

PART I
REVIEW OF ACTIVITIES

July 1, 1959 - June 30, 1960

REPORT OF THE CALCOFI COMMITTEE

INTRODUCTION

It is the purpose of this review by the CalCOFI Committee to elucidate the present position of the program and to point out the directions in which the program is developing and our thinking is evolving. The objectives and statements of objectives of the CalCOFI program have been given much thought and expression during the life of the program, and, naturally, have evolved. In August 1960, the CalCOFI Committee reformulated the objectives as follows:

To acquire knowledge and understanding of the factors governing the abundance, distribution, and variation of the pelagic marine fishes. The oceanographic and biological factors affecting the sardine and its ecological associates in the California Current System will be given research emphasis. It is the ultimate aim of the investigations to obtain an understanding sufficient to predict, thus permitting efficient utilization of the species, and perhaps manipulation of the population.

This statement formalizes some aspects of such research that have long been recognized: first, that no pelagic fish, such as the sardine, can be studied in nature as a creature isolated from his natural associates; second, that there is an ultimate responsibility of such research to the needs of society and that this responsibility takes the form of an ultimate goal of attaining an understanding sufficient for the guidance of society in the utilization of the resource.

To examine this matter further, it is a responsibility of the scientist to ask questions of nature. In this case, to ask questions about pelagic fish: what is their food? how does it vary? what ultimately kills them? how is their spawning carried out? how successful is their spawning? what is the water like in which they live and how does it affect these creatures? and a myriad of similar important inquiries.

In addition, scientists in a program such as this have two further essential tasks. The first is to weld their findings with previous knowledge, thus furthering the general or basic understanding of the way nature functions in order that future questions can be formulated more meaningfully. At the same time, the scientist must be in a position to answer the questions of society to the best of his knowledge. Yet the needs of society change, and it is essential that these questions change to fit the changing needs. For example, what was once the important question to the CalCOFI program: how large will be the available sardine stock next year?—perhaps is not now

so immediately important as is: what can be expected of the sardine stocks in the more distant future?; and: are there under-utilized stocks of fish that are complementary to the sardine, that is stocks that increase at a time of diminution of the sardine stocks and vice versa. Surely the changing answers that society needs in this area can best be drawn from the most general knowledge, extensive yet intimate knowledge on the stocks of pelagic fishes off our coast, their numbers, biology, needs, habits, fluctuations, and their fishery.

This matter of the dual obligations of the scientist who must integrate the findings, the scientific synthesist, has been discussed above at some length for it is this position of research that is occupied by the CalCOFI Committee, with an attendant duality of "masters." As the research progresses, the members of the CalCOFI Committee must look in both directions and attempt to answer both questions: how does a finding or line of inquiry help us understand the pelagic environment of the California Current System? and how does it help us answer the questions of society?

Rephrasing these thoughts to the conduct of research, the following emerges. Specialized research to answer an immediate question posed by society is a consumer of basic knowledge and understanding. This specialized research will be most successful when there is adequate basic knowledge, and, as a corollary, failure of the specialized research to supply society with significant practical results is most likely ascribable to inadequate basic understanding. It follows that the principal tasks of the CalCOFI Committee are to: develop projects to answer questions posed by the public to the extent that there is sufficient basic knowledge; and encourage research in disciplines and areas where lack of basic knowledge blocks the success of the program.

When the program was initiated it was realized that the principal lack was basic knowledge, so even though there was a most alarming and serious fisheries crisis, the originators and sponsors established the research on a broad fundamental basis. Because of this we are now approaching the answers to the original questions. Even more important we are also approaching a position from which we can answer a broad spectrum of questions about our pelagic resources. This is an important and happy aspect of this program of investigation, and its truth will be increasingly apparent in the discussion to follow.

FINDINGS

What have been the major findings and what is the picture that has emerged and is emerging from this inquiry?

We know that the sardine has not recently been a major component of the pelagic fish fauna of the California Current. It has often been a conspicuous component because of its habit of schooling relatively close to shore, but many other species of fish have been and are now greatly more abundant in the California Current waters. This includes several species of ecologically important deep-sea smelts, lantern fish, and the anchovy, hake, and jack mackerel, which are also commercially important.

