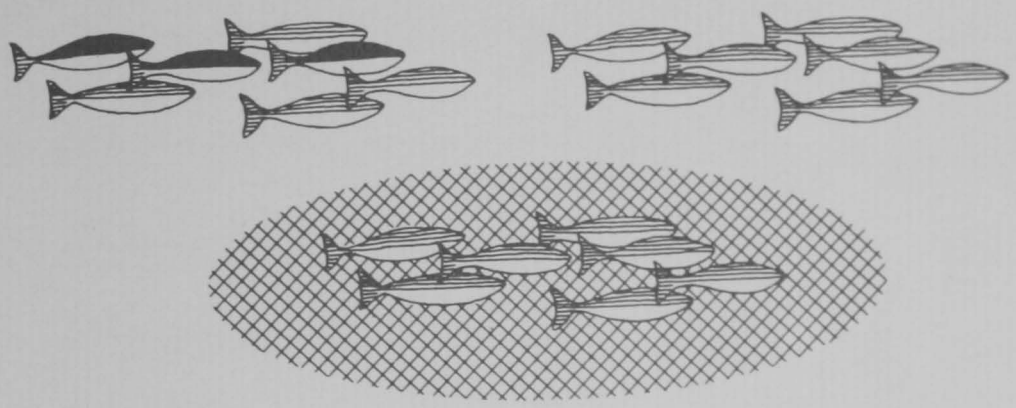
FISHERY-OCEANOGRAPHY CENTER

La Jolla, California



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

Circular 232

UNITED STATES DEPARTMENT OF THE INTERIOR

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The Fishery-Oceanography Center

La Jolla, California

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Editors

Robert I. Clutter - California Current Resources Laboratory

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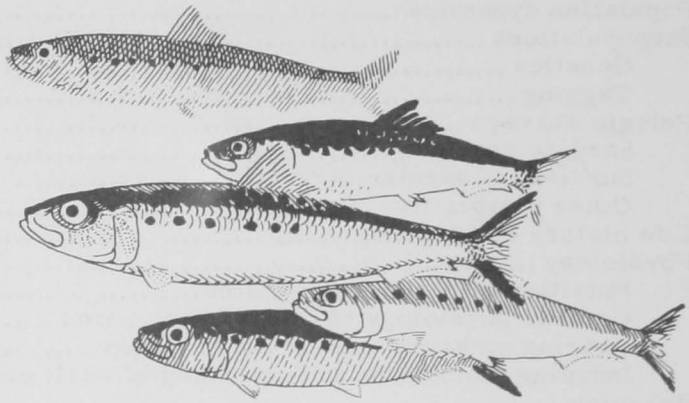
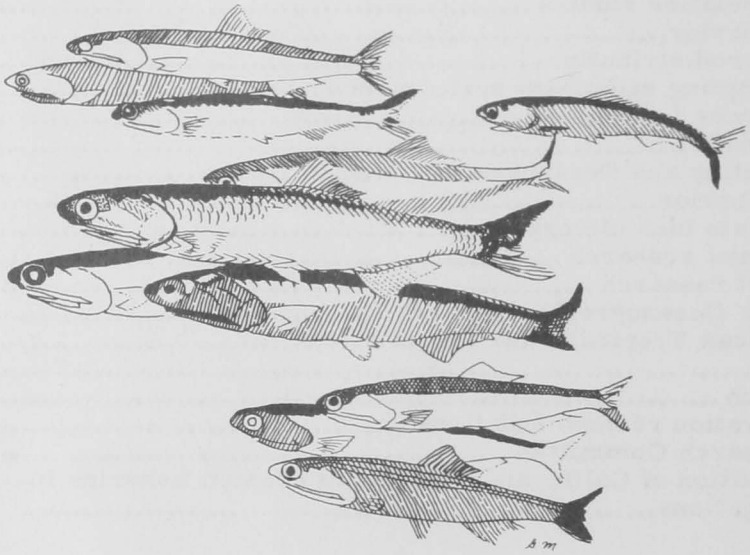




The Fishery-Oceanography Center
La Jolla, California

Fishery oceanography is the study of the living resources of the sea, using those aspects of oceanography (biology, physics, chemistry, geology, and meteorology) that affect their abundance, availability, and exploitation. The search for increased knowledge and understanding of the ocean arises both from the desire to use it more effectively for human benefit and from scientific curiosity. Secretary of the Department of Interior Stewart L. Udall recently stated that this is the "Era of Ecology" and that "we are facing the realization that only by working with nature in her ecological entirety will man realize his highest potential in the scheme of things." Thus, full and continued effective use cannot be realized without basic research on a broad scale.

FISHERY-OCEANOGRAPHY CENTER

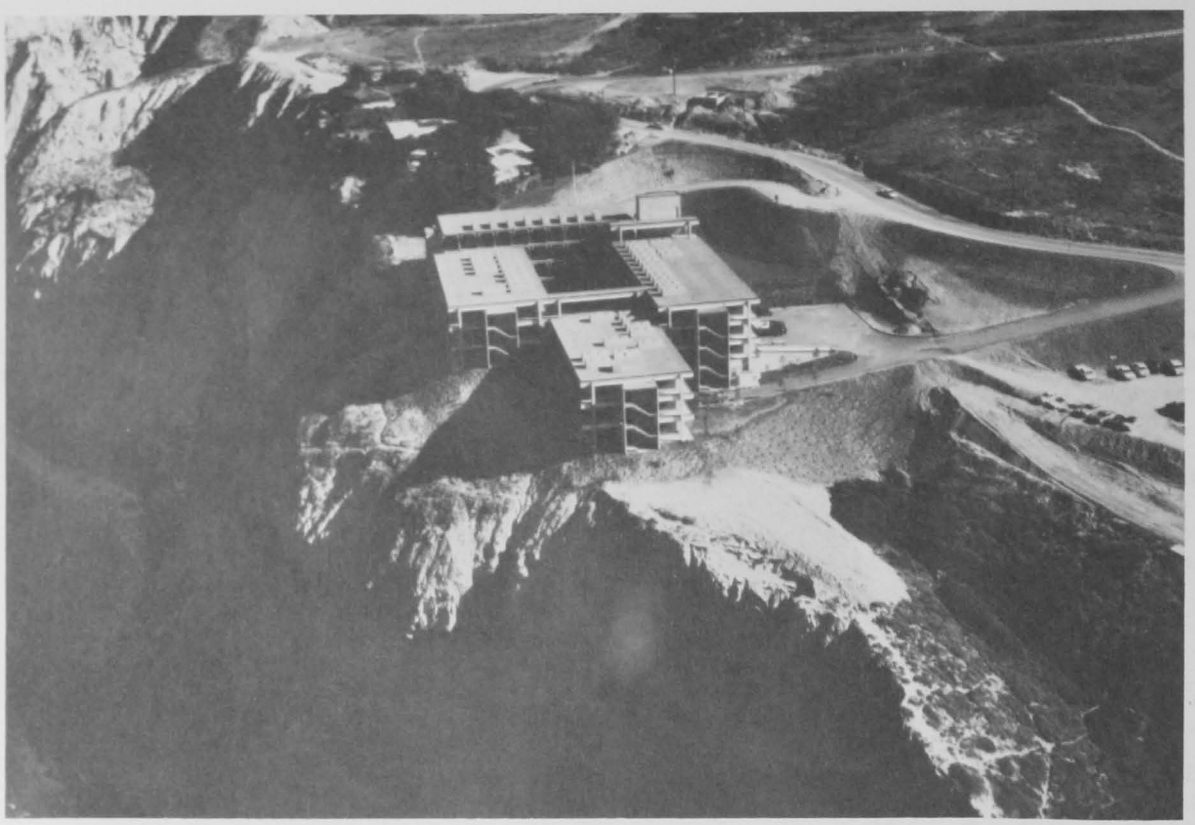
La Jolla, a suburb of San Diego, has become one of the leading fishery research areas in the United States. The Fishery-Oceanography Center, built for the U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries (BCF), on land deeded to the Government by the Regents of the University of California, brings together the California Current Resources Laboratory and the Tuna Resources Laboratory of the Bureau of Commercial Fisheries, the Inter-American Tropical Tuna Commission (IATTC), Scripps Tuna Oceanography Research (STOR) of the Scripps Institution of Oceanography (SIO), the office of the Coordinator of the California Cooperative Oceanic Fisheries Investigations (CalCOFI), and a small field office of the U.S. Geological Survey.

These groups are devoted to research on the living resources of the sea and their environment; therefore, close association has increased exchange of information and ideas. Great benefit also derives from location on the campus of the University of California at San Diego, where large library and machine computation facilities are available and where close liaison can be maintained with scientists in the various departments of the University, especially SIO.

RESEARCH FACILITIES

The Center is a laboratory building of unusual construction. Vertical prestressed columns support spans of poured-in-place concrete channels whose tops are the floors and whose bottoms are the ceilings on each level. By virtue of outside corridors and small but numerous utility columns all 50,000 square feet of inner space are usable. This space is divided into central administrative offices, individual units combining laboratory with office, and larger research laboratories. All of these are grouped into functional complexes suitable for each particular investigation. The various laboratories are or will be equipped to study taxonomy, anatomy, physiology, radiobiology, population ecology, behavior, culturing of marine organisms, and chemical and physical oceanography. A Center library is being established.

Fishery research is environmental biology. Field studies on animal populations are essential, but insufficient to understand thoroughly the physical, chemical, and biological factors that influence distribution and abundance. The Center, therefore, has special experimental facilities. These include temperature control rooms for physiological studies and rearing experiments, and an experimental sea-water aquarium. The sea-water system delivers 200 gallons per minute (g.p.m.) via epoxy-lined asbestos concrete and polyvinyl chloride pipe lines (doubled to facilitate cleaning and decrease marine growth) from the SIO pier. A heat exchange system within the building is capable of cooling 50 g.p.m. to 10° C. and heating 150 g.p.m. to range from ambient sea temperature to 20° C. The main aquarium includes a large area for water tables and work benches. Partitions can be erected to create individual spaces as required. Six partially isolated cubicles for individual experiments, four isolated cubicles for individual



(Courtesy, U.S. Navy.)

Fishery-Oceanography Center, December 1964.

(Courtesy, G.M. Mattson.)

View from west wing of the Center, past SIO pier to La Jolla beyond.

(Courtesy, U.S. Navy.)

Offices and laboratories of the Center from the central patio.

(Courtesy, G.M. Mattson.)

Laboratory in BCF Physiology section.

experiments, and four isolated-environment rooms for behavior studies are associated with the experimental aquarium. The latter rooms are completely separated by cushioning from the rest of the floor and building to eliminate vibration. They can be sealed off while observations are made through ports in the ceiling, and will be equipped with temperature and light control systems. The Center eventually will house and provide research facilities for more than 200 persons, including students from universities throughout the Nation and marine scientists from throughout the world.

The Center is situated on the coast about 15 miles from San Diego proper and 35 miles from Mexico; it is easily accessible by auto, bus, train, and plane. A variety of housing is available. The climate is classified as Mediterranean with cool summers and mild winters. Average temperature is 65° F. Average rainfall is 9 to 10 inches per year; most falls in winter.

RESEARCH VESSELS

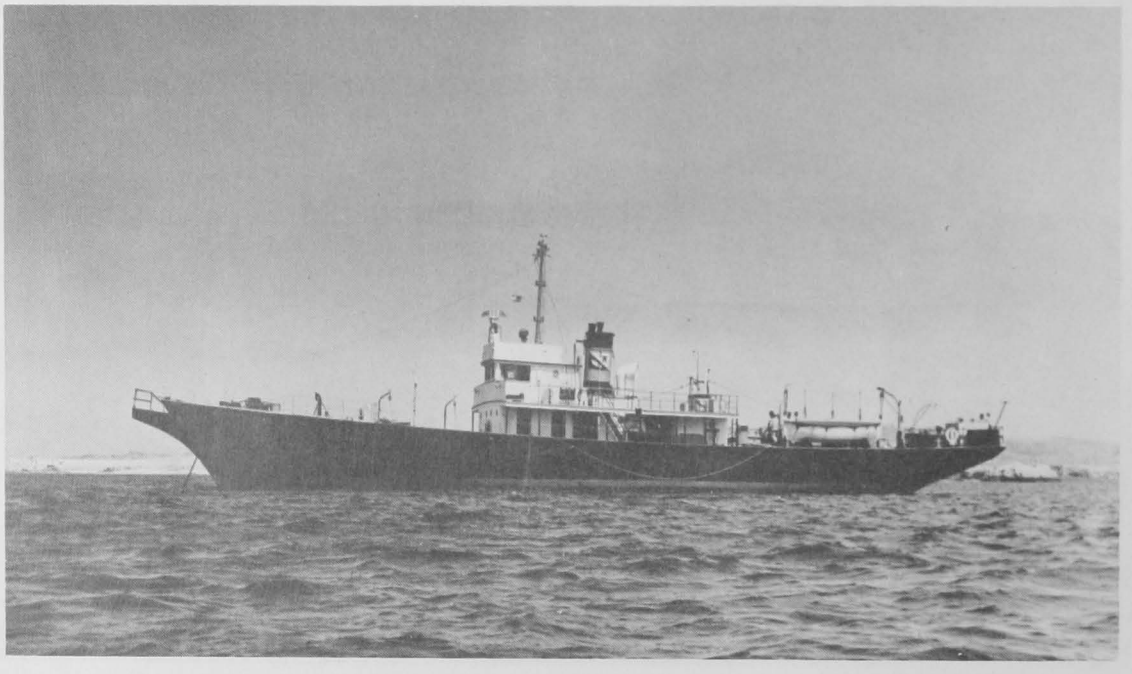
In investigating the habitat of pelagic fishes, the BCF California Current Resources Laboratory operates the 133-foot vessel Black Douglas. Cruises varying from 1 day to 1 month are made off California and Baja California, Mexico.

The 35-year-old Black Douglas is being replaced by a new ship named after America's most prominent ichthyologist and first President of Stanford University, David Starr Jordan. The David Starr Jordan is all-welded steel and has a 171-foot length, 37-foot beam, and 11-foot draft. Twin diesel engines of over 500 hp. will drive it at a cruising speed of 12 knots. The ship will cruise over 8,000 miles and remain at sea up to 40 days. More than a third of its enclosed space is devoted to scientific laboratories and their support areas.

Special laboratories will be used for handling live biological specimens, hydrography, water chemistry, radioactive substances, and sonar surveying. A 150-cubic foot walk-in freezer specifically for specimen storage, a photographic darkroom, scientific information center, and data processing room complement the laboratories.

Additional features include underwater observation stations fore and aft, two 450-cubic foot live specimen wells, a stern ramp and gantry for handling nets and other equipment over the stern, and a special below-decks winch room for the combination seine-trawl winch, as well as two hydrographic winches, a bathythermograph winch, a powered trawl net reel, and a special instrument winch. Living and working spaces for 22 crew members and 13 scientists will be air conditioned. A unique bow propulsion system will enable the ship to be pivoted in any direction, or, when used in combination with the main engines, allow the ship to move sideward.

Several research groups in the Fishery-Oceanography Center also have access to the marine facilities and research vessels of Scripps Institution of Oceanography, and make cooperative cruises with this and other State and Federal agencies.



(Courtesy, R. C. Counts.)

BCF research vessel Black Douglas.

(Courtesy, Christy Corp.)

BCF research vessel David Starr Jordan at launching, December 1964.

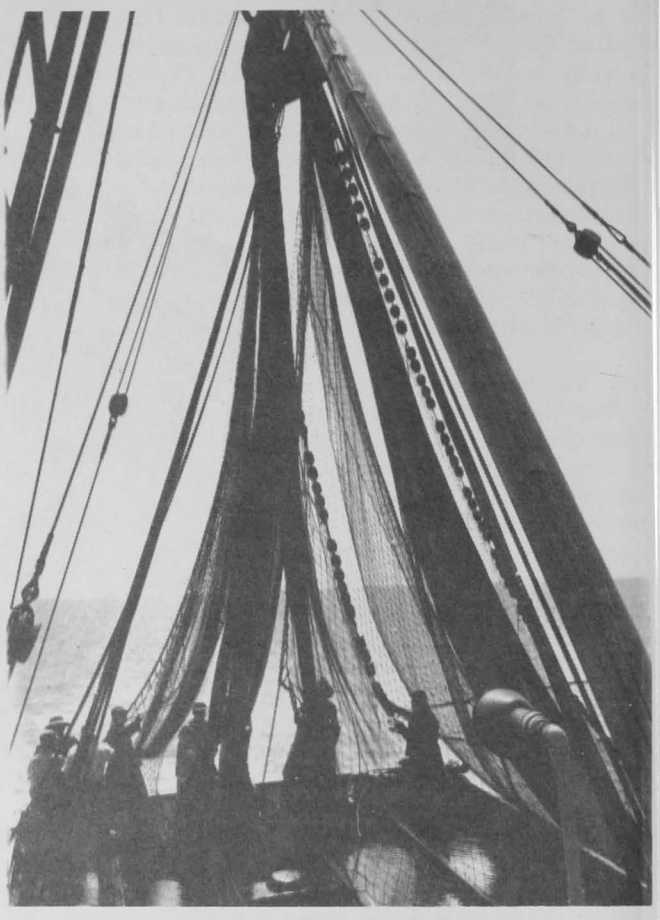
(Courtesy, Christy Corp.)

BCF research vessel David Starr Jordan.

U.S. FISH AND WILDLIFE SERVICE, BUREAU OF COMMERCIAL FISHERIES

The Bureau of Commercial Fisheries, by authority of the Fish and Wildlife Act of 1956, has responsibility for carrying out a national fishery policy with three objectives: (1) to increase and maintain America's fishery resources at a level to yield a maximum sustainable annual harvest, (2) to strengthen and maintain a vigorous fishery industry, and (3) to perform these duties in partnership with the States and in accordance with America's international obligations.

