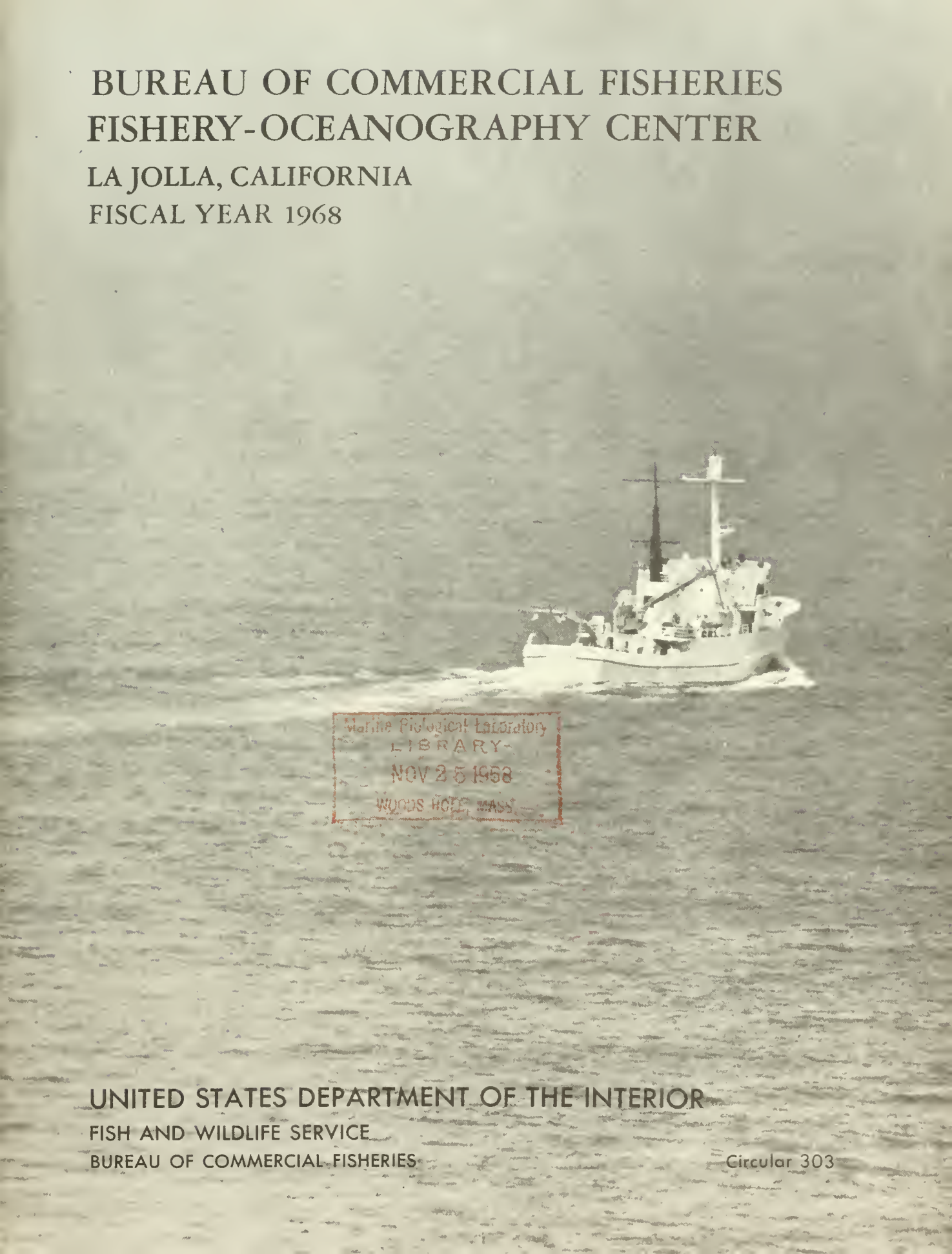
BUREAU OF COMMERCIAL FISHERIES
FISHERY-OCEANOGRAPHY CENTER
LA JOLLA, CALIFORNIA
FISCAL YEAR 1968



UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF COMMERCIAL FISHERIES

Circular 303

G. Mattson

Bureau of Commercial Fisheries
Fishery-Oceanography Center, La Jolla

Cover DAVID STARR JORDAN

UNITED STATES DEPARTMENT OF THE INTERIOR
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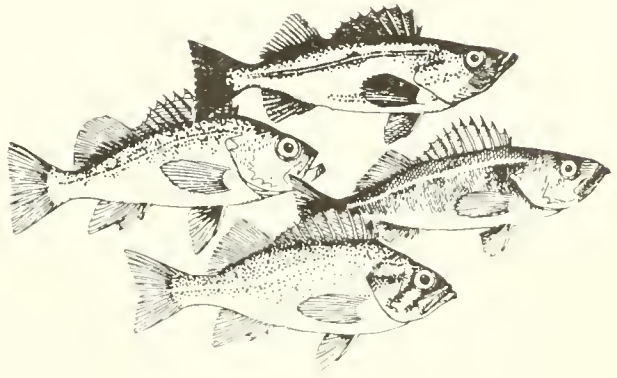
ALAN R. LONGHURST, LABORATORY DIRECTOR



Circular 303

WASHINGTON, D. C.
September 1968

ABSTRACT

This report describes the facilities now available for research and gives an account of research done from July 1967 through June 1968.

The main accomplishments of the Center during this period have been completion of the EASTROPAC surveys of seasonal changes in the biology and oceanography in the eastern Pacific, and design of computer methods of analysis and presentation of survey data; design and construction of an experimental deep-sinking tuna purse seine net; partial elucidation of the genetically distinct racial structure of the northern anchovy; and completion of studies of the feeding budget of the California sardine population during the rise and fall of the fishery.

David Starr Jordan, *the Center's major research vessel.* G. Mattson

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Bureau of Commercial Fisheries
Fishery-Oceanography Center, La Jolla

PREFACE

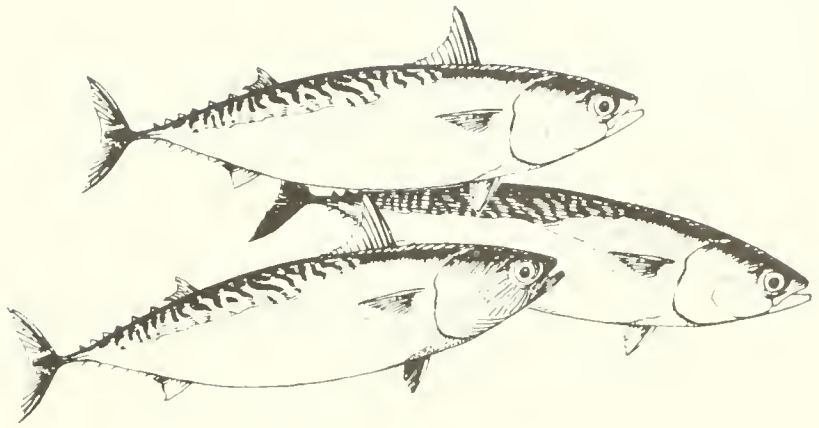
In late 1964, the new Fishery-Oceanography Center of BCF (Bureau of Commercial Fisheries) was dedicated; it stands on a clifftop on land deeded by the University of California to the north of SIO (Scripps Institution of Oceanography) at La Jolla.

Into this building moved the two BCF Biological Laboratories from La Jolla and San Diego, together with several tenant agencies, including the IATTC (Inter-American Tropical Tuna Commission) and STOR (Scripps Tuna Oceanography Research). In June 1967, the two BCF Laboratories were merged into a single laboratory known simply as the Fishery-Oceanography Center, La Jolla; it is the purpose of this report to describe the research carried out in the first year following this reorganization, the present aims of the laboratory, and the material facilities which it now has at its disposal.

The Fishery-Oceanography Center is the Federal laboratory charged with fishery research in the BCF Pacific Southwest Region, which encompasses California and various inland states. Research at the Center is intended to supplement that of the State agencies, with which it collaborates, mainly within the framework of CalCOFI (California Cooperative Oceanic Fisheries Investigations).

The Center conducts research ashore in its laboratories and afloat on its research vessels, on the high seas fished by the distant water fleet from California ports and the home waters fished by smaller vessels. The Center's research vessels operate throughout the California Current and much of the eastern tropical Pacific Ocean from Mexico to Peru, and westwards towards the Marquesas and Hawaiian Islands.

In addition to research on problems relevant to specific fisheries and designed to improve their status, BCF is also charged with advancing basic fishery science. The Fishery-Oceanography Center is active in such fields, as is appropriate from its location, which is adjacent to the laboratories of the Scripps Institution of Oceanography, and of the Institute of Marine Resources, organizations with which the scientific staff of the Fishery-Oceanography Center have close relations.



THE RESOURCES AND THE PROBLEMS

In 1966, the latest year for which published statistics are available, the California fish industry used as its raw material just over a quarter of a million metric tons of fish and invertebrates of about 50 species worth $87 million. Of this total, 60,000 tons, valued at $32 million, were caught by foreign fishing vessels and transshipped to California where it was used by the California processing plants; these imports represent 22 percent of the weight and 37 percent of the value of the raw material used by the industry.

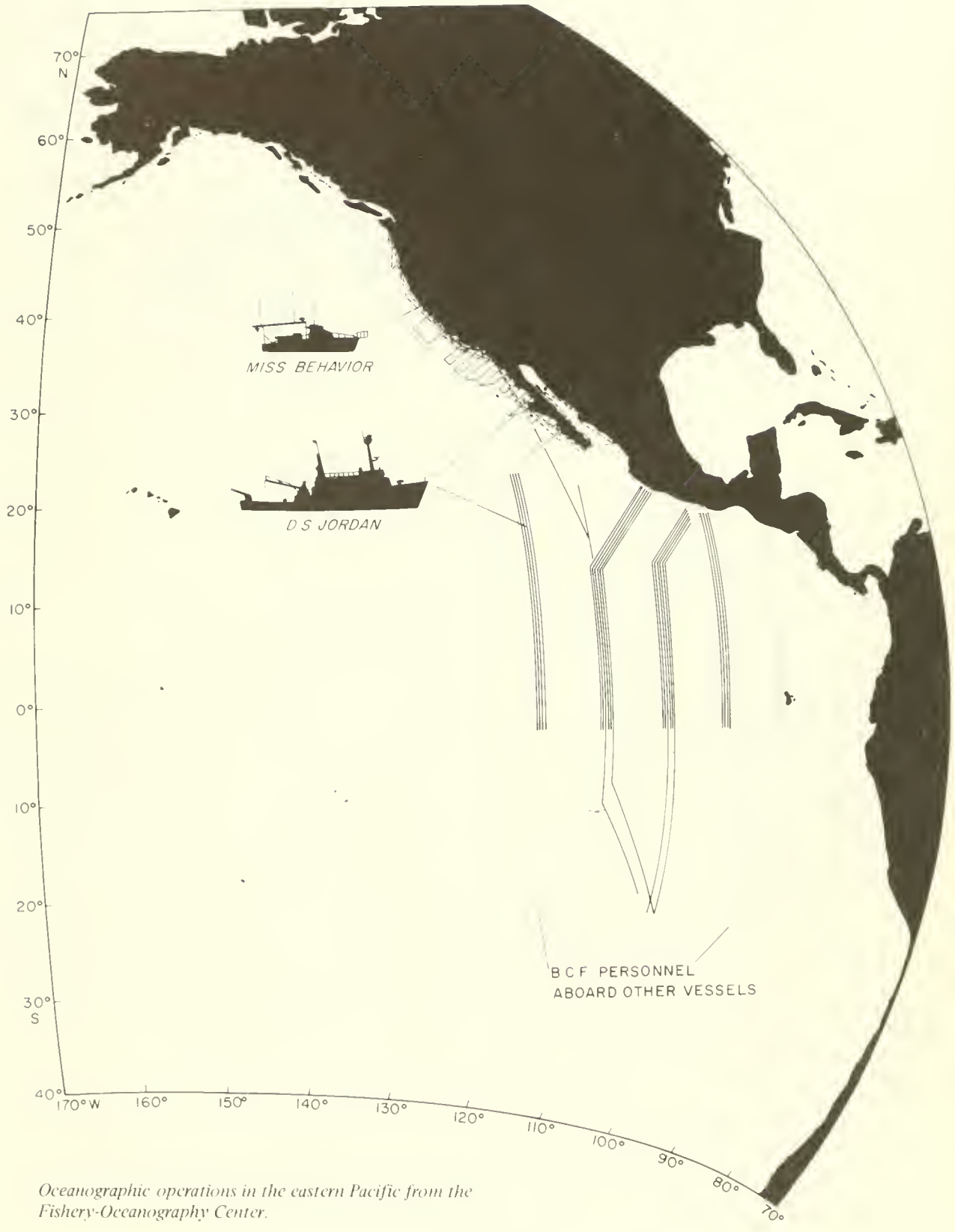
The 1966 statistics represented the culmination of a long trend of declining landings, which by this time had fallen to less than a third of their 1939 figure, and were offset, for tuna, by an increased dependence on the catches of foreign fishing vessels. In 1939, the total catch of the California fleet was more than three-quarters of a million metric tons, valued at $18 million, supplemented by only about 3,000 tons purchased from foreign fishing fleets.

This decline, in brief, is the basis of the problems facing the California fish industry and its fishing fleet. Attributable to no single cause, the failure to participate in the generally rising prosperity of the California economy can be blamed on unwisely heavy fishing of some resources, on natural changes in resource abundance due to climatic trends, and on increasing foreign competition in the tuna fisheries and in the fish meal and oil markets.