From the years up to 1949 the sardine maintained a population comparatively larger than in more recent years, although the years of the earlier period were markedly varying in character, with warm and cold years and years of other character in alternation. During this period the populations of sardines and anchovies were about the same size, with anchovies possibly in slightly greater abundance.

The years of the decade beginning about 1948 to 1957 were, however, of a different character, relatively colder, but not so cold as some of the cold years of the previous two decades that produced good year classes of sardines. The outstanding characteristic of this recent decade was its relatively monotonous steadiness of temperature, winds and salinity. During this period, the population of sardines off California fell to new lows while the population of anchovies apparently reached new highs. Plankton volumes reached very high values during this latter decade, but it is doubtful if the food material in the plankton that is of value to the sardine increased similarly. In other words, much of the increased plankton consisted of jellies, salps, doliolids and pyrosomes that have little food value in themselves and, that as a matter of fact, compete with the sardine and anchovy for planktonic food.

Why then should the anchovy population increase while that of the sardine declined, and why should this occur when previously an occasional moderately-cold year produced a good year class?

This is possibly so because the anchovy spawns at a somewhat lower temperature than the sardine and at a more favorable season with respect to zooplankton food. In addition the anchovy may be better fitted to feed on phytoplankton than is the sardine, and, hence, can better compete with salps and other cold-water plankton.

In addition an important factor in the survival of sardine larvae is their opportunity to migrate to the coastal nursery grounds. That is, much of their larval mortality may consist of their being swept away into inhospitable waters from which they cannot return. The anchovy with its more northerly distribution along the Pacific Coast, has a greater opportunity for its spawn to remain in the California Current as larvae during periods of strong currents.

That these factors may be important ones is supported by a number of findings: Smaller year classes

were produced during the years 1949-56, when the California Current was strong and steady and the good year classes were produced when the California Current was often weak and unsteady. In the period when sardine spawning was general along the entire Pacific Coast, the sardine larvae had a much improved opportunity to remain in the California Current and to reach the nursery grounds, much to the same degree as the anchovy now does, and sardine spawning was more successful.

Other tentative findings indirectly support this general picture. It appears that large sardine larvae are very spottily distributed. Thus, it is possible that good survival of the sardine larvae is not the result of general environmental conditions, but the combination of many favorable conditions and few unfavorable conditions in small patches in the ocean. One would expect such patchiness of favorable and unfavorable conditions to be more common in rapidly varying years than in steady years.

How does this hypothesis stand up under the most recent history? We believe that the years 1957 and 1958 were years much like those of the early period when sardine recruitment was strong. That is, they were variable years, warmer than average, with a decreased strength of the California Current, and a decrease of the northern forms. Yet in these two years the sardine apparently had only modest year classes!

Apparently a reversion to many of the conditions under which the sardine previously was successful did not result in a return of success to the sardine. The continued presence of a large population of anchovies was one conspicuous condition that did not reverse, and it is possible that this and other competitors are obstacles to the return of the sardine's success.

Superimposed on these physical and biological conditions is, of course, the effect of the fishery. Although the fishery may have little effect on the total amount of all forage fish, the selective nature of the fishery probably favors the survival of competitors of the sardine to some unknown degree.

This experience has led also to a greater understanding of the relationships between the large predaceous fishes that constitute one trophic level and the sardine and other plankton-feeding forage fish that constitute a lower trophic level. The yellowtail, barracuda, and bonito appear to be as abundant as ever. When the waters warmed up in 1957 these three species became available by moving into the range of the sportfishery, even though the sardine population and sardine fishery remained at a low level. The sardine population shifted northward *one year later* in 1958 and the commercial catch rose to 107,000 tons. Thus the predators in 1957 moved north in the virtual absence of sardines, presumably content with the other forage fish and the increased temperatures. Apparently these predators can do well if the total forage-fish population is adequate, that is they are not specific in their forage-fish associations.

Perhaps it is not inappropriate to reiterate here that it takes more than a large population of fish to

guarantee good fishing, the fish must be where they can be caught. Apparently the populations of yellow-tail, barracuda and bonito were just as high during the cool years, but they were abundant only off Mexico. Similar to many of the game species, sardines are located farther north during warm years and farther south during cool years. For example, the outstanding 1939 year class of sardines may have appeared larger than it actually was because it was so available as two-year old fish during the hot year, 1941. Clearly, availability of pelagic fishes is influenced by water temperatures.

