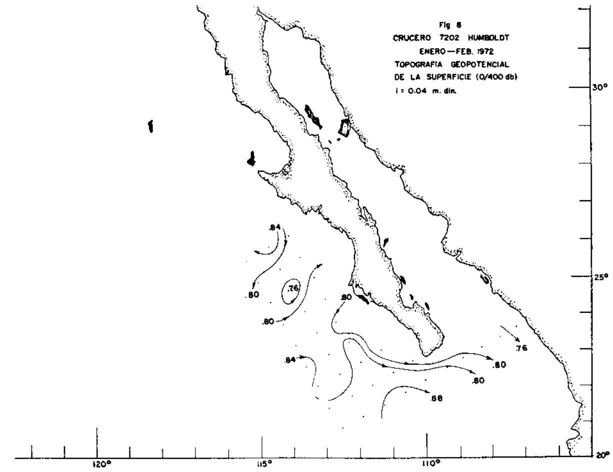

FIGURE 8. HUMBOLDT, Jan–Feb 0/400 decibars, Geopotential topography. Contour interval 0.04 dyn. m.

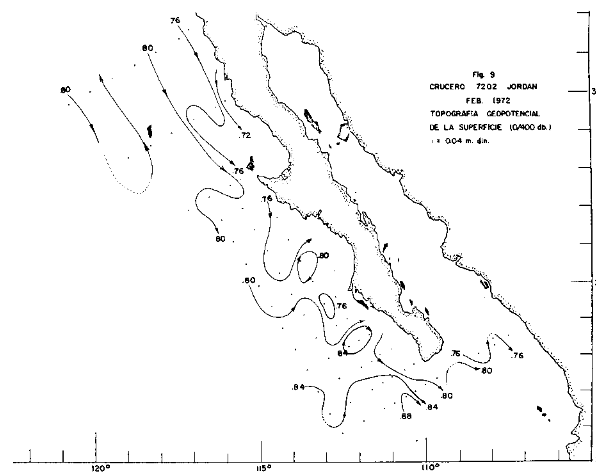

FIGURE 9. JORDAN, February 0/400 decibars. Contour interval 0.04 dyn. m.

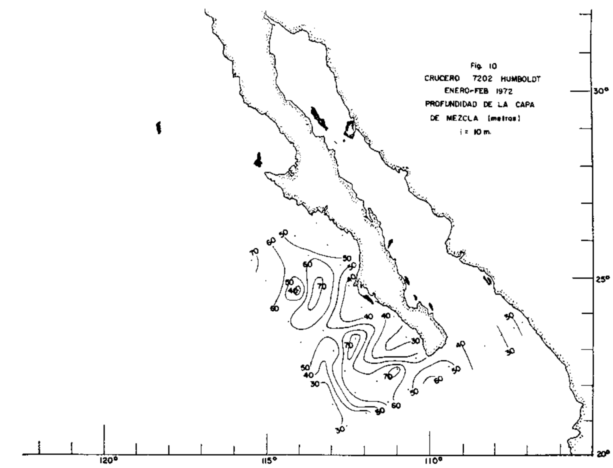

FIGURE 10. HUMBOLDT, Jan–Feb Depth of the mixed layer. Contour interval 10 m.

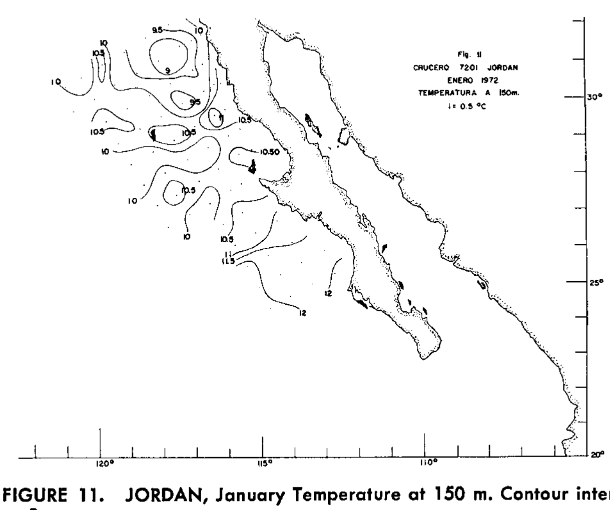

FIGURE 11. JORDAN, January Temperature at 150 m. Contour interval 0.5° C.

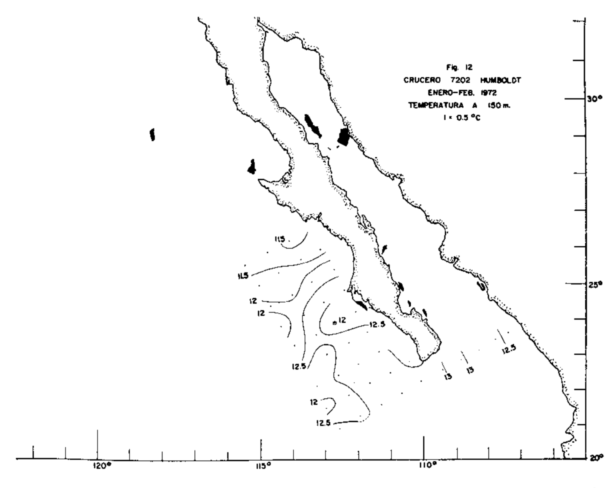

FIGURE 12. HUMBOLDT, Jan–Feb Temperature at 150 m. Contour interval 0.5° C.

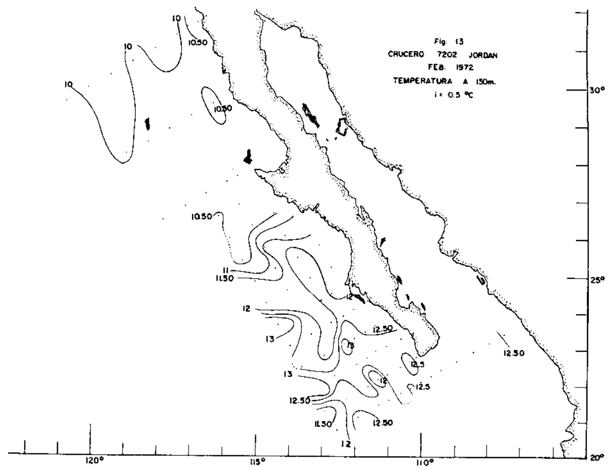

FIGURE 13. JORDAN, February Temperature at 150 m. Contour interval 0.5° C.

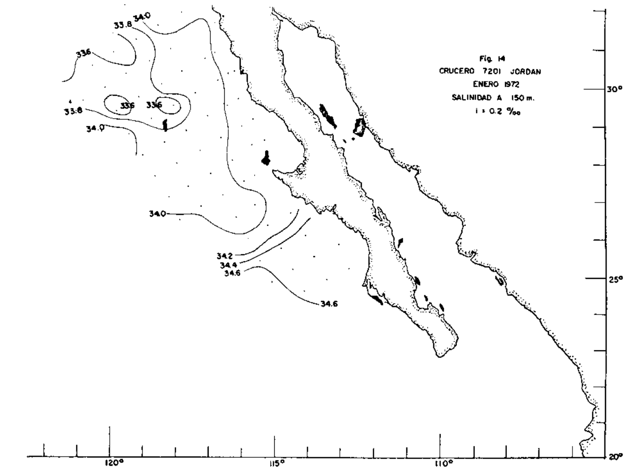

FIGURE 14. JORDAN, January Salinity at 150 m. Contour interval 0.2‰.

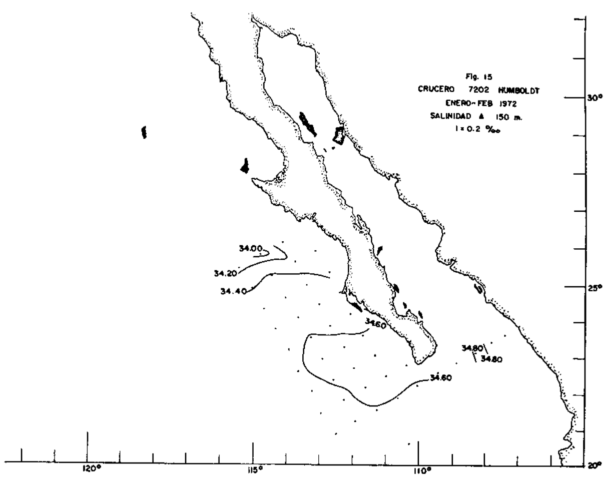

FIGURE 15. HUMBOLDT, Jan–Feb Salinity at 150 m. Contour interval 0.2‰.

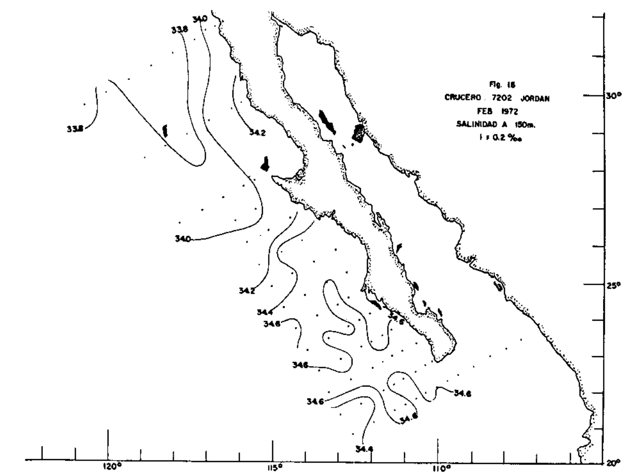

FIGURE 16. JORDAN, February Salinity at 150 m. Contour interval 0.2‰.

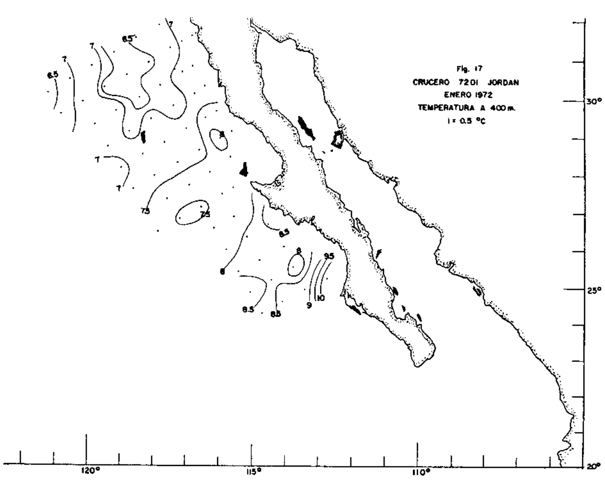

FIGURE 17. JORDAN, January Temperature at 400 m. Contour interval 0.5° C.

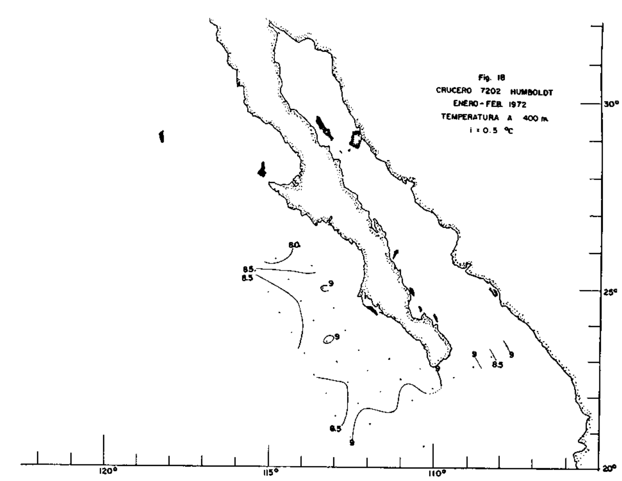

FIGURE 18. HUMBOLDT, Jan–Feb. Temperature at 400 m. Contour interval 0.5° C.

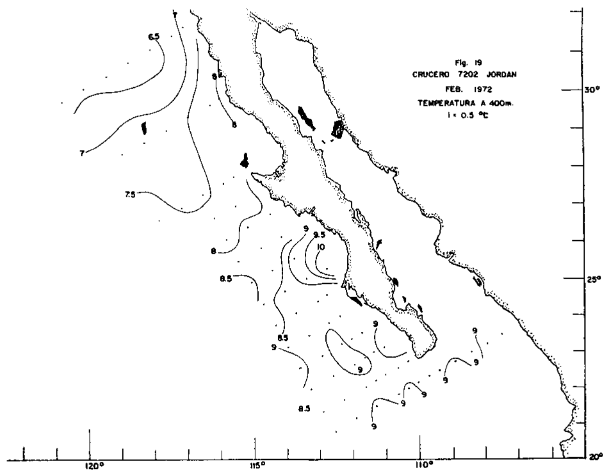

FIGURE 19. JORDAN, February Temperature at 400 m. Contour interval 0.5° C.

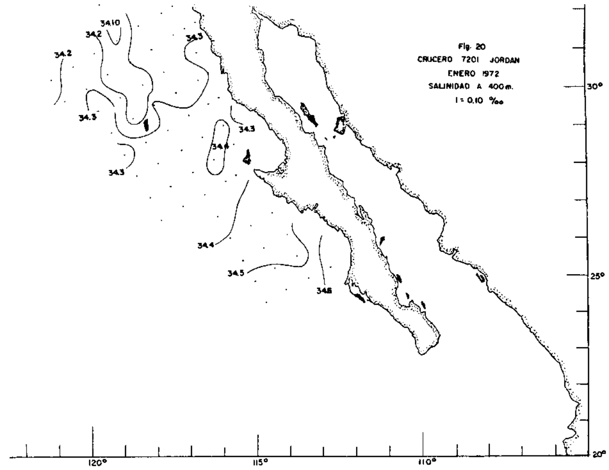

FIGURE 20. JORDAN, January Salinity at 400 m. Contour interval 0.10‰.

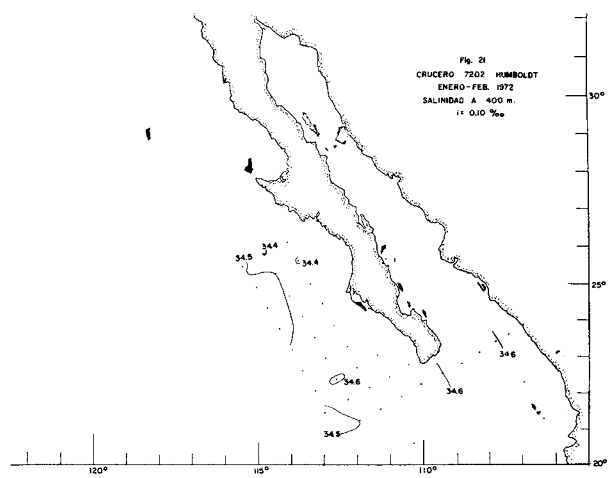

FIGURE 21. HUMBOLDT, Jan–Feb Salinity at 400 m. Contour interval 0.10‰.

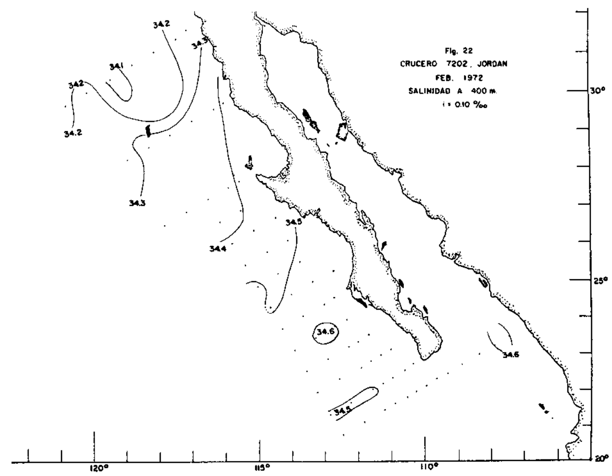

FIGURE 22. JORDAN, February Salinity at 400 m. Contour interval 0.10‰.

INVESTIGACIONES BIOLÓGICO PESQUERAS DE LOS PECES PELAGICOS DEL GOLFO DE CALIFORNIA

(Sardina monterrey)

DR. V. A. SOKOLOV
All-Union Research Institute of Marine Fisheries and Oceanography
17, Krasnoselskaya
Moscow B-140, USSR

Dentro de los planes de estudio y programas pesqueros México/PNUD/FAO, desde mediados de 1970 se iniciaron las investigaciones sistemáticas de los peces pelágicos del Golfo de California, con el fin de conocer las perspectivas del desarrollo de su pesca masiva.

Para esto, se integró un grupo científico compuesto por cinco personas, teniendo además a disposición el barco de investigación ANTONIO ALZATE, equipado con aparatos hidroacústicos de acción vertical y horizontal y con diferentes artes de pesca, incluyendo una red de cerco.

La tarea primordial de las investigaciones, fue descubrir la distribución general de la sardina monterrey, *Sardinops caerulea,* dentro de los límites del Golfo de California. Con este fin, los cruceros científicos se planearon de tal manera, que las observaciones incluyeran toda la plataforma continental (Figuras 1 y 2). Junto con la búsqueda, se efectuaron también capturas de control, que daban la oportunidad de establecer la composición por especies de los peces cuyos cardúmenes se registraron y obtener sus características biológicas. Además de los trabajos de búsqueda, durante el período indicado, se efectuaron en el Golfo de California dos levantamientos ictioplanctónicos, cada uno de los cuales abrazaba la mayor parte de la superficie del Golfo y cubría prácticamente todas las áreas de desove de la sardina.

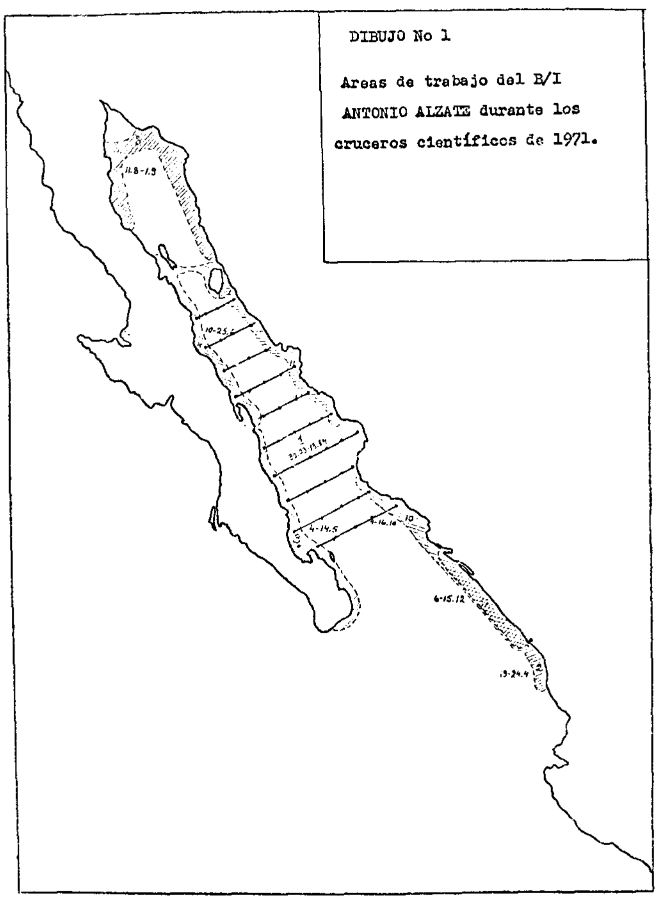

FIGURE 1. Areas of operations of R/V ANTONIO ALZATE during the 1971 scientific cruises. Dates of cruises are shown by first and last days, e.g. 11.8–1.9 is read "from 11 August to 1 September".

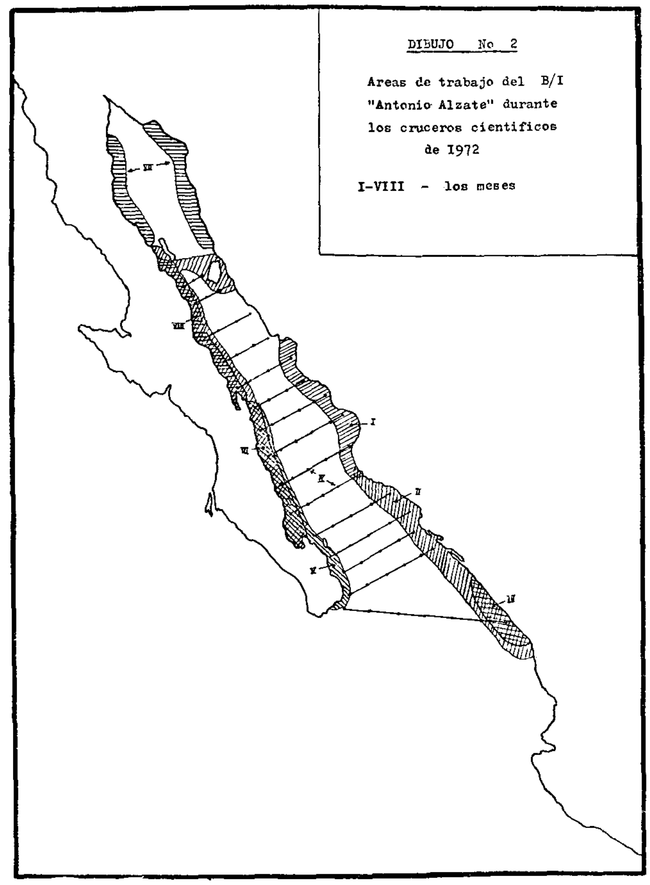

FIGURE 2. Areas of operations of R/V ANTONIO ALZATE during the 1972 scientific cruises. Numerals indicate months.

Los principales resultados obtenidos durante el cumplimiento de los trabajos mencionados en sus lineamientos generales, se mencionan a continuación.

Las observaciones de 1971–1972, mostraron que la sardina inmadura se encuentra solamente a lo largo de la costa occidental del Golfo en las aguas costeras, partiendo desde la Bahía de la Ventana hasta las Bahías de Las Ánimas de Los Ángeles (Figuras 3 y 4).

Los mismos trabajos de búsqueda permitieron descubrir concentraciones de la sardina de engorde en

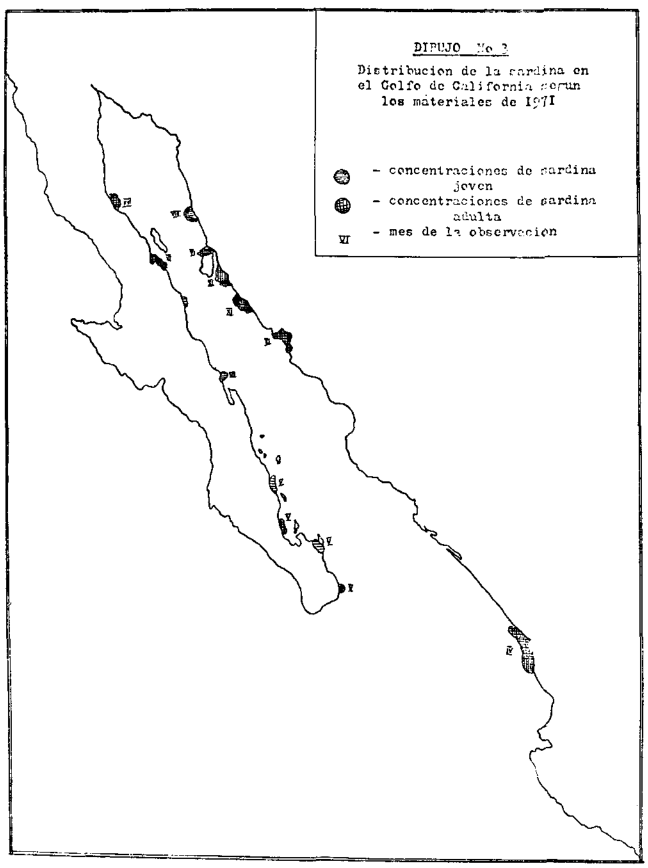

FIGURE 3. Areas and months of successful catches of sardines in 1971. Numerals indicate months; hatching indicates young sardines; cross hatching indicates adults.

los lugares adyacentes a las Islas Ángel de la Guarda y Tiburón. La sardina se concentra aquí en el período comprendido entre mayo y junio hasta octubre y noviembre, teniendo en este tiempo las gónadas en fase de reposo y un alto contenido de grasa en los músculos y la cavidad visceral.

Los levantamientos ictioplanctónicos (Figura 5) efectuados en abril de 1971 y 1972, mostraron que en este período tiene lugar el desove de la sardina y que sus áreas principales de reproducción se encuentran a lo largo de la costa oriental en la parte central del Golfo, particularmente en las áreas de Guaymas y Yavaros. En concordancia con esto, es aquí exactamente donde durante el invierno se observan poderosas concentraciones de sardina en base a las cuales surgió en 1967 la pesca masiva comercial (Guaymas). La sardina capturada aquí, tiene las gónadas en la fase IV y V de su desarrollo. Con las mismas carac-

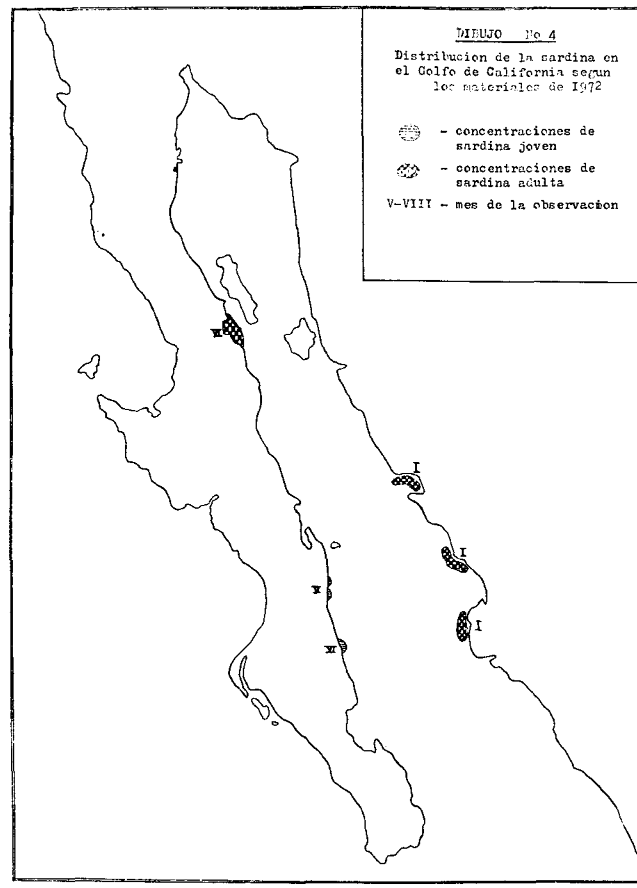

FIGURE 4. Areas and months of successful catches of sardines in 1972. Numerals indicate months; hatching indicates young sardines; cross hatching indicates adults.

terísticas se inició la captura comercial en el área de Mazatlán desde en año 1971, o sea también a lo largo de la costa oriental.

Finalmente como resultado de los trabajos de búsqueda, se encontró que las concentraciones de sardina de pre-desove se observan en noviembre en el área de la costa oriental desde la Bahía Kino hasta Guaymas, y en enero en la zona adyacente a Topolobampo. En otras palabras, el descubrimiento de esas concentraciones en las zonas intermedias entre las áreas de engorde y las áreas de conglomeración principal de las concentraciones de desove, aclara las rutas migratorias de los reproductores en el período invernal a lo largo de la costa oriental del Golfo.

En total, los datos sobre la distribución de los huevos, larvas y sardina madura e inmadura, permiten conocer los rasgos principales de la distribución de la sardina dentro de los límites del Golfo de California y suponer en líneas generales sobre su esquema preliminar de migraciones (Figura 6).

Los movimientos de la sardina se inician desde las primeras épocas de su vida. La existencia de huevos

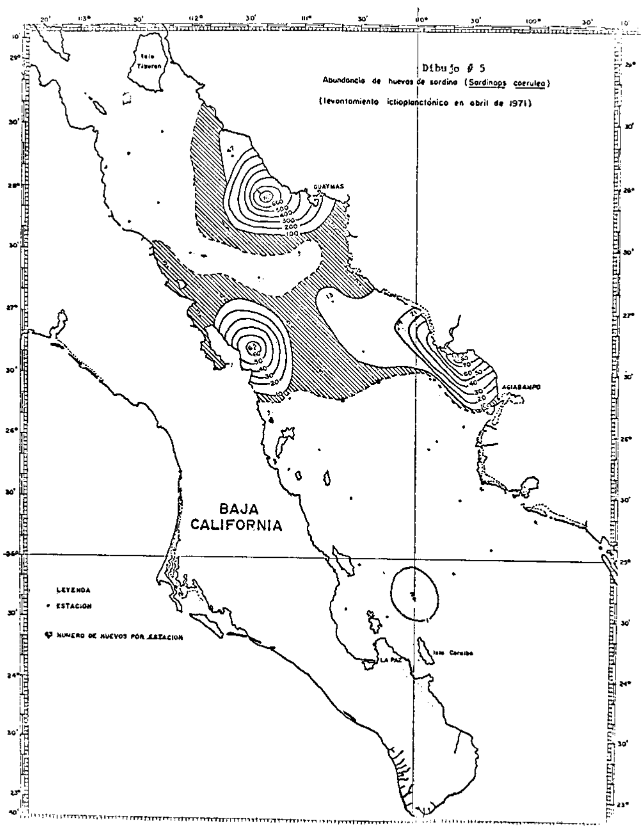

FIGURE 5. Abundance of sardine eggs (ichthyoplankton survey, April 1971). Number of eggs per station.

pelágicos presupone por sí misma, los traslados a merced de las corrientes predominantes. En realidad las áreas del desove de la sardina observadas cerca de la costa oriental en las zonas de Guaymas y Yavaros, están demasiado lejos de las áreas de concentración de la sardina inmadura a lo largo de la costa occidental del Golfo. La aclaración de tal hecho, puede encontrarse en el reconocimiento de la existencia de la deriva de los huevos y larvas bajo la influencia de las corrientes superficiales con dirección occidental y sud-occidental.

Los juveniles de sardina efectúan sus traslados independientemente de las corrientes. Como se mencionó anteriormente, las concentraciones de esa categoría se observaron a lo largo de la costa occidental del Golfo desde la Bahía de la Ventana hasta las Bahías de Las Ánimas y de Los Ángeles. Esta zona es probablemente el lugar donde efectúan sus traslados haste que alcanzan la madurez y se reúnen con la parte madura de la población. Esto último occurre según nuestra opinión en la zona de la Isla Ángel de la Guarda en el segundo año de vida de la sardina y en la época de engorde de la sardina madura en los meses de verano y otoño. De aquí surge la suposición de que la sardina inmadura hace sus traslados a lo largo de la costa occidental de las áreas sureñas hacia el norte, durante su período de crecimiento.

Los movimientos de las masas de sardina madura deben ser indudablemente más complejos. Pero en este caso, es posible aclarar las direcciones más generales de tales traslados. Es claro que deben existir movimientos estacionales de la sardina entre las principales zonas de engorde y desove.

Como índice de tales traslados se tienen los descubrimientos de grandes concentraciones de cardúmenes

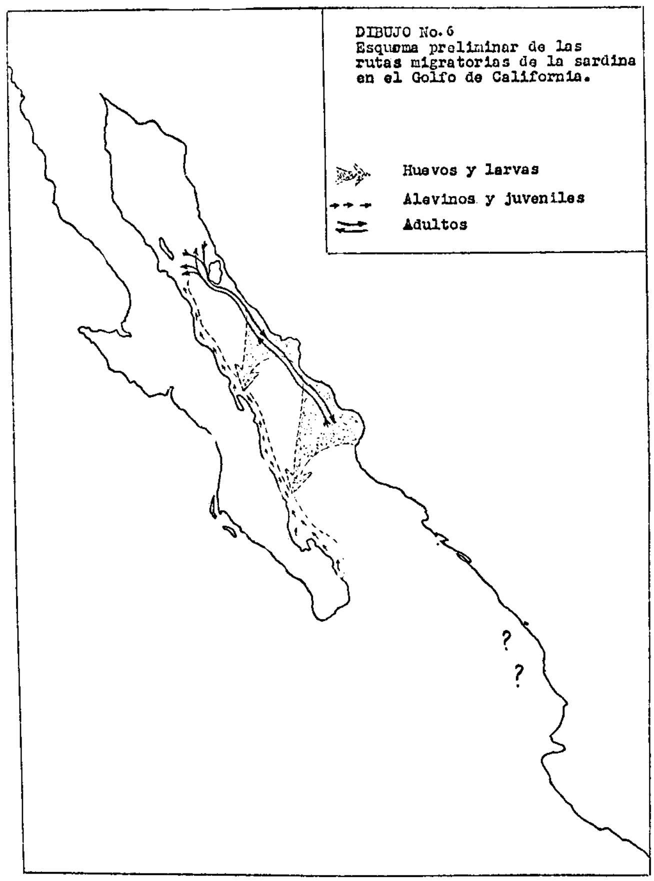

FIGURE 6. Tentative scheme of the migration of sardines in the Gulf of California. Stippled areas, eggs and larvae; short arrows, alevins and juveniles; long arrows, adults.

de sardina de pre-desove en el área de la Bahía Kino y más al sur, en noviembre de 1971 durante los trabajos de búsqueda del barco ANTONIO ALZATE. La época de observación de la sardina en este lugar precede directamente al período de la formación de las concentraciones de la sardina desovada cerca de Guaymas.

Es también muy probable que el descubrimiento de los cardú menes de sardina en 1972 en el área adyacente a Topolobampo está relacionado con sus movimientos posteriores hacia el área de Mazatlán. Este puerto es conocido desde 1971, como un área de concentración de la sardina en cantidades comerciales durante el período de febrero a abril.

Los antes mencionado permite suponer sobre la existencia de la migración de desove anual de la población de la sardina del Golfo de California a lo largo de la costa oriental desde el área de la Isla Tiburón y probablemente hasta Mazatlán durante la época invernal en el período de noviembre a abril-mayo.

Actualmente no hay materiales directos que indiquen las rutas de regreso de la sardina desde los lugares de desove hasta las áreas de engorde. Solamente se puede suponer que este regreso tiene lugar también a lo largo de la costa oriental del Golfo pero ya en dirección norte alcanzando las áreas de Isla Ángel de la Guarda e Isla Tiburón donde la sardina pasa su período de engorde y recuperación hasta la iniciación del próximo ciclo de reproducción.

El dibujo número 6 presenta gráficamente el esquema de las rutas migratorias de la sardina en el Golfo de California.

El esquema propuesto puede ser apoyado por algunos conocimientos generales sobre el régimen hidrológico del Golfo de California (Figura 7).

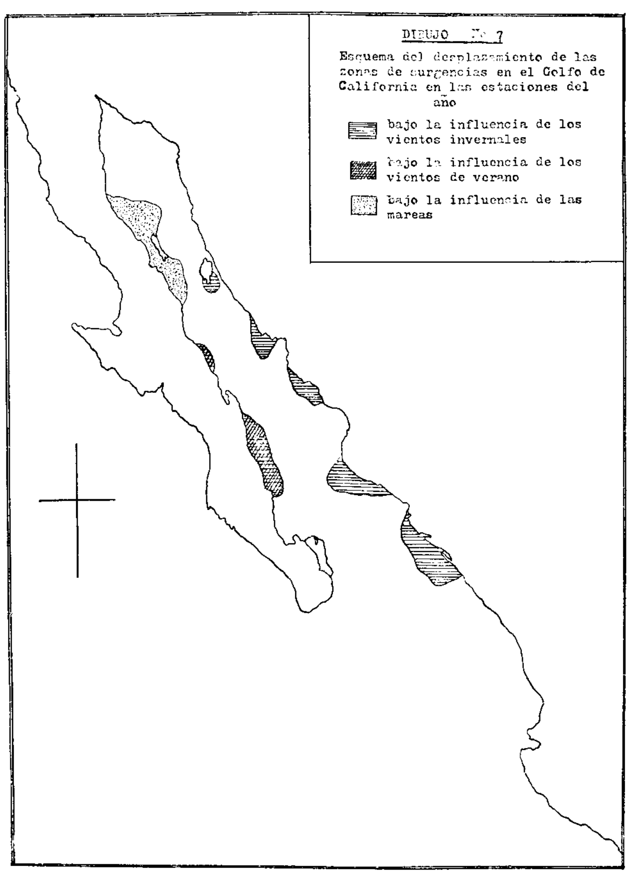

FIGURE 7. Upwelling in the Gulf at different seasons. Hatching indicates areas where upwelling occurs during the winter wind regime; cross hatching, summer. Stippling indicates upwelling related to tides.

Con base en estos conocimientos, encontramos que en el Golfo tienen lugar profundos y notorios cambios estacionales en las condiciones ambientales que por sí mismos deben conducir a los cambios en la distribución los peces.

Los vientos estacionales juegan un papel importante en la formación de régimen del Golfo de California. En el período invernal predominan aquí los vientos de dirección norte. Estos propician el nacimiento de un fenómeno de surgimiento y de acuerdo con esto, la formación de las áreas con una productividad biológica mayor. Esto último proporciona condiciones favorables para la alimentación de especies tales como crinuda, anchoveta y sardina. Esto se aclara en gran parte por la presencia de las concentraciones invernales de sardina a lo largo de la costa oriental.

