CALIFORNIA COOPERATIVE SARDINE RESEARCH PROGRAM
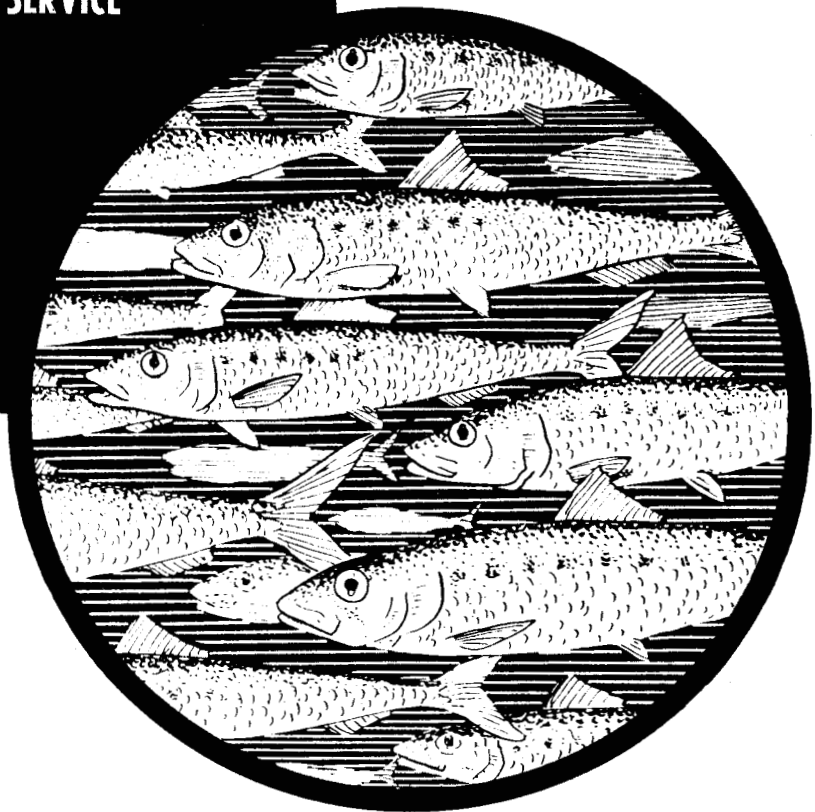
Progress Report 1950

By

CALIFORNIA ACADEMY OF SCIENCES
CALIFORNIA DIVISION OF FISH AND GAME
SCRIPPS INSTITUTION OF OCEANOGRAPHY
U. S. FISH AND WILDLIFE SERVICE

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
MARINE RESEARCH COMMITTEE

I

CALIFORNIA COOPERATIVE SARDINE

RESEARCH PROGRAM

Progress Report 1950

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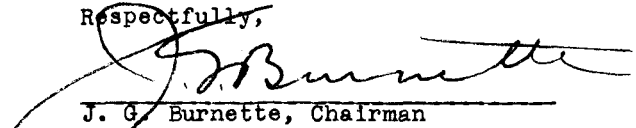
MARINE RESEARCH COMMITTEE

Pier 47, Foot of Jones Street
San Francisco 11, California
December 1, 1950

His Excellency Earl Warren
Governor of the State of California
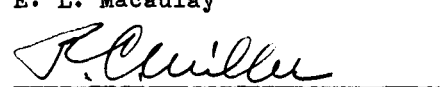Sacramento, California

Sir:

     Three years ago, when sardine landings had unaccount-
ably sunk to the lowest point in recent history, the State of
California embarked on a remarkable experiment in scientific
research. Under the sponsorship of the Marine Research Committee,
four agencies -- the California Academy of Sciences, the California
Division of Fish and Game, the University of California's Scripps
Institution of Oceanography, and the U. S. Fish and Wildlife Ser-
vice -- were asked to apply their resources and scientific skills
to the sardine problem. The scientists have been at work for al-
most three years; for the past two years they have conducted
oceanographic surveys off our coast that are unparalleled in scale.
In this paper they report their findings to date. We of the Com-
mittee feel their work deserves the attention of everyone interested
in preserving and better utilizing an incalculably valuable natural
resource.

Respectfully,

J. G. Burnette, Chairman

E. L. Macaulay

W. W. Ambrose

R. C. Miller

J. R. Biven

J. V. Morris

Harvey Hastain

D. T. Saxby

J. F. Janssen

Abstract

THE PROBLEM

In order to develop plans for the responsible management of the sardine resource and to attempt to derive workable methods of predicting where sardines will be found and in what quantities, it is imperative to know certain underlying principles which govern the sardine's behavior, availability, and total abundance. Work under the California Cooperative Sardine Research Program is aimed at determining those principles.

METHOD OF ATTACK

The four agencies participating in the program are investigating the Pacific sardine in relation to its physical and chemical environment, its food supply, its predators and its competitors, and attempting to evaluate the findings in terms of the survival of young and in terms of the distribution and availability of the sardines when they reach commercial size.

RECENT FINDINGS

The 1950 cruises have confirmed the 1949 finding that there are at present two centers of heavy sardine spawning off our coast. The first is in the vicinity of Cedros Island, off Baja California, and is relatively restricted in area; the second is off Southern California and northern Baja California. It covers the larger area; within it, though, spawning is more diffuse than near Cedros Island.

During the spring of 1950, surface temperatures were lower than they were in 1949, which may indicate more intense upwelling during the season.

The cruises for 1949 and 1950 have shown that most sardine spawning takes place within narrow temperature ranges. During the 1950 spawning season 98.4 percent of all sardine eggs sampled were taken in waters between 12.5° and 16°C. (54.5° and 60.8°F.).

Under laboratory conditions, sardines have been shown to exhibit predictable behavior patterns in the presence of electrical fields. Larger-scale studies of this subject are planned.

Length and age studies of the commercial catch show that during both the 1948-49 and 1949-50 seasons the major support of the fishery came from the 1946 and 1947 year classes. There are no indications as yet that the 1948 and 1949 year classes will appear an the fishing grounds in exceptional numbers. It is still too early to attempt to assess the 1950 year class. The 1946 and 1947 groups will presumably have to supply much of the tonnage taken in the next two or three years.

Studies of the mechanism of upwelling, a factor that may be of great importance in the sardine problem, have shown that spring and summer upwelling off Cape Mendocino and Point Conception can be correlated with weather conditions.

The first two full years of work under the program have brought the development of important new instruments for oceanographic research, the accumulation and partial analysis of a great mass of data on the offshore waters, the development and refinement of the techniques of collecting and processing the data.

PLANS FOR 1951

In the main, work under the California Cooperative Sardine Research Program will continue along the present lines during 1951. The seagoing work cannot as yet be curtailed or simplified without running the risk of failing to obtain information of basic importance. Any changes will be those dictated by the necessity of studying changing oceanographic and biological conditions. Both at sea and ashore, several new studies that promise to enlarge our understanding of the Pacific sardine will be pursued.

Contents

Illustrations

Introduction

Although the California Cooperative Sardine Research Program has now been under way for almost three years, few attempts have been made to review the work as a whole. Papers on separate phases have been published in the scientific journals (more are to come), and brief, condensed progress reports have been issued quarterly since early in 1949, but the present report is one of the first to try to present an over-all picture of the program. This we hope to do by telling how the work is done, what has been accomplished so far, and what in the way of research is planned for next year.

When the annual sardine conference was held this summer in La Jolla (it was the 15th such meeting, by the way; sardine research on the coast has a considerable history), three crowded days of discussion were needed to review the year's progress in the field. Yet the aim of all the work on the sardine can be stated quite briefly. It is:

To seek out the underlying principles that govern the Pacific sardine's behavior, availability, and total abundance.

(If those principles were known, it should be possible to forecast, within reasonable limits of accuracy and some months or years in advance, where sardines will be found and how many will be found.) Scientists are investigating the sardine in relation to its physical and chemical environment, its food supply, its predators and its competitors, and attempting to evaluate the findings in terms of the survival of the young and in terms of the distribution and availability of the sardines when they reach commercial size. The pursuit of these studies has occasionally led researchers into some fields that may seem, at first glance, to have little to do with sardines. Investigations have been undertaken that were impracticable a few years ago. But the integrating principle of them all is the patient quest for more knowledge of the Pacific sardine.

No great program of scientific research comes—to put it bluntly—out of a hat. Sardine studies are not new in California; that patient quest started many years ago. What the Marine Research Committee is sponsoring today is an expansion and acceleration of investigations which have been carried on for several decades. Those early studies laid the solid foundation of careful observation and long-considered theory upon which the present program has been built.

The early work had to be done; if it had not been done then, it would remain to be tackled today. Its existence meant that when the California Academy of Sciences, the California Division of Fish and Game, the University of California's Scripps Institution of Oceanography, and the U. S. Fish and Wildlife Service were called upon in 1947 to coordinate and intensify their sardine investigations they were able to get to work with little waste motion. They knew what they were after and the best way to get it.

Until the present program began, it was not possible to investigate adequately how the sardine is affected by its environment. Such an investigation is necessarily a long-term project, requiring the simultaneous employment of a number of vessels gathering data at sea. It has been approached at times by the Division of Fish and Game and the U. S. Fish and Wildlife Service. The Scripps Institution of Oceanography, a department of the University of California, entered sardine research some years ago by investigating oceanographic conditions in the spawning areas off Southern California. Scripps scientists cooperated in cruises on the Division of Fish and Game's vessel *Bluefin* in 1937, making oceanographic observations while the Division of Fish and Game personnel conducted drift-bottle experiments. The work with drift bottles and the analysis of the oceanographic data brought to light new knowledge on currents off Southern California. The Scripps Institution conducted a second cruise in 1938. From 1939 through 1941, when the outbreak of war in the Pacific stopped all nonmilitary oceanic investigations, the Scripps Institution and the U. S. Fish and Wildlife Service cooperated on further cruises in the spawning areas.

Although it is reasonable to suppose that changes in oceanographic conditions must profoundly affect sardine life, just how they do has never been very fully explained. As yet not much is known of the annual variations in the physical properties of the ocean. Scientists have not had enough information available on which to establish that immensely useful fiction, the "normal" year. For that, the data from many years of frequent survey cruises are needed.

Under the California Cooperative Sardine Research Program, those data are being accumulated. It was, in fact, the possibility that changing oceanographic conditions were mainly responsible for the decline in sardine landings that led to the establishment of the present program.

What might be called the oceanographic approach to the sardine problem is the feature which makes the present work unique; it has never been tried on such a scale before anywhere in the world. What—very briefly—the scientists hope to do is to correlate changes in water conditions with sardine spawning, availability, and abundance. The work on the sardine's environment is, beginning on page 23, described in detail. The efforts

made towards the correlation of oceanographic conditions with other factors are mentioned in other sections.

Only when a child is born, or when the census taker comes around, do most of us become even momentarily aware of the science of vital statistics. Yet one of the outstanding (and, scientifically speaking, one of the most exciting) achievements of our century has been the rapid growth and refinement of methods of studying populations—human and otherwise—by such means. The bulk of the classical work in fisheries research has been based on the painstaking collection and analysis of vital statistics. The best way to get vital statistics of fish is by sampling the commercial catch. In California, this work has been carried on continuously since 1919 by the Division of Fish and Game, assisted since 1941 by the U. S. Fish and Wildlife Service. This is continuing work. It cannot be allowed to lag. In the past some special studies have had to be dropped or conducted on a part-time basis because of the pressure of keeping up with the flood of current data. Expansion of the sardine program meant that people could be hired to cope with current material, leaving more experienced investigators free to concentrate on special aspects of the work. It meant too that previously planned studies could be undertaken. Some of these are described in this report, as are recent results of the continuing studies.

From sampling of the commercial catch come the statistics on the size and age distribution of the sardines. The Division of Fish and Game has accumulated almost half a million individual observations on the size of sardines. The ages are determined by a technique first successfully applied in sardine work by the U. S. Fish and Wildlife Service a few years before World War II. The size and age data form the basis for several other studies, some of which are discussed in this report.

Vital statistics on the birth rate can be gathered only on spawning surveys. The amount of spawning, the areas in which it occurs, the oceanographic factors that influence its comparative success or failure—information on all these topics is badly needed. The pre-war surveys did not cover all the areas then suspected and now known to be centers of intense spawning. One of the prime objectives of the present program is to gather more information on spawning. The U. S. Fish and Wildlife Service is doing the work. Beginning on page 37, the progress of the past two years, which is of wide interest both to scientists and the industry, is reported in detail.

One problem in sardine research—this a particularly tough and vitally important one—is availability, the determination of how many fish are where the fishing boats can get them. This problem is being attacked with statistical methods by scientists of the U. S. Fish and Wildlife Service and the Division of Fish and Game, and is being investigated in the field by Division of Fish and Game personnel aboard the *Yellowfin*. On page 44

will be found a review of what has been learned about the subject during the past two years.

Between the first month or two of life and the time the fish is caught there lies a period of the sardine's life of which next to nothing is known. Yet it should be possible to make a fairly good estimate of year-class strength at least some months in advance if enough schools of young fish are located and counted. This important work is being done by the Division of Fish and Game. The findings of the 1950 survey are summarized on pages 43-44.

If many periods of the sardine's life are little understood, one reason is the lack of factual knowledge of the individual sardine, its behavior and physiology. The California Academy of Sciences is working on behavior and physiological studies. On page 46, the results, which are very interesting ones, are described.

We have mentioned the main lines of attack on the sardine problem. It might be well to summarize:

(1) The California Division of Fish and Game is working on its continuing statistical studies, on young fish surveys, and on methods of locating and identifying sardine schools.

(2) The U. S. Fish and Wildlife Service is also working on the continuing studies, and on the spawning surveys and recruitment research.

(3) The Scripps Institution of Oceanography is working on oceanographic surveys, including studies of plankton and marine vertebrates.

(4) The California Academy of Sciences is working on behavior and physiological studies.

Fortunately, the division of work is not quite as rigid as, so summarized, it might appear. Oceanographic observations are made on all cruises of all ships; personnel from two or more agencies frequently work on specific projects together.

The sardine is a restless and far-traveling creature. When California, Canada, Washington, and Oregon were conducting tagging operations, large sardines tagged off Southern California in February were retaken off British Columbia in the following July. Fish tagged in Sebastian Viscaino Bay were found as far north as the Columbia River. The same experiments showed that sardines released off British Columbia were taken in Central and Southern California, and some fish released off Central California ended up in British Columbia, and others in Southern California. The fact is, the sardine respects neither state lines nor national boundaries. It is of interest not only to California but also to Washington, Oregon, and Canada, and they have for many years engaged in sardine research. Consequently the Fish Commission of Oregon, the Washington Department of Fisheries, and the Fisheries Research Board of Canada, though not participating directly, have shown keen interest in the present program.

The shape the sardine program has taken represents compromises among the various agencies. Getting it under way has taken much planning and hard work. Decisions on the main lines of research solved only the first of the questions posed. Ways of implementing the program had to be decided.

The spawning and oceanographic surveys demanded the participation of several ships if the area was to be covered frequently. The survey area is just over four times that of the State of California. About 140 stations were planned for each cruise. The U. S. Fish and Wildlife Service had no vessel available for such research until 1949. The *E. W. Scripps* was committed to carrying out other studies under way at the Scripps Institution, and the Division of Fish and Game's *N. B. Scofield* and *Yellowfin,* which had been just recently contracted for, were needed for special studies. New ships were a necessity. The *Crest* and *Horizon* were obtained by the Scripps Institution.

A second need was crews to man the ships and trained technical personnel to assist the scientific staff in the collection and processing of data. The shortage of trained technical personnel was especially acute. Ordinarily such work is done by the scientists themselves, with the aid of highly trained laboratory assistants. But there were neither enough scientists nor assistants available to carry on the work demanded by a program of this great scope. A training program had to be set up for newly recruited technical personnel.

The instruments ordinarily used in oceanographic research cannot be operated at the speed, and sometimes not with the precision, required by the present program. It was obvious that much attention would have to be paid to the development of instruments. Some of the most ingenious and potentially valuable work to come out of the program so far has originated in the workshops of the Scripps Institution, where there are being developed oceanographic instruments (page 18) which often do their work faster and better than any we have ever had before. Other agencies have also made useful contributions to the improvement of collecting gear.

As has been said, sardine research is not a new thing in California. But sardine research on the scale of the past two years is new not only in California but in the nation. Because it is new, and because the many practical problems of carrying out the work have been adroitly solved, the way the work is done seems worthy of description.

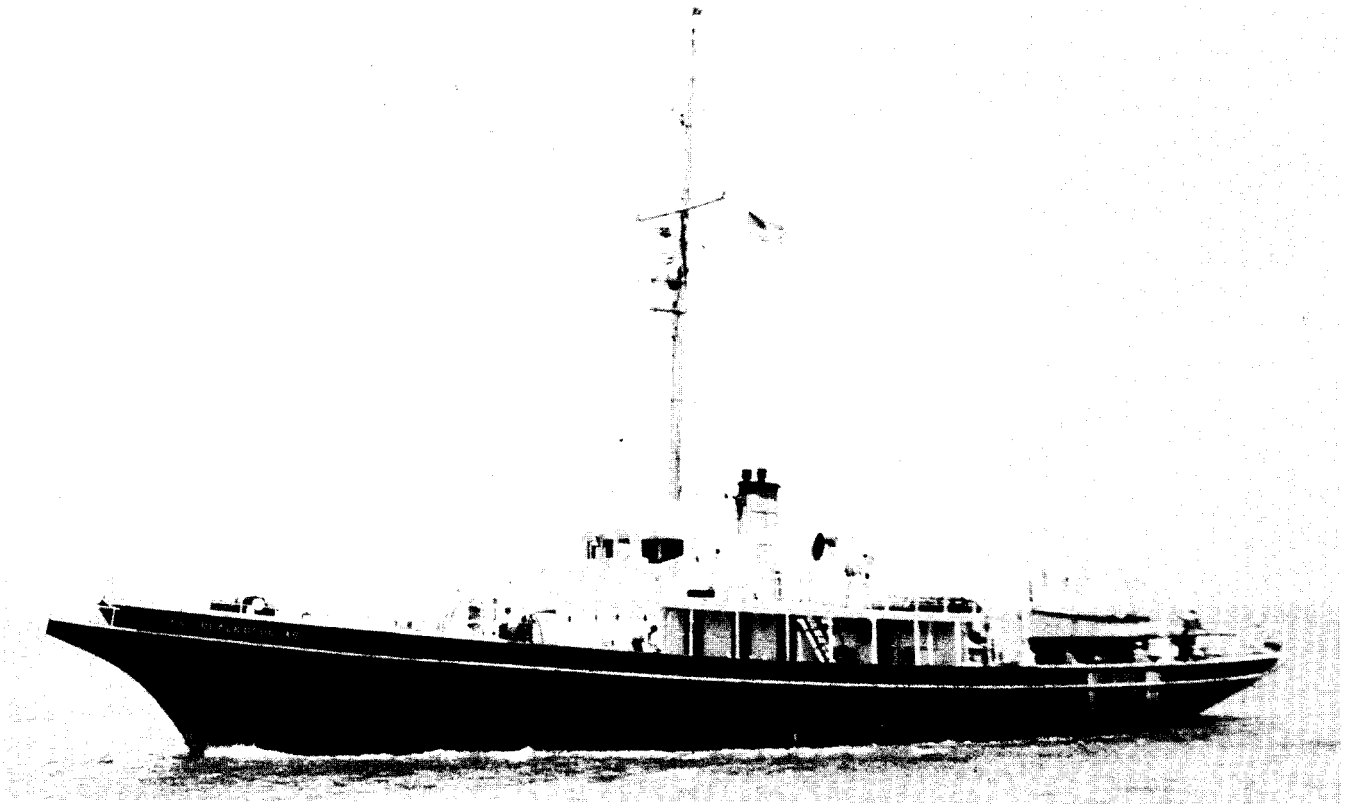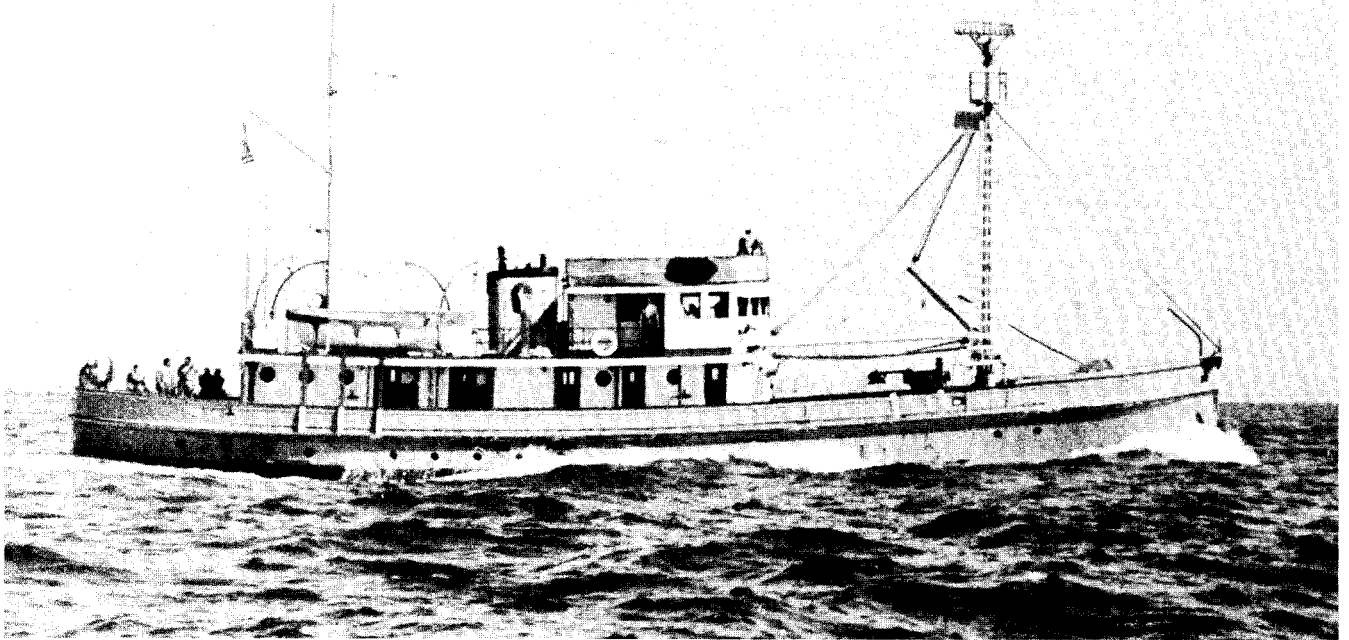FIGURE 1.   (UPPER) The *Yellowfin*, owned by the California Division of Fish and Game, is used for young-sardine surveys and in the collection of samples and oceanographic data from waters where schools containing sardines are present.   (LOWER) The *Black Douglas*, owned by the U. S. Fish and Wildlife Service, participates in routine oceanographic-biological surveys of the entire research area.

How the Work Is Done

THE SHIPS

Vessels belonging to three agencies regularly participate in the work at sea under the sardine research program. The ships are the *Yellowfin*, of the California Division of Fish and Game; the *Black Douglas*, of the U. S. Fish and Wildlife Service; and the *Crest* and *Horizon*, of the Scripps Institution of Oceanography. These four vessels are shown in Figures 1 and 2. The *N. B. Scofield*, of the California Division of Fish and Game, participated in some of the early cruises, and the Scripps Institution's *Paolina T* and *E. W. Scripps* occasionally have been used.

The *Yellowfin, Black Douglas, Crest*, and *Horizon* have all been acquired since the program began. They have been equipped as floating laboratories, the work being only partially done from sardine funds. Dimensions and speeds of the vessels are:

	Length (ft.)	Tonnage	Speed (knots)
Yellowfin	114	272 (gross)	10
Black Douglas	118	371 (gross)	9
Crest	136	320.27 (displacement)	10
Horizon	143	600 (displacement)	10

The cruises these ships make can be divided into three types:

(1) The routine oceanographic-biological survey cruises covering the entire area under investigation at approximately monthly intervals;

(2) Occasional cruises that are limited in scope and designed to further special studies being made under the program;

(3) Survey cruises made as part of the work on availability and young fish.

The last type of cruise is made only by the *Yellowfin*, which, as one of the research vessels of the California Division of Fish and Game, is available for sardine work during only part of the year. The other ships are available for both the routine cruises and those connected with special studies.

THE STATION PLAN

By far the bulk of the seagoing work consists of the occupation of the oceanographic stations—arbitrary geographic locations—which pattern the survey area. The region under survey covers approximately 670,000 square miles (Fig. 3). About 45 stations are occupied by each ship on each cruise. In density of observations, oceanography, the science of the sea, has a long way to go to catch up with the science of the air, meteorology. The area of the region surveyed is more than four times that of the State of California. The total number of stations occupied per cruise is about 140. There are 311 meteorological stations in the State of California.

The station plan now in use is a flexible one. Stations are added or dropped as the need arises. During the spawning season, for instance, several new stations are occupied in areas where spawning is most intense. However, since the whole point of the program is to gather oceanographic data by means of which average conditions in the sea can be determined, nearly the entire area is covered on almost every cruise.

The station plan was determined in this way: a line was drawn that roughly parallels the coast (true bearing 330 degrees) and the lines of stations were plotted at right angles to this base line. Most oceanographic features off the California coast, such as currents and temperature distribution, approximately parallel the coast. Having the grid oriented at right angles to the base (or coast) line allows better description than if it were along the lines of latitude and longitude. Under the system now in use (adopted early in 1950), the major station lines lie 120 miles apart and are numbered in multiples of 10. Lines can be spaced as closely as 12 miles apart and still have individual numbers. The plan also permits individual numbers to be given stations spaced only four miles apart. Most of the stations are 40 miles apart; they are numbered in multiples of 10. The numbering system would permit the survey area to be subdivided into many stations, each of which would represent an area 12 miles long by four miles wide. However, in the present plan most stations represent an area of either 40 by 40 miles or 40 by 120 miles. In referring to a station under the present plan, the line number is given, then a decimal point, then the station number. The scheme facilitates quick identification: station 120.60 is station 60 on line 120, for example.

