

PART I
REVIEW OF ACTIVITIES

July 1, 1960 - June 30, 1962

REPORT OF THE CALCOFI COMMITTEE

INTRODUCTION

This series of reports serves as a means of directly publishing some of the scientific results of the CalCOFI research program, especially certain lengthy contributions particularly well served by the format. These occupy the bulk of each issue. In addition, it serves as a general report to the public by indicating the complete scope of the scientific research through an annotated bibliography, including general reports on the status of the fisheries, and describing the activity of the individual laboratories. Finally, especially in this section, an attempt is made to unify the diverse approaches and results of the several laboratories hoping thusly to more nearly approximate the singularity and unity of the natural world.

This last is perhaps the most important function for it strives to achieve cohesiveness and continuity, gives meaning to the total scientific effort by integrating the findings and activities of individual research projects, and presents an intimation of the impact of these findings on the concepts by which the program is guided.

In an equivalent statement in Volume VIII of the Reports, the Committee summarized its objectives and findings and asked a series of critical questions as to the regime of the sardine and other pelagic fishes in the California Current System. Since then much progress has been made in clarifying the conditions under which pelagic fishes live. In particular much is being learned about the interaction of two major species, the sardine and the anchovy. The emerging results are particularly gratifying.

Viewed from the development of marine science the results are a source of encouragement, as they reveal the possibilities for understanding the interplay of various species and their environment—an exciting ecological rapport exceedingly difficult to achieve in the vastness of the ocean. Viewed from the development of marine resources, such understanding opens up the possibility of a more realistic appraisal of the effect of fishing on the ecological system and even of directing man's intervention so that a more useful ecosystem is established.

DEVELOPMENTS

The period July 1, 1960 through June 30, 1962 has seen an accelerated expansion of Marine Sciences. The rapid world-wide development of new fisheries; the power of the seaborne deterrent, Polaris; the interest in sea water conversion; the recognition of vast mineral deposits on the sea floor; the Mohole project;

and many other developments have more clearly focused the attention of scientists and the public upon the significance of the vast ocean resources to meet human needs. The increased requirements of man to dispose of his wastes, atomic and other, and even the increased need for outlets for adventure and recreation have also brought added attention to the marine realm and increased recognition of its challenge.