Por otro lado, durante el invierno junto con la formación de surgimientos, aparece cerca de las costas orientales según nuestra opinión, el traslado de las aguas superficiales en dirección occidental y sudoccidental, donde como se mencionó antes, durante Con esta base, es posible suponer la existencia de la deriva de los huevos y larvas desde las áreas de desove cerca de la costa oriental hacia las áreas de la costa occidental, donde como se mencianó antes, durante el verano se concentran grupos de sardina pequeña e inmadura. En las mismas áreas durante el período de verano, con el cambio de los vientos estacionales de norte a sur, aparecen las zonas de surgimiento de alta productividad biológica y por ello se forman las condiciones favorables para la alimentación de los juveniles.

Junto con la existencia de las áreas de alta productividad estacional en el Golfo de California, en el área de las Islas Ángel de la Guarda y Tiburón, tienen lugar las zonas de salida de las aguas profundas probablemente de carácter permanente como resultado de la influencia de las poderosas corrientes de mareas. Posiblemente en el período de verano cuando los contrastes de temperaturas deben ser más grandes, aparecen áreas de muy alta concentración de alimento. Esto es la causa de la llegada a dichos lugares de gran cantidad de peces pelágicos para engorde veraneal—sardina, crinuda, macarela, etc.

De esta manera, es posible suponer que el esquema que proponemos de las migraciones de la sardina dentro de los límites del Golfo de California, tiene apoyo en la dinámica de los principales procesos hidrológicos de la cuenca.

Es necesario subrayar también que en todas las fases más importantes de su vida (reproducción, crecimiento de juveniles, engorde, traslados de pre y post-desove) la población de la sardina del Golfo de California puede caracterizarse como local. Dicha estimación está de acuerdo con la opinión de algunos investigadores norteamericanos sobre la existencia en el Golfo de California de una sub-población de sardina.

La última circunstancia permite suponer que la abundancia de sardina en el Golfo de California, no depende de la abundancia de sardina en la costa pacífica de Baja California y que para esta población debe elaborarse un régimen propio de explotación. Ya en los primeros años de los estudios, la determinación del volumen de la biomasa de la parte madura de la población presentaba gran interés, pretendiendo obtener la posibilidad de evaluar las magnitud de las capturas posibles, es decir, las perspectivas del desarrollo de esta especie en dicha área.

Con este objeto, en los años 1971 y 1972 se efectuaron dos levantamientos ictioplanctónicos, ambas veces durante el mes de abril ya que supomenos que este es un período de tiempo en el cual se desarrolla una intensa reproducción de sardina monterrey en el Golfo de California.

El material más significativo se obtuvo durante el levantamiento de abril de 1971, el cual permitió efectuar los cálculos del número de reproductores de sardina en este período. Tomando en cuenta que la temporada de reproducción abarca 4 meses, el número de reproductores determinado en abril fue multiplicado por 4. Con este resultado se obtuvo la cifra total de la parte madura de la población alcanzando la cantidad de 200 mil toneladas.

Esto nos da una idea sobre el volumen de las posibles capturas de sardina en el área estudiada. Por el momento se establece que el nivel de explotación de la población de sardina del Golfo de California no debe exceder del 25% del recurso total, es decir, de 50 mil toneladas. Sin embargo, las investigaciones posteriores precisarán esta cifra.

SUMMARY

In accordance with the plans for the scientific work of the Program of Fishery Investigations and Promotion, Mexico/PNUD/FAO in the Gulf of California, beginning in the second half of 1970, investigations were begun on the distributions, biology and abundance of pelagic fishes with principal attention to the Monterrey sardine.*

The present scientific work on board R/V ANTONIO ALZATE has permitted clarification of the principal uncertainties in the distribution of the sardine, the spawning areas, the feeding zones and the locations of concentration of immature individuals. Based on this information it was possible to imagine a preliminary outline of the routes of migration of the sardine within the Gulf of California.

The ichthyoplankton observations made on board the ANTONIO ALZATE provided the possibility of evaluating the fishing potential of the mature part of the sardine population of the Gulf of California and on the basis of this it was possible to establish a recommendation for taking 50,000 tons of sardines in 1972.

* Sardina Monterrey = *Sardinops caerulea*.

BIOLOGÍA DE LA SARDINA DEL GOLFO DE CALIFORNIA

(Sardinops sagax caerulea)

Biol. MYRNA WONG
Instituto Nacional de Pesca
Mexico 7, D. F., Mexico

INTRODUCCIÓN

Este trabajo forma parte de los planes de estudio y proyecto pesquero MEXICO/PNUD/FAO y está basado en los resultados de los cruceros, observaciones decampo, análisis del material y procesamiento de los datos obtenidos desde mediados de 1970 a la fecha por personal del Instituto Nacional de Pesca, con la colaboración especial de la Biól. Consuelo Gutiérrez Hernández.

La fecundidad se calculó en una muestra de 28 ejemplares de sardina capturada en noviembre de 1970 en el área de Guaymas. Los ejemplares de dos años de edad, tenían un promedio de 14,360 óvulos, el promedio de los ejemplares de tres años, fue de 17,310, los de 4 años 19,130 y los de 5 años, 13,330. El promedio total de la muestra es de 16,212 óvulos.

Debido al pequeño tamaño de la muestra, estos valores solamente proporcionan una idea de la fecundidad en la parte madura de la población en general y para los distintos grupos de edad en el área mencionada.

Los valores mas altos corresponden a las edades de 3 y 4 años, que se acercan mucho a los resultados obtenidos por otros investigadores en las observaciones de la sardina del Pacífico.

FRECUENCIA DE SEXOS

La proporción de hembras en los muestreos es frecuentemente mas alta que la de los machos, aunque a menudo, en la época de pre-desove durante el otoño se encuentran cardúmenes formados por ejemplares de un solo sexo. Es importante establecer si se conserva esta proporción durante todo el período de reproducción o tiene lugar solamente en el período inicial, cuando comienza el movimiento masivo de los reproductores de las áreas de engorda hacia las áreas de desove.

Es necesario poner atención en el estudio de este fenómeno porque el conocimiento exacto de la proporción de sexos en la población de sardina es muy importante para hacer los cálculos del tamaño del recurso cuando se utiliza el método de levantamiento ictioplanctónico.

COEFICIENTE DE MADUREZ

Se ha observado que en la sardina el coeficiente de madurez disminuye durante el período de desove, probablemente por la existencia de varias ovoposiciones durante el período de reproducción, algunos investigadores consideran que son tres. El mas alto coeficiente de madurez 12–14 se observa en ejemplares jóvenes, los cuales expulsan la primera porción de óvulos al principio del período de desove.

Los valores mas bajos corresponden probablemente a la expulsión de la segunda o tercera proción de óvulos en los siguientes lapsos de este período.

DESARROLLO DE LAS GÓNADAS

Mediante observaciones de ovarios y testículos de los ejemplares muestreados, se pudieron determinar las fases del desarrollo gonádico de esta especie a lo largo período de estudio.

Los juveniles fueron encontrados solamente en los meses de mayo y junio en la costa occidental, los ejemplares en fase II de recuperación y los individuos de ambos sexos en fase II se encuentran en abril, junio, agosto y octubre principalmente en el área de Bahía Kino a Guaymas. Las fase III se presentó en los meses de abril, junio, agosto, noviembre y diciembre, los ejemplares con las gónadas en fase IV se encontraron a lo largo del año en enero, abril, junio, octubre y noviembre. Los de fase V se encontraron en abril, junio y diciembre y la fase VI solamente se observó en el mes de diciembre.

La distribución de juveniles y adultos se explica por los movimentos de migración, deriva, áreas de surgencia y áreas de desove.

Los ejemplares con las gónadas en las fases II, III y IV estuvieron presentes en mayor número en nuestros muestreos.

Una de las fases mas importantes del ciclo vital lo constituye la reproducción, en esta especie se ha observado una época de engorda y preparación en los individuos de primera madurez, y de engorda y recuperación en los adultos, en la que además del desarrollo de las gónadas, se almacena gran cantidad de grasa en la cavidad visceral. Esta caracterizada por el aumento del coeficiente de nutrimiento que se presenta en el verano y se prolonga hasta principios del invierno, generalmente de junio a septiembre y fue observado en los ejemplares capturados en las áreas de Bahía de Las Ánimas, Bahía de Los Ángeles y cerca de la Isla Patos. Esta zona se encuentra al norte de la región de pesca de sardina mas importante del Golfo de California, adonde posteriormente se dirigen ya que también constituye la principal área de desove.

Las aglomeraciones migratorias de pre-desove caracterizadas por el avanzado desarrollo de las gónadas se presentan durante el otoño en la costa oriental del Golfo comprendida entre la Isla Tiburón y Guaymas.

Durante el invierno en las áreas de Guaymas y Yavaros, se concentran los cardúmenes de pre-desove y reproducción, constituídos a menudo por individuos del mismo sexo cuyo coeficiente de nutrimiento es bajo.

LONGITUD Y PESO

El crecimiento es muy marcado en los primeros años de vida y se ha registrado una longitud máxima de 25 cms. La composición por tamaños de los cardúmenes, varía con relación a la estación y el área de captura.

Los ejemplares mas pequeños, juveniles de 7 cms. de longitud, fueron encontrados en mayo y junio en la

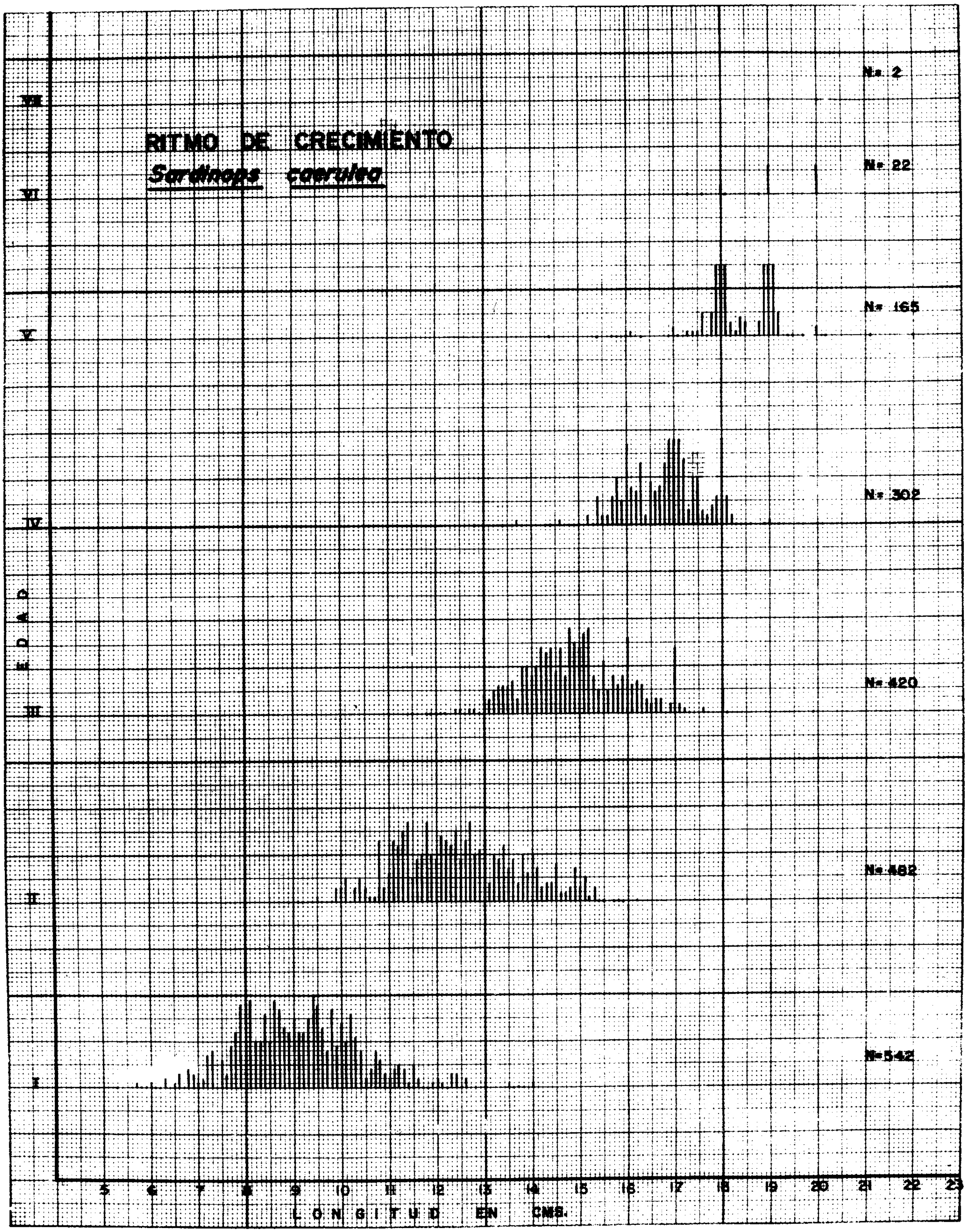

FIGURE 1. Relation of age in years to length in sardines in the Gulf of California.

costa occidental del Golfo de California. En el área de Guaymas, que es el principal lugar de pesca comercial de la sardina, el rango de longitud es de 14 a 20 cms. y predominan los ejemplares de 16 a 17 cm.

Los peces capturados en la zona de Mazatlán, fluctúan entre 16 y 22 cms. en estas muestras predominan los ejemplares de 17–18 cms., que presentan ya un tamaño comercialmente explotado.

Durante el verano la sardina se encuentra en la zona norte de las Islas Tiburón y Ángel de la Guarda, y los cardúmenes están constituídos por individuos de 14 a 24 cms. con predominio de los grupos de 16 a 19 cms.

Las tallas registradas indican que la sardina de la costa oriental del Golfo es de major tamaño que le capturada en la costa occidental. Mas al norte de la Isla Tiburón, cerca del Cabo La Libertad, las concentraciones están formadas por diferentes grupos de tamaño y el rango se extiende desde 12 a 22 cms. y las clases principales están representadas por las tallas de 13 a 14, 15 a 16 y 19 a 20 cms.

Durante el octoño los cardúmenes que aparecen de nuevo en el área de Guaymas, están formados por individuos de 16 a 19 cms. de longitud en su mayor parte.

Estrechamente relacionado con la longitud, está el peso de esta especie, el rango es amplio y sus extremos están representados por los ejemplares de 6 y 152 grs. la mayor frecuencia se encuentra entre 56 y 88 grs. Se puede observar que la talla de 8 a 9 cm. corresponde al grupo de 8 a 16 grs., los ejemplares de 17 a 18 cm. pesan de 64 a 80 grs. y constituyen el grupo mas frecuente en las concentraciones de sardina adulta. El registro máximo del peso es de 114 a 152 grs., que corresponde a la longitud de 24 a 25 cm.

EDAD

La sardina se concentra en grupos de edad, habiendo sido determinados hasta 7 anillos de crecimiento en neustras observaciones con los siguientes rangos y promedios: (Figura 1).

En el 1er. año los peces alcanzan hasta 14 cm. con un promedio de 9.5 cm. En el 2do. año, el rango es de 9 a 16 cm. de longitud y el promedio es de 13⁻ cms.

Los ejemplares de 11 a 20 cms. y 15.3 de promedio, mostraban 3 anillos en sus escamas, el rango de longitud de los de 4 años es de 13 a 22 cms., siendo la longitud de 17 cms. la que tenía mayor número de representantes.

Durante el 5o. año, alcanzan desde 15 hasta 24 cm. y la longitud promedio es de 18.5 cm.

La variación es menor en los ejemplares de 6 y 7 años que fueron encontrados muy pocas veces y sus promedios son 19 y 19.5 cm. respectivamente.

Los ejemplares de menor edad fueron localizados en la costa Occidental del Golfo y los de mayor edad y tamaño en la costa Oriental, principalmente en el área de Guaymas.

ALIMENTACIÓN, CONTENIDO DE GRASA Y CONTENIDO ESTOMACAL Y COEFICIENTE DE NUTRIMIENTO.

La alimentación de la sardina es constituída principalmente por algas y diatomeas (Figura 2) y se ha observado que es más alta durante los meses de verano, ésto muestra la existencia de un período de engorda que se efectúa en las áreas de Isla Ángel de la Guarda e Isla Tiburón, en esta época la sardina tiene una gran cantidad de grasa sobre las vísceras. En el otoño la alimentación disminuye en intensidad y está relacionada con las migraciones de pre-desove, también decrece la cantidad de grasa sobre las vísceras. Esto indicia que la grasa acumulada durante el período de engorda se emplea en el desarrollo de las gónadas. Además, en la época de reproducción, el grado de alimentación disminuye notablemente.

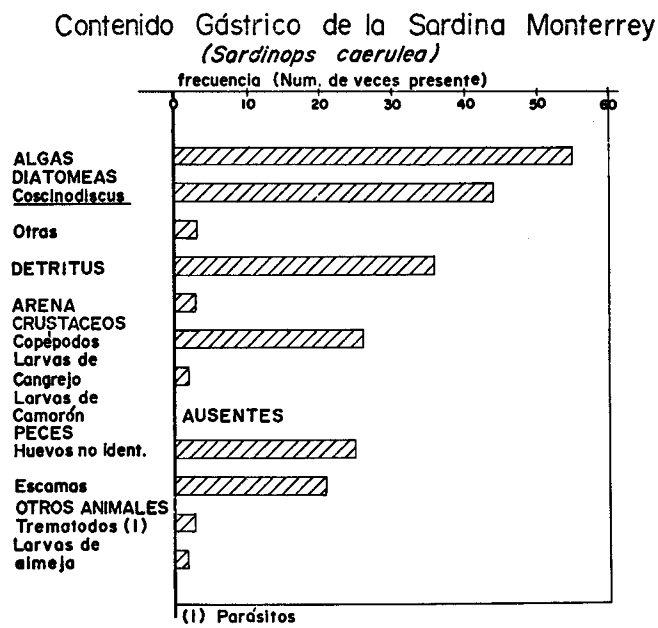

FIGURE 2. Stomach contents of sardines in the Gulf of California. Relative number of occurrences of different planktonic groups.

BIOLOGÍA DE LA SARDINA DEL GOLFO DE CALIFORNIA

RESUMEN

Se describe en este trabajo la biología de la sardina del Golfo de California. La reproducción de esta especie se efectúa en los meses de enero a abril. Las áreas de desove se encuentran en la costa Oriental del Golfo de California. Los ejemplares juveniles fueron encontrados en mayo y junio a lo largo de la costa Occidental.

Fue notorio el período de recuperación gonádica y almacenamiento de grasa en los meses de junio a septiembre. En octubre se inician los movimientos de migración hacia las áreas de desove. El coeficiente de madurez alcanza su nivel máximo en invierno y el mínimo en mayo, que es el final de la época de reprodución. El índice de fecundidad promedio es de 16,000 huevecillos por hembra, independientemente de la edad.

Es notorio el predominio de las hembras sobre los machos. En la época de pre-desove, es frecuente encontrar cardúmenes compuestos por ejemplares de un solo sexo.

La alimentación se basa principalmente en algas, diatomeas, copépodos y huevos de peces. El coeficiente de nutrimiento de la sardina, es más alto en verano y otoño y disminuye en el invierno.

Mediante lecturas de escamas, se han encontrado ejemplares hasta de 7 años de edad. En las capturas comerciales predominan los grupos de 2 a 4 años de edad. El crecimiento es muy marcado en los primeros años de vida y existe una relación muy estrecha entre el aumento de longitud y el peso.

Se pretende conocer el ciclo de vida de esta población, con el fin de determinar las áreas de reproducción y engorda, así como los movimientos relacionados con las diferentes etapas de su desarrollo, ésto proporcionará un base para la administración de la pesquería.

SUMMARY

Reproduction of *S. sagax caerulea* occurs from January to April along the east coast of the Gulf of California. Juveniles are found along the west coast of the Gulf. Recuperation of gonads and fat storage occur from June to September. Migration toward the spawning area begins in October. The coefficient of maturity is highest in winter and lowest in May. Average fecundity is 16,000 eggs per female, and is independent of age. Females are much more numerous than males; before spawning, schools composed of a single sex are frequent. Food consists principally of algae, diatoms, copepods and fish eggs. The nutrient level is highest in summer and autumn and lowest in winter. Scale readings indicate that individuals reach an age of 7 years. The commercial catch consists predominantly of fish 2 to 4 years old. Growth in length is fastest in the early years, and is closely related to increase in weight. This study has been undertaken to help supply a basis for management of the fishery.

RESULTS OF THE EXPLORATORY CRUISES OF THE ALEJANDRO DE HUMBOLDT IN THE GULF OF CALIFORNIA[a]

C. P. MATHEWS[b], J. L. GRANADOS and J. ARVIZU
FAO/UNDP and Instituto Nacional de Pesca
Apartado M-10778, Mexico (1), D.F., Mexico

ABSTRACT

During the year April 1971–March 1972, R/V ALEJANDRO DE HUMBOLDT operated by the Mexico/FAO Research and Development Project of the United Nations Development Program, carried out preliminary cruises in the Gulf of California to evaluate the potential fishery resources.

A stock of hake, *Merluccius* sp., found principally north of Isla Tiburon and along the east coast of the Gulf as far south as Guaymas was surveyed in three cruises between June 1971 and March 1972. The abundance was greatest in February and March, with a total estimated biomass in the northern Gulf at that time of 28000 metric tons.

Langostino[1] or squat lobster, *Pleuroncodes planipes,* was found to be widely distributed in the Gulf south of Isla Tiburon, with the major part of the population north of Guaymas.

South of the latitude of Bahía de Yavaros the trawls brought up samples of sediments and other material with evidence of active anaerobic decay. The depth at which this occurred decreased southward to the mouth of the Gulf, and the greatest depth yielding appreciable amounts of groundfish decreased in the same way. Measurements of dissolved oxygen indicated that these conditions prevailed where the sea floor was within the oxygen minimum layer.

In spite of this limitation of space available to groundfish, a potential annual yield to a fishery was estimated to lie between about 70000 and 190000 metric tons. The total annual bycatch in the shrimp fishery was found by calculation to lie within this range.

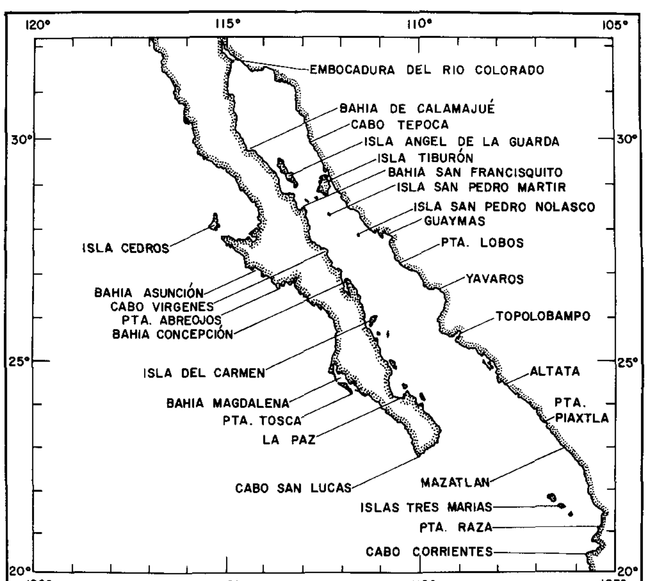

Figure 1. Map of Gulf of California.

INTRODUCTION

During the year April 1971–March 1972 the R/V ALEJANDRO DE HUMBOLDT, operated by the Mexico/FAO Research and Development Project of the United Nations Development Programme, carried out extensive exploratory and prospective cruises in the Gulf of California. The chronology and areas covered are shown in Table 1 and Figure 1.

The early cruises, April through June 1971, attained three main objectives: exploratory fishing throughout the Gulf, shaking down the ship, and educating the crew and scientists in conducting operations. After this period the crew and scientists could handle the fishing gear as deep as 1000 m, the limit imposed by the equipment available. Subsequently because of mechanical difficulties fishing was confined to depths less than 600 m.

Preliminary study of the results led to setting up several long term objectives: concentrating effort on the eastern shelf and slope which is more favorable for trawling than the narrow and rocky western shelf; investigating the population of large hake, *Merluccius* sp., in the northern Gulf; investigating the stock of langostino, or squat lobster, *Pleuroncodes planipes,* in the area between Isla Tiburon and Bahía de Yavaros; and obtaining additional data on the

TABLE 1

Chronology of operations by R/V ALEJANDRO DE HUMBOLDT under the Mexico/FAO Research and Development Project of the United Nations Development Program from April 1971–October 1972

Date	Area of operations	Shown in figures[1]
1971		
April, May	Mazatlán to Yavaros, coast of Sinaloa, and La Paz	13, 23
May, June	Yavaros to R. Colorado, coast of Sonora and northern Gulf	3, 9
July	I. Angel de la Guarda to C. San Lucas, coast of B. California	3
July	Mazatlán to C. Corrientes, coast of Nayarit	22
August	Northern Gulf, north of I. Tiburón	4
August	I. Tiburón to Guaymas, coast of Sonora	4, 10
September	Northern Gulf, north of I. Tiburón	4
November	Transects across shelf, Mazatlán to C. Corrientes	24
Nov, Dec	Transects across shelf, Mazatlán to Yavaros	14
December	Transects across shelf, near I. San Pedro Nolasco	11
1972		
Feb, March	Northern Gulf, to I. San Pedro Nolasco	5, 12
October	Pacific coast of Baja California	--

[1] All areas shown in figure 1.

[a] This is not necessarily the view of FAO.
[b] Present address: Department of Fisheries Oceanography
Unidad de Ciencias Marinas, UABC
Apartado Postal 453
Ensenada, Baja California
[1] The currently accepted name for *P. planipes* appears to be langostilla.

extent and effects on fish of oxygen-deficiency and anaerobic conditions in the deeper waters and floor of the Gulf. No other ground fish stock seemed sufficiently large or important to justify any special investigation, but some fishing effort was expended on the mixed groundfish stock in the course of other work. As a result a considerable volume of data on these stocks was obtained.

Methods and Equipment

The ALEJANDRO DE HUMBOLDT is a 450 gross ton stern trawler, provided with biological and hydrographic laboratories. The fishing equipment used during this study was an otter trawl, provided with otter boards to keep the net mouth open. Figure 2 shows a schematic representation of the fishing equipment used. The mesh size of the wings was fairly small (<10.0 cm) while that of the cod-end varied: until June 1971 a material of 5.5 cm mesh was used, while from July onwards a 4.5 cm mesh cod-end was substituted. The ratio of warp out to depth was usually 3.0:1 to 3.5:1; this was increased to around 5.0:1 in February 1972. For depths greater than 500 m, lower ratios were used. The speed at which the net was hauled along the bottom varied from 2.0 knots at depths over 450 m to 4.0 knots in very shallow waters, but most hauls were carried out at from 3.0 to 3.5 knots.

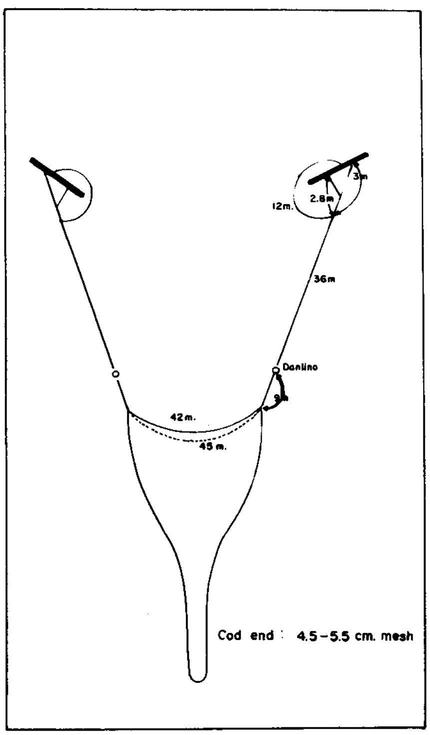

Figure 2. Schematic drawing of the otter trawl used, not be scale.

During the whole year's observations only three otter trawl nets were available; by the end of this period these nets had suffered very considerable distortion, and the vertical distance separating footline from headline may have been as little as 2–3 m, when it should have been 3–4 m. Such distortion of the equipment is likely to result in lower than normal catches being obtained and, if no correction is made, calculated abundances would be likely to err on the low side, particularly in February–March, 1972.

The depth during each trawl was monitored continuously by means of an echosounder, and whenever possible the ship's course was adjusted so as to keep trawling at a constant depth. If a considerable change in depth was unavoidable (>10% of the initial depth) the haul was usually ended; for most hauls depth did not vary by more than 2–3%. The ship's speed was recorded at the beginning and the end of each trawl. The swept area technique was used for conversion of the catch in kilograms to abundance in kilograms per hectare (kg/ha), and the following assumptions were made: (i) that the otter boards and danlinos were effective in startling fish and so made all fish between the otter boards accessible to the net; (ii) that the otter boards were 60 meters apart during trawling (this was based on measurements of a simple scale model); (iii) that, because of escapement around and through the net, only 50% of the accessible fin fish were caught; (iv) that no adjustment owing to escapement was necessary for *Pleuroncodes planipes.*

The catch per unit area, C_a, is calculated from the measured catch C as follows.

$C_a = C/K$ kilograms per hectare (kg/ha)

where K is the area swept.

$$K = \frac{60 \times 1853 \times Vt}{10000} = 11 \times Vt \text{ hectares}$$

where 60 is the distance between the otter boards in meters

1853 is the number of meters in a nautical mile

V is the average ship's speed during the haul in knots

t is the duration of the haul in hours

10000 is the number of square meters in a hectare

The abundance of fin fish, that is, the total biomass living on unit area, assuming 50% escapement, is estimated as,

$A = 2C_a$

The abundance of langostino is estimated as $A = C_a$.

The hydrographic work was carried out with a Bisset-Berman Salinity/Depth/Temperature Recorder (STD), model 9060, which was calibrated from time to time. Nansen bottles and reversible thermometers were used to obtain samples for oxygen and salinity determination and for checking STD observations. The methods used were those standardized by the U. S. Hydrographic Office (U.S. Naval Oceanographic Office, 1970).

RESULTS

1. HAKE (*Merluccius sp.*)

Hake were first caught in quantity in June. Figure 3 shows the locations of hauls and the calculated abundances. More than half (60) of the 105 exploratory hauls were made on the shelf or delta sediments where the depth to the seafloor was less than 180 m (100 fm), and 52 of these hauls caught no hake or only negligible quantities. Out of the 45 hauls at greater depths, the catches in twelve hauls were equiv-

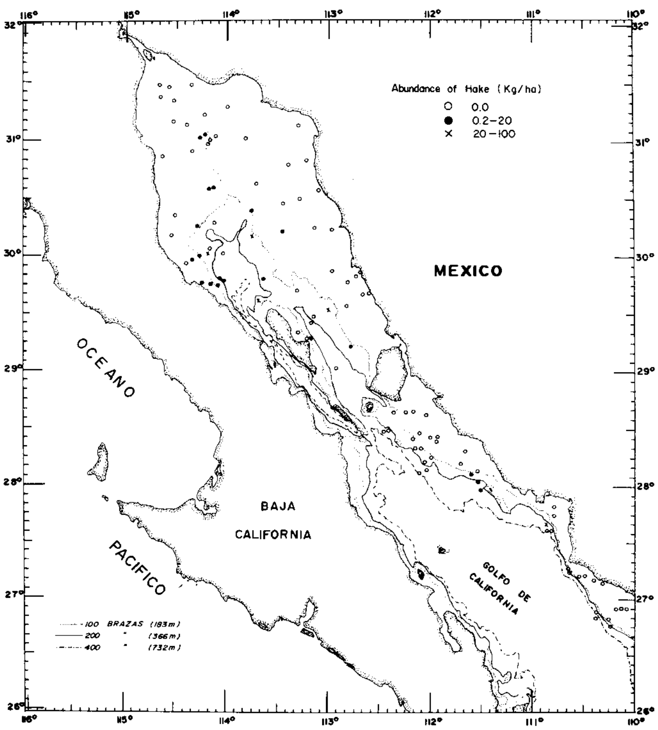

Figure 3. Location of hauls and abundance of hake in the northern Gulf of California, June 1971.

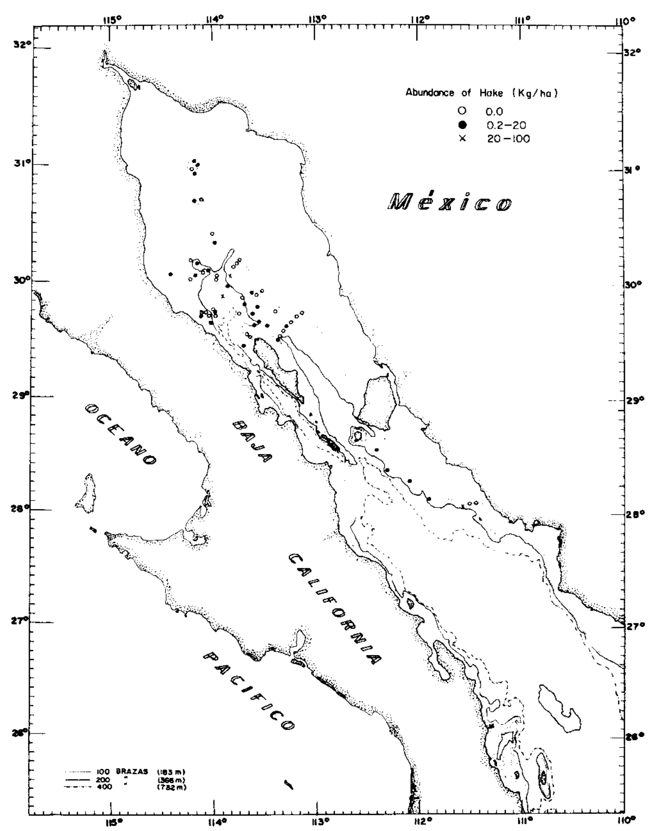

Figure 4. Location of hauls and abundance of hake in the northern Gulf of California, August–September 1971.

alent to abundances between 0 and 20 kg/ha and in five hauls to abundances between 20 and 100 kg/ha. All but four of these productive hauls were north of Isla Tiburón and Isla Ángel de la Guarda. The remaining four were on the slope near Isla San Pedro Nolasco and Guaymas. Figure 6 shows that while hake were taken at all depths from 105 m (at night) or 160 m (daytime) to 540 m, the bulk of the fish were caught between about 180 and 400 m.

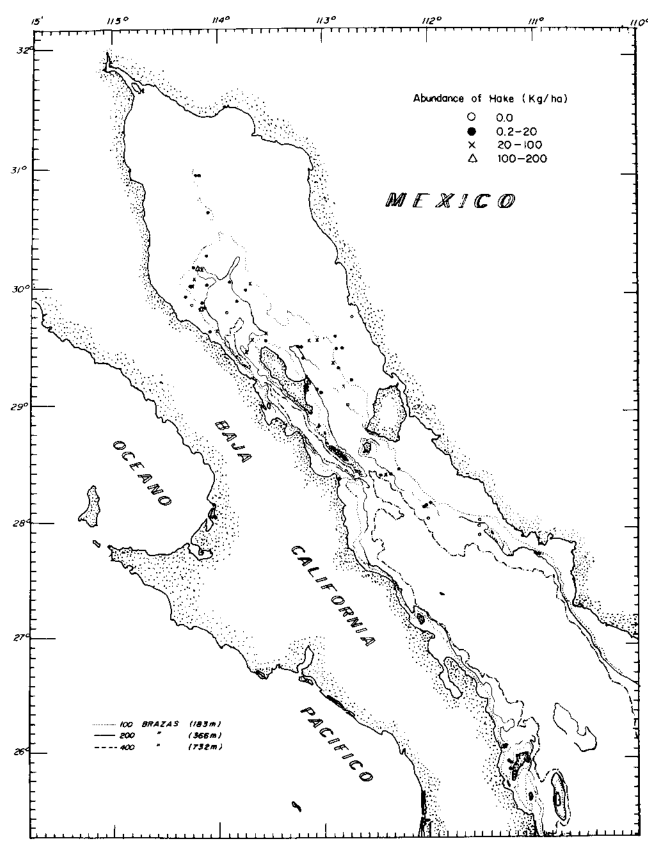

Figure 5. Location of hauls and abundance of hake in the northern Gulf of California, February–March 1972.

During the August–September cruise, in order to conserve effort while attempting an approximate estimate of the total biomass of hake in the northern Gulf, all hauls were made in the areas which had proved productive in June, namely, those below the 180 m level marking the edge of the shelf and delta deposits (Figure 4). Out of the 60 hauls, the catches in 27 were

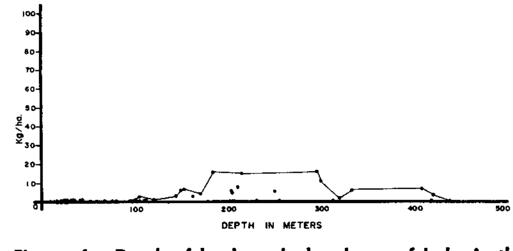

Figure 6. Depth of hauls and abundance of hake in the northern Gulf of California, June 1971.