The scheduling of new cruises is worked out at monthly meetings of representatives of the U. S. Fish and Wildlife Service and the Scripps Institution of Oceanography, and at less frequent meetings of representatives of these organizations with representatives of the California Division of Fish and Game. At these informal conferences it is decided which ships are to go where, who will be aboard each vessel, what stations will be occupied. Also at these conferences, the difficult problems of priorities are settled. They are difficult chiefly because everyone is interested in using the vessels during the same periods; when the sardines are spawning, oceanographic conditions are changing most rapidly and markedly. It must be decided whether a few stations off Northern California can be safely by-passed in the interest of adding a few more off Cedros
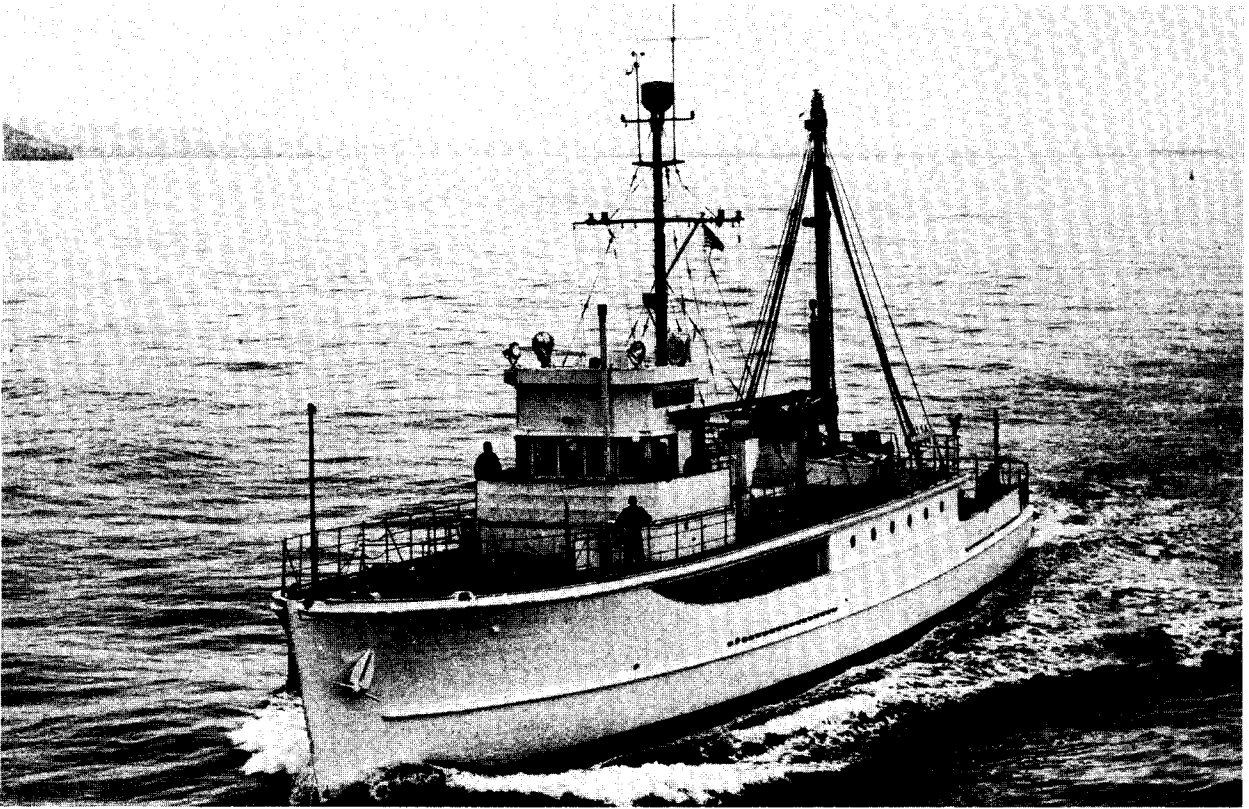
FIGURE 2. (UPPER) The *Crest*, owned by the University of California's Scripps Institution of Oceanography. (LOWER) The *Horizon*, also owned by the Scripps Institution of Oceanography. Both vessels participate in the routine survey cruises.

Island. Such decisions carry responsibility; data from those few stations off Northern California may later be badly needed to confirm variations in oceanographic conditions.

Each vessel carries a complement of scientists and marine technicians whose job it is to measure the ceaseless changes of the ocean. (Sometimes they are called upon for other sorts of work; in October, 1949, the *Black Douglas* came to the rescue of the survivors of a shipwreck off Northern California.)

COLLECTION OF DATA

"Oceanographic conditions" is a useful but rather vague phrase in which are lumped all the measurable characteristics of sea water. In any sample of water, scientists are particularly interested in the following:

(1) Temperature

(2) Salinity

(3) Amounts of dissolved oxygen and dissolved inorganic phosphorus present

(4) Transparency of the water

(5) Amounts and kind of living organisms present

Over the years instruments to get that information have slowly evolved. Some of them (trawls, for example) have been borrowed from fishermen. The search for one of the most useful instruments—a device that would entrap and allow bringing to the surface an uncontaminated sample of subsurface water—occupied scientific men for almost 300 years. It ended only in the first years of this century with the invention of the Nansen bottle, the instrument now most widely used for the purpose. When a station is occupied, a series of Nansen bottles is attached to the hydrographic wire and lowered from the ship (Figs. 4 and 5). At the desired moment, the first messenger, a small weight that slides down the wire, is let loose. It trips the first bottle and releases the next messenger. The bottles reverse and close tightly on the samples of sea water. Attached to the bottles are reversing thermometers which show the temperature at the moment of reversal.

Details of the work on station have been modified during the progress of the program, but the basic routine (which has been established by years of research in oceanography) remains unchanged. At each station, the following observations are made:

(1) Plankton tow to 75 meters. This is made with a nonclosing one-meter plankton net (Fig. 6). Fish eggs and larvae are collected in this way.

(2) Hydrographic cast to 1,200 meters (if possible) for temperature, salinity, oxygen, and phosphate data. Nansen bottles attached to the wire collect samples from 15 standard depths. The hydrographic cast takes almost an hour to complete.

(3) Bathythermograph observations. This instrument records water temperature to a depth of 137 meters (450 feet).

(4) Phytoplankton cast (again using Nansen bottles) to 70 meters.

In addition, all ships engage in dip-net fishing under a light at night, and note the occurrence and abundance of marine birds and marine mammals. Weather data are collected and transmitted to the U. S. Weather Bureau four times daily. Occasionally, deep plankton hauls are made.

As the vessel arrives on station, it is slowed; while it is losing way, the plankton net is readied and lowered into the water. The quantity of water strained during a haul is measured by a current meter fastened in the mouth of the net. The angle-of-stray of the towing wire is read at one-minute intervals during a haul. When the net tow is completed, the sample is removed, labeled, and preserved for analysis ashore. The vessel then swings into position for the hydrographic cast. The depth of the water is read from the fathometer and recorded. When the ship has lost way, the Nansen bottles and bathythermograph are attached to the hydrographic wire and lowered to an appropriate wire depth.

Four minutes are allowed after the Nansen bottles arrive down before releasing the messenger. The wire angle is measured with an inclinometer just after releasing the messenger. During the time between the cast's arriving down and starting up the weather and the state of the sea are observed and recorded. As the cast is raised, the bathythermograph and the Nansen bottles are removed from the wire. In the 15 minutes or so required for the thermometers to come into equilibrium with the air (both the air temperature and the sea temperature as recorded by the reversing thermometers are needed for computations of the true sea temperature), the phytoplankton cast is made. This completes the work on station. The entire process will be repeated at the next station, 40 miles away. Between stations, the temperatures at the 15 standard depths are read and recorded. Water samples are analyzed for their chemical constituents. Salinity (which is determined by means of chlorinity titrations) is determined ashore; the rest of the measurements are made at sea. A 250-milliliter sample from each depth is analyzed for dissolved oxygen; duplicate 100-milliliter samples for each depth are analyzed for dissolved inorganic phosphorus. During an average cruise (3 ships, 140 stations) the following number of analyses are run: 2,100 oxygen, 4,200 phosphate, and 4,200 chlorinity.

The ships keep in touch with the shore by means of radiotelephone, reporting regularly on the progress of the work.

PROCESSING OF DATA

The data collected by the techniques just described are subjected to considerable refinement. The processing of the mass of original data comprises a full-time job for 20 employees at the Scripps Institution of Oceanography and 15 employees of the U. S. Fish and Wildlife Service. Still more workers are needed. The
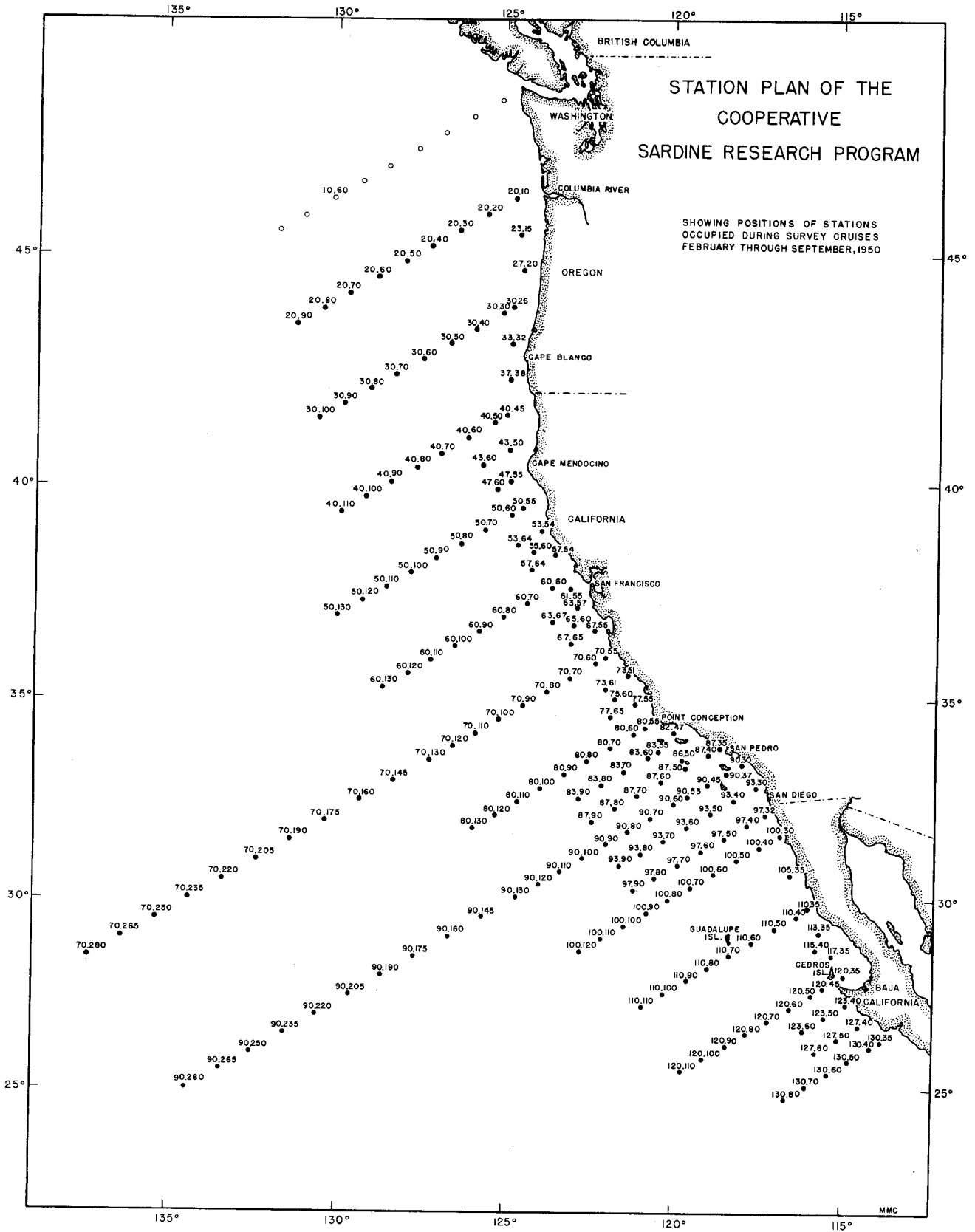
FIGURE 3. Present station plan of the California Cooperative Sardine Research Program. The numbering system, adopted early in 1950, is planned so that the station lines are 120 miles apart, individual stations 40 miles apart. Extra stations have been added in regions of particular interest in sardine work (note density of station network off Southern California).

FIGURE 5. The Nansen bottle. (UPPER) Attaching the bottle to the hydrographic wire. (LOWER) Attaching the messenger. The perforated shield encloses the three thermometers used. When a messenger strikes the tripping mechanism at the top, the bottle reverses and closes on a sample of sea water, and the messenger at the other end of the bottle is freed to slide down the wire and trip the next bottle.

DEPTH (METERS)

100
200
300
400
500
600
700
800
900
1000
1100
1200

NANSEN BOTTLE
BT
MESSENGER
WEIGHT
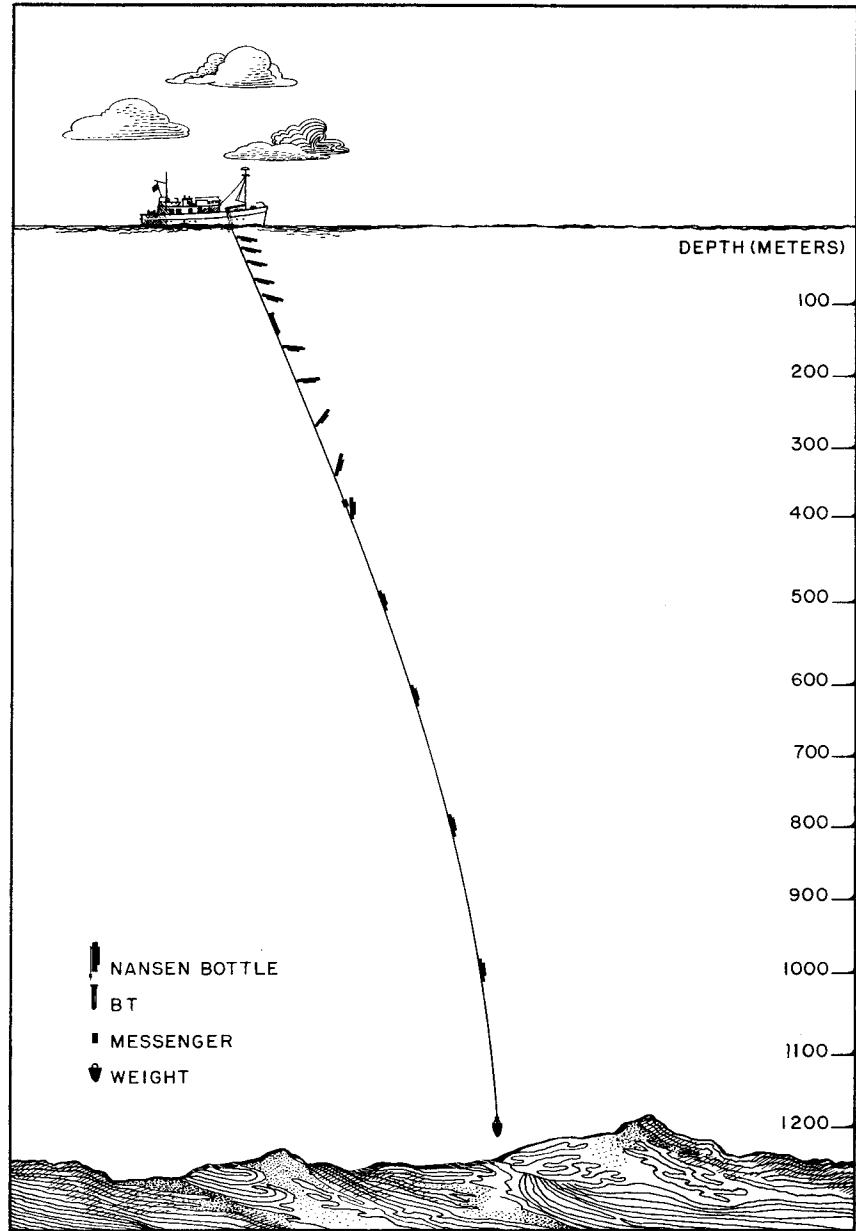
FIGURE 4. The hydrographic cast. Water samples are taken as nearly as possible from specified standard depths by means of Nansen bottles. The bathythermograph provides a continuous trace of temperature to 137 meters (450 feet). The bottles are more closely spaced near the surface because oceanographic conditions are more variable there. Making the hydrographic cast takes approximately one hour.
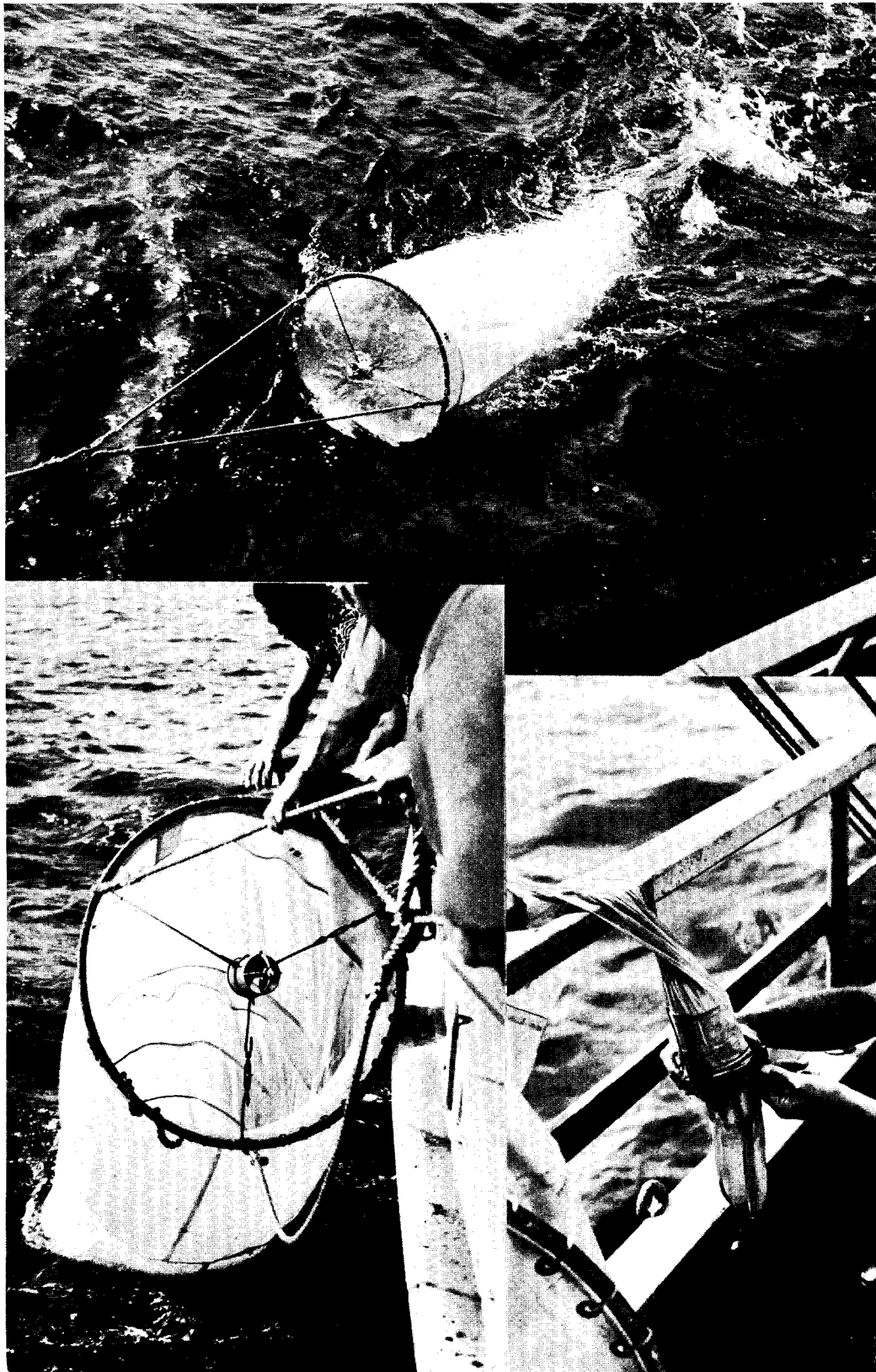
FIGURE 6.   Plankton tow, using the one-meter net. As the vessel arrives on station, it is slowed; while it is losing way, the plankton net is readied and lowered into the water. The quantity of water strained during a haul is measured by the current meter fastened in the mouth of the net. When the net tow is completed, the sample, which is collected in the removable cod end (lower right) is removed, labeled, and preserved for analysis ashore.

ORIGINAL OCEANOGRAPHIC DATA

SCRIPPS INSTITUTION OF OCEANOGRAPHY   UNIVERSITY OF CALIFORNIA

PROCESSED OCEANOGRAPHIC DATA

SCRIPPS INSTITUTION OF OCEANOGRAPHY   UNIVERSITY OF CALIFORNIA

FIGURE 7. Two of the forms used in working up oceanographic data obtained on the sardine cruises. (UPPER) The original oceanographic data noted at a single station. Location, time, weather, state of sea, and depth as shown by fathometer are among the items entered. (LOWER) The processed data. Still more computations are needed, however, before the data are in their final form. Approximately 2,200 stations have been occupied since the program began; the collection and processing of the oceanographic data alone require the services of 20 full-time employees.

collection and compilation of such data forms the core of the sardine research program. Two of the forms used for original and processed oceanographic data are shown in Figure 7.

Eventually the oceanographic data from the cruises will be published in permanent form. Plans for the publication of the 1949 material are under way. Meanwhile, the results of each cruise are for convenience being mimeographed and distributed to those working on the program.

INSTRUMENTATION

During the past two years, some of the most intensive and fruitful work under the sardine research program has gone into the development and testing of a group of new instruments designed to improve methods of obtaining biological samples. This work has been done at the Scripps Institution of Oceanography.

Midwater Trawl

One of the problems of the complete investigation of any fishery is the adequate sampling of the adults of the species. Most of the data on the adults of the species from the sardine research program have come from commercial catches or from special vessels utilizing what is essentially commercial gear. The floating fish-larvae trap has to some extent approached the problem of adequately sampling the older forms of sardines, but is able to take only larvae and small juveniles. A new approach has been attempted on this problem by the development of a midwater trawl. This is a net of about the dimensions of ordinary otter bottom trawls but with a mouth made considerably higher in order to capture fishes not ordinarily found near the bottom.

Tests on a preliminary model of such a net have been extremely encouraging. A net designed on radically different principles, 10 feet wide across the mouth, 12 feet high, and about 35 feet long, has been developed. The mouth is kept open by a special beam which also acts as a depressor. The instability inherent in such a design is corrected by a small piloting depressor attached below this beam. One of the 43-pound homogeneous depressors has been used with success as the pilot. This comparatively large net has been towed at relatively high speeds and great depths. At a towing speed of about four knots a depth of 1,500 fathoms (about a mile and a half), was reached, and several heretofore unreported deep-sea forms of fishes were captured. The net has also been towed at about 60 meters depth at a speed of six knots. Fish as active as
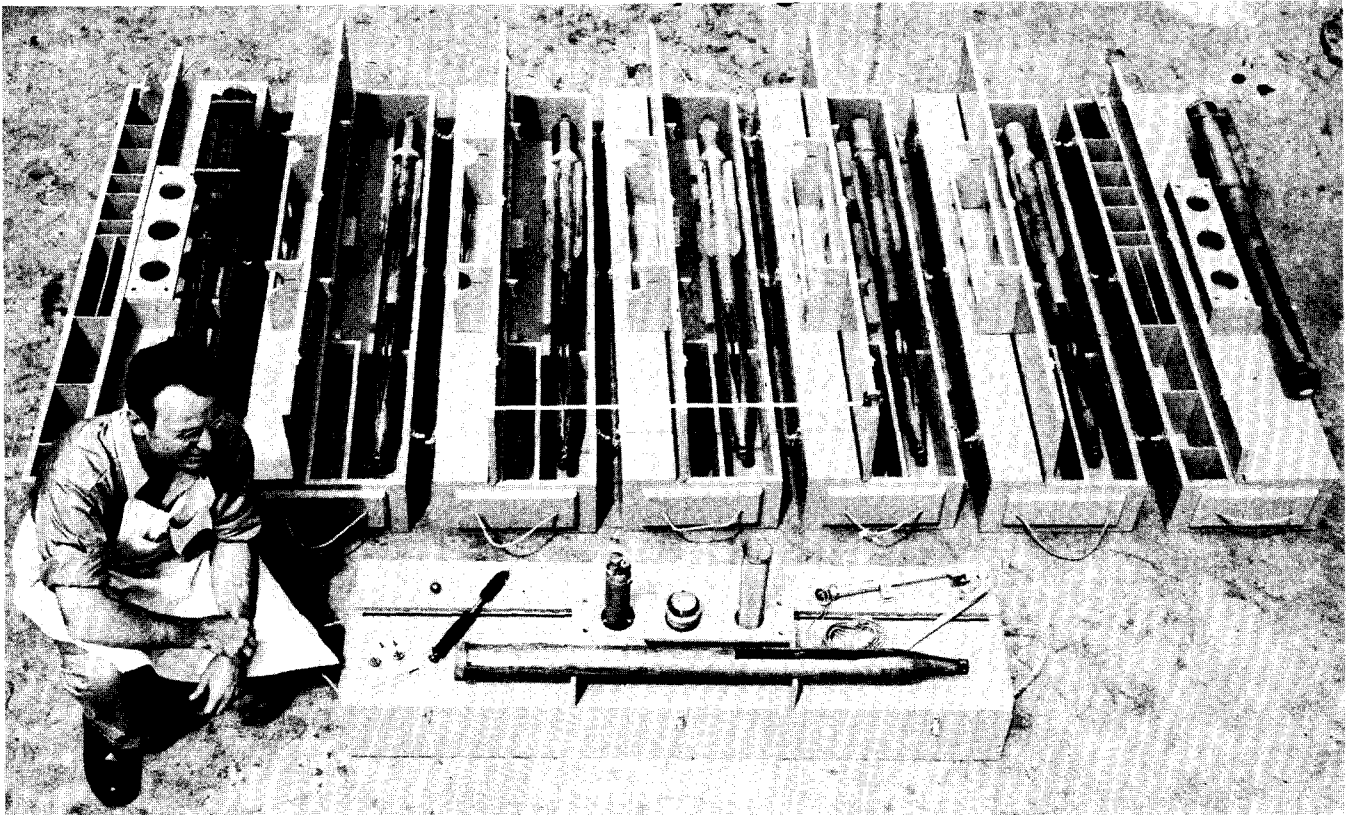
FIGURE 8. The plankton collector was developed as part of the sardine research program. Eight are shown here. The collector was designed to allow high-speed sampling. With the collector in the lower part of the picture are shown (at left and right) devices used in two methods of attaching the collector to the cable: at the left are a stainless steel ball and Allenhead screws; at the right equipment by means of which a ball made of an alloy of low melting point can be cast directly on the cable. It is melted off after use. In the center are (left to right) the recorder and bellows, propeller assembly, and collecting net. The collector at the upper right is a specially designed adaptation for low-speed work.

or more active than sardines have been captured in these few shallow tows but no adult sardines have been caught. Further tests will be made where sardines are known to be present. A larger net approximately 17 feet across the mouth and 50 feet long has been constructed, and will soon be tested at sea.