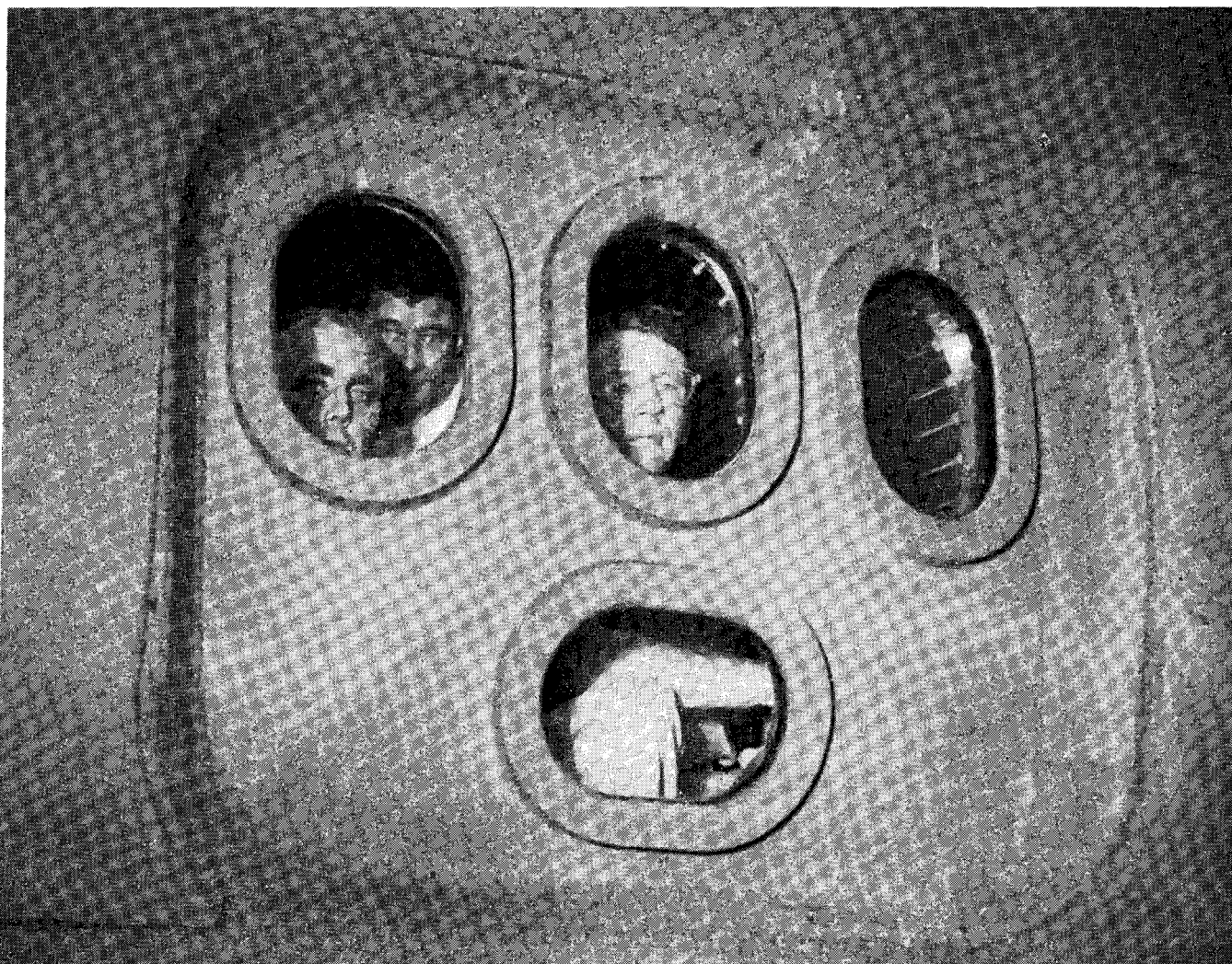
It is not surprising, therefore, to find the CalCOFI Program during this period not only expanding its scope but also intensifying its concentration on the factors influencing the organisms in pelagic waters. Furthermore, additional support has been forthcoming to aid in the expansion and intensification of the research with new facilities becoming available. The M/V ALEXANDER AGASSIZ has been obtained and outfitted especially for the Scripps portion of the CalCOFI Program; a new ship is on the drawing boards for the Bureau of Commercial Fisheries; the Bureau has funds and plans for a new laboratory building. A new hydraulic facility suitable for large scale biological experiments is funded and soon to be constructed by the University of California. Research supported by CalCOFI in other organizations is becoming independently supported. The deep sea research of the Department of Oceanography of Oregon State College, encouraged by CalCOFI support, is now proceeding independently with the new ship, ACONA. Similar work at the Dillon Beach Laboratory of the "University" of the Pacific will probably be independently supported next year.

These developments are further detailed in the separate reports of the individual agencies. The above is a resume of the increasing importance of marine research, the physical facilities, and financial support that CalCOFI is receiving, but research cannot be measured in terms of the level of support that it receives.

FINDINGS

The real substance of this report is the understanding that has been achieved and the illumination that has been shed on the problem of the ecology of the California Current System, the inhabitants and, in particular, on the sardine as a member of a community.

In Volume VIII of the CalCOFI Report the Committee expressed the hypothesis that the niche occupied by the sardine has been largely taken over by the anchovy, perhaps mediated by a long period of colder



The Alaska's underwater viewing ports. Photograph by Charles H. Turner, Department of Fish and Game.

than normal years and abetted by the activity of the fishery in concentrating mainly on the sardine. Subsequent investigations have lent support to this opinion. The sardine plus the anchovy may act as a single population in exploiting the environment and in filling the space that is available. It appears that the sardine-plus-anchovy population of the California Current is now enjoying the success and abundance previously enjoyed by the sardine virtually alone. The two species may act in close concert in utilizing the environment and may exist in widely varied equilibria, with sardines in dominance at one time and a preponderance of anchovies at another.