To understand more clearly what has happened in the California fisheries, we need to compare in more detail the years 1939 and 1966; in each year, five elements of the fishery can be recognized: *tuna, salmon, industrial fish, fresh fish*, and *invertebrates*.

Tuna landings by 1966 had increased by only about one-third over the 1939 landings, while the proportion formed by each of the species remained about the same: yellowfin tuna *(Thunnus albacares)* dominated in 1966, as in 1939. Although only 3,178 tons were purchased from abroad by the canners in 1939, this component had risen to a total of 60,832 tons in 1966; these imports formed 45 percent of the value of the raw material used by the tuna processors, compared with only 5 percent in 1939.

By the early 1960's it became evident, mainly as a result of the research work of IATTC, that the stocks of yellowfin tuna fished by the California fleet had reached their maximum sustainable harvest, and in 1966 they came under effective international regulation for the first time, on the recommendation of the Commission.



Oceanographic operations in the eastern Pacific from the Fishery-Oceanography Center.

Further sustained expansion of landings of yellowfin tuna from domestic vessels thus being unlikely, there was now an imperative need to increase the harvest of underutilized species of tuna or face an ever-increasing dependence upon foreign-caught fish. Fortunately, it appears possible that the skipjack tuna *(Katsuwonus pelamis)* population and perhaps those of the temperate tunas are not fully harvested and ways of increasing the take of these species by California vessels are now being studied within the Fishery-Oceanography Center.

This work is aimed at the solution of two related but different sets of problems. First, the problems with the search for new fishing grounds for skipjack tuna in the tropical waters to the west of the present fishing areas off Central America, along the routes by which they migrate to and from the Central Pacific. This search involves seasonal surveys of the biological and physical oceanography of wide areas of the eastern tropical Pacific, and also studies of methods for artificially aggregating the rather widely dispersed skipjack tuna in these oceanic regions so that they may be caught. Second, the problems of how tuna react to changes in the environment while migrating and feeding must be studied so that week-to-week movements of fish in response to monitored environmental conditions may be predicted in real time and the United States fishing vessels so advised (as are the Japanese on their fishing grounds).

The salmon fishery off northern California has maintained rather stable landings since the late 1930's, though their value has increased. State agencies and the Bureau of Sport Fisheries & Wildlife are both active in research in this fishery and so far the Fishery-Oceanography Center has not been asked to participate.

In comparison with the others, the industrial fishery is deeply in trouble: known in California as the "wetfish fishery," it uses many pelagic species in the California Current, which are reduced to fish meal and oil, canned as inexpensive canned products (largely for export) and processed into various animal foods. The decline of this fishery from the days of its great prosperity in the 1930's and 1940's (the heyday of Cannery Row) to its present state is well known. In 1939, the landings exceeded half a million tons and by 1966 they had fallen to little more than 60,000 tons.

Most of this decline is attributable to the catastrophic collapse of the northern subpopulation of the Pacific sardine *(Sardinops caeruleus)* which began during the 1940's and reached a nadir in the 1950's. In 1939, the landings of this species were 79 percent by weight and 34 percent by value of the total California landings: from just half a million tons in 1939 they fell to a few hundred tons in 1966.

In 1949, in response to the evident decline in landings, the Fish and Wildlife Service and State laboratories began intensive and cooperative research on the California sardine within the framework of CalCOFI, thus formalizing cooperative sardine research that began earlier. It became evident after some years of work that the problem of the Pacific sardine was due to an interaction among heavy fishing, climatic changes which reduced spawning success, and subsequent ecological competition of a related species, the northern anchovy *(Engraulis mordax)*. That a fishery has not developed for the expanding anchovy population is caused by a complex set of constraints: the low price of the raw product compared with the sardine, both inherently and because of

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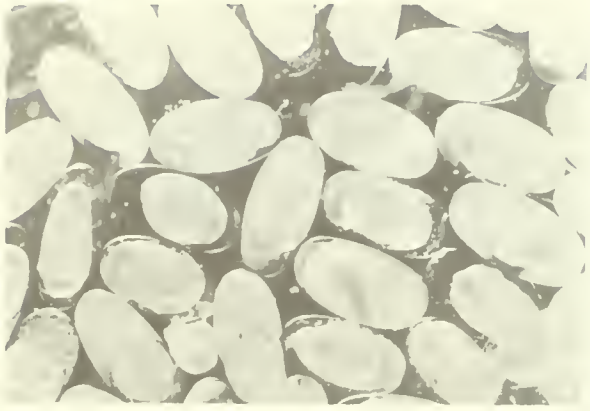
Purse seiners.



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Resource monitoring anchovy eggs from the CalCOFI surveys off California.

price competition from the booming fishery for the Peruvian anchovy *(Engraulis ringens);* the disagreement between commercial and sports fishing interests as to how such a fishery might effect the harvested stocks; and the depressed economic state of the fishing fleet consequent upon the sardine decline and the collapse of the industrial fishery.

In response to these findings, the CalCOFI investigations gradually changed their direction, towards seeking an understanding of the complex and dynamic equilibrium among the many pelagic species (both of fish and invertebrates) in the California Current, in an attempt to understand their reaction to a changing and unstable environment and to changing fishing pressures on some of them.

The almost unmatched accumulation of data, spanning 20 years which are now available, combined with computer methods of handling such voluminous data, give great promise that these continuing investigations will bring a real understanding of an unusually complex fishery situation. Only from such an understanding can a rational management program be developed. The Fishery-Oceanography Center and State fisheries agencies both remain active in this endeavor.

The work demands activity in many fields of research: physiology and biochemistry to determine the energy requirements of the components of the biological population, including the commercial fish; population dynamics of the harvested populations of pelagic species, competing and interacting with each other and with the fishery; physical and biological oceanography to understand, to monitor, and to predict the environment; gear and operations research to give assistance to an economically depressed and out-of-date fishing fleet.

The fishery for fresh fish for the tables of Californians is in a less depressed state than the industrial fishery; the landings remained at about the same level in 1966 as in 1939, though their value was higher.

Research on the fresh fish fishery is handled by State agencies, and has much overlap with research on sports fisheries since in several instances the same species are involved in both fisheries. The Fishery-Oceanography Center is involved in this work in only minor ways.

The California fishery for invertebrates has remained of minor importance in the overall fishery economy of the State, despite a more than doubling of the landings, mainly due to increased exploitation of squid and market crab. State laboratories are active in research on these resources, and again the Fishery-Oceanography Center is involved in only minor ways.

FACILITIES FOR RESEARCH

The Fishery-Oceanography Center, 4 years after its establishment, is now a fully operational fishery laboratory with many unique features. About a quarter of the laboratory space is allotted to other research agencies; IATTC is the largest tenant agency, followed by STOR, the Bureau of Sport Fisheries and Wildlife, the California Department of Fish and Game, and the U.S. Geological Survey. The remainder of the space is fully occupied by the scientists and supporting staff of the Bureau of Commercial Fisheries and comprises scientist's offices, laboratories, an experimental aquarium, a library, mechanical and electronic workshops, computing and data-communications facilities, administrative offices, and storage rooms for scientific collections.

The design of the building has proved to be excellent as an environment for research. Among the outstanding facilities is the experimental aquarium (occupying the whole of the basement of two of the four adjoining buildings) which has been heavily used and is probably superior to that in any other fishery laboratory. The delivery, from overhead facilities, of 750 liters per minute of filtered and ultraviolet-treated fresh sea water, optionally at 10° or 20°C., has permitted wide use of inexpensive, temporary tanks designed especially for each experimental use. We have been able to maintain adult pelagic fish, such as anchovy or jack mackerel *(Trachurus symmetricus),* indefinitely in a healthy condition and to rear eggs of many species through the subadult stage and beyond. The isolated environment rooms have proved invaluable in studies of schooling behavior where insulation from vibration and other influences was essential.

Although not specifically planned in the design of the building, a data-communications facility has been developed by means of which the Fishery-Oceanography Center is linked to the U.S. Navy Fleet Numerical Weather Central at Monterey, and to data circuits main-

Fishery forecasting for temperate tuna—the data communications center.

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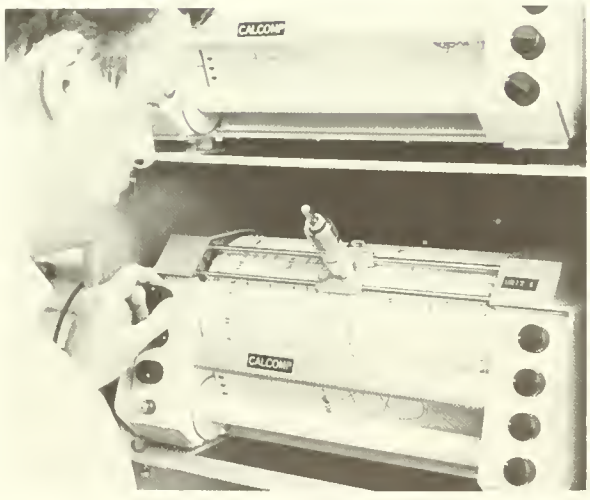
tained by Federal Aviation Administration and ESSA-Weather Bureau; telegraph and high-speed landlines and the Bureau-licensed radio station WWD are involved in these links. This facility also has access to the computer center of the University of California adjacent to the laboratory for processing, analysis, and presentation of data in a cheap and efficient manner, since the Fishery-Oceanography Center is now an important part of the University computer system.

The degree to which the other laboratory facilities have developed since the Center was established will be clear from a reading of the accounts of research which appear later in this report. In fact, with few exceptions, the individual laboratories are now well endowed with equipment and other facilities.

The Fishery-Oceanography Center operates two research vessels and a number of small workboats. The major vessel, *David Starr Jordan* (52 m.), was put into service in 1966. Since then she worked in the California Current before embarking on the EASTROPAC operations; during these she completed six 2-month cruises in the tropical Pacific with very short turnaround periods. This vessel has now developed into a sophisticated research tool for fishery oceanography, and has a very complete set of observational equipment.



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Fishery forecasting—receipt of computer generated meteorological predictions.

Included in *David Starr Jordan's* new capabilities are the following: salinity, temperature, and depth sensing to 1,500 m. with STD apparatus, including digital data logger and an electrically actuated rosette of 12 water-sampling bottles; continuous surface thermosalinograph with analog recorders; expendable bathythermo-

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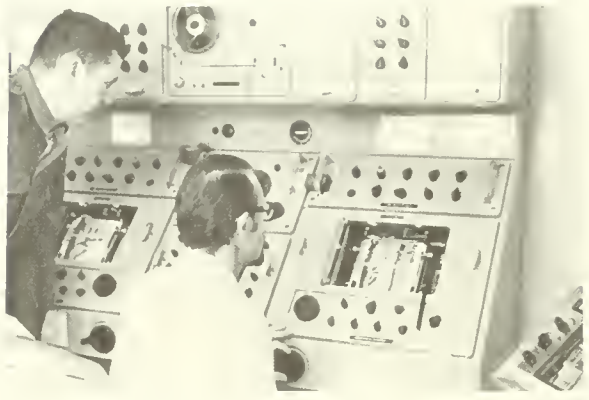
Testing a zooplankton pump before an EASTROPAC survey.

graph system with automatic data logger and data transmitter; autoanalysis of water samples for nitrate, nitrite, phosphate, and silicate; chlorophyll determination by fluormetry in both discrete in vitro and continuous underway in vivo modes; multiple serial plankton samplers (or Longhurst-Hardy plankton recorders); and shipboard data processing with desk top programmable computers.

These capabilities are in addition to those designed and built into the vessel: normal equipment for hydrocasts and biological collecting; underwater observation chambers in the bow and on the port side; physiology laboratory and constant temperature culture room, both with temperature controlled sea water supplies; research fish-finding sonar and sounder; live bait tanks and precision depth recorder.

The smaller vessel, *Miss Behavior*, was a Navy AVR (Aviation Rescue) received on loan in 1964 by the Behavior Program of the then Biological Laboratory, San Diego. She is an 18 m. wooden-hulled vessel with twin diesels each of 380 hp. Capable of fast day-trips from San Diego and extended coastal cruises, she is equipped with an experimental CTFM (Continuous Transmission Frequency Modulated) sonar and with tanks for transporting fish alive to the Fishery-Oceanography Center for use in behavior and other studies in the aquarium. During the last year she has made coastal cruises from the Gulf of California to the waters off northern California.