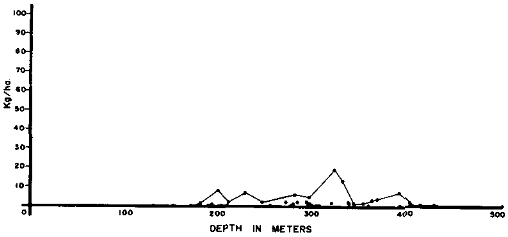

Figure 7. Depth of hauls and abundance of hake in the northern Gulf of California, August–September 1971.

equivalent to abundances between 0 and 20 kg/ha and in three hauls to abundances between 20 and 100 kg/ha. Figure 7 shows that the bulk of the fish were taken between about 200 and 400 m.

During the February–March 1972 cruise, most hauls were made below the edge of the shelf (Figure 5). Out of the 63 hauls, the catches in 37 were equivalent to abundances between 0 and 20 kg/ha, in 14 hauls between 20 and 100 kg/ha, and in three hauls between 100 and 200 kg/ha. Figure 8 shows that the productive catches were made within roughly the same depth

TABLE 2

Frequency of occurrence of catches corresponding to different abundances of hake in the northern Gulf of California

Abundance level (kilograms per hectare)	June 1971	Number of catches		
		June 1971 eliminating 60 hauls at less than 180m	August–September 1971	February–March 1972
None	80	28	30	9
0.2–20	20	12	27	37
20–100	5	5	3	14
100–200	0	0	0	3
Total	105	45	60	63

range as in previous months, and corresponded to a considerably higher average abundance.

During other cruises, hake were caught as far south as Bahía de Yavaros off the Sonora coast and Isla del Carmen off the Baja California coast, but in abundances never greater than 4 kg/ha.

Table 2 summarizes the hauls and corresponding abundances of hake in the northern Gulf. On the sea floor at depths below 180 m, the mean abundance was considerably higher in February–March 1972 than during the preceding summer. Mathews (in preparation) proposes a migration pattern consistent with this fact. Table 3, showing the catch rates (kg/h) for large hake (more than 45 cm in total length) during this exploratory fishing, suggests that during February–March it might support a commercial fishery.

TABLE 3

Catch of hake more than 45 cm in total length

	Catch rate (kilograms per hour)	Maximum length (centimeters)
June 1971	80.7	94
August 1971	11.1	84
February–March 1972	343	107

The total biomass of hake in the northern Gulf during each cruise period can be estimated by multiplying the mean abundance in each depth zone by the area of sea floor in that zone. Table 4 shows the results of such a calculation. Since the mean abundance as shown above is highest at depths between about 180 and 370 m, most of the hake biomass in the northern Gulf appears to occur between these depths.

However, reviewing the whole body of data while writing this paper, and noting that in February–March out of ten hauls made at or above 180 m, eight yielded abundances of 0.2–20 kg/ha, it seems possible

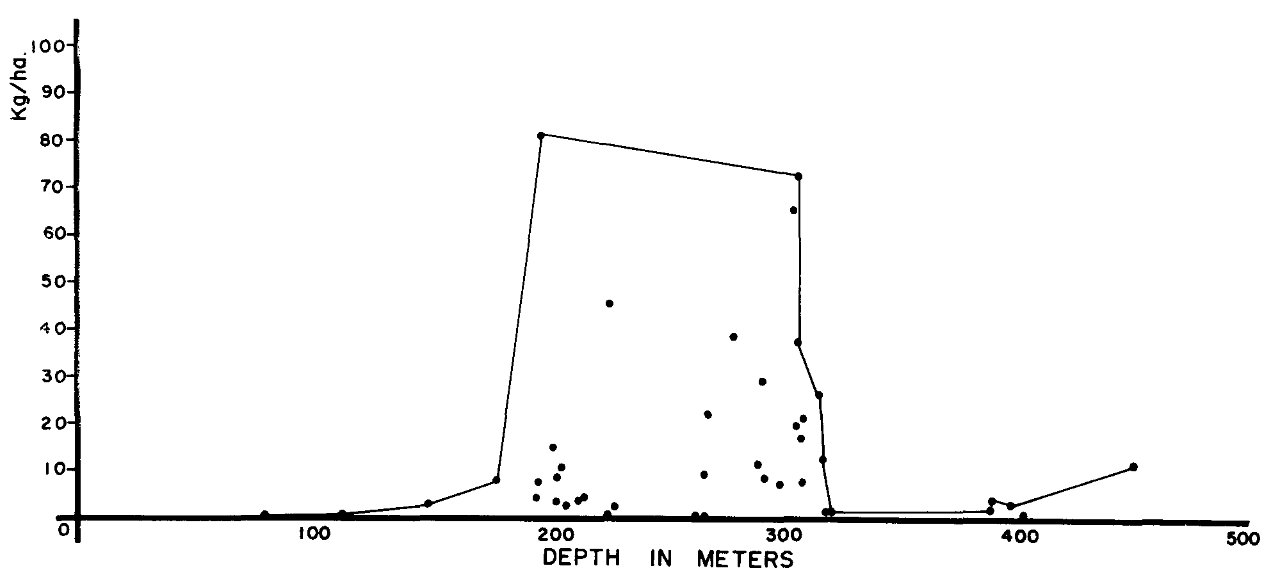

FIGURE 8. Depth of hauls and abundance of hake in the northern Gulf of California, February–March 1972.

that further testing of the productivity of the shallow portions of the shelf is warranted.

Estimates of mortality based on approximately 900 pairs of otoliths taken between June 1971 and March 1972 indicate that natural mortality (M) is about 0.29

TABLE 4

Estimated biomass of hake north of Isla Tiburón and Isla Ángel de la Guarda

Depth (meters)	Mean abundance (kilograms per hectare)			Area (thousands of hectares)	Biomass (metric tons)		
	June 1971	Aug–Sept 1971	Feb–Mar 1972		June 1971	Aug–Sept 1971	Feb–Mar 1972
147–183	1.6	0.6	4.6	312	500	200	1,400
184–366	10.6	4.4	36.2	679	7,200	3,000	24,600
367–549	3.8	2.6	7.0	305	1,200	800	2,100
Total	--	--	--	--	8,900	4,000	28,100

for females and 0.47 for males. Assuming that harvesting would occur mainly in the season of maximum biomass (February–March, Table 4) and that the maximum yield would be obtained when the fishing mortality is adjusted to equal the natural mortality (Gulland 1970, p. 2) then the maximum would be between:

$$0.29 \times 0.5 \times 28000 = 4060 \text{ metric tons.}$$
$$\text{and } 0.47 \times 0.5 \times 28000 = 6580 \text{ metric tons.}$$

The mean of about 5000 tons is the best available estimate pending further study of the stock.

2. LANGOSTINO *(Pleuroncodes planipes)*

Langostino was widely distributed in the Gulf south of Isla Tiburón, but has not been found north of the island. The highest concentrations were found off the coast of Sonora between Isla San Pedro Mártir and Guaymas (Figures 9–12). From Guaymas to Bahía de Topolobampo catches were smaller. From Bahía de Topolobampo to Mazatlán, usually less than 50 individuals were obtained in a catch and south of Mazatlán, catches were very low. Figures 13 and 14 show the distribution in April–May and November respectively from Bahía de Yavaros to Mazatlán.

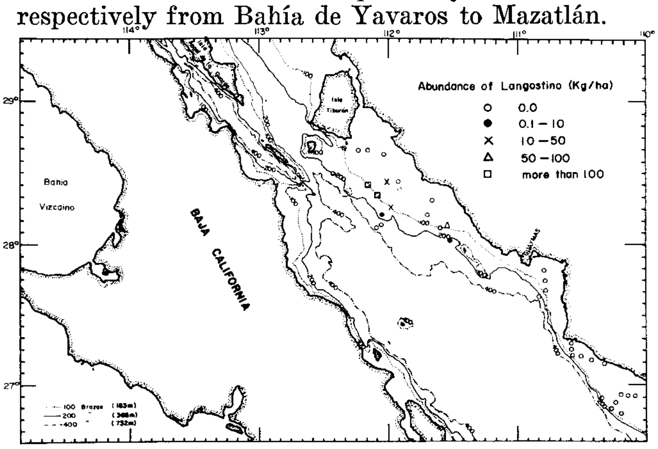

Figure 9. Location of hauls and abundance of langostino between Isla Tiburón and Guaymas, June 1971.

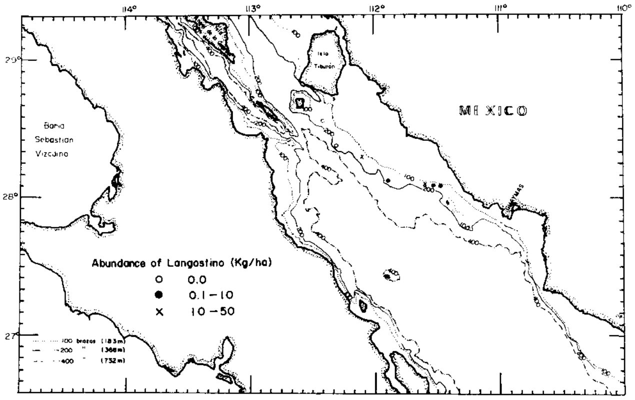

Figure 10. Location of hauls and abundance of langostino between Isla Tiburón and Guaymas, August 1971.

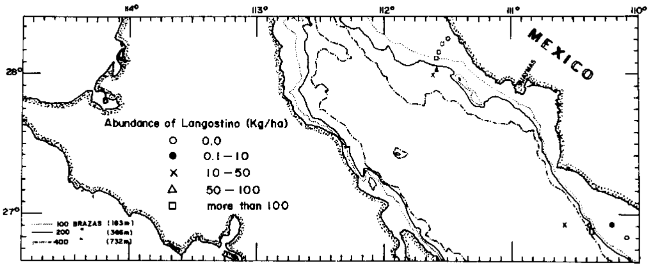

Figure 11. Location of hauls and abundance of langostino near Guaymas, December 1971.

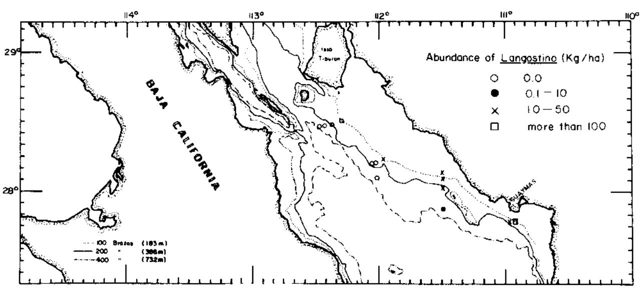

Figure 12. Location of hauls and abundance of langostino between Isla Tiburón and Guaymas, February–March 1972.

Table 5 shows the calculated abundances corresponding to catches made at different depths in each of the seasonal cruises in the area between Isla Tiburón and Bahía de Yavaros. The largest number of catches yielding large abundances were made in December and June. In December and June, 10 catches were made (out of a total of 14 productive hauls) yielding abundances greater than 70 kg/ha. No catch was made in any other month yielding an abundance greater than 27 kg/ha. Only in December did the catches suggest large populations at depths greater than 370 m. One catch (abundance between 10 and 50 kg/ha) in December was made at more than 700 m. In January 1972 a single catch in shallow water (75 m) corresponded to an abundance of more than 400 kg/ha. Further work is necessary to define the depth distribution of langostino. In the area south of Bahía de Yavaros only four catches were made corresponding to abundances greater than 10 kg/ha. All were at depths less than 370 m (Figures 13 and 14).

In Figures 13 and 14, positions are also plotted at which the trawl brought up solid material or objects,

TABLE 5

Numbers of catches and abundances of langostino between Isla Tiburón and Bahía de Topolobampo at different depths and seasons [1]

	June 1971 (36 hauls)			September 1971 (7 hauls)		
Depth (meters)	0–180	180–370	370–730	0–180	180–370	370–730
Abundance (kilograms per hectare)						
Negligible	22	3	4	0	2	0
0.1–10	0	1	1	0	3	0
10–50	1	1	0	0	2	0
50–100	1	0	0	0	0	0
More than 100	1	1	0	0	0	0

	December 1971 (10 hauls)			Feb–March 1972 (14 hauls)		
Depth (meters)	0–180	180–370	370–730	0–180	180–370	370–730
Abundance (kilograms per hectare)						
Negligible	2	0	1	1	3	3
0.1–10	1	0	0	0	0	1
10–50	0	0	2	2	2	1
50–100	0	0	1	0	0	0
More than 100	1	2	0	0	1	0

[1] For locations see Figures 9, 10, 11 and 12.

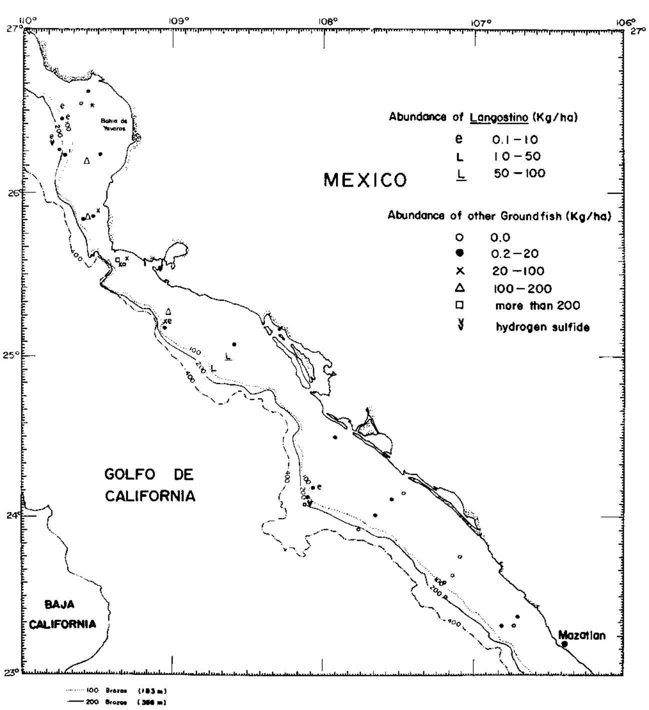

Figure 13. Location of hauls and abundance of mixed groundfish and langostino, Bahía de Yavaros to Mazatlán, April and May 1971.

such as sediment, waterlogged and decaying wood and decaying bones accompanied by readily evident hydrogen sulfide. Figures 15, 16 and 17 show hydrographic data, including temperature, salinity, and dissolved oxygen concentration in December along a section northwest of Isla San Pedro Nolasco (Figure

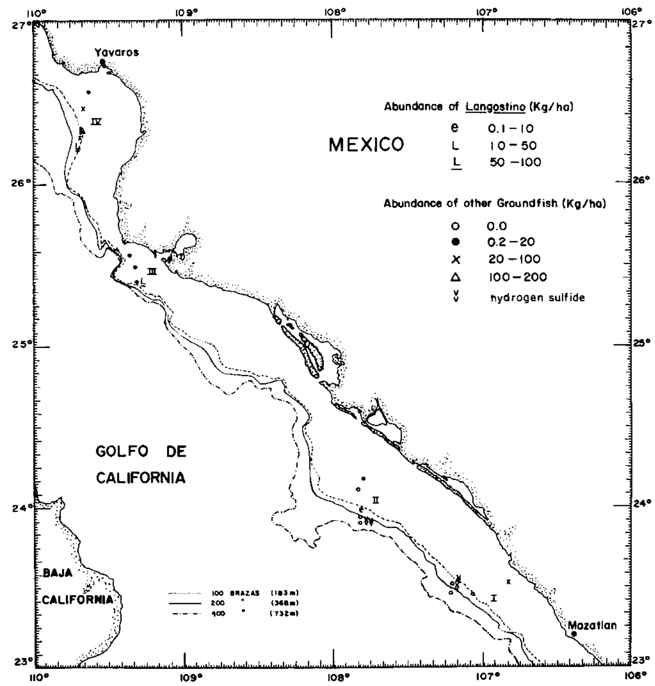

Figure 14. Location of hauls and abundance of mixed groundfish and langostino, Bahía de Yavaros to Mazatlán, November–December 1971.

11). Between the surface and the sea floor at 500 m the temperature decreases a great deal, and the rate of decrease is especially rapid between about 50 and 100 meters, showing that vertical mixing at this level is slow. Partly as a result, the dissolved oxygen concentration below 300 m is very low, less than 0.5 ml per liter of sea water. The numbers along the sea floor are related to the abundance of langostino

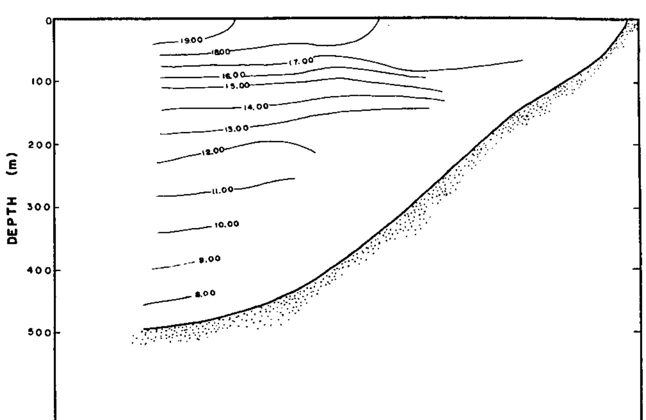

Figure 15. Temperature (centigrade) in a section northwest of Isla San Pedro Nolasco (see Figure 11) December 1971.

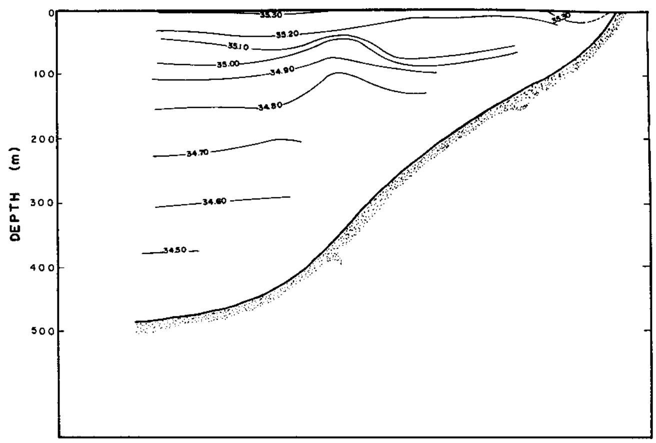

Figure 16. Salinity (parts per thousand) in a section northwest of Isla San Pedro Nolasco (see Figure 11) December 1971.

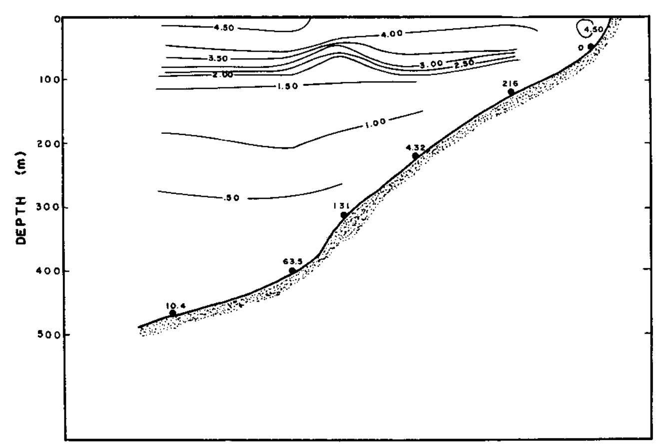

Figure 17. Dissolved oxygen (milliliters per liter) in a section northwest of Isla San Pedro Nolasco (see Figure 11) December 1971. Numbers on the sea floor show abundance of langostino, kg/h.

derived from those catches. The abundances in this set of catches are largest at intermediate depths and oxygen concentrations. The range of salinities is small and unlikely to be critical. The temperature range is large and the temperature at both the least and the greatest depths may be unfavorable and may therefore in part control the depth distribution of langostino. It is also natural to regard the very low oxygen concentrations as limiting. However, as Figures 13 and 17, and Table 5 show, catches of langostino were made at depths greater than 370 m in the southern Gulf (see also Figures 9, 11, and 12). Oxygen concentrations as low as 0.1 ml per liter have been observed in a considerable body of water between 400 and 800 m between the latitudes of Bahía de Yavaros and Guaymas (Roden 1964, Mathews and Granados, in preparation). This is discussed further below. It seems possible that langostino tolerates oxygen concentrations much lower than do many other organisms.

Size frequency distributions were obtained on two samples of langostino taken from catches in June 1971. The samples were small and the size frequency distribution irregular but the modal body length in both samples was close to 54 mm. During February–March 1972 collections were made off the Pacific coast of Baja California between Bahía de Asunción and

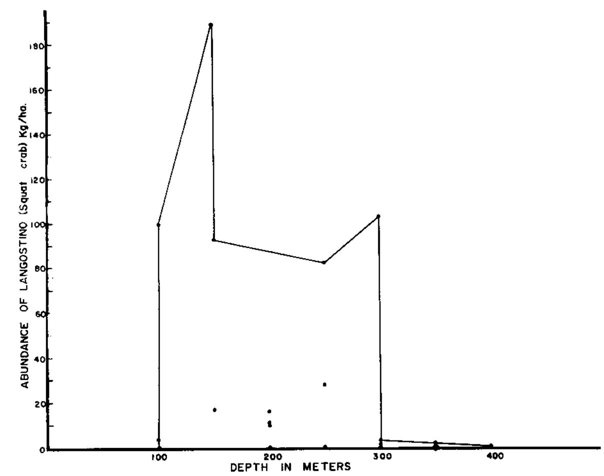

Figure 18. Depth of hauls and abundance of langostino in Pacific waters between Bahía de Asunción and Cabo San Lucas, February and March 1972.

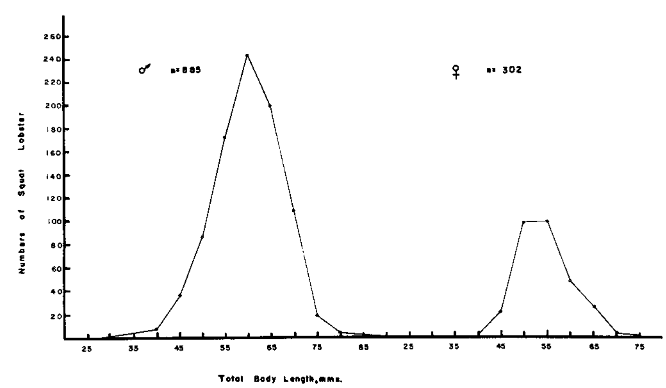

Figure 19. Size frequency distribution of male and female langostino taken in Pacific waters, February and March 1972.

Cabo San Lucas. Figure 18 shows that abundances were high and all of the productive catches were in water no deeper than 300 meters. The size distribution frequency for males and females separately was obtained on samples of all catches as shown in Figure 19. The modal length for males appears to be 60 mm, and for females it lies between 50 and 55 mm. The modal length for the Gulf samples and the mean of the two modal lengths for the Pacific samples are close. The sex ratio for the Pacific catches was 2.8 males to 1 female in January–February and nearly the same in October.

3. GROUNDFISH

Groundfish other than hake or langostino were taken throughout the length of the Gulf in considerable quantities. Tables 6, 7, and 8 show the abundances obtained at different seasons and depths in the north-

TABLE 6

Estimated biomass of groundfish other than hake and langostino north of Isla Tiburón, June 1971

Depth (meters)	Number of hauls	Mean abundance (kilograms per hectare)	Area (thousands of hectares)	Biomass (metric tons)
0–183	44	23	3,230	74,500
184–366	16	16.2	679	10,800
367–549	5	7.4	305	2,300
Total	65	--	--	87,100

TABLE 7

Estimated biomass of groundfish other than hake and langostino north of Isla Tiburón, August 1971

Depth (meters)	Number of hauls	Mean abundance (kilograms per hectare)	Area (thousands of hectares)	Biomass (metric tons)
0–146	0	--	2,918	67,300[1]
147–183	7	33.8	312	10,500
184–366	38	13.8	679	9,400
367–549	10	15.8	305	4,800
550–914	1	11.4	79	900
Total	56	--	--	92,900

[1] Assuming that the abundance at 0–183 m equalled that in June (23 kg/ha).

ern Gulf. The highest abundances were found in February–March and were concentrated in the shallowest areas. Table 9 summarizes the information for the other areas surveyed. In general abundances were lower than in the northern Gulf, especially in deeper water. South of Bahía de Yavaros the decline in catches in deep water is especially noticeable. In Figures 13, 14, 20, 21, and 22 the locations of hauls and abundances of groundfish are indicated.

For the areas south of Isla Tiburón, where mixed groundfish abundance varies little with season and for which few data are available, an average figure has been chosen to represent abundance the whole year round. Table 9 shows the calculated total biomass for these areas. The total biomass in the areas listed in Table 9 was 62000 mt, of which 59000 were concentrated in the first 183 m.

TABLE 8

Estimated biomass of groundfish other than hake and langostino north of Isla Tiburón, February–March 1972

Depth (meters)	Number of hauls	Mean abundance (kilograms per hectare)	Area (thousands of hectares)	Biomass (metric tons)
0– 78	0	--	1,790	174,000[1]
79–183	5	97.8	1,440	140,000
184–366	33	28.6	679	19,500
367–549	6	7.8	305	2,400
Total	44	--	--	335,900

[1] Assuming that the abundance at 0–78 m equalled that at 79–183 m.

TABLE 9

Estimated biomass of groundfish other than hake and langostino in the Gulf of California

Area	Depth (meters)	Mean abundance (kilograms per hectare)	Area (thousands of hectares)	Biomass (metric tons)
Isla Tiburón	0–183	20	480	9,600
to	184–366	10	206	2,100
Guaymas	367–549	2	206	400
Guaymas	0–183	20	686	13,700
to	184–366	10	69	700
Bay of Yavaros	367–549	2	103	200
Topolobampo shelf	0–183	30	206	6,200
Topolobampo	0–183	10	2,813	28,100
shelf to	184–366	0	412	0
C. Corrientes	367–549	0	--	0
Bay of La Paz	0–183	10	137	1,400
	184–366	0	69	--

Total biomass (metric tons) in various depths:

0–183 m	59000
184–360 m	2800
367–549 m	600
Total	62400

No data are presently available for estimating any of the population parameters of the mixed groundfish stock; in the absence of such data it is suggested that the sustainable yield is unlikely to be less than 0.2 or more than 0.5 of the biomass. Using these

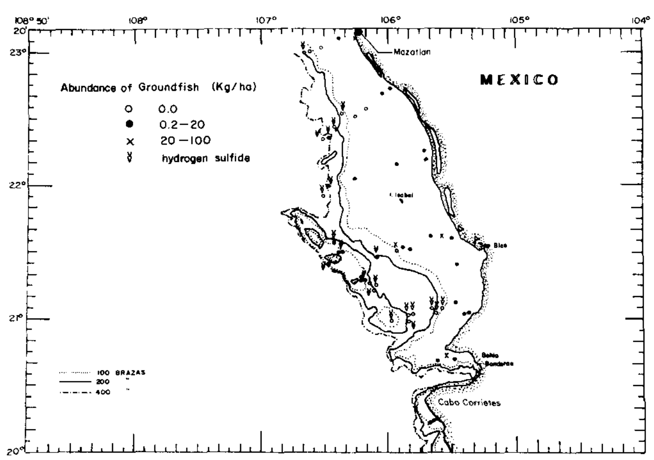

Figure 20. Location of hauls and abundance of groundfish, Mazatlán to Cabo Corrientes, July 1971.

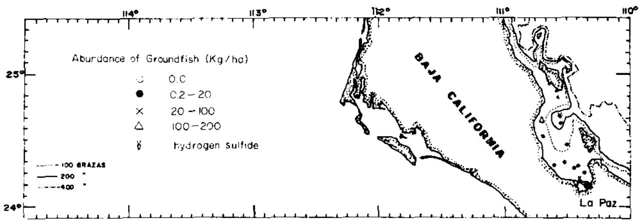

Figure 21. Location of hauls and abundance of groundfish, Bahía de La Paz, April 1971.

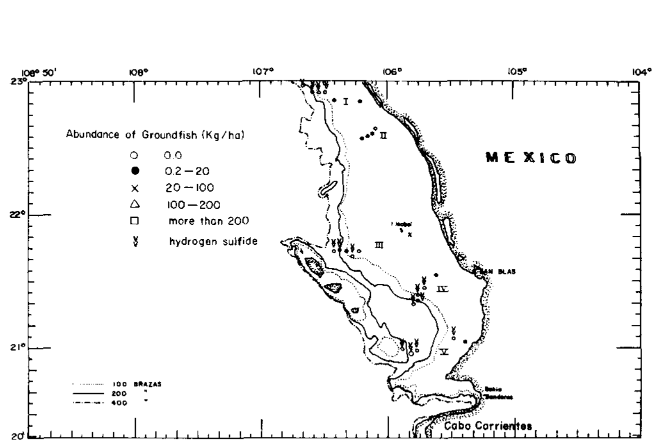

Figure 22. Location of hauls and abundance of groundfish, Mazatlán to Cabo Corrientes, November 1971.

figures, it is possible to estimate the yield from the Gulf of California groundfish. It is assumed that any fishery would be concentrated on these stocks during the period of highest abundance. It is further assumed that an estimated yield of less than 1000 mt would be of no commercial interest; this assumption holds if the groundfish are principally intended for reduction, but may require revision if a substantial fraction of the fish caught could be destined for human consumption. Table 10 shows that the total yield is likely to lie between 73000 and 186000 mt. Of this nearly 90% would be obtained from the area north of Isla Tiburón.

TABLE 10

Estimated potential yield of the Gulf of California groundfish other than hake and langostino (metric tons per year)

	North of Isla Tiburón	Isla Tiburón to Guaymas	Guaymas to Yavaros	Topolobampo Shelf	Topolobampo to Cabo Corrientes
Biomass above 183 m	314,000[1]	9,600[2]	13,700[2]	6,200[2]	28,100[2]
Minimum estimated yield	62,000	1,900	2,700	1,200	5,600
Maximum estimated yield	157,000	4,800	6,900	3,100	14,000
Minimum estimate for the whole Gulf	--	73,000	--	--	--
Maximum estimate for the whole Gulf	--	186,000	--	--	--

[1] Season of maximum biomass (February to March) from Table 8.
[2] From Table 9.

It is instructive to compare the figures given in Table 10 with the commercial production of groundfish in the Gulf of California. Attention is drawn to the largest component, i. e. to the bycatch. An extensive study of the bycatch of the Gulf of California shrimp fishery (Anon) is available based on 1117 trawls carried out in the months of July and August. Of these trawls 80% were carried out from 0–36 meters and the rest from 36–90 meters; only a very few were carried out below 73 meters, which may be regarded as the usual limit for the commercial shrimp fishery in the Gulf of California. As a result of this study, Chávez (personal communication) suggests that the best estimate of the ratio of the bycatch to the shrimp catch is 5:1 by weight. In 1971, statistics provided by the Secretaría de Industria y Comercio show that shrimp landings in Baja California and Sonora totalled 8300 mt and landings in Sinaloa and Nayarit totalled 15300 mt. Using Chávez's ratio, the corresponding bycatches are shown in Table 11.

TABLE 11

Geographical distribution of calculated bycatches and estimated potential yields of groundfish other than hake and langostino (metric tons per year)

Calculated bycatches		Estimated potential yields	*minimum*	*maximum*
B. Calif. and Sonora	41,500	North of Yavaros	66,600	169,000
Sinaloa and Nayarit	76,000	Topolobampo and south	6,800	17,100
Total (rounded)	117,000		73,000	186,000

The calculated bycatch for the whole Gulf is well within the range of the estimated yields. However the ratio of the bycatches separately calculated from the shrimp landings in the northern and southern Gulf states does not compare well with the estimated potential yields in the northern and southern Gulf (Table 11). This disparity suggests that a considerable fraction of the landings in southern parts may have been taken in the northern Gulf, or alternatively altogether outside of the Gulf.

DISCUSSION

As previously noted, in the southern section of the Gulf, many hauls brought up from the sea floor decaying organic matter smelling of hydrogen sulfide. Hydrographic samples from deep water had low concentrations of dissolved oxygen. Table 12 shows in a section off Pta. Raza (see section V in Figure 22) that at 40 meters the oxygen concentration was 2.6 ml/liter and at 140 meters and below, it was not more than 0.3 ml/liter (the lowest value that could be

TABLE 12

Abundance of groundfish, presence of hydrogen sulfide in sediments, and oxygen content of water at different depths (samples taken along section V in Figures 23 and 24)

Soundings (meters)	Hydrogen sulfide in sediments	Abundance of groundfish (kilograms per hectare)	Oxygen concentration: Sample depth (meters)	Oxygen concentration: milliliters per liter
57	–	1.5	40	2.62
146	+	0	140	0.3
270	+	0	243	<0.3
341	+	0	340	<0.3
457	+	0	433	<0.3

\+ present.
– absent.

read with the available equipment). Figure 23 shows that the oxygen concentration decreased sharply from above 4.0 ml/liter at 20 to 40 meters to less than 1.0 ml/liter at 70 to 80 meters. Figure 24 shows one of the hydrographic features related to this distribution, namely a temperature decrease of 10°C in the upper 60–70 meters. Since the salinity changed only 0.4‰ in this layer, the temperature drop was necessarily accompanied by a great increase in density with

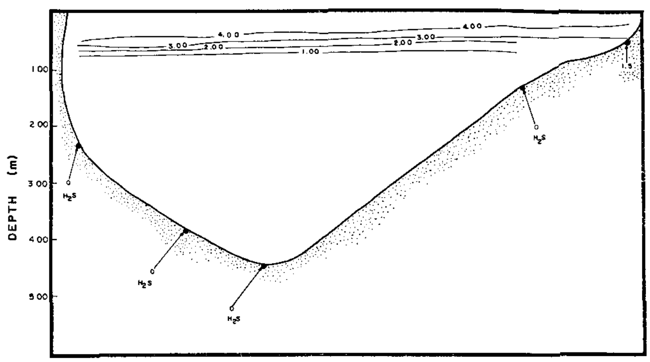

Figure 23. Dissolved oxygen (milliliters per liter) in a section off Pta. Raza (section V in Figure 22). The number and dot on the sea floor indicate the abundance (kg/ha) of groundfish found at that depth. The other labels indicate the presence of hydrogen sulfide in material from the sea floor.

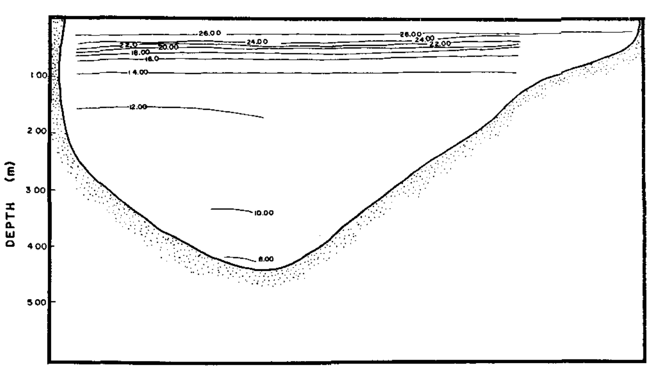

Figure 24. Temperature (centigrade) in a section off Pta. Raza (section V in Figure 22).

depth, and hence by very slow vertical mixing. The other important hydrographic feature is the water in the depths of the southern Gulf, which is part of a great body of such cool and oxygen-poor water in the eastern tropical Pacific (Roden 1964, Wyrtki 1966).

