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A REPORT ON THE PROBLEMS AND OBJECTIVES OF THE COOPERATIVE SARDINE RESEARCH PROGRAM

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with assistance from many persons
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Research Program

Year — ?

INTRODUCTION

This report is not one of the regular series of quarterly progress reports on the cooperative sardine research investigations; it is intended as a supplement to these reports. The latter, because they summarize the research being carried out during a portion of a year only, have emphasized details of the research rather than the reasons for doing it. This report is intended to fill the gap by setting forth some of the problems and objectives of the cooperative sardine research investigations.

The contributions of the four cooperating agencies, the Scripps Institution of Oceanography, the U. S. Fish and Wildlife Service, the California Division of Fish and Game and the California Academy of Sciences are summarized in the progress reports, agency by agency. Inasmuch as most of the research is truly cooperative, two or more agencies working together in the study of most problems concerning the sardine, the writers of the present report have thought it advisable to center their attention on the problems being investigated, rather than on the agencies doing the work. However, a very brief resume of the activities of the four cooperating agencies seems desirable in this introduction.

The oceanographic investigations are the primary responsibility of the Scripps Institution of Oceanography, although one of the three vessels taking part in the collection of oceanographic data at sea is operated by the Fish and Wildlife Service. Scripps Institution has divided their activities in the present investigation into five divisions: physical oceanography, chemical oceanography, phytoplankton, zooplankton and marine vertebrate studies. Physical oceanography is concerned with the distribution of temperature and salinity in the ocean, with the transport of water (horizontal currents), with mixing or diffusion processes, with the effect of tidal forces, and with the mechanism of upwelling (vertical currents). The physical oceanographers are not only concerned with the description of these processes, but also with determining the causal mechanisms behind the circulation in the ocean. Chemical oceanography is directly concerned with determining the distribution (both vertically and horizontally) of inorganic nutrients essential to plant growth. Determinations are being made of phosphate-phosphorus, which is one of the basic nutrient materials and an indicator of the distribution of other inorganic nutrients as well. Determinations are also being made of the distribution of dissolved oxygen in sea water: the determinations may give valuable information on 1) the process of upwelling, 2) the presence of large populations of marine plants, 3) the presence of large concentrations of oxygen consumers and 4) mixing processes in the surface layer (0-200 M) of the ocean. Phytoplankton research is concerned with assessing the "crop" of marine plants (particularly diatoms), the primary producers of foodstuffs in the ocean. The research also deals with the relation of fluctuations in the productivity of marine plants to physical and chemical processes in the ocean, particularly enrichment processes, and with the effect of these fluctuations on the animal populations. The principal objective of the zooplankton studies is to determine the significance of plankton in the life of the sardine, especially 1) as it affects the survival of the sardine larvae and 2) as it affects the distribution, movements and survival of the adult sardines. The division of marine vertebrates is cooperating with the Fish and Wildlife Service in the study of recruitment, is investigating several of the species of fish that compete directly with the sardine, particularly the anchovy and saury, and in addition is conducting some studies on productivity.

The recruitment research is the primary responsibility of the Fish and Wildlife Service, although it is also a cooperative program, especially in the collection of material and data at sea. The long range objective of this program is the determination of the factors underlying the success or failure of year broods of sardines. If this can be done, we should eventually be able to predict the strength of a year class fully $1\frac{1}{2}$ to $2\frac{1}{2}$ years in advance of its entry into the fishery. The more immediate objectives of the recruitment research may be summarized as follows: the determination of 1) the extent and time of sardine spawning, 2) 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 rate of survival of young fish resulting from the spawnings, and 4) the correlation of all the above with conditions in the physical, chemical, and biological environment.

The California Division of Fish and Game is also working on one phase of the recruitment problem: an attempt to assess the abundance of each year class when about four to six months old. They plan, after doing exploratory work on distribution and on methods of censusing, to conduct an annual census of juvenile sardines on the nursery grounds. As a part of this program they are obtaining statistics on young sardines in the bait fishery of southern California.

Studies on availability of adult sardines to the commercial fishery are also being made by the California Division of Fish and Game. They are concerned with the problem of why adult sardines are less available to the commercial fishery during some seasons than during others. The problem is basically one of sardine distribution: a study of the where, when, and why of sardine schools. To get at "where" sardines occur it is necessary to be able to locate schools of fish effectively and rapidly. Echo ranging and echo sounding gear on the MV "Yellowfin", the vessel used in this research, have proven effective for this purpose. To determine the "when", surveys are being made throughout the year. The "why" involves the reasons for sardine distribution: this is primarily a study of the effects of physical and biological environmental conditions on the distribution of adult sardines. Synoptic oceanographical data are being collected at the places where schools are found, and these will be correlated with the more extensive oceanographic data being collected by the Scripps Institution and the Fish and Wildlife Service. The problem of availability is treated in some detail later in this report.