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David Starr Jordan *tracking gray whales off San Diego with the research sonar in collaboration with a U.S. Navy scientist.*

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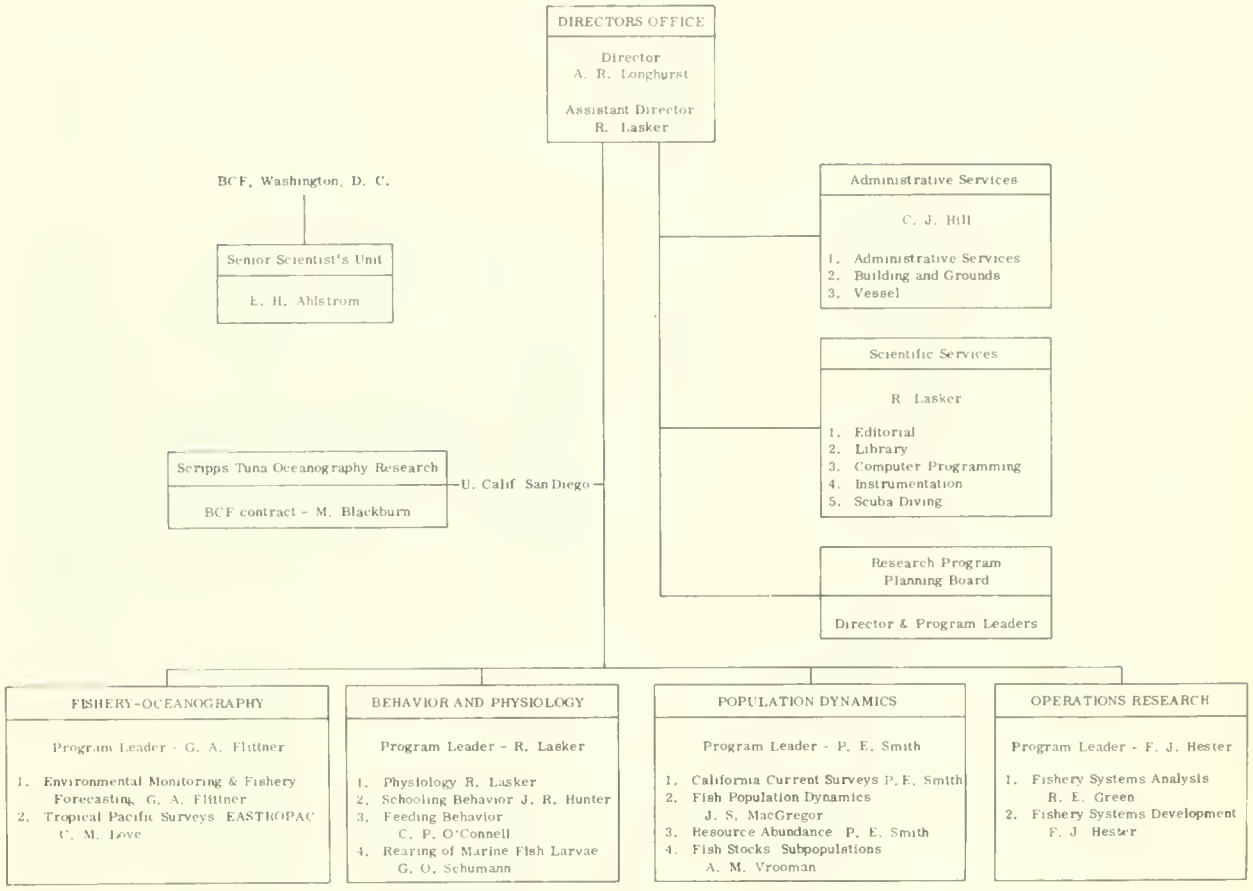
AVR Miss Behavior, *equipped for CTFM sonar research.*



RESEARCH STAFF

Of 90 employees at the Fishery-Oceanography Center, 23 are scientists, 40 are technicians, 9 are in the administrative offices, and 18 man the Center's vessels.

The research staff thus forms more than two-thirds of the total, and is organized into four programs: Fishery-Oceanography, Population Dynamics, Behavior-Physiology, and Operations Research. These programs represent a considerable reorganization from the previous arrangement, and within the four programs are elements from the 8 or 10 programs of the original laboratories.

Also housed in the Fishery-Oceanography Center is the research unit headed by E.H. Ahlstrom, a Senior Scientist of the Bureau of Commercial Fisheries; this unit studies the taxonomy and zoogeography of larval fishes in the Pacific Ocean.

Supported by the Bureau of Commercial Fisheries at the Fishery-Oceanography Center are the STOR scientists and (to a variable extent) a number of visiting scientists: from overseas, from universities, on sabbatical leave; from the National Science Foundation; and from other organizations.

The work of these scientists will be referred to later in this report; the scientists, and their organizations are listed here.

Maurice H. Blackburn William L. Thomas Frank F. Williams Bernt L. Zeitzschel	*Scripps Tuna Oceanography Research, La Jolla, Calif.*
Edward L. Krehbiel	*Grossmont College, El Cajon, Calif.* (June to August 1967–Investigation of lactate dehydrogenase isozyme patterns of some pelagic fish)
Paul E. LaViolette	*Navoceano, Washington, D.C.* (March 1968 -Use and production of marine atlases)
Walter Nellen	*Institut für Meereskunde, University of Kiel, German Federal Republic* (May 1967 to February 1968–Taxonomy of larval fish)

William G. Pearcy	*Department of Oceanography, Oregon State University, Corvallis, Oreg.* (September 1967 to June 1968–Schooling behavior of pelagic crustacea)
Nelson C. Ross	*National Oceanography Data Center, Washington, D.C.* (November 1967 to April 1968–Development of quality control methods for STD data logger tapes)
George Seeburger	*Wisconsin State University, Whitewater, Wis.* (July and August 1967–Galvanic responses of marine fishes in relation to the design of electro-fishing gear)
Evelyn Shaw	*American Museum of Natural History, New York, N.Y.* (June to August 1967–Schooling of larval fish and net avoidance)
Isadore L. Sonnier	*Western State College of Colorado, Gunnison, Colo.* (July and August 1967–Analysis of oceanographic data)
Robert E. Strecker	*San Diego City College San Diego, Calif.* (June to August 1967–Locomotory behavior of calanoid copepods)
Manual Vegas	*Faculty of Fisheries, Universidad Agraria, Lima, Peru* (November 1967–Taxonomy of larval fish)

Mention must also be made of the people who visit the Fishery-Oceanography Center for training, because during their stay they participate actively in the research work of the Center; during the period of this review two trainees have been accommodated: Mario Carreno R. of Chile, sponsored by the Food and Agriculture Organization of the United Nations, Rome, who spent 6 months in 1968 under the supervision of P.E. Smith, Leader of the Population Dynamics Program and Vincent Price, Fisheries Department, Kenya, sponsored by the African-American Institute, who spent the summer of 1967 under the supervision of R.E. Green of the Operations Research Program.

The Fishery-Oceanography Center has cooperated with SIO in the National Science Foundation Summer Program since 1960 by providing high school students with the opportunity to work with Bureau scientists. In 1967, the Center accepted 5 such students from various areas in the United States; and in 1968, 12 students have begun work.

Many members of the scientific community at large visit the Fishery-Oceanography Center. Among many others, we have been pleased to welcome the following:

June 1967	Edward L. Dillon, National Council on Marine Resources and Engineering, Washington, D.C.
	Edward Wenk, National Council on Marine Resources and Engineering, Washington, D.C.
July 1967	Manuel Flores V. and associates, Instituto Nacional de Investigaciones, El Sauzal, Baja California, Mexico
September 1967	Bui Thi Lang, Faculty of Science, University of Saigon, South Viet Nam
October 1967	John R. Hendrickson, Oceanic Institute, Honolulu, Hawaii
	Milner B. Schaefer, Science Adviser to the Secretary of the Interior, Washington, D.C.
November 1967	Henry M. Stommel, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution, Woods Hole, Mass.
December 1967	Karl F. Lagler, Department of Fisheries, FAO, Rome, Italy
January 1968	C. Maurice Yonge, Department of Zoology, University of Glasgow, Glasgow, Scotland
February 1968	George D. Grice, Woods Hole Oceanographic Institution, Woods Hole, Mass.
March 1968	Jean Y. Lee, Co-Director, FAO/UNSF Project, Ivory Coast
May 1968	Raoul Serene, UNESCO, Singapore
	James E. Shelbourne, White Fish Authority, Isle of Man
	H. Steinitz, Hebrew University of Jerusalem, Jerusalem, Israel
June 1968	Brian McK. Bary, University of British Columbia, Vancouver, B.C.
	R. I. Currie, Scottish Marine Biological Association, Argyle, Scotland

G.E.R. Deacon, National Institute of Oceanography, United Kingdom, Wormley, England

G. Dietrich, Institut für Meereskunde, Kiel, German Federal Republic

B.V. Hamon, CSIRO, Cronulla, Australia

Gotthilf Hempel, University of Kiel, German Federal Republic

Raul Herrera and Hellmuth A. Seivers, Instituto Hidrografico de la Armada de Chile, Valparaiso, Chile

H. Kasahara, United Nations, New York, N.Y.

G.A. Knox, University of Canterbury, Christchurch, New Zealand

Michel Legand, Centre ORSTOM, Noumea, New Caledonia

N.K. Panikkar, National Institute for Oceanography, Rafe Marg, New Delhi, India

Mario Ruivo, Department of Fisheries, FAO, Rome, Italy

Lucian M. Sprague, Rockefeller Foundation, New York, N.Y.

K. Voigt, Institut für Meereskunde, Warnemünde, German Democratic Republic

CONFERENCES AND SYMPOSIA

Attendance and presentation of papers at scientific meetings continued normally during the period, as chronicled below:

September 1967 American Fisheries Society, Toronto, Ontario:
G. O. Schumann "Extent and causes of early mortality in fish"

November 1967 15th Pacific Tuna Conference, Lake Arrowhead, Calif.:
A. R. Longhurst "Zooplankton of EASTROPAC cruises"

N.E. Clark "Influence of large-scale heat transfer processes on fluctuation of sea-surface temperatures in the North Pacific Ocean"

G.A. Flittner "Fishery forecasting: recent developments in methods and applications"

F. J. Hester "Visual contrast perception in fishes"

R.M. Laurs "Micronekton of EASTROPAC: preliminary results"

December 1967 CalCOFI Conference, Lake Arrowhead, Calif.:
E. H. Ahlstrom, "Meso- and bathypelegic fishes in the California Current region"

A.R. Longhurst "Pelagic invertebrate resources"

P.E. Smith "ADP and biological requirements of the CalCOFI sampling grid"

March 1968 Conference on the Future of the U.S. Fishing Industry, Seattle, Wash.:

E.H. Ahlstrom "An evaluation of the fishery resources available to California fishermen"

May 1968 International Association of Biological Oceanography, Woods Hole, Mass.:

E. H. Ahlstrom "The quantitative collection of fish eggs and larvae"

A.R. Longhurst "Development and deployment of a system for multiple serial plankton sampling"

P.E. Smith "Full spectrum pelagic sampling"

COOPERATION WITH OTHER ORGANIZATIONS

The Fishery-Oceanography Center is fortunate in its neighbors, and BCF scientists have daily contacts with their colleagues from the various agencies of the University of California at San Diego, at seminars and more informally in each other's laboratories. Several members of the Fishery-Oceanography Center staff (Ahlstrom, Lasker, and Longhurst) have received honorary appointments to the University faculty and staff and have partic-

ipated in formal course work; in 1967, a course in Marine Biology at the University was staffed completely from the Center.

Other, more formal, arrangements with the University and, more particularly, with SIO, are fundamental to the well-being of the Center: the deeding of the land on which the Center is built; the sea-water supply to the experimental aquarium; the cooperative operation of radio station WWD; the supply of computer facilities; and many other matters.

In addition to these neighborhood relations with SIO, the Center has participated in cooperative research in the last year with the following organizations:

CalCOFI

California Academy of Sciences, San Francisco, Calif.
California Department of Fish and Game, Terminal Island, Calif.
Estacion de Biologia Pesquera, El Sauzal, Baja Calif.
Hopkins Marine Station, Monterey, Calif.
SIO, University of California, San Diego, Calif.

EASTROPAC

IATTC

Direccion General de Pesca e Industrias Conexas, Mexico
Instituto del Mar, Lima, Peru
Instituto Hidrografico de la Armada, Valparaiso, Chile
Instituto Nacional de Pesca, Guayaquil, Ecuador
Bernice P. Bishop Museum, Honolulu, Hawaii
Bureau of Commercial Fisheries, Tropical Atlantic Biological Laboratory, Miami, Fla.
Environmental Science Services Administration, U.S. Coast and Geodetic Survey
Environmental Science Services Administration, U.S. Weather Bureau
National Oceanographic Data Center, Washington, D.C.
National Science Foundation, Washington, D.C.
Office of Naval Research, U.S. Navy, Washington, D.C.
SIO, University of California, San Diego, Calif.
Smithsonian Institution, Pacific Program, Honolulu, Hawaii
Texas A&M University, College Station, Tex.
U.S. Coast Guard Oceanographic Unit, Washington, D.C.
U.S. Naval Oceanographic Office, Washington, D.C.

Finally, there is the continuing cooperation in the fishery forecasting project; in its ninth year, this project uses data which are produced by about 25 separate agencies or individuals including international organizations, U.S. and foreign Government departments, commercial and fishing vessels and volunteer individuals, such as lifeguards and lighthouse keepers, working in strategic localities. Without their generous cooperation and without the material assistance of the U.S. Navy Fleet Numerical Weather Central at Monterey, Calif., this project could not survive.

RESEARCH PROGRAMS

Research at the Fishery-Oceanography Center is organized as four programs, each containing several projects which are the responsibility of individual scientists: the Fishery-Oceanography Program investigates the relations between fish and their environment, and seeks to predict this relationship for the fishermen; the Population Dynamics Program investigates the structure of the population of animal populations, their effects on one another, and the effects of fisheries upon some of them; the Behavior-Physiology Program investigates the trophic relations of animals which are important in the food web in the sea, seeking to understand the nature and quantity of food needed by each, the methods by which this food is obtained; and the Operations Research Program studies the fisheries by means of systems analysis and from determination of the costs, earnings, and methods structure of fisheries suggests new methods by which individual fisheries may be made more profitable.