There is apparently no limitation on the size of this type of net other than the ability of the gear aboard the vessel to handle it. It is believed that a 25-foot net could be handled aboard the *Horizon,* and with the installation of special booms, nets up to perhaps 50 feet could be handled. Such nets become rapidly heavier and more unwieldy as their size is increased. To date all tows of this net have been made for the purpose of determining its hydrodynamic characteristics and ascertaining the types of fish which it can capture.

High-speed Gear

The small nets conventionally used for the collection of animal plankton have several disadvantages. One of the more serious is of course their slowness of operation. Making a net tow means that the vessel must greatly decrease its speed. Now an instrument has been developed which, although not replacing (and not intended to replace) the plankton net, allows plankton tows to be made while the ship is under way. The instrument is the high-speed plankton collector (Fig. 8). The U. S. Fish and Wildlife Service has cooperated in its development.

When a net is used to collect plankton, probably it works an area where some of the fish larvae and other nektonic creatures have been disturbed by the passage of the cable. Thus, a consideration in the design of the new collector was to have the fishing end somewhat ahead of the cable on which the collector was operated. The collector has been so constructed that it can be mounted on the cable by means of a special spherical cable clamp; this allows the cable to pass through the collector at its forward third point. The actual fishing is done some 12 or 14 inches ahead of the point of attachment.

A separable depth-flow meter is used with the collector. (Although designed primarily for that use, the depth-flow meter has a general application to all problems in which depth and distance hauled need to be known.) A continuous record is made of the depth of the meter and the flow of water past it. The fundamental components of the meter may be divided into (1) an impeller and gear train, (2) a pressure element and stylus, and (3) a recording spool and tape guides. Thirty-five-millimeter clear acetate film is used for recording tape.

The spherical cable attachment designed specifically for use with the high-speed plankton collector is also likely to have much wider applications. It was felt necessary to design such a clamp so as to permit freedom of the attached instrument with respect to the cable. Such an arrangement permits the cable to spin as loads are applied and prevents the instruments from being twisted about. The clamp, which is made of bronze, consists of two hemispheres held together by Allen-head screws.

The high-speed plankton collectors were tested on the May cruise of 1950. Four collectors were attached to a single cable, giving a simultaneous record of the distribution of plankton at several depths. The four collectors were towed about 600 miles during this cruise.

Simultaneously with the development of the high-speed collectors, it was necessary to find a method to keep the cable and collectors under the surface while they were being towed. When a ship at full speed tows an object, the forces impelling that object to the surface become enormous. The search for a device to bring about a suitable depressing force was concluded with the development of the new homogeneous depressor (Fig. 9).
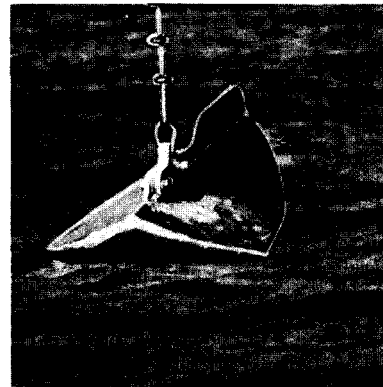
FIGURE 9. Although designed specifically for use with the high-speed plankton collector, the homegeneous depressor promises to have far wider applications in the field of oceanography. Cast of bronze, the 43-pound depressor exerts a 750-pound depressing force at 10 knots. The depressor is inexpensive, and can be made in sizes that depend upon the work to be done.

The depressor is cast from bronze. It is specifically designed so that (1) gravity orientation can be obtained with the use of a single material, and (2) the flow pattern is fixed over a large range of speeds. This permits balancing in air, eliminates the unbalancing effect of permeation by water, and permits operation at various speeds. It can be cast in several sizes, depending on the job that has to be done. A 43-pound depressor exerts a 750-pound depressing force at 10 knots. A depth of 50 meters can be obtained at that speed with $\frac{1}{4}$-inch cable. A depth of 100 meters can be attained with $\frac{5}{32}$-inch wire. The depressor is cheap; the 43-pound size should cost no more than $25 if commercially produced. The depressor has been towed at 25 knots by a destroyer without instability. It then developed a 3,000-pound depressing force.

A simple inexpensive hydraulic dynamometer has been designed for use on the cables towing depressors. This easily read indicator of cable stress is a necessity when towing plankton collectors at high speeds.

This new depressor is regarded by scientists working on the program as one of the significant recent technological advances in the science of oceanography. Apparently it is going to permit the development and use of hitherto impracticable scientific instruments, and will thus offer the opportunity for gaining important new knowledge about the ocean.

Floating Fish-larvae Trap

Another invention developed under the sardine research program is the floating fish-larvae trap (Fig. 10).
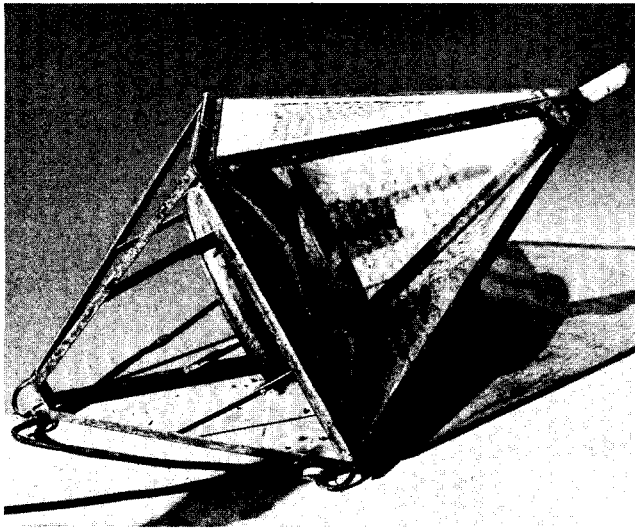
FIGURE 10. The floating fish-larvae trap is used when the ship is anchored at night. Attracted by the electric light, larval and postlarval fish enter the trap through conical holes, pointed inward, in the wire mesh sides. Flaps at the top collect fish swimming just beneath the sea surface.

Customarily fish larvae and young fish are sampled by collection with a dip net. The larvae and young are attracted by a light hung over the side of the ship at night and dipped up in the net. The floating fish-larvae trap promises to do this work more effectively. It should collect quantitative samples of the larval and postlarval forms of sardines, other surface fish, and surface invertebrates. In form, the trap is an inverted pyramid of wire mesh. The sides are pierced by a number of small conical holes. The cones have a base diameter of $1\frac{1}{4}$ inches and are directed inward $1\frac{1}{4}$ inches, terminating in a $\frac{1}{4}$-inch hole. The trap contains a float, beneath which is an electric light which attracts the fish. The trap rests with the flat base of the pyramid on or just below the surface of the water. At the surface are flap valves which seem to collect forms swimming close to the surface film. Tests have shown that the trap collects larval and postlarval fish far more efficiently than does a dip net.

Plankton-sample Splitter

The plastic plankton-sample splitter (Fig. 11) is used in the work ashore. It has been constructed to obtain aliquot divisions of a sample of plankton too bulky to handle by ordinary methods. It is in regular use in the recruitment studies.

Chlorinity Titrator

One of the immediate products of an oceanographic cruise is a large number of bottles filled with sea water, the salt content of which must be determined. In order to run these determinations more rapidly and more accurately than can be done by traditional methods, the automatic chlorinity titrator is being developed. This instrument carries out automatically a potentiometric titration of halides with silver nitrate solution, the end point being indicated by the difference in potential between a silver-silver chloride electrode in the titration vessel and a reference silver-silver ion electrode. When the titrator is in use, the operator has merely to place a sample of sea water in the titration vessel, push the appropriate buttons, and, in a few minutes, record the chlorinity.

ASOP

In the past most shipboard colorimetric analyses had been carried out with visual colorimetric instruments. Although development of the photoelectric cell has permitted the design of much more sensitive and accurate colorimeters, most instruments available commercially are ill-suited to the rigors of shipboard use.
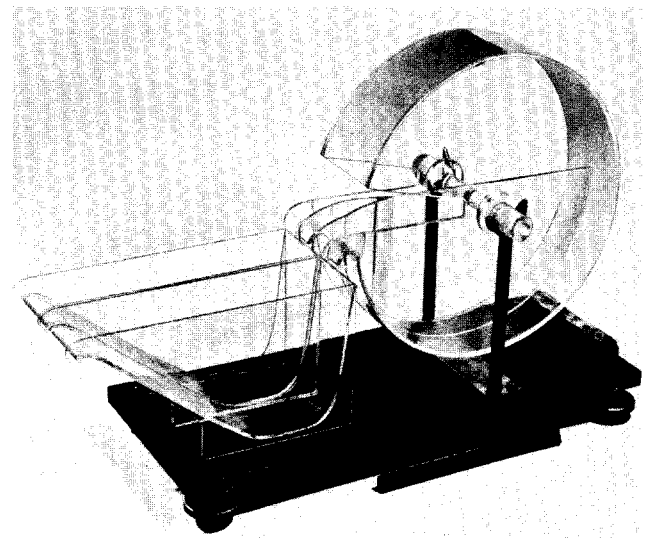
FIGURE 11.   The plastic plankton-sample splitter. This instrument was constructed to obtain aliquot divisions of a sample of plankton too bulky to handle by ordinary methods. It is in regular use in the recruitment studies.

In order that colorimetric determinations of nutrients such as phosphate could be carried out as a matter of routine, it was necessary to develop a rugged seagoing instrument.

ASOP (automatic servo-operated photometer) is a double photocell instrument, in which the electrical unbalance between the two photocells is used to control a servo-motor. This in turn drives a slide wire in the proper direction to eliminate the unbalance. Essentially monochromatic light is used, resulting from a projection bulb and interference-type filters. After the instrument is balanced initially, one has only to introduce the sample and read off its transmittance.

Other Projects

The work ashore and at sea has required the frequent development and modification of equipment. Some of the other projects undertaken at the Scripps Institution include the development of shipboard filters; the production of stainless steel graduates, filter flasks and other laboratory equipment for seagoing use; the design of automatic reagent dispensers (Fig. 12) for rapid metering of small fixed fluid volumes of chemicals; the construction of equipment for the calibration of reversing thermometers; development of a slow-speed microscope stage drive; design of a non-metallic pump for the collection of uncontaminated water samples; the very successful modification of a centrifuge for use in chlorophyll analysis; design and testing of a wire drum and sheave to handle piano wire, by means of which it is hoped to reach depths of more than 200 fathoms at a speed of 10 knots; development of a deck-recording surface thermometer of great sensitivity.

Many of these devices are to be protected for scientific work by patent applications.

U. S. Fish and Wildlife Service personnel have devised an angle-of-stray indicator (Fig. 13) which consists essentially of a steel ball damped in mineral oil in a curved glass tube which is mounted on a large protractor. The instrument is suspended from the towing wire during net hauls, and provides a continuous record of the wire angle, knowledge of which is necessary in making the haul and in estimating the depths at which the net fished. A similar device has also been developed at the Scripps Institution of Oceanography.
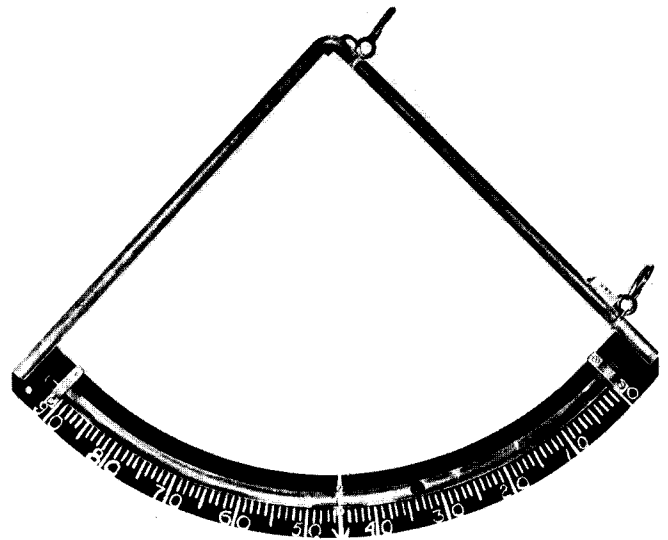
FIGURE 13. Angle-of-stray indicator. When suspended from the towing wire during net hauls, the instrument provides a continuous record of the wire angle.
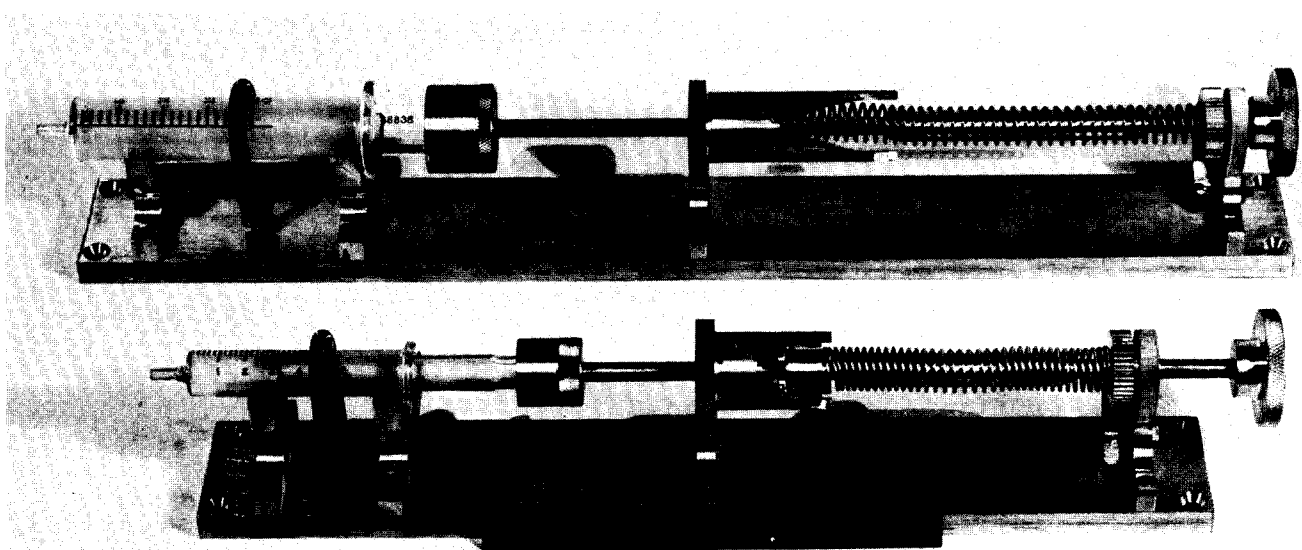
FIGURE 12.   By the use of the automatic reagent dispensers, small volumes of reagents are rapidly and accurately metered by the oil displaced by the assembly. These are for laboratory use ashore and at sea.

U. S. Fish and Wildlife Service personnel have devised a wire clamp (Fig. 14) consisting of two hinged members which are clamped over the wire by means
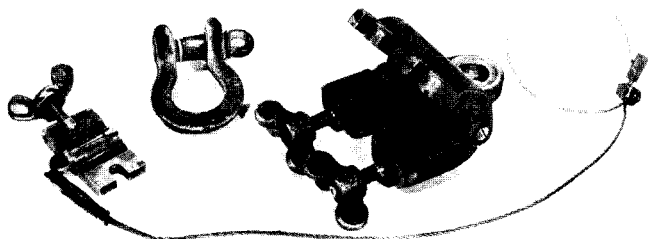
FIGURE 14.   Wire clamp. A small size is used as a safety clamp for Nansen bottles, a larger size as a wire clamp for plankton nets.

of toggle bolts and butterfly nuts. A small size is used as a safety clamp for Nansen bottles, a larger size as a wire clamp for plankton nets.

Use of Soundings to Locate Sardine Schools

One important aspect of the work on instruments in the sardine research program has been the California Division of Fish and Game's testing of sonic methods for the location of fish schools. This work is now a standard technique aboard the *Yellowfin*. The vessel is equipped with a Navy surplus sonar (echo-ranging) device and with a recording echo-sounder. The work aboard the *Yellowfin* has shown:

(1) The sonar equipment installed aboard the vessel is practical for locating schools of fish up to a range of 800 yards from the vessel.

(2) The sonar equipment installed aboard the vessel is not practical for locating schools of fish in water of depths of less than 50 fathoms. The transmission angle of the projector permits return from the bottom at short ranges in shallow water, masking out any schools of fish which might be present.

(3) The recording echo-sounder installed aboard the vessel is practical for locating schools directly underneath the vessel, and for determining the vertical distribution of these schools (Fig. 15), but not for identifying their composition. As yet species of similar size and schooling habit cannot be separated by the trace on the recording echo-sounder.

The equipment aboard the *Yellowfin* is bulky, expensive, and requires the services of a trained operator. Its experimental value is considerable, but commercial exploitation is regarded, at least at present, as scarcely justified.

The methods of echo-sounding and echo-ranging are similar to those developed by the Navy for locating submarines. The sonar head is not used for active scanning; it is left at 45 degrees on either bow. When an indication of the presence of a school of fish appears, the head is rotated and the vessel maneuvered to come directly over the school. When the school appears as a trace on the recording echo-sounder, a small explosive charge is dropped and samples are collected. The method is used only as a supplement to visual location.
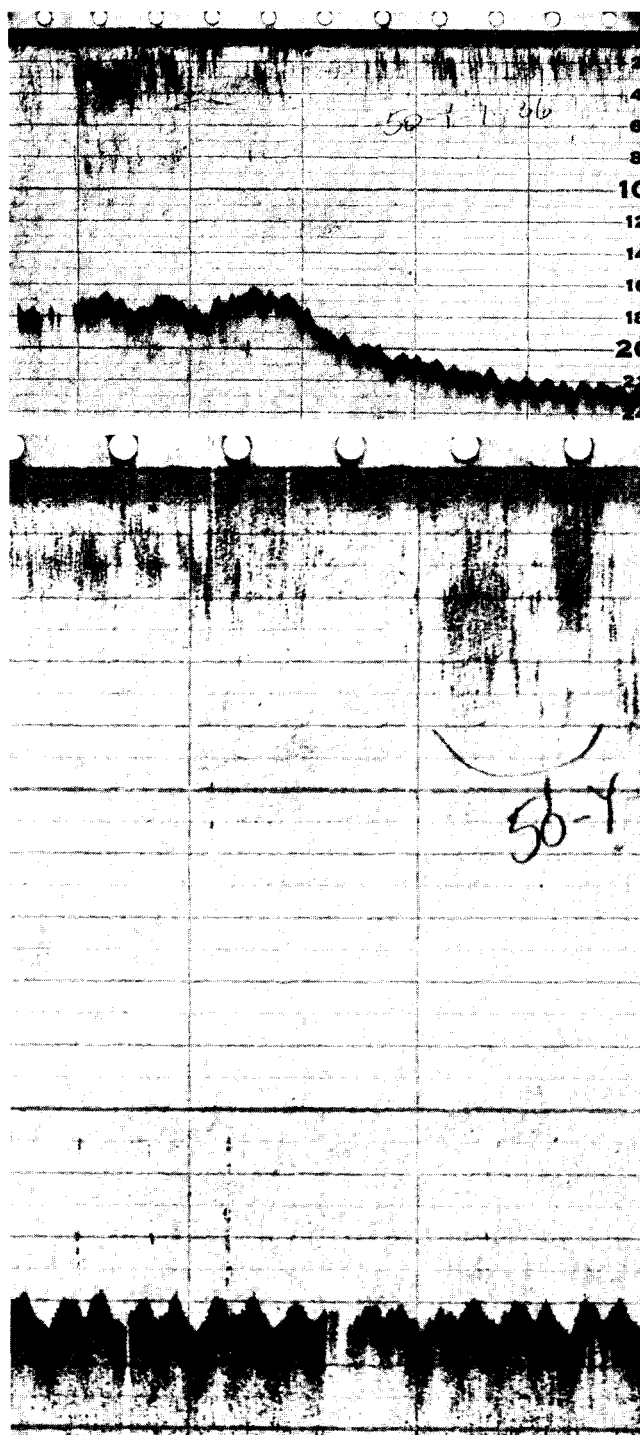
FIGURE 15.   Two examples of the use of echo-sounding apparatus aboard the *Yellowfin* to help in locating sardine schools. (UPPER) On Cruise 50-Y-7-36, 23 July 1950, a school was found about one mile off Cedros Village. The light trace near this top was made by echoes from the school (the lower, darker trace is the bottom). Vertical distribution of the school was from 10 to 80 feet. The vessel probably cruised over the school. Sampling resulted in the taking of 81 sardines and 4 jack mackerel. (LOWER) This school was located visually on Cruise 50-Y-7-33. It was found 19 miles south-southeast from Morro de Santo Domingo in Sebastian Viscaino Bay. The bottom is at approximately 260 feet. The upper trace shows the vertical distribution of the school to be from 16 to 60 feet. More than 100 sardines were taken. Observers estimated that the school contained 30 tons of sardines.

What Has Been Accomplished

STUDIES OF THE SARDINE'S ENVIRONMENT

Physical Oceanography

The physical environment as it affects the sardine not only directly but indirectly is being investigated under the California Cooperative Sardine Research Program. The recruitment studies have shown that most spawning takes place within a narrow temperature range. Oceanographic data are being collected in the presence of sardine schools in an effort to correlate physical factors with sardine availability. The effects of temperature on sardine behavior are being studied in the laboratory. Much work is going into a fourth line of inquiry—how the physical environment affects the sardine indirectly by affecting its food supply.

The basic marine food supply, phytoplankton, live only in those upper few hundred feet of the sea that sunlight can penetrate. These minute plants produce organic matter from dissolved inorganic nutrient salts, using light for photosynthesis. The nutrients, which are produced by bacteriological decomposition, are often found in higher concentrations below the euphotic zone than in it.

By means of photosynthesis, solar radiation provides the energy that drives the life cycle itself; and it is solar radiation again that, through a completely independent chain of events, sets in operation the physical processes by which nutrients are restored to the euphotic zone.

Not all the energy emitted by the sun penetrates the atmosphere, but of that which does a major part is absorbed by the surface layers of the sea. A sizeable portion of this absorbed energy is re-emitted and/or given off to the atmosphere as latent heat. How much latent heat the atmosphere receives from the sea depends upon season, proximity to continents, and latitude. The variability in amount of latent heat given off induces the prevailing circulation in the atmosphere, that is, winds, clouds, high and low pressure areas, storms—the elements that make up weather in general. What we have here, however, is not a one-way process: the latent heat transmitted to the atmosphere by the sea largely controls the weather, but the weather also vitally affects conditions in the sea. It is true that the sea receives a major share of the solar energy and to some extent is influenced directly by it, but the atmosphere acting as a heat engine is the factor which effectively converts heat originally received by the sea into kinetic energy. And it is the drag of the prevailing winds on the ocean's surface that forces the waters in the upper layers to circulate. The Kuro

Shio current, the California current, and the Equatorial current all are part of a huge gyral maintained by the winds. But the winds do more than initiate great slow-moving horizontal currents; they set up waves, bring about vertical mixing of the upper layers of the water, cause the water over large areas to converge and sink or to diverge and rise. And these wind-induced phenomena to a large degree determine the physical environment of the sardine and other ocean life.

These facts have long been known, but our present program represents by all odds the most intense endeavor yet made to relate them to a practical problem —in this instance, the abundance and availability of sardines. We need to know not only the principles of the oceanic circulation but its details as they occur off the California coast and affect the Pacific sardine. Our ships in their routine cruises are getting that information for us.

Upwelling

One of the significant advances made under the California Cooperative Sardine Research Program has been the accumulation of data relating to upwelling, which occurs when the surface waters diverge. Then deep water, rich in nutrients, is brought to the surface. It spreads throughout a wide area of the euphotic zone. The ascent of deep water is evidenced by a sharp decrease in temperature, an increase in salinity, and decided drop in oxygen concentration (Fig. 16). We have found that near the California coast, notably off Cape Mendocino and Point Conception, there is unquestionable evidence of the occurrence of upwelling.

This upwelling off the California coast, which brings about accompanying changes in the current pattern at the surface, is induced directly by the occurrence of winds having a strong northerly component. In the areas of Cape Mendocino and Point Conception, such winds are most frequently found during the spring and summer. In those seasons the Pacific atmospheric high-pressure cell intensifies and extends up along the coast. During the winter, on the other hand, when storms are moving in on us from the North Pacific, the winds are for the most part southerly and easterly; upwelling is suppressed. The occurrence of upwelling changes with changing weather conditions. Compare the apparent upwelling in 1941 with that in 1949 (Fig. 17).