Much more is being learned about these two species, their associates, and the conditions under which they exist. The existence of separate spawning stocks (sub-populations) of sardines has been established. Community associations of zooplankton species have been related to particular water masses. Research has pointed out mechanisms by which organisms become highly concentrated along coast lines; has expanded into the nature of growth and mortality of larval fish; and has elucidated details of circulation of the Cali-

fornia Current which so profoundly influence its inhabitants. One major discovery has been that preserved samples may be more readily converted into biomass indices than would have been thought possible from fresh samples. This has allowed the beginnings of a program of biomass analysis. Further comments on these and other investigations are included in the sections to follow. *E. H. Ahlstrom, J. D. Isaacs, G. I. Murphy, J. Radovich.*

AGENCY ACTIVITIES

California Department of Fish and Game

The Department conducted investigations on most commercial and sportfishes inhabiting the waters of California. Investigations of the pelagic wet fisheries—sardine, anchovy, Pacific mackerel, jack mackerel, herring, and squid—were conducted by the Department's Pelagic Fish Investigations. A major portion of the effort expended on these species was directed toward collecting basic information, data providing a foundation for more sophisticated studies by all CalCOFI scientists.

Our investigative work included:

- (1) Determining the amounts landed of anchovy, herring, Pacific mackerel, jack mackerel, sardine and squid.
- (2) Measuring the sizes of year-classes of the anchovy, Pacific mackerel, and sardine fisheries. Aging of the sardine and anchovy catches is done in cooperation with the U.S. Bureau of Commercial Fisheries.
- (3) Measuring fishing effort and determining fishing localities. This was done through fishermen interviews and log books.
- (4) Measuring the relative abundance and distribution of fish populations with particular emphasis on the sardine. This work was done at sea, on the fishing grounds and beyond, to cover those portions of the various populations not accessible to the fishing fleet. The survey area extends from central California to the southern tip of Baja California, Mexico, and occasionally into the Gulf of California.
- (5) Measuring abundance and distribution of inshore pelagic fish schools, particularly of the anchovy, by aerial surveys.

In addition to the regular work, special cruises were conducted to improve fish sampling techniques and to obtain live sardines for serological studies conducted by the Bureau of Commercial Fisheries.

One cruise, in early 1962, into the Gulf of California to obtain sardines for blood genetics proved to be of special significance. Sardines were collected throughout most of the Gulf and were serologically tested by U.S. Bureau of Commercial Fisheries personnel. These tests established that Gulf sardines constitute the third known, distinct, non-interbreeding, subpopulation. The other two subpopulations, designated as "northern" and "southern" occur off California and Baja California, Mexico. In conjunction with the serological studies that are designed to distinguish the different stocks of sardines along the coast, the Department continued sardine morphometric studies. This attempts to determine if phenotypic differences can be recognized corresponding with the genetic separation obtained from the serological work.

In order to facilitate fish sampling at sea, the research vessel, ALASKA, was fitted with an underwater viewing chamber. Viewing ports in this chamber will also allow observing fish behavior in a natural environment.

Work was continued on the effect of water temperatures on fish distribution and two papers were published on the subject. A density dependent model describing the relationship between year class size and stock size was developed and the model with its supporting evidence was published.

Hopkins Marine Station

In the period July 1, 1960-June 30, 1962, the Hopkins Marine Station of Stanford University has continued to monitor the marine climate and plank-

ton in the Monterey Bay area. Approximately weekly cruises were made on Monterey Bay, daily shore temperatures were reported from Pacific Grove and Santa Cruz, and once a month shore temperatures were taken at selected stations along the coast between Monterey and Morro Bay. The data collected in these operations have been compiled and distributed to interested agencies and individuals in the form of mimeographed quarterly and annual data reports. The general findings during this period indicate the end of the warm trend, and a return to the general oceanographic conditions prevailing in the first half of the decade 1950-1960.