To pursue these objectives in the California area, the Bureau has established the California current Resources Laboratory and the Tuna Resources Laboratory to investigate the pelagic marine fishes important to the commercial fisheries of the region.



Purse seine used in Pacific sardine fishery.

(Courtesy, G. I. Murphy.)

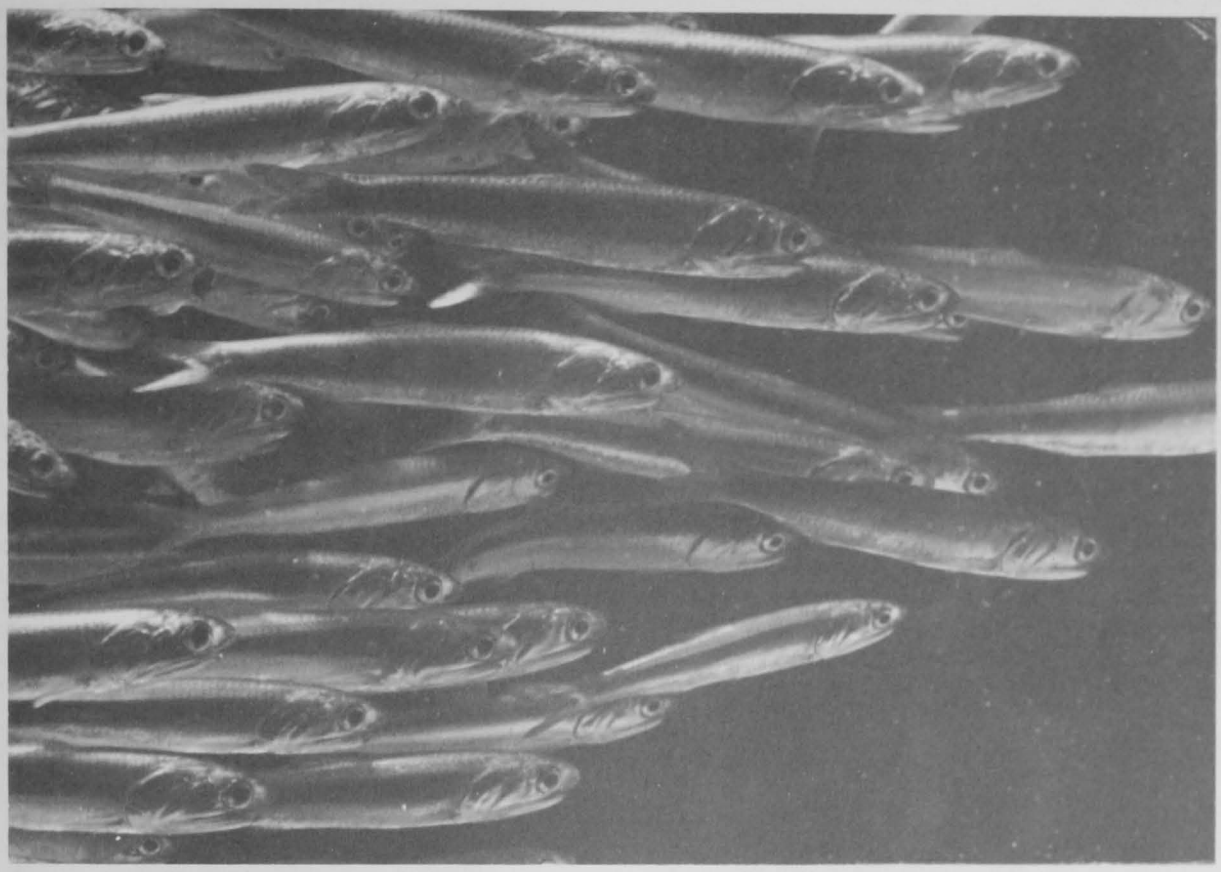
CALIFORNIA CURRENT RESOURCES LABORATORY

BACKGROUND

The California Current Resources Laboratory originated in 1937 when the former U.S. Bureau of Fisheries established a laboratory at Stanford University to do research on the Pacific sardine, which then supported the largest fishery in the Nation. Since 1954 the laboratory has been located on the campus of the University of California at San Diego.

Population dynamics of the Pacific sardine is the coordinating program of the Laboratory. Age and growth, abundance, mortality, availability, and fluctuations in success of recruitment of the sardine population are investigated. Homogeneous interbreeding populations can be treated as units, but genetically distinct subpopulations must be treated individually. Therefore, our discovery that the sardine has at least three genetically distinct subpopulations was very important. In recent years population studies have been extended to species ecologically associated with sardines, including Pacific mackerel, jack mackerel, and particularly northern anchovy.

Research on sardines and related species is part of the California Cooperative Oceanic Fisheries Investigations (CalCOFI--see Marine Research Committee section). CalCOFI survey cruises, in which SIO cooperates, combine physical and chemical observation of the environment with simultaneous collection of fish eggs and larvae by means of plankton hauls. Both BCF and SIO collect samples and data at sea. SIO chiefly processes and analyzes oceanographic observations and studies taxonomy and zoogeography of planktonic organisms other than fishes. BCF compiles biological data related to fishes and biomass. Through the CalCOFI program, the California Current Resources Laboratory has accumulated an outstanding collection of fish larvae and information on their taxonomy, embryology, morphology, zoogeography, ecology,



(Courtesy, G. M. Mattson.)

School of northern anchovies, competitors of Pacific sardines.

and physiology. The surveys have proved invaluable in evaluating the pelagic fishery resources of the California Current.

The distribution and abundance of adult fish resources has been evaluated for several years. Four cooperative cruises have been made with the BCF Exploratory Fishing and Gear Research Base, Seattle, Wash. We sample plankton with our research vessel Black Douglas to locate areas of heavy recent spawning, particularly of hake and anchovies. These areas are then surveyed by the Base's research vessel John N. Cobb, which locates fish concentrations with echo sounding gear and samples them with a large pelagic trawl. Large numbers of spawning hake have been taken, some in commercial quantities. Recent improvements in operating the pelagic trawl may produce larger catches.

Fluctuations in distribution and abundance of commercially important fish populations may be caused by shifting patterns in the oceanic environment, as well as by intrusion of man into the ecosystem. These irregularities may directly affect the physiology of members of a population or indirectly effect changes in predators, competitors, or food supply. Therefore, we have basic environmental and experimental programs on physiology, behavior and plankton dynamics. These programs are not easily separable in practice, nor should they be. Nutrition especially is of common interest to all three of these programs because Physiology deals with basic energy requirements and utilization, Behavior investigates processes of food acquisition, and Plankton studies distribution and abundance of food. Food web relationships cannot be determined adequately without knowledge of energy exchange and behavior in both the predator and prey populations. Knowledge of these relationships, together with information on direct physiological responses of the organisms at various stages of development, is indispensable to understanding thoroughly the dynamics of commercially important populations.

POPULATION DYNAMICS

The population dynamics program investigates the biology of sardines, anchovies, and other fishes of the California Current,

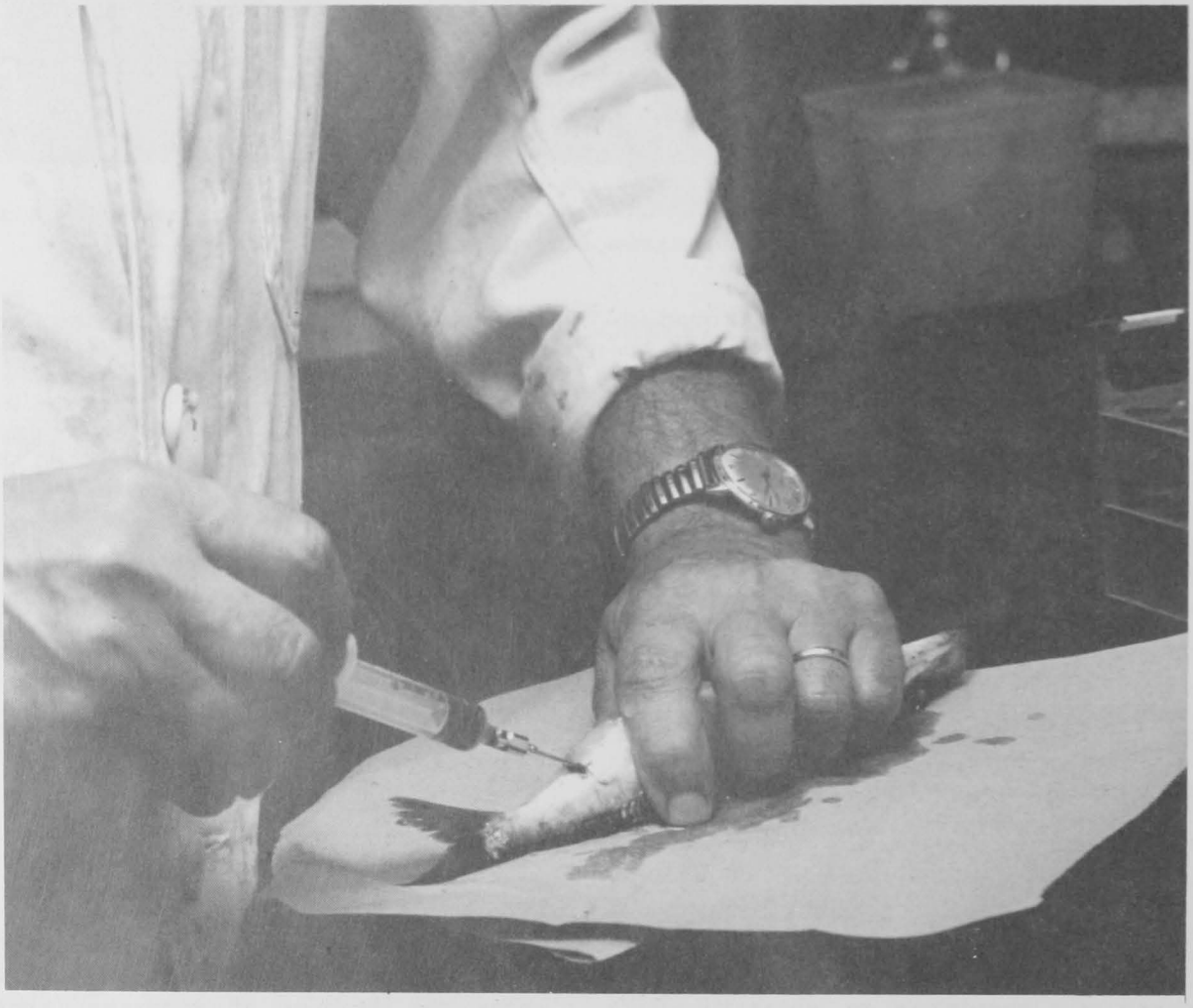
emphasizing population size and effects of physical, chemical, and biological factors (including fishing) on population structure.

The Pacific sardine probably has been studied more intensively than any other marine fish population in coastal waters. In 1920 W. F. Thompson of the former California Division of Fish and Game submitted a long-term program for research on the sardine. Those studies dealt with techniques of sampling the commercial catch, analysis of fluctuations in the fishery, availability, and size-class dominance, and were supplemented by comprehensive tagging from 1936-42, when World War II curtailed activities. Tag recoveries were made through 1946, providing information on migration patterns, differential distribution with age, growth, and survival.

In 1937, the former U.S. Bureau of Fisheries established a laboratory at Stanford under the direction of O. E. Sette. Subsequently several investigators, including L. A. Walford, R. P. Silliman, J. C. Marr, M. B. Schaefer, T. M. Widrig, C. C. Taylor, and others, investigated various aspects of sardine population dynamics, including population size and fluctuations, recruitment, year-class size, effects of fishing and fishing mortality, natural mortality and its causes, the "critical period," availability, growth, and sampling problems.

Data on age and length composition of the U.S. commercial sardine catch are available from 1932 to the present. Also, the sardine fishery in Baja California, Mexico, is sampled and data on landings of other species are collected by the California Academy of Sciences under contract to BCF. For the past decade both sardine and anchovy age and length data have been collected routinely. A random sample of 50 fish is taken from each boatload at the port of landing. Weight, length, and sex of each fish are recorded. Scales are taken from a subsample of 10 fish and are aged later by a scale reading group consisting of two persons each from BCF and the California Department of Fish and Game.

Recent critical reappraisal of criteria for identifying annuli (annual rings) on scales has shown that determining the precise location of the first year growth ring is the primary source of error in aging sardines. The length at age 1 year, as calculated from the radius



(Courtesy, R. C. Counts.)

Extraction of sardine blood for serological tests to detect subpopulations.

of the first annulus, has been used in the past to indicate changes in population structure. Apparently at least part of the ostensible increase in length at age 1 year that began in the mid-1940's resulted from turnover in scale reading personnel. Recently a selected series of scales from 1941-42 through 1961-62 was read independently by seven present or former scale readers, including three of the original readers, to resolve this problem. Further, small sardines are being held in a bait tank in San Diego Bay for an extended period and sampled at regular intervals to define features of scale growth throughout the year.

Fecundity estimates have been made for a number of commercial species and other numerically abundant species represented in the collections of eggs and larvae taken in the regular CalCOFI plankton hauls. Estimates of the relative biomass of spawning adult populations of sardines and anchovies are made by combining fecundity data with CalCOFI pelagic fish egg and larva survey data. Estimates of total biomass are possible for sardine, anchovy, hake, rockfish, and jack mackerel when the data are refined further. Unfished resources such as hake, rockfish, and anchovy, can be inventoried by this method, and this method provides an independent check on estimates of sardine and jack mackerel abundance obtained from commercial landings.

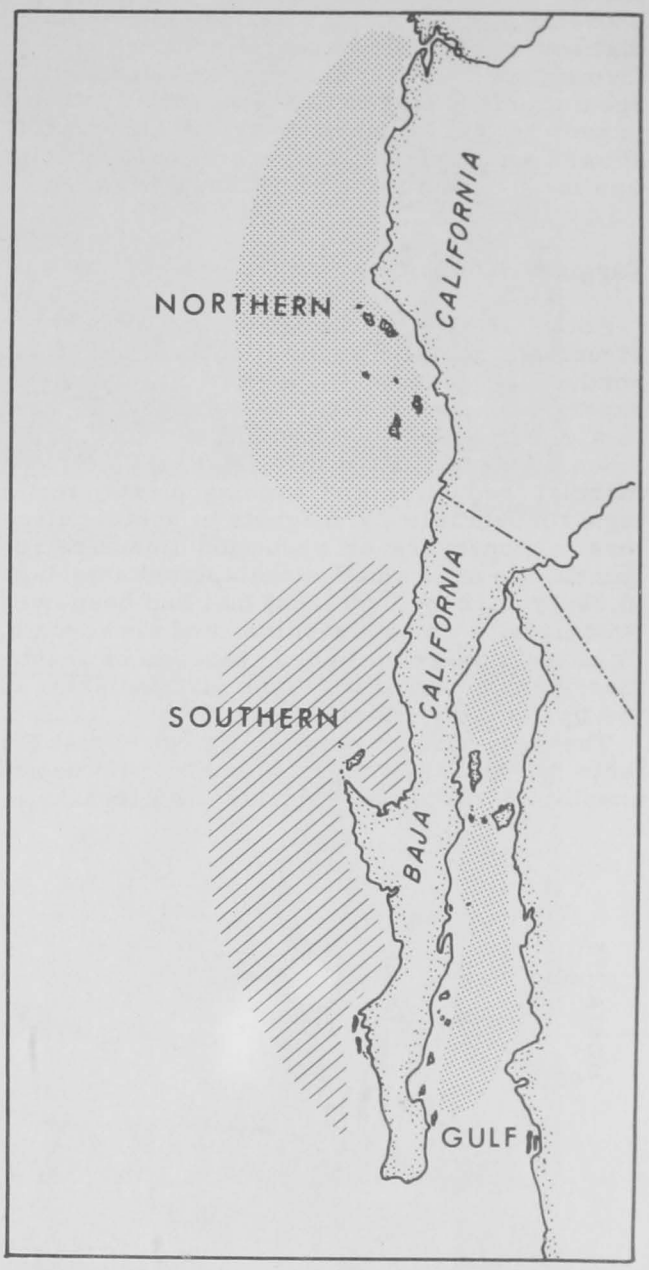
SUBPOPULATIONS

Genetics

Genetically distinct "Northern", "Southern," and "Gulf" subpopulations of Pacific sardines have been separated by serological methods. In the Northern subpopulation, 13.5 percent have a C-positive (C+) blood group factor on their red cells, detected through standard agglutination techniques. The Southern subpopulation has 6.5 percent C+ and the Gulf subpopulation has 17.2 percent C+.

Distribution of the Northern and Southern subpopulations is variable from year to year and from season to season. Both tend to move north in late summer and fall, and south in winter. Seasonal distribution of subpopulations determines their availability to the commercial fishery and their respective contributions to the commercial catches of Mexico and the United States. For example, during the 1964 season the northern subpopulation was the sole contributor to the U.S. catch; it also made up a relatively small portion of the Ensenada, Mexico, landings. The southern subpopulation contributed only to the Mexican catch and probably constituted the major portion of 1964 landings.

Reagents and techniques are being developed for serological investigation of northern anchovy population structure similar to that performed on the sardine. Other pelagic fishes,



Geographical distribution of sardine subpopulations.

such as mackerels, will be investigated in the future when techniques are developed.