Fishery-Oceanography Program

This program includes three projects: the temperate tuna forecasting project devoted to monitoring of the environment and forecasting of the West Coast summer fishery for albacore *(Thunnus alalunga)* and bluefin tuna *(T. thynnus);* the EASTROPAC project, devoted to a biological and physical oceanographic survey of the eastern tropical Pacific—one of the aims of which is to evaluate latent skipjack and other tuna resources in this area; STOR project (BCF contract No. 14-17-007-742) devoted to basic research in fishery-oceanography particularly of the tropical tuna of the eastern Pacific.

TEMPERATE TUNA FORECASTING

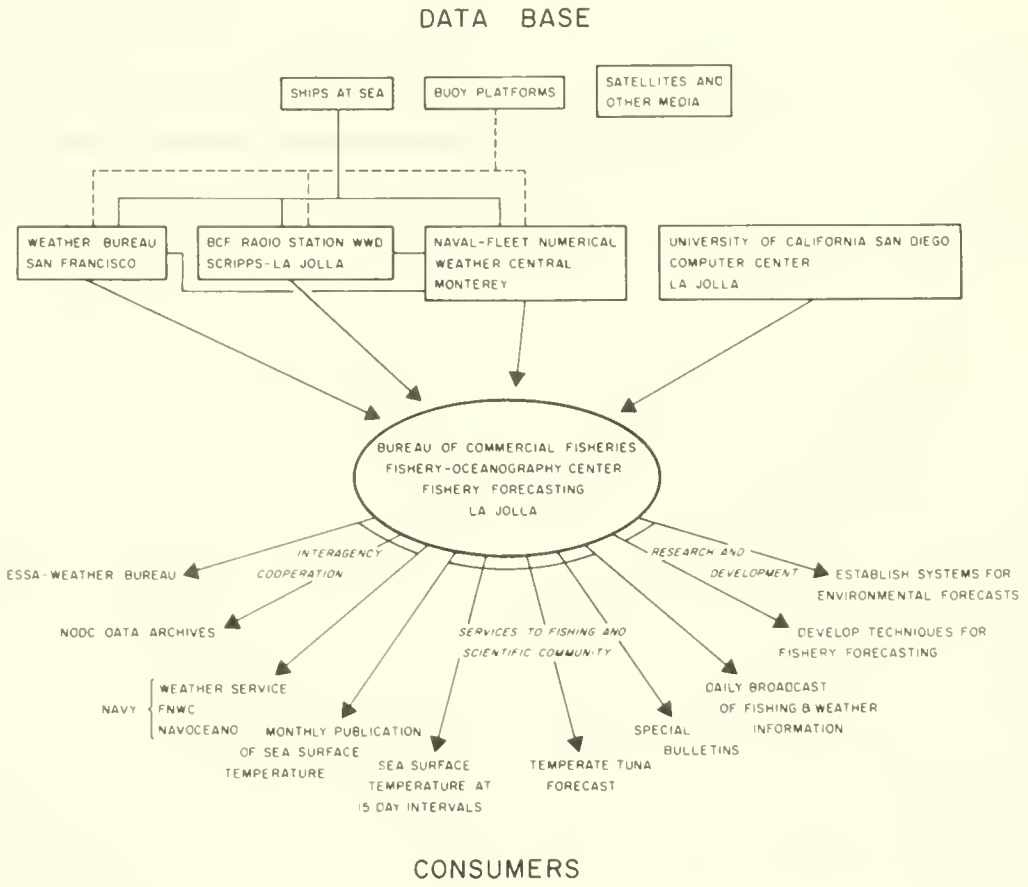
It is the purpose of this project to investigate and develop the techniques on which fishery prediction services must be based, by continuing to expand and improve a service now entering its ninth consecutive year for the temperate tuna fisheries on the West Coast. More than in its considerable value to the albacore and bluefin tuna fishery, its real importance lies in its theoretical studies in the understanding and prediction of processes in the biological and physical environment of the sea; these studies are sharpened by being tested in the context of the forecasting service each summer.

The predictive service contains three elements: monthly and 15-day oceanographic charts, showing the actual environmental situation; daily fishery advisories radioed to the fishing fleet through station WWD at La Jolla; and occasional bulletins mailed throughout the fishing season describing trends in the environment and the fisheries, and including prognoses of future trends.

G.A. Flittner and his colleagues continue to investigate the complex train of events which preludes the seasonal arrival of albacore and bluefin tuna off the Pacific Coast each year. The facilities which they use have been greatly improved in the last 12 months, primarily with the establishment of the new data communications center, adjacent to their forecasting office, in which are mounted several electronic plotters, on-line to the U.S. Navy Fleet Numerical Weather Central at Monterey, together with a suite of other telecommunications equipment. Data collection from expendable bathythermograph equipment placed aboard fishing and research vessels continues, and the raw data from this communications center are fed directly into the Navy computers at Monterey.

The merits of this system have recently been recognized by the Marine Technology Society, who presented a special commendation to P.N. Wolff, of Monterey, and to G.A. Flittner, in recognition of their joint success in its development and operation.

The 1967 long-term season prediction was made in mid-May and was based on a "cooler than usual" trend in oceanographic conditions maintained over the preceding months. This trend suggested that the albacore tuna might move to the Oregon-Washington region later than in 1966 and consequently, that a good southern California fishery would develop during July.



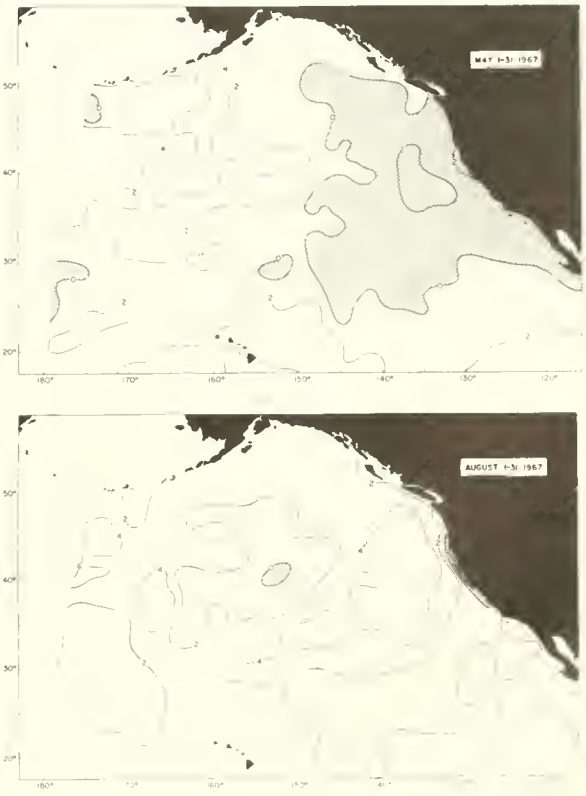
Organizational chart of fishery forecasting service.

G. Mattson

Fishery forecasting– environmental prediction charts.

After this prediction of cooler than normal water was issued, the environmental monitoring system indicated an unpredicted and anomalous warming of a very large oceanic area to the north of California, due to abnormally light cloud cover and slight winds over a great part of the northeast Pacific Ocean. A bulletin was immediately issued to the fishing community, warning that the predicted trend had not materialized and that the actual conditions were likely to result in a rapid movement to the north of the main body of the migrating albacore tuna population. Such a movement would probably result in a bumper catch in the Oregon-Washington area during the later part of the summer. This prediction was realized, and that region experienced its best albacore tuna season since 1944. The large landings were in part due to the early warning received by the fleet, to which a large number of the vessels responded. Also, the arrival of the tuna in the area coincided with spawning concentrations of saury, which tended to hold them in the region of the fishery. California, on the other hand, had a poor year and boats which, for one reason or another remained there had an unprofitable season.

Thus, two things were conclusively demonstrated during the summer of 1967: that the persistence of large-scale ocean conditions more than 15 days ahead was significantly more difficult to predict than had previously supposed for this region, and that predictions for periods less than 15 days were of real value to the daily operations of the fishing fleet. In addition, the 1967 experiences had dictated that long-term forecasts of landings and fishing areas should be temporarily suspended, to be replaced by heavier reliance on short-term bulletins of predictions based on currently observed trends.



Temperature anomalies of sea surface from long-term means; shaded areas are negative anomalies.

The prediction for the 1968 season, issued in mid-June, coincided with the detection of early arriving albacore tuna by *David Starr Jordan* outside the California offshore islands during an anchovy-sardine survey.

This year (1968) the open ocean on the migratory route of albacore tuna towards the Pacific Coast has shown strong warming trends in late May and early June. If this warming continues, we can expect to see an appreciable portion of the incoming migrants diverted into northern California waters instead of towards Baja California. Thus, the area near Guadalupe Island may produce few early-season catches, and we expect the fishery to advance relatively rapidly toward central California, from San Juan to Davidson Seamounts.

Total California landings for the season cannot yet be estimated, but we expect they may fall near the long-term average of about 15,000 tons. The Oregon-Washington region is expected to receive a significant portion of the total U.S. West Coast catch of albacore tuna this year.

In 1968, the bluefin tuna fishery is expected to develop later than usual because southern Baja California has had a period of strong northerly winds; heavy weather created by these winds has severely limited fishing and has caused intense upwelling with a near-shore band of green waters and sea temperatures considerably lower than normal.

These events have combined to delay the onset of the fishery well into the month of June and may cause the bluefin tuna to remain farther offshore than usual. One consequence of the delay in the start of the bluefin tuna season will be a northward shift in the center of production and a delay in the period of maximum catch. Rapid warming in the region north and east of Guadalupe Island may cause bluefin tuna to appear earlier than last year in southern California waters.

G.A. Flittner and his colleagues also continue basic environmental research and investigate the methods of predictive analysis. R.J. Lynn has completed his reworking of the data base from the CalCOFI oceanographic studies in the California Current and has reanalyzed the seasonal variation of temperature and salinity at 10 m. in the California Current; these studies permit much more precise definition of seasonal anomalies to be made and are of direct application in the predictive process.

N.E. Clark has started work on the heat flux at the sea surface in the northeastern Pacific Ocean and has accumulated oceanographic and meteorological data for a long period of years. He is using these data to write and test computer programs for prognostic charts of sea surface temperature, from historical data and his heat flux computations. He has also been studying, from historical data, the winds and sea surface temperatures off California, to describe the mechanisms involved, and to predict coastal upwelling.

R.J. Lynn has been continuing his collaboration with J.E. Reid of SIO on the characteristics and circulation of deep and abyssal waters. Potential temperature and salinity of these waters in the major areas of the world ocean have been reexamined in the hope that recent data may extend the conventional concept of the formation and circulation of the deeper waters.

The results were consistent with the conventional notions of deep flow except for potential density, which appears not to fit in the Atlantic. Further examination has revealed that above the bottom in the western Atlantic is a potential density maximum which represents fairly well the lower north Atlantic deep water. Introduction of a new density increase explains the peculiarities of the distribution of potential density.

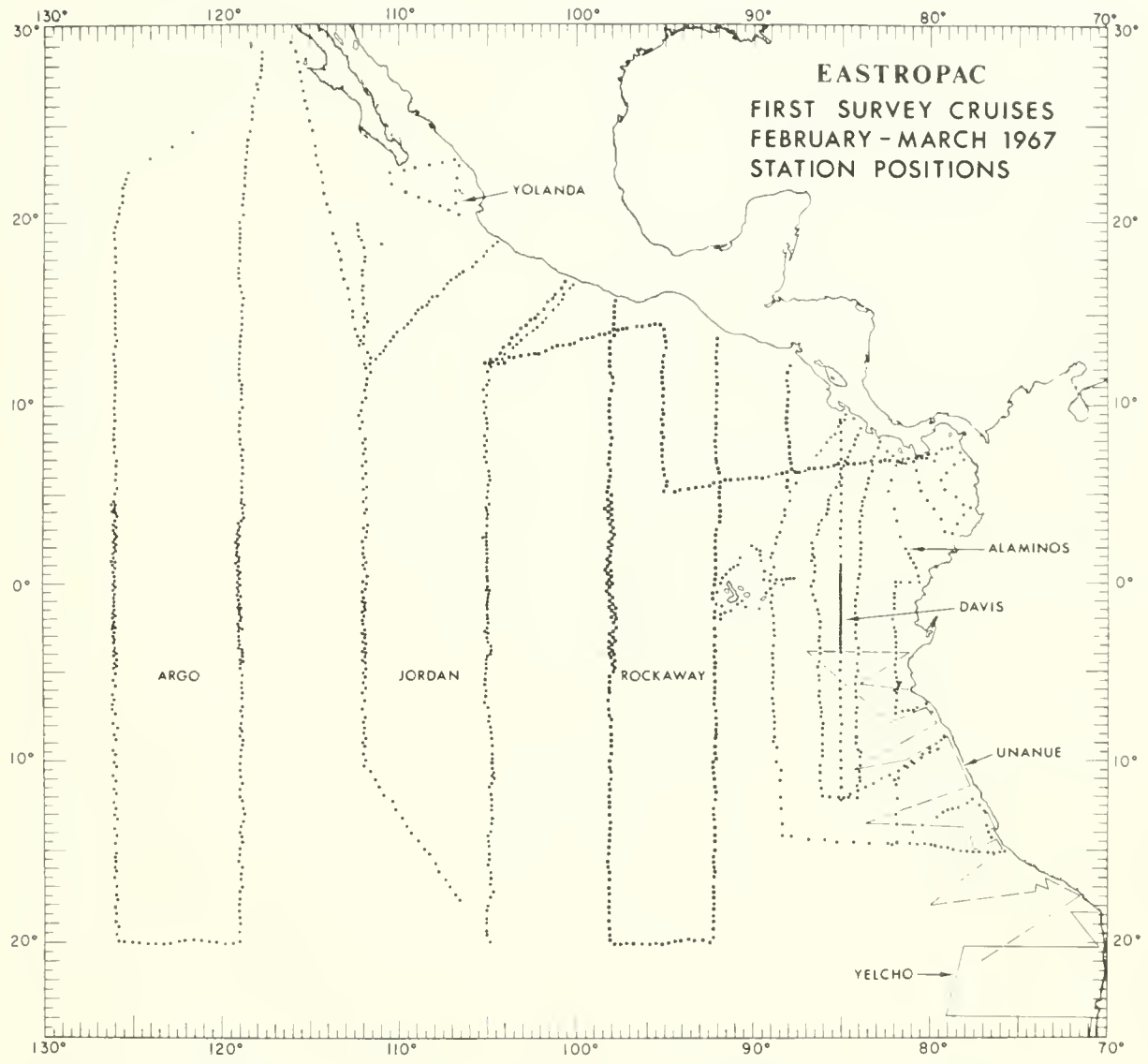
A second study concerns also the abyssal waters of the world's ocean and presents new techniques in the analysis of deep water along density surfaces. This project uses these techniques to develop a model that describes the sources and paths of waters which mix and ultimately fill the depths of the Pacific Ocean. This deep Pacific water is relatively homogenous in its characteristics; as defined within a narrow range of temperature and salinity it has been termed "common water" and constitutes 44 percent by volume of the Pacific Ocean. It is thus very important in determining the major characters of this ocean basin.