Table 12 and Figure 23 show at 57 m a modest catch of groundfish, with negligible catches below, while at each of the greater depths the trawl brough up matter smelling of hydrogen sulfide. Absence of fish, low oxygen concentrations in the water, and anaerobic decay in the sediments (producing hydrogen sulfide) are correlated throughout the Gulf. Table 13 shows the greatest depths at which hauls for groundfish were successful in localities surveyed, from the area north of Isla Tiburón to the area between Mazatlán and Cabo Corrientes. Proceeding from north

TABLE 13

Greatest depths at which groundfish were taken in localities from north to south in the Gulf of California

Locality	Date	Maximum depth (meters)
North of Isla Tiburón	June 1971	not less than[1] 400
North of Isla Tiburón	Aug–Sept 1971	not less than 550
North of Isla Tiburón	Feb–Mar 1972	not less than 400
Isla Tiburón to Guaymas	June 1971	not less than 400
Isla Tiburón to Guaymas	Sept 1971	not less than 300
Isla Tiburón to Guaymas	Feb–Mar 1972	not less than 400
Guaymas to Bahía de Yavaros	May 1971	not less than 450
Bahía de Yavaros	May 1971	not less than 200
Topolobampo shelf	May 1971	not less than 100
Altata to Mazatlán	April 1971	not less than 200
Pta. Piaxtla to Pta. Raza	Nov 1971	not less than 100
Mazatlán to Cabo Corrientes	July 1971	not less than 800[2]
Bahía de La Paz	April 1971	not less than 100

[1] "Not less than" means that catches were made down to this depth, but no deeper hauls were attempted. In all other cases, hauls were made at greater depths but catches were negligible.
[2] Catches were negligible between 200 and 700 meters. Moderate catches were made at 700 and 800 meters, and a haul at 1000 meters was unproductive.

to south the trend is upwards, that is fish are taken only in shallower and shallower water. This trend also appears in Table 9 where the abundances of groundfish decrease to the south, especially below 183 meters. While during the November and December cruises there was some trouble in measuring low oxygen concentrations aboard ship, the results were consistent with information on the distribution of dissolved oxygen in the Gulf available from other sources (Roden 1964, Scripps Institution 1965). Table 14 summarizes a pertinent aspect of this distribution as observed during four months in 1957. It is clear that the upper limit (defined as <1.0 ml per liter, Wyrtki, 1966) of the layer of oxygen-poor water slopes upward toward the mouth of the Gulf. During the cruises of the ALEJANDRO DE HUMBOLDT it was observed that in no case where the water close to the sea floor was found to have an oxygen content significantly higher than 0.3 milliliter per liter was hydrogen sulfide detected in a trawl in the same locality.[a]

As shown by Roden (1964) and the 1957 cruises by Scripps ships (Scripps Institution 1965) in the southern Gulf over a considerable area, a layer several hundred meters thick, e.g., between the depths of 400 and 800 m) contains less than 0.1 milliliter per liter of oxygen. Below this, slightly higher concentrations are found. While langostino can perhaps tolerate conditions within the layer, and there were observed in the present surveys two small to moderate catches of groundfish at 700 and 800 m (Table 13), for fishes valued commercially at the present time, the deeper waters of the southern Gulf do not appear promising.

[a] Since writing this paper one of us (CPM) has participated in a cruise on the R/V ALEXANDER AGASSIZ during which 10 trawls were carried out with a small otter trawl net, the foot rope of which was ~ 11 feet (3.35 m) long. Hydrocasts were taken at some localities where trawls were carried out. The results obtained confirmed the correlation between low O_2 concentrations and very low or zero fish catches. Sediment samples were taken with a box core by Mr. A. Soutar, and showed that H_2S did not appear in the sediments above depths of ~ 30–35 cm, nor did it appear outside of the zone where the O_2 minimum intersected the bottom.

TABLE 14

Least depth at which dissolved oxygen was less than 1.0 ml/liter

Station lines		Scripps Institution of Oceanography cruises 1957							
Number	Location (approximate)	February 5702	[a]	April 5704	[a]	June 5706	[a]	August 5708	[a]
108	N. of I. de la Guarda	--	--	--	--	X500	1	--	--
109	N. of I. de la Guarda	--	--	X200	1	--	--	X200–300	3
110						X250	1		
113	Between I. de la Guarda	--	--	X800	1	--	--	X100–700	4
114	and I. Tiburón	--	--	--	--	X1000	1	X800	1
115				X300–800	2				
116	S. of I. Tiburón	600	1	--	--	--	--	--	--
117	S. of I. Tiburón	X200–250[b]	3	--	--	--	--	--	--
121	S. of Guaymas	150–200	3	--	--	--	--	--	--
127		150–400	4	150–300	5	200–300	5	300	3
139	N. of I. del Carmen	75–200	4	100–150	4	200–250	5	250–300	5
145	Opposite La Paz	75–150	4	--	--	--	--	--	--
151	Opposite Altata	75–150	6	75–150	6	75–150	6	150–200	6
157	N. of Mazatlán in the	--	--	75–150	5	50–100	5	100–150	5
160	open Pacific	75–100	5	75–150	5	--	--	--	--

[a] These columns show the number of stations occupied on that line in that month. When there was more than one station occupied in a line, the two numbers show the shallowest and deepest observations. There was a tendency for the surface of the layer of low oxygen content to be shallower on the east side of the Gulf, so that the number on the left usually characterizes the area trawled.

[b] The X indicates that at all depths down to the greatest depth (or depths) sampled, as shown, the oxygen content was greater than 1.0 milliliter per liter.

ACKNOWLEDGEMENTS

We are particularly grateful to Mr. R. C. Lockerman of the U.S. National Oceanographic Data Centre of N.O.A.A., for his advice and assistance; we are also very grateful to Mr. B. C. Bedford, Fisheries Laboratory, Lowestoft, for much advice and invaluable assistance during work both at sea and in the laboratory. Biol. H. Chávez has also been very helpful to us.

Of course we are responsible for any errors this work may contain. Of the many others who helped us carry out our work we wish to single out Captain F. Hernández Ascencio of the R/V ALEJANDRO DE HUMBOLDT, and Ingeniero Adolfo Torres May of the Superintendencia de Buques in Mazatlán. Without their invaluable support most of what we did would not have been done.

We also wish to acknowledge the assistance of Dr. G. L. Kesteven, then Project Manager, and Dr. M. Ruivo, Fisheries Division at FAO in Rome, whose efforts made it possible to carry out this work.

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DISTRIBUTION AND ABUNDANCE OF FISH EGGS AND LARVAE IN THE GULF OF CALIFORNIA

H. GEOFFREY MOSER, ELBERT H. AHLSTROM,
DAVID KRAMER, and ELIZABETH G. STEVENS

INTRODUCTION

From time to time during its 24 year history the oceanographic cruises of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) have extended beyond the California Current system. One example is the multivessel NORPAC Expedition which encompassed much of the northeast Pacific in 1955. Another such example is the series of seven oceanographic cruises made into the Gulf of California during 1956 and 1957.

Ships and personnel from the National Marine Fisheries Service (NMFS) and Scripps Institution of Oceanography (SIO) took part in the seven cruises, employing methods described by Kramer et al. (1972). On the first of these cruises (5602) the NMFS vessel BLACK DOUGLAS occupied 93 stations from the mouth of the Gulf northward as far as Tiburón Island from February 6 to 18, 1956 (Figure 1). On the second cruise (5604) the BLACK DOUGLAS occupied 129 stations throughout the full length of the Gulf from 8 to 24 April, 1956. On the third cruise (5612) the SIO vessel HORIZON occupied an abbreviated set of 79 stations, primarily on the western side of the Gulf and as far north as Tiburón Island from December 3 to 17, 1956. On cruise 5702 the SIO vessel SPENCER F. BAIRD occupied 70 stations as far northward as Tiburón Island February 9–20, 1957 (Figure 3). The remaining cruises in 1957 (Figure 3) each occupied a pattern of stations throughout the entire Gulf. On cruise 5704 the BLACK DOUGLAS occupied 125 stations from 7 to 22 April. The SIO vessel STRANGER occupied 132 stations on cruise 5706 from June 9 to 23.

The oceanographic observations from these cruises have been published by Scripps Institution of Oceanography (1963, 1965). Except for Ahlstrom's illustration of the distribution of Pacific mackerel on cruise 5602 (Ahlstrom, 1956, Figure 21), the data on the fish eggs and larvae have never been reported, largely because their identification has been accomplished over a long period, when time has permitted diversion from the task of identifying eggs and larvae from regular CalCOFI cruises. It is the purpose of this paper to give an overview of the seasonal abundance of the fish larvae collected on six of these cruises (5602–5706) and to give the patterns of geographic distribution for the abundant species which are important as commercial or forage fishes. Eggs of the Pacific mackerel and sardine were identified for three cruises (5602, 5604, 5702) and are used to estimate the spawning biomass of these species for those years. Finally the distribution and abundance of fish larvae is discussed in relation to the special oceanographic conditions in the Gulf and in relation to zoogeographic patterns of the subtropical and tropical northeast Pacific. Before embarking on this, however, it would be useful to review briefly the environmental characteristics of the Gulf of California and to give some general background information on its ichthyofauna.

This unique body of water is bounded by arid Baja California on the west and the Mexican states of Sonora and Sinaloa on the east. It extends about 1400 km between latitudes 23 and 32 north and has an average width of about 150 km. Wegener (1922) proposed that the Gulf was formed by the separation of Baja California from the Mexican mainland, a supposition which has been strengthened by recent investigations into sea floor spreading in that region (Elders et al., 1972). The northern $\frac{1}{3}$ of the Gulf is separated

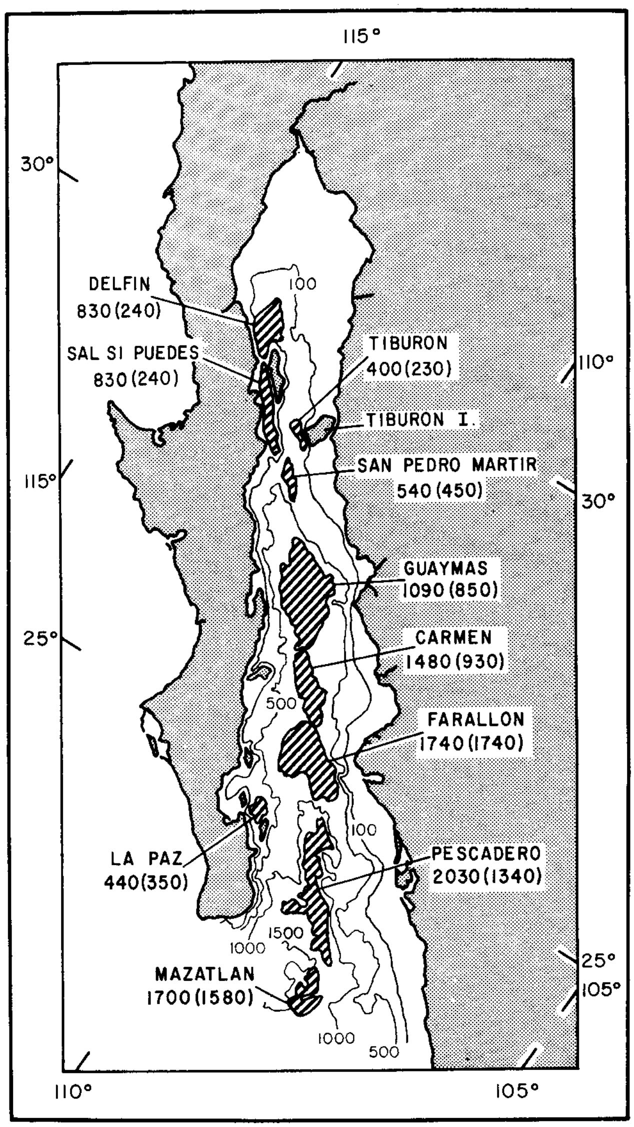

FIGURE 1. Basins of the Gulf of California with their maximum depths and sill depths (fathoms). Redrawn from van Andel (1964) and depth data from same publication.

from the lower part by two large islands, Ángel de la Guarda and Tiburón. Except for two basins, Delfín and Sal si Puedes shown in Figure 1, the head of the Gulf is shallow, with an average depth of about 200 m. Alluvial deposits, largely from the Colorado River, have filled the trough in this region to produce a smooth concave sea floor. This contrasts sharply with the bathymetry south of Tiburón and Ángel de la Guarda, which is characterized by a series of deep basins (down to 3000 m) running along the axis of the trough. These basins are separated by transverse sills of about 1500 m depth and the entire series is separated from the shallow Delfín and Sal si Puedes basins by a shallow sill of 200–250 m. The coastal features of the eastern and western sides of the Gulf are in sharp contrast. The Baja California coast south of Ángel de la Guarda is characterized by steep rocky escarpments broken occasionally by sandy beaches and by two major bays, Bahía La Paz and Bahía Concepción. Bordering the coastline is a linear series of small rocky islands. The sandy beaches become more extensive north of Bahía Concepción and are almost unbroken in the north. The eastern shoreline of the Gulf, except for a region of rocky headlands between Bahía Kino and Guaymas, is characterized by a wider shelf than is found on the western shore and by extensive beaches of sand or mud.

What is known about the oceanography of the Gulf has been reviewed in a series of papers by Roden (1958), Roden and Groves (1959), and Roden (1964). Situated between arid and mountainous Baja California on the west and the arid mainland to the east, it is an evaporation basin with highly saline and generally warm surface waters. Surface salinities show a general increase from south to north with a range of 34.8‰ to 36‰ but there is little seasonal variation for any given latitude. Surface temperatures, however, show a very large seasonal range that increases from about 9°C at the Gulf entrance to about 16°C at the head of the Gulf. Composite tidal range also increases markedly from south to north in the Gulf. From the Gulf entrance to Tiburón the increase is only slight with a spring range of about $1\frac{1}{2}$ m. North of Tiburón the range increases rapidly to a maximum spring range of 10 m at the mouth of the Colorado River. This strong tidal mixing in the northern part of the Gulf is thought to be the reason for the year-round low surface temperatures in the vicinity of Ángel de la Guarda and Tiburón Islands, and for the relatively high temperatures, salinities, and oxygen concentrations at great depths in the isolated Delfín and Sal si Puedes Basins.

The water in the central and southern regions of the Gulf is in communication with the Pacific, and has the properties of Equatorial Pacific water. Below the thermocline the water is similar to that in the neighboring Equatorial Pacific with a salinity minimum of about 34.5‰ between 600 and 1000 m and a pronounced oxygen minimum of 0.1–0.2 ml/L between 400 and 800 m. Above the thermocline is a water mass referred to by Roden and Groves (1959) as "Gulf water." They view it as Equatorial Pacific water which has been transformed into water of higher salinity by evaporation.

The fish fauna indicates that the Gulf is clearly part of the Tropical American or Panamic faunal province. Walker (1960) in his review of the Gulf ichthyofauna, recorded 586 species of fish in the Gulf, of which 526 are shorefishes. Nearly $\frac{3}{4}$ of the shorefish are tropical or subtropical species with their principal ranges to the south of the Gulf. About 50 species, or 10% of the total, have their principal distributions to the north of the Gulf. The majority of these are found in the northern region of the Gulf, as disjunct species from the Southern California or San Diegan fauna. The remaining 92 species, or 17% of the total, are endemic to the Gulf.

In comparison with the Panamic fauna to the south, Walker has noted that the Gulf has an unusually high number of rocky shore species, a relatively poor representation of muddy bottom forms, and a high percentage of endemic species. The blennioid families Clinidae, Tripterygidae, and Chaenopsidae are perhaps the best examples of the profusion of rocky shore fishes in the Gulf. These groups have been reviewed extensively by a number of investigators including Hubbs (1952), Springer (1958), Rosenblatt (1959) and Steens (1963), and are among the best known of eastern Pacific shorefishes.

The high degree of speciation and endemism in these families might be accounted for by the abundance of semi-isolated rocky habitats, particularly on the peninsula coast of the Gulf. Also, the long stretch of sandy shoreline running from Guaymas to Mazatlán acts as a faunal barrier isolating the rocky shore fishes of the Gulf from those to the south. The paucity of muddy bottom species, most notably the

TABLE 1

Major constituents of three mid-water trawling expeditions to the Gulf of California

Species	Percent of Total Catch		
	Lavenberg and Fitch (1966)	Robison (1972)	Brewer (1973)
Myctophidae			
Triphoturus mexicanus	88.8	68.0	80.6
Diogenichthys laternatus	0.1	7.2	5.8
Benthosema panamense	5.0	2.8	0.9
Other myctophids	0.4	1.6	1.9
Gonostomatidae			
Vinciguerria lucetia	0.4	10.2	2.4
Cyclothone spp.	--	8.2	--
Bathylagidae			
Leuroglossus stilbius	0.5	0.6	5.4
Clupeidae			
Sardinops sagax caeruleus	1.6	--	--
Merlucciidae			
Merluccius sp.	1.3	--	--
Scombridae			
Scomber japonicus	0.6	--	--
All others	1.3	1.4	3.0

TABLE 2

Summary of occurrences and abundance (standard haul totals) of fish larvae in the Gulf of California during 6 cruises in 1956–1957

Kinds of larvae	5602		5604		5612		5702		5704		5706		Total	
	occ.	std. no.	occ.	std. no.	occ.	std. no.	occ.	std. no.	occ.	std. no.	occ.	std. no.	occ.	std. no.
Clupeidae:														
Sardinops sagax caeruleus	34	1,108	45	1,856	23	1,660	28	1,511	45	1,865	0	0	175	8,000
Etrumeus teres	11	122	40	1,090	12	335	11	172	24	757	10	278	108	2,754
Opisthonema spp.	0	0	0	0	0	0	0	0	0	0	55	23,217	55	23,217
Engraulidae	3	29	6	140	4	60	1	6	9	297	33	2,880	56	3,412
Bathylagidae:														
Bathylagus nigrigenys	8	57	6	85	2	13	3	27	8	123	13	90	40	395
Leuroglossus stilbius	50	1,139	42	1,217	14	209	32	2,168	27	357	1	6	166	5,096
Argentinidae:														
Argentina sialis	1	6	2	7	0	0	2	12	3	32	0	0	8	57
Gonostomatidae:														
Vinciguerria lucetia	35	4,718	37	4,278	32	1,800	38	18,218	34	6,818	87	19,231	263	55,063
Diplophos taenia	0	0	0	0	1	15	0	0	1	3	0	0	2	18
Sternoptychidae:														
Argyropelecus sp.	0	0	0	0	0	0	0	0	0	0	1	26	1	26
Stomiatidae:														
Stomias atriventer	1	3	2	20	0	0	1	15	1	6	6	43	11	87
Melanostomiatidae:														
Bathophilus filifer	0	0	0	0	3	22	0	0	3	19	0	0	6	41
Synodontidae:														
Synodus spp.	0	0	1	34	2	22	1	9	2	79	32	1,069	38	1,213
Aulopidae	0	0	0	0	0	0	0	0	0	0	1	4	1	4
Myctophidae:														
Benthosema panamense	12	115	0	0	36	1,438	0	0	2	148	56	5,685	106	7,386
Diaphus pacificus	0	0	0	0	4	187	0	0	1	12	2	13	7	212
Diogenichthys laternatus	45	2,142	45	2,301	32	1,342	41	2,178	29	2,326	49	2,451	241	12,740
Hygophum atratum	4	31	3	37	3	58	12	146	6	50	3	17	31	339
Lampanyctus spp.	8	103	9	103	6	45	1	10	7	62	13	140	44	463
Myctophum aurolaternatum	1	6	0	0	1	3	0	0	3	21	0	0	5	30
Triphoturus mexicanus	10	64	24	348	41	2,298	10	156	44	1,179	72	14,798	201	18,843
Myctophidae (unidentified)	2	18	0	0	5	71	2	26	3	34	18	290	30	439
Scopelarchidae:														
Scopelarchoides nicholsi	1	5	1	12	2	18	0	0	0	0	0	0	4	35
Paralepididae	0	0	0	0	2	12	0	0	0	0	2	6	4	18
Exocoetidae:														
(mostly *Oxyporhamphus*)	0	0	0	0	0	0	0	0	1	3	17	122	18	125
Gadidae:														
Merluccius sp.	5	35	19	460	0	0	4	24	9	67	0	0	37	586
Moridae:														
Physiculus spp.	5	27	3	172	2	20	6	49	1	6	0	0	17	274
Other	0	0	0	0	1	9	0	0	0	0	2	16	3	25
Macrouridae	0	0	5	47	2	21	2	19	2	11	0	0	11	98
Bregmacerotidae:														
Bregmaceros bathymaster	24	10,461	6	16,339	10	1,185	13	1,384	9	486	75	17,916	137	47,771
Fistulariidae	0	0	0	0	1	8	0	0	0	0	7	63	8	71
Syngnathidae	0	0	2	20	0	0	0	0	0	0	3	9	5	29
Melamphaidae	2	12	2	17	3	20	4	35	0	0	4	16	15	100
Leptocephali	6	29	5	42	11	102	7	66	16	115	44	263	89	617
Scombridae:														
Auxis sp.	0	0	1	13	1	3	1	2	2	27	60	1,789	65	1,834
Euthynnus	0	0	0	0	0	0	0	0	0	0	19	164	19	164
Sarda chiliensis	0	0	0	0	0	0	0	0	0	0	11	396	11	396
Scomber japonicus	34	6,469	64	2,891	7	100	29	2,969	50	4,008	4	17	188	16,454
Scomberomorus sp.	0	0	0	0	0	0	0	0	1	5	11	114	12	119
Unidentified	0	0	0	0	0	0	0	0	0	0	16	362	16	362
Apogonidae	0	0	0	0	1	5	0	0	0	0	2	7	3	12
Atherinidae	0	0	1	1	0	0	0	0	3	15	0	0	4	16
Bramidae	0	0	1	11	0	0	0	0	0	0	0	0	1	11
Branchiostegidae	0	0	0	0	0	0	0	0	2	15	2	14	4	29
Carangidae	2	17	13	90	17	281	3	21	6	36	56	1,317	97	1,762
Carapidae	1	3	1	3	1	40	1	17	1	5	7	56	12	124
Clinidae	0	0	0	0	0	0	0	0	3	38	0	0	3	38
Coryphaenidae	0	0	0	0	1	3	0	0	4	28	15	94	20	125
Gempylidae	0	0	0	0	2	5	0	0	0	0	0	0	2	5
Gerridae	0	0	0	0	0	0	0	0	0	0	27	2,064	27	2,064
Gobiidae	4	20	10	216	5	79	3	65	8	79	48	1,301	78	1,760
Kyphosidae	0	0	1	17	0	0	0	0	0	0	35	960	36	977
Labridae	1	6	0	0	0	0	1	129	1	7	16	95	19	237
Lutjanidae	0	0	0	0	0	0	0	0	0	0	2	6	2	6
Microdesmidae	0	0	0	0	0	0	0	0	0	0	3	11	3	11
Mugilidae	3	28	0	0	0	0	0	0	0	0	24	192	27	220
Nomeidae	0	0	0	0	9	149	0	0	8	93	42	415	59	657
Ophidiidae—Brotulidae	3	13	5	32	7	60	3	32	4	16	39	797	61	950
Polynemidae	0	0	0	0	0	0	0	0	0	0	6	141	6	141
Pomacentridae	9	153	0	0	0	0	0	0	1	2	15	218	25	373
Pomadasyidae	0	0	0	0	0	0	0	0	0	0	25	1,373	25	1,373
Sciaenidae	4	98	18	522	4	64	9	180	12	160	38	2,864	85	3,888

TABLE 2

Summary of occurrences and abundance (standard haul totals) of fish larvae in the Gulf of California during 6 cruises in 1956–1957 (Continued)

Kinds of Larvae	5602		5604		5612		5702		5704		5706		Total	
	occ.	std. no.	occ.	std. no.	occ.	std. no.	occ.	std. no.	occ.	std. no.	occ.	std. no.	occ.	std. no.
Scorpaenidae:														
Sebastes spp.	8	75	15	87	5	101	6	174	1	6	0	0	35	443
Other	17	116	5	29	19	229	8	92	11	108	77	1,468	130	2,042
Serranidae	1	5	1	11	6	104	2	9	5	44	82	3,508	97	3,681
Sphyraenidae	0	0	0	0	0	0	0	0	1	4	15	136	16	140
Stromateidae	0	0	1	22	2	124	0	0	2	17	0	0	5	163
Tetragonuridae	0	0	0	0	2	20	0	0	0	0	0	0	2	20
Trichiuridae	4	37	1	13	12	232	2	32	1	5	28	4,668	48	4,987
Triglidae	2	18	4	41	4	23	2	21	12	166	38	510	62	779
Bothidae	9	76	48	620	31	536	15	145	22	138	141	2,746	264	4,261
Cynoglossidae:														
Symphurus	19	131	6	33	13	171	10	282	8	91	43	362	99	1,070
Balistidae	0	0	0	0	0	0	0	0	0	0	2	6	2	6
Tetraodontidae	0	0	0	0	0	0	0	0	0	0	4	35	4	35
Lophiidae	0	0	0	0	0	0	0	0	0	0	1	5	1	5
Gigantactinidae	0	0	0	0	0	0	0	0	1	6	0	0	1	6
Disintegrated	4	29	13	85	4	38	3	39	12	90	83	3,403	119	3,684
Unidentified	16	87	38	747	27	1,304	15	219	33	987	95	3,394	225	6,738
Total	93	27,611	129	34,109	79	14,644	70	30,659	125	21,072	132	123,657	628	251,752

croakers and catfishes, is more difficult to explain. Walker suggests that the wide expanse of open water across the mouth of the Gulf acts as a barrier isolating the Cape San Lucas region and lower peninsular coast from the mainland, but the general paucity of Panamic muddy and sandy bottom fishes in other areas of the Gulf probably relates to the lower temperatures and greater seasonal temperature ranges as compared to waters south of the Gulf. Certainly these are important limiting factors in the upper Gulf, which has only ½ the number of shore fish species found in the central and southern Gulf. Here also, the great tidal ranges probably also are a limiting factor.

The midwater fish fauna of the Gulf is reasonably well known, owing to recent studies by Lavenberg and Fitch (1966), Robison (1972), and Brewer (1973). Although their trawls differed in mouth size and in mesh size, essentially the same species were dominant in the three surveys (Table 1). As in midwater trawl surveys in other areas of the world, the family Myctophidae or lanternfishes dominated the three Gulf surveys, however, the dominance of these fishes was even more striking in the Gulf. They made up 94% of the catch in the Lavenberg and Fitch study, about 80% in Robison's samples, and 89% in Brewer's. A single myctophid species, *Triphoturus mexicanus*, was by all odds the dominant species; it represented 89%, 68% and 81% of all fish taken in the three surveys. As in the shorefishes, most of the midwater species of the Gulf have their principal distributions to the south of the Gulf, the notable exceptions being *T. mexicanus* and *Leuroglossus stilbius*, which are temperate-subtropical in distribution. To our knowledge there are no endemic midwater fishes in the Gulf, although several midwater fishes including *Hygophum atratum*, *L. stilbius* and *T. mexicanus* were described originally from the Gulf.

In general, the major midwater families are represented by a reduced number of species compared with waters at the same latitudes on the outer coast and adjacent waters south of the Gulf. For example, in the Myctophidae, about 30 species and 20 genera are found in outer coast waters and in adjacent waters to the south. Thirteen of these species and 10 of the genera, or less than half, are found in the Gulf. The same can be said for the Gonostomatidae, with about 10 species occurring on the outer coast and only 4 in the Gulf. Likewise, there are 5 species of bathylagid smelts in the outer coast waters and only 2 in the Gulf. A single species of the family Scopelarchidae has been taken in the Gulf whereas 5 species representing 4 genera are found on the outer coast. Typically, those midwater species recorded from the Gulf do not penetrate very far north and most are limited to the southernmost basins. Only *Vinciguerria lucetia*, *Diogenichthys laternatus*, *T. mexicanus*, and *L. stilbius* are widespread and abundant in the southern and central regions of the Gulf. *Benthosema panamense* and *T. mexicanus* are the only midwater species that occur in significant numbers in the upper regions of the Gulf.

Midwater trawls are highly selective sampling devices as shown by comparing their catches with relative abundances of species taken as larvae in plankton nets. The results of the CalCOFI cruises in the Gulf as shown below form an interesting comparison with those of the midwater trawl surveys.

RESULTS

Over a quarter of a million fish larvae (standard haul totals) were obtained on the six cruises. As shown in Table 2 the total numbers of larvae varied considerably from cruise to cruise. Cruise 5612 had the lowest total number of larvae, although on the basis of numbers of larvae per station, 5704 was the lowest with about 172 larvae per station. Cruise 5706 ranked highest in total numbers and in numbers per station with 937. Nearly as many larvae were collected on this single cruise as on the other five cruises combined.

In contrast to the fluctuation in numbers of larvae from cruise to cruise there was a general consistency in the kinds of larvae that were most abundant during the six cruises.

The larvae of two commercial species, the Pacific mackerel, *Scomber japonicus*, and the Pacific sardine, *Sardinops sagax caeruleus*, were highly prominent. Pacific mackerel larvae ranked second in total abundance on three of the six cruises (5602, 5702, 5704) and third on 5604 (Table 2). Overall they ranked fifth with 6.5% of the total larvae obtained on all six cruises (Table 3). They were widespread, as well as abundant, and on 5604 and 5704 had the highest number of occurrences of any species collected (Table 2). Spawning of *S. japonicus* (a species of northern affinity) was found to be curtailed sharply during the

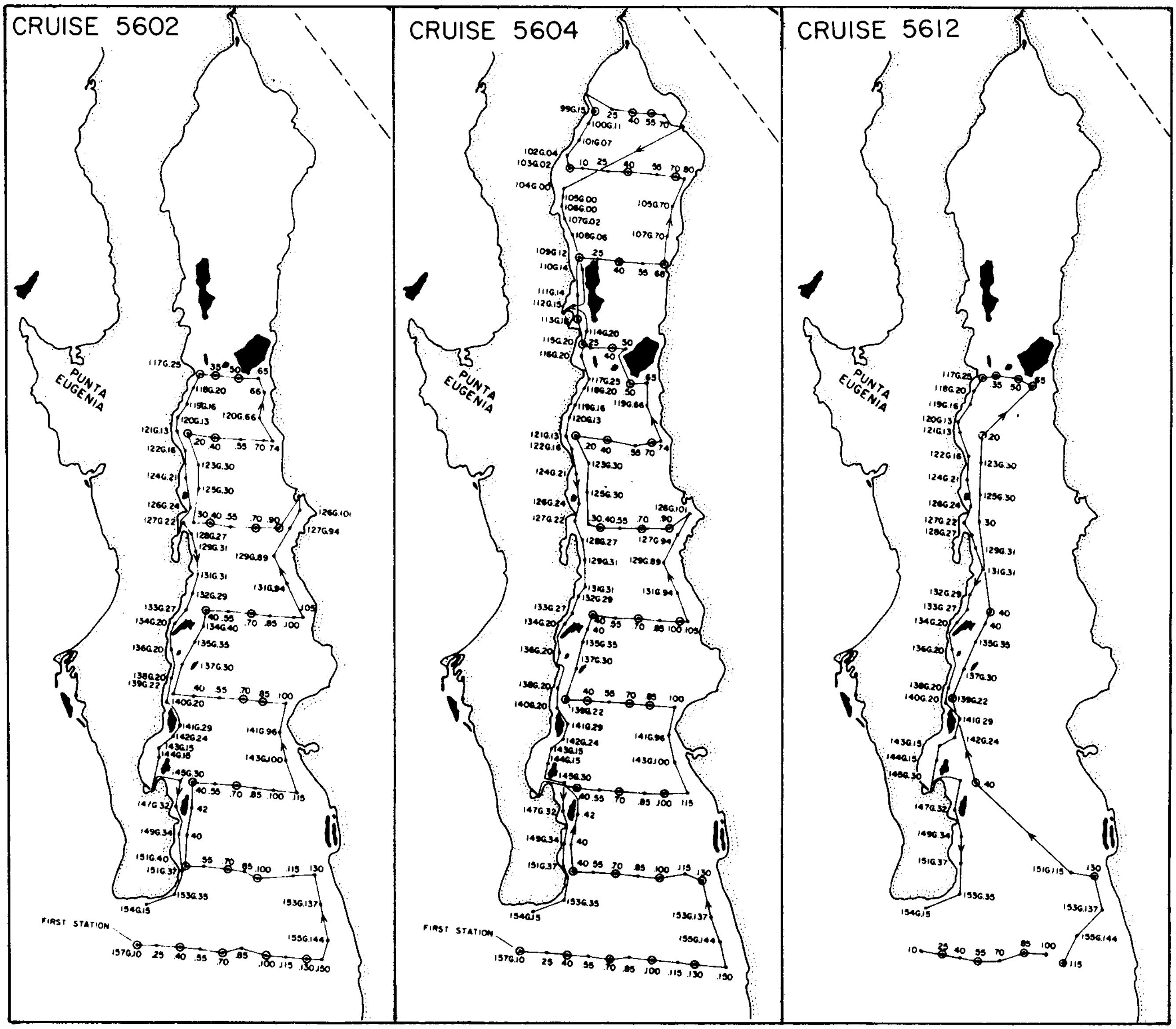

FIGURE 2. Station pattern for CalCOFI cruises into the Gulf of California in February, April, and December, 1956. From Oceanographic Observations of the Pacific: 1956 (SIO, 1963).

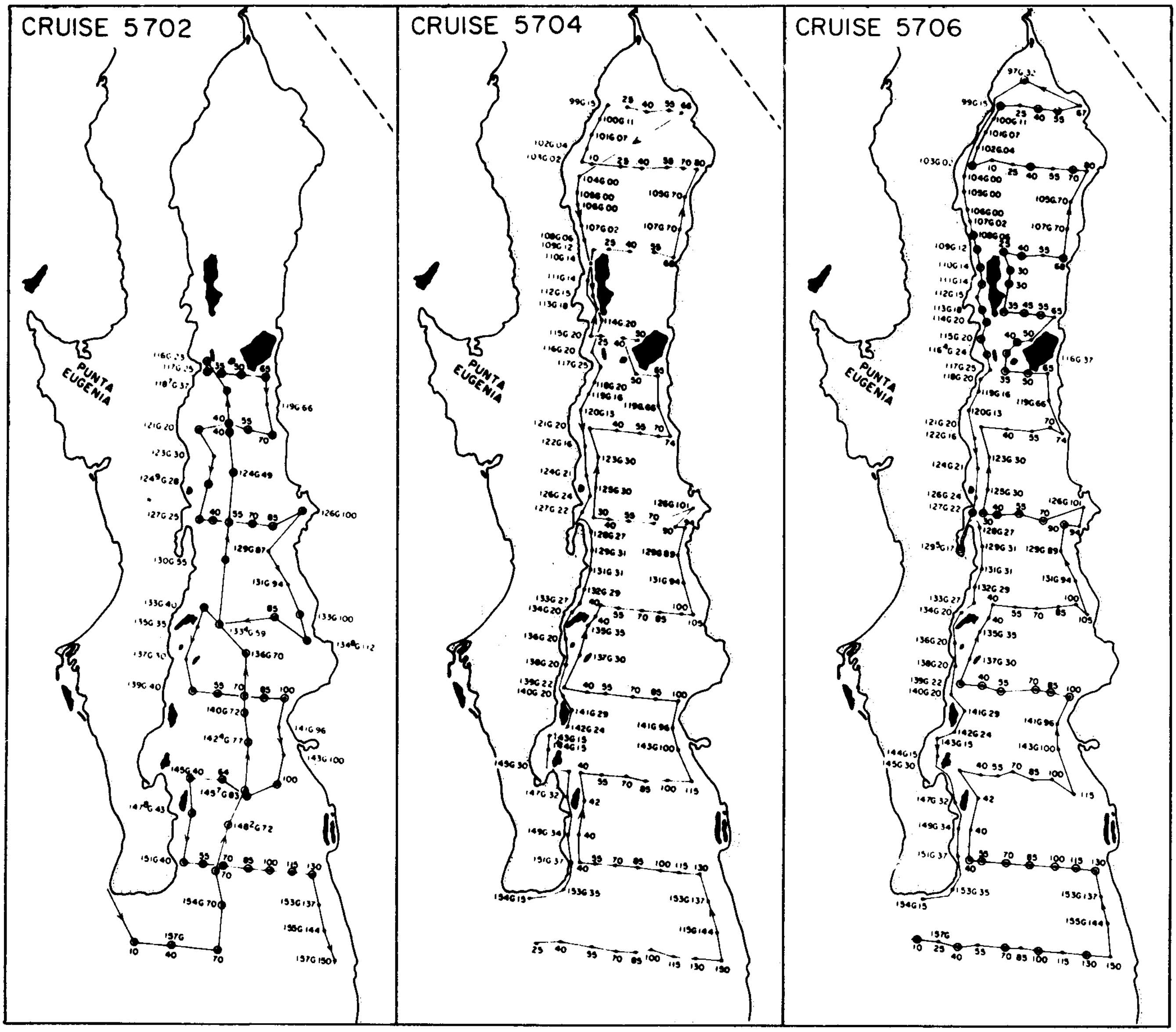

FIGURE 3. Station pattern for CalCOFI cruises into the Gulf of California in February, April, and June, 1957. From Oceanographic Observations of the Pacific: 1957 (SIO, 1965).

warm water cruise of 5706, and the larvae of tropical scombrids (*Auxis, Sarda, Euthynnus, Scomberomorus*) appeared in the collections.

Pacific sardine larvae were more consistent in relative abundance than those of Pacific mackerel, although they ranked as high as third on only one cruise (5612). They ranked sixth on 5602, fifth on 5604 and 5702, and fourth on 5704. It too is a species of cold water affinity and was not taken on 5706, but was replaced by larvae of the tropical clupeid genus *Opisthonema,* which ranked first in total abundance on that cruise.

Another species of potential commercial importance, the round herring, *Etrumeus teres,* was consistently represented on all but cruise 5706, it ranked no lower than eleventh and on two cruises, 5604 and 5704, ranked seventh.

The most consistently abundant species was the eastern Pacific lightfish, *Vinciguerria lucetia.* It ranked no lower than third in total abundance (5602), and on two cruises (5702, 5704), it ranked first. On 5702 it accounted for almost 60% of the total fish larvae collected. On 5706, it ranked second but occurred on 87 stations, the highest number of occurrences for any species during the six cruises. Its overall rank for all cruises was first, contributing 21.9% of all fish larvae obtained.