Other vital parts of this picture are emerging; many of them long anticipated.

A particularly important finding is the verification of the existence of two genetically-separated populations of sardines—a northern group and a southern group. It has long been suspected that sardines off the central and lower Baja California Coast and the fish from the northern Baja and California Coasts were distinct stocks. Subsequently it has been found that some of the sardines in the southern area were fall spawners while those in the north spawned in the spring and summer. These may be the stocks that constitute the two genetically-distinct groups of sardines as determined by blood type.

There is reason to believe that it is the northern stock which has decreased most over the last decade. The southern group also migrates north, but in greater or lesser amounts depending on oceanographic conditions. The migrants contribute at least to the southern California fishery.

Also, it has been found that the major fluctuations of the oceanographic conditions of the California Current undoubtedly are a part of fluctuations involving most of the North Pacific if not the entire Pacific. These, in turn, appear to result from or to be associated with, major changes in the atmospheric circulation. Apparently, the events that trigger these changes take place some distance from the California Current System and as much as a year passes before the changes are fully felt on this coast. This gives real hope for prediction of oceanographic conditions, in a general way perhaps a year ahead.

There exists a basic aspect of the sardine problem that requires other answers intimately related to the public need. The most frequent question is: can man influence the future size of his catch or the population by voluntarily changing the harvest? That is, for example, by catching fewer or more sardines. This has been studied longer and with less satisfactory results than any other aspect of the sardine problem. The problem is very difficult because it involves primarily the relation between the numbers of spawners and the numbers of progeny. Obviously, an animal that spawns many thousands of eggs per year does not have a simple, steady relation between numbers of parents and numbers of young. An additional complexity is that removal of adult fish does more than decrease the spawning stock of the species. Such removal tends to enhance the survival rate of its own young, but similarly, it may also allow competitors of the species to be more successful by increasing the

food supply available to them and other effects. On the other hand it may divert predators to the competing species.

Thus the problem on the relation between numbers of parents and numbers of progeny is very complex, and it has never been successfully resolved with respect to any marine fish. Most of the studies of marine fish, and the regulations, involve managing the age at which recruits are harvested, not managing the numbers of recruits, and our research clearly shows there is nothing to be gained by managing the age of harvesting the sardine. Theory states there must be some relation between spawning stock size and the numbers of recruits. Yet, we know there is no simple relation. We need to define the extent of this relation and to define the extent to which it will yield point to point predictions. This latter will, of course, involve the interplay of the population and the environment.

The attempts to understand the environment have already been discussed. In order to focus on the effect of the fishery we need to know the catch in detail, a routine project for a number of years. In addition we need to know the size of the spawning population and the size of the recruited population. The present program of sampling the fishery provides much of this information and can perhaps provide more in the future if additional information is gathered. Spawning stocks have been estimated from egg surveys, and have and are being estimated from "fish surveys." When all these data are fully available, which will be soon under present plans, we should have a fresh look at the population problems insofar as the direct influence of man is concerned.

SUMMARY

The picture that emerges from these results is that the sardine, a rather minor part of the biomass, can prosper when there is much variation in the environment, but that under steady conditions, or at least under steady cool conditions, the sardine, perhaps abetted by the pressure of man, gives way to its competitors. However, with the firm establishment of competitors in the habitat of the sardine, a brief return of otherwise favorable environmental conditions is inadequate to re-establish stocks of sardines in the more northerly portions of its range, although in warm years the southern stocks become available to California fishermen.

It is also clear that shifts in the relative abundance among sardines and other forage fish has little effect on the population of predators.

With this picture developing from the inquiries of the CalCOFI program we must slowly change the program to make the most of our new understanding. Since we must understand the broad changes of the oceanic conditions, the routine surveys are being expanded. Since we can recognize the types of oceanographic changes from fewer data, the major surveys are being made less frequently (quarterly) and the lines farther apart. The ship time so released is being used for more direct studies of the environment, the conditions and competitors in the sardine spawning

area, spottiness of larvae and plankton, countercurrents, etc.

This intensification of effort also is being devoted to the sardine itself, the conditions of its eggs, its light preferences, its distribution and associates as larvae and juveniles, and its growth rate as associated with the strength of year classes.