How the winds cause upwelling is shown quite well from an analysis of the data taken on Cruise 3 of the present program (Fig. 18). (In the figure, the data from Cruise 1, representing conditions where no upwelling was occurring, are included for comparison.
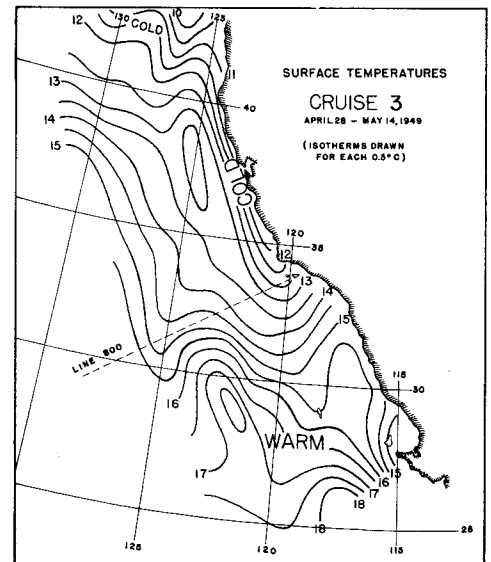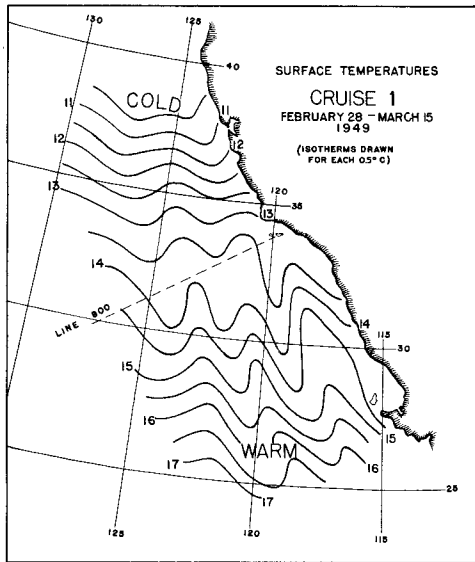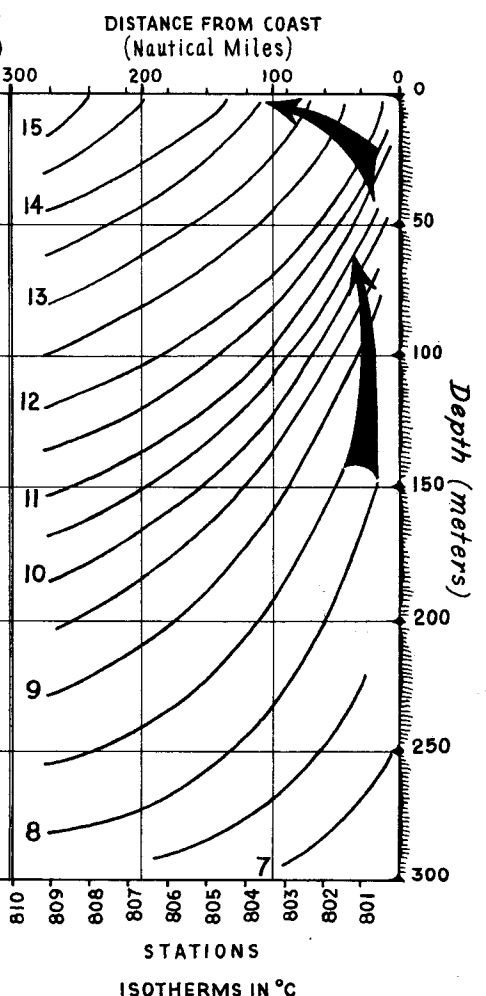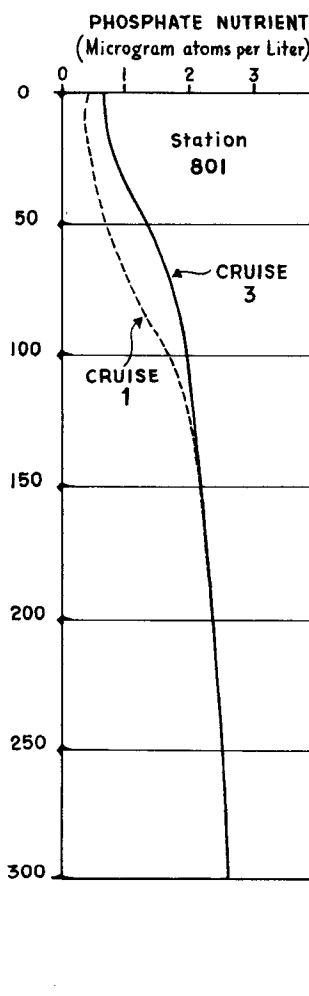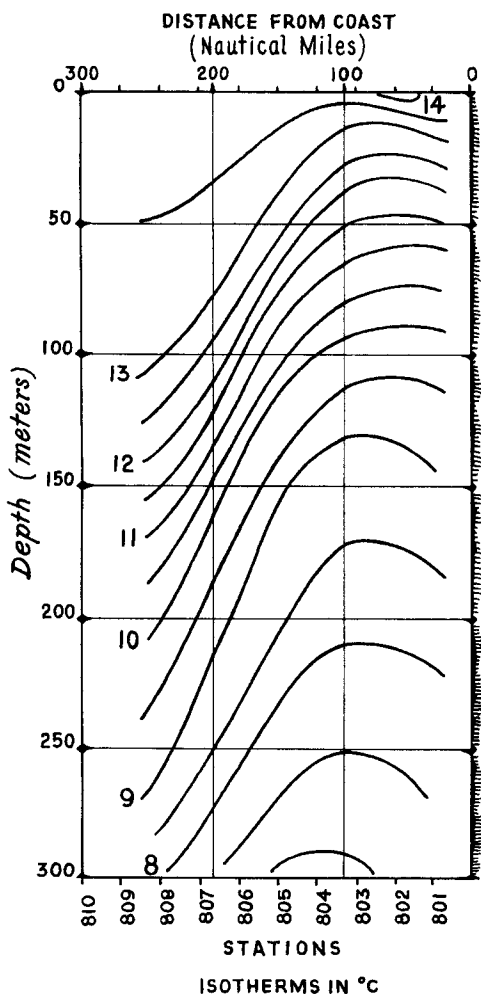
FIGURE 16.   Evidence of upwelling between Cruises 1 and 3.   (UPPER LEFT) Surface temperatures, Cruise 1.   (UPPER RIGHT) Surface temperatures, Cruise 3.   (LOWER LEFT) Profile of temperature along line 800, Cruise 1.   (LOWER RIGHT) Profile of temperature along line 800, Cruise 3. Note cooling adjacent to coast.   Arrows indicate vertical circulation.   (LOWER CENTER) Change in phosphate nutrient at Station 801 between Cruises 1 and 3. The enrichment of the upper layers of the water is a main feature of upwelling.
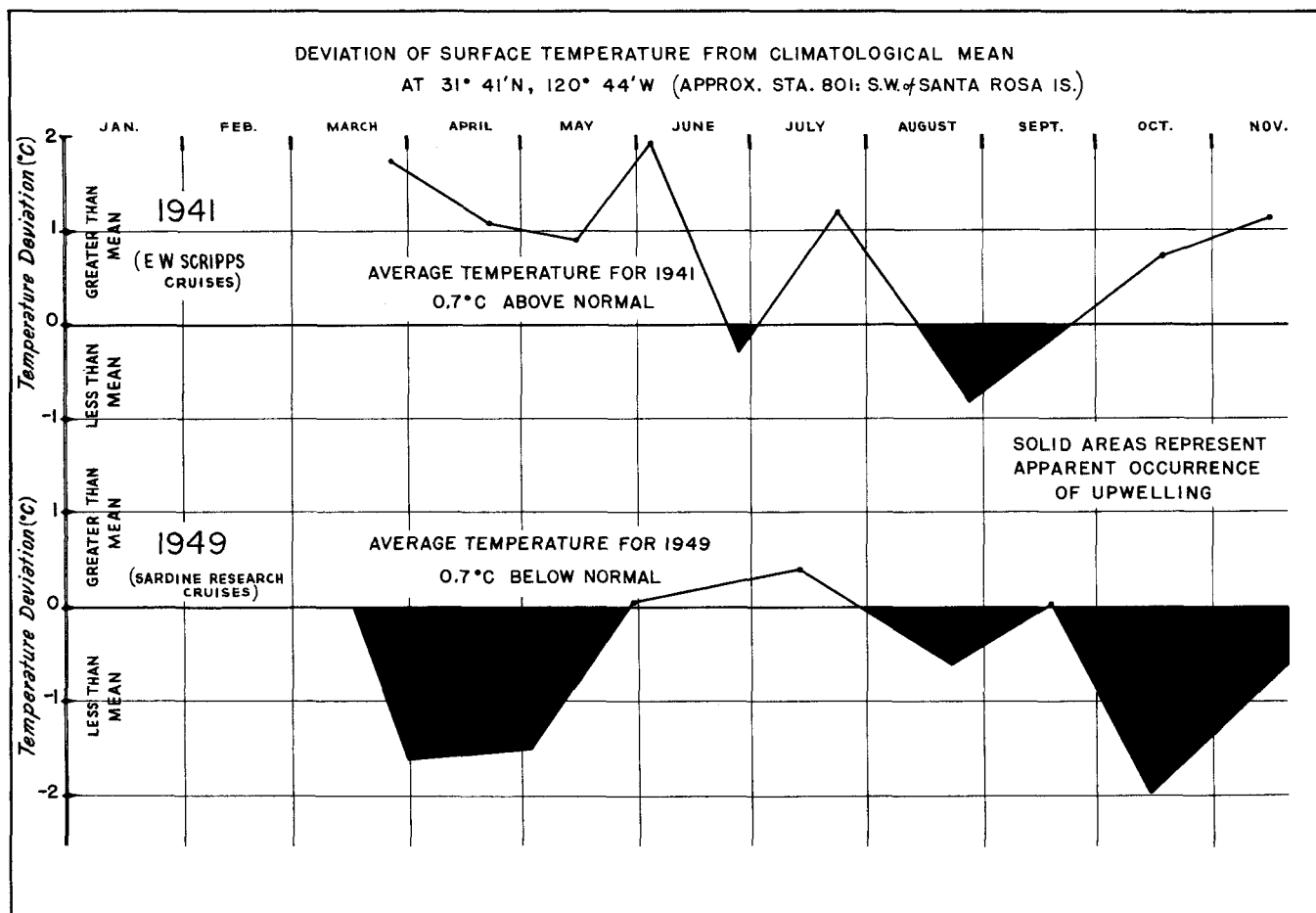
FIGURE 17. Apparent occurrence of upwelling in 1941 and 1949 at Station 801. Station 801 (old system of numbering) lay to the south of Point Conception, at approximately the location of the present Station 83.55. There are 659 surface temperature observations, ranging over several years, available for the area. The deviation of the surface temperature from the climatological mean shows that during 1941, when the average temperature was above normal, upwelling probably occurred briefly in June and during August and September. In 1949, when the average temperature was below normal, upwelling apparently occurred during March, April, May, and again from the first part of August through November.

During upwelling, the northerly winds push the surface waters away from the coast and cause the deeper waters from below to rise up to replace the warmer, lighter water. The result is not only that nutrients are brought up but also that the surface of the sea is lowered in the region of upwelling, owing to the greater density of the water which ascends. The actual lowering of the sea level is slight—usually not much more than 10 inches—but it is enough to cause the currents offshore to increase towards the south and even at times to reverse from north-flowing to south-flowing currents. All this evidence is in accord with theoretical considerations.

The currents induced by upwelling disperse the nutrients they have brought from depths and disperse also the minute plants and the sardine larvae. When the flow is directed towards the south, conditions are presumably right for spawning, for not only does the nutrient material come to the surface, thus facilitating the production of marine plants, but also these plants are swept into regions where temperature conditions are right for spawning (Fig. 19).

Mixing

Upwelling is not the only means by which nutrients can be replenished. The overturning, or mixing, of surface waters through the action of the winds may effectively keep the dead organic matter in the euphotic zone long enough for it to become converted into nutrient material. Mixing undoubtedly plays a part, though perhaps a slight one, in the process of enrichment. (The variability in abundance and productivity of the marine plants is more than can be explained by the variability in mixing.)

Evaporation

Another method by which nutrients ascend, and one which must play a considerable role off the California coast because of our unique geographical features, is by the action of evaporation. When excessive evaporation occurs over the sea, the water vapor takes with it to the atmosphere a large amount of heat in the form of latent heat of vaporization. A cooling of the surface waters and an increase in salinity are thereby brought about. Both cooling and the increase in salinity

SEA-SURFACE PROFILES FOR LINE 900 - 1949
(BEARING 30° S of W *from* SAN CLEMENTE IS.)

DISTANCE FROM COAST (*Nautical miles*)

CRUISE 1   MARCH 1949

7.7 inches

SURFACE CURRENT

1.9 n. mi/day
toward SSE

5.9 n. mi/day
toward NNW

RELATIVE
HEIGHT
OF SEA
SURFACE
(*meters*)

CRUISE 3 - MAY 1949

11.8 inches

SURFACE CURRENT

1.6 n. mi/day
toward SSE

4.0 n. mi/day
toward SSE

RELATIVE
HEIGHT
OF SEA
SURFACE
(*meters*)

REPRESENTATIVE WIND VELOCITIES AT LINE 900
COMPONENT TOWARD COAST

FEB.   MARCH

CRUISE 1

WIND METERS/SEC.

TOWARDS COAST

AWAY FROM COAST

APRIL   MAY

CRUISE 3

AWAY FROM COAST

WIND METERS/SEC.

COMPONENT ALONG COAST

FEB.   MARCH

CRUISE 1

TOWARDS NORTH

TOWARDS SOUTH

APRIL   MAY

CRUISE 3

TOWARDS SOUTH
(*Northerly wind*)

FIGURE 18.   Sea-surface profiles and wind conditions at line 900, Cruises 1 and 3. During upwelling, northerly winds push the surface waters away from the coast. The deeper waters below rise and replace the warmer, lighter water. Note the lowering of the sea surface on Cruise 3, when there were strong northerly winds.

CRUISE ONE

FEB. 28 - MARCH 16
1949

TOPOGRAPHY OF SEA SURFACE

CORRECTED FOR TIDAL EFFECT

0 OVER 1000 DECIBARS

CONTOUR INTERVAL 0.05 Meters

CURRENT DIRECTION
INDICATED BY ARROWS

SHADED AREA REPRE-
SENTS REGION FOR
WHICH TEMPERATURES
ARE FAVORABLE FOR
SPAWNING IN THE UPPER
50 METERS.

LITTLE UPWELLING X
UNFAVORABLE COASTAL
CURRENTS.

CRUISE THREE

APRIL 28 - MAY 14
1949

TOPOGRAPHY OF SEA SURFACE

CORRECTED FOR TIDAL EFFECT

CONTOUR INTERVALS 0.05 METERS

CURRENT DIRECTION
INDICATED BY ARROWS

SHADED AREA REPRE-
SENTS REGION FOR
WHICH TEMPERATURES
ARE FAVORABLE FOR
SPAWNING IN THE
UPPER 50 METERS.

INTENSE UPWELLING XX
FAVORABLE COASTAL
CURRENTS.

FIGURE 19. Currents induced by upwelling. (LEFT) On the first cruise, when there was no apparent upwelling, there was only a weak north-flowing current in the cooler water. (RIGHT) On the third cruise, when upwelling was apparently taking place, there was a strong south-flowing current in the cooler water. It has been induced by upwelling close to shore. Such currents sweep nutrients, plants and larvae into areas where temperature conditions are favorable for spawning.

INTERNAL WAVE EFFECT
(SCHEMATIC)
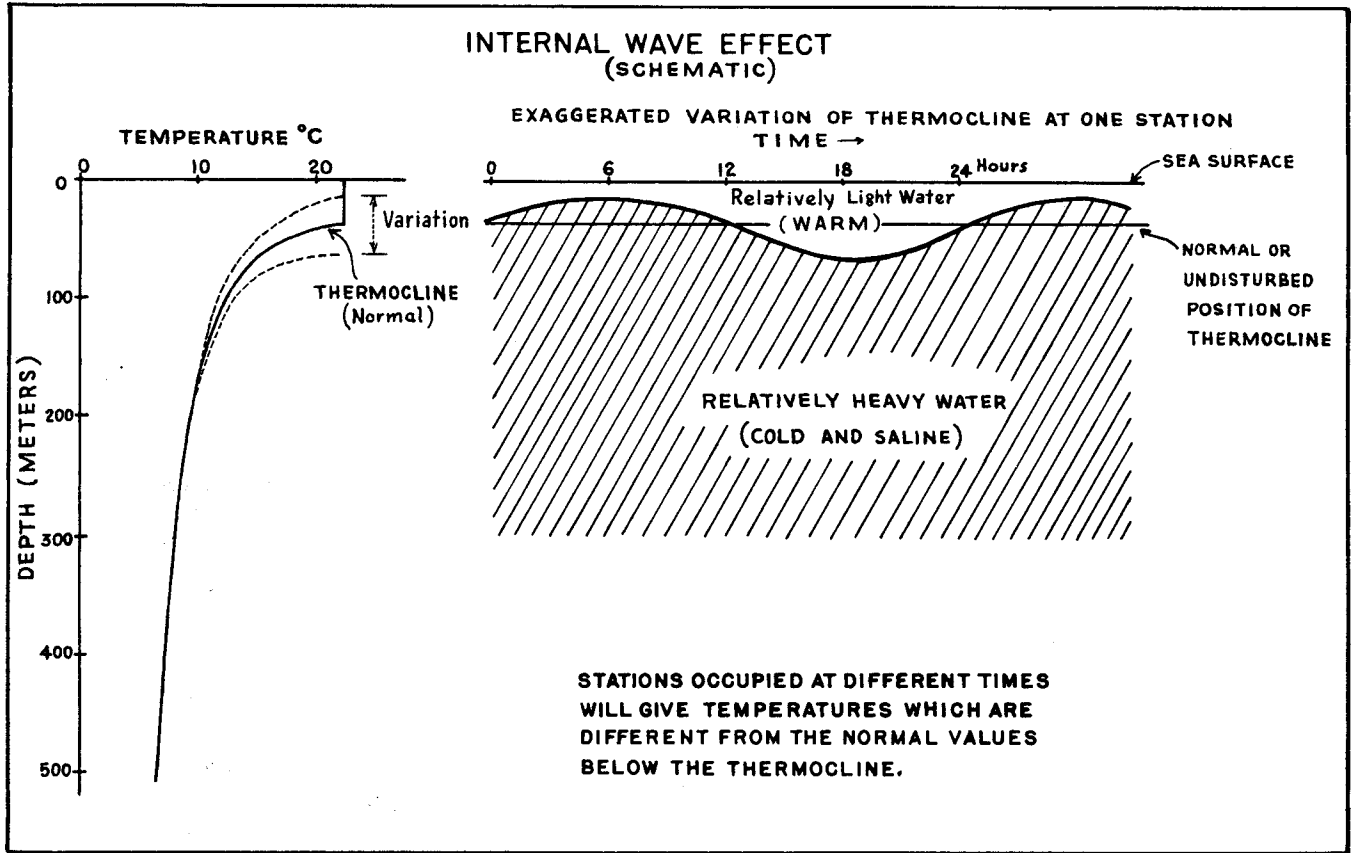
FIGURE 20.   Schematic diagram of the internal wave effect. The depth of the thermocline (the region in which the temperature
change is most pronounced) varies with time.
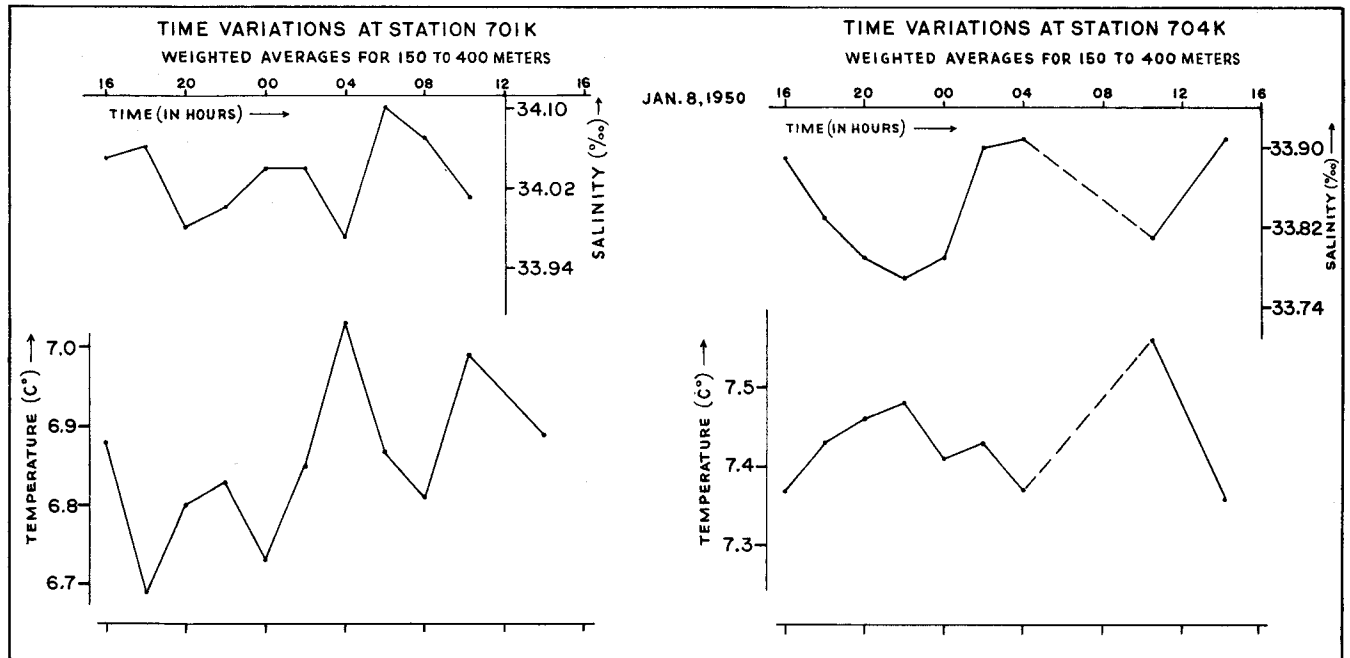
FIGURE 21.   Time variations in salinity and temperature at fixed hydrographic stations. Note the decided differences in the two sets of curves at 0400.

work to increase the density near the surface and thus cause the water to become unstable. As a result, vertical convection cells are set up that extend down to and even below the lower limit of the euphotic zone. As the surface water sinks, deeper water must ascend to take its place. The water in the surface layers becomes thoroughly mixed and is replenished to some extent with nutrients from below.

The conditions for such large-scale evaporation as would bring about a significant increase in nutrients are provided by either strong winds or dry air (or both). The coming of Santa Ana winds in Southern California, occurring during the fall, presents optimum conditions. Santa Anas occur when the Pacific high extends into California and Nevada and stagnates. Very warm, very dry air is blown out towards the coast and to sea. The presence of large-scale evaporation is evidenced by the onset of fog all along the coast region following the Santa Ana regime.

Internal waves

Another mechanism which might be responsible for the mixing of coastal waters is the action of internal waves (Fig. 20). These waves are extremely high (sometimes 50 feet or more). Since they are present below the surface, they are unobservable by eye from a ship. They occur at the interface between layers of different densities. Such an interface can be identified as the depth of maximum temperature change (thermocline). To some extent, internal waves occur in all oceanic regions. They have been observed by making serial measurements of temperature and salinity at fixed hydrographic stations. Figure 21 shows the results of such data, as taken on Cruise 10 at two stations north of Point Conception. In the Mediterranean, internal waves have been observed to break in shallow water very much as ordinary surface waves do. The breaking is accompanied by an overturning and mixing of the subsurface waters, and consequent lifting of some nutrients to the surface layer.

If the sea were a static environment the dead organic matter would sink out, the oxygen of the deeper water would become virtually exhausted, and since small amounts of nutrients would be produced by aerobic bacteria, much less would be brought back to the surface; the present type of life in the sea would be at a minimum. When the sea tends toward such a static condition, when it "slows down," life in the sea slows down as well, although there may be a large time-lag in the response of the living creatures to their environment. This natural lag would be a rather critical thing if it were about the same as the time between successive regimes of full replenishment, such as by upwelling or other intermittent phenomena.

Delineation of spawning areas

The physical data collected on the sardine research cruises provide the answer to such questions as the

frequency of upwelling, extent and amount of replenishment. Because sardine spawning occurs within relatively narrow temperature limits, the data can also be used to delineate areas where spawning might take place. In the end, it should be possible to estimate from the weather data of a previous year, together with supplementary oceanographic data, what the total bulk of nutrient replenishment has been as well as the frequency of its occurrence. Then from a knowledge of the nutrients' effectiveness on production of organic matter (which enables larvae to live) one phase of the success of spawning can be dealt with on a rational, measurable basis. However, the very important factors of mortality by predation or by disease will have to be considered jointly with the question of food supply.

Problems of processing

The problems that have been encountered in the work of adequately describing the physical environment should not go unmentioned. First, there is the problem of obtaining sufficiently accurate data on temperature and depths. Much time and effort have gone into this. Second, there is the problem of setting up a smooth, efficient scheme for recording and processing all data, and making final plots of temperature, salinity, and current charts. Third, there is the problem of checking the calculations of currents from the dynamic topography of the sea surface; trajectory studies, using specially designed equipment, are being carried on for this purpose. Fourth, there is the problem of eliminating from the data the confusing effects of internal waves. It has been found in the oceanographic work that because the stations were occupied at different phases of the internal waves, large eddies in the current pattern were apparent. These eddies have no real, physical existence in the sea; they must be eliminated before any sense can be made from the data.

These and other problems in the processing techniques have been solved to some satisfaction. But it is important to remember that even with the greater efficiency of the present techniques of processing, the data collected from a single year's cruises are far in excess of those taken by any other oceanographic expedition. The *Carnegie* occupied more than 160 hydrographic stations in both the Atlantic and Pacific during a single year. It was about a decade before the data could be published. The three ships usually employed on the present program occupy more than 120 stations in two weeks. So far about 1,200 stations have been occupied each year. At each station there are 15 levels of observation. The first year's physical and chemical data have already been issued in mimeographed form to the interested agencies.

Much of the time spent to date in the physical oceanographic program has been devoted to processing. It is naturally expected that additional time will be necessary in order to analyze these data thoroughly and correlate them with the biological data.

Chemical Oceanography

The chemical studies under the sardine research program are concerned with an investigation of variations in the distribution of nonconservative chemical constituents of sea water and their relation to physical processes as well as to the distribution of phyto- and zooplankton. On all cruises routine measurements are made of chlorinity, dissolved oxygen, and inorganic phosphorus.

Dissolved inorganic nutrient salts, such as phosphate, can be considered the first link in the food chain —nutrients, phytoplankton, zooplankton, fish, man— and a study of their distribution is a study of the supply of food available to phytoplankton, the primary producers of organic matter in the sea. Dissolved oxygen is another useful chemical parameter, being produced during photosynthesis and consumed during respiration and oxidation of decaying organic matter. As oxygen is consumed, nutrient salts are released to become again available for use. Chlorinity data are essential to the calculation of density, and hence to the dynamic computation of currents.

Because of the great numbers of analyses to be run, a great deal of time and thought have gone into the improvement of these methods, both to increase accuracy and to increase the rapidity of analysis. An improved setup for manual titration of chlorinities has been designed, and the development of an automatic chlorinity titrator has been pushed. The method for oxygen determination has been streamlined, so that all of the samples collected on a station can be analyzed in less than an hour.

Existing methods for phosphate analysis were found to be unsatisfactory. A study of the method showed that reagent concentrations had to be changed, the time between addition of reagents and reading carefully controlled, and temperatures of samples and standards measured. Automatic reagent dispensers were developed for the careful measurement of small volumes of reagents at sea. A new seagoing photoelectric colorimeter, simple and accurate in operation, was developed. Duplicate phosphate samples from all depths on a station can now be run in less than an hour.