Another consistently abundant species was the small gadoid fish, *Bregmaceros bathymaster.* It was the most abundant species on the first two cruises, decreased in

TABLE 3

Rank and percentage contribution by cruise of categories of fish larvae that ranked among the top 25 for all cruises combined in Gulf of California during 1956–1957

Kinds of Larvae	5602		5604		5612		5702		5704		5706		Total	
	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%
Clupeidae:														
Sardinops sagax caeruleus	6	4.0	5	5.4	3	11.3	5	4.9	4	8.8	0	0	7	3.2
Etrumeus teres	10	0.4	7	3.2	9	2.3	11	0.6	7	3.6	--	0.2	17	1.1
Opisthonema spp.	0	0	0	0	0	0	0	0	0	0	1	18.8	3	9.2
Engraulidae	22	0.1	15	0.4	24	0.4	--	<0.1	10	1.4	10	2.3	16	1.4
Bathylagidae:														
Leuroglossus stilbius	5	4.1	6	3.6	13	1.4	4	7.1	9	1.7	--	<0.1	10	2.0
Gonostomatidae:														
Vinciguerria lucetia	3	17.1	2	12.5	2	12.3	1	59.4	1	32.4	2	15.5	1	21.9
Synodontidae:														
Synodus spp.	0	0	25	0.1	--	0.2	--	<0.1	21	0.4	20	0.9	24	0.5
Myctophidae:														
Benthosema panamense	11	0.4	0	0	4	9.8	0	0	13	0.7	5	4.6	8	2.9
Diogenichthys laternatus	4	7.8	4	6.8	5	9.2	3	7.1	3	11.0	13	2.0	6	5.1
Triphoturus mexicanus	16	0.2	12	1.0	1	15.7	12	0.5	5	5.6	4	12.0	4	7.5
Bregmacerotidae:														
Bregmaceros bathymaster	1	37.9	1	47.9	7	8.1	6	4.5	8	2.3	3	14.5	2	19.0
Scombridae:														
Auxis rochei	0	0	--	<0.1	--	<0.1	--	<0.1	--	<0.1	15	1.4	20	0.7
Scomber japonicus	2	23.4	3	8.5	21	0.7	2	9.7	2	19.0	--	<0.1	5	6.5
Carangidae	--	0.1	17	0.3	11	1.9	--	0.1	--	0.2	18	1.1	21	0.7
Gerridae	0	0	0	0	0	0	0	0	0	0	14	1.7	19	0.8
Gobiidae	--	0.1	13	0.6	22	0.5	18	0.2	22	0.4	19	1.0	22	0.7
Pomadasyidae	0	0	0	0	0	0	0	0	0	0	17	1.1	23	0.5
Sciaenidae	13	0.4	10	1.5	23	0.5	10	0.6	12	0.8	11	2.3	13	1.5
Scorpaenidae:														
(incl. *Sebastes*)	7	0.7	16	0.3	10	2.3	8	0.9	16	0.5	16	1.2	18	1.0
Serranidae	--	<0.1	--	<0.1	18	0.7	--	<0.1	--	0.2	7	2.8	14	1.5
Trichiuridae	18	0.1	--	<0.1	12	1.6	23	0.1	--	<0.1	6	3.8	11	2.0
Bothidae	15	0.3	9	1.8	8	3.7	13	0.5	14	0.7	12	2.2	12	1.7
Cynoglossidae:														
Symphurus spp.	9	0.5	--	0.1	15	1.2	7	0.9	19	0.4	--	0.3	25	0.4
Disintegrated specimens	23	0.1	19	0.2	--	0.3	20	0.1	20	0.4	8	2.8	15	1.5
Unidentified	14	0.3	8	2.2	6	8.9	9	0.7	6	4.7	9	2.7	9	2.7
All others	--	2.0	--	3.6	--	7.0	--	2.1	--	4.8	--	4.8	--	4.0

rank to seventh, sixth, and eighth during the next three cruises, and increased again to third on 5706. Its composite rank for all six cruises was second. Except for cruise 5706, this species was characterized by a relatively low number of occurrences. For example, on cruise 5604 it occurred on only six stations but accounted for nearly half the fish larvae taken on the entire cruise. Similarly clumped occurrences of this species were found on EASTROPAC cruises (Ahlstrom 1972).

Three species of lanternfishes of the family Myctophidae were abundant. The most consistent of these was *Diogenichthys laternatus* which ranked among the top five kinds of larvae in total abundance on all cruises except 5706, and ranked as high as third on two cruises (5702, 5704). It also had a consistently high number of occurrences, ranging from 29 in 5704 to 49 in 5706. For all cruises *D. laternatus* ranked sixth with 5.1% of the total larvae. Another lanternfish, *Triphoturus mexicanus,* ranked among the top ten on only three cruises, but on these it ranked first in abundance on 5612, fifth on 5704, and fourth on 5706. For all cruises *T. mexicanus* larvae ranked fourth with 7.5% of total fish larvae. *Benthosema panamense* ranked among the upper ten most abundant only on 5612 and 5706, but on these cruises ranked fourth and third, respectively. Its overall ranking was eighth.

Another midwater species, the deepsea smelt, *Leuroglossus stilbius,* was consistently abundant on five of the six cruises. It ranked fifth on 5602, sixth on 5604, thirteenth on 5612, fourth on 5702, and ninth on 5704. It also was characterized by a high number of occurrences, and on 5602 had the most occurrences (50) of any species collected. Being a species of northern affinity it occurred on only a single station on the warm water cruise of 5706. Its overall rank was tenth, with 2.0% of the total larvae.

It is interesting to compare the relative abundance of species of these cruises with the rankings for waters of the same latitudes on the outer coast. In 1956 (Table 4) the northern anchovy, *Engraulus mordax,* was by far the most abundant species, at about 38% of the total, followed by the hake, *Merluccius producuts,* with about 28%. These were followed by the sardine, *Sardinops sagax caeruleus,* and the genera *Sebastes* and *Citharichthys,* each of which made up about 4% of the catch. The lanternfish, *Triphoturus mexicanus,* and the tropical gonostomatid, *Vinciguerria lucetia,* ranked sixth and seventh at about 3% of the catch. In 1957, a warmer year, *E. mordax* remained the most abundant, but was followed closely by *V. lucetia*

TABLE 4

Relative abundance of fish larvae obtained on all CalCOFI cruises off the western coast of Baja California in 1956

Species	Rank	Standard No. of larvae	Percent of total	No. of occurrences
Engraulis mordax	1	116,464	37.6	363
Merluccius productus	2	87,708	28.3	281
Sardinops sagax caeruleus	3	13,975	4.5	149
Sebastes spp.	4	12,489	4.0	284
Citharichthys spp.	5	12,102	3.9	218
Triphoturus mexicanus	6	10,526	3.4	296
Vinciguerria lucetia	7	9,781	3.1	220
Leuroglossus stilbius	8	6,934	2.2	253
Trachurus symmetricus	9	5,907	1.9	156
Diogenichthys laternatus	10	3,123	1.1	115
Stenobrachius leucopsarus	11	2,009	0.6	98

TABLE 5

Relative abundance of fish larvae obtained on all CalCOFI cruises off the western coast of Baja California in 1957

Species	Rank	Standard No. of larvae	Percent of total	No. of occurrences
Engraulis mordax	1	66,502	26.0	376
Vinciguerria lucetia	2	54,369	21.2	546
Merluccius productus	3	46,298	18.1	227
Triphoturus mexicanus	4	15,308	5.9	578
Citharichthys spp.	5	14,224	5.5	326
Diogenichthys laternatus	6	11,581	4.5	398
Trachurus symmetricus	7	10,093	3.9	178
Sardinops sagax caeruleus	8	7,711	3.0	148
Leuroglossus stilbius	9	3,742	1.4	155
Stenobrachius leucopsarus	10	1,244	0.4	51
Sebastes spp.	11	1,014	0.3	227

(Table 5). The hake remained abundant, in third place, followed by *T. mexicanus*, *Citharichtys* spp., and the warm-water lanternfish, *Diogenichthys laternatus*.

It is also useful to compare the relative abundance of species of the Gulf cruises of 1956 and 1957, with those of a recent cruise in a restricted area of the northern Gulf (Table 6). In March 1972 the Mexico/FAO/UNDP Fisheries Research and Development Program research vessel, ALEJANDRO DE HUMBOLDT, occupied 28 stations, largely in the cold water region around Ángel de la Guarda and Tiburón Islands. The hake, *Merluccius* sp., made up over half of the the total followed by *Leuroglossus stilbius* and *Citharichthys* spp. at about 9% of the total. The gadoid genus, *Physiculus*, ranked 4th at about 4%, followed by *Etrumeus teres*, *Diogenichthys laternatus*, and *Sardinops sagax caeruleus* each at about 3%. It is apparent that the rankings from this cruise in a restricted area of cold water in the northern Gulf correlate more closely with the rankings for the outer coast waters during 1956 and 1957 than with those within the Gulf for those years.

The seasonal fluctuations in areal distribution of fish larvae within the Gulf are shown in Figures 4–24.

Larvae of the Pacific mackerel, *Scomber japonicus*, were widespread in the southern region of the Gulf during the February cruises of both years (Figures

TABLE 6

Relative abundance of fish larvae obtained on cruise 7203 of the Mexican research vessel ALEJANDRO DE HUMBOLDT in the Gulf of California

Kinds of Larvae	Rank	Standard No. of larvae	Percent of total	No. of occurrences
Merluccius spp.	1	4,301	56.6	17
Leuroglossus stilbius	2	716	9.4	9
Citharichthys spp.	3	709	9.3	14
Physiculus spp.	4	314	4.1	13
Etrumeus teres	5	253	3.3	12
Sardinops sagax caeruleus	6	205	2.7	10
Diogenichthys laternatus	7	205	2.7	5
Sebastes spp.	8	194	2.6	16
Unidentified	9	123	1.6	13
Scomber japonicus	10	76	1.0	5
Argentina sialis	11	74	1.0	5
Triglidae	12	74	1.0	8
Vinciguerria lucetia	13	54	0.7	4
Carangidae	14	42	0.6	2
Bregmaceros bathymaster	15	41	0.5	1
Stromateidae	16	37	0.5	2
Stomias atriventer	17	35	0.5	5
Scorpaenidae	18	32	0.4	4
Benthosema panamense	19	25	0.3	1
Symphurus spp.	20	25	0.3	1
Macrouridae	21	21	0.3	3
Disintegrated	22	19	0.2	4
Heterostomata	23	12	0.2	3
Sciaenidae	24	6	0.1	1
Triphoturus mexicanus	25	5	0.1	1
Leptocephali	26	3	<0.1	1

4, 5). Abundance tended to diminish towards the north and their distribution terminated well south of Tiburon Island. In the April cruises, *S. japonicus* larvae were widespread and abundant throughout all regions of the Gulf with some regions of coastal concentration and with a marked absence at the cold water region around the large islands of the upper Gulf. The lower abundance toward the north on the February

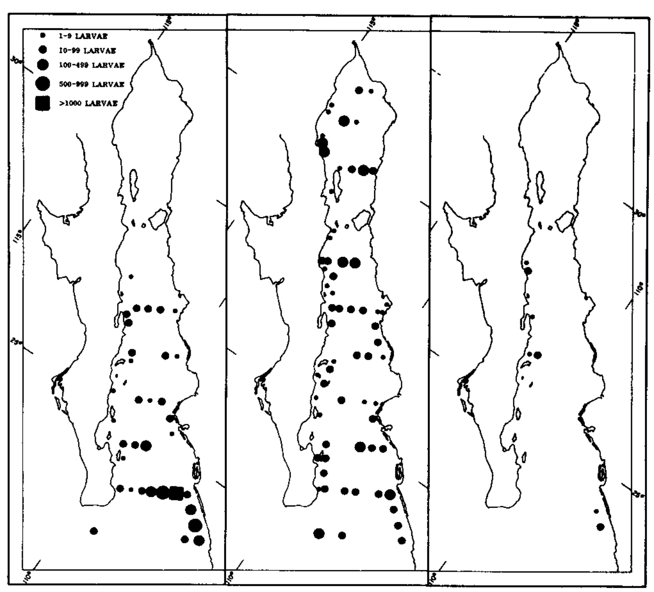

FIGURE 4. Distribution and abundance of *Scomber japonicus* larvae in the Gulf of California on CalCOFI cruises 5602 (left), 5604 (center) and 5612 (right).

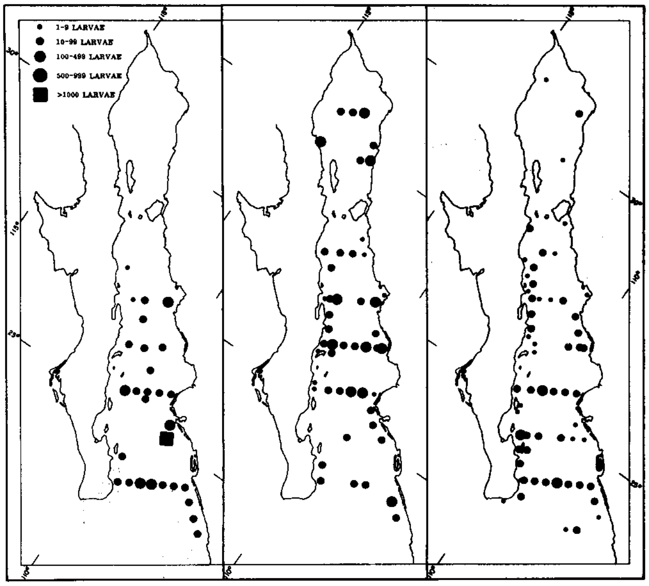

FIGURE 5. Distribution and abundance of *Scomber japonicus* larvae on CalCOFI cruises 5702 (left) and 5704 (center) and *Auxis rochei* larvae on cruise 5706 (right) in the Gulf of California.

cruises suggests a progression of spawning related to rising surface temperatures.

Larvae of *S. japonicus* were strikingly more abundant and widespread in the Gulf than on the outer coast, where they averaged about three larvae per station during the spawning seasons of 1956 and 1957. In the Gulf the average for the February and April cruises was about 39 larvae per station.

The abundance of *S. japonicus* in the Gulf is even more apparent from egg abundance, which was over 3,000 per station in some areas of the Gulf (Figure 6).

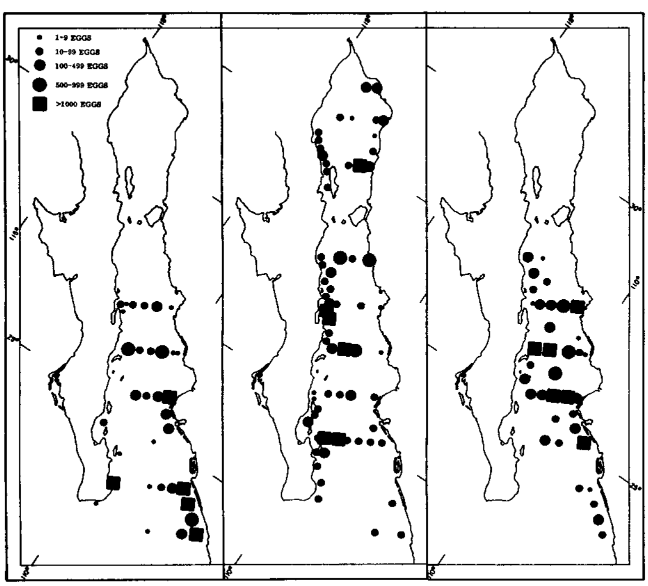

FIGURE 6. Distribution and abundance of *Scomber japonicus* eggs in the Gulf of California on CalCOFI cruises 5602 (left), 5604 (center) and 5702 (right).

The widespread nature of spawning in 5604 is shown in the chart, as is the avoidance of the cold water region around the large islands. Approximate calculation of spawning stock size from egg abundance, using the method of Ahlstrom (1968), gives a conservative estimate of about 500,000 metric tons for 5602 and about 300,000 tons for 5604 and 5702. This is at least five times the estimate for the spawning stock on the outer coast during the same years.

Concomitant with the marked scarcity of *S. japonicus* larvae on cruise 5706, the larvae of other scombrids made their appearance. Larvae of the bullet mackerel, *Auxis rochei,* were abundant and widely distributed in the central and southern Gulf and occurred on a few stations in the upper region (Figure 5). Larvae of the black skipjack, *Euthynnus lineatus,* occurred in the southern region but were fewer in the central region and did not occur in the north (Figure 7). The larvae of the bonito, *Sarda chiliensis,* and the

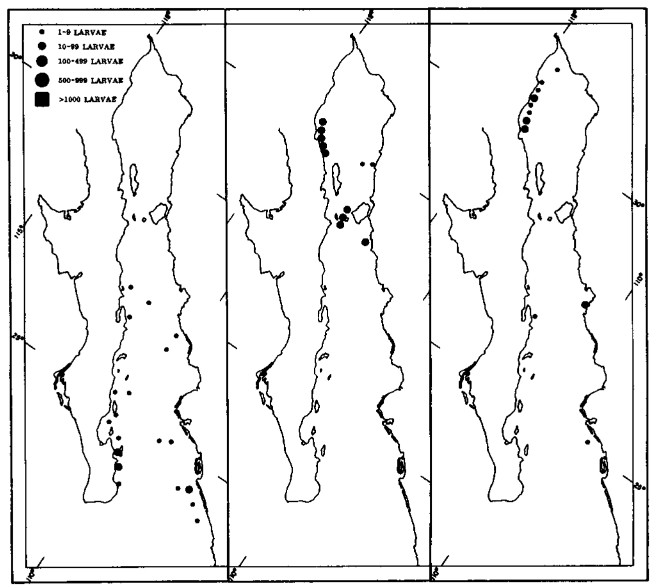

FIGURE 7. Distribution and abundance of larvae of *Euthynnus lineatus* (left), *Sarda chiliensis* (center) and *Scomberomorus* spp. (right) on CalCOFI cruise 5706 in the Gulf of California.

sierra, *Scomberomorus* spp., showed a nearly opposite distribution with a small area of high concentration along the western coast of the upper Gulf and only a few occurrences to the south (Figure 7).

The sardine, *Sardinops sagax caeruleus,* is a species of northern affinity, occurring from British Columbia to the Cape San Lucas region. On the February cruises (Figures 8, 9) its larvae were widespread and abundant in the central region and diminished to the north and south. In the April cruises larvae occurred widely in the upper Gulf but remained most abundant in the central region of the Gulf. The eggs showed a patchy and more restricted distribution, with high numbers in the central portion of the Gulf and isolated patches in the northern and southern regions (Figure 10). Calculation of spawning stock size from egg abundance gives an estimate of about 48,000, 505,000 and

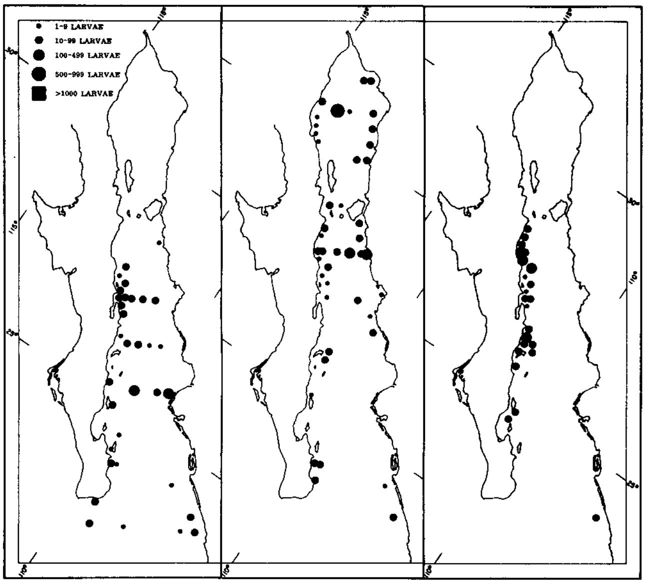

FIGURE 8. Distribution and abundance of *Sardinops sagax caeruleus* larvae in the Gulf of California on CalCOFI cruises 5602 (left), 5604 (center) and 5612 (right).

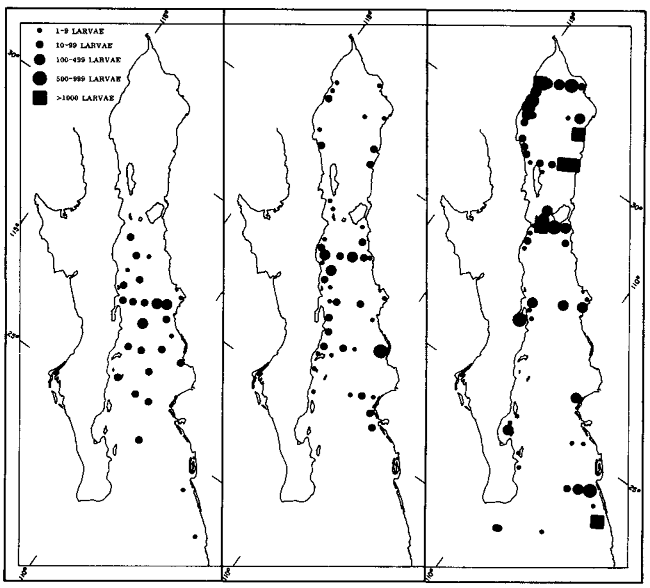

FIGURE 9. Distribution and abundance of *Sardinops sagax caeruleus* larvae on CalCOFI cruises 5702 (left) and 5704 (center) and larvae of *Opisthonema* spp. on cruise 5706 (right) in the Gulf of California.

74,000 metric tons for 5602, 5604, and 5702 respectively.

As with other species of northern affinity, the larvae of the sardine were not present during the June cruise. This void was filled by the larvae of the tropical clupeid genus, *Opisthonema* (Figure 9). The larvae were patchily distributed throughout the Gulf with pockets of high concentration in coastal areas, and even in Bahía Concepción.

Larvae of the round herring, *Etrumeus teres,* had a seasonal fluctuation in abundance (Figures 11, 12).

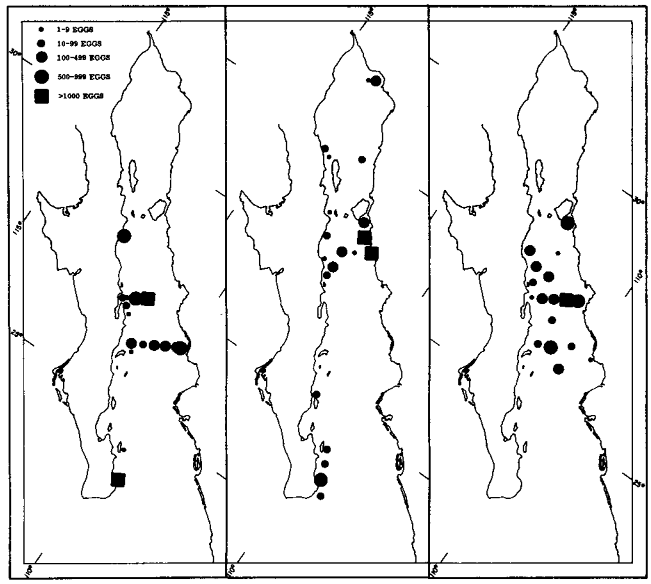

FIGURE 10. Distribution and abundance of *Sardinops sagax caeruleus* eggs in the Gulf of California on CalCOFI cruises 5602 (left), 5604 (center) and 5702 (right).

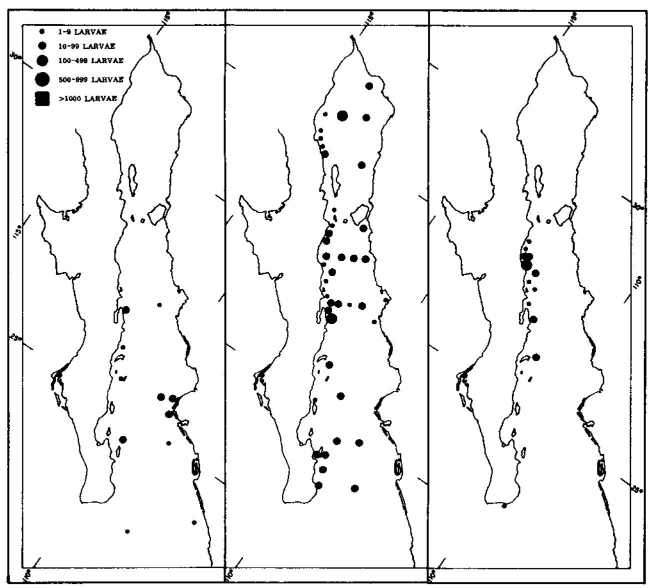

FIGURE 11. Distribution and abundance of *Etrumeus teres* larvae in the Gulf of California on CalCOFI cruises 5602 (left), 5604 (center) and 5612 (right).

They occurred scantily in the southern and central regions during February. In April of 1956 they were widespread and abundant throughout the entire Gulf but in 5704 they were only abundant in the upper and central regions and were almost absent in the southern region. In 5706 they occurred only in the upper Gulf and on two stations in the vicinity of La Paz.

Vinciguerria lucetia has the typical distributional pattern for tropical midwater species in the Gulf—decreasing abundance from south to north (Figures

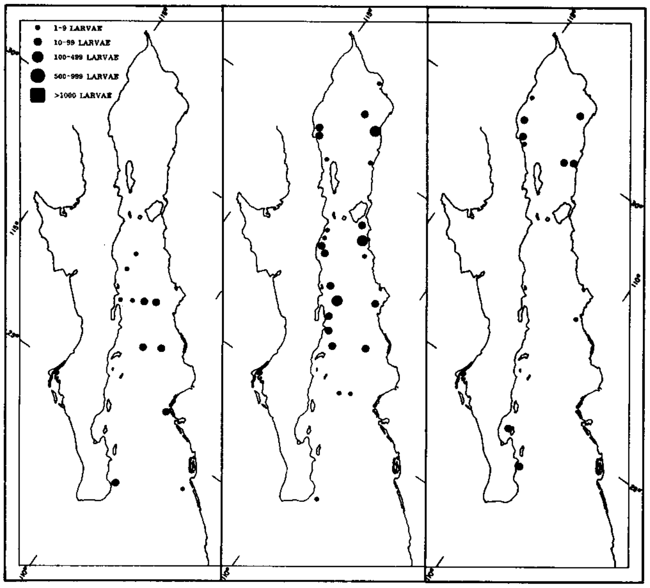

FIGURE 12. Distribution and abundance of *Etrumeus teres* larvae in the Gulf of California on CalCOFI cruises 5702 (left), 5704 (center) and 5706 (right).

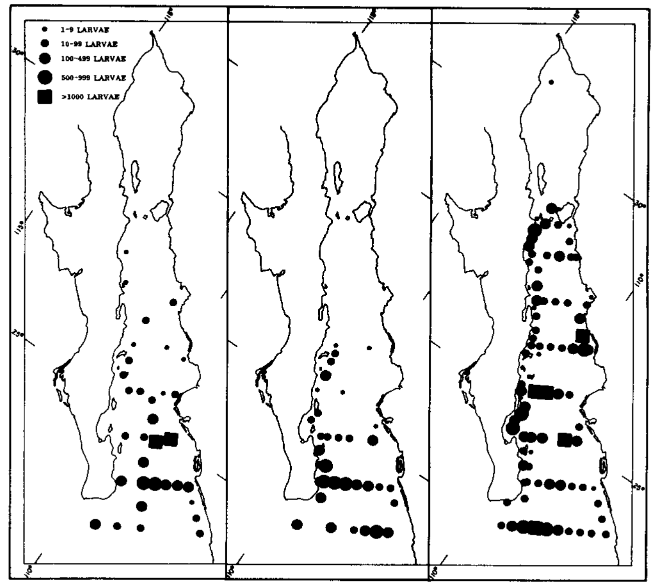

FIGURE 14. Distribution and abundance of *Vinciguerria lucetia* larvae in the Gulf of California on CalCOFI cruises 5702 (left), 5704 (center) and 5706 (right).

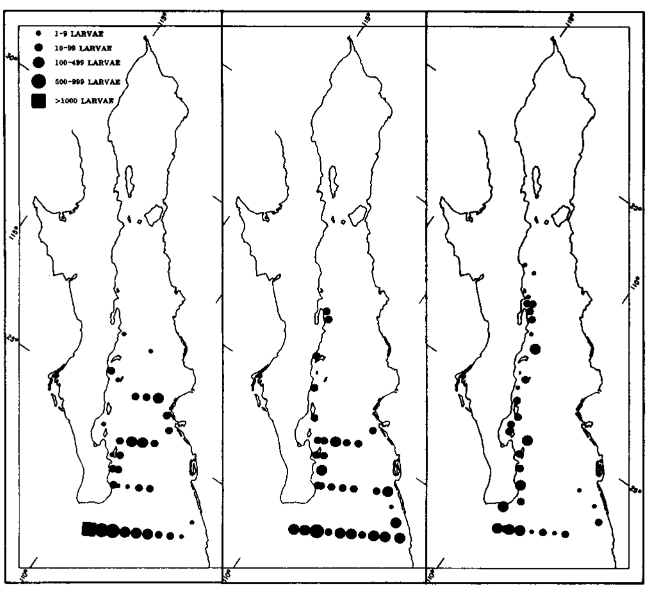

FIGURE 13. Distribution and abundance of *Vinciguerria lucetia* larvae in the Gulf of California on CalCOFI cruises 5602 (left), 5604 (center) and 5612 (right).

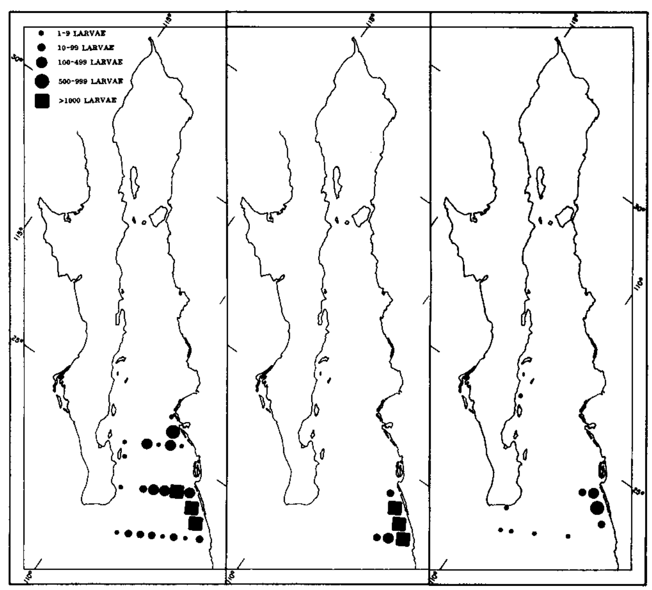

FIGURE 15. Distribution and abundance of *Bregmaceros bathymaster* larvae in the Gulf of California on CalCOFI cruises 5602 (left), 5604 (center) and 5612 (right).

13, 14). In five of the six cruises shown, this species was widespread and abundant in the southern Gulf, scattered and much less abundant in the central Gulf, and absent from the upper portion. Only in 5706 did the larvae appear in abundance as far north as Tiburón Island. Here also there was a single record in the upper Gulf. Within its latitudinal range in the Gulf, *V. lucetia,* like other abundant midwater species, tends to be more concentrated over the deep waters of the central and western side of the Gulf, compared with the shallower waters of the eastern side.

Larvae of *Bregmaceros bathymaster* had a highly concentrated and restricted distribution at the southern end of the Gulf on five of the six cruises (Figures 15, 16). On 5706 the larvae were widespread and abundant as far north as Tiburón Island. On all these cruises it is evident that the species is concentrated near shore and shows a general diminution over open water areas of the Gulf. This is consistent with Ahlstrom's (1971, 1972) findings that *B. bathymaster* is a coastal species in the eastern tropical Pacific.

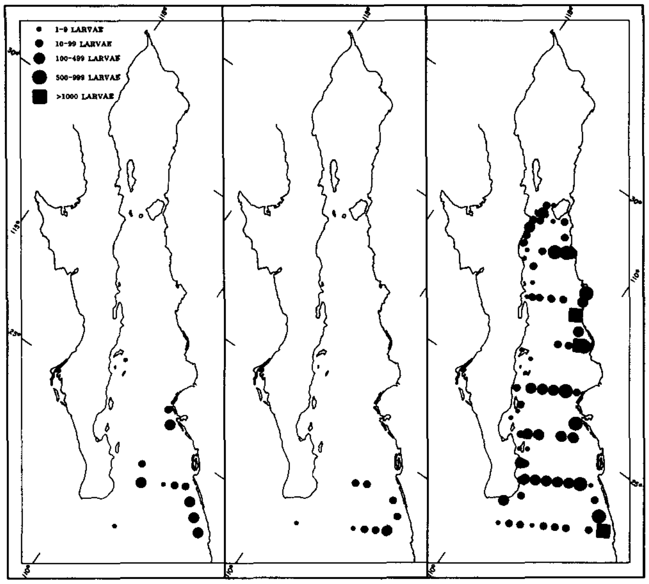

FIGURE 16. Distribution and abundance of *Bregmaceros bathymaster* larvae in the Gulf of California on CalCOFI cruises 5702 (left), 5704 (center) and 5706 (right).

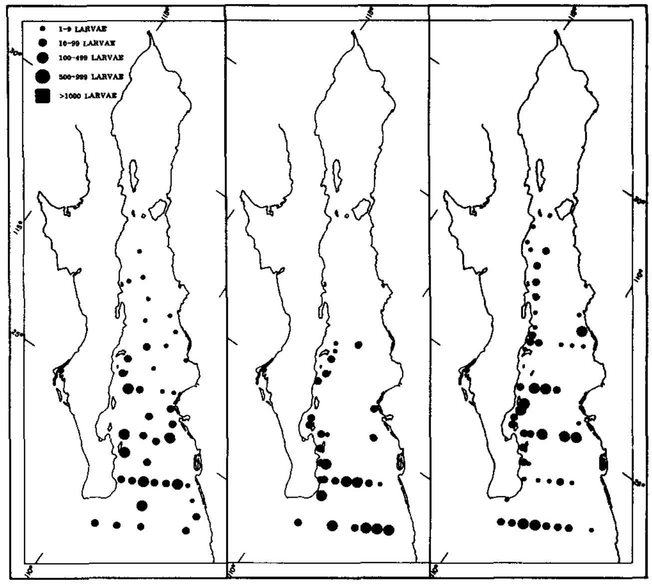

FIGURE 18. Distribution and abundance of *Diogenichthys laternatus* larvae in the Gulf of California on CalCOFI cruises 5702 (left), 5704 (center) and 5706 (right).

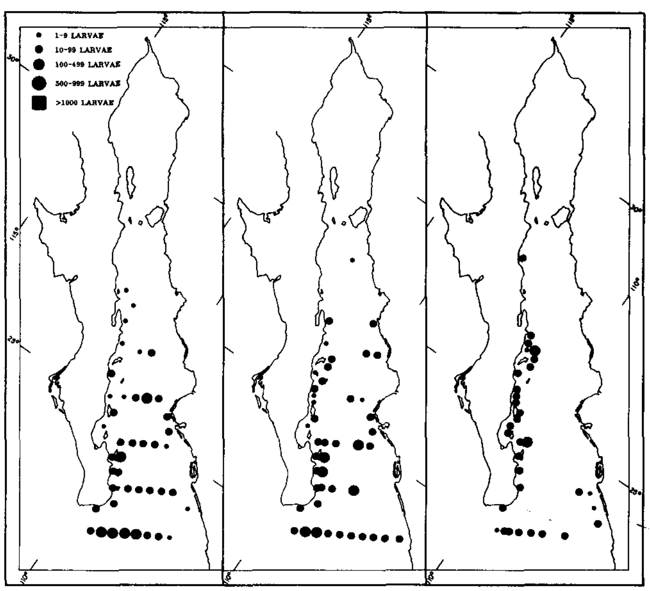

FIGURE 17. Distribution and abundance of *Diogenichthys laternatus* larvae in the Gulf of California on CalCOFI cruises 5602 (left), 5604 (center) and 5612 (right).

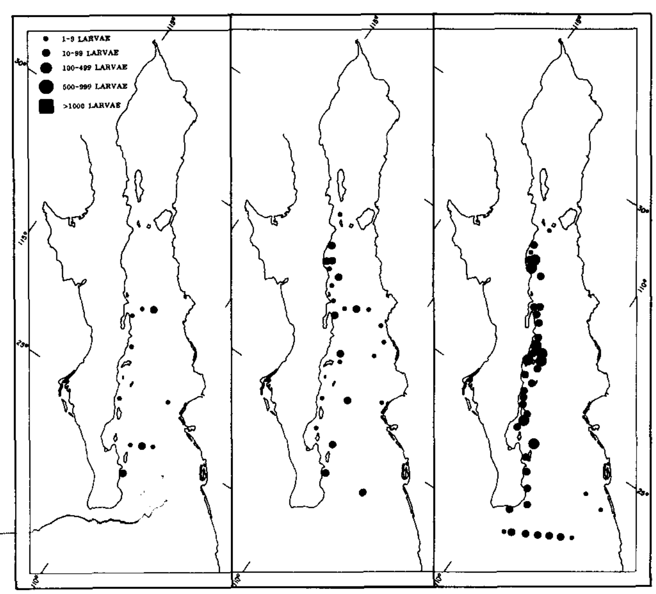

FIGURE 19. Distribution and abundance of *Triphoturus mexicanus* larvae in the Gulf of California on CalCOFI cruises 5602 (left), 5604 (center) and 5612 (right).