Like blood group antigens, other specific body proteins may be genetically controlled, and their presence or absence could be used in subpopulation studies. Environmental factors, especially diet, may influence the protein complex of some tissues, which would preclude their use for genetic characterization. The eye lens, because of its relative isolation from the circulatory system, is one of the tissues least likely to be affected by the environment.

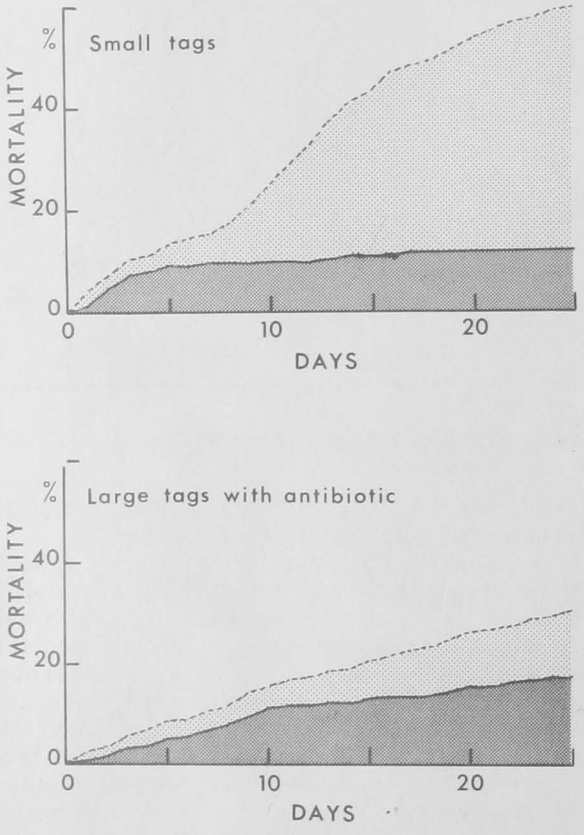
We made aqueous extracts of eye lens proteins from each of several sardines, northern anchovies, opaleye perch, and rainbow trout.

When extracts were subjected to electrophoretic tests in polyacrylamide gel columns, distinct patterns of bands of soluble proteins formed. The patterns were consistent within species but varied between species. Larvae, juveniles, and adults of the same species showed similar patterns. No change in proteins was found among fish fed different diets.

Tagging

Anticipating the need to know population structure, movement, and abundance of the northern anchovy, we performed controlled experiments on feasibility of anchovy tagging in a floating bait receiver in San Diego Bay. Since the source of tag returns would be commercial reduction and canning plants, metal tags recoverable by magnets or metal detectors in conveyors or reduction lines are required. We used small nickel-plated steel tags (0.02 by 0.12 by 0.50 inch) that had been used successfully on both sardines and anchovetas. Tags were inserted in body cavities of anchovies through small incisions just posterior to the tips of the pectoral fins.

The experiments were designed to test effects of the following on mortality: (1) use of anesthetic, (2) tag size, (3) handling technique, (4) use of antibiotic, and (5) conditioning of test fish by confinement. Use of anesthetic was discontinued when 4 to 33 percent of the fish anesthetized with Quinaldine died within 1 hour after tagging, while only 1 fish out of 1,200 died when no anesthetic was used. Heavy bacterial infection caused high mortality when nonsterile standard tags were used. Mortality from infection was reduced by using one-half size (0.02 by 0.12 by 0.25 inch) tags, but these were shed by the fish at a rate which offset the advantage. The larger tag covered with antibiotic paste (Tetracycline HCL 10 percent in petrolatum) effectively reduced mortality from infection but increased the amount of tag shedding slightly. The average loss of tagged fish through both death and tag shedding was only 35 percent after 30 days in three separate experiments of about 200 anchovies each. Better results were obtained with recently caught fish than with those held in the bait receiver for a few days prior to tagging.



Cumulative daily loss of tagged anchovies; dark shading is mortality, light shading is tag shedding.

PELAGIC SURVEYS

Egg and larva surveys have been the major research of the California Current Resources Laboratory. These surveys have been made in cooperation with SIO, making two to four vessels available. Early in this study, we found distribution and abundance of sardine eggs and larvae variable enough in time and space to require systematic coverage of an extensive area off California and Baja California. Distribution and abundance of adults at time of spawning is assessed by determining distribution and abundance of eggs. In recent years sardines have spawned mainly south of Pt. Conception off southern California and all along Baja California. We have demonstrated empirically a close relation between distribution of fish at time of spawning and their subsequent availability to the California fishery.

Sardine larvae are studied to determine what environmental factors influence their survival. Analysis of the nature and causes of fluctuations in success of year classes of fishes is an essential part of population dynamics. Since plankton survey samples include the eggs and larvae of most pelagic fishes in the California area, they are invaluable for overall resource evaluation.

Sardine Spawning

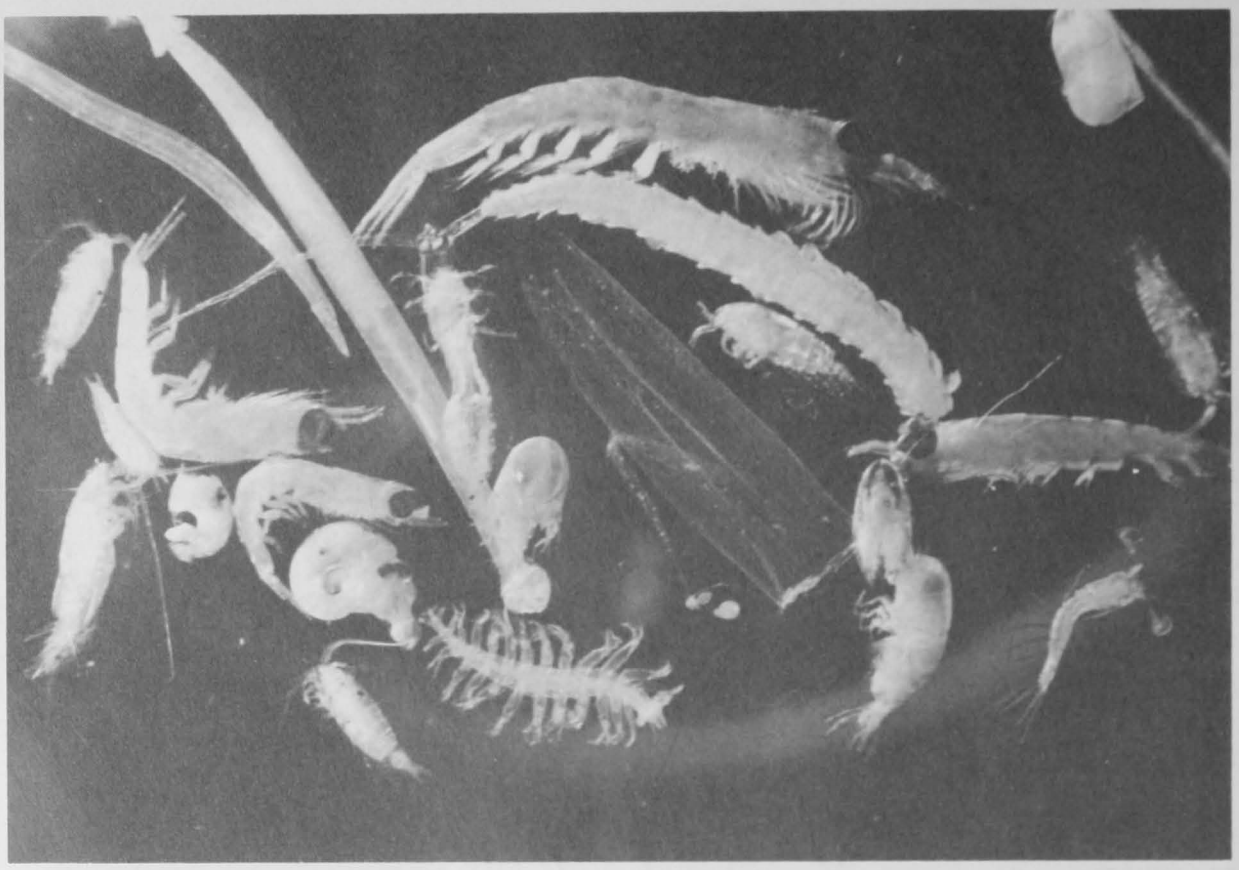
The principal CalCOFI surveys of sardine spawning were made during the 1950's, when sardine spawning occurred mainly between Pt. Conception, Calif., and Pt. San Juanico, Baja California. Distribution of eggs was different from year to year even within this zone. In 1952 and 1953, very little spawning occurred off southern California and northern Baja California while

(Courtesy, G. M. Mattson.)

Determining plankton volumes as indices of biomass.

(Courtesy, G. M. Mattson.)

Sorting plankton samples for pelagic fish eggs and larvae.



(Courtesy, G. M. Mattson.)

Zooplankton of the California Current; these animals are predators, competitors and food of the sardine at different stages of its life.

spawning was heavy off central Baja California. In 1954 an explosive spread northward to waters off northern Baja California and southern California caused the distribution of sardine eggs and larvae to be the most widespread of the decade. A moderate increase in temperature occurred between 1953 and 1954, but there were no marked oceanographic changes that would account for the observed dispersion of sardines. A plausible explanation is that sardines spread out in response to an increase in population abundance resulting from the recruitment of the fairly successful 1952 year class. Sardines that came to California waters to spawn in spring 1954 remained during the commercial season. The catch increased from 4,000 tons in the 1953-54 season to 68,000 tons in the 1954-55 season. The change in spawning distribution preceded the change in catch, demonstrating that egg surveys could furnish advance information on availability of sardines to the California fishery.

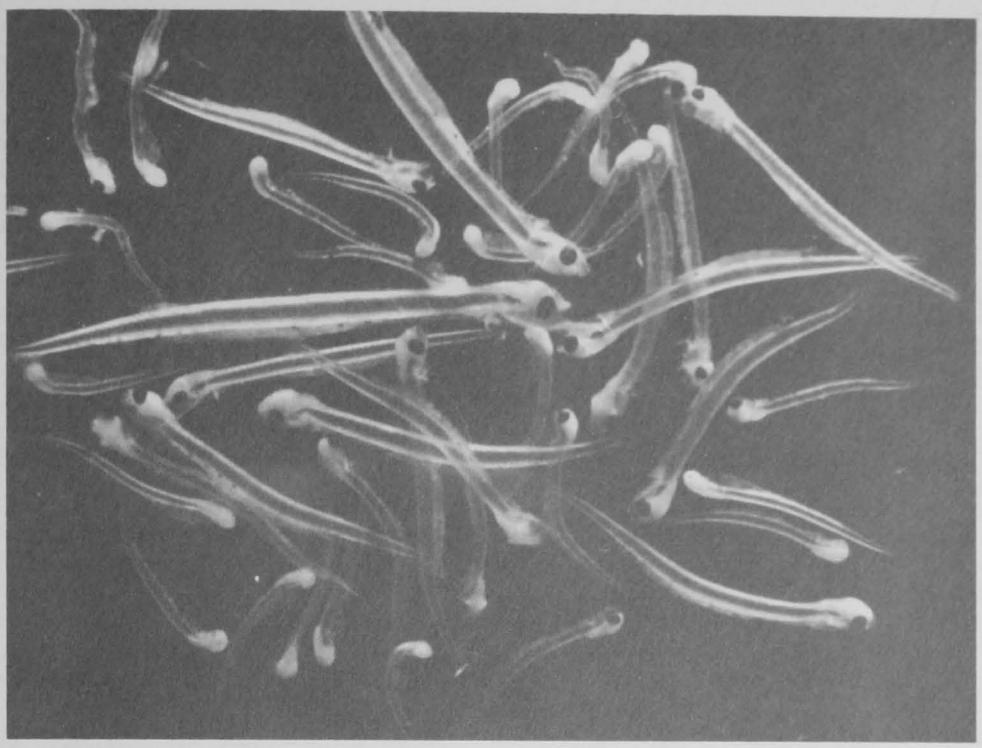
A marked warming of California Current waters occurred during 1957-59, amounting to an increase of several degrees in many parts of the region. The temporal distribution of sardine spawning changed markedly, especially off southern California. During the previous years (1951-56), sardine spawning off southern California was confined mostly to May and June. In 1958 the peak was in January, and spawning was spread over a 7-month period, January-July.

Survival of Sardine Larvae

We are gathering evidence that may help solve some aspects of the critical problem of marked fluctuations in survival of year classes of pelagic marine fishes. Our comprehensive egg and larva surveys can obtain consistent data. During the 1950's, the 1952-, 1956-, and 1957- year classes made the largest contribution to the commercial catch. Based on egg and larva data, these were the best survival years.

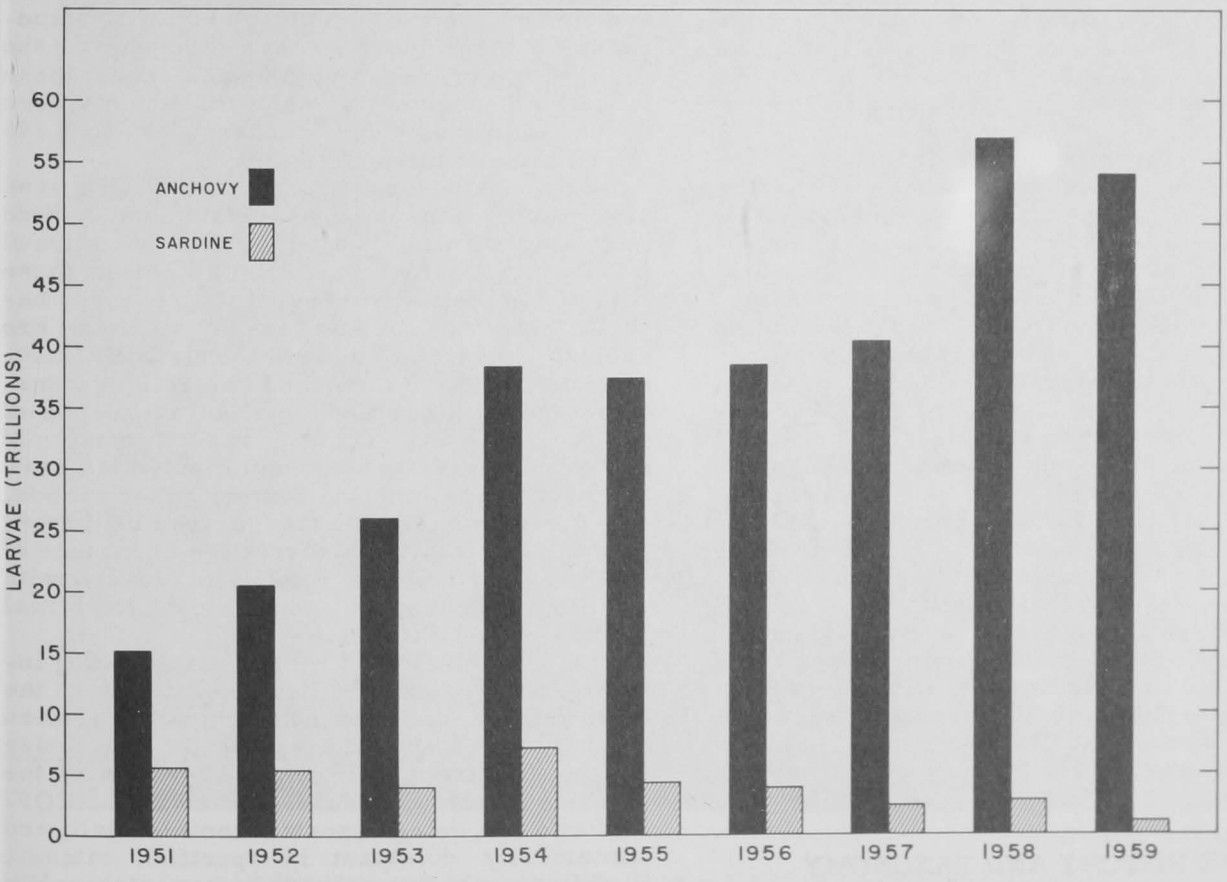
From our data, evidence of marked differences in rate of survival during the larval period is lacking, because the relative proportion of larvae of each of the several size categories collected during successive years has been very similar. Even more striking constancy occurred in the apparent rate of survival of anchovy larvae.

The amount of sardine spawning has gradually decreased since 1954 even though the 1956 year class apparently had the best survival during the decade. Sardine spawning has



(Courtesy, G. M. Mattson.)

Anchovy larvae taken in plankton samples.



Census estimates of anchovy and sardine larvae 1951-59.

been minimal and, confined mostly to inshore waters since 1959, in contrast to the widespread offshore distribution observed in earlier years.

Other Pelagic Fish Larvae

Egg and larva surveys are primarily important in fish resource evaluation, especially off California, where fish resources are only partly used. The great value of systematic egg and larva surveys for resource evaluation has not been fully appreciated. Since most of our marine fishes spawn in the open sea, their eggs and larvae can be sampled with plankton nets quantitatively. The CalCOFI surveys have revealed abundant and widespread hake eggs and larvae, jack mackerel eggs and larvae, and rockfish larvae. They have allowed us to follow the increase in distribution and abundance of the anchovy population. Anchovy larvae more than tripled in abundance between 1951 and 1958, and have become more numerous during the early 1960's. As anchovy larvae have become more numerous and widespread, they have tended to occur more frequently with sardines. By 1958, 94 percent of the sardine larvae were taken in hauls containing anchovy larvae; in subsequent years this high incidence of co-occurrence continued. The largest number of anchovy larvae taken during a single cruise was obtained in spring 1962. About as many anchovy larvae were taken on this one cruise as during all cruises made in 1955 or 1956.