It is clear that we soon will have considerable detailed understanding of the actual conditions under which sardines and perhaps other pelagic fishes experience high survival.

To date in this program there have been extensive scientific results. There has been a long period of pioneering and exploration and the slow development of a picture of the place of the pelagic fishes in the California Current System. With this development of perspective, there is increasing opportunity to feed the findings back toward more meaningful research and greater opportunity to answer the question of society.

Perhaps the most important product of the program is a perspective of the sardine and its associates. We know that the sardine was once a conspicuous and valuable component of the population. Well may it be again. But we now realize that the sardine is like the gold of California, a conspicuous, valuable, easily-harvested element in the midst of less-conspicuous riches of far greater potentialities but requiring painstaking development.—E. H. Ahlstrom, J. D. Isaacs, G. I. Murphy, and J. Radovich.

AGENCY ACTIVITIES

California Academy of Sciences

Studies on the behavior and reactions of sardines and related species were continued, utilizing one investigator and assistance as needed. Specific investigations during the year included studies on the responses of anchovies to ultraviolet and infra-red radiation, and their responses to gradients of white light. In addition, further tests were completed on the responses of anchovies, jack mackerel, Pacific mackerel, and sardines to various electrical fields. Studies on the schooling of anchovies were conducted at Marineland.

California Department of Fish and Game

The Department of Fish and Game continued its basic monitoring of the pelagic wet fish fisheries of California. This includes: sampling sardines, anchovies and Pacific and jack mackerel, to determine the age and length composition of the catch; interviewing fishermen to obtain information on fishing localities and fishing effort; and working with the Department of Fish and Game statistical unit to insure that the catch records are accurate.

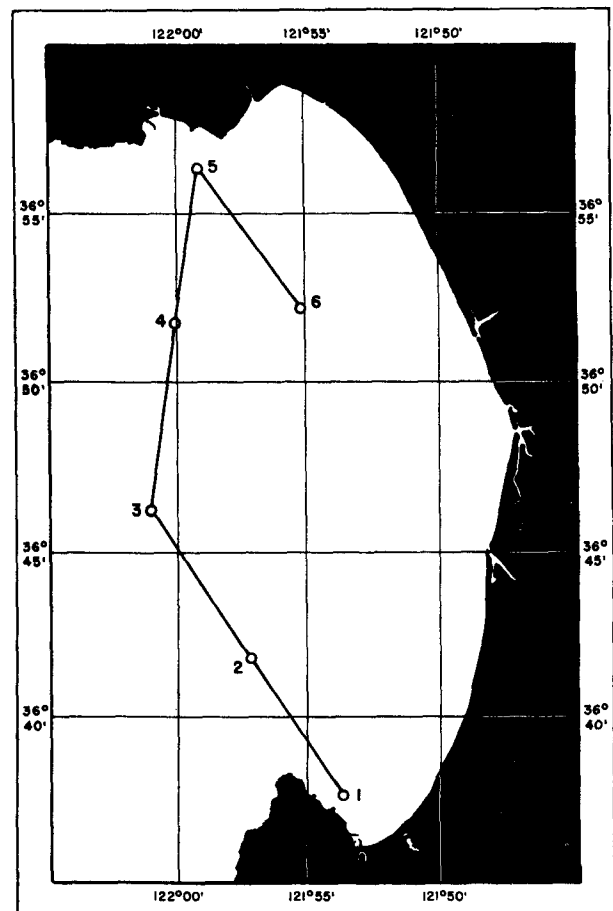
The department also continued its fish survey work which, in effect, extends the type of information obtained from the fishery to areas beyond those presently occupied by the fishing fleet. The pelagic species are sampled at sea and information is obtained on the distribution and relative abundance of fish. The fish

are aged and measured, live samples are saved for genetic studies by the U. S. Bureau of Commercial Fisheries, and other fish are preserved for further study ashore by the Department.

These two routine projects for four species represents most of the Department's effort in the CalCOFI program. Although routine, they are basic to the needs of the entire program, since before causes of variation in abundance and availability can be investigated, the variation must be described.

In addition to the routine work, measurements were made for morphometric studies on about 2,500 sardines. This is part of a study to determine if sufficient differences can be recognized in fish from different regions of the coast to enable one to recognize "types" and thereby, follow sardine movements from year to year. One other aspect of the morphometric study is to look critically at samples of fish whose blood has been typed to see if phenotypic differences can be detected which correspond with the genetic separation obtained from serological work.