The lanternfish, *Diogenichthys laternatus*, has a distribution similar to that of *Vinciguerria* (Figures 17, 18). It is widespread and abundant in the southern region, diminishes markedly in abundance in the central region, and is totally absent from the upper Gulf. Like *Vinciguerria* it tends to be more abundant in the center and along the western side of the Gulf, generally avoiding the shallow areas of the eastern side.

The lanternfish, *Triphoturus mexicanus*, showed a marked seasonal abundance (Figures 19, 20). On the two February cruises, larvae were scarce and were restricted to the central and southern regions of the Gulf. Larvae were abundant and widespread on the two April cruises but remained restricted to the central and southern regions. The tendency for larvae to be concentrated along the western side of the Gulf and to diminish in density towards the east and near the mouth of the Gulf is beginning to be evident on these cruises. This tendency is strikingly illustrated on 5706, where abundance has increased markedly and some larvae occurred in the upper Gulf. It is obvious that the center of distribution of *T. mexicanus* in the

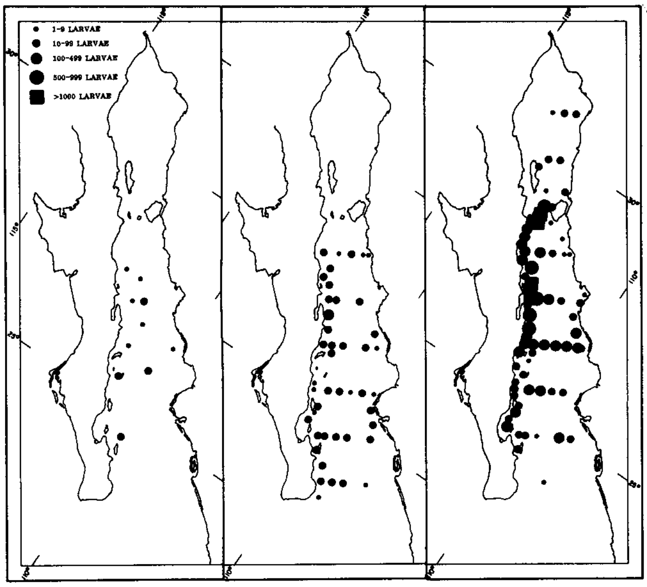

FIGURE 20. Distribution and abundance of *Triphoturus mexicanus* larvae in the Gulf of California on CalCOFI cruises 5702 (left), 5704 (center) and 5706 (right).

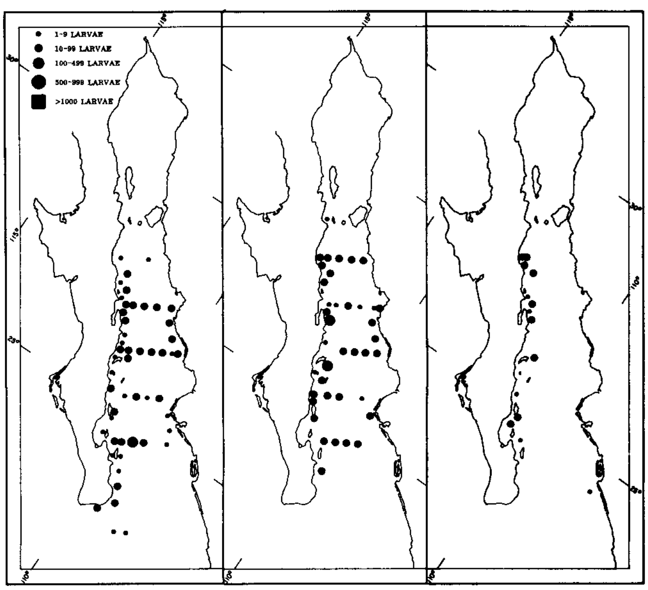

FIGURE 21. Distribution and abundance of *Leuroglossus stilbius* larvae in the Gulf of California on CalCOFI cruises 5602 (left), 5604 (center) and 5612 (right).

Gulf is in the central region along the islands of the western coast. A very similar pattern of distribution is shown for the myctophid, *Benthosema panamense* (Figure 22).

The deep sea smelt, *Leuroglossus stilbius,* is essentially a cold water species that ranges from Cape San Lucas to the Gulf of Alaska. It has a distributional pattern that is somewhat similar to that of *T. mexicanus* although spawning occurs more evenly throughout the cold months of the year (Figures 21, 22). Larvae were abundant and widely distributed throughout the central region of the Gulf during February and April but their northward distribution terminated abruptly at Tiburón Island and more gradually southward towards the mouth. Within its latitudinal range in the Gulf, *L. stilbius* is evenly distributed and does not appear to concentrate along the western side like *T. mexicanus.*

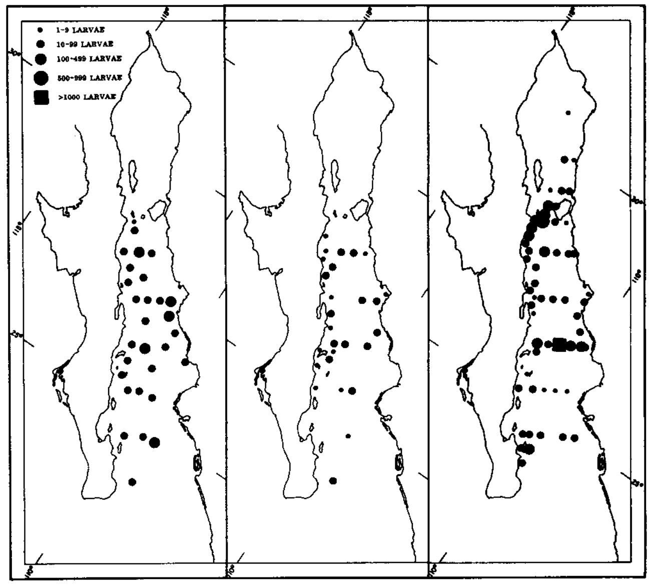

FIGURE 22. Distribution and abundance of *Leuroglossus stilbius* larvae on CalCOFI cruises 5702 (left) and 5704 (center) and *Benthosema panamense* larvae on cruise 5706 (right) in the Gulf of California.

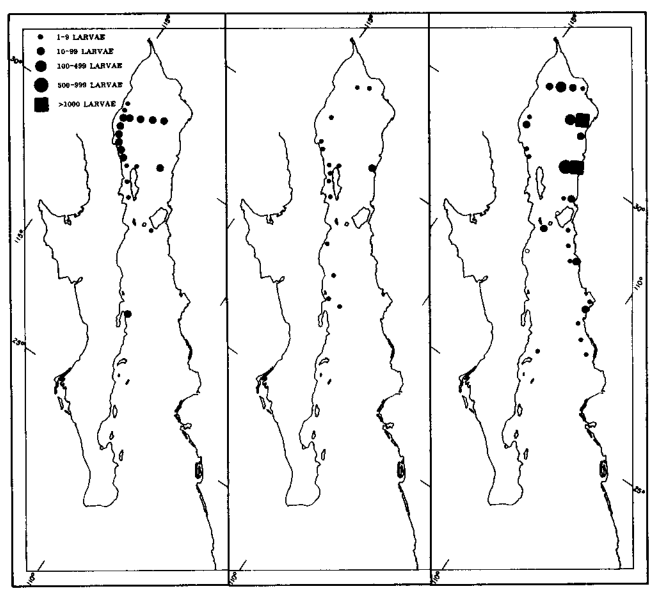

FIGURE 23. Distribution and abundance of larvae of *Merluccius* sp. on CalCOFI cruise 5604 (left), larvae of *Sebastes* spp. on cruise 5604 (center) and *Trichiurus nitens* larvae on cruise 5706 (right) in the Gulf of California.

Larvae of the genus *Sebastes* are definitely cold water fishes, and the restriction of their larvae to the cold water region around the large islands in the

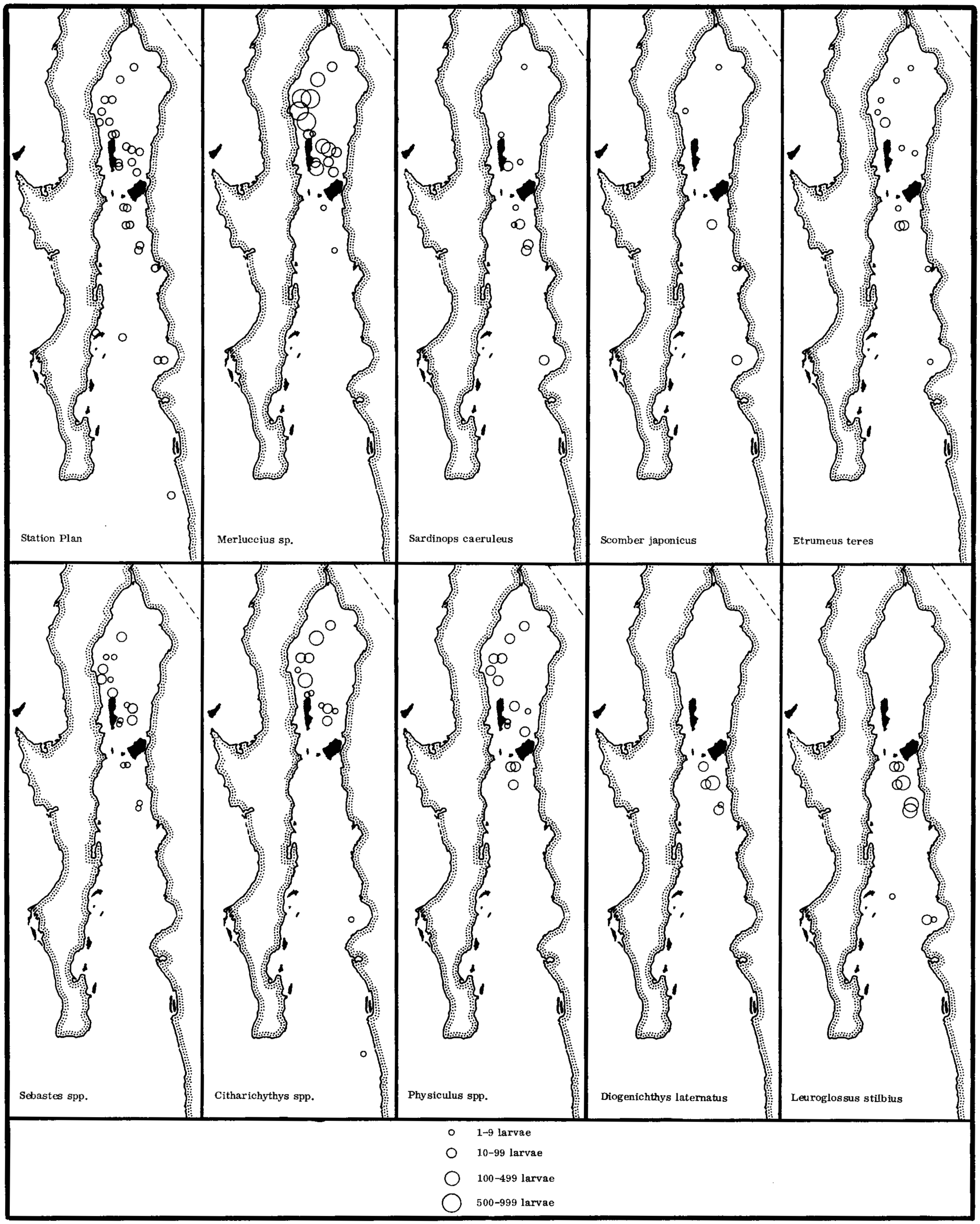

FIGURE 24. Distribution and abundance of the nine most abundant larvae obtained on cruise 7203 (March, 1972) of the Mexico/FAO/UNDP Fisheries Research and Development Program in the Gulf of California.

upper Gulf is shown in Figure 23. The larvae of the hake, *Merluccius* sp., have a similar distribution in the vicinity of these islands (Figure 23). According to Dr. Mathews (see this symposium) these larvae are of an endemic species which occurs southward as far as Bahía Concepción. The larvae of the cutlassfish, *Trichiurus nitens,* has an interesting distribution (Figure 23). It is abundant along the eastern coast of the upper Gulf and is scantily distributed along the eastern coast in the central region of the Gulf.

Areal distributions and abundances of larvae from the cruise of the ALEJANDRO HUMBOLDT in March of 1972 are shown in Figure 24. Although the pattern of stations was largely concentrated in the vicinity of the large islands in the upper Gulf, the larval distributions correlate closely with those shown by the more extensive CalCOFI cruises. The hake, *Merluccius* sp., was extremely abundant near and to the north of the island. The three epipelagic species, *Sardinops sagax caeruleus, Scomber japonicus,* and *Etrumeus teres,* were move evenly distributed throughout the station pattern. The rockfishes, *Sebastes* spp., had a distribution similar to *Merluccius*, as did the larvae of the gadoid genus *Physiculus*. The two midwater species, *Leuroglossus stilbius* and *Diogenichthys laternatus,* were restricted to south of Tiburón Island.

DISCUSSION

The Gulf of California offers a paradoxical environment for those organisms that would invade its waters and flourish. On one hand it has some of the greatest environmental extremes of any of the world's seas. With a seasonal surface temperature flux that increases from 9° C at the mouth to as high as 22° C at the head, it offers the most extreme annual temperature range of any region in the eastern Pacific. An evaporation basin, its surface salinities are typically 1–2‰ higher than waters of the outer coast and increase 1–2‰ from the mouth to the head of the Gulf. The extreme tidal ranges of the upper Gulf, as great as 10 m, are well known. Equally well known is the pronounced oxygen minimum of 0.1–0.2 ml/L at 400–800 m depth in the central and southern Gulf.

Counterposed against these conditions is the great productivity of the Gulf. Prevailing northerly winds during the winter months induce upwelling in the lee of islands and capes along the eastern coast, while during summer months, the prevailing southerly winds cause upwelling along the peninsular coast. Tidal currents around the large islands of the upper Gulf insure a continual vertical mixing of water in that region. The result of this widespread upwelling of nutrient-rich water is an enormous productivity. The year-round plankton blooms are a notable feature of the Gulf and provoked the early explorer, Ulloa, to name it the "Vermillion Sea" (van Andel, 1964). Such productivity, with its attendant abundance of life at higher levels of the food web would seem to assure a propitious environment for those fish species capable of meeting the environmental demands outlined above. That the harsh environmental factors reduce the attractiveness of this environment is obvious from an examination of the ichthyofauna.

The depauperate nature of the shorefish fauna has been described by Hubbs (1960), Hubbs and Roden (1964) and Walker (1960). Isolated from the effects of the cold California Current, except in the area of Cabo San Lucas, the elevated water temperatures have allowed Panamic shorefishes to dominate the Gulf and extend considerably northward of their limits on the outer coast. The paucity of certain Panamic groups (croakers, catfishes, and anchovies) indicates their inability to adapt to the environmental extremes of the Gulf. In contrast, these extremes, along with the abundance and isolated nature of rocky shore habitats have allowed an impressive evolution of blennioid fishes.

The midwater fish fauna, also dominated by warm water species, is even more depauperate than the shorefish fauna (Lavenberg and Fitch, 1966; Robison, 1972, Brewer, 1973). These investigators have established that only a few midwater species are abundant and that most of midwater species recorded for the Gulf are restricted to the southern portion. This is even more graphically shown by the data on larvae presented herein. The larvae of only six mesopelagic species were abundant. The gonostomatid, *Vinicguerria lucetia,* ranked first among all species recorded and represented 22% of all the fish larvae obtained in the six cruises. Striking in their total absence were the larvae of the gonostomatid genus, *Cyclothone,* which are extremely abundant in waters adjacent to the Gulf. Less abundant than *V. lucetia* but prominent on certain cruises were the myctophids, *Benthosema panamense, Diogenichthys laternatus,* and *Triphoturus mexicanus* and the bathylagid smelt, *Leuroglossus stilbius.* The gadoid, *Bregmaceros bathymaster,* was abundant on all cruises and ranked second in overall abundance with 19% of all larvae obtained on the six cruises. Only a few adults of *B. bathymaster* were recorded from the three midwater trawling expeditions, indicating that plankton hauls obtain a much more representative sampling of a fauna than do midwater trawls.

Except for *T. mexicanus* and *B. panamense,* which occurred sparsely in the upper Gulf on cruise 5706, the larvae of the abundant midwater species were restricted to the central and southern Gulf. The proclivity of these species for waters of the western side of the Gulf is strikingly illustrated by the distribution of *T. mexicanus* larvae on cruise 5706. Larval abundance of the warm water species, *V. lucetia, B. panamense, D. laternatus, T. mexicanus,* and *B. bathymaster,* increased with rising water temperatures and were most abundant on cruise 5706. Also, the areal extent of spawning increased northward with rising water temperatures. This is best illustrated by *B. bathymaster* larvae which were restricted to the extreme southern Gulf from December to April but were abundant and widespread northward to Tiburon Island in June of 1957. Larvae of the bathylagid smelt, *L. stilbius,* of northern affinity, showed an opposite pattern of seasonal abundance. They were abundant and widespread during the cold months and all but absent on the June cruise.

The larval distributions clearly show that the abundant midwater species of the Gulf are restricted areally and in season of reproduction. Why these few species should be able to flourish in the Gulf, while the members of the rich midwater fauna of adjacent waters are excluded is of great interest. All of the abundant Gulf species have wide latitudinal ranges outside the Gulf and are equipped to tolerate the seasonal temperature range of the Gulf. Probably more important than this is their ability to tolerate the low oxygen concentrations at 400–800 m depth. The effect of this oxygen-poor zone is certainly obvious where it impinges on the coast, as Parker (1964) has shown that these areas are all but devoid of animal life. Also suggestive of the importance of the oxygen minimum zone is the fact that *Scopelarchoides nicholsi,* the sole scopelarchid recorded from the Gulf, has the greatest development of gill filaments of any member of that family (Johnson, 1971). The vertical distributions of most of the abundant midwater species of the Gulf are shoaler than 400 m (Robison, 1972) thus they have adapted to the oxygen minimum zone by simply avoiding it. The exception, *T. mexicanus,* whose daytime depths overlap broadly with the oxygen minimum zone, may adapt behaviorly by becoming lethargic as suggested by Barham (1970).

The epipelagic species of commercial importance are largely unaffected by the oxygen minimum layer. The larval data shows that two species of northern affinity, *Scomber japonicus* and *Sardinops sagax caeruleus,* are strikingly abundant throughout the Gulf. These species have broad latitudinal ranges outside of the Gulf and are well suited to tolerate the Gulf's annual temperature extremes. Spawning of these species is restricted to the cold water months as illustrated by the near absence of their larvae in the June cruise. During warm water months *Sardinops* larvae are replaced by those of the warm water Clupeid genus, *Opisthonema,* which appears to be heavily concentrated in the upper Gulf. The data suggests that these thread herring may be the most abundant pelagic fishes in the Gulf since their larvae represented 9 percent of the total fish larvae even though a fraction of their probable spawning season was sampled. The larvae of *Scomber* are replaced by those of the more tropical scombrids *Auxis, Euthynnus, Sarda* and *Scomberomorus.* Of these, *Auxis* larvae are the most widespread and abundant, although the restricted distributions of the others may simply reflect the partial sampling of their spawning seasons.

The data from the recent plankton tows of the ALEJANDRO DE HUMBOLDT in March 1972 indicate that the demersal hake, *Merluccius* sp., is an extremely abundant fish in the upper Gulf, particularly in the areas just east and north of Angel de la Guarda Island. This abundance was not apparent from the data of the CalCOFI cruises, since only on cruise 5604 were significant numbers of larvae taken. A possible explanation for this is that the reproductive season of the species is very short. It may reach its peak in March, as suggested by the data from cruise 7203, and may last only a month. This could explain the poor representation of *Merluccius* larvae in the CalCOFI samples of February and April. Such an abbreviated reproductive season, limited to the coldest time of the year, is also typical of *Sebastes* and other pleistocene relicts of the upper Gulf.

ACKNOWLEDGEMENTS

The authors are indebted to a number of people of the National Marine Fisheries Service, La Jolla, for assistance in the preparation of this paper. Roy Allen drafted Figure 1. Nancy Wiley developed a technique for handling the data from cruises 5612, 5704, and 5706 by computer. Technical assistance was provided by Robert Counts, Mary Kalin, Patricia Lowery, Elaine Sandknop and the many people who painstakingly collected and prepared the plankton samples.

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Part IV

SCIENTIFIC CONTRIBUTIONS

THE MORTALITY RATE OF *ENGRAULIS MORDAX* IN SOUTHERN CALIFORNIA[1]

ALEC MacCALL[2]
Marine Resources Region
California Department of Fish and Game

ABSTRACT

The annual mortality rate for the northern anchovy, *Engraulis mordax*, is estimated to be 66.5% in southern California waters, although the mortality rate increases sharply for older fish. A method for evaluating recruitment regularity and age constancy of mortality is presented.

INTRODUCTION

With the rise of a commercial reduction fishery exploiting the northern anchovy, *Engraulis mordax*, in California waters, questions have arisen concerning the proper management of this fishery. Many of these questions remain without concrete answers due to lack of basic knowledge regarding population parameters. In an effort to fill an important gap, I have developed an estimate for instantaneous and annual natural mortality rates of the adult northern anchovy population in southern California waters.

Three previous estimates of the mortality rate for the northern anchovy have been made by various workers, but there was little agreement among them. Beverton (1963) gave 0.9 as an estimate of the apparent instantaneous total mortality rate (Z). He states in the same paper that there is a strong tendency for Z to increase with age in the case of short-lived engraulid fishes. Beverton used the method of calculating mortality rates proposed by Heincke (1913), which was demonstrated by Robson and Chapman (1961) to underestimate the mortality rate when there is higher apparent survival in the younger age groups used in the calculation. Thus Beverton's estimate is probably low.

Bayliff (1967) arrived at a well documented estimate of $Z = 1.7$, using the catch curve analysis proposed by Chapman and Robson (1960); however, his choice of data led to erratic results. He used catch data from the live bait fishery, which was fraught with sampling errors (Crooke, 1969). The live bait catch is also subject to a strong bias: live bait fishermen consciously avoid taking large anchovies, since they are less desirable for bait than smaller anchovies. Bayliff also erred in lumping data from both central and southern California in arriving at his estimate. Firstly, there is good evidence that catch data from north of Point Conception are not fit for catch curve analysis due to extreme fluctuations in year class strength (Ahlstrom, 1956; Baxter, 1967), partially accounting for the lack of consistency in Bayliff's choice for age at full recruitment. Secondly, anchovies north of Point Conception probably are not characterized by the same population parameters as anchovies in southern California. In Bayliff's tabulation of individual mortality estimates from his various sources of data, he lists the reciprocal of the maximum age (T_{max}) of the fish in each source. The fish from north of Point Conception appear to be more long-lived than their southern counterparts which strongly suggests a lower mortality rate according to the relation between Z and T_{max} discussed in the same paper, as well as by Beverton (1963). Some other parameters, such as length-at-age appear to differ considerably between central and southern California anchovies (Collins, 1969).

Schaefer (1967) published a third estimate of $Z = 1.1$, however, he failed to document his work so little can be said concerning the assumptions he made.

All three estimates were based on the same group of data: Miller, et al. (1955), and Miller and Wolf (1958). Bayliff used one additional catch curve, obtained from Clark and Phillips (1952). All three papers considered the estimated total mortality rate (Z) to be a reasonably close approximation to the natural mortality rate (a) due to the low fishing pressure on the stock.

MATERIALS

Catch data for this study were gathered by the California Department of Fish and Game Pelagic Fish Investigations Sea Survey Project between October 1966 and April 1971 (Mais, 1969a, b, 1971a, b, c, 1972). Standard sampling gear was a 50 foot midwater trawl (occasionally replaced by a smaller 30 foot version when the larger net was damaged) towed for 20 minutes between 5 and 20 fathoms depending on sea conditions and depth of fish schools. Tows were generally made during hours of darkness, and were geographically distributed in an attempt to fully represent both inshore and offshore waters. When anchovies were taken, a random sample of ten fish was aged using otoliths (Collins and Spratt, 1969), and age frequency of combined samples for a single cruise was called the catch curve for that cruise. Catch curves were obtained from 16 cruises in southern California waters.

I obtained another independent set of catch curves from records of the anchovy reduction fishery catch at San Pedro (Hardwick, 1969; Collins, 1969, 1971; Spratt, 1972, 1973). The commercial fleet tends to operate near San Pedro, with most fishing effort expended in the San Pedro Channel. Most catches are made over deep water due to legal regulations prohibiting inshore fishing. Since the area sampled is very localized, catch curves are highly affected by migrations of fish. For the purpose of sampling the entire population, these samples depend on movement

[1] This study was conducted in cooperation with the Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, under Public Law 88-309, Project 6-3-R.

[2] Marine Biologist, Department of Fish and Game, 350 Golden Shore, Long Beach, California 90802.

of fish into and out of the sampling area. Various subdivisions of seasonal catch were tried, but any division smaller than the entire seasonal catch resulted in a loss in consistency of age structure, so each season's catch was treated as a whole. Unfortunately there were almost no fish taken for reduction in southern California during the 1967–1968 fishing season due to low fish prices (Hardwick, 1969), creating a discontinuity in my data.

METHODS

The apparent instantaneous mortality rate (Z) was estimated by applying the catch curve analysis proposed by Chapman and Robson (Chapman and Robson, 1960; Robson and Chapman, 1961). This method was shown to yield an unbiased estimate of the annual survival rate and was proven to be subject to the smallest sampling error of the various methods that can be devised.

The annual survival rate(s) is estimated by:

$$s = \frac{T}{n + T - 1}$$

and the variance about s is estimated by

$$\sigma_s^2 = \frac{s(1-s)^2}{n}$$

$$\text{with } n = N_0 + N_1 + N_2 + N_3 + \ldots + N_K + \ldots$$

$$T = N_1 + 2N_2 + 3N_3 + \ldots + KN_K + \ldots$$

where:

K = coded age, where $K = 0$ for the youngest age group fully vulnerable to the sampling, assuming all older ages are completely vulnerable.

N_K = number of fish of age K present in the catch.

Validity of catch curve estimations of mortality rates by the method of Chapman and Robson (1960) depends on three conditions: (1) Year classes must not vary in strentgh, (2) survival must be constant over all ages used in the analysis, and (3) survival must not vary on a seasonal or yearly basis. It is highly unlikely that all three provisions are met in a real situation. However, if violations are small, the mortality rate estimate can be shown to be a good approximation.

A convenient method for determining variability of recruitment as well as changes in mortality rate with age (i.e. assumptions 1 and 2) is analysis by logarithms of ratios of abundance of successive year classes. This method follows from a model based on the usual formula for number of fish surviving a source of mortality over a period of time:

$$N_t = N_o e^{-Z(t-t_o)} \quad (1)$$

where N_t = number of fish alive at time t.

N_o = number of fish alive at time t_o.

Z = instantaneous coefficient of mortality from all causes.

This equation can be rewritten as:

$$N_{i,t} = R_i e^{-ZT}$$

where the new symbols are:

$N_{i,t}$ = number of fish belonging to year class i which are alive at time t.

R_i = Recruitment: number of fish belonging to year class i which were alive at a standard age, at which the fish became subject to the mortality rate described by Z.

$T = t - t_o$, for simplicity, where t is the time of estimation of $N_{i,t}$, and t_o is the time at which $N_{i,t} = R_i$, a standard date in the lifetime of every year class.

Individual year classes will occur in a catch with frequencies proportional to their abundances once they become fully available to the sampling gear. Moreover, the ratio of frequencies of two year classes in a catch will approximate the ratio of numbers of fish in those groups residing in the sampling area. Thus the catch ratio, $C_{i,t}$ will be defined as:

$$C_{i,t} = \frac{n_{i+1,t}}{n_{i,t}} = \frac{N_{i+1,t}}{N_{i,t}} \quad (2)$$

with: $n_{i,t}$ = number of fish of year class i appearing in a catch at time t.

And, according to (2),

$$C_{i,t} = \frac{R_{i+1}e^{-Z(T-1)}}{R_i e^{-ZT}} \quad (3)$$

which assumes Z is constant.

However, if Z varies with age, the equation must assume a form requiring integration. The formulation can be simplified for practical purposes by letting Z vary as a step function of age. The mortality rate for each age interval K will be called Z_K. Now (3) can be revised as:

$$C_{i,t} = \frac{R_{i+1}e^{-(Z_1+Z_2+\ldots+Z_{K-1})}}{R_i e^{-(Z_1+Z_2+\ldots+Z_{K-1}+Z_K)}}$$

with $K = t - i$. Finally, taking logarithms of both sides, the duplicate Z_K values cancel leaving:

$$\ln C_{i,t} = \ln R_{i+1} - \ln R_i + Z_K$$

or:

$$\ln C_{i,t} = \ln \frac{R_{i+1}}{R_i} + Z_K \quad (4)$$

The logarithm of the catch ratio of two year classes will be equal to the mortality rate of the older year class during the previous year plus a constant which is the logarithm of the ratio of recruitment strengths for the two year classes under consideration. Since ln $C_{i,t}$ is undefined when either n_i or n_{i+1} is 0, catch ratios containing values of 0 are simply discarded.

If ln $C_{i,t}$ is plotted with respect to age K and the points for each year class i are joined, the behavior of Z_K and R_{i+1}/R_i can be observed. The slope of the line will indicate the rate of increase or decrease in Z_K. Thus a horizontal line would indicate no change Z or a constant mortality rate over all ages. Similarly, the constant factor ln (R_{i+1}/R_i) will displace the line upwards or downwards depending on whether the younger year class was recruited in greater or smaller numbers than the older year class. Constant recruitment strength would give little variation in vertical displacement so plots of various year classes would tend to coincide. In short, assumption 1 (constant year class strengths) will be tested by observing the degree to which the lines are coincidental, and assumption 2 (constant mortality rates for all ages) will be tested by observing the degree to which the lines depart from the horizontal. Violations of assumption 3 (constant mortality from season to season) cannot be tested by this model except to the extent to which variable mortality, along with other factors, will affect the degree to which plots resemble each other in shape.

A single value for Z, ignoring age differences, was obtained from the annual survival by:

$$Z = -\ln s - \frac{(n-1)\,(n-2)}{n(T+1)\,(n+T-1)}$$

which is no longer an unbiased estimate (Chapman and Robson, 1960), but the extent of bias is very small.

Instantaneous fishing mortality (F) was calculated using the catch equation:

$$C = P\frac{F}{Z}(1-s)$$

or solving for F:

$$F = \frac{CZ}{P(1-s)} \qquad (5)$$

where: C = annual harvest

P = recruited population

with the simplifying assumption that C and P have the same age distribution. Instantaneous natural mortality (M) is then the remaining portion of Z:

$$M = Z - F$$

In terms of annual fishing mortality m and annual natural mortality n, F and M are substituted respectively for Z in (1) and the time interval is set at one year. Annual mortality is then the ratio of N_t to N_o. Finally it should be noted that annual mortality rates m and n will not superficially add up to the total mortality rate a, due to interactions between m and n. Letting a equal the total annual mortality rate $(1-s)$:

$$a = m + n - mn$$

RESULTS

The best estimate of Z is 1.09 (Table 1) based on combined results from sixteen Sea Survey cruises. The estimated annual mortality rate a of anchovies in southern California waters is 66.5%, with a pooled standard error of 7%. For comparison, mortality estimates based on commercial landing data (Table 2) indicate Z is 1.16 and a is 68% with a pooled standard error of 19%, based on between-sample variance alone. The within-sample variance estimator used in the Chapman and Robson (Robson and Chapman, 1961) method gives unrealistically small estimated standard errors due to large sample sizes in commercial landing data.

TABLE 1

Mortality Rate Estimates Based on Sea Survey Data

Cruise	Date	Number sampled*	Annual mortality rate (a)	Standard error of a	Instantaneous mortality rate (Z)
71A7	9-13-71 to 9-28-71	162	.66	.030	1.06
71A3	4- 7-71 to 4-30-71	92	.61	.040	.94
71A1	2- 1-71 to 2-19-71	85	.71	.042	1.20
70A7	9-28-70 to 10-22-70	111	.67	.037	1.11
70A4	5-22-70 to 6-14-70	145	.73	.032	1.30
70A1	1-22-70 to 2-18-70	92	.75	.040	1.35
69A11	11-10-69 to 12- 8-69	127	.72	.034	1.26
69A8	8- 5-69 to 9- 1-69	146	.68	.032	1.13
69A6	5-12-69 to 6-10-69	105	.66	.038	1.07
68A9	11- 1-68 to 11-25-68	55	.62	.052	.95
68A8	9-12-68 to 10-11-68	128	.69	.034	1.17
68A4	4-18-68 to 5- 7-68	145	.53	.030	.75
68A1	1-18-68 to 2- 6-68	34	.72	.067	1.22
67A8	10-24-67 to 11-12-67	40	.63	.062	.97
67A2	4- 1-67 to 4-20-67	60	.66	.050	1.07
66A8	10- 3-66 to 10-22-66	106	.60	.037	.90
Mean			.665	.068†	1.09

* Number of fish 2 years old or older.
† Standard error from pooled variances.

TABLE 2

Mortality Rate Estimates Based on Commercial Catch Data

Season*	Number sampled†	Annual mortality rate (a)	Instantaneous mortality rate (Z)
1965–1966	533	.65	1.01
1966–1967	1,882	.62	.95
1968–1969	648	.65	1.06
1969–1970	2,688	.79	1.56
1970–1971	3,209	.70	1.20
Mean	--	.68‡	1.16

* Insufficient samples were taken during the 1967–1968 season.
† Number of fish 2 years old or older.
‡ Standard error is .19 based on between-sample variance only.

The logarithmic analysis described in the previous section was applied to data from the two sources. A graph of the commercial catch data (Figure 1) according to equation (4) presents a clear picture because of the periodicity of fishing seasons. Sea Survey data graphed in the same manner (Figure 2) yield a more confusing picture because of irregular spacing of cruises and much smaller size of samples taken. Nevertheless there are many features common to the two independent sets of data. In particular, the 63–64 plot shows a peculiar peak between the third and fifth year in both figures, and the 64–65 plot indicates a sudden rise from a low catch ratio at age 3 to a high catch ratio around ages 4 and 5. These events appear independently in both sampling programs, and strongly indicate a biological cause. Another event of importance is the exceptionally large catch ratio values in 66–67. Collins (1969) indicated the 1967 year class seemed to be exceptionally strong and these data support his observation. The mortality rate estimates obtained using the Chapman and Robson catch curve analysis reach a peak with the influx of the 1967 year class which became 2 years old in the summer of 1969 (Table 1). This is to be expected when a strong year class becomes the youngest age group used in the calculations.

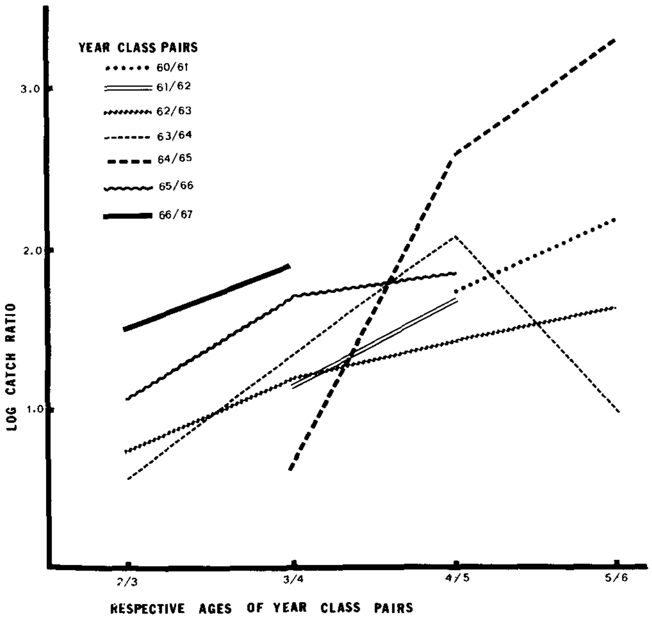

FIGURE 1. Commercial landings data: mortality rates and recruitment strengths of *Engraulis mordax* as determined by logarithms of catch ratios of year class pairs at successive ages.