The time sequence of the increase in anchovy abundance is well documented. The causes of the increase are still conjectural. Three factors seem to be important: (1) exceptionally poor survival in 1949 and 1950, caused a decrease in the abundance of sardines (2) a selective fishery exploited the sardine population, and (3) oceanographic conditions prevailed that favored anchovy spawning. Anchovy and sardine larvae are directly competitive because they eat the same kinds of food. The anchovy has a lower temperature threshold for spawning than the sardine, 11 - 12° C, rather than 13° C. Therefore main anchovy spawning has preceded sardine spawning in most years, particularly off southern California. This gave juvenile anchovies an initial advantage on the inshore nursery grounds. Although the stage of life history when competition between sardine and anchovy is most severe has not been determined, there can be little doubt that the flourishing anchovy population deters resurgence of the sardine population.

LIFE HISTORY AND TAXONOMY

This program evaluates pelagic fish resources by relating the distribution and abundance of juveniles and adults to their distribution and abundance as eggs and larvae.

Several cruises have been made in cooperation with the Exploratory Fishing and Gear Research Base, Seattle, Wash., to evaluate the Pacific hake resource especially. The Black Douglas searches for concentrations of fish eggs and larvae, especially hake. Where large concentrations of newly spawned hake eggs are found, spawning adult hake are located by the John N. Cobb with echo-sounding gear and by operating a pelagic trawl with an opening of 70 by 80 feet. Concentration of hake eggs and spawning adults were found west of the Santa Barbara Channel Islands near the San Juan Seamount, and between Geronimo and Cedros Islands off Baja California. Many such areas must exist off California and Baja California, because hake eggs and larvae are very widespread in the CalCOFI survey area.

We have found that hake eggs and larvae occur mostly below the upper mixed layer. The distribution of adults in offshore waters accords with these observations. The bathymetric range was about 80 to 225 fathoms; the fish occupied lesser depths at night. One spawning aggregation of hake was estimated to occupy an area of about 23 square miles. Hake spawn principally during winter; the spawning season is shorter than that of most pelagic fishes.

During April 1964, the John N. Cobb took anchovies in more than half the trawls, sometimes in large numbers even though only the cod-portion of the trawl had small enough mesh to retain anchovies. Some of the schools were surprisingly deep; one occurred at about 185 fathoms in daytime.

Additional surveys over the CalCOFI area have been made using a 10-foot Isaacs-Kidd midwater trawl, and a collapsible beam trawl (10-foot by 15-foot mouth). Catches by these nets incompletely represent the resource because only smaller and less active fishes are caught. Since the nets are relatively fine-meshed they have furnished valuable information on the kinds and relative abundance of pelagic deep-sea fishes, predominantly of ecologic rather than economic potential, such as myctophids, deep-sea smelts, stomiatids, and gonostomatids. These surveys confirmed that the distribution and relative abundance of juveniles and adults correlate closely with similar information obtained from larval studies of these fishes.

The life history of rockfishes is being investigated systematically. Sebastodes is the largest genus of fishes in the temperate eastern north Pacific. Over 50 species of Sebastodes are known from California; it is one of the most abundant kinds of fishes in the CalCOFI survey area, being important commercially and numerically dominant in sportfish catches. Rockfish young are released after hatching. By collecting females with developing embryos, we associate the eggs and newly hatched

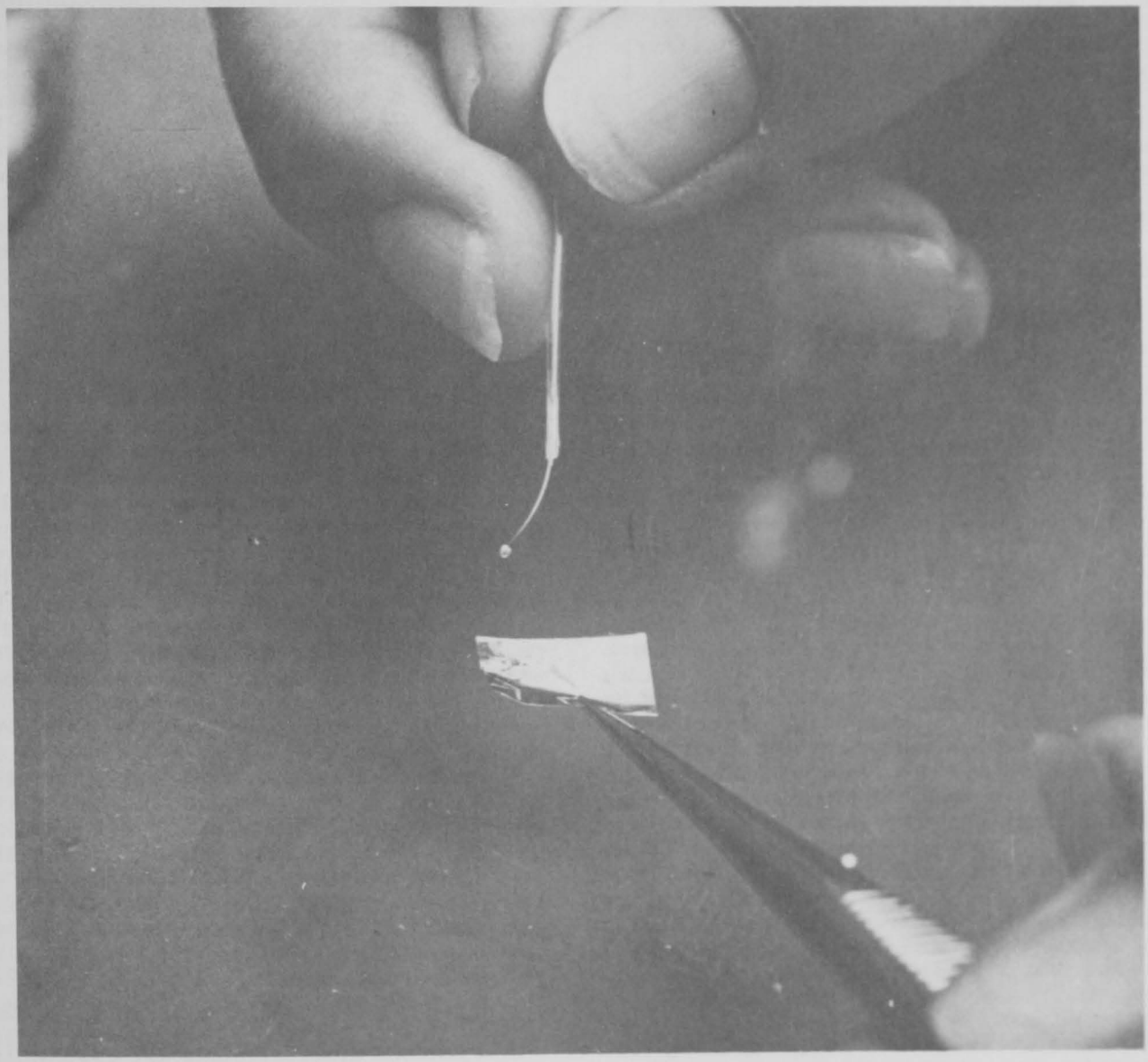
larvae with identifiable parents. We are systematically collecting adult rockfishes at all seasons of the year off southern California, and in other areas as the opportunity affords, to obtain the embryonic stages.

PHYSIOLOGY

Knowledge of the responses of marine organisms to their environment is fundamental to understanding the dynamics of their populations. All animals have major physiological functions in common (e.g., growth, feeding, digestion, respiration, salt balance, sensory responses) but differ in the way they perform them. These differences may significantly affect survival, and, consequently, our ability to predict future population fluctuations.

Our studies have emphasized the nutritional aspects of sardine embryos, larvae and adults, including energy requirements and energy utilization. Our many related investigations combine the study of physiology of marine organisms with ecology. Chief among these is quantitative evaluation of energy exchange in the marine food chain. We emphasize food organisms of sardines anchovies, and tuna, such as euphausiid shrimps (small, deep-sea crustaceans that eat phytoplankton, smaller zooplankton, and detritus).

Another major investigation in progress is rearing pelagic marine fishes from



(Courtesy, G. M. Mattson.)

Sardine larva (curled on tip of probe) being placed on aluminum foil for drying and subsequent biochemical analysis.

eggs through metamorphosis in the laboratory.

Other investigations include nutrition of the purple sea urchin; use and deposition of fats in adult fishes; body salt regulation in fish larvae; oxygen uptake by herring and sardine embryos and larvae; biochemistry of developing herring eggs and larvae of different racial origin; and analysis of a substance from starfish that causes escape responses in marine snails.

Most of our studies with living planktonic fish eggs and larvae have necessitated adaptation or development of special techniques for handling and analyzing small animals. For example, determination of dry weight requires an electrobalance with microgram (0.000000035 ounce) sensitivity (small sardine larvae weight about 30 micrograms). We adapted the reference diver technique of P. F. Scholander and his associates for measuring oxygen consumption of single sardine eggs and larvae, and devised capillary tube sampling devices of withdrawing larval sardine yolk. We use other general tools of the biology and biochemistry laboratories, such as gas chromatography, electrophoresis, radiation-measuring equipment, and carbon analyzers.

Nutrition of Marine Organisms

A study of the efficiency and rate of yolk utilization by developing sardine embryos and larvae showed that larvae lapse into metabolic deficit prior to complete yolk absorption and the formation of a functional jaw. If the larvae do not eat after the jaw is functional, they draw on their own tissues for sustenance, and ultimately die. Conversion of yolk to animal tissue is extremely efficient, but respiration exceeds input from this source prior to complete yolk utilization. Efficiency of converting yolk to sardine tissue is 78 percent. The yolk utilization study showed how much energy, in terms of copepod nauplii, a sardine larva must have to maintain its metabolism at a constant level. We observed that one nauplius per hour at 14°C. is needed to provide for basal maintenance alone, and almost four per hour are needed to provide for all metabolic requirements.

Sampling and analysis of adult sardines for biochemical constituents have produced quantitative information on the energy required for growth, reproduction, fat deposition, and maintenance. Sardines digest live shrimp with more than 80 percent efficiency. A study of the qualitative changes in fat due to diet showed that ovarian fat is deposited almost unchanged from the current food supply (for example, copepods), and that mesenteric and muscle fats are used chiefly as a source of energy for swimming and other metabolic requirements.

A study of the digestion of brown algae by the purple sea urchin, in collaboration with R. A. Boolootian of UCLA, showed that the urchin can digest giant kelp with 80 percent efficiency, whereas the animal is less able to digest a variety of other brown algae found in its environment. The pattern of distribution of nutrients in the animal (detected by tracer techniques) gave evidence for the hypothesis that the blood system of the sea urchin is a true circulatory system. The role of the cells in the body cavity fluid and blood system of the urchin was also studied.

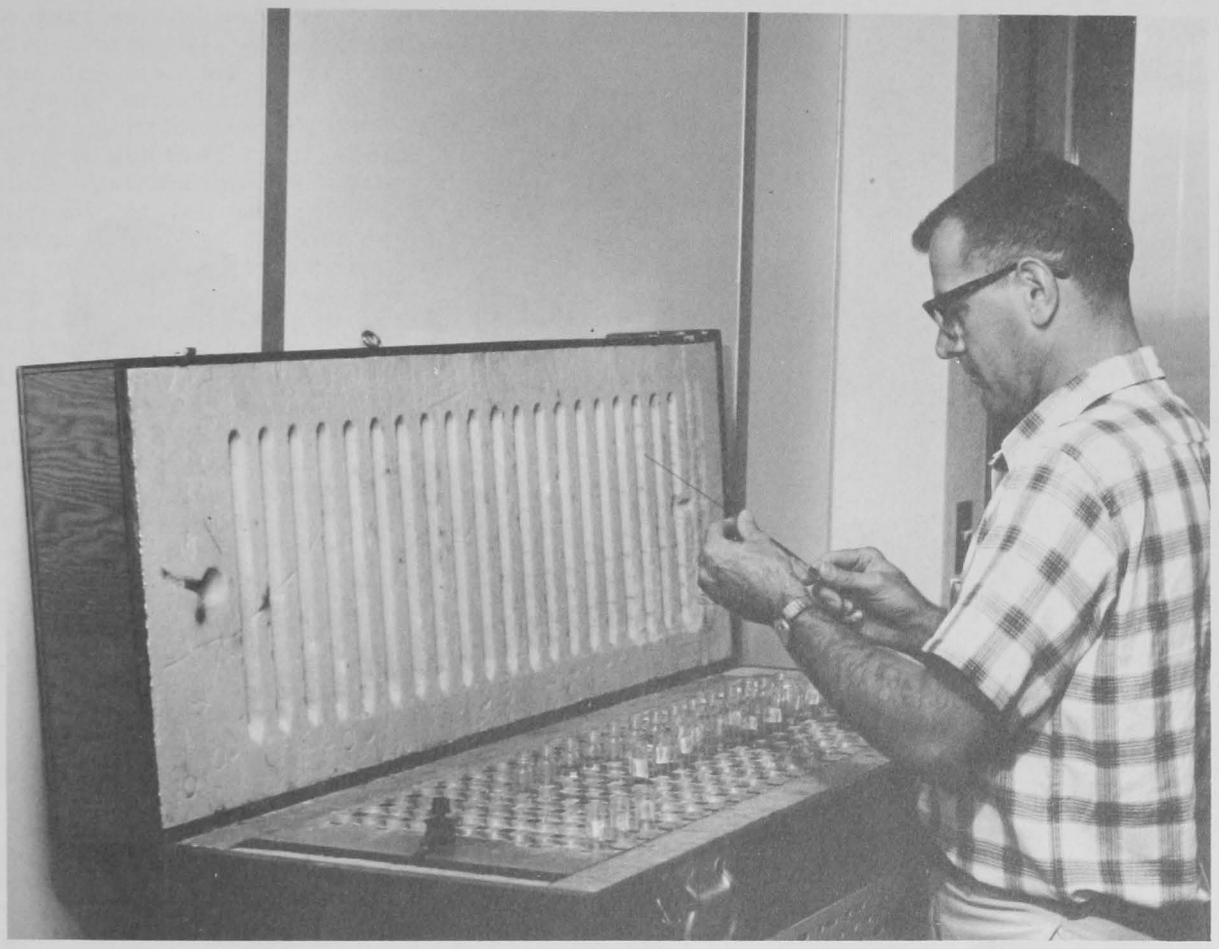
An understanding of food chain dynamics is needed to predict how many animals of a given kind the ocean can support. The marine food chain is extremely complicated, but laboratory studies permit us to dissect the essential parts of the chain (for example, herbivores feeding on phytoplankton or carnivores feeding on zooplankton) and to study them individually. An initial investigation showed the feasibility of studying the flow of carbon through the first level in the food chain using carbon 14 as a tracer. A euphausiid shrimp, Euphausia pacifica, an important member of the pelagic plankton, is the chief organism used in this study. This crustacean will eat either phytoplankton or small zooplankton and can be used to study two levels of the food chain. Our ability to keep this animal alive in the laboratory also permits us to study other aspects of its biology, such as molting frequency and its quantitative aspects, and growth, as well as carbon incorporation and overturn.

General Physiology of Marine Organisms

Salt balance regulation by sardine embryos and larvae was studied in relation to developmental energy requirements. We showed that even though newly hatched larval sardines lack gills and an open mouth, and have only primordial organs, they regulate salt balance to the same extent as adults, and use very little energy in the process. In their integument the newly hatched larvae have special "chloride secretory" cells (revealed by electron microscopy) that may be the active salt balance regulating sites.

All developmental processes of fish larvae are regulated by temperature, and energy requirements increase with increasing temperature. A study of effect of temperature on incubation time, development, and growth of sardine larvae showed that all processes studied double their rate over the major environmental range of 15-21° C. This implies that food requirements also must double over this range of temperature. Sardine larvae develop abnormally at temperatures below 13° C., but anchovy larvae develop normally at temperatures as low as 11° C.

Respiration measurements are essential for calculating energy requirements of all aerobic organisms. Sardine larvae double their basal energy requirements when swimming actively; herring larvae increase the basal level tenfold. Oxygen uptake per unit of respiring tissue



(Courtesy, R. C. Counts.)

NFS sponsored visiting investigator at the Fishery-Oceanography Center, preparing a blood enzyme for incubation in a temperature gradient block. The temperature block is used also for studies of development of sardine eggs and larvae.

differs very little between different races of herring eggs and larvae but overall oxygen need is much greater in the larger Norwegian herring eggs than in the smaller Baltic herring eggs. Osmotic stress did not increase respiration.

Many marine organisms have behavioral responses to chemical influences in their environment. The avoidance reaction of snails to the presence of starfish is one of these. A study of the chemical nature of the starfish substance, in collaboration with H. Feder of Hartnell College, Salinas, Calif., showed that it is confined to the epithelium of the starfish tube foot and can be purified partially in the laboratory.

Rearing Embryos and Larvae of Pelagic Marine Fishes

There has been only slight success in rearing the larvae of pelagic marine fishes and none on sardines, anchovies, and mackerels. To study experimentally the effects of various physical, chemical, and biological environmental factors on survival of different species and their subpopulations, it is necessary to establish criteria and conditions for rearing them successfully.

We observed that at the onset of feeding sardine larvae spend only 25 minutes of every hour in motion, while food is being captured. The duration of each active or quiescent period was 30 seconds to 10 minutes. Longer or more energetic active periods were followed by correspondingly longer quiescent periods. Possibly metabolite level increases during activity and is reduced by diffusion while the larva rests motionless in the water. Small (0.2 inch) larvae do not have evident vascular systems, oxygen and waste products of metabolism diffuse through the skin.

