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 semifluid (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 cencentrations 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 under-

standing 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 identi-

fied 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 $\frac{1}{2}$ 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