The information accumulated in the survey of the Monterey Bay area during the years 1954-1960 is summarized and interpreted in a paper appearing elsewhere in this Report (Bolin and Abbott—Studies on the marine climate and phytoplankton of the central coastal area of California). The findings discussed bear out the value of continued monitoring of conditions in selected areas, providing the sort of information on marine conditions that weather stations provide on atmospheric conditions.

Scripps Institution of Oceanography Marine Life Research Program

The Marine Life Research (MLR) Program, Scripps' portion of the CalCOFI Program, has undergone a number of important developments and changes in the last two years. Many of these changes have been the result of new discovery and evolving concepts. Others have stemmed from the quickening tempo of marine research in general. The following is a brief summary of the research and developments of the Marine Life Program. Detailed results have been published elsewhere.

In the early years of the CalCOFI Program, the waters of the California Current region were characterized by surface temperatures somewhat lower than the long-term mean. In 1957, however, the temperature began to rise and in 1958 and part of 1959 the waters were substantially warmer nearly everywhere over the region.¹

In 1960 conditions became more nearly normal, that is, instead of the huge areas of above or below normal temperatures that had characterized the "unusual" years, there were small areas of above or below normal temperature irregularly alternating over the region. Thus the last two years of the California Current region cannot be categorized as either warmer or colder than normal. This period of "normal" temperature has lasted through October, 1962.

These variations of temperature have been shown to be related to the behavior of the wind. The period from 1948 through 1956 was characterized by winds from the north that were somewhat stronger than the mean; 1957 and 1958 showed weaker winds than normal. Since 1959 the winds have varied rapidly and irregularly, and no consistently strong or weak periods have occurred. The first component of an atlas of