An experimental compressed air pump sampler has been tested at sea. Organisms attracted to a 1,000-watt light near the pump intake were trapped by the high velocity inflow and drawn to the surface in excellent condition. We set the gear to a depth of 250 feet in 6 1/2 minutes and recovered it in 2 1/2 minutes. One test run delivered 36 squid and

(Courtesy, R. C. Counts.)

Warburg respirometer used in studies of oxygen consumption by marine animals.

1 anchovy to the deck, along with euphausiids, mysids (opossum shrimp), and copepods. This indicated that the device will collect organisms that can pass up the 3-inch diameter hose if they come close to the intake. After some refinement, the gear will be used at subsurface "night light" stations to obtain larvae and adult fishes with matured gonads.

Inducing Maturation and Spawning of Adult Pelagic Fishes

Gonads of most pelagic fishes held in aquaria do not mature. Therefore, it is impossible to obtain eggs for experimental studies or to determine experimentally the number of batches of eggs spawned per season in relation to fish age, size, and condition. The Pacific sardine population is now known to be composed of at least three subpopulations. Normal maturation in aquaria and rearing of eggs and larvae are necessary if controlled genetic studies such as cross-fertilization are to be done on these subpopulations. We must determine whether failure to mature is caused by 1) inadequate space, which could be remedied by holding the fish in a large oceanarium or 2) inadequate food, which could be remedied by improved diet, or 3) endocrine response to confinement, which could be remedied by hormone injections, or 4) more subtle physiological or psychological imbalances.

BEHAVIOR

Food-getting, reproduction, and avoidance of predators are important determinants of survival of the individual fish and the species. By knowing the behavior associated with these vital activities, we can predict the effect of environmental fluctuations on population size, availability and vulnerability. Knowing the roles of fishes in their ocean environment cannot be reached directly because the problem is complex. But we can approach this through a combination of field investigation, experimentation, and studies in functional morphology.

Field Studies

Primary emphasis of field studies is on the distribution and availability of the food of the

Pacific sardine and anchovy in various parts of their ranges. Methods for tracking and sampling the fish are being developed. Research with sonar aboard the David Starr Jordan will contribute much to this.

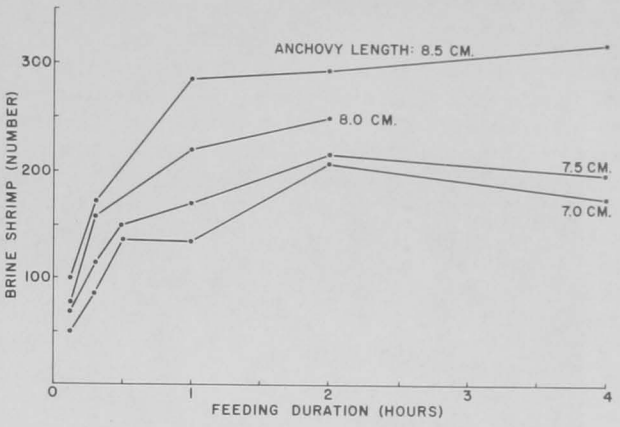
In some fishes the rate of feeding is greater for patchy distributions of food than for even distributions of the same average density. This difference must be considered when we attempt to measure the availability of food. Sampling must describe distribution in detail, as well as provide precise estimates of mean density. With this purpose, a 6,000-square-mile area known to be inhabited by the sardine was surveyed to determine the requirements for sampling the various small zooplankters that are its predominant food. A towed high-speed plankton pump system was used on cruises consisting of two-stage random sampling patterns. Within predetermined zones, blocks were selected at random, and contiguous samples were collected within blocks. Results showed that precision in estimating mean density is influenced more by number of blocks sampled than by number of samples within blocks.

Behavior Experiments

To evaluate behavior responses efficiently it is necessary to control and manipulate the environment; therefore, we are recording the activities of sardines and other small pelagic schooling fishes in a 30,000-gallon observation tank. One study involves determination of activity-rest ratio relative to swimming speed. Results will be coordinated with energy expenditure work being conducted by the physiology program. Other observations are made of responses to alterations in environment such as presence of barriers, presence of known predators, changes in illumination, controlled movement of objects, and combinations of these.

As in field studies, the primary emphasis is on food-getting behavior. We wish to know how particular species find and capture food, and how feeding efficiency is affected by kind, size, density, and distribution of food in relation to physical factors such as illumination and temperature.

On contact with concentrations of particulate food, anchovies go into feeding frenzies and schools disperse. After a few minutes of feeding schools gradually re-form, until, after 1 or 2 hours, schools often become more compact than prior to feeding. Controlled feeding experiments showed that the size of schools does not affect the rate of ingestion by individuals within the schools when food is available in surplus. This knowledge will expedite further experimentation because small schools are easier to manipulate than large ones. On the average, larger fish ingest more food per unit time than smaller fish; but individual variation



Relation between quantity of brine shrimp in stomachs and duration of feeding in anchovies of different lengths.

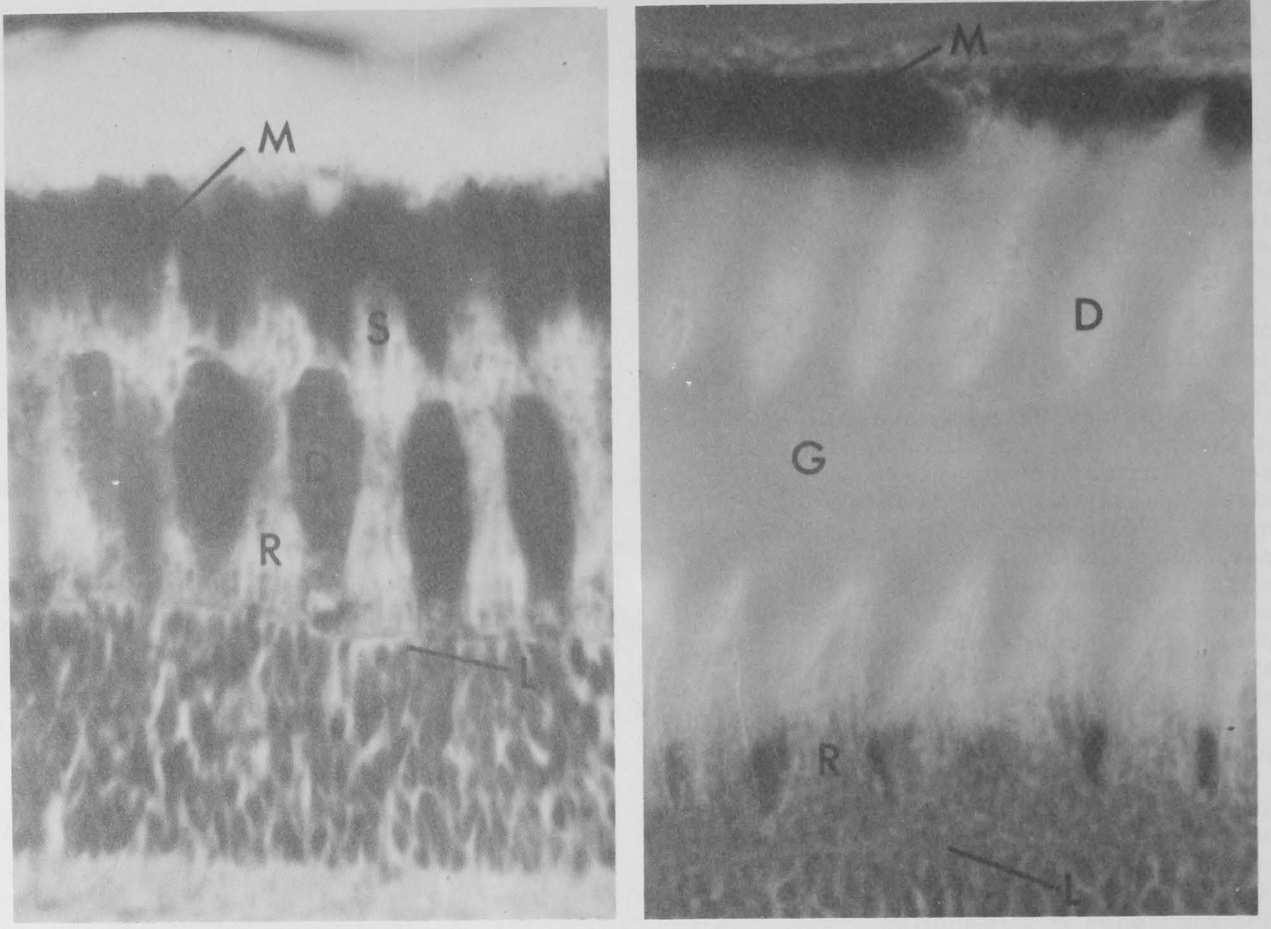
is such that one fish of a given length may ingest twice as much as another of the same size.

Functional Morphology

Vision is assumed to be the dominant sensory mechanism of pelagic schooling fishes. Studies of vision especially, but olfactory and auditory mechanisms as well, will indicate environmental information these fishes respond to. Neurophysiological as well as behavioral techniques will be used to determine thresholds.

Completed work on visual systems shows that the eyes of sardines and anchovies are structurally different, especially in the pigment epithelium of the retina. In sardines the cells of this layer contain granules of dark pigment that change their distribution as the eye shifts from light-adapted to dark-adapted condition. In anchovies these cells contain large amounts of guanine and smaller amounts of dark pigment. This reflecting layer behind the visual receptor cells was generally assumed to improve sensitivity in dim light, but recent work on the reflecting layer in shark eyes suggests that it increases rate of dark adaption rather than absolute sensitivity, so that little temporary loss of vision occurs when the animals move between zones of light and darkness. The dark pigment may be a counter-shading mechanism that prevents the eyes from showing as bright spots, rather than a screening mechanism that shields rods from bright light, as in fishes without reflecting pigment. The pigment layer in anchovies is being studied to determine relevant differences between visual capabilities of anchovies and sardines.

Studies of feeding behavior probably will raise questions of odor perception and lead to study of olfactory mechanisms. Eventual investigations of avoidance behavior and of long-range orientation to other school groups will



(Courtesy, C. P. O'Connell.)

Cross sections of pigment epithelia of dark-adapted retinae of Pacific sardine (left) and northern anchovy. Cones are masked by pigment cells in the anchovy. D, double cone; G, guanine; L, external limiting membrane; R, rod; S, single cone. Magnification 970.

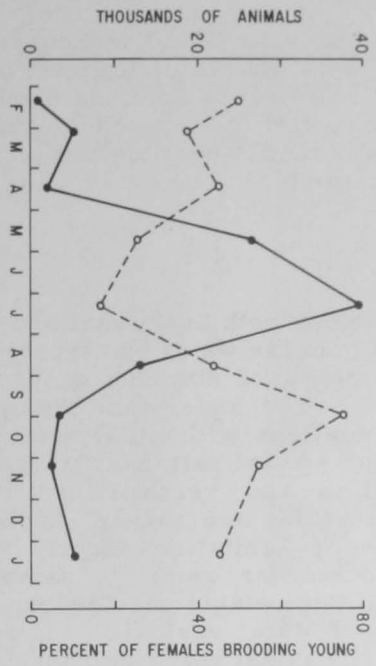
stimulate studies of auditory mechanisms. This is needed because the function of a connection between the gas bladder and inner ear is unknown. Earlier workers generally rejected the hypothesis that the connection provides pressure and depth cues and concluded that it must increase auditory perception. We have reviewed the ear-gas bladder connection and described the morphological differences between anchovies and sardines. Sardine bladders are single-chambered with exterior openings behind the vent, whereas anchovy bladders have two chambers separated by well-developed sphincter muscles and have no openings. These could be adaptions that minimize distortions of the inner ear caused by hydrostatic changes during vertical movements. Description of their functions will be an important aspect of the study of auditory mechanisms.

PLANKTON DYNAMICS

Standing crop and productivity of plankton organisms can be determined only by precise and accurate sampling techniques devised to account for the distributional and behavioral characteristics of the pertinent populations. Accurate sampling cannot be done with equipment that significant numbers of the animals avoid, and knowledge of their pattern in nature is indispensable to precision. Besides being of intrinsic scientific interest, studies of plankton population dynamics, plankton behavior, microdistribution and sampling equipment performance are necessary in the study of commercially important fishes.

Population Studies

In a population study involving field analyses and laboratory culture to determine growth

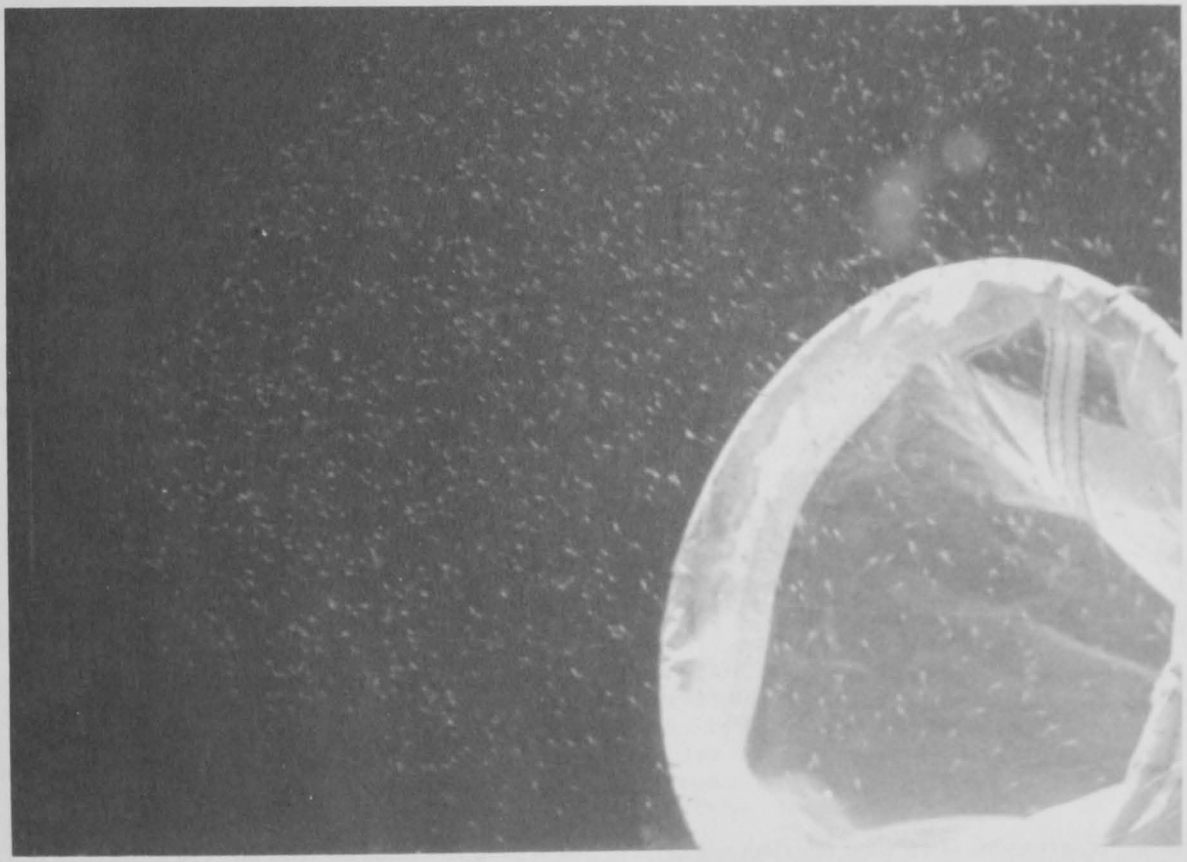


Relation between population size of immature and adult pelagic mysids (solid line) and rate of reproduction (dashed line), suggesting a feedback mechanism for population control.

rates and time between generations, we are finding that both control of predation and changes in rate of reproduction are affected by social behavior. The evidence suggests a feedback mechanism that operates by lowering the reproduction rate when population density increases. Changes in reproduction rate are associated with numbers of adult and immature mysids which swarm together selectively, but not with total population including juveniles, which occur in separate swarms. Experiments demonstrated that mysids will feed on their own young. This may be a direct feedback mechanism for population size control.

Behavior

We are studying schooling and avoidance behavior because of their relation with microdistribution and sampling efficiency. Statistical evidence and observation indicate that most marine organisms school in some manner. Some kinds of plankton exhibit highly integrated schooling behavior. Dye experiments with four species of crustacea (mysids and euphausiid shrimps) showed that movements of swimming appendages not only provide propulsion, respiratory currents, and feeding

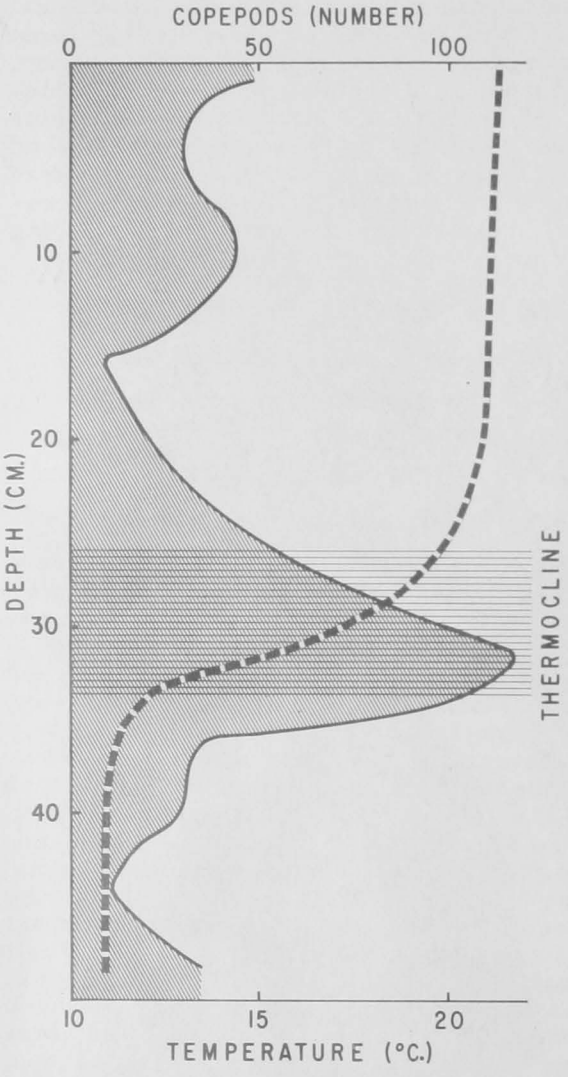


(Courtesy, R. I. Clutter.)