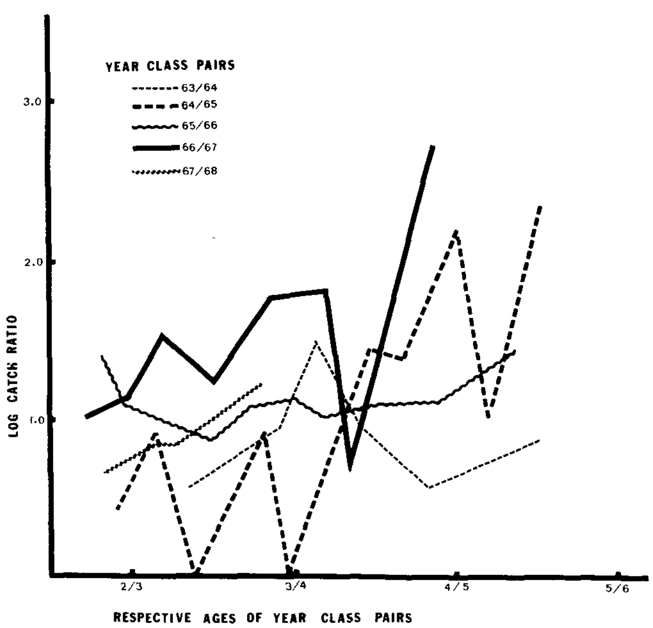

FIGURE 2. Sea survey data: mortality rates and recruitment strengths of *Engraulis mordax* as determined by logarithms of catch ratios of year class pairs at successive ages.

All in all, the assumptions on which the Chapman-Robson analysis is based are met very poorly by northern anchovies in southern California waters. Recruitment can vary by as much as 50% from year to year, which results in low confidence in the mortality rate estimated from any single catch curve. However, when a series of estimates based on data collected over several reproductive seasons are combined, the effect of irregular year class strengths is minimized. The high apparent mortality rate estimates resulting from entry of a large year class into the catch are balanced as that year class tends, in later years, to swell the ranks of the older fish and decrease the apparent mortality rate.

There is a strong tendency for the logarithms of the catch ratio to increase with age (Figures 1 and 2), substantiating Beverton's (1963) statements concerning the occurrence of increasing Z with age in engraulid fishes. In the commercial catch, the mean log catch ratios are 0.9 for ages 2/3, 1.3 for ages 3/4 and 1.9 for ages 4/5 and 5/6, which should provide rough estimates of the magnitude of the mortality rates at these ages. While the trend is apparent, the data at present are insufficient to support definitive estimates of mortality rates-at-age, and I present these values only as a crude starting point. For a good estimate by logarithmic analysis of catch curves, an independent set of estimates of year class strengths will reduce equation (4) to only one unknown. Moreover a longer uninterrupted series of catch curves will provide several sets of year class pairs which can be followed from recruitment to disappearance from the fishery.

Estimates of fishing mortality are difficult to make at the present low level of exploitation of the northern anchovy resource. Annual catches have ranged in magnitude from less than 10,000 tons in the mid sixties to 102,348 tons in 1970 (Crooke, 1972), with a 7 year mean of 41,836 tons. Since central California landings are included in the totals, but are relatively small, I have considered the mean annual catch in southern California to be 40,000 tons. The estimated standing biomass of anchovies in southern California is 2.5 million tons (Messersmith et al., 1969). Equation (5) estimates the instantaneous fishing mortality to be .026, which corresponds to an annual fishing mortality of 2.6%. Instantaneous natural mortality is then estimated to be 1.06, which corresponds to an annual natural mortality of 65%.

Increased fishing intensity in the most recent years yields higher estimates of fishing mortality, with $F = 0.066$ ($m = 6.4\%$) for the 1970 catch. This increase in fishing mortality may have also contributed somewhat to the slightly elevated total mortality rate estimates in late 1969 and 1970 (Tables 1 and 2).

CONCLUSIONS AND RECOMMENDATIONS

The northern anchovy in southern California has a mortality rate which increases with age. This makes a single valued mortality rate estimate somewhat inappropriate. However, since a more complete description is not presently feasible, I have presented an estimate for use in low level modeling and other general applications needed for management decisions.

The annual mortality rate is 66.5%, and can be separated into a natural component of 65%, and a fishing component of 2.6%. The instantaneous total mortality rate is 1.09 and the natural mortality rate is about 1.06.

Fisheries which exploit other species with similar mortality rates usually harvest a large portion of the standing biomass annually. Such is the case on the west coast of South America with the anchoveta, *Engraulis ringens*. There is little doubt that the northern anchovy, *Engraulis mordax,* in the waters off California could sustain a much greater harvest than is presently being attempted. However, due to the multiple uses of this fish, such as live bait, sportfish fodder, and commercial food production, the fishery should be expanded carefully.

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EXPLOITATION AND RECRUITMENT OF PACIFIC MACKEREL, *SCOMBER JAPONICUS*, IN THE NORTHEASTERN PACIFIC

RICHARD H. PARRISH *
California Department of Fish and Game
Long Beach, California

The Pacific mackerel stock discussed in this paper originally extended from the Gulf of Alaska to Punta Eugenia, Baja California and the fishery has been centered in southern California and northern Baja. The fishery, biological knowledge, and current status of the resource were recently reviewed by Blunt and Parrish (1969) and Kramer (1969) has prepared a synopsis of this species in the northeastern Pacific.

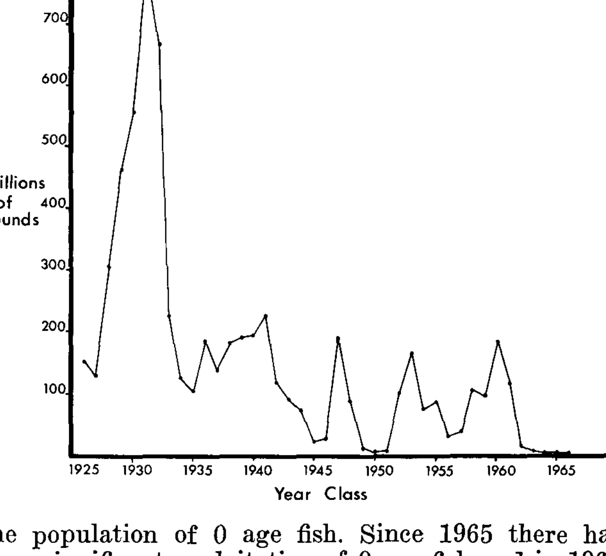
Population estimates used in the paper are based on a Murphy method (1966) program using age composition data derived from otolith readings (32,841) of Pacific mackerel, *Scomber japonicus*, sampled in the southern California commercial catch. Age composition data representing landings from 1939 to 1967 were taken from a series of papers describing the southern California catch. (Fitch 1951, 1953a, 1953b, 1955, 1956, 1958, Hyatt 1960, Parrish and Knaggs 1971, 1972). The 1926 to 1938 data were estimated by using length frequency data taken from market samples during the early fishery, age-length data from the otolith readings, and separating the mixture of normal distributions into separate normal distributions; this was accomplished using a computer program (NORMSEP).

The Murphy method is essentially an expanded virtual population estimate. It uses an assumed natural mortality rate and produces a calculated fishing mortality rate for each age group of each year-class.

The Murphy method program was run for three instantaneous natural mortality rates; 0.4, 0.7, and 1.0. The 1.0 value gives an unreasonably large population estimate in the early fishery where this mortality rate produced population biomass estimates which approach the magnitude of the sardine population in the early 1930's. In the recent fishery instantaneous fishing mortality rates are so large (up to 2.29) that there is little difference in the total annual mortality between an instantaneous natural mortality rate of 0.7 or 1.0. The 0.4 instantaneous natural mortality rate gives exploitation rates greatly in excess of those found by tagging studies. This 0.4 rate gives exploitation rates from 0.25 to 0.50 for the late 1930's and early 1940's, while Fry and Roedel (1949) found exploitation rates from 0.08 to 0.19 for the same period. The 0.7 instantaneous natural mortality rate was thus chosen as the best estimate of natural mortality.

SPAWNER–RECRUIT RELATIONSHIP

The recruit biomass (Figure 1) used throughout the study is the Murphy method estimate for each year class at the beginning of its second year (age group I). For most of the fishery, the fish first entered the fishery as 1 year olds. Since population estimates represent the biomass present at the beginning of a season, the method cannot validly estimate the population of 0 age fish. Since 1965 there has been significant exploitation of 0 age fish and in 1967 0 age group fish comprised more than 65 percent of the poundage landed. For the purposes of this paper, however, exploitation of 0 age fish has been omitted.

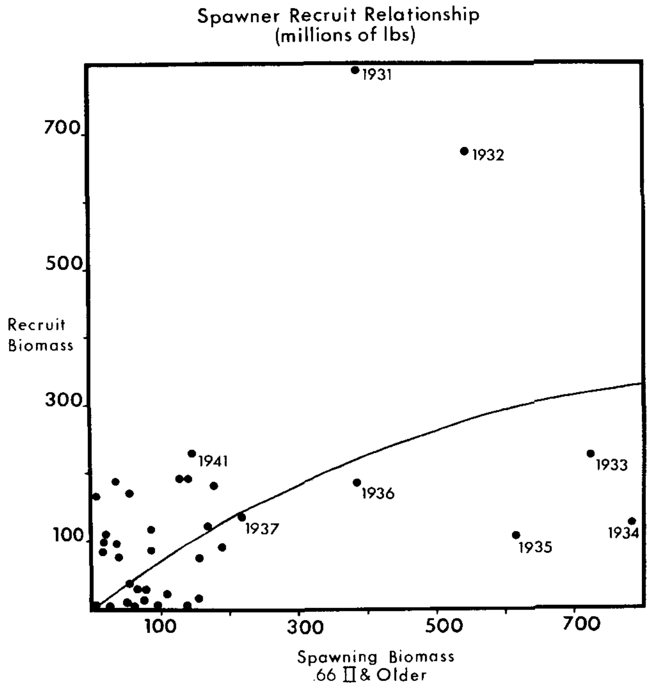


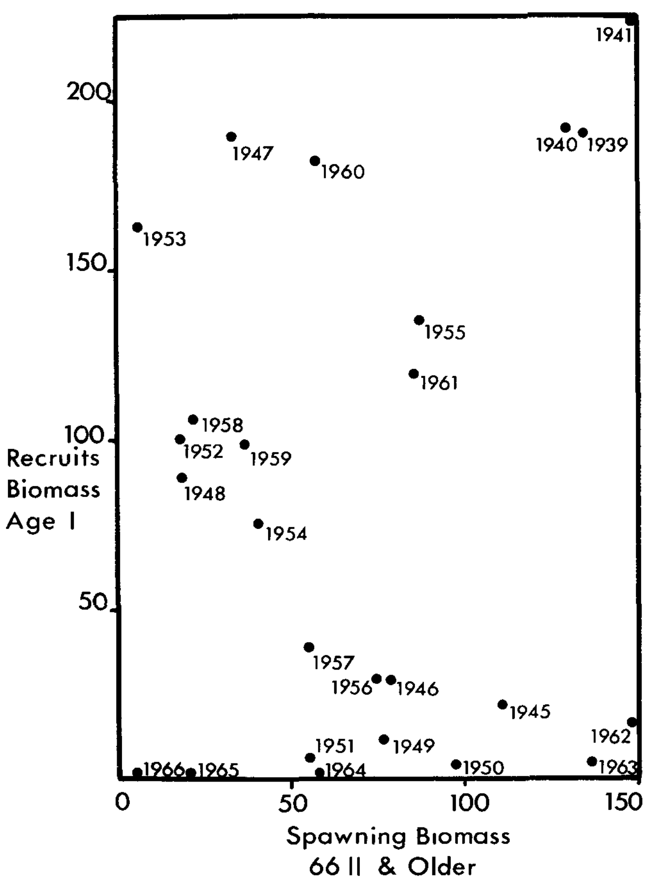
Estimates for spawning biomass were considered to be 66% of age group II fish plus all older fish. Recent evidence, (Knaggs and Parrish, 1972) showing that approximately 23% of age group I females spawn, was excluded since Fry (1936) did not find age group I fish spawning during the period of the early fishery. This spawning of age group I fish in recent years may be in response to the very low biomass and better condition of individual fish.

Calculation of a Ricker spawner-recruit curve for Pacific mackerel results in a shallow curve ($R = 0.7780Se^{-0.00000008117S}$) with increasing recruitment as spawning biomass increases: both spawners (S) and recruits (R) are in units of thousands of pounds. The curve (Figure 2) remains positive for the entire range of observed data, 1931 to 1966. The extremely small constant in the exponent reflects a small hindrance to relative recruitment with increasing spawning biomass. However, the model predicts that recruitment is directly density dependent over the observed range of spawning biomass. Thus, the greater the spawning biomass, the greater the mean resultant year-class.

The shallow Pacific mackerel spawner-recruit curve suggests that there is little resiliency in the Pacific mackerel population. For example, at a spawning biomass level of 500 million pounds, the spawner-recruit curve predicts that each pound of spawners will pro-

*Present address: Oregon State University, Corvallis, Oregon



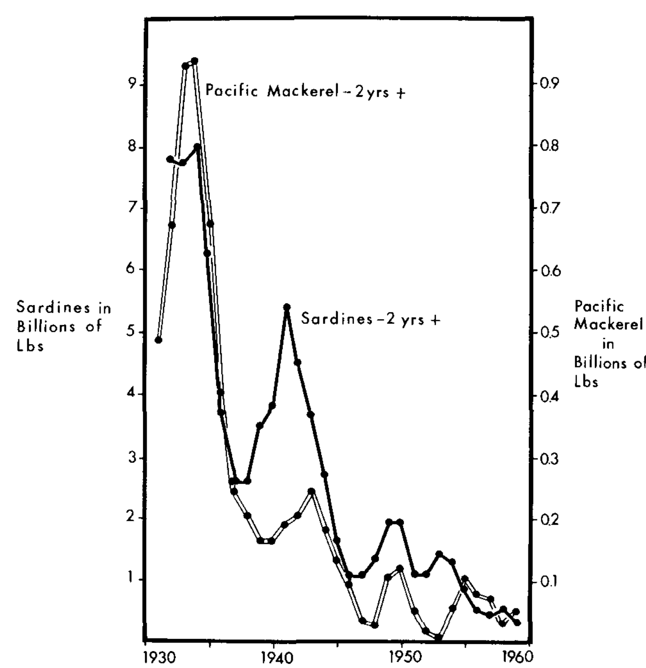


duce 0.5185 pounds of recruits. This rate only rises to 0.7173 pounds at a spawning biomass of 100 million pounds and 0.7717 pounds at 10 million pounds. If the exploitation rate exceeds the level at which growth and survival allow a year class to produce a spawning biomass, spread over its life span, equal to its parent biomass the Pacific mackerel population will continue to shrink; according to the model.

The large amount of scatter about the spawner-recruit model limits the predictive value of the model over a short time period. However, it does reflect mean recruitment within a given spawning biomass level.

A look at recruitment (Figure 2 and 3) from a time series suggests several factors. First, the extremely large biomass that accompanied the fishery peak in the mid-thirties was produced by the 1931 and 1932 year classes which were much larger than any succeeding year classes. Second, spawning success is aperiodic and varies in series of from 2 to 10 or more years. The period of 1933 to 1944 was characterized by a wide range of spawning biomass and relatively stable recruitment of between 70 and 230 million pounds. This period was followed by a period (1945 to 1948) of much smaller spawning biomass and the same general range of recruitment; however, there were two relatively weak year classes (1945 and 1946). There were then three poor year classes (1949 to 1951) at the same general spawning biomass levels. Good recruitment then returned for 10 years (1952 to 1961). Following the end of this good recruitment period (1962), the spawning biomass reached almost 150 million pounds, the highest level since 1944.

Since 1962, there has been a near total spawning failure and the spawning biomass fell below 5 million pounds in 1966 (Figure 3) and below 1 million pounds in 1967.

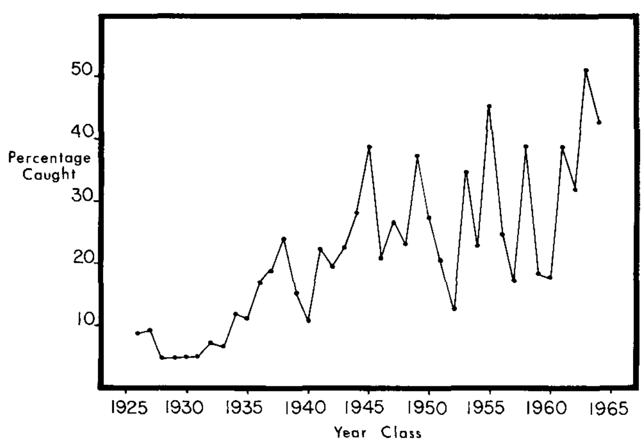


It appears Pacific mackerel recruitment is heavily influenced by factors other than spawning biomass. This hypothesis is strengthened by the association between Pacific mackerel population estimates and Murphy's (1966) sardine population estimates. Murphy's estimates included 2 year old and older sardines. Using Pacific mackerel of the same ages for comparative estimates (Figure 4), it appears that the years of decline in both the sardine and Pacific mackerel are very similiar; suggesting that both populations may have been influenced by the same or related factors.

FISHING MORTALITY AND EXPLOITATION RATES

There has been a long trend of increasing fishing mortality rates during the fishery's history. Although older age groups show increases in fishing mortality, the younger age groups (0's and I's) exhibit the greatest increases. Age group 0 fish were virtually unexploited before 1965. The first season that fishing mortality for age group I exceeded 0.5 was 1964. The overall trend is demonstrated by the percentage of recruits which were caught from each year class (Figure 5). These data are based on the assumption that instantaneous natural mortality equals 0.7 and include the combined catch of each year class from age group 0 to V.

Percentage of Pacific Mackerel Recruits (Age I) Taken by the Fisheries From Age O–V (numbers) at M =.7



The scatter about a trend line, and possibly the trend line itself, is primarily caused by the fact that poor year classes are exploited at a higher rate than strong year classes. High exploitations in 1945, 1949, 1963, and 1964 were all on very weak year classes. The 1955 year class was of moderate biomass. Low exploitation in 1940, 1952, 1959, and 1960 was due to strong year classes; 1957 was a low, moderate year class. For the period of 1931 to 1966, there is a correlation coefficient of —0.6 between the catch per recruit from 0 to V and the size of the year class. This correlation coefficient of —0.6 also is found between the catch per recruit and total population size of Pacific mackerel present at time of recruitment. In addition, exploitation is affected by following year classes, and by the population size of other fish, particularly sardines and jack mackerel. Market demand, of course, has an overriding control of the fishing effort exerted on the species and economic factors have affected the exploitation rates.

To illustrate the relationship between population biomass and exploitation rate, data since 1950 were separated into three categories:

(1) high biomass, which includes 8 years and levels between 154 and 322 million pounds;

(2) low biomass, which includes 8 years and biomass between 23 and 109 million pounds; and

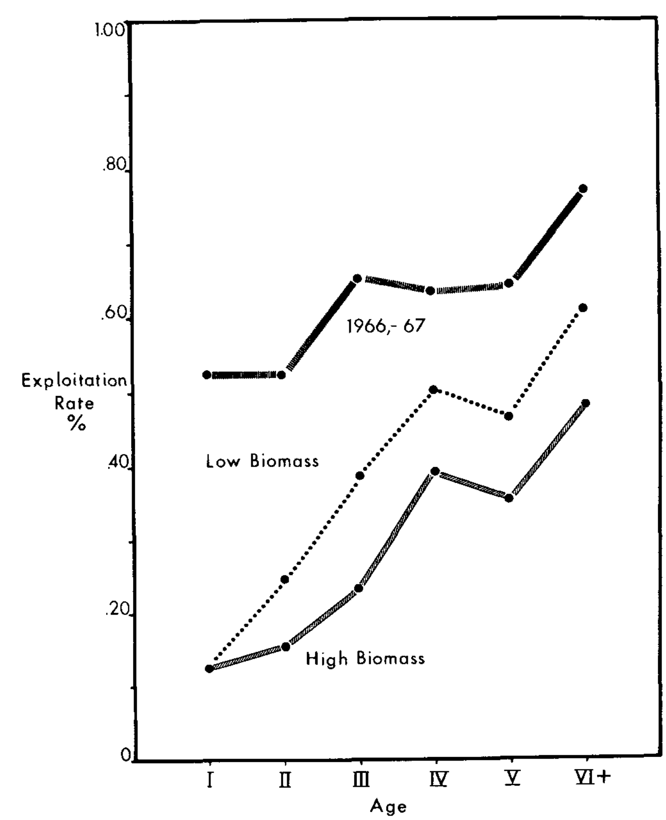
(3) the very low biomass of the 1966–67 to 1967–68 seasons, which includes biomass levels of 1.1 to 6.7 million pounds.

This last level is close to expected exploitation rates since the 1967–68 season because the biomass has been very low since the 1966–67 season.

These exploitation levels do not include age 0 fish which did not have exploitation rates exceeding 0.05 until 1965. Exploitation rose to 0.43 in 1966 and remained high until the moratorium went into effect in 1970.

Exploitation rates in the low biomass years run in excess of 0.10 higher than the high biomass years (Figure 6). Very high rates have been operating on age IV and older fish at all biomass levels since 1950. The very low biomass seasons of 1966–67 and 1967–68 have exploitation rates well above those that any fishery could sustain. In these seasons, all age groups have

Population Biomass VS Exploitation Rate in Pacific Mackerel



rates above 0.5, and the bulk of the spawning age fish have rates in excess of 0.6.

Although the fishermen traditionally prefer larger fish, during these years of very low population levels, their exploitation of immature fish, 0's, I's and II's, increased greatly. The demise of the scoop fishery which was more selective for older fish than the purse seine fishery also is a factor.

These high exploitation rates came at a time, 1966–68, when fishing mortality should have been reduced because there had been a series of poor recruitment years.

CONSEQUENCES OF ALTERNATE MANAGEMENT DECISIONS

In view of the fact that regulation of the commercial Pacific mackerel fishery is the responsibility of the State Legislature, avenues of management seem to include four possibilities: no catch limitations; a size limit; a moratorium, and a catch quota. Rapid changes in biomass that result from wide variation in Pacific mackerel recruitment appear to me to exclude a management policy based on a maximum sustained yield concept. A quota method of management must therefore include flexibility to change the quota annually. This could encourage fishing during years of good recruitment and limit or close the fishery when recruitment is poor.

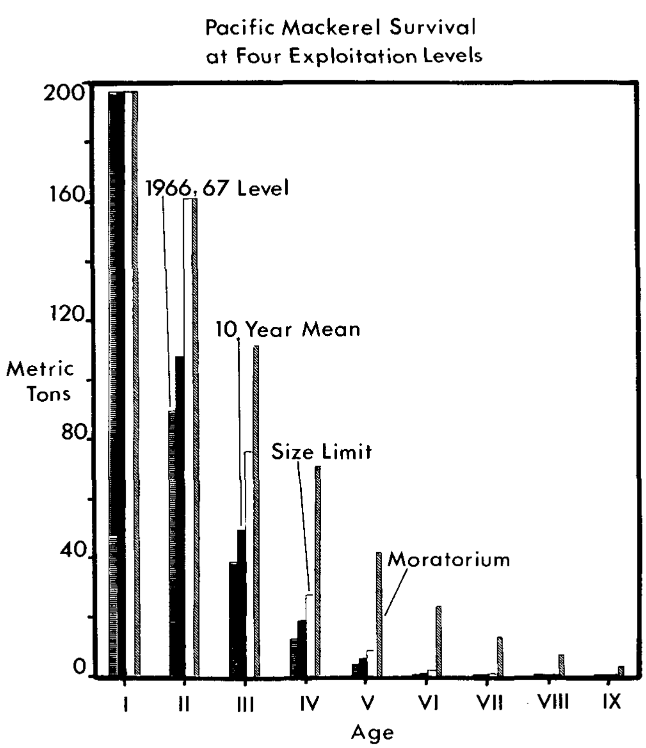
A no catch limitation policy would result in exploitation rates similar to those of the recent past and I have separated these into two exploitation levels; that of a 10 year mean, 1958–67, and second, the level of 1966–67, 1967–68. This second level would be similar to that which would be expected if commercial fishing were to begin at the present low population level. Both of these levels are underestimates of total exploitation of a year class since they do not include fishing mortality on 0 age fish.

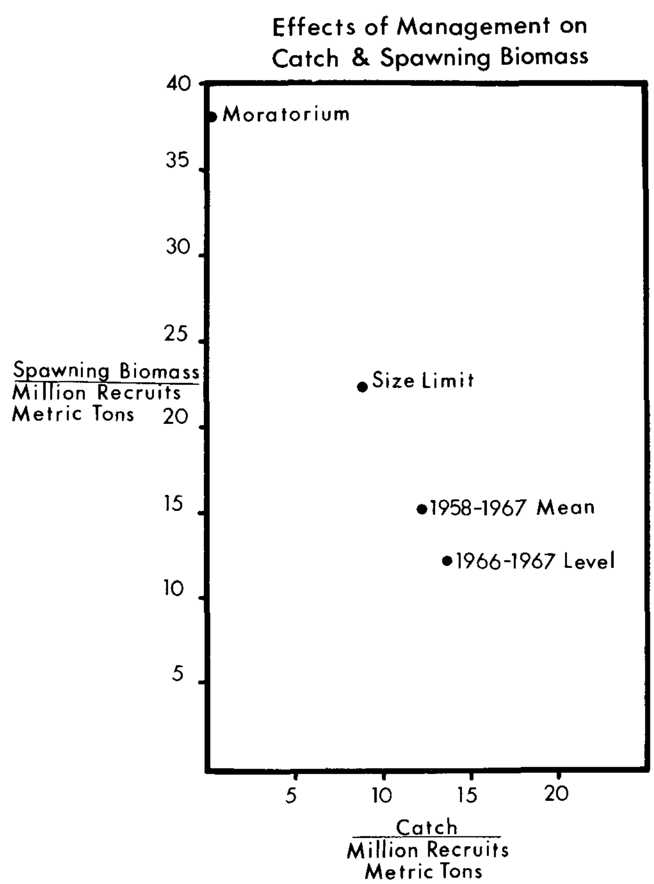
A size limit would only protect the 0 and I age-group fish, since by the time Pacific mackerel reach age group II they travel in schools of mixed ages. A size limit of 11 inches with a 15% allowance for smaller fish would be an expected regulation if a size limit policy were decided upon.

The third category, a moratorium, is presently in effect.

The three exploitation levels listed above and the moratorium each have different survivor curves. The surviving biomass from 1 million recruits is shown for each curve (Figure 7). In both exploitation levels that might result from a no catch limitation management policy, the surviving biomass drops very quickly and few fish reach spawning age. Under a size limit management plan there would be significantly greater numbers at age groups II and III, but little difference by age group IV. Under a moratorium, the surviving biomass is greatly increased at the older age groups.

The relationship between catch and surviving spawning biomass contribution from 1 million recruits under these management plans shows significant variation (Figure 8). The greatest contribution to spawning is under a moratorium. With the size limit plan, there is a large drop in spawning biomass and a predicted





catch of 8.8 metric tons per million recruits. With both of the exploitation levels from a no catch limitation management plan, the spawning biomass is further reduced and the predicted catch per 1 million recruits rises to 12.2 and 13.6 metric tons.

PRESENT SITUATION

Present estimates of the population size of Pacific mackerel off southern California, exclusive of the 1971 year class which should have been detected by November 1971 but was not, is a hopeful 1,000 tons, of which less than 300 tons are spawning stock. These estimates are based on the assumption that 25% of age group I fish will spawn.

The best recruitment per spawner occurred in the low spawning biomass of 1953 when each pound of spawners produced 23.6 lbs. of recruits. The second and third best years were 1947 and 1952 when 5.5 and 5.4 lbs. of recruits were produced by each pound of spawners.

If the present spawning biomass is as large as we hope (i.e., .6 million lbs.) and if it could have spawning success equal to the best year since 1931 (i.e., 23.6 lbs. of recruits per lb. of spawners), we could only expect 14.1 million lbs. (7,050 tons) of recruits. Thus, the best observed spawning success with the spawning biomass at the present level would produce a year-class that could only be described as a failure. It is obvious the present spawning biomass is too low to produce a strong year class. Therefore, it appears the only logical management decision at this time is to continue the moratorium. This policy will allow the population a chance to increase to a level where an optimum recruitment year could produce a strong year class.

ACKNOWLEDGEMENTS

Pat Tomlinson wrote the computer programs and did most of the work in producing the population estimates used in this paper; his employment by the Chilean Government prevented him from completing the work. Tim Farley ran the spawner-recruit models and Clark Blunt and Herb Frey reviewed the manuscript.

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SOUTHERN CALIFORNIA'S INSHORE DEMERSAL FISHES: DIVERSITY, DISTRIBUTION, AND DISEASE AS RESPONSES TO ENVIRONMENTAL QUALITY

ALAN J. MEARNS
Southern California Coastal Water Research Project
El Segundo, California

INTRODUCTION

The Southern California Coastal Water Research Project (SCCWRP)[1] has been established to study the coastal water environment, especially with respect to the effects of municipal wastewater discharges. In the summer of 1971, the project began an intensive analysis of fish data that was being collected by coastal monitoring agencies using small otter trawls. The objectives of the SCCWRP study were (1) to determine whether or not previously reported diseased and abnormal fish populations were related to the discharge of wastewaters in southern California and (2) to determine whether or not information useful to marine pollution control problems was being taken by these trawl surveys.

Today, I am going to summarize some of our observations on the abundance, diversity, and health of southern California's inshore demersal fish populations and, for purposes of discussion, present some new hypotheses on the possible impact of man's activities on these fish populations.

[1] The project is jointly sponsored by the five agencies (Ventura County, the Cities of San Diego and Los Angeles, and the County Sanitation Districts of Orange and Los Angeles Counties) responsible for most of the municipal wastewater discharges into the ocean off southern California. A commission of local civic leaders administers the project; scientific guidance is provided by a consulting board of environmental experts. The project has received two grants from the Environmental Protection Agency and has recently released a report summarizing its first 3 years of research (Southern California Coastal Water Research Project 1973).

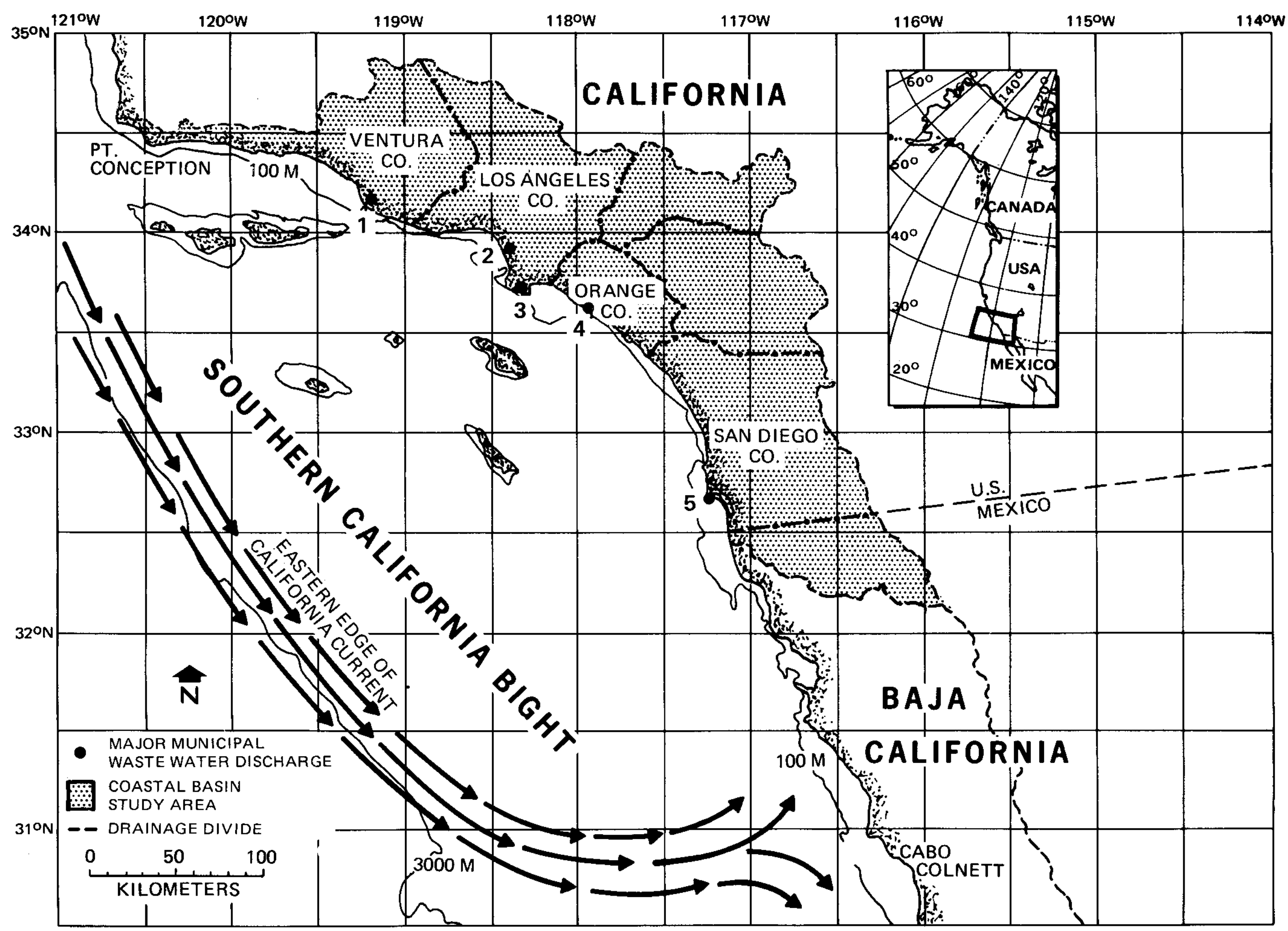

FIGURE 1. The Southern California Bight and the adjacent coastal basin. Major municipal wastewater discharges are (1) City of Oxnard, (2) City of Los Angeles, (3) County Sanitation Districts of Los Angeles County, (4) County Sanitation Districts of Orange County, and (5) City of San Diego.

STUDY AREAS AND METHODS

The Southern California Bight (Figure 1) is the major area of concern in all of SCCWRP's physical, chemical, and biological investigations. The Bight is defined on the east by the coastal shoreline extending from Point Conception, California, to Cabo Colnett, Baja California, and on the west by the California Current. At present, we have fish data for only a small fraction of the Bight—primarily, the waters near the most densely populated areas of the southern California coast.

Most of the data obtained and analyzed by SCCWRP were collected in trawl surveys off Los Angeles County during 1957–63 (Carlisle 1969) and off Ventura, Los Angeles, and Orange Counties between 1969 and the present. The data were taken by several different agencies, including the California Department of Fish and Game, local sanitation districts, and universities and colleges. Most of the investigators used 25 ft (headrope length) shrimp trawls with 1½ in. mesh and ½ in. cod ends or cod-end liners. The County Sanitation Districts of Los Angeles County, which trawled off the Palos Verdes Peninsula, used a 40 ft trawl with slightly larger mesh size. Trawls were made at depths of 10 to 400 meters; most tows were 10 minutes in duration, but the area sampled varied according to vessel speed.

SCCWRP is now analyzing data from about 1,800 otter trawl hauls for species composition, relative abundance, dominance, information-theory diversity, disease frequency, and recurrent groups. In 1971 and 1972, we made special collections to identify and resolve problems concerning species identifications, gear characteristics, disease descriptions, and methods of measuring fishes. The following summary is based primarily on data from approximately 300 samples taken at 119 stations (Figure 2) since 1969.