EASTROPAC

EASTROPAC is a multiagency, international series of expeditions designed to investigate the seasonal changes over a rather large part of the eastern tropical Pacific Ocean, extending from the west coast of Mexico to the northern coast of Peru, and to 122°W., far to the west of the Galapagos Islands. The field surveys began in early 1967 and continued through April 1968.

BCF, through the Fishery-Oceanography Center, was the lead agency. W.S. Wooster of SIO was initially Coordinator of the expeditions and was responsible for early planning and organization. Subsequently, A.R. Longhurst, of the Fishery-Oceanography Center, became Coordinator.

Six vessels from the United States worked the main observational lines in the offshore survey area; these cruises ranged from one-ship to four-ship surveys and comprised one summer and two winter surveys, linked by four single-ship monitoring cruises in the interim periods. Five vessels from Mexico, Peru, Ecuador, and Chile participated in the expeditions and timed their cruises to coincide with the major offshore surveys. In addition, five U.S. vessels which passed through the EASTROPAC survey area were considered to be ships of opportunity and worked oceanographic transects which



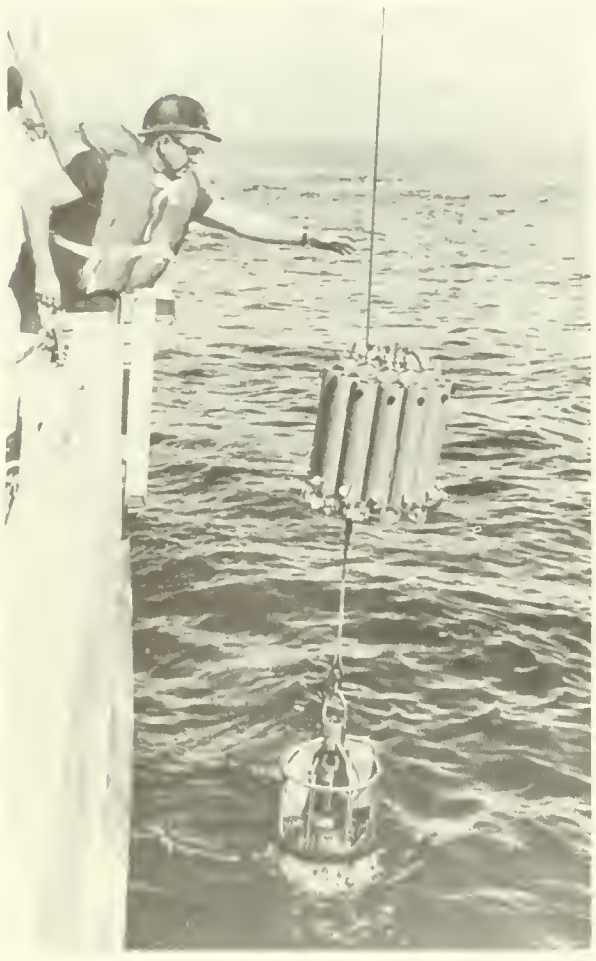
will be incorporated within the EASTROPAC data base.

On the criterion of number of stations and number of observations, EASTROPAC was a major oceanographic effort, comparable with the International Indian Ocean Expeditions, the NORPAC, and the EQUALANT expeditions.

This large number of stations has involved the EASTROPAC staff in a monumental data processing problem. The basic oceanographic tool around which the expedition was based was the electronic STD probe with its associated digital data logger; this equipment was used on almost all the major cruises. To an extent, this procedure has eased the problem of handling data, since, although the number of information bits was very much greater from the STD than from a Nansen cast, a computer can easily handle the data. Available techniques for editing the data tapes were by no means satisfactory and had to be developed during and after the expedition, mainly by J. Jones.

Almost 5,000 plankton samples from the expeditions have now accumulated in the Fishery-Oceanography Center and have caused another major data-acquisition problem: arrangements have been made with the staff of IATTC to sort out the eggs and larvae of pelagic fish from these samples. W.L. Klawe of IATTC directs this sorting, which is progressing very well and is expected to be completed by the end of 1968. Already, some data are available from these biological studies.

With the completion of the work at sea, plans have been made to produce a data atlas which will be edited by C.M. Love. Because of the great number of data, we have decided not to produce classical data reports but to



G. Mattson

David Starr Jordan—*lowering electronic salinity-temperature-depth probe with rosette of sampling bottles.*

archive the edited magnetic tapes of data in the National Oceanographic Data Center. We will produce as rapidly as possible a comprehensive atlas of vertical sections and horizontal plots of physical, chemical, and biological properties. The scope of the expedition, the number of observational lines, and the number of stations have rendered it impractical to produce such an atlas within a reasonable period by classical methods of cartography. The data are all stored on magnetic tape, so computers and electronic plotters can be used to generate mechanically drawn plots and profiles. These plots, modified where necessary by hand drafting, will form the basis of the atlas. F. Miller, of IATTC, working with the EASTROPAC project, has written a number of computer programs for the generation of the plots. The programs have been remarkably successful, and we hope that, once the problem of editing the original data logger tapes has been completely solved, the production of an atlas will proceed with very little delay; it will be produced in loose-leaf form and batches of sheets will be issued as soon as they become available, before the entire atlas is completed.

The physical data are largely in the hands of SIO scientists, who will be responsible for their analysis and for subsequent studies on the results. W.H. Thomas, of STOR, will be responsible for processing and analysis of the data on dissolved nutrient salts.

Many of the biological data, on the other hand, are in the hands of BCF scientists in the Center. R.W. Owen, assisted by B.F. Zeitzchel of STOR, is responsible for the phytoplankton data—both primary productivity measurements and chlorophyll determinations. The most immediate product of this work will be distributions of standing stocks and production rates over the EASTROPAC year. The final product is to be a description of seasonal changes, of the principal mechanisms that produce these changes, and of the relation between phytoplankton and other trophic levels in the region.

G. Mattson

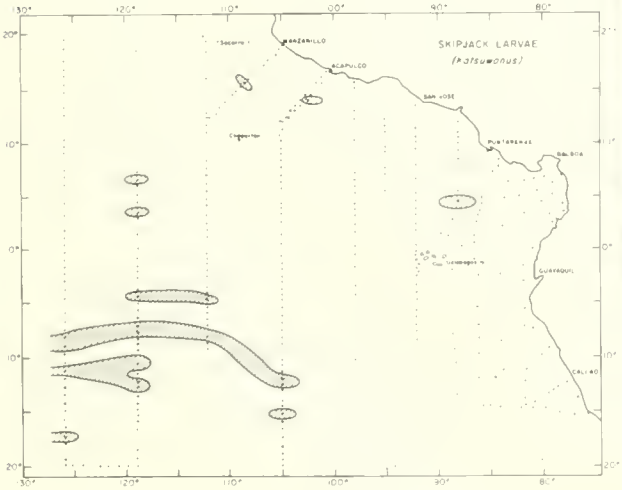
Resource surveys—skipjack tuna larvae from the EASTROPAC expeditions.

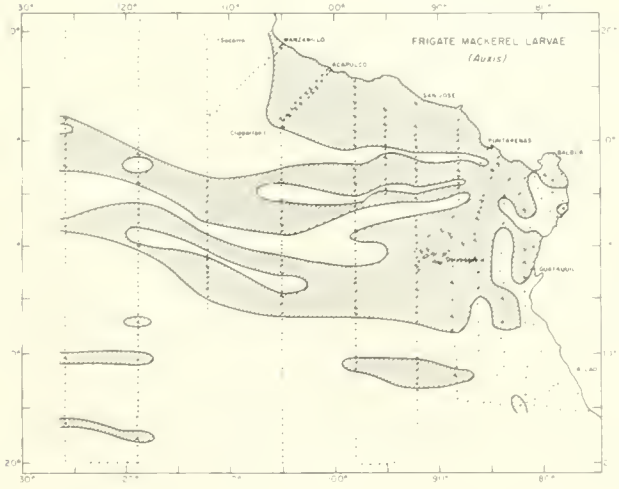
G. Mattson

Resource surveys—yellowfin tuna larvae from a tropical Pacific survey.

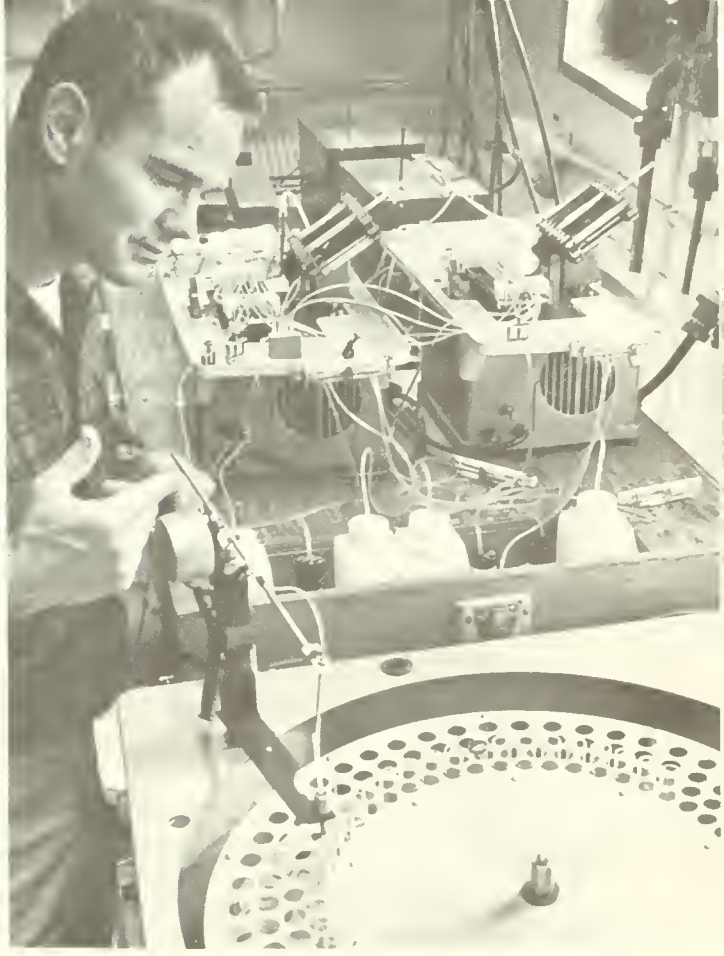
R. W. Owen has also obtained data on total particulate carbon for complete profiles at many stations from six cruises, together with light-scattering data from many of the same profiles. A good correlation has been detected between particulate-carbon concentration and the volume-attenuation coefficient of green light. Such correlation indicates that organic particles have a high degree of influence on the inherent particulate properties of these tropical waters.

Of over 5,600 productivity samples from 800 stations and 14,000 plant pigment measurements from 1,200 stations, about 10 percent have been processed and examined. Preliminary analyses of these samples show that the distribution of chlorophyll and seston agrees well with expectation and give evidence of seasonal cycles of chlorophyll and seston. Unexpectedly high concentrations of plant pigments were found beyond equatorial waters; they sometimes exceeded equatorial values, despite the apparently greater local enrichment by upwelling along the equator.





Occurrence of larvae in samples from first EASTROPAC survey; shaded are areas of occurrence.