The pressure of routine processing of cruise data has forced interpretation of the data to play a secondary role. Charts of the horizontal distribution of oxygen and phosphate are being prepared, and a few studies of the data have been made.

Recently work has been done on the "high-oxygen" layer. This layer was arbitrarily defined as the greatest depth at which oxygen saturation is 90 percent or greater if shallower than 75 meters, or 80 percent or greater if deeper than 75 meters. Topography of the surface of 80 percent saturation would be equally useful and requires fewer calculations. Topographies of the bottom of the high-oxygen layer were plotted for the six cruises of *E. W. Scripps* in 1938 and compared with the dynamic topographies. These data show that a deep high-oxygen layer is associated with clockwise circulation, or convergence, and a shallow high-oxygen layer with counterclockwise circulation, or divergence. Thus the depth of this layer is a useful indication of the location and extent of divergences and convergences. The presence of a shallow high-oxygen layer is a more reliable criterion for upwelling than is the presence of a low dissolved oxygen content at a fixed depth.

Correlation of the logarithm of average diatom count with depth of the high-oxygen layer yielded a low but significant negative correlation. In general, low diatom counts were associated with deep layers and high diatom counts with shallow layers, probably owing to the mechanical effect of vertical circulation on the vertical distribution of phytoplankton.

Another study of *E. W. Scripps* data showed no correlation between diatom counts and surface oxygen content. Counts of diatoms retained by a silk net give a poor estimate of the effective phytoplankton crop. Furthermore, other processes controlling the distribution of oxygen are superimposed on the effect of photosynthesis and tend to obscure any apparent relationship.

Under way at present are studies of the effect of internal waves and of the wind and evaporation on stirring in the euphotic zone. An explanation for the observed variations in distribution of deep phosphate is being sought. An attempt is being made to relate distributions of chemical factors with those of physical and biological factors, so that an understanding of the interrelationship of physical, chemical, and biological processes can be gained.

Additional studies of analytical methods are being made. A wet-ash method for determination of carbon has been developed; it is hoped to establish the relationship between measured chlorophyll content of phytoplankton in this region and their content of organic matter, as indicated by carbon.

Although the rates of utilization and regeneration of nitrate may be quite different from those of phosphate, nitrate analyses are made only infrequently because of the difficulty of the present method. A study of an improved method has been started. A study is also being made of methods for determination of hydrogen ion concentration. Some measurements of silicate distribution have been made, and more silicates will be run if the data prove to be useful.

Biological Oceanography
Marine botany

Phytoplankton, the floating plant life of the sea, is measured in an effort to determine what and how much there is available for creatures of the sea to eat, and how these organisms vary throughout the season and from year to year. And since phytoplankton makes new organic matter, it is measured so that some estimate
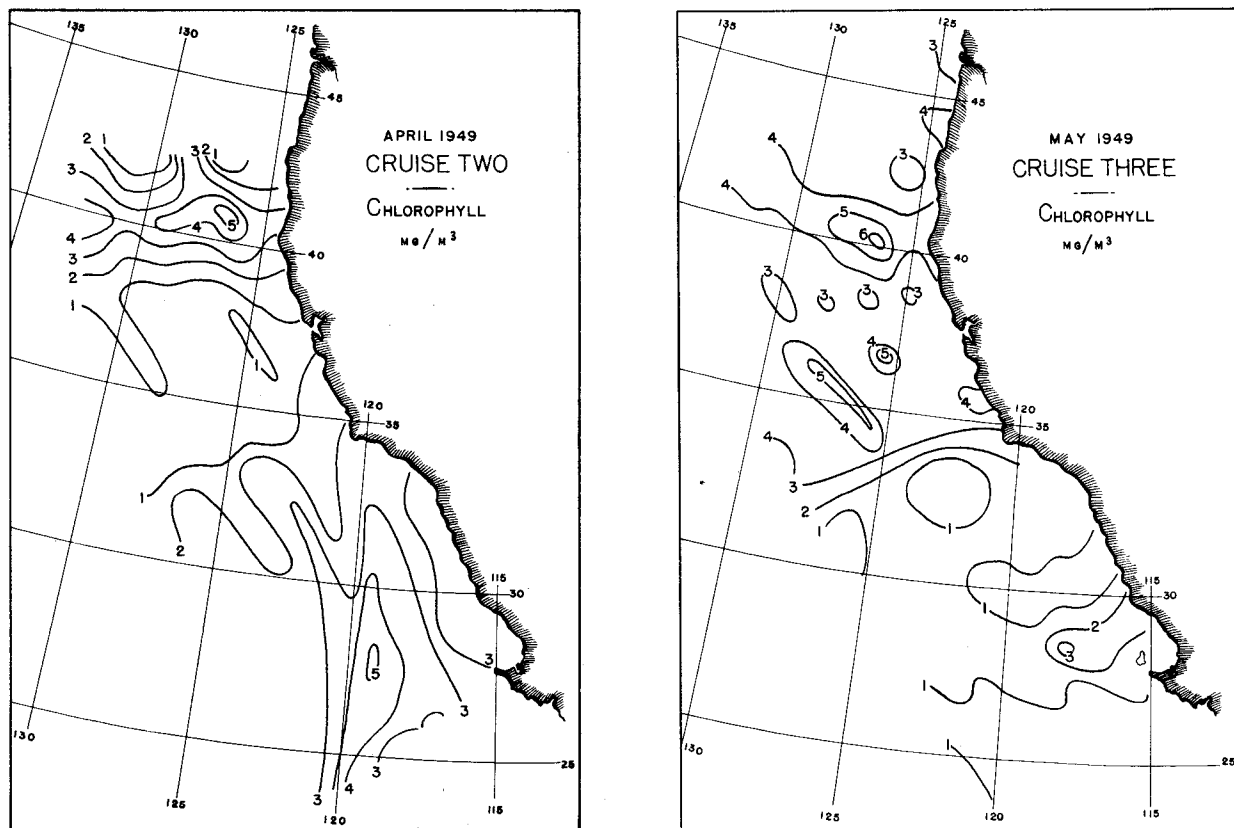
FIGURE 22.   Distribution of chlorophyll, April and May, 1949.
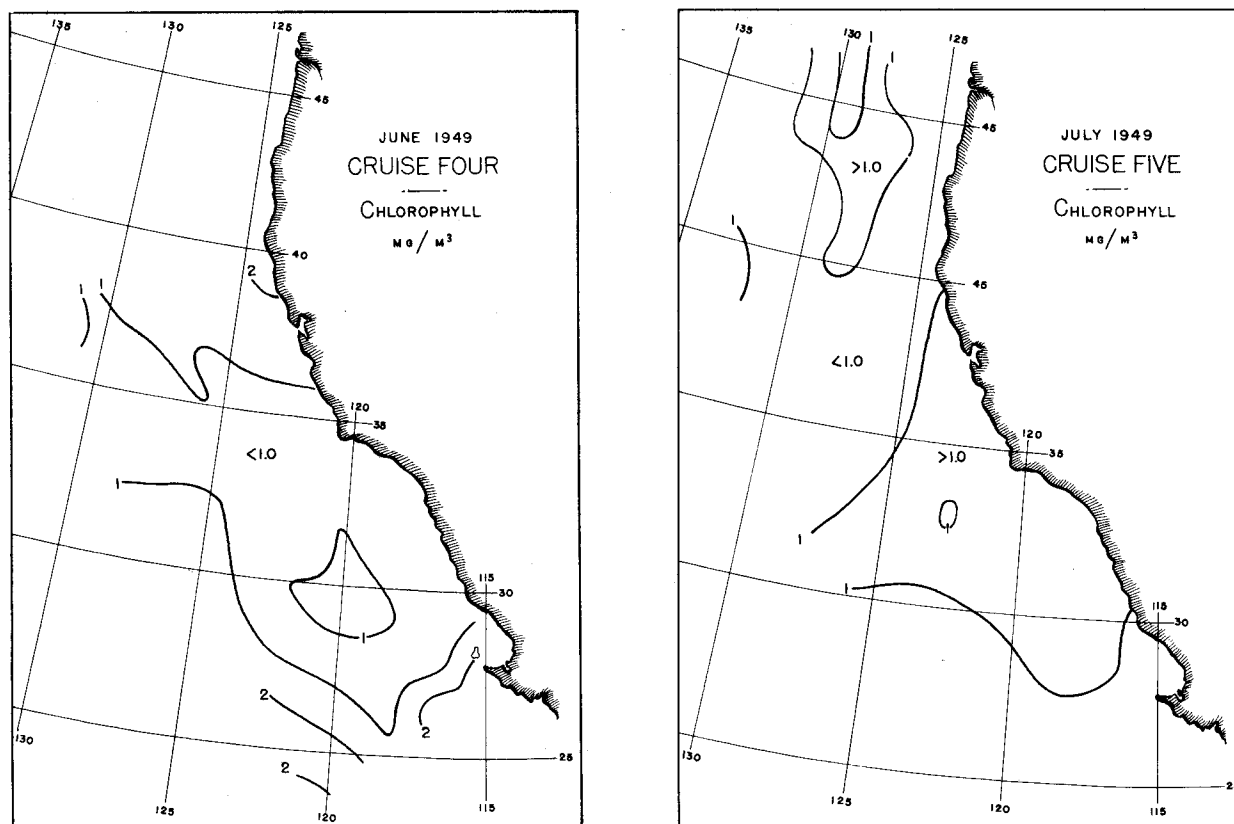
FIGURE 23.   Distribution of chlorophyll, June and July, 1949.

can be made of the amount of machinery for the production of organic matter. A difficulty crops up here; different types of phytoplankton have different rates of production of organic matter. Chlorophyll is the likeliest factor by which the production of new organic matter can be measured, but the rate of chlorophyll production is variable.

What can be measured at present are the numbers and kinds of living cells in a sample of sea water. It is hoped some day to measure the amount of organic matter present, but the possible methods are complicated.

The steps in measuring phytoplankton are, briefly, these:

(1) A measured quantity of sea water is filtered through a fine paper filter or centrifuged,

(2) The material collected is extracted with a solvent,

(3) The absorption of light in the solution is measured. With some qualifications and exceptions, we can use this final value as a measure of the amount of chlorophyll present in phytoplankton. Figures 22 to 24, inclusive, show the distribution of chlorophyll in the top 70 meters of the sea during Cruises 2 through 7, April through September, 1949.

Several features stand out on these charts. In the first place the stations are close enough together to give some indication of the topography of the distribution. Although earlier in the program we drew only generalized charts, we have more recently come to have some faith in the details. There are still too many contours based upon a single value, but the majority of the contours are related to each other in ways that indicate real features.

In 1949 the chlorophyll content, and hence the phytoplankton population, reached its highest over-all levels in April and May and in September. During each of these months chlorophyll concentrations of five to six or more milligrams per cubic meter occurred at some stations. Concentrations as high as three milligrams per cubic meter occurred at more than one-third of the stations occupied. During June and July no concentration as high as three milligrams per cubic meter occurred anywhere. During August, higher concentrations than this were found at only two stations. Seasonal cycles of phytoplankton populations with spring and fall maxima occur in many waters and have been observed locally at the Scripps pier for 30 years.
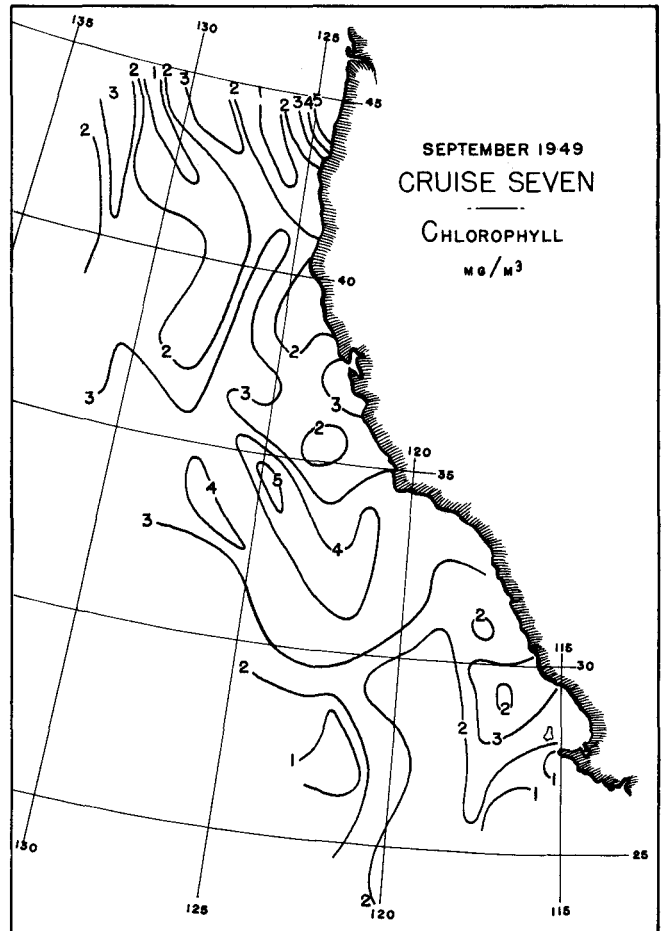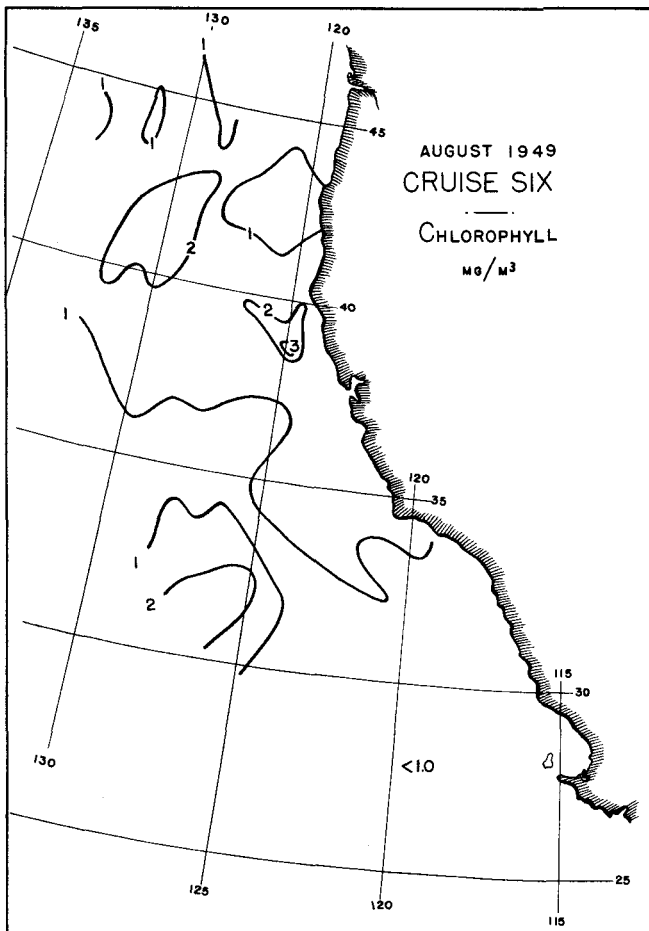
FIGURE 24.   Distribution of chlorophyll, August and September, 1949.

The general population level, equivalent to nearly three milligrams per cubic meter of chlorophyll during the spring and fall cruises and little more than one milligram per cubic meter during the summer, is comparable with that on the high seas over large parts of the world. However, population levels equivalent to four or five times the highest chlorophyll content observed during the 1949 cruises (6.4 milligrams per cubic meter at station 404 in May) have been observed in other waters. There is good reason to believe that populations of this magnitude occur locally. Many of the largest populations observed in 1949 were at offshore stations, and only a few (e.g., during May at Stations 201, 401, 402, and 701 and during September at Stations 201, 501, 1101, 1102, and 1103) at stations close to shore. Many earlier investigations along this coast have indicated that the largest populations are usually found close in. We believe therefore that although the station network is close enough for a general survey, detailed studies of some small areas may uncover centers of large phytoplankton populations which could be critical for an understanding of the sardine problem.

Another conspicuous characteristic of the 1949 situation is that there seem to be at least three different centers of population. In the whole area north of the latitude of Cape Mendocino, the chlorophyll concentration was relatively high during all the cruises. Far to the south, in the neighborhood of Guadalupe Island, there were relatively large populations during most cruises. In between these is an area west of Point Conception in which very large populations occurred during May and September.

Marine invertebrate plankton

In order better to understand the biological environment of the sardine and other fishes, especially those with planktonic eggs and larvae, the Scripps Institution is engaged in a study of the invertebrates collected with the fish eggs and larvae in the net samples.

The task of analyzing the plankton qualitatively to determine the relative importance of the myriads of constituents progresses only slowly. The samples currently being collected, together with past collections along the coast, are providing a picture of the occurrence of species that are believed to be important for reasons of their (1) abundance, and, therefore, significance in the life of the sardine and general biological economy of the coastal area; (2) probable use as indicators of degree and pattern of dispersal of free-living floating life; (3) fluctuations in geographic range of species shown to be characteristic of either the southern or northern sections of the coast, or of inshore or offshore situations. Any marked increase in southern species to the north or northern species to the south can be an indication of the relative strength of the

prevailing water currents or movement of water masses off our coast.

Crustacean plankton—In the samples examined, copepods are usually overwhelmingly dominant numerically and usually also in bulk. They, together with the euphausiids, form most of the more "substantial" plankton and will accordingly be given a great deal of attention in the analysis of the plankton.

Especially significant because of their abundance or because of characteristic geographic range are the following species of copepods:

Acartia clausi—inshore

Acartia danae—offshore

Calanus finmarchicus—abundant over whole range, but less frequent at far offshore stations

Calanus minor—moderately abundant in the southern range

Calanus tonsus and *C. cristatus*—sometimes exceedingly abundant in northern sections and extending southward to latitude of about Point Conception

Candacia spp.—on the basis of earlier collection some of the six or more species show a restricted range, but more study is needed to determine the relationships

Eucalanus bungii californicus—abundant over the whole of the southern range, but diminishing noticeably along the coast in north

Eucalanus bungii bungii—abundant in the north, but diminishing towards the south where it is apparently completely replaced by the southern variety off the Southern California coast

Metridia lucens—sometimes abundant

Other genera of large calanoids that occur in sufficient numbers to enter the routine counts of aliquot samples of each haul include especially *Euchirella* (six species), *Scolecithrix*, and *Centropages*.

There are many characteristically deep-water species (especially of the genus *Pleuromamma*), some of which are numerous in night hauls. These await further analysis together with the deep-water samples being taken on the more recent cruises.

The small copepods are being studied from separate hauls which have thus far been taken only at pattern II stations. They include a large array of microcalanids, and among the cyclopoids especially the genera *Oithona*, *Oncea*, and *Corycaeus*.

These microcopepods (especially *Oithona*), their larvae, and the larvae of larger species must be highly important in the diet of the sardine larva following absorption of the yolk sac.

Charts that are being prepared for copepod distribution show a varying degree of southward extension of typically northern forms offshore to the regions of about San Francisco to Point Conception or a little
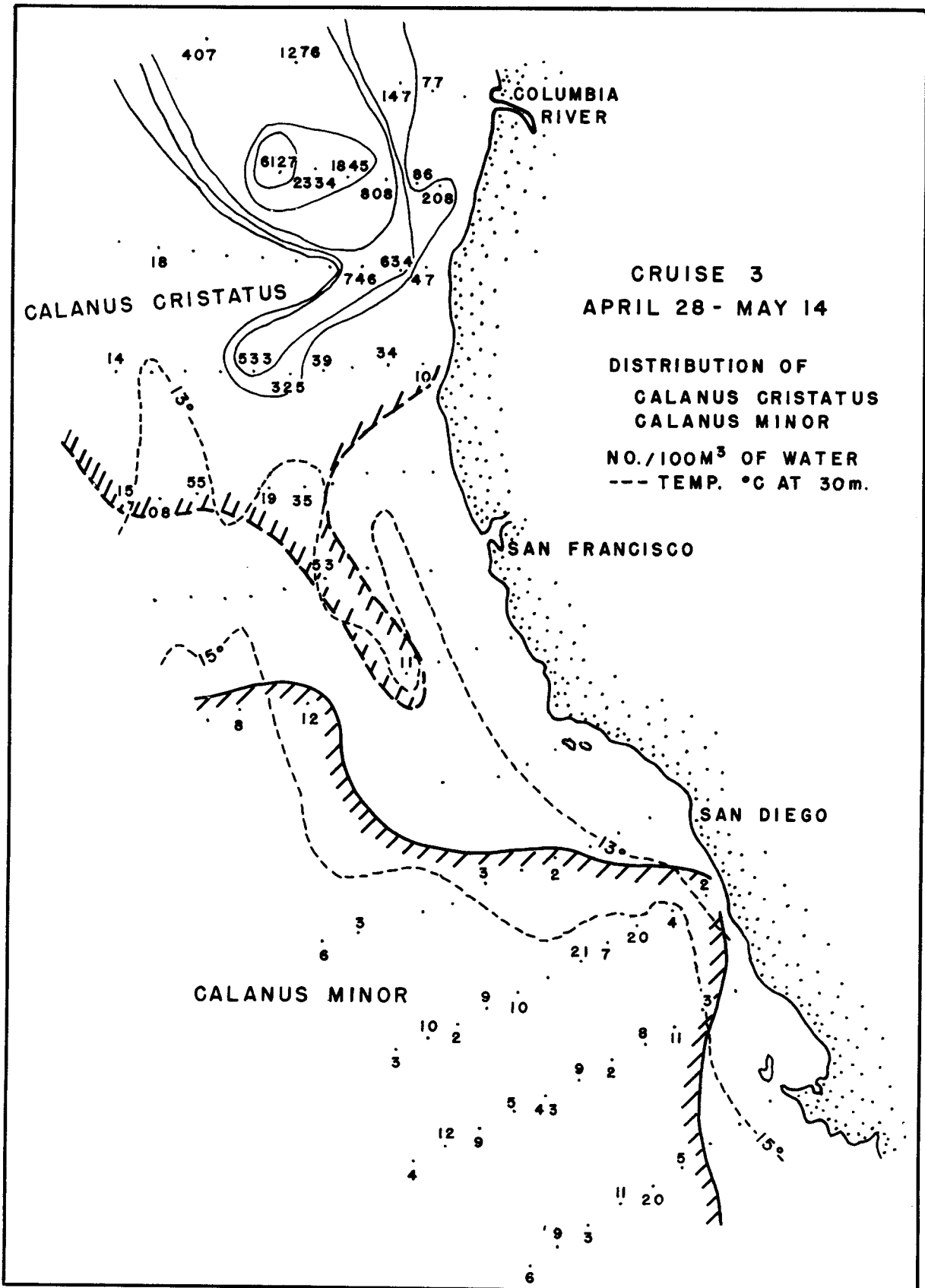
FIGURE 25.   Distribution of *Calanus cristatus* and *Calanus minor* on Cruise 3. The 13° and 15° C. isotherms in general
follow the northern and southern lines of distribution.

farther south. There is also some indication that as the season progresses there is a gradual "retreat" northward or that deeper water is sought below the relatively shallow range of the nets. The typically southern species, for example *Calanus minor* or *Mecynocera clausi*, have their greatest northward extension in the offshore waters.

In Figure 25 is given an example of the distribution of two species of copepods with geographical ranges that are characteristic of several other species. The numbers given at each station are based on aliquot samples of the total catch at the station and therefore represent the areas of principal population density. A more detailed examination of the total catch shows a considerable overlapping of the populations by stragglers of *Calanus cristatus* to the south and *Calanus minor* to the north. The line of greatest demarcation between northern and southern forms appears to fall most noticably between the 13° and 15° C. isotherms at a depth of 30 meters.

From a study of the euphausiids, it appears that *Euphausia pacifica*, a north temperate neritic species, is the numerically dominant species and is important because of its abundance in the plankton community. There are in the area about 17 other species in seven genera. Some of these are mainly deep-water forms which are probably only night-time visitors to the surface stratum sampled by the regular hauls. The following tentative list includes the more outstanding examples of species thus far appearing to be either southern or northern in geographical range in the area under survey:

Thysanopoda aecualis—southern, oceanic form—straggler

Euphausia eximia — entirely southern, mainly oceanic—promises to be a good indicator of southern water

E. gibba—straggler from southern waters

E. hemigibba—southern, oceanic form

Thysanoessa longipes—rare straggler from northern waters—possibly very good indicator

T. gregaria—bipolar form, found at greater depths in the tropics—15.5° C. is apparently the upper limit of thermal tolerance.

The season of recruitment of the more abundant species is being considered through study of the occurrence of larval and juvenile stages.

The enumeration and plotting of the geographic range of the more abundant euphausiid species suggests a region of overlapping or division of ranges between northern and southern species in the area between the 14° C. and 15° C. isotherms at 30 meters depth.

The biology of several other invertebrate groups is being considered in more or less detail. Among these are included especially the amphipods, chaetognaths and zoea larva of sand crabs.

Fifty-seven species of pelagic amphipods have been identified. The frequency of occurrence and numerical abundance of many of these are too limited to allow conclusions relative to their distribution. The genus *Parathemisto* appears to be the dominant amphipod wherever it occurs. It may reach considerable numbers and its predacious habit makes it important in the plankton community.

Dispersal by water currents—The degree of dispersal of fish eggs and larvae together with other planktonic organisms is difficult to determine. In an attempt to obtain evidence along this line, a special study is being made on the horizontal distribution of the planktonic zoea larvae of the sand crab *Emerita analoga*. The adults of *Emerita* live intertidally from whence the larvae must originate. The plankton hauls taken during the present and the 1940-41 cruises off Southern California demonstrate a surprisingly wide dispersal of the larvae in offshore waters to distances of about 200 miles seaward. This can be illustrated by reference to cruises 10, 11, and 12 of 1940 when respectively 73, 78, and 74 percent of the stations yielded *Emerita* larvae, a few occurring at the outermost stations of the lines and in numbers ranging up to 150 per standard haul at more coastal stations.

This study may provide useful information on the degree of dispersal that can occur and on the extent of lateral water mixing and type of flow.

Plankton volumes—Measurements of the displacement volume of zooplankton (after the larger forms such as jellyfish, salps, etc., have been removed) were made for each station by the U. S. Fish and Wildlife Service. As mentioned earlier, a qualitative study of these data usually shows a preponderance of copepods and euphausiids. Thus far no attempt has been made to evaluate the contribution to the volume of the more watery forms such as chaetognaths and the small salps, siphonophores and medusae.