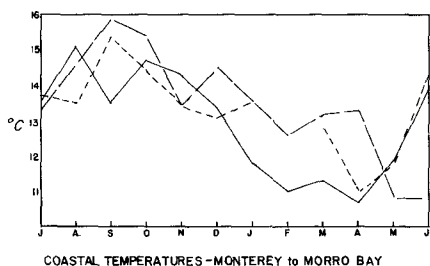
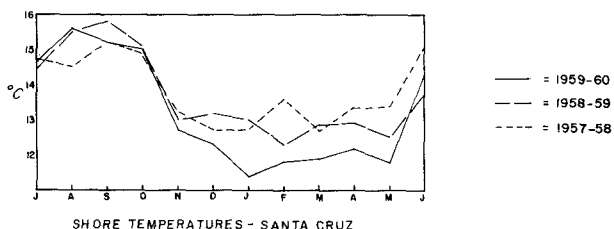
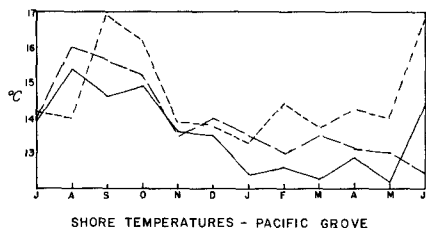
The live bait catch sampling was continued as was the airplane surveys of the anchovy population. Studies on the effect of water temperatures on fish distribution continued and the results will be published.



Monterey Bay, showing cruise pattern and station locations.

Hopkins Marine Station, Stanford University

Throughout the year the Hopkins Marine Station has continued to keep a finger on the pulse of the Pacific in the central California area through a program of three correlated activities: 1) Daily shore temperatures were taken at Pacific Grove and Santa Cruz. 2) At approximately weekly intervals, dependent upon the weather, cruises were made covering six stations in Monterey Bay. At each of these stations reversing thermometer temperatures and water samples for salinity determinations were taken at the surface and 15 meters. A bathythermograph was also lowered to 50 meters, except at stations 1 and 5 where shallow water limited the depth of the casts to 30 and 20 meters respectively. Vertical hauls for phytoplankton and zooplankton were also made at each station. 3) Each month 26 shore temperature stations were occupied between Monterey and Islay Creek, 20 miles south of Morro Bay on a day during or close to the period when CalCOFI ships were operating off-shore in the same latitudes.



During the early part of the period covered by this report (July 1959-June 1960), monthly averages of daily shore temperatures taken at Pacific Grove and Santa Cruz indicated conditions only slightly cooler than those of the warm-water periods prevailing during the previous two years. At Pacific Grove the period averaged about 0.6° C colder than in 1957 and about 0.4° C colder than 1958, but during August and October the water was actually somewhat warmer than during the corresponding month in one or the other of

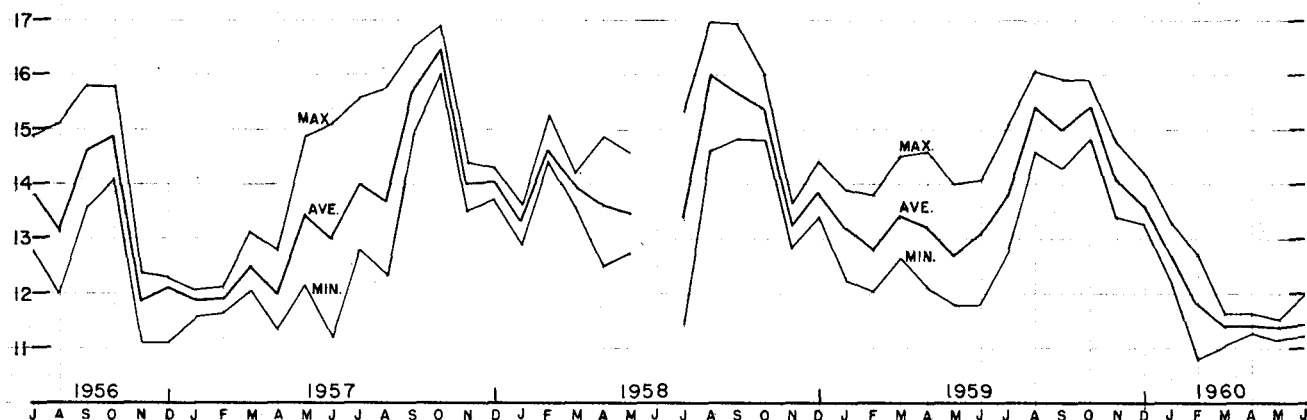
the preceding two years. At Santa Cruz the temperature differences were much less; they were about equal to those of 1957 and averaged only 0.2° C colder than those of 1958. During each of these first five months the temperatures were equal to or warmer than those of one of the preceding two years, and in August they were warmer than both.