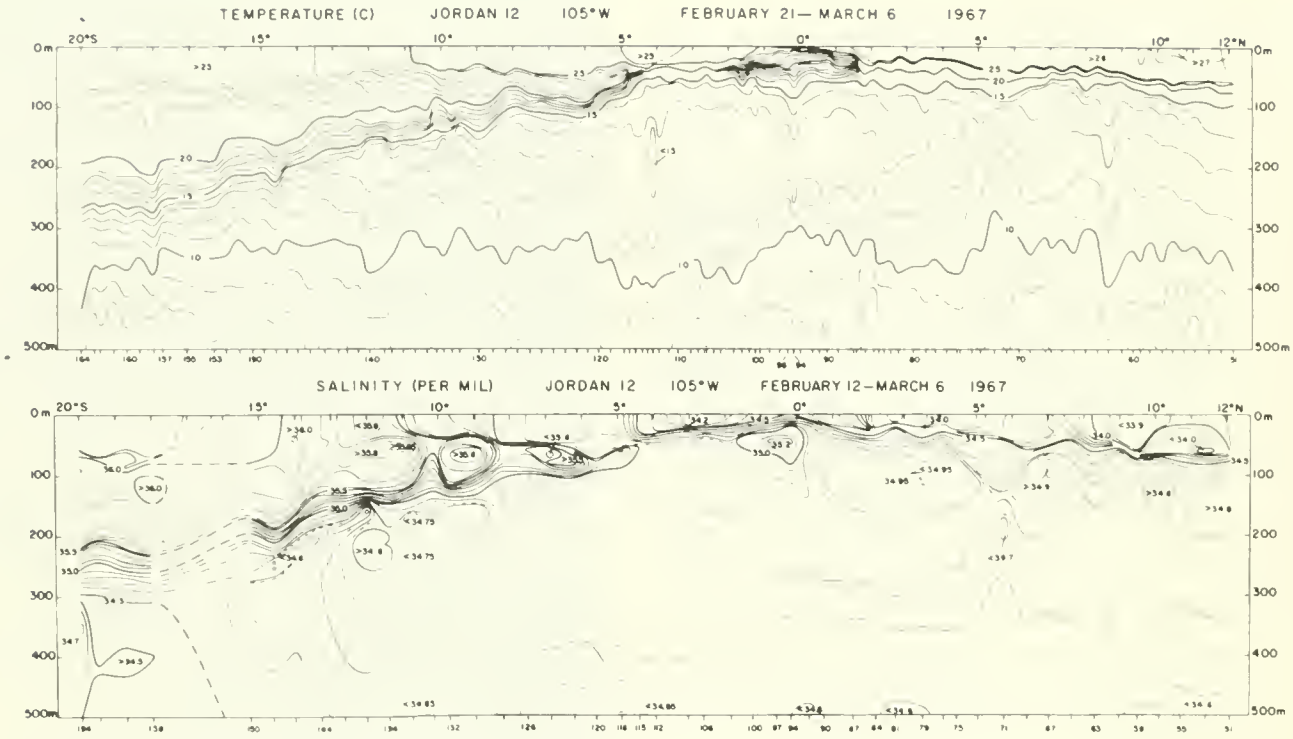


G. Mattson

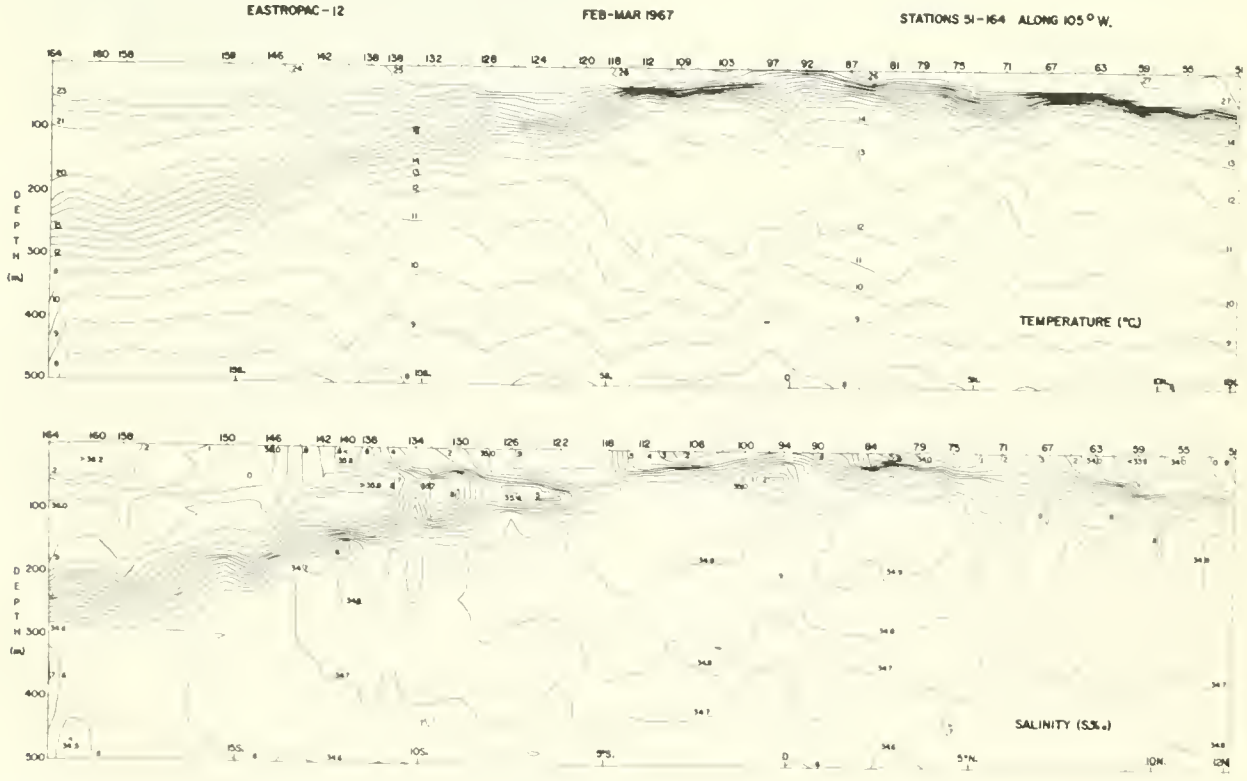
David Starr Jordan—*shipboard autoanalysis of concentrations of nutrient chemicals in sea water samples.*

The continuous in vivo chlorophyll records from the surface water taken during most of the EASTROPAC cruises are very useful for analyzing small scale variations and for locating areas of large changes of pigment concentrations, such as at oceanic fronts. Diurnal changes of in vivo fluorescence, which occur mainly in equatorial waters, indicate, however, that this measurement is not a particularly good tool for surveys of large areas.

R.M. Laurs, who is directing the work of processing of zooplankton samples taken on EASTROPAC, reports that it is progressing well. Volume measurements of samples from 1.0- and 0.5-m. nets have been completed for all collections taken on the first and second survey cruises, and on all monitor cruises, and are well along for the third survey cruise. Computer listings of standardized volumes are now available for the first survey, and the first two monitor cruises, data from other cruises are being punched on computer cards.



Hand drawn vertical sections of temperature and salinity for leg 3 of David Starr Jordan's *EASTROPAC 12 cruise, including STD and XBT data.*



Computer generated vertical sections of temperature and salinity for leg 3 of David Starr Jordan's *EASTROPAC 12 cruise, based only on STD data.*

The King-Hida method of adjusting for day-night variation in zooplankton volumes was tested. Statistical problems due to a strong bias of hauls taken near noon or midnight, and, more important, the enormous geographical extent of the EASTROPAC cruises, which covered a great diversity of ecological situations, preclude the use of the method. Other methods of normalizing the data are being examined, but, until a satisfactory method is found, only night-time hauls are being used, except for determining concentrations of such organisms as fish larvae which do not undertake diel migrations.

All EASTROPAC micronekton collections, except those from one cruise, have been sorted into major taxonomic categories and volumes measured. In addition, about 25 percent of the samples have been sorted for crustaceans down to family level. R.M. Laurs and M. Blackburn (STOR) are collaborating in these micronekton studies and have begun some statistical examination of the data.

A.R. Longhurst has continued his study of vertical distribution of zooplankton in the EASTROPAC area by means of profiles taken with his multiple serial plankton sampler from 500 m. to the surface. These profiles were taken during five cruises, and each contains between 50 and 75 subsamples; sorting into major ecological and systematic groups has been completed for the first three cruises. Data from the first cruise have been punched onto computer cards and run through a program which generates histogram-type vertical profiles for each sorted category. These profiles show a remarkable concordance between widely separated stations within similar oceanographic regimes. They also show considerable differences between profiles that are typical of different oceanographic regimes, or different ecological situations.

G. Mattson

Zooplankton ecology removing plankton samples from filtering gauzes of new plankton recorder.

SCRIPPS TUNA OCEANOGRAPHY RESEARCH

M. Blackburn and his group continue their studies of the relation between tropical tuna and their environment. They have been heavily involved in the field work for EASTROPAC and have contributed in a major way to the data collection. At the same time, they have been completing their analysis of the work which has occupied them for the previous 3 years on the "local banks" fishery for yellowfin and skipjack tunas off the western coast of Baja California. This study is of great importance to the fishery forecasting project described earlier, with regard to both the general relation between tuna and their environment, and to the planned extension of this predictive service to cover the fishery for tropical tunas.

Behavior-Physiology Program

Each of the four projects within this program is devoted to a particular aspect of the trophic and behavioral relations of the important commercial fish in the California region.

The physiology project seeks to understand the energy budgets of our important commercial fishes and of the organisms on which they feed.

The schooling behavior project is planned to provide information on the internal structure of schools of adult fish, including an understanding of the manner in which fish react to one another and so maintain the structure of a school under varying conditions.

The feeding behavior project recognizes that the ingestion of food by an individual fish is the climax of a complicated and plastic behavior pattern. This project is planned to describe this behavior, particularly for anchovy and sardine.

Finally, the rearing project seeks to develop techniques for rearing larval pelagic fish from the egg through the larval stages and into the subadult stage under experimental conditions in the laboratory.

PHYSIOLOGY

R. Lasker's group has continued its studies of the trophodynamics of the California Current food chain, and Lasker maintained his interest in food chain research during his sabbatical leave at the University of Aberdeen, Scotland, where he investigated a sand-living copepod *(Asellopsis intermedia),* important in the food chain of Loch Ewe, and a dominant food organism for the flatfish living there. Since he found that the population of copepods is discrete, spawns during a restricted period, and has short-lived individuals, he was able to complete an analysis of growth, mortality, and recruitment by means of a length-frequency analysis and a carbon budget from respiration studies.

G. Mattson

Larval fish behavior -anchovy larva, alive and under experimental conditions in the laboratory.

While Lasker was in Aberdeen he took advantage of access to an electron-microscope to continue his studies on the mechanism of salt excretion of the Pacific sardine larvae under different salinities. The studies involved examination of sections of the larval skin. The results showed that in both hypotonic and hypertonic environment all larval sardine skin cells increase in volume and subsequently return to normal or near normal despite continued immersion in the test solution. No morphological changes occur within the normal skin cells, but changes are profound in the microtubular structure of the "chloride cells." It now seems probable from the accumulated evidence that these cells do in fact participate in osmoregulation of the sardine larva.

A further study of osmoregulation has begun, in collaboration with the California Department of Fish and Game, on the effect of increasing salinity on the success of fertilization, larval mortality, and development of fish larvae in the Salton Sea in California.

The long-term study of the energy budget of the Pacific sardine has reached the stage at which a first synthesis may be made. R. Lasker has found that growth accounts for 18.5 percent of the assimilated energy of the average sardine during its first year of life. Energy needed for growth declines in succeeding years to as little as 1.0 percent in the sixth year. Respiration is the dominant energy-consuming process throughout the sardine's life, requiring 82 to 99 percent of the assimilated calories, and reproduction accounts for only about 1.0 percent of this energy.

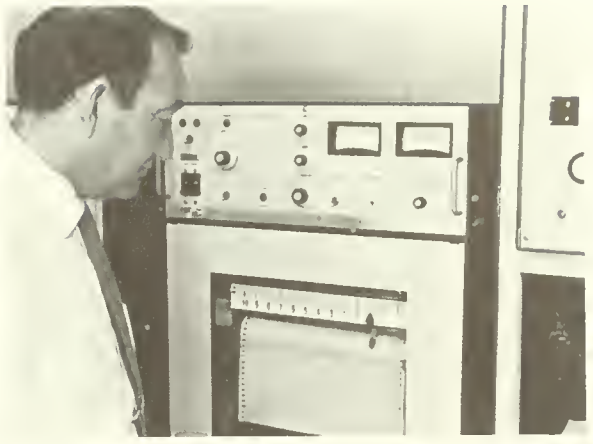
An annual fat cycle was shown to alternate with the reproductive cycle. Fat accumulated at the peak of

Experimental physiology- croaker eggs and larvae from the Salton Sea, alive and just hatching in salinity tolerance experiments. G. Mattson

the fat cycle could provide only enough energy for about 1 month and is used up almost completely during maturation of the gonads.

The amount of energy, in calories, needed for respiration by the standing stock of sardines in the California Current was shown to be 2.8 X 10^{12} kilocalories per month during the years of maximum biomass, 1932-1934. With the decline of the sardine biomass to the 1956 level, a major fraction of these calories became available to other predators and may be reflected, as others have postulated, in the resurgence of the numbers and biomass of the northern anchovy, now the major planktotrophic fish in the California Current.

Doubt has recently been cast on the classical estimates of the efficiency of digestion of marine organisms which have been grossly overestimated if a large fraction of material was lost by the excretion of soluble organic matter, which is undetectable by the usual methods. Because of the importance of this measurement, a study was begun this year to measure excreted dissolved organic material by the shrimp *Crago* sp., chosen because of its large size and ease of maintenance in the laboratory. The results, in fact, show that although soluble compounds were measurable, they were always low, relative to fecal production, and would not seriously alter any digestion coefficient estimates obtained by other methods.



G. Mattson

Physiology—analog recorder of a carbon, hydrogen, nitrogen analysis apparatus.

R. Lasker served as cruise leader on *David Starr Jordan* in June to study the physiology of fish eggs and zooplankton organisms. The sea-water system was put in

A. Gomes

David Starr Jordan—*shipboard oxygen electrode is tested prior to respiration experiments.*

G. Mattson

David Starr Jordan—*taking live plankton sample for shipboard physiology studies.*

operating condition and found to be a valuable tool for sea-going laboratory investigations.