Reaction of schooling mysids to sampling net. Animals at periphery of swarm sense the presence of the net partly by activity of those nearer the source of disturbance.

currents, but produce sizable wakes that may be a means of communicating position and orientation to other animals. This in part may explain why certain species retain schooling capability even in darkness. Schooling improves efficiency of reproduction. Slow-motion films of mysids indicate that copulation is dependent on detection by males of a chemical substance released by females on molting. A cooperative study with the physiology program of this laboratory has been organized to extract, assay, and describe this substance.

In our studies of individual and group escape reactions we find that all crustacean zooplankton thus far observed are capable of oriented movement out of the path of sampling devices. For example, recent analysis of slow-motion films has shown that the copepod



Combined observations of vertical distributions of isolated planktonic copepods, Calanus helgolandicus, in an experimentally induced thermocline (dashed line is temperature curve).

Labidocera acutifrons is capable of directed movement at a rate of 30 inches/sec. (230 body lengths/sec.) over a distance of 6 inches. The vulnerability of schooled plankton to capture apparently is reduced by collective vigilance and escape reactions not engaged in by solitary animals.

Microdistribution

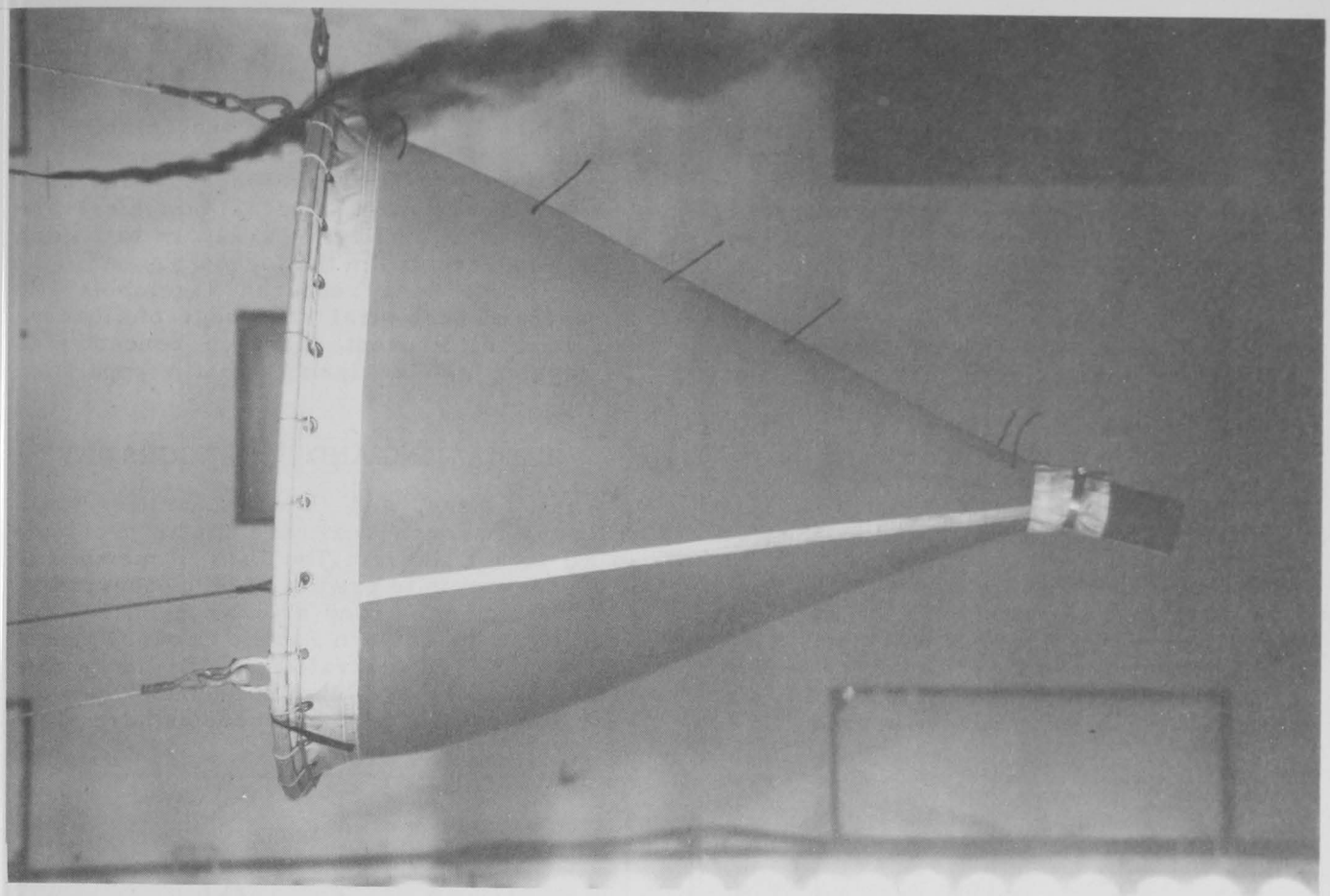
We are studying both horizontal and vertical distributions because we cannot expect to make precise estimates of standing crops of animals efficiently nor understand the dynamics of their populations without determining the details of their spatial patterns. Marked horizontal zonation and vertical stratification occur; distributions are rarely random even within zones of habitation. Highly variable individual counts for replicate samples are characteristic of pelagic marine organisms. Assessment of this variability has led to sampling designs that will make successively better total population evaluations, including: 1) number of patches per unit area 2) average patch size, and 3) average concentration within patches. This assessment will allow more accurate and precise estimates of population size and permit study of the function and evolutionary adaptiveness of patchiness.

Sampling Equipment Performance

"Net plankton" constitutes vital segments of the marine food web and of early life stages of commercially valuable food resources. Our knowledge of this group is determined by the catching characteristics of plankton nets. Net plankton is delimited at the lower end of the net by mesh aperture size and at the upper end by the responses and mobility of the animals. Thus, operational plankton net designs are compromises between mesh retention of small organisms and the speed and filtration efficiency necessary to entrap mobile organisms.

Detailed controlled experiments on avoidance of towed nets by zooplankton to determine the effect of behavior on the accuracy of sampling indicate that fairly small crustacea are capable of avoiding capture. This capability differs among species and is influenced by the environment.

Experiments have been done to describe filtration in nets now in use so that guidelines can be set for designs that decrease directional sensory cues ahead of the net and are optimum for the required sampling precision. These show that part of the water in the path of a net is filtered and part is accelerated. The relative volume of water accelerated is determined by: (1) mesh aperture size; (2) ratio of mesh aperture to mesh filament; (3) ratio



(Courtesy, U.S. Navy.)

Dye flow pattern around mouth of experimental plankton net, showing partial rejection of water due to inadequate mesh area in net; a part of comprehensive tests on hydrodynamics of plankton sampling devices done at the U.S. Navy David Taylor Model Basin, Washington, D.C.

of mesh aperture area to net mouth area; (4) water temperature; and (5) velocity of tow. Acceleration forces inside the nets produce "forward acceleration fronts"; some accelerated water is shunted to all sides ahead of nets.

TUNA RESOURCES LABORATORY

BACKGROUND

The Bureau established the Tuna Resources Laboratory in 1959 for oceanographic and biological research on the tunas of the eastern Pacific Ocean and for studies of tuna fishing operations. The primary aim is to apply the findings to specific problems of the tuna industry.

Principal investigations are: (1) oceanography of the environment, to understand the distribution of tuna species and to predict variations in availability and abundance; (2) research on responses and behavior of tunas, to be applied to the improvement of present fishing techniques; (3) studies of life history, ecology, and population dynamics of the temperate tuna species that are least known at the present; and (4) operations research to develop optimum fishing strategies based on the integrated experience of all segments of the tuna fishing fleet and the results of biological and oceanographic research.

Laboratory scientists work closely with scientists of the Institute of Marine Resources (IMR) and SIO of the University of California, the Inter-American Tropical Tuna Commission, and the California Department of Fish and Game. Part of the laboratory's oceanographic research is done by IMR and SIO under contract with the Bureau (see section on Scripps Tuna Oceanography Research).

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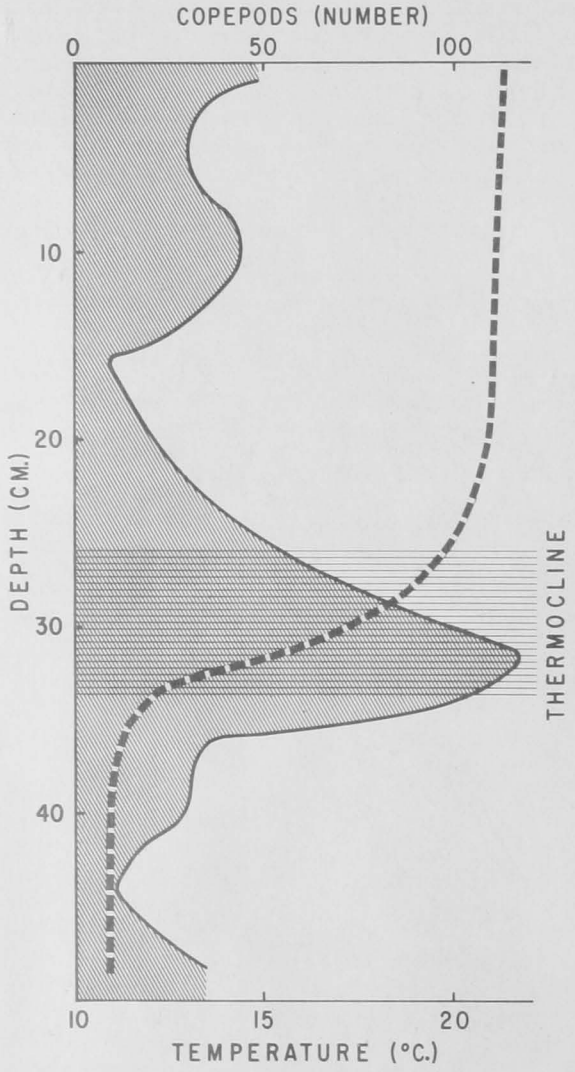

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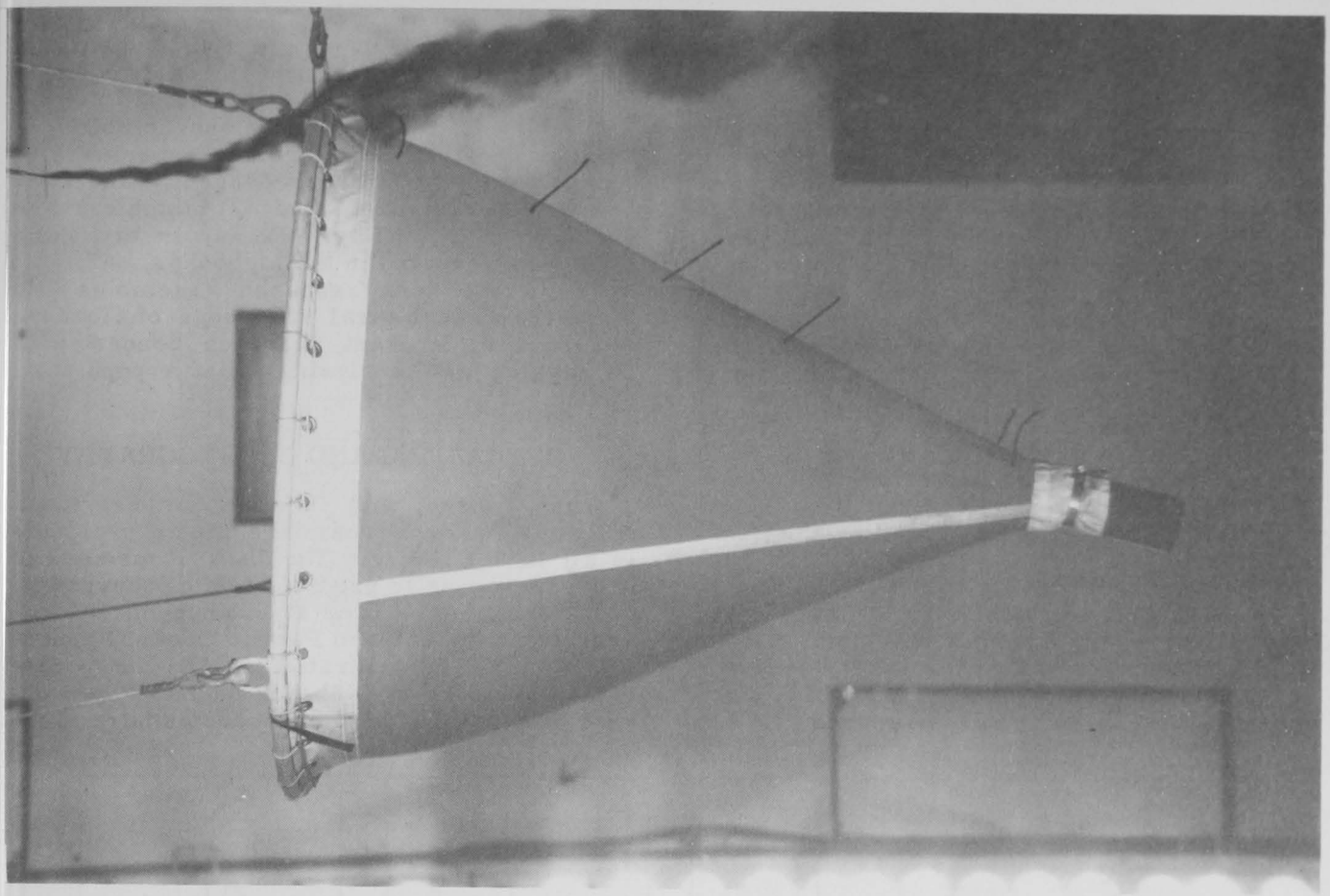

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and banks where tuna schools tend to congregate. Issuance of annual forecasts for the beginning and end of the West Coast albacore tuna fishery has aided the fishing and canning industry materially. Oceanographic research includes analyses of physical, chemical, and biological data, both from historical records and from current information, to detect features of the environment that are valuable in predicting when and where tuna will occur. Principal investigations in behavior research are: visual factors in net avoidance; nature of the thermocline (layer of rapid temperature change) and its effect on success of seining for tuna; and laboratory experiments on schooling behavior of juvenile tunalike fishes. Other studies include the taxonomy, life history, and aspects of the behavior of porpoises and sharks associated with tropical tunas.

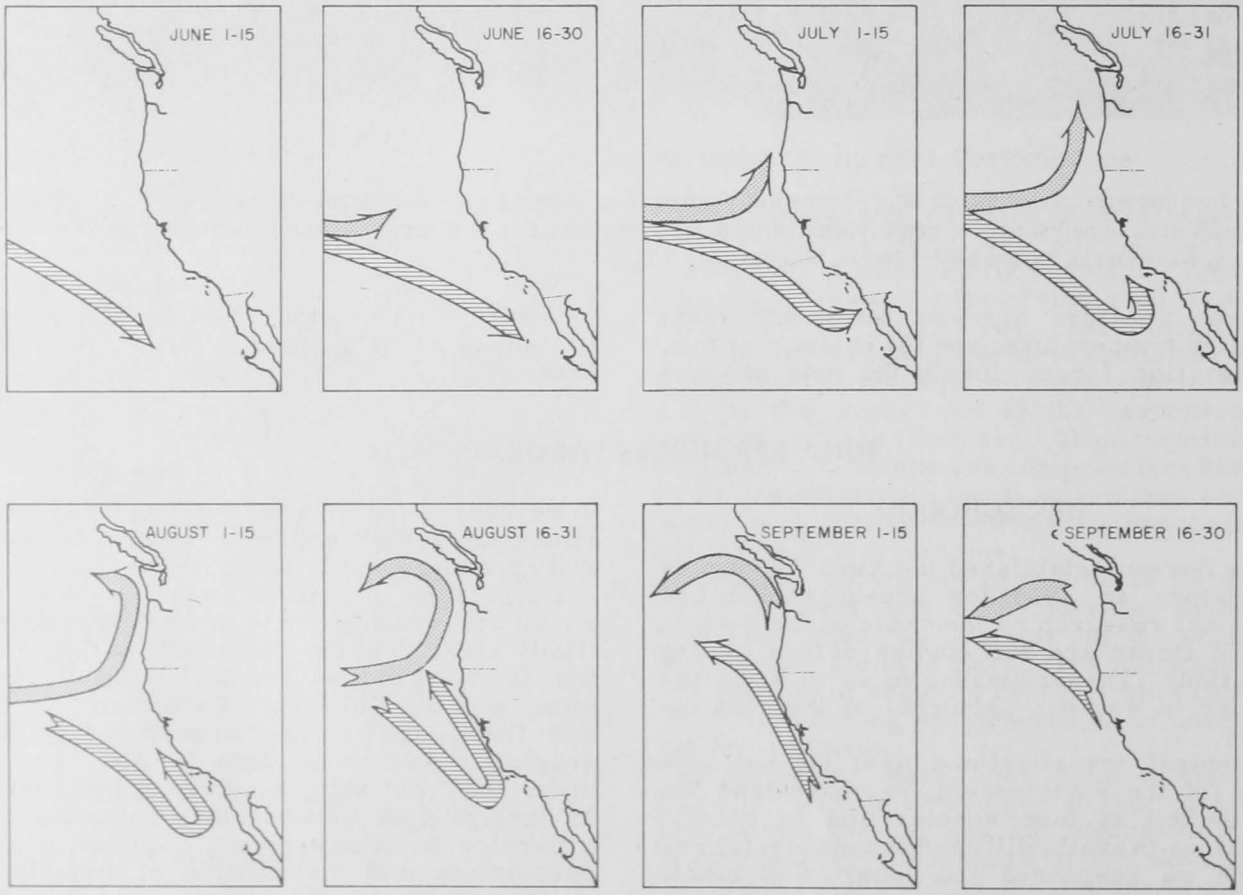
A contract has been given to Straza Industries of El Cajon, Calif., to investigate the feasibility of continuous transmission frequency modulated (CTFM) sonar for behavior research and commercial fishing. The first phase of the project included applying CTFM sonar techniques to single fish targets; the second phase is attempting to study schools of fishes at sea.