During the next six months from December, 1959 through May, 1960, the situation changed markedly. At both extremes of Monterey Bay, the average temperature in each of these months was markedly colder than that of the corresponding months of the two preceding years. At Pacific Grove this period averaged 1.30° C colder than that of 1957-58 and 0.7° C colder than that of 1958-59. The situation was similar at Santa Cruz; the corresponding values were 1.2° C and 0.9° C June provided what might be considered a return to warm water conditions with temperatures above those of 1959, but below those of 1958. It should be mentioned here, that although winter and spring were characterized by water colder than that of the prior two years, temperatures between October and February were still higher than those prevailing in 1956-57 just before the onset of warmer conditions along the California coast.

The temperature situation in Monterey Bay, as outlined above and based on daily observations, was extremely well corroborated by the averages of 26 shore stations occupied at monthly intervals along the coastline to the south. Here, too, the summer and fall of 1959 appeared to be typical of the recent warm-water period, but the following winter and spring yielded temperatures markedly colder than in the preceding two years. The warming noted in June in Monterey Bay, took place somewhat earlier toward the south and the curve of the coastal run approached that of 1957-58 in May as well as in June.

The abrupt decline in surface temperatures during the winter and spring is perhaps more strikingly shown by monthly averages of the data collected on the weekly cruises. These are not so strongly influenced by shallow-water warming as are those taken along shore. They show clearly that the surface temperatures are depressed well below those of 1957-58 and 1958-59. In fact, the surface temperatures during these months are comparable to the very cold period of 1955-56.

Bathythermograph temperature averages showed little change over those of the previous year in the first half of the period under discussion, although there was a slight lowering at all depths in September, October and January. However, with the onset of upwelling in February, there was a concomitant overall lowering of temperatures to approximately 1° C below those of the previous year. Although this condition prevailed until June, at which time the temperature rise noted at inshore areas prevailed in the upper 10 meters, the persistence of relatively low values was probably not due to continued upwelling. Lowered temperatures of late winter and early spring are normally the result of upwelling. Upwelling is typically indicated by a spread between the maximum and minimum values for any given month. This temperature



SURFACE TEMPERATURES — MONTEREY BAY, CALIFORNIA MONTHLY AVERAGES

difference is due to the presence of cold freshly upwelled water at stations over or adjacent to Monterey Canyon, and of surface-warmed eddies at the extremities of the Bay. It is noteworthy that between March and June, 1960, a period which in normal years is characterized by a conspicuous spread in the maximum and minimum curves, these lines ran close together. Although it must be admitted that this may throw doubt on the validity of the spread as an index of upwelling, it may also indicate that the cooling was due to factors other than upwelling. In this connection, it may be pointed out that the only sizeable plankton bloom (another indicator of upwelling) occurred in March, just subsequent to the upwelling of February as shown by the spread of the maximum and minimum in that month. No further sizeable plankton production was noted and it is probable that no enrichment from deep waters took place. Evidently the cooling was not due to upwelling but was a result of a widespread phenomenon affecting a large area of the North Pacific.

Salinities in the Bay were slightly higher from July through September over the previous year. They were somewhat lowered in the period from January to March, especially in February when rainfall and runoff affected surface salinities. It was not possible to interpret differences in salinities of corresponding months in various years as indicators of upwelling.

Phytoplankton volumes have remained low throughout the past year, and the total volume of samples was less than half of that obtained in each of the previous two years. The most noticeable bloom was in March, when hauls were far above those of 1958 and 1959, and comparable to 1957 volumes, the latter being the last year when phytoplankton was present in marked quantity in the Bay.