In Figure 26 is given the distribution of displacement volume adjusted to 1,000 cubic meters of water filtered by the 1.0-meter net towed obliquely in steps from 70 meters to the surface. It is seen that the volume of plankton in the northern sections of the survey tend to be well above the average for the whole area, while those in the southern section are quite consistently below average. In both northern and southern areas there is a general decrease in volume at the stations situated at the outer (seaward) ends of the lines. While it is possible to discern major areas of greater or lesser plankton concentrations, still there is within these areas a great deal of patchiness. Night hauls are usually more voluminous than day hauls in the same areas owing to upward migration of some forms to the surface at night. Data from deeper hauls might change the picture but it is believed that the

CRUISE THREE

APRIL 28 - MAY 14, 1949

TOTAL ZOOPLANKTON VOLUMES
SHOWN AS PER CENT OF MEAN
VOLUME FOR COMPLETE AREA.

EQUAL GEOMETRIC INTERVALS

MORE THAN 800
400 - 800
200 - 400
100 - 200
50 - 100
25 - 50
LESS THAN 25

MEAN FOR AREA:
208 $^{cc}/_{1000}$ m³ of water

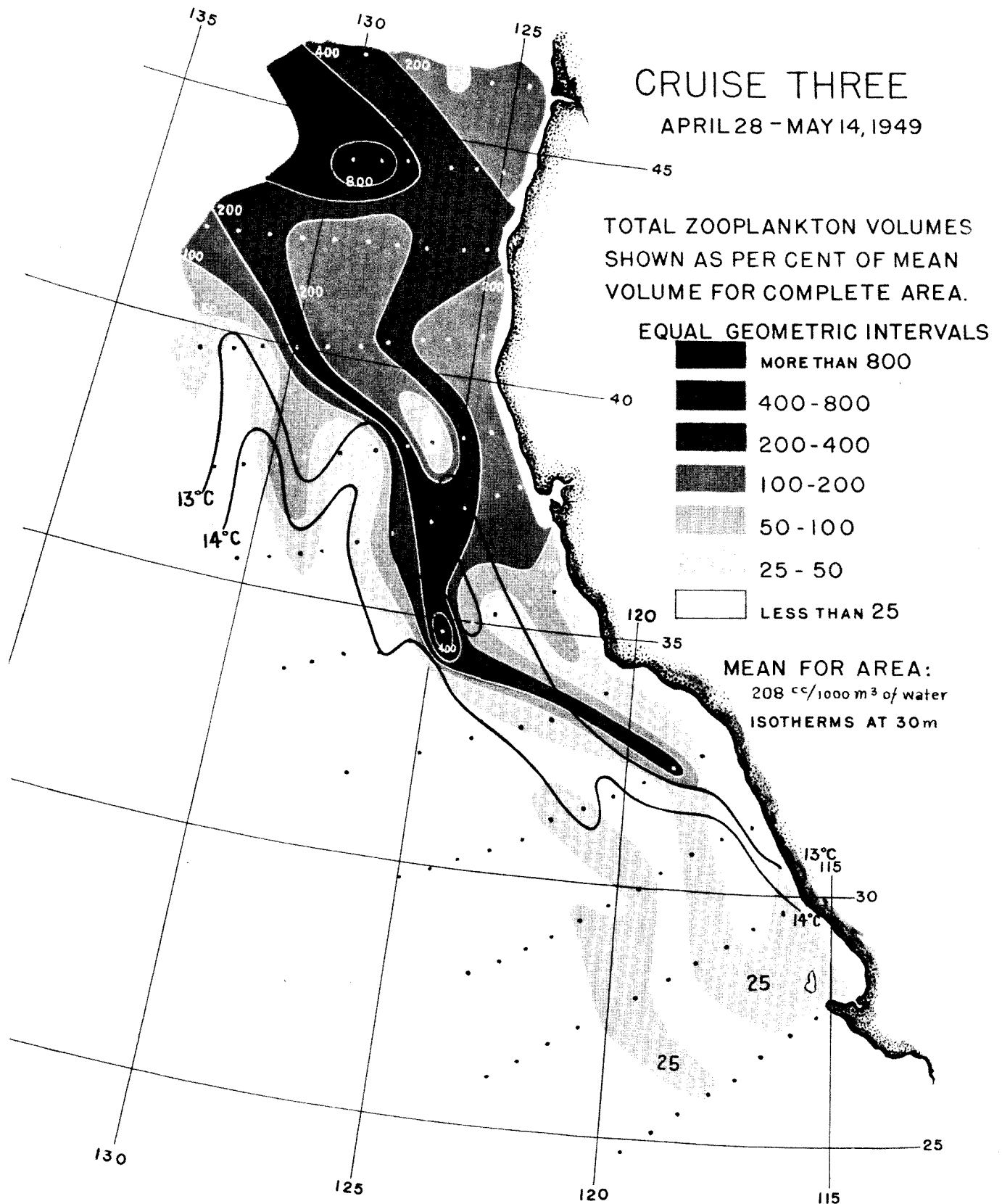ISOTHERMS AT 30 m

FIGURE 26. Total zooplankton volumes shown as percent of mean volume for complete area. The volume of plankton in the northern sections of the survey area tend to be well above the average for the whole area; those in the southern section are quite consistently below average. In both areas there is a general decrease in volume at the stations at the seaward ends of the lines.

figure given depicts rather well the plankton population in which the sardine must live by day and by night, provided these fish do not normally go below the depth of the hauls taken during the daylight hours.

RECRUITMENT RESEARCH

An important phase of investigation in the program is directed toward determining the factors underlying the success or failure of year classes of sardines. A solution to this problem is a prerequisite if we are to attain one of our primary goals—the prediction of the strength of year classes in advance of their entry into the commercial fishery. The investigation of sardine recruitment is primarily the responsibility of the U. S. Fish and Wildlife Service.

The immediate objectives of the recruitment research are: (1) the determination of the extent and time of sardine spawning; (2) the determination of the amount of spawning, i.e., the number of eggs spawned, and, as a corollary, the estimation of the size of the spawning population; (3) the determination of the rate of survival of the young fish; and (4) the correlation of all of the above with environmental conditions—physical, chemical, and biological.

Given enough data, it should be possible to predict year-class strength one to two years in advance of the time the year class would be of importance in the commercial fishery. But, as has been emphasized re-

peatedly, prediction is a long-range objective. Its attainment will require: (1) intense coverage during the spawning season of the whole spawning area of the sardine, and (2) such coverage over a sufficient period of years so that a norm can be established.

Sardine eggs are spawned in the open sea near the surface, and the young sardines after hatching remain in the upper water layers (usually above 50 meters). They can be sampled quantitatively by using very fine-meshed silk nets. Occurring with the sardine eggs and larvae in the plankton collections are the eggs and larvae of other fish, as well as many kinds of small animals. The collections are analyzed at the laboratory on Point Loma, where the fish eggs and larvae are first separated from the other constituents of the plankton and then are identified and enumerated. The sardine larvae are measured to determine the number of larvae of successive stages present in each collection. The sardine eggs are separated into the several days' spawning present in each sample. The development of the egg to the post-larval stages is shown in Fig. 27.

The first task has been to find out where and when the sardines spawn. This must be known if we are to estimate either the amount of spawning or the survival rate of the young sardines. Investigations during the 1949 and 1950 spawning seasons have shown that there are, at present, two major areas of sardine spawning: a compact area of intense spawning around and to the south of Cedros Island, central Baja California, and a much larger area of diffuse spawning off Southern California and adjacent northern Baja California. In the waters separating these two spawning centers very little spawning has been encountered during either season, and this little has been confined to a coastal strip.

The 1950 Sardine Spawning Season

The times of occurrence of sardine spawning in different parts of the spawning area have been quite similar during the two seasons covered by survey work. At the beginning of each season, sardine spawning has been confined to the southern portion of the area being surveyed, then has gradually progressed northward as the spawning season advanced. This can be illustrated by following the distribution of spawning month by month during the 1950 season.

FEBRUARY: On this, the first cruise of the 1950 season, sardine spawning was confined to the southern portion of the survey area, around and to the south of Cedros Island (Fig. 28).

MARCH: Although still confined to Baja California, spawning was found to extend somewhat farther north (Fig. 29).

APRIL: The most intense spawning of the season was encountered during this month (Fig. 30). The spawning extended as far north as Southern California, occurring in a coastal belt about 520 miles long and 100 miles wide. During this month spawning was especially intense off central Baja California.

MAY: Although fewer sardine eggs were taken in May than during the previous month, the abundance of sardine larvae reached its peak during this month. The larvae
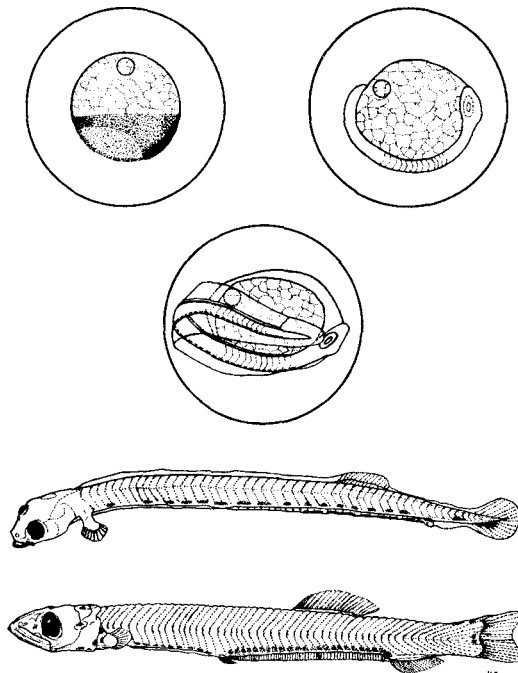
FIGURE 27. Successive stages in the life of the sardine. (UPPER LEFT) The egg 12 to 18 hours after spawning. (UPPER RIGHT) The egg about a day and one-half after spawning, midway between spawning and hatching. (CENTER) The egg just before hatching. The yolk sac remains attached to the larva and is absorbed as food. (LOWER) Postlarval sardines. The upper of these sardines is about 10 mm. long, the lower about 25 mm. long. In these stages, it is impossible to determine their ages with any exactitude.
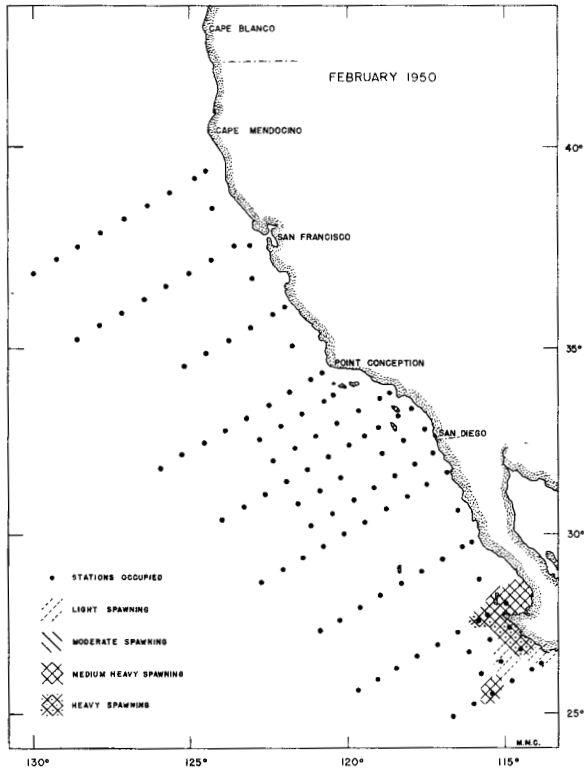
FIGURE 28. Spawning in February, 1950. Spawning was confined to the southern portion of the survey area, around and to the south of Cedros Island.
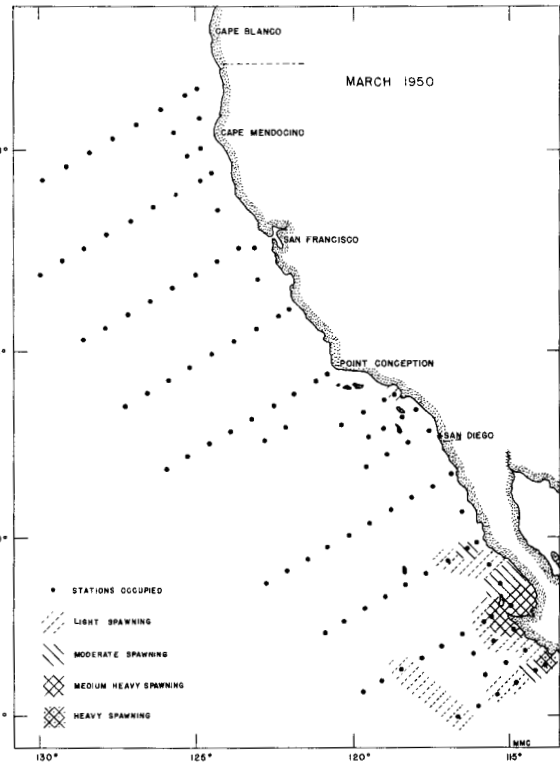
FIGURE 29. Spawning in March, 1950. Although still confined to Baja California, spawning was spreading northward.
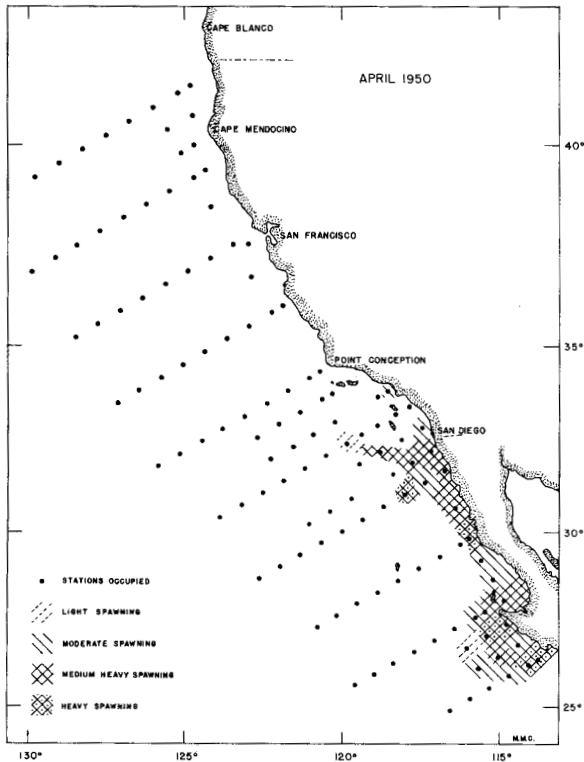
FIGURE 30. Spawning in April, 1950. The most intense spawning of the season was encountered during this month. Spawning extended as far north as Southern California; it was particularly heavy off Baja California.
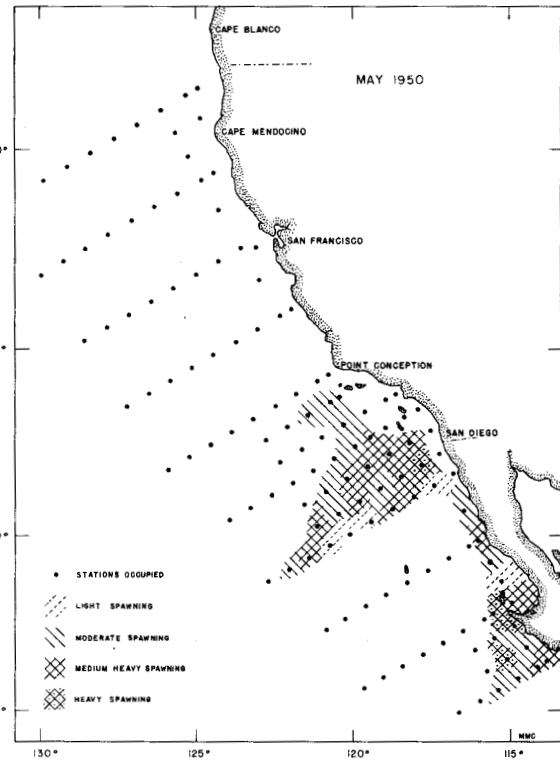
FIGURE 31. Spawning in May, 1950. Fewer sardine eggs were taken, but sardine larvae were at their peak abundance in this month.

JUNE: were abundant in both centers of spawning. Off Southern California and adjacent Baja California the larvae were found over an extensive area, occurring as far seaward as 330 miles on one line of stations (Fig. 31). No evidence of spawning was encountered to the north of Point Conception.

JUNE: Spawning had progressed farther northward during June, occurring off San Francisco (Fig. 32). However the spawning to the north of Point Conception, although rather wide in extent, was very small in amount. The Cedros area, for the first time during the season, had fewer eggs or larvae per collection than elsewhere. The collections in the Southern California area still showed moderately heavy spawning, although sardine larvae were more important in the collections than sardine eggs.

JULY: The collections taken during this month contain the tag end of the spawning (Fig. 33). Although sardine larvae occurred in collections from Cedros to off San Francisco, their abundance amounted to only 2 or 3 percent of the number taken during May.

AUGUST: The survey cruise extended as far north as the Columbia River. No evidence of sardine spawning was obtained off Oregon, and a negligible amount off California.

Relation of Sardine Spawning to Oceanographic Conditions

The sardine apparently seeks out water masses having favorable temperatures. During the 1949 survey all sardine eggs were taken in water of 13.3° to 16.2° C. This is a temperature range of less than three degrees. Our accumulated observations, made during a number of spawning seasons, on the temperature of spawning show that this temperature range is somewhat too narrow: a more inclusive range would be 12.5° C. to 16.5° C. During the 1950 spawning season 98.4 percent of all sardine eggs sampled were taken within a $3\frac{1}{2}$ degree temperature range, 12.5° to 16° C.

The northward progression of spawning during both the 1949 and the 1950 seasons was associated with the northward progression of favorable spawning temperatures, while the gradual elimination of spawning from the southern part of the spawning area coincided with the rise in temperature above the favorable range for spawning.

It is noteworthy that the two centers of heavy spawning previously discussed are in areas enriched by upwelled water. Upwelling appears to be important not only because of the nutrient enrichment associated with it, which increases the food supply available to the sardine larvae, but also because the temperature of upwelled water is likely to be favorable for spawning, especially in the warmer southern part of the spawning range.

The extent of the two spawning centers appears to be influenced by the manner in which the upwelled water is dispersed by the currents in the two areas.
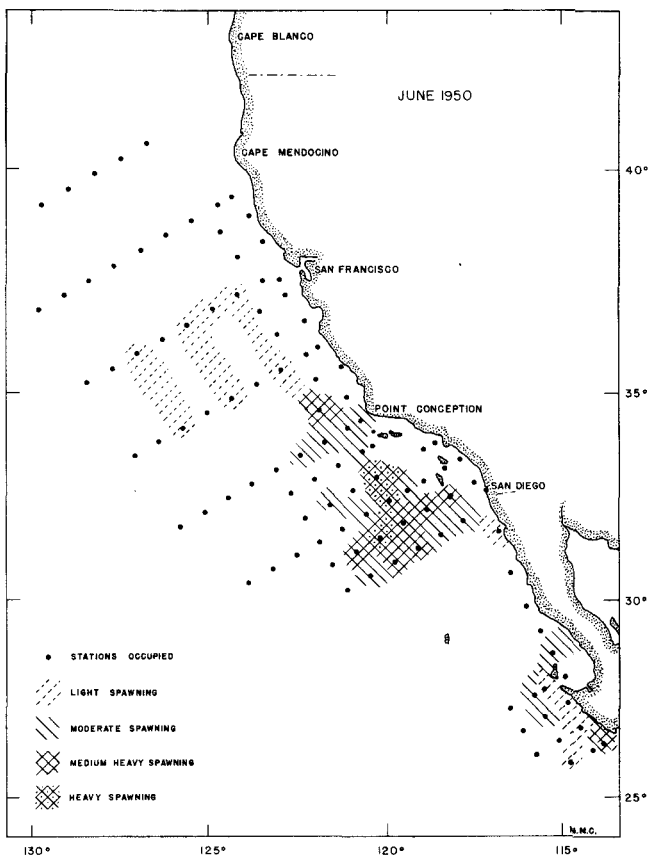
FIGURE 32. Spawning in June, 1950. Spawning had progressed to the north of Point Conception, although it was light there. For the first time in the season, the Cedros Island area had fewer eggs or larvae per collection than did other areas.
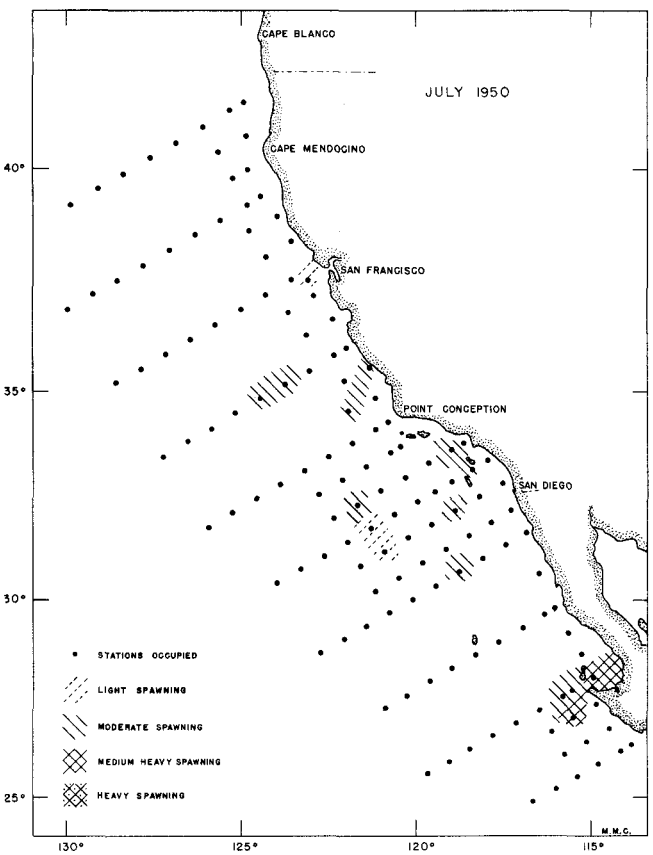
FIGURE 33. Spawning in July, 1950. Though spawning was widespread, the collections taken during this month contain the tag end of the season (only 2 or 3 percent of the number of eggs and larvae taken during May appeared in the collections).

Currents carrying upwelled water from above and around Point Conception sweep seaward in a broad arc before bending inshore off Baja California. In this area spawning occurs offshore, mostly beyond the island area of Southern California, and may extend as far seaward as 300 miles or so. In the Cedros area, on the other hand, the currents are much closer to shore; as a result, spawning is concentrated within a coastal strip 60 or 80 miles wide.

From the data available for the 1949 and 1950 seasons, it is difficult to assess the success of spawning. For one thing, the coverage of the major spawning areas during the 1949 season was not intensive enough for an adequate determination of the amount of spawning. This fact was known and carefully considered when laying out the 1949 survey plan. However, before the areas of major spawning could be surveyed intensively, it was first necessary to determine their location, and this was achieved by the wide coverage of the 1949 survey. During the 1950 season a much more intensive coverage was made of the major spawning areas, while at the same time an extensive coverage was effected by shifting the survey northward as the spawning season progressed.

One difference between the two seasons that may have bearing on the success of the two spawnings will be noted. Water temperatures were lower during the 1950 season (Fig. 34), and it is likely that this was due, at least in part, to more intensive upwelling during the 1950 season. Walford [1] has presented evidence in support of the thesis that good year-class survival occurs during seasons when upwelling is more intense than usual. However, a few words of caution should be inserted at this point. We have not carried on our surveys over a long enough period to establish a norm for upwelling. Until this is done, any comparisons such as the one noted above must be tentative. For we still do not know whether the 1950 season was above average, average, or below average with respect to upwelling intensity.

WORK ON OTHER FISHES

There are two reasons why work on other fishes is an integral part of the cooperative sardine program: (1) many species compete with the sardine for available food and living space, while others prey upon

[1] Walford, Lionel A., 1946, *Correlation Between Fluctuations in Abundance of the Pacific Sardine (Sardinops caerulea) and Salinity of the Sea Water*, Journal of Marine Research, Vol. VI, No. 1, 31 December 1946, pp. 48-53.

FIGURE 34. Surface temperatures, Cruise 12, March, 1950. During the spring, surface temperatures were somewhat cooler than they were during the spring of 1949 (compare with Fig. 16, upper left). The decrease may have been due to more intense upwelling during the 1950 season.

SURFACE TEMPERATURES

CRUISE 12

MARCH 2 - MARCH 18
1950
(ISOTHERMS DRAWN
FOR EACH 0.5° C)
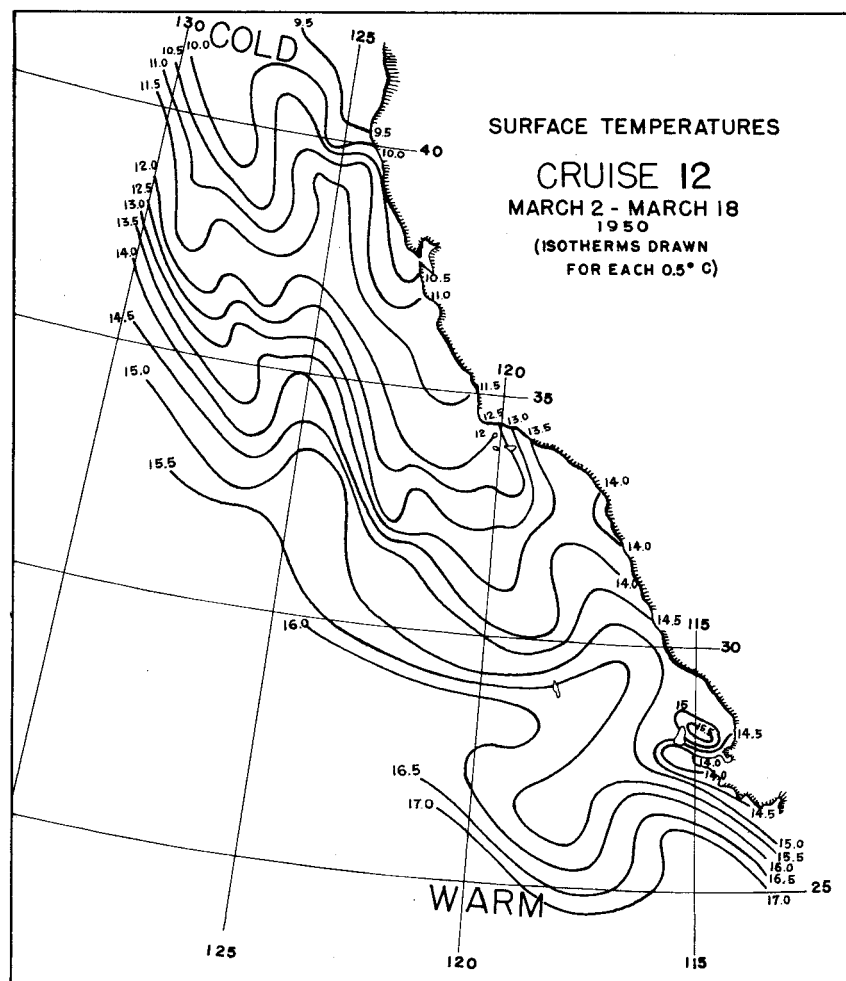
the eggs and young of the sardine; (2) some of these fish may constitute fishery resources of considerable potential value. If the sardine catch were to remain very low, it might be possible to use the same equipment to catch and process some other species. As a matter of fact, the anchovy has been suggested for this purpose. A few are canned at present. No reduction has been permitted. Just after World War II there was a boom of sorts in the canning of squid—which is not a fish, of course—for export. However, there has been relatively little investigation of the abundance, availability, and possible uses of much of our marine food resources.