FINDINGS

Populations and Communities

The data from the trawl samples showed that at least 121 species, representing 41 families of cartilaginous and bony fishes, were present on or near the bottom of the coastal shelf survey areas. The 20

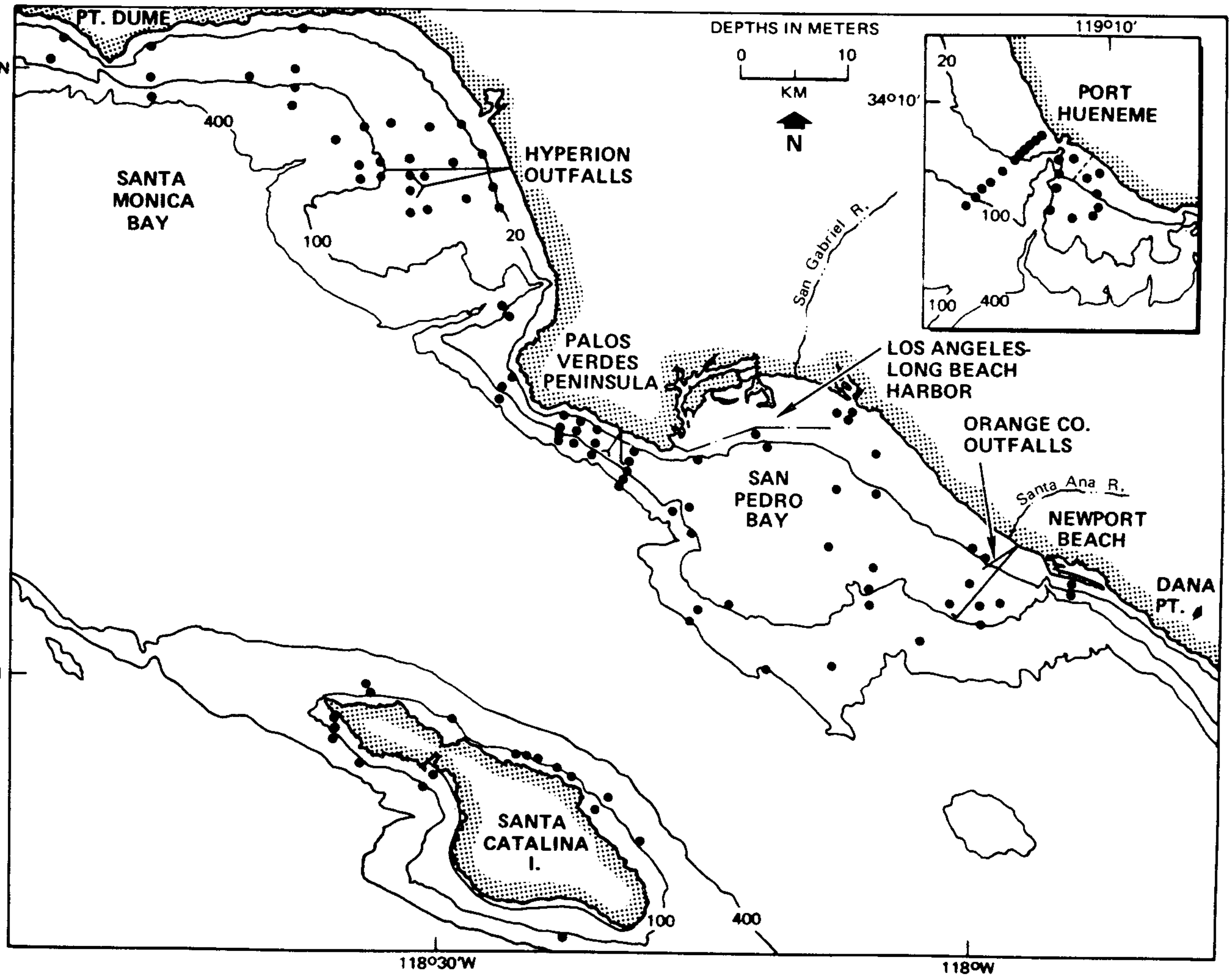

FIGURE 2. Station locations for the 1969–72 trawling surveys of southern California nearshore demersal fishes.

most abundant species are listed in Table 1. Although the catches were dominated by flatfishes, rockfishes, and perches, there were occasional large catches of white croaker, *Genyonemus lineatus*, and northern anchovy, *Engraulis mordax*. The dover sole, *Microstomus pacificus*, was the most common and among the most abundant species captured; this species is also interesting because (1) it was apparently rare in some 200 trawls taken by the University of Southern California between 1912 and 1922 in the same coastal areas (Ulrey and Greeley 1928) and (2) it is represented by populations bearing several kinds of diseases.

TABLE 1

Total number of specimens of each of the 20 species most abundant in samples from the 1969–72 trawling surveys of southern California coastal waters

Species	Common Name	No. of specimens
Citharichthys stigmaeus	Speckled sanddab	17,626
Citharichthys sordidus	Pacific sanddab	10,312
Microstomus pacificus	Dover sole	9,375
Sebastes saxicola	Stripetail rockfish	5,535
Genyonemus lineatus	White croaker	4,155
Porichthys notatus	Plainfin midshipman	3,943
Lyopsetta exilis	Slender sole	3,893
Symphurus atricauda	California tonguefish	3,590
Sebastes semicinctus	Halfbanded rockfish	3,310
Icelinus quadriseriatus	Yellowchin sculpin	2,836
Cymatogaster aggregata	Shiner perch	2,008
Zalembius rosaceus	Pink surfperch	1,975
Engraulis mordax	Northern anchovy	1,952
Glyptocephalus zachirus	Rex sole	1,865
Seriphus politus	Queenfish	1,864
Zaniolepis latipinnis	Longspine combfish	1,402
Sebastes diploproa	Splitnose rockfish	1,186
Pleuronichthys decurrens	Curlfin sole	1,063
Lycodopsis pacifica	Blackbelly eelpout	849
Zaniolepis frenata	Shortspine combfish	815
Total		79,554
Total (all species)		87,418

Fish populations occurred in all bottom areas sampled, including those highly contaminated by discharged wastes. There were considerable differences in fish abundance (catch per haul) and diversity (species per haul) in the various areas: Median catches ranged from 60 to 100 fish per haul in the Santa Catalina Island and Port Hueneme surveys to 200 to 500 fish per haul in the San Pedro Bay and Orange County coast surveys. As different sampling methods were used in each survey, it was not possible to relate variations in catch and species per unit effort to the environmental conditions in the areas. However, when a single vessel and gear combination was used for all sampling in an area, fish abundance and diversity (Table 2 and Figure 3) was related to depth, season, and in some cases, proximity to wastewater discharge.

Diversity, as measured by the Shannon-Weaver information theory formula,[2] was high off Laguna Beach (2.1), Santa Ana River (1.7 and Santa Catalina Island (1.5), moderate off Palos Verdes (1.3) and in Santa Monica Bay (1.3), and low off Port Hueneme (1.14), at many shallow stations, and at several stations near the Palos Verdes discharges (0.9 to 1.1) but not at other discharge sites. Diversity appeared to increase with decreasing latitude (Table 2), but additional sampling during all seasons is required to verify this trend. In general, diversity in the areas sampled was moderate compared to that reported for demersal fish populations in Texas, Georgia, and Puget Sound, Washington.

[2] Diversity $= H' = -\Sigma_i^s (n_i/N) \log_e (n_i/N)$, where N is the total number of fish per sample, S is the total number of species per sample, and n_i is the number of fish of the ith species per sample.

TABLE 2

Description of 1969–72 trawling surveys of southern California coastal waters

Area	Depth range (ft)	No. of samples	No. of species	Median catch/ haul	Mean species/ haul	Mean diversity/ haul
Port Hueneme	30–600	18	48	314	11.5	1.14
Santa Monica Bay	60–600	49	72	135	9.9	1.34
Palos Verdes	75–600	76	72	117	9.8	1.30
San Pedro Bay	30–1,200	51	88	225	12.3	1.47
Santa Ana River	35–465	48	86	475	17.3	1.68
Laguna Beach	80–300	9	47	250	18.0	2.10
Santa Catalina Island	75–450	13	41	217	12.0	1.48

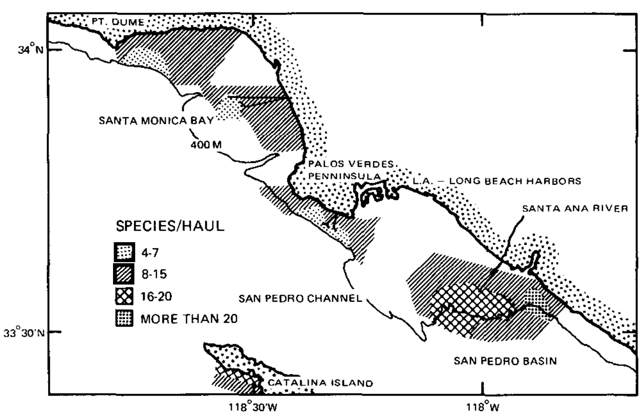

FIGURE 3. Number of species collected in southern California traw surveys, February to April 1971.

Recurrent group analysis (Fager 1957) revealed at least five groups of associated species among the most common species (Figures 4 and 5). Three depth-related flatfish groups were identified (Group 1, mid-depth dover sole group; Group 2, shallow-water speckled sanddab group; Group 4, slender sole/rex sole group). The yellowchin sculpin and longspine combfish (Group 5) formed a middepth association. The white croaker dominated a nearshore group of free-swimming fishes that had affinity with the northern anchovy.

Distinct recurrent groups were not noted in samples from some areas off Palos Verdes and Santa Catalina Island and in Santa Monica Bay. Several members of the groups described above were not found in these areas: Most notable was the absence of the yellowchin sculpin off Palos Verdes (this species was present in the area 50 years ago and is otherwise widely distributed). These observations suggested that fish community relations in these areas were, in fact, different than those in adjoining areas, possibly re-

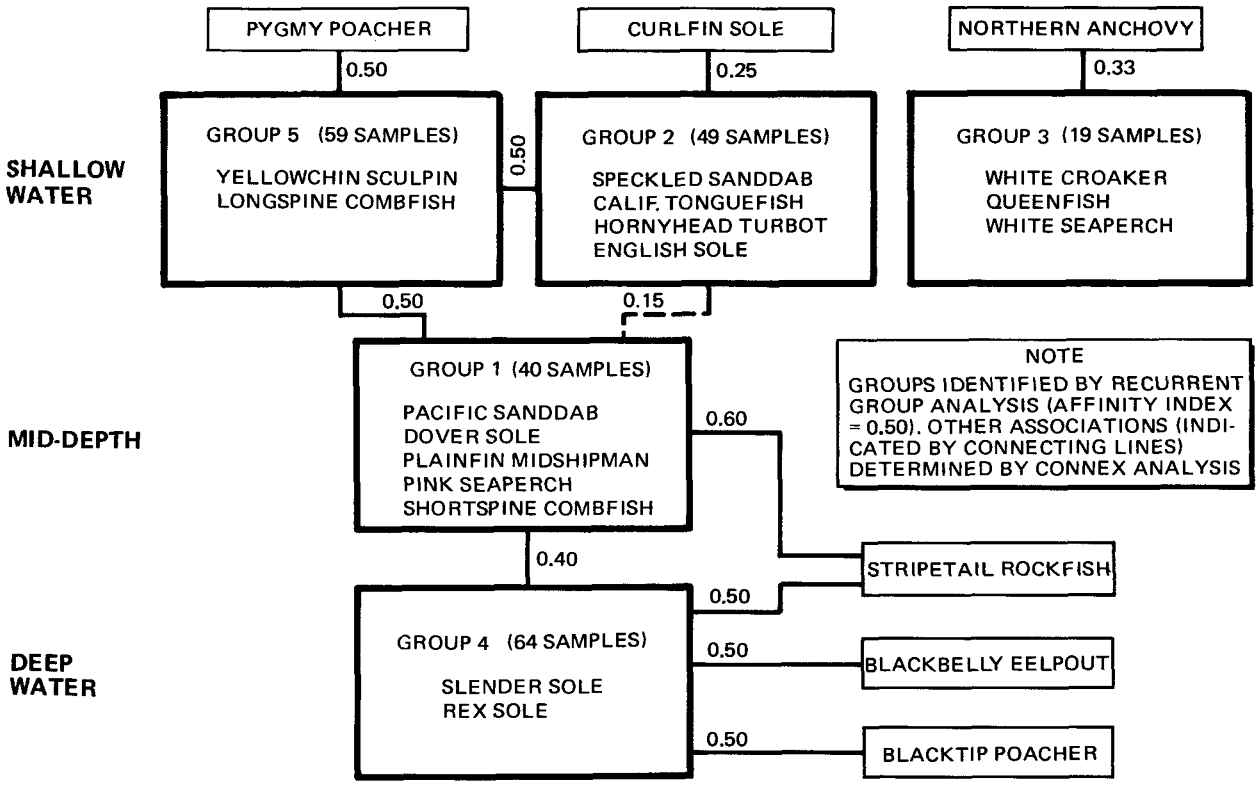

FIGURE 4. Species associations of southern California nearshore demersal fishes, 1969–72.

flecting the influence of the Palos Verdes wastewater discharge. However, the differences cannot be clearly attributed to wastewater discharges without additional observations of other communities. Likewise, the value of Santa Catalina Island as a "control" site for coastal demersal fish studies was not particularly evident from these observations.

Several special analyses indicated that some demersal fish species—in particular, the dover sole and white croaker — were attracted to wastewater discharges, even while normal periodic migrations were in progress. However, regional trends in the population density of these species could not be established because of the differences in vessels and gear used in collecting the data for each region.

Upwelling may be a factor determining the abundance and distribution of bottom fish in the coastal zone. Although benthic water quality data are rarely taken in conjunction with trawl surveys, water characteristics were measured during several of the trawl surveys in Santa Monica Bay during 1970. The data revealed a major benthic influx of cold, highly saline water of low oxygen content extending far into the shelf region of Santa Monica Bay in the late spring of 1960 (indicated by dissolved oxygen contours in Figure 6). The density of bottom fish in the bay appeared to be inversely related to the presence of this water at the bottom: The bottom fish populations appeared to move inshore in response to the onset of upwelling. This response has been noted in many coastal areas but apparently has not been used in recent monitoring surveys as an aid in understanding the distribution of fishes. Bottom water properties should always be measured as part of bottom fish surveys of coastal shelf areas.

Diel (day/night) changes in nearshore fish communities also may occur along the southern California coast. Some of our observations suggest that sampling is much more efficient at night, and further, that a number of species such as the shortbelly rockfish, *Sebastes jordani*, Pacific hake, *Merluccius productus*, and sable fish, *Anoplopoma fimbria*, may be present in shallow areas and at wastewater outfall sites only at night. Probable diel changes in fish populations must be considered in any future work on the biomass and food web dynamics of nearshore bottom fish populations.

Diseased and Abnormal Populations

Approximately 1% of all the fish collected in the recent surveys were diseased or abnormal in some way. At least five distinct disease syndromes were noted. Four of these (skin tumors in dover sole, lip papillomas in white croaker, tail erosion in white croaker, and bone deformities in sand bass) occurred in samples from all areas surveyed. These diseases were related to changes in population density (as shown for tail erosion in white croaker in Figure 7).

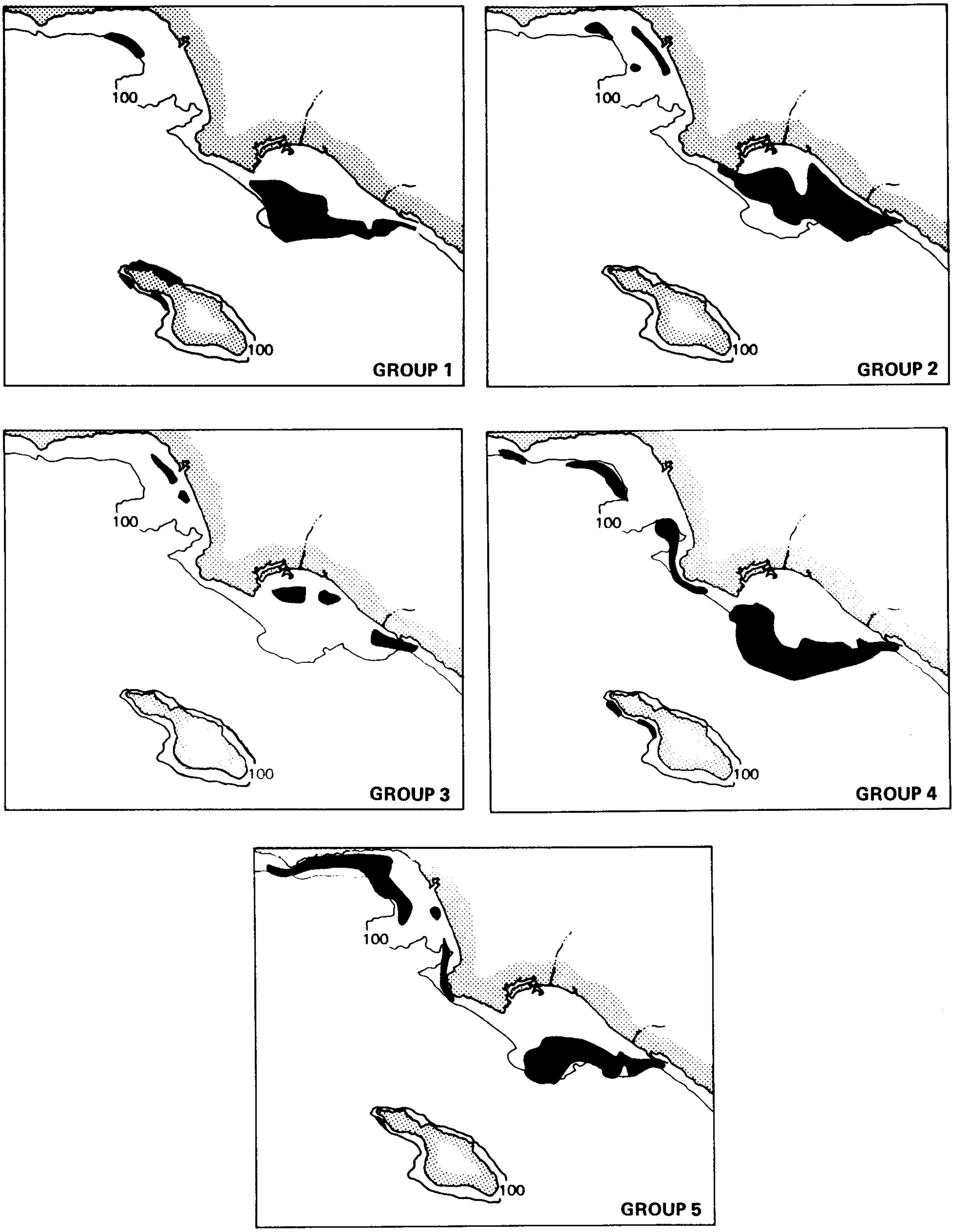

FIGURE 5. Distribution of recurrent groups of southern California nearshore demersal fishes, 1969–72. Depth line is 100 meters.

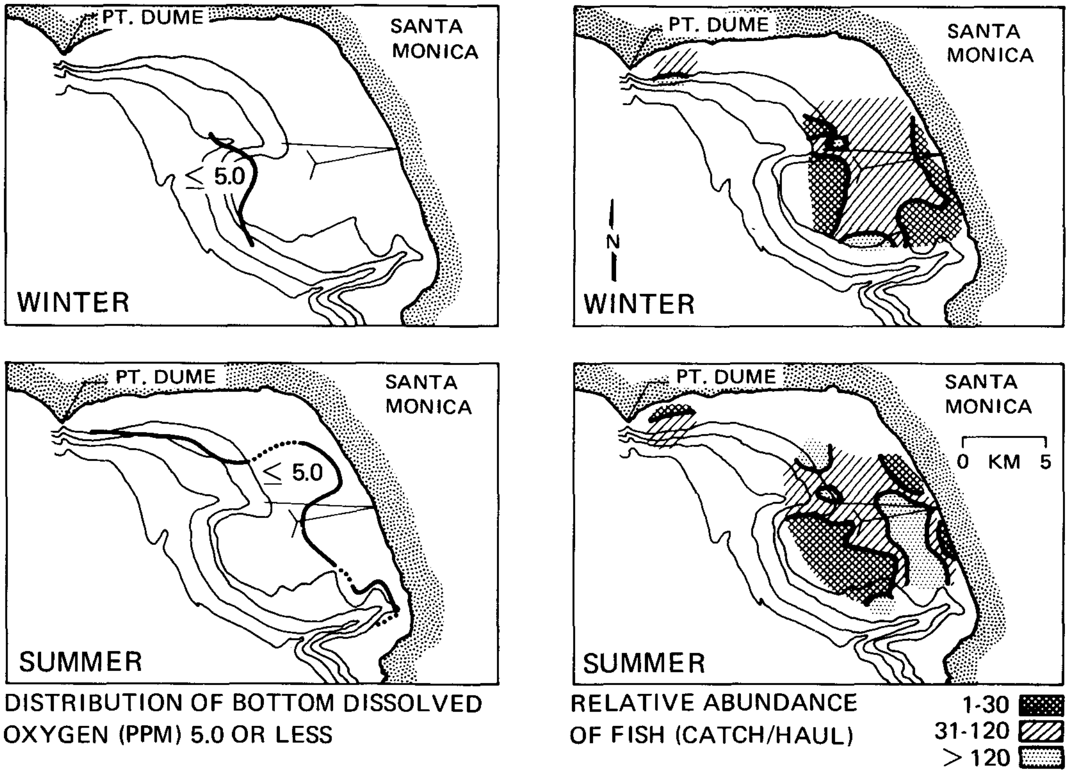

FIGURE 6. Bottom dissolved oxygen and fish abundance in Santa Monica Bay, winter (January–February) and summer (June–July) 1960.

age, or some other characteristic of the sampled populations. Figure 8 shows that the tumor size in dover sole was related to the size (standard length) of fish, indicating that the disease was, in part, a function of the juvenile biological characteristics of the species.

SCCWRP's observations on these four disease syndromes suggest that wastewater discharges, even when not the cause of a disease, may influence the disease indirectly by enhancing the survival of anomalous fish or the density of the fish population. Information on wastewater characteristics that enhance some but not all fish populations is needed: I believe such factors include freshwater, temperature, nutritional content of sewage particles, and sewage characteristics stimulatory to the benthic organisms that are food for the affected fish species.

A fifth disease, fin erosion in benthic fish, was limited to the sewage discharge sites off Palos Verdes and in Santa Monica Bay and, recently, to the new Orange County deepwater discharge. This disease appeared to be directly related by proximity to these discharges but was unrelated to the other diseases and anomalies such as skin tumors. The length frequency relations of this disease in dover sole are shown in Figure 9. The dover sole was always the most affected species, with infection frequencies of 20 to 100% of samples taken off Palos Verdes and 5 to 20% of samples taken at the head of Santa Monica Canyon. A detailed study of the environmental and physiological aspects of this disease revealed that the disease syndrome (1) included gill hyperplasia, which was not detected aboard ship, (2) was histologically detectable in fish that did not display gross symptoms, (3) was apparently not systemic in origin (internal organs were not affected), (4) was statistically related to predicted benthic locomotor activity, and (5) was unrelated to liver concentrations of 10 metals or flesh concentrations of DDT. These observations generally support the hypothesis that the disease is external in origin and not related to body-burden buildup of these toxicants; it may result from contact of the fins with contaminated bottom sediments in the vicinity of the discharges. There is a definite need to determine if the cause of the disease is an infectious (microbial) or irritation (physical or chemical) process.

SUMMARY AND DISCUSSION

Data on the distribution, abundance, and diversity of fishes collected in recent years along the coastal shelf of southern California shows the demersal fish fauna of this region to be moderately diverse and abundant compared to that in other coastal areas. Diversity is low near some wastewater discharge sites; however, there is no area that can be called a "biological desert" relative to all areas studied.

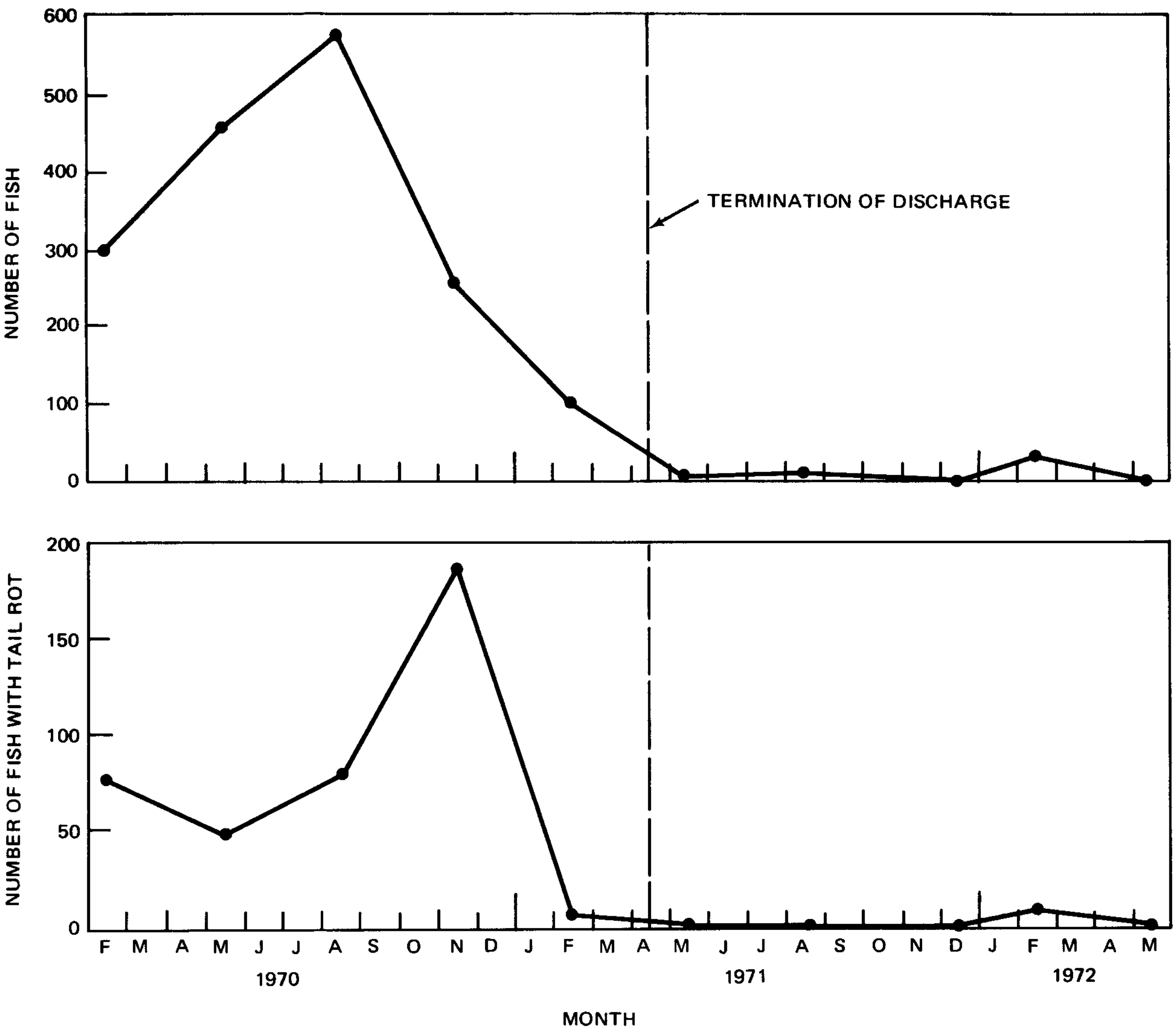

FIGURE 7. Incidence of tail erosion in white croaker from the Orange County shallow water outfall area, 1970–71.

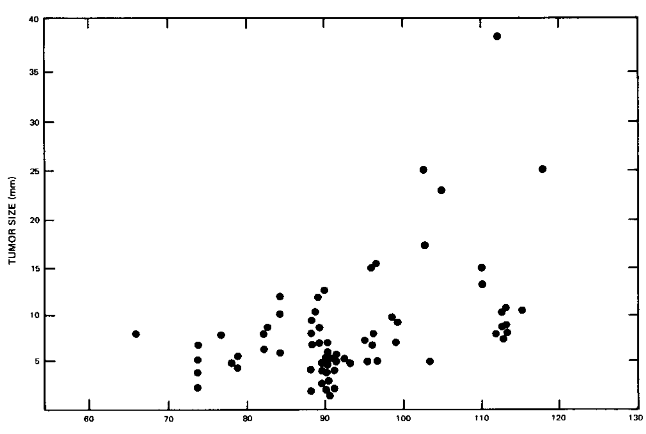

FIGURE 8. Relation between the length of tumor-bearing dover sole and the tumor size (diameter).

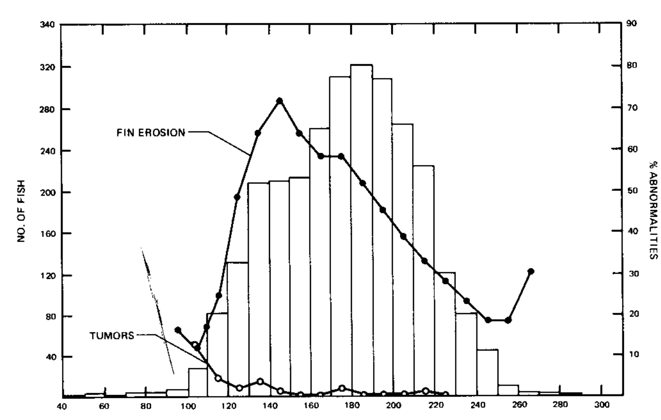

FIGURE 9. Length frequency distribution of normal and diseased dover sole populations off Palos Verdes.

Although a variety of bottom fishes were found in the southern California coastal zone, concern about the quality of this fauna remains. It appears that great shifts in the relative and absolute abundance of some species have occurred (Stephens, 1972). The occurrence of diseased anomalous populations is a further sign of instability and imbalance of some bottom fish communities. Predators apparently are not in sufficient abundance to remove sick or injured fish commensurate with their rate of injury, no matter what the cause. Our observations suggest that the affected populations are over-abundant, that predators are avoiding or being removed from the anomalous communities or that both factors are operating.

Human activities in the coastal zone may be indirectly enhancing the survival rates of some populations and increasing mortality rates in others. Some conditions that may have affected the structure of bottom fish communities are:

A. The change in the character of the coastline from depositional to erosional as a result of flood control projects (maximum activity, 1930–50).
B. The relatively constant freshwater inputs through wastewater outfalls (now estimated to be 1,231,000 acre-ft/year).
C. The relatively constant particulate input through outfalls and dumping and dredging in the coastal zone.
D. The reduction in backbay spawning and rearing grounds resulting from construction in the coastal zone.
E. The removal of predator and competitor species through sport fishing (current rate of increase: 100,000 fish/year).
F. The current lack of a significant bottom fishery, which would reduce the number of forage fish.
G. Local toxicity and biostimulation from outfalls.

From the standpoint of coastal fish populations, the important effect of these activities over the past 50 to 100 years may have been the enhancement of nearshore species that favor organically rich, silty benthic habitats and those with an innate attraction to constantly flowing freshwaters or areas of depressed salinity. The species composition of the present coastal shelf fauna of the Los Angeles area appears oriented toward a mud or silt (rather than sand) assemblage. This change in basic community orientation is exemplified by the increased commonness of the dover sole over the past 60 years.

It is clear that man and nature act at many levels of fish population dynamics and community structure and that management of coastal zone resources must be based on an understanding of all long-term influences. Conversely, there is as yet no evidence that control of one factor, such as wastewater discharges, will return the coastal fish fauna to some particular former state.

Quantitative studies in areas not now affected substantially by man (such as the Gulf of California and Pacific coasts of Baja California) should provide better understanding of man's impact on the coastal zone. And, in areas already affected, changes that have occurred—such as the apparent increase in abundance of dover sole—should be viewed in terms of their resource potential and managed accordingly.

ACKNOWLEDGEMENTS

The author greatly appreciates the contribution of SCCWRP staff members to this work, especially David Young, chemical oceanographer, and James Allen, Marjorie Sherwood and Ricard Gammon. Individuals from a number of local public and private agencies and colleges contributed a great deal of background information and data: Particular appreciation is given to Doug Hotchkiss, oceanographer for the County Sanitation Districts of Los Angeles County; D. Chamberlain, Allan Hancock Foundation, U.S.C.; Charles Mitchell, Marine Biological Consultants, Inc.; and Jack Carlisle, California Department of Fish and Game. John Isaacs, Scripps Institution of Oceanography, G. W. Klontz, Jr., Idaho Cooperative Fisheries Unit, and John Stephens, Occidental College, have continued to provide valuable perspective for our work.

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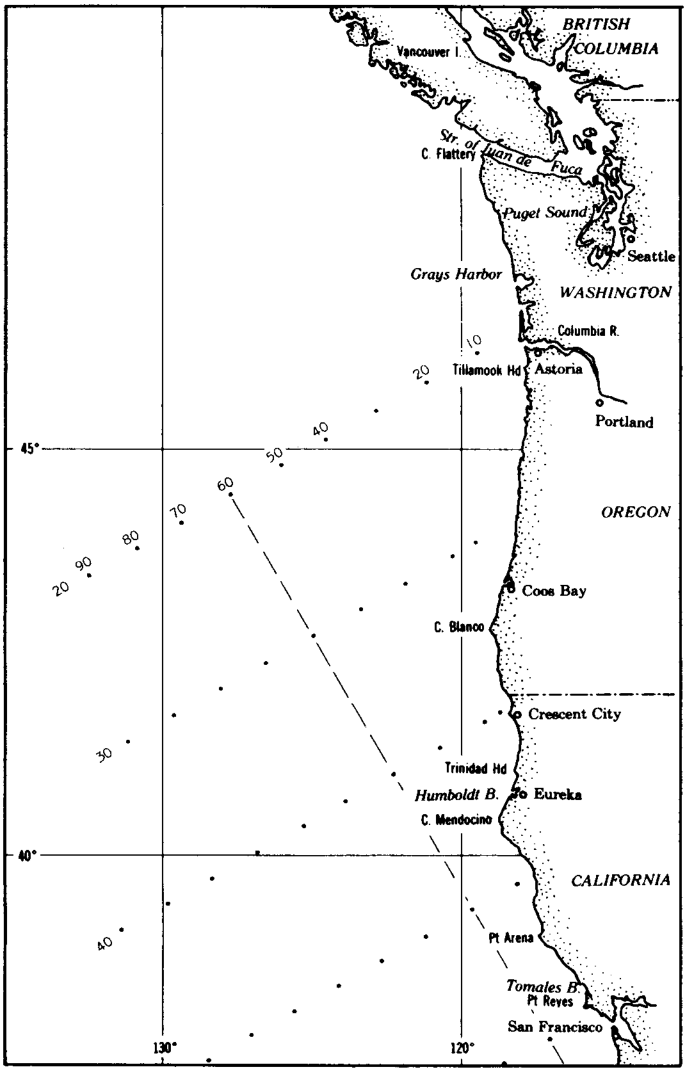

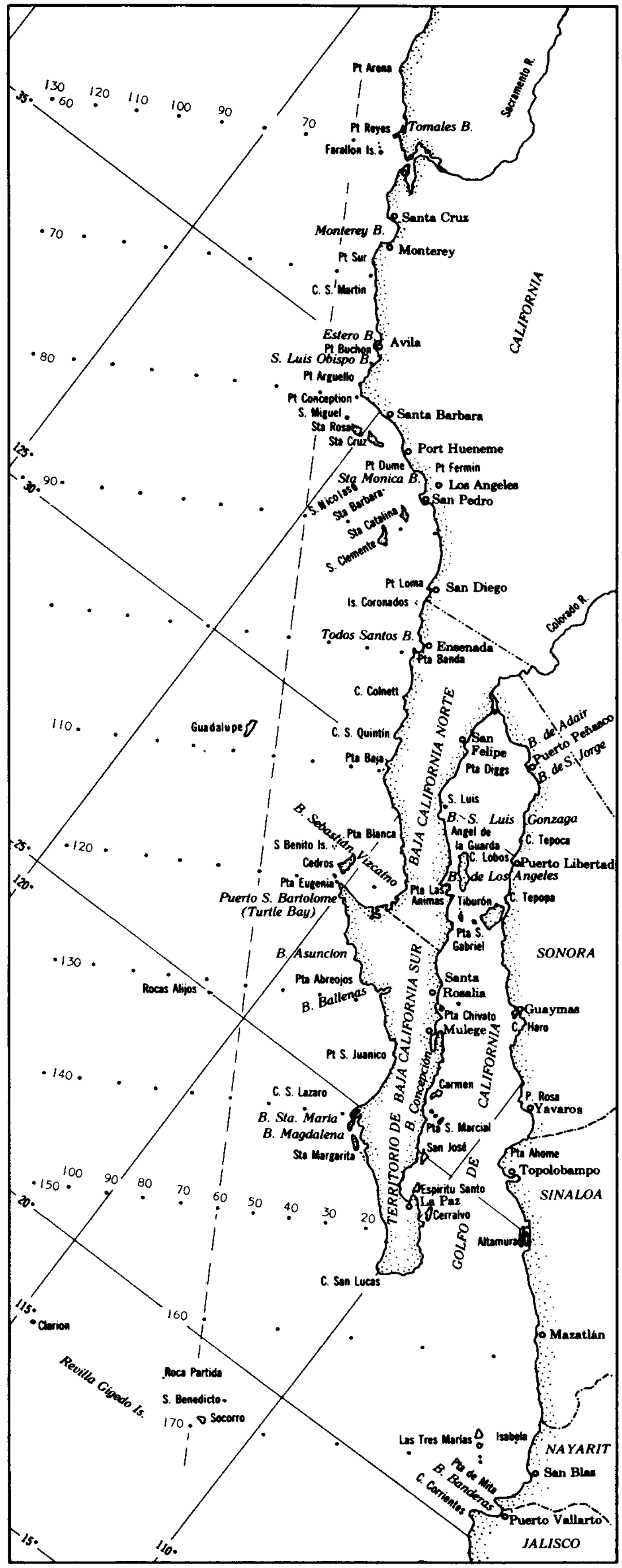

These maps are designed to show essential details of the area most intensively studied by the California Cooperative Oceanic Fisheries Investigations. This is approximately the same area as is shown in color on the front cover. Geographical place names are those most commonly used in the various publications 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