Division of Marine Resources Scripps Institution of Oceanography University of California

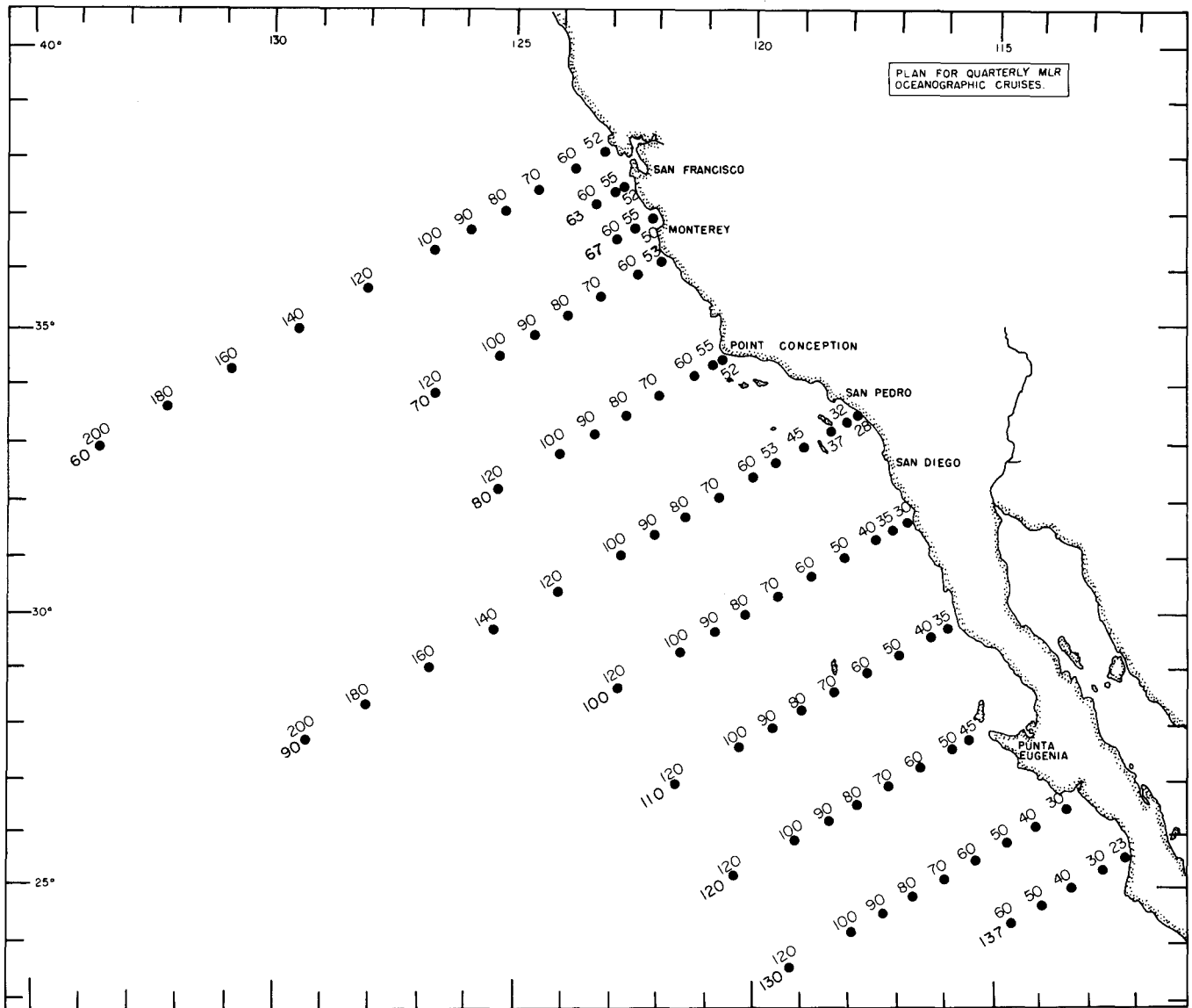
With the completion and publication of almost ten years of measurements of the oceanic conditions of the California Current System, the CalCOFI's ocean-

ographic program is being modified. To a great extent this modification is the result of the perspective and the broader recognition of problems presented and summarized in the CalCOFI's report of last year Volume VII. In particular, the fact that the changes in the local waters of the California Coast are related to fluctuation in conditions over much of the Pacific, is receiving increased recognition. The surveys are being extended to reach farther north and farther to sea, and the number of station lines occupied is being reduced. These changes stem from: the need to obtain a broader and more general look at the California Current; the ability to recognize change from fewer data as a result of understanding from previous studies; and the necessity to carry out concentrated studies on special features of the environment that have been pointed up. The modified field program will thus consist of a basic extensive survey plan, as shown, and a series of special oceanographic studies concerned with such subjects as: the nature of the countercurrent circulation, direct current measurements, the ecology of spawning areas, and the nature of plankton succession.