By use of a temperature block, a time-temperature curve was obtained for the development and hatching of jack mackerel eggs; a sea-going respirometer was tested and functioned successfully in a gimbal arrangement; and experiments with the oxygen electrode and an activity meter were done in *David Starr Jordan's* laboratory.

R. Laske

David Starr Jordan—*using temperature block for larval development studies at sea.*

FEEDING BEHAVIOR PROJECT

C.P. O'Connell has brought his studies of the mechanism of feeding in the northern anchovy to completion during this year. Using experimental tanks, with nauplii and adults of brine shrimp *(Artemia salina)* as food, he has analyzed the two kinds of feeding: biting and filtering. He has shown that even at extremely high densities of both kinds of food the biting attack on adult *Artemia* is much more efficient. He has extended his laboratory observations to an analysis of the likely efficiency of filtration at varying concentrations of zooplankton organisms above 100 microns, basing his estimates on his previous work with towed zooplankton pumps in the California Current. From his pump samples, he concludes that only rather limited areas have a sufficient biomass of zooplankton organisms for the nutritional requirements of anchovy that feed by filtration alone. He therefore concludes that the biting attack is a necessary and usual complement to filtration.

He has also investigated other relations between biting and filter feeding in schools of anchovy when presented with different mixtures of adult and larval *Artemia.* He has shown that even in the presence of dense concentrations of nauplii some individuals will bite preferentially at the sparse adult *Artemia*, and he concludes that this behavior indicates that the biting attack normally operates so that anchovy graze preferentially on large organisms.

C.P. O'Connell is now beginning comparable work on the feeding of the Pacific mackerel, which he finds will not respond to *Artemia* nauplii at any density but will change from biting to filtration in the presence of great enough densities of adult *Artemia.*

FISH SCHOOLING BEHAVIOR

Many commercially important marine fish live in schools, and indeed the harvesting of these fishes may be economically practicable only because of this habit. Schooling influences all aspects of the life of pelagic marine fish: their migration, feeding habits, availability to the fishery, and even their reaction to fishing gear. Thus, knowledge of the behavior of schools is essential for improvement of fishing techniques, understanding life histories, and prediction of the availability of fish.

Over the last few years, J.R. Hunter has developed automatic data processing techniques for the quantitative analysis of fish schools from photographs. Use of these techniques has allowed him to study the effects of feeding, light intensity, fish size, and predators on the behavior of schooling fish, and to investigate the communication of velocity changes within fish schools.

Recent accomplishments include the determination of a visual threshold for schooling in jack mackerel *(Trachurus symmetricus)*, and the determination of some of the mechanisms involved in the communication of velocity changes among fish in schools. The visual threshold for schooling was between 6×10^{-7} and 6×10^{-6} ft.-lambert. Comparison of these data with measurements of light in the sea indicated that jack mackerel would be able to maintain schools near the surface on a moonless, starlit night.

Studies of communication in fish schools revealed that the latency of the response of a fish to an increase in velocity by another fish in a school depends on the extent of apparent movement by the other fish and therefore upon visual perception of movement. Thus, a fish reacts sooner to changes in velocity by fish to the side and by ones within its binocular field than to changes by fish located elsewhere. Communication was faster and appeared to be more effective, however, among fish in the same rank than among fish in the same file.

J.R. Hunter has also begun to develop techniques for artificially congregating schools of fish on the high seas. Floating objects attract many species of pelagic fishes, including tuna, and the fish normally remain near the object for many days. The shape and displacement of an object affording maximum attraction has been investigated, and future work will be designed to determine the optimum size and color for attraction, and also to evaluate the effects of olfactory attractants.

Such studies are obviously desirable because of the widely dispersed nature of many important pelagic fish in the open ocean far from land. If artificially aggregated by such means they may become available to the catching gear of the fishing fleets.

An apparatus for measuring the speed of pelagic marine fish is currently being calibrated, and this, together with high-speed photographic equipment, will permit analysis of the swimming movements of fish and the determination of their maximum sustained velocities. Information will also be collected on tail-beat amplitudes and frequencies which will be used together with the CTFM sonar in the identification of the fish targets. Data on maximum sustained velocity will be used in determining the energy that our local pelagic marine fish require for swimming and will be used by R. Lasker in his energy budget calculations.

Development of the techniques of rearing pelagic marine fish from the eggs in this Center has permitted J.R. Hunter to begin behavioral studies of larval anchovies and other pelagic species. He has developed techniques for cinephotography of live larval fish as small as 7 mm. Photographic and other techniques will be used to investigate swimming abilities, behavior, and schooling activities at various stage of development.

G Mattson

Feeding behavior of anchovy - experimental tanks in the aquarium.

MARINE FISH LARVAE

G.O. Schumann's investigation of the methodology of rearing the larvae of pelagic fish in the experimental aquarium at the Center culminated during this period in an effective, if empirical, rearing technique.

G.O. Schumann was able to carry a number of species through to the subadult stage from fertilized eggs collected in plankton nets at sea; these fish included species previously impossible to rear because of the very small size of the newly hatched larva (such as Pacific sardine and northern anchovy), together with other species of pelagic and demersal fish. Particularly spectacular was the development of a large school of Pacific mackerel *(Scomber japonicus)* which were reared in this way to adult size in circular plastic swimming pools in the aquarium.

The rearing technique depends for its success on a number of factors but is essentially the building of a model eutrophic ocean in rather large aquarium tanks. Earlier attempts to culture sardine and anchovy larvae in 15- to 30-liter tanks did not succeed, because the larvae injured their jaws by repeated contact with the aquarium walls. Subsequently fiberglass aquaria with one plate-

glass side and a capacity of about 1,500 liters were designed. These tanks were painted matte green inside to reduce light reflection in the corners. The aquaria are filled with sea water from the main laboratory supply, and a slow upwelling of water is induced in each by a fine airstream. Only distilled water to replace evaporation is added.

Sardine and anchovy larvae prefer high levels of illumination during the first week of feeding, and they aggregate in areas of highest light intensity until they are about 15 mm. long, when they move gradually deeper in the aquarium. Four 100-watt (or 24,000 lumen) mercury vapor lamps produce sufficient light with low heat. Continuous illumination is used to allow the larvae to feed uninterruptedly.

A bloom of *Chlorella*-like species of algae is permitted to develop in the aquarium several days before eggs are stocked. The primary purpose is to provide food for the large numbers of copepod nauplii and copepodites added later, when the fish are ready to feed.

Sardine and anchovy eggs, together with those of other species, are collected at sea off La Jolla by towing a 1-m. plankton net close to the surface. Up to 20,000 eggs are put in each aquarium, and very high percentages of them hatch successfully.

When the larvae are ready to feed, collections of food organisms are made each day with a fine-meshed tow net in Mission Bay, San Diego. Collections are returned to the laboratory in buckets, larger organisms are removed by straining the catch through a 260 micron plankton mesh, and the contents of each bucket poured into larger tanks where the copepods may be concentrated with a point source of light and collected with a siphon.

When food organisms are relatively scarce, larvae cannot be cultured with a reasonable chance of success in large volumes of water, because few larvae survive in low concentrations of food. A method of confining larvae in relatively small volumes of water was developed to permit larvae to be cultured successfully during these periods. The method consisted of rearing larvae in very thin (0.0025 mm.) polythene bags during the early critical days of active feeding. The bags are filled with green water and are suspended in the large aquaria by an air-inflated plastic ring. The bags are fully expanded by filling with water slightly above the water level in the aquarium. An airstream in the aquarium circulates water around the bag, and the thin plastic wall acts as a semi-permeable membrane, permitting gaseous exchange. The thin plastic wall of the bag apparently possesses sufficient elasticity to prevent larvae from injuring themselves when they swim into it. After larvae have grown to a length of about 8 mm. and are able to swim well, the bag is slit open and the fish are released in the larger area of the aquarium.

By these empirical techniques, the survival of fish past early critical periods has ranged in recent experiments mostly from 30 to 50 percent of the original stock of eggs. Occasionally, batches of several hundred fish were reared through metamorphosis to the subadult stage with considerably higher survival rates than this.

Population Dynamics Program

This program has four projects: a continuing commitment to the resource surveys of this region within the framework of CalCOFI; the BCF commitments to cooperative collection and analysis of data on the dynamics of harvested fish populations in the California Current; analysis of the racial structure of some of the important commercial fish species in the California fishery; and the analysis of historical data on zooplankton abundance by computer methods and use of this analysis to increase the efficiency of future surveys, and to develop new and more efficient survey methods.

CALIFORNIA CURRENT RESOURCE SURVEYS

This project is designed to analyze the flow of information which is derived from the BCF participation in CalCOFI, especially the data on eggs and larvae of commercially valuable fishes, together with the larvae of associated fishes.

The samples are collected in cooperation with SIO (Marine Life Resources Program). Generally, the staff for biological collections are furnished by the Center and those who collect physical data are furnished by SIO.

Primary sorting of the samples to obtain the number and length frequency of the larvae of sardine and anchovy, together with the number of unclassified eggs and larvae is immediately undertaken ashore in the Center. Subsequently, unclassified larvae are identified to family, genus, or species. This process has been completed through the end of the samples for 1966, and only samples from one or two cruises in subsequent years remain to be processed. The product of this analysis is an estimate of the numbers of spawning adults in the CalCOFI grid, of Pacific sardine, northern anchovy, Pacific mackerel, jack mackerel, and Pacific hake *(Merluccius productus).*

During the past year, J.R. Zweifel has coded for automatic data processing all of the biological and many of the physical data, including those taken on monthly CalCOFI cruises from 1951-60. This work furnishes an excellent data base (though it will be added to subsequently for 1961-66) for analyses of spawning seasons for each species, and of yearly anomalies from the long-term average.

Although most of this work so far has been designed to control the quality of the data, P.E. Smith has made some preliminary analyses of them. He has generated long-term summaries of anchovy, sardine, and saury eggs by region and by month. These long-term averages permit him to assign relative confidence limits, based on binomial probability, to the estimates each month for all the available years. He has defined the average spawning centers for each species to help him design the extensive CalCOFI cruises planned for the calendar year 1969.

CalCOFI survey cruises have continued on a reduced basis during the past year in preparation for the 1969 surveys. The autumn 1967 cruise was aborted because of vessel breakdown, but a summer 1967 cruise was made by the SIO vessel *Ellen B. Scripps* (170 stations), a winter 1967-68 survey was made by *Horizon* (216 stations), and a spring 1968 survey was made by *David Starr Jordan* (194 stations). Data were collected on these cruises from San Francisco south to Magdalena Bay in Baja California.

Pacific sardine (1951-59). During this period some sardine spawning occurred in each month of the year in Los Angeles Bight and Sebastian Vizcaino Bay, although most spawning occurred during May, when eggs were taken over an area of more than 75,000 square miles (258,000 km.^{2}). Long-term summaries showed a northern and a southern spawning center. The southern area had higher concentrations of eggs than the northern, though this difference was probably a characteristic of the decade following the decline of the northern sardine subpopulation.

Northern anchovy (1951-59).—Most anchovy spawning occurs in February, March, and April in the California Current but some takes place in all months; major spawning areas appear to be within 80 miles (148 km.) of the coast; the total area over which eggs occurred varied from 67,000 square miles (230,000 km.^{2}) in January and April to 14,000 square miles (48,000 km.^{2}) in October. A number of separate spawning localities can be recognized in the long-term averages. The Ensenada region shows a single spawning peak during February; in Vizcaino Bay spawning occurs in March; from the Los Angeles Bight to San Diego, spawning is significant from February through June and outside the Channel Islands there is a single spawning peak in April. These locations are reflected both in the frequency of occurrences of eggs and in the number of eggs in samples in which eggs occurred.

Jack mackerel (1951-60).—Most jack mackerel larvae occur in the CalCOFI grid from March through June though this grid does not sample the offshore nor the northern extent of the spawning range of this species. Most spawning appears to be more than 80 miles (148 km.) offshore, and the spawning region moves northward as the season progresses.

Pacific mackerel (1951-60). Pacific mackerel larvae occur over the entire year within the CalCOFI grid, but they have never been abundant and the grid does not appear to reach the southern limit of spawning of this species.

Pacific hake (1955-59). Hake larvae appear in the samples in December, reach maximum numbers in February and maximum areal extent in March; spawning after April is limited. Spawning extends from Cape San Lucas to Central California, but the northern limit of the spawning of this species has been identified in only some years by the CalCOFI samples, which have usually undersampled the northern area.

DYNAMICS OF FISH POPULATIONS

For more than 25 years BCF and California Department of Fish and Game have had a cooperative program for sampling and aging sardines, anchovies, jack mackerel, and Pacific mackerel from the California Current. This project is the Bureau contribution to this cooperative research. During the year, arrangements were made to bring the Mexican Federal Laboratory at El Sauzal, Baja California, into the sampling program; the fisheries for these four species are common to both United States and Mexican waters, so a cooperative program of sampling and data exchange has become necessary.

J.S. MacGregor continues to direct the Bureau phase of the cooperative scale reading; work has been in progress on reading the scales from the 1966-68 seasons. J.S. MacGregor is also continuing his studies on the fecundity of pelagic species and is analyzing a considerable body of historical data on the development of the gonads of the Pacific sardine in the California Current with respect to year and area. This information, taken together with the data on egg abundance and distribution, and water temperatures corresponding to the years in which the samples were taken will enable him to investigate the relation between fecundity and the environmental variables and geographical areas. His studies on the fecundity of the northern anchovy have been completed and are being used for population estimates from the egg and larva surveys.