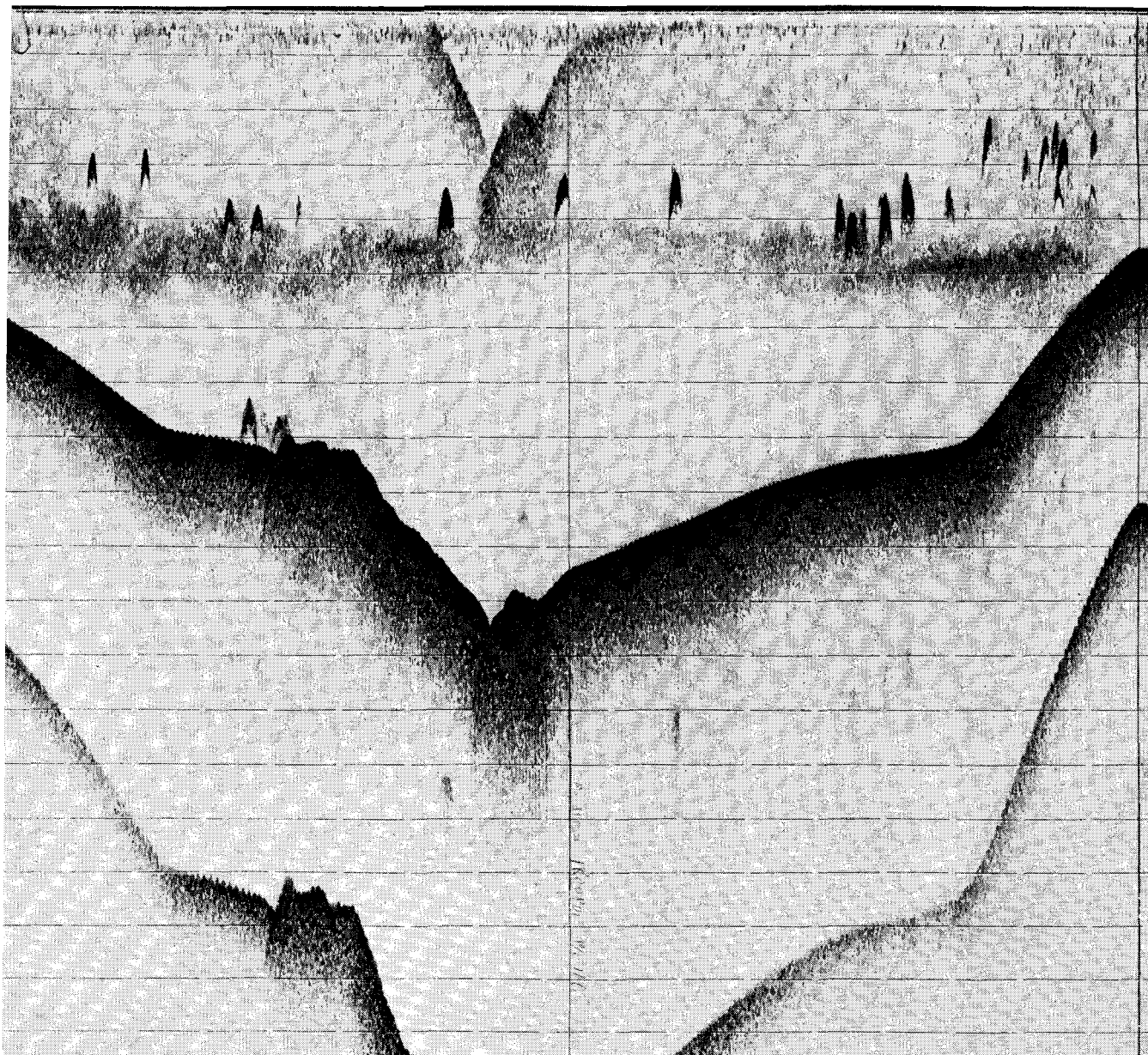
¹ The weather, oceanography, climatology, and biology of the period 1948 to 1958 were extensively reviewed in the CalCOFI Report No. VII.

the California Current (10-meter conditions) has been completed.

Direct current measurements have been continued in critical parts of the California Current. Studies with drogues in the area off central California in autumn have revealed details of the annual beginning of the northward-flowing coastal Davidson Current. Its full development in mid-winter has shown speeds up to 0.4 knot and a width about 50 miles. The existence of the northward flowing undercurrent along the California coast, indicated by the distribution of heat, salt, oxygen, and density has been directly confirmed by studies with drogues 250 meters beneath the sur-

face. These showed that the current had a maximum speed of 0.4 knot and a width of about 40 miles (Reid, 1962). A more detailed study of small-scale eddies has been carried out off northern Baja California, and clearly showing their important role in the process of mixing, and dramatically confirming the efficiency of standard oceanographic methods as a means of describing even small scale features of the currents.

The Cape Lookout Survey revealed strong internal wave activity and a great concentration of zooplankton organisms associated with it. A similar survey of conditions off Cape Colnett also revealed great concentrations of organisms. These were vertical migrat-



Acoustic record of deep scattering organisms and schools of predators concentrated off Cape Colnett. The vertical scale is 20 fathoms per line. The inverted "V" shaped echoes are predator schools which are so dense as to show secondary reflections over the lower of the two false bottoms. The diffuse trace at 100 fathoms is the scattering layer. Two secondary reflections of the bottom are shown, one above and one below the heavy central bottom trace. These are the result of sound bouncing back and forth between the bottom and the ship.

ing zooplankters carried in over the continental shelf by the current that sweeps shoreward in this area. Some phases of this concentration involved intense predation by resident fish in which hake and anchovies were present.

Mutant strains of bacteria for the bio-assay of 19 trace amino acids, vitamins, etc., have been developed. These substances can now be detected in concentrations as small as ten-parts per billion. Development of additional mutants has ceased and we are preparing to carry out synoptic surveys of some of the substances in the California Current System.