In the area of interpretation of the oceanographic data, the program is becoming more involved with prediction. The basic correlation of temperature, wind, and sunshine has been worked out and the next step will involve dynamic prediction, that is, prediction that considers currents. Studies of the broad climatology of the Eastern North Pacific are receiving increased emphasis.

Correlation between the oceanographic conditions and the plankton of the areas is receiving attention. Work is proceeding on the zoogeography of the region, and all major groups of *zooplankton* are now receiving attention. It is now possible to examine associations of zooplankters, the association of zooplankton, and, for example, fish larvae, and the association of these organisms with the oceanographic conditions, and this is under way.

In this direction, preparation of charts displaying the oceanographic conditions throughout the years is



being undertaken, to permit a more facile comparison of biological conditions with the oceanographic weather. This is also a step in the preparation of a comprehensive description of the California Current System.

In the field of instruments, progress has been made toward substituting moored stations for ship observations, although these are not yet routinely in use. Nets to solve special problems of fish and plankton behavior and distribution have been constructed, the deep-free vehicle has been expanded to include carrying an experimental current meter, and equipment for routine direct observation of the ecology of pelagic areas are under development.

U.S. Bureau of Commercial Fisheries (BCF)

The program of research of the La Jolla Laboratory, Bureau of Commercial Fisheries, is made up of 10 investigations, 8 of which center directly on the sardine and 2 that are tangential. In the former category are

investigations of population dynamics, population size, year-class size, availability, age and growth, fecundity, genetics (subpopulations) and physiology; the tangential programs include plankton studies (data on plankton volumes are issued annually) and ecologically associated fishes (including anchovy, jack mackerel and Pacific mackerel).

Perhaps the most exciting research results were obtained in the genetic studies of subpopulations. The "C" system, one of three blood systems that have been distinguished, has proven of value in separating subpopulations of sardines. A more northerly distributed group of sardines (off California and at times northern Baja California) average over 13% "C" positive individuals, while a more southerly distributed group (Magdalena Bay, Baja California, to as far north as San Diego) averages less than 6% "C" positive fish.

The most recent investigation initiated by the La Jolla Laboratory, physiology studies, is obtaining interesting results in several fields: osmoregulation

and energy requirements of sardine eggs and larvae, organic constituents (fatty acids) of the ovary, nutrition of sardine-related species and rearing of post-yolk sac sardine larvae.

Availability studies are concerned with investigating the manner in which the environment influences the distribution and behavior of the sardine. A phase of the behavior project completed during the year compares, on the basis of eye structure, the relative visual capacities of the Pacific sardine, northern anchovy, Pacific mackerel, jack mackerel and some other fishes. The sardine has the highest visual acuity and the lowest sensitivity, thus should be able to discriminate objects better than the other species in bright light, but not as well as others in dim light. Exploratory behavior experiments are being started, and the experimental facilities are being improved. An improved plankton pump is being built to be used in

studies of the distribution dynamics of sardine food organisms.

Sardine spawning in 1960 had the type of distribution that has been typical of warm years since 1957. Spawning was less widely distributed and closer inshore than previously, with major centers in the Channel Island area of Southern California and in Sebastian Viscaïno Bay, Baja California. Based on preliminary scanning of samples, the amount of spawning appears to be low. Fecundity studies have shown that during the recent warm years, sardines off Southern California mature at much smaller sizes, have a more prolonged spawning season and are much less uniform with regard to stage of ovarian development. A preliminary examination of sardine larval data for 1952-1957 indicates that larval survival after the yolk sac stage has been relatively constant—larger larvae (15.5 mm and longer) comprising between 1.5% and 3% of the total larvae.