Some of the basic scientific work on fishes other than the sardine is now being undertaken, with special attention being paid to other herring-like fishes. This work is only partially supported by sardine funds. The studies are being made jointly by personnel of the Scripps Institution of Oceanography and of the U. S. Fish and Wildlife Service. The same scientists are also cooperating on a study of another food fish of proven importance, the albacore, dealing with the food of the species and the relation between catches and surface temperatures.

Young of Other Fishes Associated with the Sardine

Plankton hauls for sardine eggs and larvae also contain eggs and larvae of other fishes spawning in the area. These eggs and larvae are removed from the plankton collections along with those of the sardine and are identified and tabulated. Larval fishes often differ greatly from the adults. As the young of most species have never been described, study has been necessary in order to identify correctly the younger stages. Fortunately, we are now able to identify almost all fish larvae occurring in our collections.

Jack mackerel

Of considerable interest is the information, gathered incidentally to the sardine cruises, on the abundance and distribution of young jack mackerel. The spawning season is similar to that of the sardine, but the jack mackerel spawns over a large area. The larvae of the jack mackerel are exceedingly abundant, with the center of their distribution well offshore.

Anchovy

The anchovy is another species of considerable importance in our study, since it occurs in about the same localities as the sardine and seems equally as abundant. The anchovy spawns over a longer period than the sardine. Unlike the sardine, the anchovy larvae are fairly abundant over the whole north-south extent of the area being surveyed. This species constitutes one of our most important latent fishery resources.

Saury

Another species of exceptionally wide distribution is the saury. The species has been sampled at almost every station occupied, being attracted readily to a light hung over the side of the vessels at night. However, the saury is not abundant in waters close to shore and less than 20 fathoms deep. The Japanese fish this species, landing a considerable tonnage. It is a fish of excellent quality, which might make a pack at least equal to or better than the sardine if methods can be developed for taking it in commercial quantities. Large numbers of these fish do, however, carry a parasitic copepod which may affect their utilization as food. The saury may also prove to be a desirable bait species. The occurrence of small young at all times of the year indicates that spawning is not restricted to a definite season, although variations in spawning intensity may occur in time and space. Some progress has been made in the determination of age and rate of growth. It would appear that growth in length is more rapid than in the sardine or anchovy.

Other food fishes

Space does not permit listing all of the species taken that are of present or potential importance to the commercial fishery. Although studies of these fishes are not being specifically undertaken under the sardine program, the presence of the young in the plankton hauls is, of course, noted. The hake is an example of a species abundant off our coast that is not considered particularly desirable as a food fish in our area, although related species are prized in other parts of the world. Rockfish larvae also occur in considerable numbers, and surprisingly enough are regularly taken as far as 300 miles at sea off Northern California.

Fodder fishes

Of less immediate interest to the fishery, but of fundamental importance in the economy of the sea are the "fodder" fishes, particularly the lantern fish and deep-sea smelts. Most of the larvae taken in the net hauls belong in this category. While usually small in size, the fodder fishes are so exceedingly abundant that they must provide much of the food of carnivorous species. The analyses of stomach contents of albacore and jack mackerel have indicated this to be true. The role played by fodder fishes has not been sufficiently appreciated. Lantern fishes have been considered as curiosities rather than as one of the most abundant kinds of fishes in the ocean. More interest is being taken in this group, however, and the possibility of their use as bait may soon be explored.

Adults of Other Fishes
Northern anchovy

The stocks of northern anchovy (*Engraulis mordax mordax*) inhabiting the coastal waters from British Columbia to Baja California have been found to be segregated into several populations, between which intermingling is limited or absent. At least three such populations have been identified. These inhabit the regions from British Columbia to Northern California, Southern California and northern Baja California, and southern Baja California, respectively.

The mean number of vertebrae, the character used most widely in detecting the presence of fish populations, is not sufficiently precise for this purpose in the anchovy. Using vertebral counts alone as a criterion it is not possible to distinguish between adults from British Columbia south to northern Baja California. On the basis of dorsal, anal, or pectoral fin-ray counts, however, marked differences are indicated between anchovies taken to the north and to the south of Point Conception (Fig. 35). Anchovies from Northern Cali-
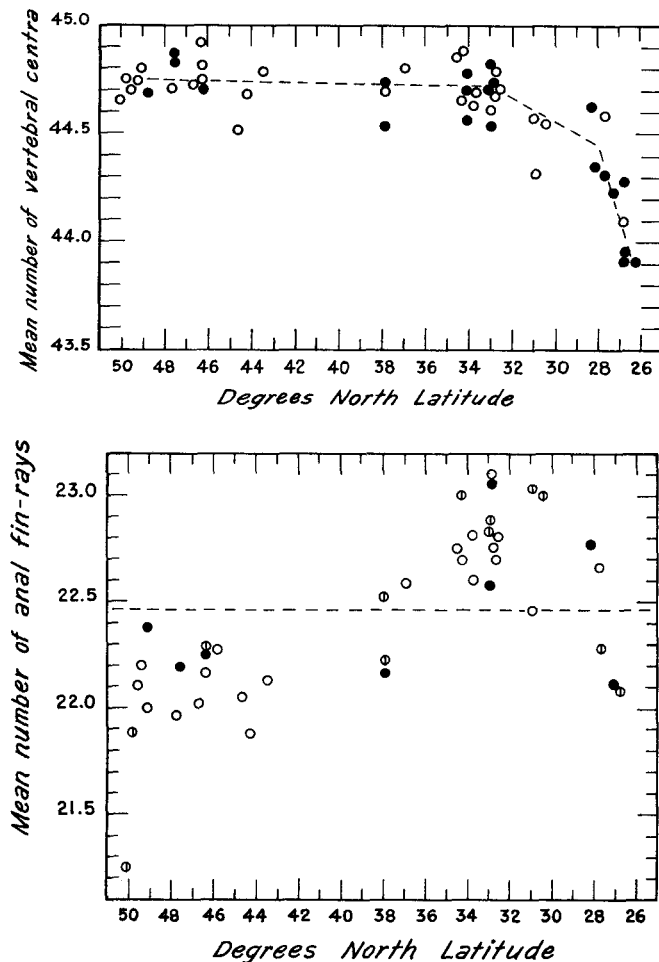
FIGURE 35. Mean number of vertebral centra and mean number of anal fin-rays of the anchovy. (UPPER) Counts of mean number of vertebral centra show few differences between anchovies off coast except in southern-most part of region, where consistently smaller number may indicate separate population. Open circles are adults, filled circles are postlarvae and young. (LOWER) Counts of mean number of anal fin-rays reveal a different picture; on this basis, separate anchovy populations may be presumed to inhabit waters off (1) British Columbia to Northern California, (2) Southern California and northern Baja California, (3) southern Baja California. Open circles, adults; filled circles, larvae; partially filled circles, young.

fornia and the Pacific Northwest have fewer fin-rays on the average than do those from Southern California. The results of this study are in process of publication.

These anchovy population studies are being continued in order to gain further knowledge of the differences between California and Baja California fish.

Progress is also being made in developing methods of age-determination.

The work on anchovies has posed the question of whether similar studies on the Pacific sardine might establish the existence of several relatively independent local populations.

The distribution of mean vertebral number in adult sardines had been investigated before the present studies were commenced; there is no evidence from vertebral counts that more than one population occurs from British Columbia to northern Baja California. Studies of other characters, such as the numbers of fin-rays and of gill-rakers, now under way, so far suggest that intermingling is not complete between Southern California and the regions to the north. It is too early to state definitely that these differences in the sardine are as clearly marked as has proved true for the anchovy.

In the central section of the coast of Baja California, mean vertebral number in postlarval sardines varies significantly with season. If vertebral number can be used in this area to define populations, it would seem that the ranges of the northern and southern populations overlap at this point. The northern fish may spawn here in winter and spring and the southern group may migrate northward to spawn in the same region in summer and early fall. This problem is being given considerable attention.

Similar investigations of the herring stocks in California waters indicate that, as is true in waters of Alaska, British Columbia and Washington, several populations occur along the California coast. North-south migration in this species is probably more restricted than in the anchovy and sardine.

Herring-like fishes

Along the Pacific Coast, from Alaska to the southern tip of Baja California, at least 20 species of sardine-like and anchovy-like fishes are known to occur. Information on the distribution and abundance of these species is being gathered, and studies are progressing on the identification of the larval stages of many.

The sardines of the Japanese, Peruvian, South African, Australian, and New Zealand coasts, though considered distinct species, are known to be closely related to the Pacific sardine. Opinion is not unanimous as to the degree of relationship between these species, primarily because no adequate studies have been made. A project has been under way for some time to compare these forms critically. The results to date indicate that the differences, if any, are extremely slight. This work, when complete, will be of value in understanding the past history and movements of the sardines of the world.

Albacore

Records of albacore caught on jig-lines during survey cruises have provided valuable information on the temperatures at which the species occurs in the

surface waters. In general, the average temperature at which catches are made is higher than the average surface temperature for all stations occupied during the cruise. This may not indicate that temperature directly governs the presence of fish, since albacore are not normally taken close to shore, even when the temperature appears favorable. Furthermore, the average temperature at which catches are made increases from north to south, and also increases in each area as the season progresses.

Studies of albacore stomach contents show that a wide variety of organisms is eaten. Organisms living near the surface constitute the most important food in terms of volume. However, forms are commonly found that occur normally at considerable depth. Often the state of digestion indicates that the albacore must have recently come to the surface; however, since the surface-living organisms are in general better preserved in the albacore stomach, their importance as an element of diet is probably overemphasized. Species commonly found are the red swimming crab *Pleuroncodes planipes*, squid, and Euphausiids. Many fish species are eaten, those most usually found being *Vinciguerria lucetia*, sauries, anchovies, hake, and rockfish.

THE 1950 YOUNG SARDINE SURVEYS

It is necessary, if we hope to predict sardine catches, to know not only the rates of natural and fishing mortality, but to know the rate of recruitment to the population. A direct approach to determining the rate of recruitment is to measure—relatively or absolutely—the size of the successive year classes. Preferably this measurement should be made at some stage in the life history before the sardines enter the fishery. The California Division of Fish and Game has undertaken assessment of the abundance of sardines in their first year of life, after they have passed the larval and postlarval stages.

Methods of Approach

The division has for several years collected statistics of the live bait fishery of Southern California. These include records of the capture of young sardines, when they are available. Young sardines ("firecrackers") are a preferred bait. It is evident from experience, however, that in some years young sardines representing strong year classes are not available to the Southern California bait fishery. Therefore a reconnaissance of the total area where young sardines might be found should give a more reliable measure of the numbers comprising each year class.

A reconnaissance of young fish within their entire possible geographic distribution would present formidable difficulties. Adult sardines have been taken from southeastern Alaska southward along the Pacific Coast to the tip of Baja California and northward into the Gulf of California, a lineal distance of over 3,000

miles. Young sardines have been taken from Vancouver Island southward. A single research vessel, the *Yellowfin*, was available for the work. There is information at hand, however, which lends support to two assumptions which bring the geographical limits of such a survey closer to the ability of a single vessel to conduct it:

Scofield (1934)[1] compared the distribution of very young (up to 10 mm.) sardine larvae with the oldest larvae (20-35 mm.), and concluded that the main movement was inshore and to the south. Godsil (1930)[2] demonstrated that in 1928 and 1929 in the La Jolla-San Diego area all the young fish (20-100 mm.) were taken by the commercial fishery in water less than 100 fathoms deep. By far the greatest number of these young fish were taken in water less than 10 fathoms deep. On this evidence the first assumption was drawn for the young sardine survey—that the significant majority of sardines in their first year of life will be found inside the 100-fathom curve.

Clark (1947),[3] on the basis of a summary of vertebral counts of sardines, concluded that sardines from British Columbia to Point San Eugenio, central Baja California, comprise a mixture of populations, and that sardines south of Point San Eugenio probably comprise a distinct group which does not mix with the northern fish, or, if mixture occurs, the proportion of southern fish to the northern population is small. This conclusion permitted establishment of the southern limit of the survey in the vicinity of Point San Eugenio. Later information indicates this limit is not so clearly defined. The southern boundary was extended to Point San Juanico, 180 miles south. To keep the scope of the survey within the abilities of one vessel the northern limit for 1950 was placed at Point Arena, Central California.

It is known, however, that significant spawning and survival of young have occurred to the north of California. It is thought that the largest contribution to the great 1939 year class may have originated there. Sardines with maturing eggs were taken off Oregon and Washington in the summer of 1939. Great numbers of young began to appear in the inlets of British Columbia the following May. Because these young fish did not appear in shallow water until the following spring, survey of northern waters may yield more accurate results in the spring months. A reconnaissance of this area is projected, therefore, for May-June, 1951, if there is evidence of a significant spawning there in 1950.

[1] Scofield, Eugene C., *Early Life History of the California Sardine (Sardina caerulea) With Special Reference to Distribution of Eggs and Larvae*, Fish Bulletin No. 41, California Division of Fish and Game, 1934.

[2] Godsil, H. C., *A Discussion of the Localities in Which the California Sardine (Sardina caerulea) Was Taken in the San Diego Region, 1928-1929*, California State Fisheries Laboratories, Fish Bulletin No. 25, pp. 40-44, California Division of Fish and Game, 1930.

[3] Clark, Frances N., *Analysis of Populations of the Pacific Sardine on the Basis of Vertebral Counts*, Fish Bulletin No. 65, California Division of Fish and Game, 1947.

Methods of Collection

Sardines are attracted by a light suspended over, or underneath, the surface of the water. Also, schools of sardines can be located at night by the bioluminescence. Schools of young sardines were located by these means or by use of the recording fathometer as described earlier. They were taken by use of a small explosive charge dropped into the school. All the work was done at night.

Limitations

Before any conclusion can be drawn from the young fish survey the limitations of such a survey must be understood:

(1) Any measure of year-class success derived from the work must be relative. The relative measure must be compared for several years.

(2) Any change of efficiency in locating and identifying schools of young fish must be noted, and a correction applied.

(3) Proof of validity of the survey method is a comparison of values obtained from the survey with the relative measures of year-class strength of the same year classes obtained later from the commercial fishery. The 1950 year class will not appear in the commercial fishery for some time.

The 1950 Work

Four young sardine survey cruises were completed in 1950. The area from Point San Juanico, Baja California, northward to Bodega Head, central California, was surveyed. Of the many schools of fish sampled, 23 contained young sardines. The first cruise of the survey began 17 July, the last ended 20 October. Location of schools of young fish appear in Figure 36. The results of the cruises are indicated in Table I.

AVAILABILITY

There are several reasons why sardines can fail to appear in the usual numbers on proven fishing grounds. There can simply be fewer sardines, a decreasing
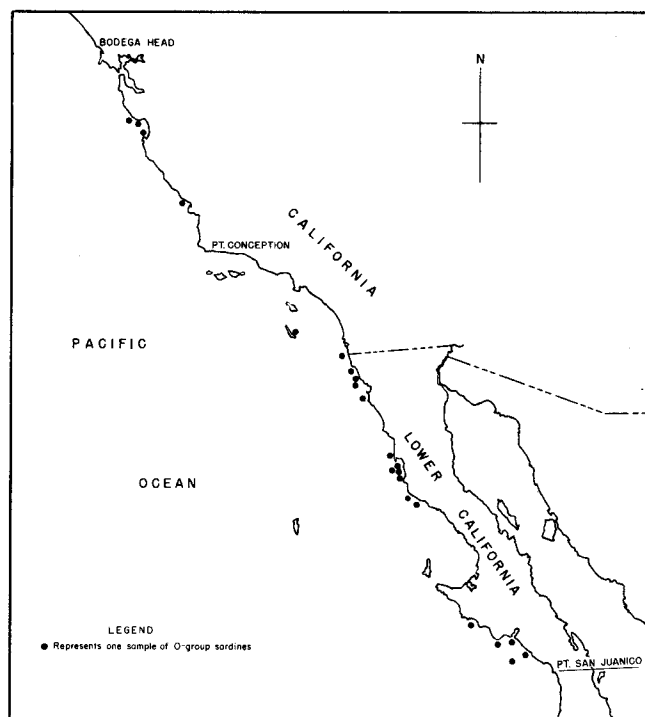
FIGURE 36. Location of schools of sardines during 1950 young-sardine surveys. Each circle represents one sample of 0-group (1950 year class) sardines.

TABLE I. YOUNG SARDINES FOUND IN 1950 YOUNG FISH SURVEY

Date	Time	N. Latitude	W. Longitude	General location	Depth of water (feet)	Number of fish	Standard length range (mm.)	Surface temperature (°C.)
26 July	2240	26° 41.6'	113° 34'	Ballenas Bay	45	1	40	18.5
27 July	0020	26° 39'	113° 16.5'	2.5 mi. S Punta Holcombe	90	3	68-79	19.0
27 July	0345	26° 24'	112° 52.5'	12 mi. NW Punta San Domingo	90	2	80-87	18.95
28 July	0440	26° 15'	113° 15'	33 mi. SE Punta Abreojos	280	62	52-89	20.0
28 July	2300	26° 28.5'	113° 35'	3 mi. S Punta Abreojos	140	47	91-127	18.3
29 July	0445	26° 59.5'	114° 05.5'	12.6 mi. SE Asuncion I.	210	100	100-182	15.5
2 Aug.	2310	29° 27'	115° 16'	4 mi. NW Punta Canoas	100	1	88	13.5
3 Aug.	0135	29° 35'	115° 27'	3 mi. SE Punta San Carlos	60	3	51-56	11.7
17 Aug.	0015	30° 00'	115° 50'	3 mi. NW Punta Baja	80	28	73-122	13.1
17 Aug.	0300	30° 03'	115° 49'	6 mi. N Punta Baja	78	2	83-118	13.2
17 Aug.	0350	30° 03'	115° 55'	8 mi. NW Punta Baja	210	63	109-125	13.6
17 Aug.	2150	30° 13.5'	115° 51'	10.5 mi. SE Cabo San Quintin	120	1	109	13.45
18 Aug.	0410	30° 29'	116° 04.5'	1 mi. E San Martin I.	70	4	56-81	14.75
21 Aug.	0305	31° 35.5'	116° 40.5'	Soledad Bay	105	24	106-128	17.3
22 Aug.	2230	31° 56'	116° 47'	1.7 mi. N Punta San Miguel	150	39	78-109	18.8
23 Aug.	0000	31° 54'	116° 46.5'	1 mi. SW Punta San Miguel	120	10	84-97	
23 Aug.	2120	32° 13.2'	116° 58'	Steamboat Rock, Descanso Bay	130	2	75-96	19.2
10 Sept.	0320	32° 31.5'	117° 09.5'	2 mi. off Mexican Boundary	80	4	84-111	18.4
11 Sept.	2235	32° 47.6'	118° 24.3'	1 mi. SE China Pt., San Clemente I.	220	5	51-88	17.75
9 Oct.	0350	36° 57.3'	121° 56.5'	1 mi. off Capitola	50	206	59-82	14.7
9 Oct.	2030	36° 56.5'	122° 00'	1.2 mi. E Pt. Santa Cruz	50	18	68-83	14.9
13 Oct.	1915	36° 36.5'	121° 53.2'	Monterey Harbor	30	292	69-89	13.7
18 Oct.	0110	35° 24'	120° 53'	1 mi. W Morro Beach	120	3	75-80	13.2

abundance. But the nonappearance can also be due to the sardines moving offshore, schooling at subsurface levels, occurring in less compact schools—there is a long list of possibilities. It was, of course, the possibility that these reasons are intimately connected with changing oceanographic conditions that led to the establishment of the present program. The study of availability —how many sardines are where the fishermen can catch them—is a major aspect of the present research. It is being attacked by the Division of Fish and Game and the U. S. Fish and Wildlife Service.

The Division of Fish and Game is trying to determine the environmental factors which influence the geographical distribution of the sardine schools. It is hoped to measure the effect of variations in physical, chemical, and biological oceanographic conditions on the availability of sardines to the fishing fleet.

The plan of the work is to measure the environmental conditions where sardines are found. A part of the work of the *Yellowfin* has been the collection of oceanographic data from waters where sardines are present. The methods of location (visually and by means of echo-ranging and echo-sounding apparatus) have been described under Instrumentation.

The *Yellowfin* was placed in service in September, 1949. By the end of October, 1950, a total of 249 pelagic schools of fish had been sampled from the vessel. Of these 249 schools, 57 percent contained more than one species of fish. Since the schools could not be identified from the sounding trace, it was necessary to collect samples. Three methods have been tried: (1) gill nets, (2) trawling, (3) explosives. The last method has proved most successful. Gill nets of a mesh size calculated to capture sardines have been very useful in areas where the fish could not be taken by other means, but the nets are highly selective with respect to the size of the fish captured. They probably do not take a random sample from the school. The trawl, which had a 12-foot opening, was towed at depths as great as 100 fathoms. At shallower depths, it was towed at speeds up to eight knots. It did not prove effective; no sardines were captured. Other species, including lantern fish and rock fish, were taken, however.

Once a school of sardines has been located and identified by a sample, the following environmental information is collected: (1) temperature (by a bathythermogram to 900 feet); (2) salinity (by water sample); (3) amount and kind of animal food (by plankton tow); (4) amount and kind of plant food (by water sample). The sardines themselves are measured, the scales are removed for age determination, and the stomachs removed for analysis of food. The gonads are saved for analysis of sexual maturity by the U. S. Fish and Wildlife Service as part of the work on spawning.

Since the *Yellowfin* was placed in service, 15 sardine cruises have been completed. They covered an area along the coast from Bodega Bay, north of San Francisco, southward to Magdalena Bay, in southern Baja

California. To 1 November 1950, a total of 216 days had been spent at sea. Samples had been taken from 145 schools containing sardines.

The schools containing sardines were found in waters ranging from 11° to 20.4° C. (51.8° to 68.7° F.). The relation of salinity to the presence of sardines cannot as yet be stated; shoreside analysis is not complete.

The analysis of the food contents of the stomachs of the sardines taken is proceeding, as is analysis of the plant and animal food found in the presence of schools. Approximately 700 stomach samples have been collected to date. The examination is necessarily a laborious job, and will take some months to complete. The studies to date have not demonstrated a tendency for the sardines to seek or avoid specific groups of organisms for food. Representatives of more than 35 groups of plants and animals, including larval fish and fish eggs, have been identified from the stomachs. The smallest organism found in the stomachs so far was 0.02 mm. in length, the largest 14.7 mm. In general those forms comprising the greatest bulk in the stomachs of the fish also comprised the greatest bulk in the water where the fish were taken.

Parasitic worms, trematodes of family Haemirudiae have been found in the digestive tracts of all fish examined to date. The role of these parasites in the life history of sardines is not yet known. They may constitute a serious handicap to the sardine or they may be tolerated without injury to the host.

Another line of investigation of availability is being followed by the U. S. Fish and Wildlife Service. The work involves the examination of previous catch records with respect to the deviations of the observed catch from the catch that would have been predicted on the basis of the age composition of the previous catches.

The advantages of this method include the use of a large number of data which are immediately available. It is also, compared to work at sea, inexpensive. But at present it can be considered only as an adjunct to the work at sea, not as a substitute for it. One disadvantage in the work thus far is the fact that the deviations observed include the effects in changes in rate of natural deaths as well as changes in availabilty.

Information on these deviations are now available from the 1941-42 through the 1948-49 seasons. The catches in the 1941-42 through the 1944-45 seasons were greater than would have been predicted. The catches in the 1946-47 through 1948-49 seasons were lower than would have been predicted. A manuscript describing the methods used and discussing the results obtained is in preparation.

Indirect evidence strongly suggests that sardine behavior, and hence availability, is influenced by temperature. The idea is borne out by the experiments on schooling behavior carried out by the California Academy of Sciences and described later in this report, and by observations on spawning. An extremely suggestive

relationship between the deviations in catch mentioned earlier and water temperatures off San Francisco has been observed. More adequate data are now being obtained so that this relationship may be investigated more thoroughly.

Data on the age composition of the catch indicate that about 25 to 50 percent of the decline in landings in the 1946-47 through 1948-49 seasons may be roughly attributed to the fish being less available or to their suffering a greater natural death rate during this period. About 50 to 75 percent of the decline may be attributed to reduced spawning success since 1939. As we see it now, this reduced spawning success is not directly related to the number of spawning fish. Therefore, the fluctuations in spawning success are apparently natural fluctuations. A manuscript on this work has been completed.

BEHAVIOR AND PHYSIOLOGY

Experimental work on the behavior and physiology of the sardines has been conducted at the California Academy of Sciences. The following results have been found:

Feeding Behavior

Preference for living (brine-shrimp) over nonliving organisms as food was displayed in the experiments.

Smaller sardines, averaging 75 mm. in length, exhibited a selective feeding habit. They displayed a rising motion to catch individual shrimp. Larger sardines (200 mm.), on the contrary, exhibited "seining" feeding, while swimming forward or circling about through the cloud of brine-shrimp. These were feeding regularly on adult brine-shrimp measuring around 8 mm. in length, but showed no response to newly hatched brine-shrimp measuring less than a millimeter.

In addition to sight, a chemical sense was used in locating food.

Schooling Behavior

Temporary isolation of a part of the school (up to 25 days) did not affect schooling tendency. Upon return to the original holding tank, isolated sardines joined and intermingled with the larger part of the school.