The first deep-midwater trawl survey was carried out over the CalCOFI Survey Pattern and the catches were analyzed. A continuation of this work has been supported by the Atomic Energy Commission, and deep collections of organisms and hydrographic data will now extend the MLR Surveys to the bottom of a large portion of the California Current System.

All major groups of zooplankton were under study and their distribution in the eastern North Pacific was collated. The limits of distribution, the changes during the years, and the associations of species of arrow worms, copepods, euphausiids, and pelagic mollusks was brought to a stage of description that has permitted the beginning of a comprehensive atlas of these creatures. The species of zooplankton with which fish larvae are associated are emerging from these studies, and the species of phytoplankton will soon be added to the analysis of associated organisms.

A major task that remains is the analysis of plankton samples in a way that reveals the most information with respect to zooplankton as grazers, as food for larval and adult fish, and as predators on larval fish and other zooplankters. Obviously there are great differences between the significance of different types of organisms. For example, how does one equate a number of jelly-like salps with a similar number of solid, shrimp-like euphausiids? The answer to this problem is probably contained in the recent discovery by the Bureau of Commercial Fisheries, which shows that the measurement of the volume of preserved plankters is a good measure of their original organic content, for they appear to shrink in storage to an almost equal concentration of previously living material. The preserved material is thus more valuable for this understanding than is the fresh catch! These basic qualities of the zooplankton can now be known and related with the changing oceanographic history of the California Current System and the fishes. A Biomass Laboratory is being organized at Scripps to capitalize on this advance.

Most important findings are emerging from the sardine and anchovy larvae data. As introduced in the general CalCOFI statement, investigations have shown that the anchovy and the sardine appear to act as a single population in their utilization of the environment. Apparently various proportions of the two species can exist and essentially fill the ecological space available.

Other very pertinent findings emerge, which will be reported in detail. For example, in years in which the sardine produces better-than-recent year classes, the

anchovy larvae apparently survive better. This only can be explained by a slower relative growth rate of the anchovy in those years. Another finding of this research is that the anchovy and sardine larvae that are caught in the *daytime* plankton hauls are a special category of larvae, and these catches appear to be a measure of the mortality of the population. The best explanation of this is that a large part of the *day* larvae are dead or dying when caught.

Besides its University and MRC funds the Marine Life Research Program received cooperative support during the period on some of its work from the Tuna Oceanography and Office of Naval Research, particularly in instrument development and in the use of special Naval ships. In addition the National Science Foundation provided funds for a quarterly cruise, and the AEC has made funds available to extend the MLR investigations to greater depth, as mentioned above. These other sources of support greatly broaden and enrich the MLR Program.

A major addition to the Marine Life Research Program was the acquisition of a new ship, the ALEXANDER AGASSIZ, for its exclusive use. This 180-foot vessel was outfitted and modified using funds loaned by the Regents of the University. She is the roomiest vessel of the Scripps fleet and perhaps the most seaworthy. She is especially outfitted for biological-oceanography investigations.

The development of unmanned deep-moored stations proceeded. A new station, taut-moored with nylon line, was developed and tested. One of these is now operating off the central California coast in 500 fathoms of water and is expected to continuously record meteorological and oceanographic conditions.

Other developments include a successful free-rising thirty-foot net that descends to 1000 fathoms and fishes to the surface; further perfection of the free fish traps that fish on the bottom in depths up to 3000 fathoms and return; and an electrical bathythermograph.

In summary, the California Current System is now the most thoroughly studied and best understood oceanic region in the world. The CalCOFI Surveys have now covered years embodying essentially all types of physical environmental conditions and change; i.e., warm years, cold years, monotonous years, years with strong countercurrents, years with invasion of tropical waters, etc. Thus, insofar as the oceanography is concerned, the range of conditions and their probability of occurrence is well understood. Since 1960, quarterly monitoring surveys have been substituted for the monthly cruises with the expectation of even a further reduction in the future.