RACIAL STRUCTURE OF COMMERCIAL SPECIES

A.M. Vrooman has continued his work on the subpopulations of the northern anchovy. His results show at least two genetically distinct subpopulations off the coast of California and Baja California. Samples from these two areas differ significantly in the frequency of three genes which control six recognizable transferrin types.

Hardy-Weinburg calculations, made on transferrin types of 694 anchovies from southern California and 506 from southern Baja California, indicated that the samples were drawn from two genetically distinct subpopulations.

The location of the division between the two subpopulations has not been established, however. All of the southern Baja California samples are from the Vizcaino Bay area, to the south of the approximate location of a possible division suggested by other studies, such as those of J.L. McHugh, who postulated that the northern anchovy off California and Baja California was divisible into three subpopulations or stocks. A.M. Vrooman has not so far been able to confirm the existence of McHugh's far northern stock with his genetic studies. He has found only a small and insignificant difference in transferrin gene frequencies in his few anchovy samples from north of Point Conception.

A.M. Vrooman has made electrophoretic comparisons of the soluble eye lens proteins of three species of hake, and found fewer absorption bands in *Merluccius albidus* from the Gulf of Mexico than in *M. productus* from California or *M. gayi* from Chile. The proteins of the latter two are very similar. Comparison of the soluble proteins in the cortex and nuclear portions of the hake eye lenses indicated that most of the proteins are found in the cortex.

A.M. Vrooman is also cooperating with the California Department of Fish and Game in a study of the development of annuli on the scales and otoliths of the northern anchovy. He is holding several thousand young-of-the-year anchovies in two batches—one in the aquarium and the other in a floating bait receiver in San Diego Bay. Of these, 6,000 have been injected with tetracycline hydrochloride to mark the growing edge of skeletal material at the time of injection, and biweekly samples are being collected from both batches as well as from the local wild stock.

New rings began to appear on scales and otoliths of some of the fish during April. In scales taken from commercial catches, the peak months for new ring formation are February, March, and April.

G.D. Sharp has begun work on the electrophoresis of tuna hemoglobins and has examined five species of commercially valuable tunas, using blood samples cumulatively collected at sea, stabilized, and returned to the laboratory. He found no intraspecific variations in the stocks of skipjack, yellowfin, or bigeye *(Thunnus obesus)* tunas which he examined. He did find a high degree of polymorphism in his samples of albacore from the West Coast.

G.D. Sharp has suggested that the polymorphism which characterized 26 of the 76 individual albacore which he examined will provide a means for a general survey of the Pacific albacore population. There are several indications that suggest that there is more than one subpopulation of albacore in the north Pacific Ocean.

MEASURES OF ZOOPLANKTON PRODUCTIVITY

J.R. Zweifel has processed the zooplankton biomass data from the CalCOFI survey for the years 1951-60 for computer analysis. This 10-year statistical summary is of high quality and continuity from Point Conception to Sebastian Vizcaino Bay, and offshore for 200 miles (370 km.) at all seasons of the year—a total area of 100,000 square miles (343,000 km.^{2}). On the fringe of this area are an additional 75,000 square miles (258,000 km.^{2}) that have seasonal and areal lapses, but which furnish useful basic information for comparison with the main data block.

These data have been summarized for use as an environmental feature, in the same way as temperature and salinity, with which to associate spawning and larval survival of commercially important fish. The standing crop of zooplankton clearly represents the difference between two unknown curves one representing the recruitment of zooplankters to the population catchable with the sampling net and the other representing the loss of zooplankters from the sampled population by the processes of natural mortality and advection.

These summaries by month and area show seasons of rapid increase and decrease, areas of extremely high and of consistently low standing crops. These averages will be used to detect anomalies which may be associated with environmental features affecting fish populations. It is evident already from the preliminary analyses that the increase of biomass of zooplankton, annually peaking around June, has no latitudinal trend as the season advances; the peak of biomass occurring in southern areas is caused by local upgrowth of the zooplankton population, not be advection from northern areas.

Operations Research Program

The projects within this program seek, in various ways, an understanding of, and the development of, the operational aspect of fisheries of the Region; they include: a systems analysis of the California fisheries from both economic and technological viewpoints and to suggest ways in which they may be placed on a more rational basis; to develop tactical search tools for fishing vessels and new and more efficient forms of fishing gear and to examine the economic constraints presently operating on the fisheries; to suggest how latent resources may be utilized profitably.

FISHERY SYSTEMS ANALYSIS

The costs and earnings analysis of the fleet of tuna boats based in California ports, which was completed some time ago, proved to be so valuable in examining the economic constraints on the prosperity of this fleet that R.E. Green has started a second economic study to investigate the economic base of the California industrial fishery—which, as has been noted earlier, is in a very depressed situation. The planning of this study was performed in collaboration with B.G. Noetzel of the BCF Division of Economics.

Among other matters of less immediate concern, the study should prove valuable in assessing the earnings lost to the fleet through the assignment of zone limits in the anchovy reduction fishery.

R.E. Green's services were given in November-December 1967 to the International Bank for Reconstruction and Development. He went on a mission to Ecuador to estimate the economic soundness of a request put to the Bank by the Government of Ecuador for the development of a small fleet of tuna purse seiners in the eastern tropical Pacific Ocean.

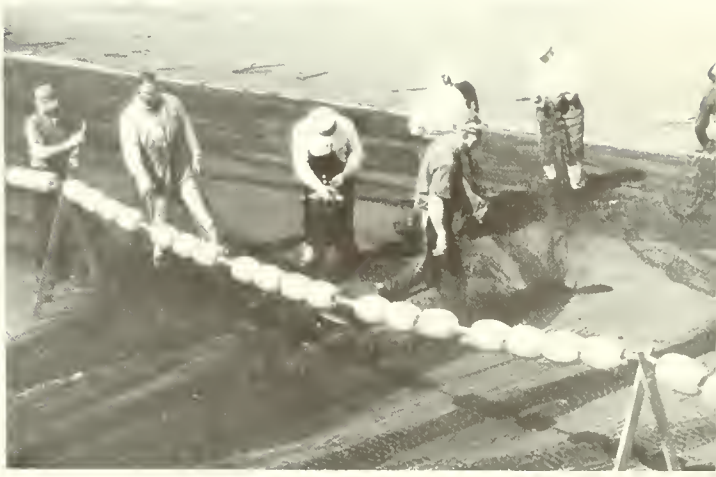
Technicians from this project have made a number of trips on tuna purse seiners in the last year. They have collected data on aspects of seining operations, principally the rate of sinking of nets of varying sizes and constructions—an important matter in view of Green's recent demonstration of the relation between the depth of the mixed layer and nature of the thermocline and the percentage of successful sets in this fishery. During these studies, bathykymographs were mounted at several points along the leadlines of purse seines and, from their records, Green has prepared diagrams of the shape of the net at critical stages during its setting.

EXPERIMENTAL PURSE SEINE

In 1966, R.E. Green studied the design and performance of purse seines with M. Ben-Yami, a fishing gear technologist from the Department of Fisheries of the State of Israel, who spent 3 months at the Fishery-Oceanography Center during that year. Comparative studies with model nets at La Jolla showed that an improved net design might increase the sinking rate by as much as twice and, moreover, fish more deeply at the net ends. These tests were so encouraging that, in collaboration with BCF Exploratory Fishing and Gear Research Base in Seattle, the construction of a full-scale tuna purse seine based on Green and Ben-Yami's design was undertaken. The net is now complete and ready for trials.

Fishing operations research testing model of experimental tuna purse seine. R Green

Fishing operations research experimental purse seine for tuna is built in a San Pedro net-yard. T Beard



This modified design incorporates a 33 percent hang-in of webbing at the corkline to allow rapid sinking with a decreasing hang-in down to 15 percent on the leadline to permit the net to stay at depth during pursing. The net is also tapered at the ends to save webbing and equipped with "gavels" which will decrease the open area next to the seiner.

The net will initially be placed aboard a chartered vessel and, suitably instrumented with bathykymographs, will be tested at sea in simulated setting operations. When tests are successfully completed the net will be loaned to a commercial vessel for the late summer bluefin and albacore tuna fisheries; the operation of this vessel and of the net will be observed by technicians from the project.

CTFM SONAR

The Continuous Transmission Frequency Modulated sonar which was installed in the AVR several years ago has now been evaluated by F.J. Hester. We had hoped that this type of sonar, developed for BCF, would enable a tuna boat to follow the very rapidly moving schools which are so difficult to follow with a conventional pulsed sonar. We had also hoped that the size of the fish in a school could be estimated, so as to prevent the contravention of regulations concerning the size of tuna which may be landed, and the enclosing of fish small enough to gill themselves in the meshes of the net.

The CTFM sonar was coupled with a high-resolution frequency analyzer to analyze Doppler shifts caused by motions and by body flexure of target fish. Targets showing complex, broad-band Doppler shift were found to be characteristic of fish schools. Interspecific variations in these broad-band Doppler patterns were found between small fish schools and single large tuna.

Unfortunately, Hester found some unforseen and intractable problems in the use of this sonar as a tactical tool; at ranges of several hundred meters, very good contact can be maintained with schools of tuna, but they have a frustrating habit of fading from contact. This disappearance has been traced to small changes in the lateral orientation of the fish in respect to the sonar beam; only when the long axis of the fish is normal to the sonar beam can fish be detected at long ranges. The same problem does not apply to contact made with schools of clupeids at the same ranges, perhaps because of their small internal intervals; for such fish the rapid scan rate of the CTFM sonar made it possible to estimate school size and movement at any instant.

We do not expect, therefore, that CTFM sonar will be applicable to commercial tuna operations as a tactical tool, but it clearly has a place in the sonar array of a fishery research vessel.

LOCAL FISHERY SYSTEMS DEVELOPMENT

During the course of other work it is inevitable that fishery problems of purely local interest should present themselves to the attention of the Operations Research Program. These questions are pursued where their solution seems likely to give an immediate economic return and work on them does not conflict with the plans of work of State laboratories.

S. Kato completed his work on the sharks associated with the eastern tropical Pacific tuna fisheries. He has turned his attention to the latent basking shark resource off California, which had not been fished since 1950 when it became uneconomic because of the start of industrial synthesis of vitamins previously extracted from shark liver oil.

S. Kato

Fishing operations research - small swordfish vessel equipped with harpoon gear, now turning to basking shark fishery in off-season.

A new use for this oil enabled Kato to reactivate the fishery in 1967, however: shark liver oil contains 25 to 60 percent of squalene, a hydrocarbon which yields, on hydrogenation, a colorless, odorless oil valuable in cosmetics and much in demand in Japan.

Several vessels, used during the summer for the harpoon fishery for swordfish, have turned in the winter to harpooning basking sharks after contact was established between them and Japanese importers of squalene. Nearly 30 tons of liver were shipped in the initial consignment in April 1968—the product of six small vessels.

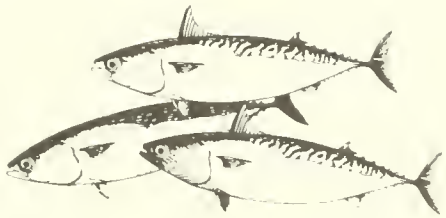
Other activities by Kato and Green on this project include the investigation of the possibility that the same swordfish vessels might change their gear from harpoons to small floating longlines in their summer fishing for broadbill swordfish. They are also investigating the pandalid shrimp resources off southern California in canyon and slope areas with lines of shrimp traps.

SENIOR SCIENTIST'S UNIT

E.H. Ahlstrom has been heavily occupied with the identification of fish larvae from the EASTROPAC samples and has completed work on one survey and two monitoring cruises; in these studies he is collaborating with W.L. Klawe of IATTC who is studying the ecology of tuna larvae. He has also devoted almost half his time to work on various manuscripts of research, review, and conference papers.

This work on EASTROPAC complements and supplements the studies of fish eggs and larvae of the California Current. With few exceptions, the same major groups of fishes are represented in CalCOFI and EASTROPAC collections in offshore waters: scombroids, *Coryphaena*, myctophids, gonostomatids, bramids, melamphaeids, paralepidids, bathylagids, ... , and nearer the coast: flatfish, scorpaenids, labrids, serranids, clupeids, engraulids, sciaenids, pomacentrids, ... In fact, a number of the tropical species of wide distribution in EASTROPAC collections also occur in the southern part of the CalCOFI pattern off central and southern Baja California, and a few of the hardier species, such as *Vinciguerria lucetia* and *Diogenichthys laternatus*, even push as far north as California.

H.G. Moser has continued his work on the description of myctophid larvae and on the distribution and reproduction of rockfishes *(Sebastodes* spp.*)*, which are a commercially important element of the fish fauna in the California Current. He participated in a cruise of *Miss Behavior* to the Gulf of California in December 1967, during which an undescribed species of *Sebastodes* was taken. Since many species of this group are viviparous, the identity of larvae taken in plankton nets may be resolved by reference to larvae taken from adult females of known species; Moser has been describing the larvae of many *Sebastodes* species in this manner.



PUBLICATIONS

The following lists indicate the status of publications by BCF scientists at the Fishery-Oceanography Center. Omitted from these lists are book reviews, popular or public-relations articles, and conference papers except where these describe new research which will not be published elsewhere. Publications from STOR, supported by BCF funds, are listed separately.

Also omitted, purely for reasons of space, are the monthly publications by FLITTNER, G.A. and associates in the series *California Fishery Market News Monthly Summary, Part II Fishing Information*, which achieved its 100th consecutive monthly issue during the last year.

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