Three larger sardines (approximately 200 mm.) when added to a school of 50 smaller sardines (approximately 75 mm.) did not show any evidence of leadership in the movements of the school.

With reduction of the same school to 10 fish, the three larger sardines led the school and appeared to determine movements of the sardine school. Response, incidentally, seems greater to a single leader.

A minimum school unit was well exhibited by a pair of fish prior to their complete adaptation to aquarium conditions.

Definite increase in tendency to form close schools was observed at water temperature from 12° down to 6°C. Reduction in this tendency is effected by the higher water temperature, from 12° to 25 °C.

Clockwise swimming of the school was most frequently observed. However, when school of dummy (rubber) sardines was run counterclockwise, the sardines joined it.

Miscellaneous Observations

Reaction to the change in direction of water current was found to be negative.

Constant swimming is not necessary for respiration of the sardine, as it is for certain other pelagic species.

Bacteriological tests using pathogens failed to reveal any antibiotic activity of sardine slime.

Electrical Stimulation of Fish in Sea Water
Conditions of experiments

Wooden tanks of the following dimensions were used: 24" x 40" x 6", water 5" deep; 12' 7½" x 20" x12", water 5" and 6" deep. By using glass barriers this tank in certain experiments was reduced to 10' 6" in length in one case, and approximately to 7' in another.

Both carbon and steel electrodes were used with no apparent difference in effect upon the fish. Polarity of electrodes was reversible to eliminate as far as possible other environmental factors.

Types of fish tested and their standard lengths were: sardine 200-300 mm., top smelt 110-120 mm., and shiner, about 28 mm.

Types of electrical current applied: All the experiments carried out were made with different types of D. C. current. They are as follows:

A.   A. C. rectified current using full wave rectifier which delivers a current with low pulsating peaks of 120 cycles per second.

A-1.   This current was also used in on-and-off pulsations from 3 to 30 cycles per second.

B.   A. C. rectified current using half-wave rectifier which delivers pulsating current equal to A. C. frequency.

B-1.   The same current with frequency varying from 45 to 68 cycles per second.

C.   Straight D. C. current supplied by D. C. welding set.

C-1.   This current was cut on and off or made pulsating from 3 to 12 pulsations per second.

C-2.   These pulsations were used with current on two or three times as long as off, and current off two to three times as long as on.

C-3.   In some cases current was cut off to zero point between pulsations, in others current was reduced to one-half ampere only between pulsations.

D.   Condenser discharge using approximately 50-mf. condenser with voltage (pressure) varying from 100 to 600 volts. Frequency of discharge was varied from four to eight discharges per second.

Definition of terms

Directional effect is immediate involuntary orientation and movement of all the fishes tested toward positive pole in the tank. Slight directional effect is immediate involuntary orientation toward positive pole, but without, or with only slight, movement in that direction.

Confusing effect is any movement induced by the current different from those listed above.

Negative effect is one when no visible response to the current was observed.

Tabulation of records and results

Total number of experiments carried out—eight.

NUMBER OF FISHES BY SPECIES PER ELECTRICAL
TYPE-TEST APPLIED

Type of electrical test

Species	A	A-1	B	B-1	C	C-1,2,3	D	Total
1. Smelt	15	5	4	4	12	11	4	55
2. Sardine	2	0	0	0	10	3	1	16
3. Shiner	2	0	0	0	0	0	0	2
Totals	19	5	4	4	22	14	5	73

NUMBER OF TESTS PER TYPE OF ELECTRICAL STIMULATION

Type A	36 tests
Type A-1	15 tests
Type B	5 tests
Type B-1	10 tests
Type C	37 tests
Type C-1,2,3	85 tests
Type D	14 tests
Total	202 tests

TEST RESULTS BY TYPE, AND TOTAL

Type of electrical test

Effect	A	A-1	B	B-1	C	C-1,2,3	D	Total
1. Directional	1	0	0	0	1	31	0	33
2. Slight directional	11	7	4	2	21	23	3	71
3. Confusing	5	6	0	1	0	17	4	33
4. Stunning	1	1	0	5	4	4	0	15
5. Negative	18	1	1	2	11	10	6	49
6. Not recorded	0	0	0	0	0	0	1	1
Totals	36	15	5	10	37	85	14	202

Conclusions

As a result of these tests the type of electrical current found to be most effective in directional and controlled stimulation and the least injurious to the fish was direct current, three to four pulsations per second, the current being on two to three times as long as it was off.

A current density in sea water higher than 35 milliamperes per square inch seemed to have a detrimental effect on the fish in the form of temporary paralysis or death, depending on duration of the current and the size of the fish. This was especially true when nonpulsating current was used.

Strength of the current most effective in producing directional movement was inversely related to the size of the fish. For example, a current of three amperes was most effective with sardines of approximately 200-300 mm., whereas a current of four amperes was necessary to stimulate top smelt of approximately 110-120 mm. in length.

Because results in the above experiments have been encouraging, plans are being developed for similar tests in larger bodies of sea water.

CONTINUING STUDIES

Length Frequencies

A very useful tool for the measurement of what is happening to the sardine population is a record of changes of size of fish in the commercial catch. Since 1919 the Division of Fish and Game has made weekly measurements of the size of the sardines taken by the fishermen at Monterey and in Southern California. Similar records have been collected for the San Francisco fishery since the mid-thirties.

These measurements of the sizes of sardines, termed length frequencies, have told us that in the twenties fish taken in both Central and Southern California were smaller during the fall months and that larger sardines moved onto the fishing grounds during the winter. The winter fish appeared off Central California in December and off Southern California in January. There are now very few of these larger fish in the population. There is at present little size difference between the sardines taken in the fall and in the winter.

The length measurements also told us that in certain seasons an unusual number of young fish appeared in the fall fishery and in the succeeding seasons the sardines in this abundant group increased in size. We were thus able to trace the progress of the group through the fishery. These abundant groups have been interpreted as representing year classes in which survival from a given season's spawning was unusually successful and are termed dominant year classes. Prior to the mid-thirties the dominant year classes appeared in the fishery at intervals of two to four years. This marked variation in spawning success plays a very important role in the total abundance of the sardine population and in turn in the success of the fishery. This has been especially true in the last decade because the larger fish have largely disappeared from the catch and the fishery has become more and more dependent on the smaller sardines. As a result, when there are several seasons in which spawning success is below average, the recruitment of young sardines is poor, and fewer fish appear on the fishing grounds.

The dominant year classes, which have been identified in the fishery by the length measurements, have also given us a measure of the migrations of sardines along the coast. With one or two exceptions, a superabundant group has first appeared in the Southern California fishery, a year later in Central California, and two to four years later in the Pacific Northwest.

Age Determinations

During the latter part of the thirties the U. S. Fish and Wildlife Service developed methods for determining the age of the sardine by an examination of its scales. The age analysis of a fraction of the length samples was started on a systematic cooperative basis

between the federal agency and the Division of Fish and Game in 1941. The work is continuing, and effort is being made to improve sampling procedures. Samples are obtained by the state agency from boats making landings in San Pedro and Monterey. The San Francisco catch is sampled by the federal agency, and scale samples are sent to its Stanford laboratory from the Oregon Fish Commission, the Washington Department of Fisheries, and the Pacific Biological Station (when there is a fishery in the Pacific Northwest).

The age and length studies have demonstrated that very good spawn survival occurred in 1939 but that during the next five years spawning success grew progressively worse. Conditions were better in 1946, and in 1947 a fairly abundant year class was produced.

The percentage distribution of the Pacific Coast sardine catch by year class for 1948-49 and 1949-50 was as follows:

	Percentage	
Year class	1948-49	1949-50
1948	0.1	7.8
1947	32.8	51.4
1946	49.9	27.9
1945	10.8	8.2
1944	3.9	4.0
1943	1.4	0.5
1942	0.5	0.1
1941	0.2	0.1
1940	0.3	---
1939	0.1	---
Totals	100.0	100.0

It is evident that in both seasons the major support of the fishery came from the 1946 and 1947 year classes, fishes one and two years old in 1948-49 and two and three years old in 1949-50. Fish older than three years were scarce and contributed less than 10 percent to the catch. There were no indications that the 1948 and 1949 year classes will appear on the fishing grounds in exceptional numbers. The 1946 and 1947 groups will presumably have to supply much of the tonnage taken in the next two or three years.

The collected data on age distribution are of value in several different lines of inquiry. Their part in availability studies has already been mentioned. They are also used in racial studies and form the basis for the study of vital statistics.

Racial studies

Racial investigations may be carried out by studies of physical characteristics, by studies of physiological characteristics, and by an appropriately designed tagging program. Ideally it would best be done by all three approaches. High costs usually eliminate tagging work.

Some preliminary collections have been made for studies of physical characteristics, but major emphasis has been placed on physiological characteristics—especially growth characteristics as revealed by the study of scales. The U. S. Fish and Wildlife Service uses as a method whereby it is believed the year-to-year fluctuations in growth caused by favorable or unfavorable environmental fluctuations can be distinguished from the inherent or heredity-connected differences in growth. This study indicates that there is a "northern type" of sardine—which grows faster and attains a larger size—and a "southern type"—which grows more slowly and does not attain such a large size. The northern type is found wherever the fishery is carried out. The southern type is most abundant on the San Pedro fishing grounds and is found in decreasing abundance to the north.

One explanation of these observations is that there are two races of sardines: one ranging from Southern California to British Columbia, the other occurring to the south of this area, but spreading north over the southern portion of the range of the northern race.

During the 1949-50 season, more fish of the groups spawned in 1943, 1944, and 1945 were caught than would have been predicted from previous catches of these year classes. According to the hypothesis just stated, this "surplus" could represent an influx of the southern race into the California fishery. Further, fish of the 1944 year class caught in 1949 were smaller than expected. This difference cannot be explained by the emigration of the larger fish of that year class; it must represent an influx of smaller fish. It should be emphasized that this is only one possible hypothesis. At least part of the observations could be explained on the basis of changes in availability.

The question whether there are one or more races of sardines is by no means settled. The above observations are only contributing pieces of evidence. This question must be answered, however, for the interpretation of all other sardine data will be influenced accordingly. A preliminary report on this work is in preparation.

Vital statistics

Since 1919 the Division of Fish and Game has collected detailed records of the daily deliveries of individual boats. These have been supplied by the dealers, who furnish the division with a copy of the original receipt given the fishermen. From these records the average monthly or weekly catch of the fishermen has been calculated each season since 1932-33. These measures of fishermen's success give us the most reliable available estimates of the abundance of sardines on the fishing grounds and of the differences in numbers of fish in each individual year class; they are therefore of inestimable value in determining the condition of the sardine population.

The fishing success in 1948-49, based on average monthly catch, was twice that of 1947-48. It doubled again in 1949-50. The greater abundance of the 1946 and 1947 year classes largely accounted for this increased success of the fishermen. However, although the catches increased in the past two seasons, they appeared highly successful only in comparison with the very lean years in 1946-47 and 1947-48. They were on a par with the catches of 1945-46.

With the vital statistics we now have it is impossible to assess the relative importance of the two death rates, that from fishing and that from natural causes.

While estimates of relative abundance of the population may be obtained from catch per unit-of-effort studies, we need estimates of absolute abundance of the population. Under present conditions, it is probably only possible to obtain such estimates from a tagging program or from trying to determine the total number of eggs spawned during a season and calculating the number of fish required to produce those eggs. Only the latter approach is being developed now.

Once an estimate of the absolute abundance of the population is obtained, information from samples of the commercial catch can be analyzed to yield the death rate from fishing and the death rate from natural causes. These results will supplement theoretical studies presently being carried out.

Compilation and analysis of data that will give information on the age composition of the catch from 1932 to 1938 (before scale samples were taken) has been undertaken by the U. S. Fish and Wildlife Service and is nearing completion. This information will add six years to the data series pertinent to vital statistics and availability studies.

MARINE BIRDS AND MAMMALS

As a matter of routine, counts of black-footed albatrosses have been made at each hydrographic station since cruises began in 1949. As indicated by the regular northward progression of the region of maximum abundance in spring, a strong northerly migration of birds took place during the spring and summer of 1949, followed by a southward and offshore movement in late fall. In 1950, on the other hand, no such regular shift in the distribution patterns has been detected. It is possible that this change may reflect differences in the oceanic circulation in the two years that affected bird movements. In 1949 it was noted that the pattern of albatross distribution corresponded in general with the annual northward migration of sardines. In that year, sardine fishing was considerably better off San Francisco than it has proved to be in 1950. Possibly the movements of sardines and birds are subject to similar influences.

Routine observations on the occurrence and abundance of whales, porpoises, and seals are being recorded. In general, whales and porpoises, as well as seals, are more abundant in the inshore areas. Certain regions of dominant abundance have been noted, for example, in the area north of Point Conception.

FIGURE 37. The occurrence and abundance of seals, other marine mammals, and marine birds are noted during the survey cruises.

Summary

Four seagoing vessels are used in the California Cooperative Sardine Research Program. In the past two years oceanographic conditions in the offshore area from Oregon to central Baja California have been regularly measured. As a result, a mass of detailed and accurate data has been accumulated. These data comprise a permanent contribution to scientific knowledge.

In the course of the program, new techniques for collecting and, particularly, for the processing the data have been worked out. New instruments have been designed, developed, and tested. Several of these, among them the gear for high-speed tows, are of outstanding importance.

Our studies of the sardine's environment have succeeded in further relating changing oceanographic conditions to changing weather conditions. We have found unquestionable evidence of upwelling, which provides conditions favorable for the survival of larvae, at several locations off the coast, notably off Cape Mendocino and Point Conception.

Two centers of spawning abundance have been located. One is in the vicinity of Cedros Island, off Baja California, the other is off Southern California and northern Baja California. Spawning is more intense, though limited to a smaller area, off Cedros Island. As shown by the 1949 and 1950 data, these are the present centers of sardine spawning off the Pacific Coast.

It has been found that most spawning occurs in waters between 12.5° and 16.5° C. During the 1950 season, 98.4 percent of the spawning samples were found within a slightly narrower range—12.5° to 16° C.

Surface temperatures during the spring of 1950 were slightly lower than in 1949 in most of the area covered.

Schools containing adult sardines have been found in waters ranging from 11° to 20.4° C. Other oceanographic factors are being examined.

Under laboratory conditions, it was found possible to cause sardines to move in a desired direction by use of electric current in sea water.

Examination of the statistics for the 1948-49 and 1949-50 sardine catches indicated that the major support of the fishery came from the 1946 and 1947 year classes. There were no indications that the 1948 and 1949 year classes will appear on the fishing grounds in exceptional numbers. The 1946 and 1947 groups will presumably have to supply much of the tonnage taken in the next two or three years.

Plans for 1951

In the main, work under the California Cooperative Sardine Research Program will continue along the present lines during 1951. The seagoing work cannot as yet be curtailed or simplified without running the risk of failing to obtain information of basic importance.

The California Academy of Sciences plans to pursue further its study of the behavior of fish in an electrical field. Other behavior patterns of sardines will be investigated.

The California Division of Fish and Game will continue its collection and analysis of the daily catches of the fishermen and, in cooperation with the U. S. Fish and Wildlife Service, the age composition of the commercial catch. Collection of records of the poundage of sardines used in the California live-bait fishery will be carried on as in the past and analyzed as a supplemental measure of the abundance of the 1951 year class. The *Yellowfin* will make a survey of the 1951 year class during the months of July through October and, in the first six months of the year, will continue the collection of data to measure the conditions under which sardine schools are found.

The Scripps Institution of Oceanography hopes to make use during the coming year of a newly developed oceanographic instrument of great potentialities. The instrument, which was developed at the Woods Hole Oceanographic Institution, is the geomagnetic electrokinetograph ("jog log"). By its use, surface current direction and speed can be measured. Such information will prove extremely useful in physical oceanography, and cannot be readily obtained in any other manner. Also, intensive work will be done at the Scripps Institution on the development of electronic instruments for use in oceanography. Efforts will be made to collect hydrographic and chemical data near shore, and to determine the amount of replenishment and to study dispersion effects, nutrients, and the accompanying productivity. Further work will be done on the heat budget and evaporation study.

The U. S. Fish and Wildlife Service will continue its recruitment studies and its participation in the routine oceanographic surveys. The Service will also continue to cooperate with the Division of Fish and Game in the collection of samples and will continue analysis of vital statistics of the sardine catch.

The year promises to see the publication of several scientific papers on various phases of the program. The physical and chemical data from at least 10 more cruises will be distributed to scientific personnel.

APPENDIX I

PERSONNEL ENGAGED IN RESEARCH UNDER CALIFORNIA COOPERATIVE SARDINE RESEARCH PROGRAM

NOTE: Not all the persons listed below are paid from sardine research funds; all, however, are contributing to research under the program.

Name	Position
CALIFORNIA ACADEMY OF SCIENCES	
Grant, Norman	Electrical Engineer
Groody, Thomas C.	Marine Biologist
Loukashkin, Anatole S.	Assistant Biologist
CALIFORNIA DIVISION OF FISH AND GAME	
Clark, Frances N.	Senior Marine Biologist
Clothier, Charles	Assistant Marine Biologist
Conner, Geraldine	Assistant Statistician
Daugherty, Anita E.	Assistant Marine Biologist
Eberhardt, Robert L.	Junior Aquatic Biologist
Herndon, Edward M., Jr.	Senior Clerk
Johnson, Einar M.	Watchman
Kuykendall, Vinna	Tabulating Machine Operator
Nelson, Helen	Supervising Account Clerk
Pinkas, Leo	Junior Aquatic Biologist
Ponder, Ruth	Junior Stenographer-Clerk
Powell, Patricia	Senior Librarian
Pratt, George W.	Watchman
Radovich, John	Junior Aquatic Biologist
Rinard, Rose	Intermediate Stenographer-Clerk
Wilson, Robert C.	Assistant Marine Biologist
Young, Parke H.	Assistant Aquatic Biologist

(Yellowfin crew)

Felando, Andrew, Jr.	Netman and Boatswain
Haldane, Herbert S.	
	Radiotelegraph Operator and Assistant Engineman
Hawkins, Glen T.	Deckhand
McLeod, Rory A.	Deckhand
Mills, Robert A.	Motor Vessel Engineman
Mitchell, Otto N.	Deckhand
Petrich, Paul D.	Master, Fisheries Vessel
Pruitt, Harold E.	Assistant Motor Vessel Engineman
Roth, Lewis	Ship's Cook
Thompson, Robert W.	Deckhand

SCRIPPS INSTITUTION OF OCEANOGRAPHY

Allanson, Audley A.	Marine Technician
Barkley, Richard A.	Laboratory Technician
Barney, Ruth M.	Typist-Clerk
Barraclough, William E.	Research Assistant
Barstow, Mary C.	Laboratory Technician
Beckwith, Warren W.	Senior Marine Technician
Berberich, Frank J., Jr.	Electronics Engineer
Bieri, Robert I.	Research Assistant
Bowman, Thomas E.	Assistant in Marine Biology
Brinton, Edward	Research Assistant
Burgeson, Willis M.	Senior Storekeeper
Carlson, Deane R.	Marine Technician
Cawley, John H., Jr.	Principal Electronics Technician
Clark, Peter S.	Marine Technician
Cunningham, Leonard M., Jr.	Marine Technician
Dare, Marjorie C.	Secretary-Stenographer
Dinkel, Charles C.	Assistant in Marine Chemistry
Edinger, Richard M.	Expediter
Edwards, Frank H.	Marine Technician
Folsom, Theodore R.	Senior Laboratory Mechanician
Fraser, Howard S.	Guard
Godfrey, Mary L.	Engineering Aide
Gossett, David A.	Marine Technician
Handley, Ruth R.	Principal Clerk
Hayes, Margaret A.	Laboratory Assistant
Herreshoff, Karl F.	Marine Technician

Name	Position
Horrer, Paul L.	Associate in Oceanography
Howard, Francis J.	Research Assistant
Hubbs, Carl L.	Professor of Biology
Huffer, Robert P.	Senior Marine Technician
Hutchins, Dorsey M.	Typist-Clerk
Isaacs, John D.	Associate Oceanographer
Johnson, Carl I.	Senior Laboratory Mechanician
Johnson, Martin W.	Professor of Marine Biology
Johnson, Norman W.	Marine Technician
Kelmers, Andrew D.	Marine Technician
Klein, Hans T.	Senior Engineering Aide
Knight, Wilbur L.	Marine Technician
McHugh, John L.	Assistant Marine Biologist
Manar, Thomas A.	Editor
Mao, Han Lee	Research Assistant
Marquardt, Robert L.	Senior Marine Technician
Moser, Douglas K.	Storekeeper
Petersen, Evans E.	Guard
Phillips, Howard	Maintenance Man
Pruitt, Milo R.	Senior Laboratory Mechanician
Rakestraw, Norris W.	Professor of Chemistry
Reid, Joseph L.	Research Assistant
Reid, Robert O.	Assistant Oceanographer
Revelle, Roger R.	Professor of Oceanography and Acting Director of the Scripps Institution of Oceanography
Riley, Gordon A.	Visiting Associate Professor
Sampson, Robert K.	Senior Marine Technician
Sargent, Marston C.	Assistant Professor of Oceanography
Sibley, Slade W.	Marine Technician
Snodgrass, James M.	Associate Marine Biologist
Squire, Mary C.	Laboratory Technician
Stockman, Arthur M.	Laboratory Assistant
Stose, Clemens W.	Marine Superintendent, Hull
Sullivan, Joe	Janitor
Sweeney, Beatrice M.	Research Associate
Trent, Luz F.	Laboratory Technician
Vetter, Richard C.	Research Assistant
Waitley, Diane	Typist-Clerk
Walker, Theodore J.	Instructor in Marine Botany
Watters, Ardis H.	Typist-Clerk
Weaver, Maxine N.	Secretary-Stenographer
Whisenand, Alice A.	Laboratory Technician
Wilburn, Virginia A.	Statistician
Wisner, Robert L.	Senior Laboratory Technician
Wooster, Warren S.	Associate in Oceanography

(Crest crew)

Brandal, G.	Captain
Fox, F. E.	Chief Engineer
Gonyea, L. J.	Marine Electrician
Kelley, G.	Second Engineer
Kelsay, W. C.	Seaman
Kittel, R. P.	Marine Electronics Technician
Mehling, M. J.	A.B. Seaman
Miller, F.	First Officer
Newbegin, R. C.	Second Officer
O'Brien, R. J.	Second Engineer
Powell, A. L.	Seaman
Robinson, W. F.	Cook
Stowe, R. D.	Seaman
Walker, J. M.	Oiler

(Horizon crew)

Carter, A. B.	Marine Electronics Technician
Chapman, T. H.	Seaman
Daniels, E. F.	Second Engineer

Name	Position
Faughn, J. L.	Captain
Fenton, G. M.	Oiler
Fleming, C. S.	Oiler
Foster, E. G.	Seaman
Keith, L. E.	Seaman
King, W. C.	Second Engineer
Lewis, C. H.	Chief Engineer
Maracin, M. W.	Second Officer
Massey, J.	Chief Engineer
Miller, H. A.	Seaman
Nolan, F. J.	Second Officer
O'Callaghan, T. J.	Oiler
Proulx, E. J.	Marine Electrician
Vaughn, F.	Cook

(*Shop* force)

Cundiff, L. A.	Second Engineer
Ringel, F.	Electrician

U. S. FISH AND WILDLIFE SERVICE

Ahlstrom, E. H.	Supervising Marine Biologist
Anas, R. E.	Biological Aid
Attebery, H. R.	Biological Aid
Ball, O. P.	Biological Aid
Calderwood, M. M.	Marine Biologist
Colter, J. C.	Chemistry Aid
Counts, R. C.	Marine Biologist
Dougherty, J. B.	Marine Biologist
Eckles, H. H.	Marine Biologist
Felin, F. E.	Marine Biologist
Giffin, B. M.	Chief Clerk

Name	Position
Higgins, M. D.	Clerk-Typist
Jordan, C. W.	Biological Aid
Kramer, D.	Marine Biologist
Marr, J. D.	Chief, South Pacific Fishery Investigations
Mead, G. W.	Collaborator
Morris, N. L.	Clerk-Stenographer
Murray, M. B.	Statistical Clerk
Myers, G. S.	Systematic Zoologist (fish)
Permenter, D. O.	Biological Aid
Reitman, M.	Biological Aid
Russell, P. S.	Clerk-Stenographer
Squire, J. L.	Biological Aid
Takeuchi, M. S.	Clerk-Stenographer
Thrailkill, J. R.	Marine Biologist
Walker, E. T.	Marine Biologist
Walser, C. W.	Marine Biologist
Widrig, T. M.	Statistician
Wilimovsky, N. J.	Collaborator

(*Black Douglas* crew)

Burbridge, A.	Cook
Byers, W. A.	First Engineer
Fedlshau, O. J.	Second Mate
Houston, G. O.	Messboy
Hovde, H.	First Mate
Jenkins, K. C.	A.B. Seaman
Joelson, S. M.	Captain
McGoldrick, W. E.	A.B. Seaman
Moller, A. E.	A.B. Seaman
Ryerson, J. L.	Chief Engineer
Schaefer, J.	Second Engineer

APPENDIX II

CURRENT PROJECTS UNDER CALIFORNIA COOPERATIVE SARDINE RESEARCH PROGRAM

CALIFORNIA ACADEMY OF SCIENCES

Project	Chief Scientist
Physiology and Behavior Studies	Thomas C. Groody

CALIFORNIA DIVISION OF FISH AND GAME

Age-Determination and Length Frequency	Anita E. Daugherty
	Leo Pinkas
Average Monthly Catch of Fishing Vessels	Frances N. Clark
	Anita E. Daugherty
Environmental Factors Affecting Availability	Robert C. Wilson
Relation of Food to Availability	John Radovich
Young Fish Survey	Robert C. Wilson

SCRIPPS INSTITUTION OF OCEANOGRAPHY

Studies in Physical Oceanography	Robert O. Reid
	Paul L. Horrer
Studies in Chemical Oceanography	Warren S. Wooster
Marine Botany	Marston C. Sargent
Marine Invertebrate Plankton	Martin W. Johnson
Marine Vertebrates	J. L. McHugh
Special Developments	John D. Isaacs
	James M. Snodgrass

U. S. FISH AND WILDLIFE SERVICE

Availability Studies	T. M. Widrig
Racial Studies	F. E. Felin
Recruitment Studies	E. H. Ahlstrom
Vital Statistics (current)	J. C. Marr
Vital Statistics (1931-1940)	H. H. Eckles

ACKNOWLEDGMENTS

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