Operations research involves compiling a summary of (1) the integrated experience of tuna fishermen from vessel logbooks and other operational records, and (2) biological and oceanographic findings that apply to fishing situations revealed in the logbooks.

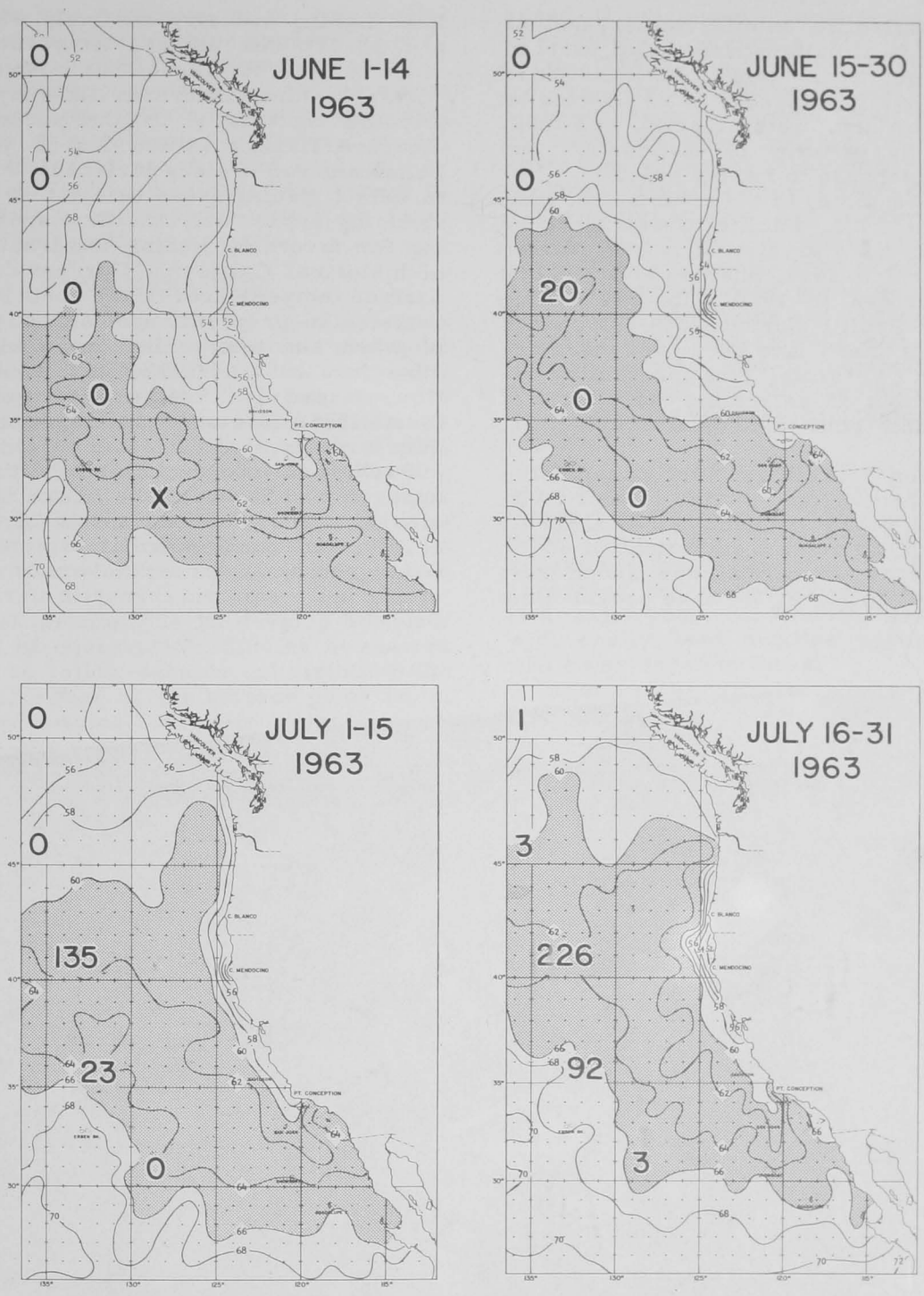
Temperate tuna research assembles life history and ecological knowledge of albacore and bluefin. Present research concentrates on tagging and analyzing bluefin population structure.

FORECASTING AND OCEANOGRAPHY

When, where, and in what numbers tunas will appear each year are major problems in all tuna fisheries. The difficult mandate of this program is to predict time of occurrence, areal distribution, and abundance of tuna resources in the eastern Pacific Ocean. Present efforts are concentrated on the temperate tunas, albacore and bluefin, because year-to-year fluctuations of these species have great



Schematic model of albacore movement off the Pacific coast, suggested by U.S. Navy radar picket vessel catches. Hatched arrow depicts the southern (early) component and stippled arrow depicts the northern (late) component of the population.



Albacore catch by U.S. Navy radar picket vessels in June-July 1963. Large numerals are catches at each station; small numerals indicate water temperature; shaded area delimits the 60^{o} to 66^{o} F. "optimum temperature zone" and "X" indicates station not fished during period.

impact on the small local boats in the fleet. An ocean information reporting service to local and high seas tuna vessels has been established to assist the fishing fleet. Day-to-day information received from the fleet is used in studies of short-term availability.

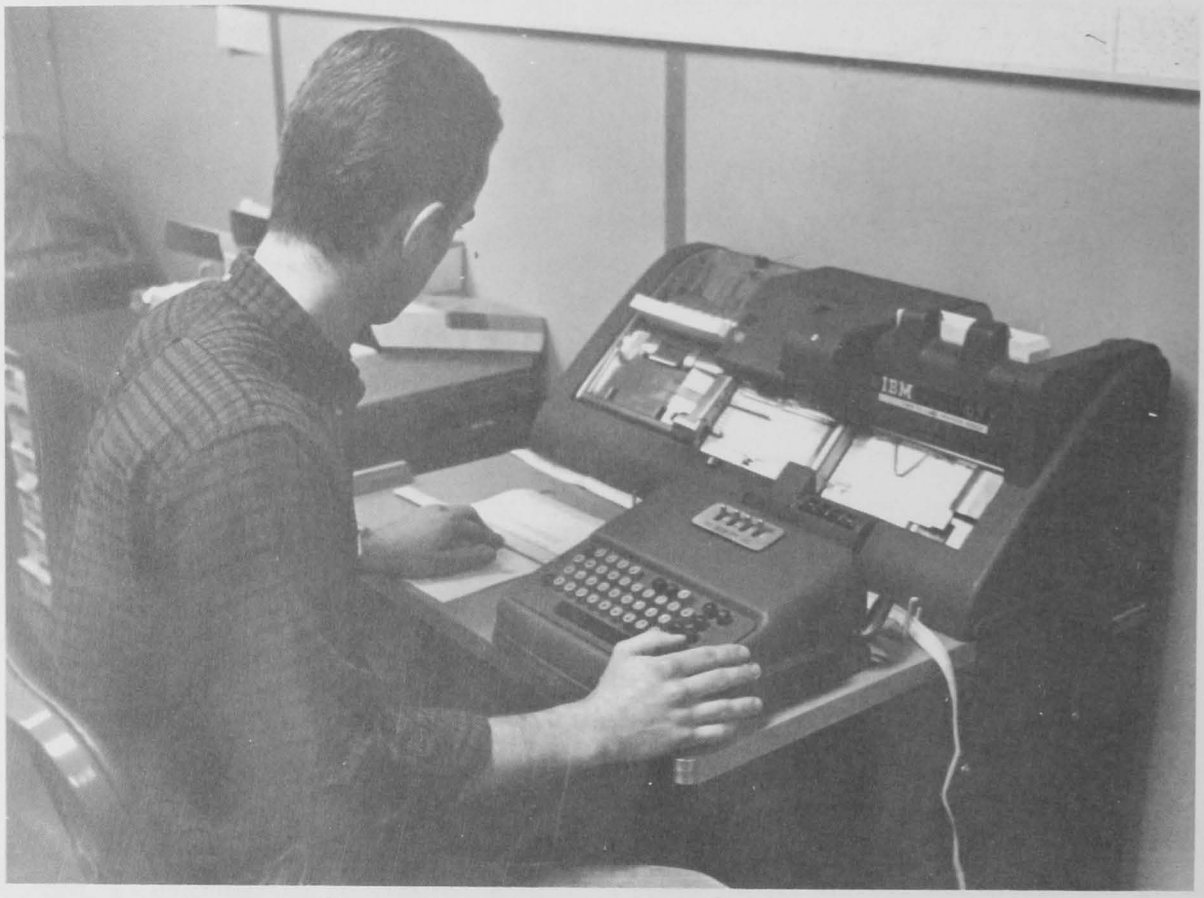
Fluctuation in availability is the major problem confronting the tuna industry. Each year variable numbers of albacore and bluefin occur in North American west coast waters during summer; at other seasons they are rare or absent. Even at the period of

maximum availability in midsummer, neither species occurs simultaneously in all parts of its known geographic range. Distribution is patchy. Catchability appears to be affected by water temperature, water clarity, and food, as well as by patterns of distribution and behavior in response to fishing gear.

Since the beginning of the commercial troll fishery about 1903, Pacific Coast albacore landings have been erratic; only one-quarter ton was landed in 1933, whereas about 36,000 tons were landed in 1950. Albacore fishing began in the Pacific Northwest in 1937; since then, landings there have been even more erratic than in California. Tuna forecasting research attempts to determine the effects of varying oceanic conditions on albacore availability.

The relation between sea surface temperatures and albacore distribution is well documented. More than two-thirds of the California domestic landings come from waters of 60° to 66° F., whereas virtually all are landed from waters of 58° to 70° F. We have provided the tuna fishing industry routinely with monthly and 15-day sea surface temperature charts since early 1960. These charts have been used widely by tuna fishermen and may have contributed materially to the success of the albacore fishery in the last 2 years. Now fishermen can use sea surface isotherm charts to select fishing areas before they put to sea, reducing appreciably the time spent in scouting for favorable fishing localities. Analyses of historical California Current data and sea surface temperatures of the north Pacific have assisted in preparation of annual predictions of when and where albacore would occur in June-July 1961-64. The fourth annual prediction, issued in 1964, proved successful in foretelling a late-starting season with reduced July landings.

Prediction of physical conditions in the upper mixed layer of the ocean is prerequisite to successful forecasting of tuna availability. Improved information reporting from fishing boats at sea and automatic processing of current ocean-wide synoptic marine weather



(Courtesy, G. M. Mattson.)

Teletype reperforator tape containing incoming marine synoptic weather reports is converted to ADP data cards automatically. Operator hand-punches data received from other sources. About 15,000 reports are processed each month for sea surface temperature charts.

observations are beginning to provide useful predictive data. The machine processing program now being used to produce periodic sea surface isotherm charts has been expanded to include air-sea interface heat budget data. These data are possible predictors of the anomalous rates of sea surface heat gain or loss in tuna fishing regions. We expect to use these data to estimate sea conditions from one to several months in advance.

TUNA BEHAVIOR

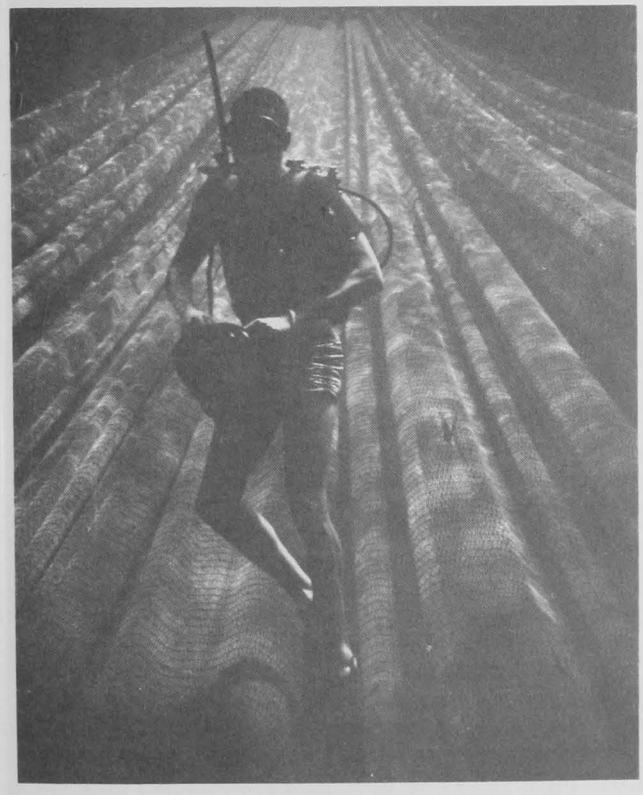
For years, the ingenuity of the fishermen has produced new fishing methods and gear modifications. But in this era of increasing fishing competition on the high seas the rate of improvement must be accelerated. To accomplish this we must increase our knowledge of the behavior of tunas; consequently, feeding responses, schooling, association with other animals and with inanimate objects, reactions to physical features of the environment, and visual acuity are of prime interest in this program.

The first problem is to develop adequate techniques of observation. Studies at sea are necessary to follow schools not visible to the human eye, either at the surface or at depth, to identify species, measure direction and speed of movement, numbers or weight, size of individuals, distance from the vessel, and depth. CTFM sonar systems are being tested for observing tuna behavior and to aid fishing. Much needs to be known about net avoidance by tuna and other pelagic fishes. We must study tuna schooling behavior to reveal characteristics that affect purse seine fishing.

Visibility studies use underwater photography performed by scuba divers and by personnel in small submarines. We have worked with standard purse seines under actual fishing conditions and experimentally with short nets so that azimuth and orientation to the observer can be controlled. Vertical movements of tuna will be determined with a sonic tag tracking system designed for this application.

Laboratory experiments on schooling behavior have concentrated on juveniles of fishes closely related to tunas, because tunas have been difficult to obtain and hold in aquariums near San Diego. Development of apparatus and perfection of study techniques is a major problem. When this is accomplished with easily held tunalike species, the work will be extended to tunas.

Other research includes behavior, taxonomy and life history studies of sharks and porpoises associated with tropical tunas, and analysis of data in tuna vessel logbooks, which reveal aspects of tuna behavior as encountered by fishermen.



(Courtesy, J. H. Taylor.)

Scuba diver inside a tuna purse seine with rings up at sea off Baja California. Net meshes are backlighted and viewed as they might appear to a tuna school.

TEMPERATE TUNA BIOLOGY

Albacore and bluefin, both temperate tunas, contribute substantially to the U.S. West Coast domestic landings. Although the regional fisheries for temperate tunas are located primarily in the California Current system, neither species is limited to it. These tunas are seasonal migrants into our coastal waters; apparently they spawn and spend much of their lives elsewhere. We know more about albacore than bluefin, but data are insufficient to permit more than a sketchy understanding of the distribution, availability, and abundance of the north Pacific stocks of either species. Preliminary information indicates that the population dynamics of these species involve ocean-wide problems with international implications.

Greater knowledge of albacore and bluefin is needed now to estimate maximum sustainable yields before the world high seas tuna catches exceed the productive capacity of these stocks. Consequently, adequate documentation of the temperate tuna fisheries must proceed in conjunction with assembly of basic data on population dynamics.

The main project in this program is the study of bluefin tuna migrations. The 1964 season marked the third year of joint bluefin tuna tagging with the California Department of Fish

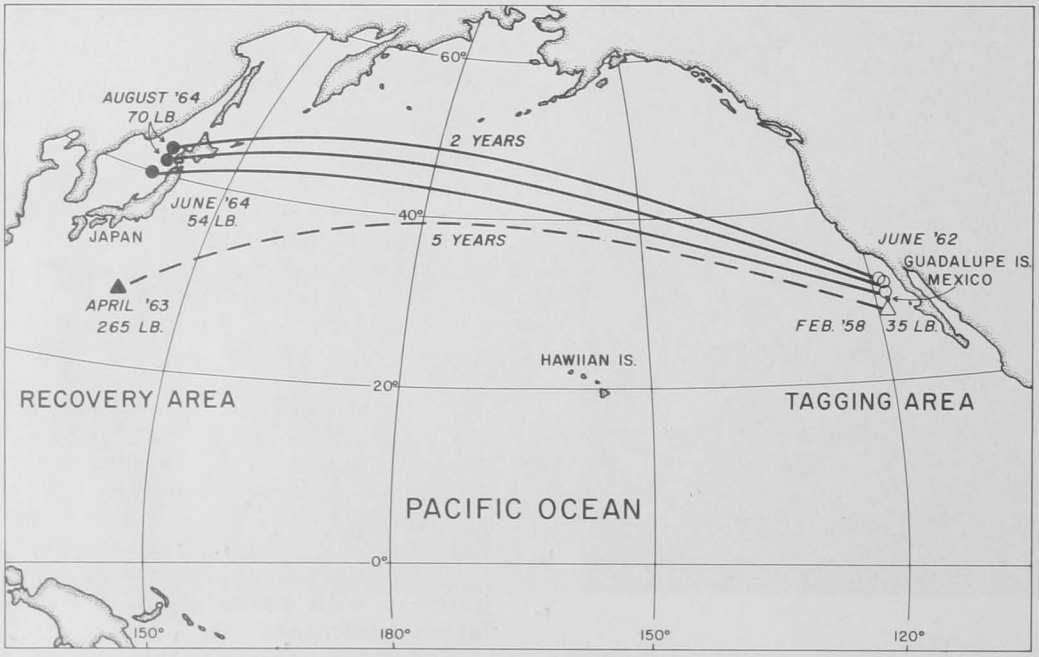
(Courtesy, G. A. Flittner.)