The concomitant biological changes, with their infinitely greater complexity, are, however, by no means as well understood. Yet we will probably never again collect such a volume of biological samples so well integrated with the oceanography.

The effort must now be intensified toward thoughtful studies of the samples and data already obtained during the last twelve or fourteen years and to special investigations to answer the more discriminating

questions that can now be asked. The sardine-anchovy interaction is a case in point where special analyses of the data already have yielded vital findings. The Biomass Laboratory is a development in this direction as is the analysis of zooplankton for associations and the special studies at sea on the currents and the accumulations of organisms.

U.S. Bureau of Commercial Fisheries (BCF)

Research at the U.S. Bureau of Commercial Fisheries Biological Laboratory, La Jolla, comprise 17 projects grouped under the following six programs: 1) population dynamics, 2) sardine spawning and larval survival, 3) subpopulation studies, 4) physiology, 5) behavior, and 6) life history and taxonomy of fishes. Five of the programs center on the Pacific sardine, the other on fishes ecologically associated with the sardine in the California Current System.

One of the major developments in furthering understanding of the population structure of the Pacific sardine has been the establishment of the existence of three genetic subpopulations, two in the area of the California Current, the third in the Gulf of California. The subpopulations were identified by serological techniques, which were employed on samples of fish (preferably 100 or more). No method is yet available for identifying individual fish to subpopulation.

The two subpopulations in the California Current System, termed "northern" and "southern" were more widely separated geographically in 1961 than in earlier years. The "southern" apparently did not enter into the area of the California fishery, and the "northern" stock contributed little or nothing to the Baja California landings. This has afforded the opportunity of studying the age and length composition of the two subpopulations by utilizing samples from the commercial catch. The northern subpopulation in 1961 was made up mostly of older fish, 4- and 5-years of age, the southern group of young fish predominantly 3- and 2-years of age. There were such marked differences in the size of fish of the same ages in the two subpopulations that there was little overlap in length frequency distributions.

The physiology program has been accumulating information on energy and nutritional requirements of the sardine egg and larvae, as well as on the biochemical and nutritional changes related to the reproductive cycle in the adult. It has been shown that larvae

do not have full ability to osmoregulate until two days after hatching, but that energy needed for osmoregulation is insignificant, so that energy derived from yolk is largely available for growth.

Biochemical analysis of the ovaries and some other tissues in the adult sardine has shown that fatty acid composition of the lipids deposited in the ovary does not vary with the stage of ova maturation. It does change, however, with changes in diet and further study on the lipids of crustaceans suggests that dietary fat is deposited largely unchanged in the tissues of the sardine as it is in the tissues of other fishes.

The physiology program advanced its work on early development of fishes by adapting a temperature gradient block for studies of growth in simultaneous ranges of temperatures. Excellent control in this apparatus allowed for rearing of eggs and larvae at 18 different temperatures at the same time. It was possible then to determine the rates of embryonic development of a single species as influenced by temperature in a single experiment.

The behavior program has been attempting to make quantitative estimates of the relations between environmental variables and the distribution and behavior of pelagic marine fishes. Field studies were conducted to determine the extent to which the distribution and movements of sardine schools and school groups are influenced by the distribution of their food organisms. Laboratory studies still in progress are investigating the response of anchovy schools to visual stimuli such as light beams and transparent fence barriers under various conditions of illumination and turbidity.

The distribution and abundance of sardine spawning was determined in quarterly survey cruises in 1961 and 1962. The spawning was small in amount and distributed mostly inshore. There was no evidence of a resurgence of the sardine population. The ecological associate of the sardine, the northern anchovy, continues in high abundance, as evidenced from the distribution and abundance of anchovy eggs and larvae.

The second quarterly cruise of 1962, in addition to the usual oceanographic-biological coverage, focused attention on the sampling of late larval and juvenile stages of pelagic fish by utilizing the Isaacs-Kidd mid-water trawl, a newly designed small beam trawl, and 2.0-meter stramin nets.