This tagged bluefin tuna, recovered in August 1964, had moved about 140 miles during 14 days at liberty.

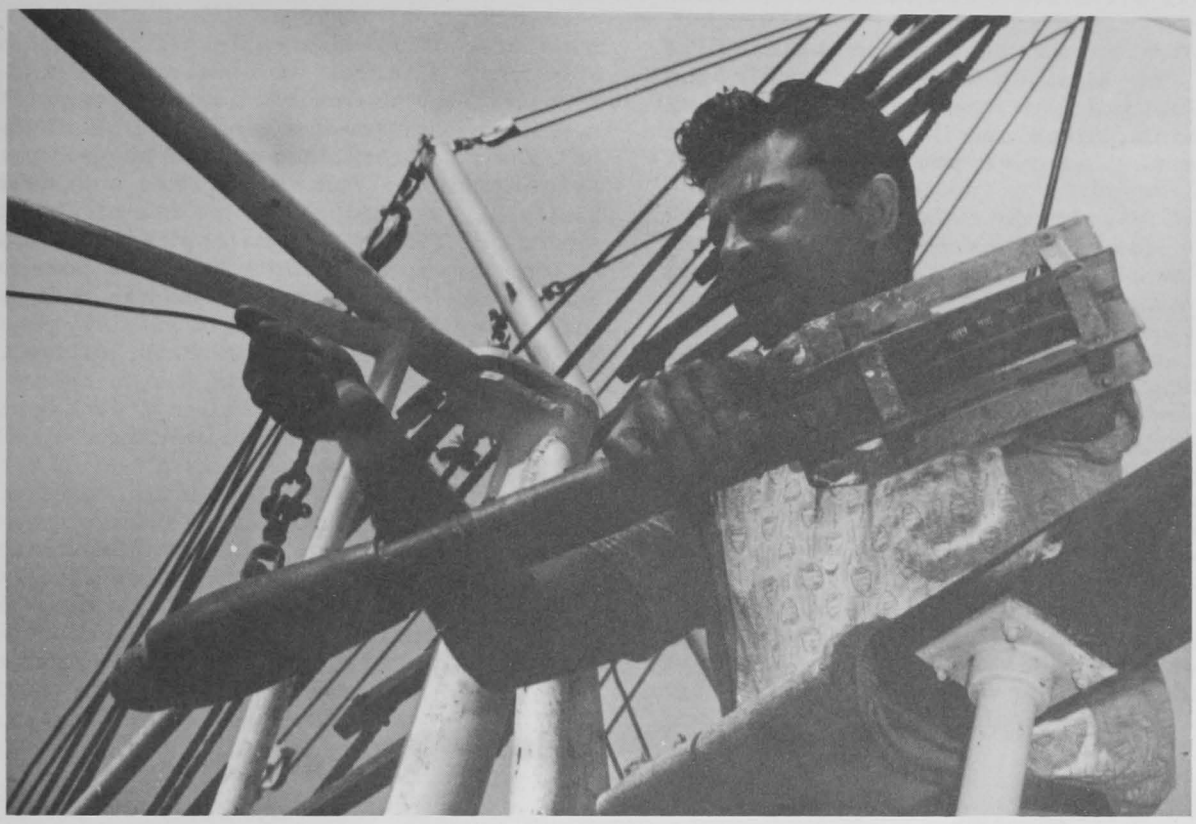
and Game. The project liberated 2,562 tagged fish through 1964. Recovery of 382 tags in 1962-64 confirmed earlier indications of the seasonal movement of the bluefin population along the Baja California-southern California coast.

The fishery begins in May and June in the Cape San Lazaro-Morgan Bank area and moves northward to southern California offshore waters in August and September. In September and October, offshore movement apparently occurs to the southwest of Guadalupe Island. The Guadalupe winter fishery is intermittent and appears to be affected by prevailing sea temperatures.

Three trans-Pacific tag recoveries were made in 1964. The first was 1 of 285 fish tagged and released on August 15, 1962, by our research team operating from the chartered purse seiner West Point 70 miles northeast of Guadalupe Island, Baja California. The tagged fish was recovered on June 18, 1964, 22 months later, in a Japanese fixed trapnet in the Sea of Japan. The fish had traveled at least 4,820 miles, growing from 23 pounds at time of tagging to 53 pounds at capture. The second trans-Pacific bluefin recovery, from the same release group mentioned above, was made 2 months later by a Japanese longline vessel on August 17, 1964, less than 30 miles from the first recovery. The third long-distance recovery was reported 11 days after the second by a Japanese live-bait vessel fishing in Tsugaru Channel between Honshu and Hokkaido. This fish was one of 16 tagged and liberated in the same area off Baja California 1 day later than the previous 2 fish.



Trans-Pacific movement of tagged bluefin tuna released off the Baja California-southern California coast, 1958-62.



(Courtesy, R. E. Green.)

First mate on tuna vessel Royal Pacific prepares to lower a bathythermograph in fishing area to obtain mixed layer temperature and rate of change with depth.

The 1962 releases yielded 172 recoveries (17.9 percent of the fish liberated).

Research will continue on population structure of bluefin and factors influencing its availability to California fishermen.

OPERATIONS RESEARCH

Operations research comprises several continuing projects to develop optimum fishing strategy for tuna fishing vessels. One completed study used information from various sources to estimate the cost of operating tuna purse seine vessels under various catch and effort conditions and market prices. These data permit us to determine optimum sizes of fishing vessels and percentage return on investment in particular fishing situations.

A continuing study of the possible relation of fishing success to the depth of the upper mixed layer and temperature gradient in the thermocline has required equipping several high seas tuna vessels with bathythermographs and winches. Cooperating vessels provide temperature data that are compared with catch success determined from logbook records.

CONTRACT RESEARCH

Tropical tuna oceanography in the eastern Pacific has been conducted through a continuing contract with the Institute of Marine Resources and Scripps Institution of Oceanography, University of California. (see Scripps Tuna Oceanography Research elsewhere in this circular).

Other contract research primarily develops instrumentation. Straza Industries studies sound reflection from fishes to determine the feasibility of using CTFM sonar in research and fishing. A contract with the Institute of Marine Resources for small inexpensive unmanned oceanographic station platforms has yielded encouraging results. A special assistance contract with the SIO Visibility Laboratory has provided valuable professional services in designing experiments to measure changes in underwater background brightness related to visibility of purse seines to tunas. Other contracts will be made as required.

SCRIPPS TUNA OCEANOGRAPHY RESEARCH

This program has been a component of the Institute of Marine Resources within the Scripps Institution of Oceanography, University of California, since July 1957. The Bureau of Commercial Fisheries provides most of its financial support, as well as space in the Fishery-Oceanography Center.

The program studies oceanography of the eastern tropical Pacific Ocean and adjacent waters, with special reference to properties, features, and processes affecting the distribution and abundance of yellowfin and skipjack tuna. Identifying, explaining, and forecasting the fishery-connected features of an ocean region involves fundamental study of most major features in the upper 3,000 feet. The work has three parts: environmental oceanographic studies, experimental field, and laboratory studies of primary productivity.

The first part involves studies of the distribution and relationships of properties and processes in the eastern tropical Pacific at large and in adjacent waters. Recent work includes a summary of physical upper ocean and weather data for the eastern tropical Pacific and north Pacific, with description and interpretation of mean monthly temperature structure, surface currents, and heat balance based on the combined data of several years. In conjunction, summaries are prepared of biological, optical, and some chemical upper-ocean data for the eastern tropical Pacific, with description and interpretation of horizontal and vertical distributions (data are inadequate for seasonal distributions) of primary productivity, chlorophyll a, zooplankton, diffuse light attenuation, nitrate, nitrite, and micronekton. In addition, theoretical studies are made on the conditions under which upwelling occurs in eastern tropical oceans.

The second part involves similar but more detailed studies of the distributions and relationships of properties and processes in special areas of the eastern tropical Pacific and adjacent waters where tunas usually school at certain seasons. Recent work includes explanation of changing horizontal seasonal distributions of yellowfin tuna in the Gulf of Tehauntepec, based on the observed succession

(Courtesy, G. M. Mattson.)

Experimental phytoplankton laboratory of the Scripps Tuna Oceanography Research program.

of changes in wind, current, density structure, and distribution of living organisms in the area. Investigations are in progress to provide a similar explanation of the distribution of yellowfin and skipjack in waters west and south of southern Baja California. Special studies, mainly in physical oceanography, are being made in the Peru Current, Costa Rica Dome, and the Cape San Lucas Front.

The work has another phase, which is separately identified because of its experimental component. Laboratory and field experiments are made to compare and analyze growth responses of cultures of tropical oceanic phytoplankton under various chemical and physical conditions that occur in the eastern tropical Pacific and adjacent waters. Recent work includes experimental evaluation of the method of measuring primary productivity by uptake of radioactive carbon, and summary of experiments on the growth responses of cultures of particular phytoplankton species to changes in temperature and light. Experiments with changes in chemical nutrients are continuing.

INTER-AMERICAN TROPICAL TUNA COMMISSION

The Inter-American Tropical Tuna Commission is an international fishery research organization that operates under the authority and direction of a Convention originally negotiated between the United States of America and the Republic of Costa Rica. The convention entered into force in 1950. It is open to adherence by other nations that participate in the fisheries covered by it. The Republic of Panama adhered in 1953, the Republic of Ecuador in 1961, and the United Mexican States in 1964. Other nations with interests in the area are considering adherence. All member governments contribute funds for operating the Commission according to a formula outlined in the Convention based on the amount of their tuna catch and use.

DUTIES

The principal duties of the Commission under the Convention are: 1) to study the biology, ecology and the population dynamics of the tunas and tuna-bait fishes of the eastern Pacific Ocean to establish how fishing affects the stocks, and 2) to recommend conservation and management measures to maintain the tuna stocks at a level that affords maximum sustainable catches, when Commission research demonstrates that such measures are necessary.

RESEARCH

Complete records of catch, effort, and landing statistics and their current analysis are basic to studying the dynamics of fish populations and the effects of fishing on them. These data, and data from vessel logbooks, are collected in all countries fishing in the area. This collection, compilation, and analysis uses about one third of the Commission's resources.

Investigation of life history, biology, population structure and vital statistics of tunas and

Porpoises such as these are often found in association with tropical tunas; fishermen scout for porpoise schools to find tunas.

(Courtesy, R. E. Green.)

baitfishes includes tagging live tunas (121,000 have been tagged and 12,000 recovered from 1955 to 1964), studies of age and growth, fecundity, spawning time, area sampling for size composition of tunas and tuna schools, and genetic research through serology.

Small changes in ocean weather and climate affect the distribution and availability of tunas. It is necessary, therefore to know the physical, chemical, and biological properties and seasonal variations of this environment. Commission scientists have participated in many oceanographic cruises with research organizations of the United States, Japan, Ecuador, Chile, and other countries in their area of interest. This participation assures that observations of specific interest to fisheries are included and that data for the complete cruises become available for fisheries interpretation.

Most of the tuna catches in years past and a fair portion of the tuna catches today are made using small forage fish for live bait. Comprehensive studies have been carried out on baitfish stocks from California to Ecuador to establish their abundance, distribution, and potential. These investigations are being continued on a reduced scale in areas where this type of fishing still dominates.

The results of Commission research to 1964 have been published by the Commission in 67 scientific Bulletins in both Spanish and English and in some 80 additional papers published in a variety of periodicals. These have been given worldwide distribution.

CONSERVATION RECOMMENDATIONS

With the recent arrival of new countries to fish in the eastern Pacific and the increasing efficiency through technological advances of existing fleets in the Americas, Tuna Commission research has shown that the yellowfin tuna stocks of this area have been overfished, specifically since 1960. This has not been shown for other important species of tuna. In keeping with its mandate, the Commission has recommended appropriate conservation measures on yellowfin tuna to Member Governments. It has not yet proved practical to implement these recommendations by all governments fishing substantially in the proposed regulatory area; but the Commission continues to monitor the condition of the stocks and to keep governments informed.

MARINE RESEARCH COMMITTEE

COORDINATION OF CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

The Marine Research Committee was established by the California Legislature in 1947. Its purpose is suggested in section 729 of the State Fish and Game Code, "...and financing research in the development of commercial fisheries of the Pacific Ocean and of marine products susceptible to being made available to the people of California."

The Committee has acted in the belief that resource utilization cannot be effective without understanding basic processes in the sea. Accordingly, it encouraged and sought financial support in the Legislature for a Scripps Institution of Oceanography program of physical, chemical, and biological oceanography in the California Current System, which led to the creation of the Marine Life Research Program.

The Bureau of Commercial Fisheries California Current Resources Laboratory also has been aided materially by grants of research funds to supplement Federal Funds, and by provision of public support for its work. For example, during negotiations between the University of California and the Federal Government for the new laboratory site, the Marine Research Committee, speaking for the people of California, indicated to the Regents that it was of the highest public interest to locate the laboratory on the San Diego campus so that close collaboration with University scientists could be maintained.

Similarly, the Committee has supported the Pelagic Fish Investigations of the California Department of Fish and Game and smaller research programs at the Hopkins Marine Station of Stanford University and the California Academy of Sciences.

The Committee's interest was particularly stimulated by the dramatic collapse of the California sardine fishery. This is still a central concern of the research programs of these diverse agencies, but the research has been broadened to include general investigation of all the pelagic plankton consumers. This has occurred mainly because the results of some of the programs, particularly the egg and larva surveys, showed that the sardine could not be considered independent of other pelagic fishes.

Although close collaboration has existed among the several laboratories from the inception of the Marine Research Committee, all felt the need for even closer coordination. This led to the formation of the California Cooperative Oceanic Fisheries Investigations Committee. The committee is comprised of a coordinator who reports to the MRC and one member from each of the three major

(Courtesy, Eva Ewing.)

Isaacs-Kidd midwater trawl fitted with plankton mesh, used by Marine Research Committee biologist in studies of catching efficiency for young stages of pelagic fishes.

agencies. The committee meets monthly, or as required, and serves as a communications link, and as a research policy and planning board. Recently, the CalCOFI Committee proposed a major ecological experiment--the controlled harvest of sardines and anchovies to determine whether the roles of the now-dominant anchovy and once-dominant sardine could be reversed. The proposal includes harvest schedules for the two species and provisions to safeguard both resources as well as specifying the research needed to understand and interpret the results of the experimental harvests. The proposal itself summarizes and highlights much of what has been learned. Its implementation would be a major step toward further understanding of the resources as well as establishing a basis for wise use of these resources by man.

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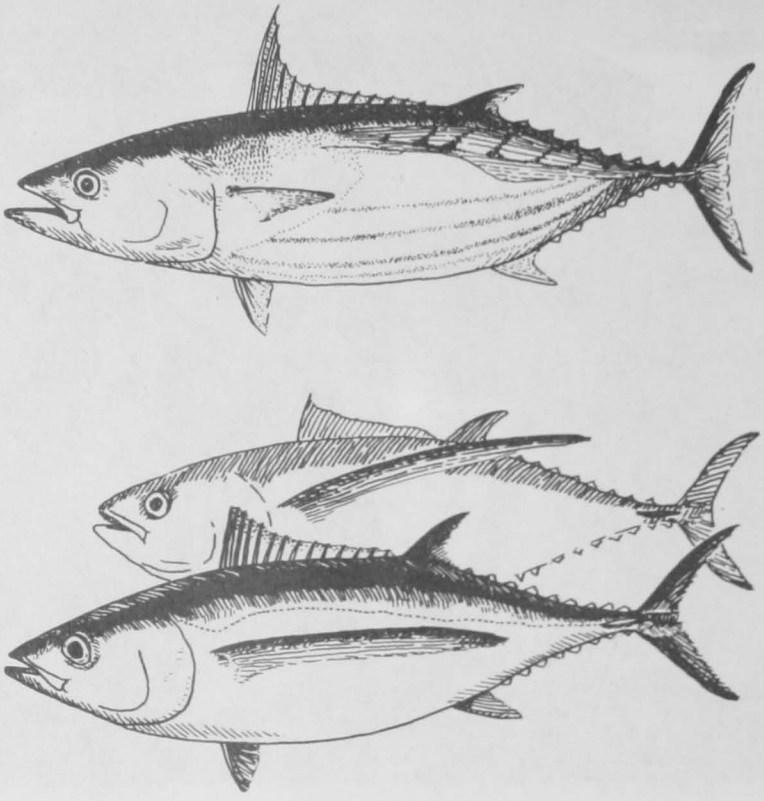

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