The behavior of sardines under experimental conditions in the laboratory is being studied by the California Academy of Sciences. The effects of such factors as temperature, currents, light, electric currents and salinity on the behavior of sardines, especially on their schooling patterns and movements, are being investigated. The results of these studies may aid materially in understanding the distribution of sardines in nature.

In addition, studies on the commercial catch have been conducted over a long period of years, and are continuing. Although this phase of sardine research will not be dealt with in the present report, it should be pointed out that the work involves a number of cooperating agencies: the California Division of Fish and Game, the U. S. Fish and Wildlife Service, as well as the Marine Fishery departments of Oregon, Washington, and British Columbia, and is a very important part of sardine research.

If we were to go exhaustively into all phases of the cooperative sardine research program, this report would be a very long, and perhaps dull affair.

The ocean is a complex environment and its study involves many problems. Each of the divisions at the Scripps Institution engaged in this research has a group of problems peculiar to its own field. The same applies to the work of the other cooperating agencies. If such detailed accounts are desired, they should be prepared as separate reports by the individual agencies engaged in sardine research.

If the objectives of the cooperative sardine research program were to be condensed into a single sentence, we consider the following to be a fair statement of the problem: The cooperative sardine research program is studying the sardine in its environment in order to understand how this environment - physical, chemical, and biological - affects the survival of the sardines when young and their distribution (availability) when they are of commercial size. The research then has two primary facets: success of recruitment and availability. The account that follows will deal primarily with these two subjects. However, the problem of productivity will loom so large in the discussion that with equal justice this could be pointed to as the primary problem of our investigation.

This report is intended as a popular account. Because of this, we are including background information that would be omitted from a scientific treatment of the same subject. Often the picture has been simplified, but we trust not overly so. Also we have not labelled all controversial subject matter as such.

SUCCESS OF RECRUITMENT

Much of the research being conducted by the Scripps Institution of Oceanography and the Fish and Wildlife Service in the cooperative sardine research program is directed toward determining the causes underlying the success or failure of year broods of sardines.

To obtain data on this problem, the cooperating agencies are investigating month by month a very extensive area off our coast, extending from Abreojos Point, Lower California, in the south to the Columbia River in the north and offshore for 400 miles. Three vessels are taking part in the survey, the "Crest" and "Horizon" of the Scripps Institution of Oceanography and the "Black Douglas" of the Fish and Wildlife Service. The California Division of Fish and Game also furnished a vessel for three cruises during 1949. Within this area approximately 120 to 130 stations are occupied on each cruise (weather permitting). At each station temperature and salinity data are obtained at 15 different levels, determinations of dissolved oxygen and phosphate phosphorus are made from samples collected at the same levels, samples of water are obtained at 4 depths between 75 meters and the surface for obtaining estimates of diatom abundance, and quantitative samples of plankton for recruitment and zooplankton studies are obtained by hauling a fine-meshed net from approximately 70 meters depth to the surface.

It should be noted that although these data are pertinent to the problem stated above, they have, almost without exception, a much wider applicability as well. Information is obtained on the spawning of many species of fish besides the sardine. The distribution and abundance of many species of fish can be more readily assessed by this method of study than by any other. The oceanographic data is of use in a number of fields. In fact, much of the interest and value in our observations result from this wider applicability of our data.

It is a well known fact that the survival from one year's spawning may be many times as great or poor as from another, even though the amount of spawning is comparable during the two years. The relative success or failure of year classes of sardines seems then to depend less upon the number of eggs spawned than upon the rigors of the environment to which the eggs and young are subsequently subjected. It is probable that the most critical period in the life of any year class of sardines is during its first few weeks or months of life.

What are the environmental "rigors" to which the young sardines are exposed? Let us consider the basic ones.

Food: The sardine larva on hatching is very small, indeed, scarcely more than 1/10 of an inch long, very thin and thread-like, with scarcely more than a 3-day supply of yolk remaining before it has to fend entirely for itself. Because of its small size, its food requirements must be very exacting. The food must be limited to the eggs and young of invertebrate plankton animals, to very small animals, and to small marine plants (diatoms). If such food is not present in sufficient abundance, a very high mortality must result among the sardine larvae. With increase in size the larvae can utilize as food an increasingly larger proportion of the plankton population.
Predators: The very small sardine larvae are subject to predation by all the larger plankton animals - copepods, amphipods, arrow-worms, jelly-fish, ctenophores, salps, as well as by all filter-feeding fish, including the older sardines. Many of the plankton animals that serve as food for the adult sardine prey voraciously upon the sardine larvae. At no period in its life history does the sardine have so large a group of potential enemies as during the first few weeks of life.
Currents: Sardine eggs and young larvae are free-floating passive agents, completely at the mercy of the currents that carry them along. Not until they develop their fins and become of some size are they able to swim about freely and resist such transport. The eggs and larvae may be carried by currents to areas quite unfavorable for their survival.

The hazards of this early period in the life of a sardine are so very great that there can be little doubt that the success of a year class for good or ill is largely determined during this period.

When the food supply available to the sardine larvae is plentiful, there are good reasons for believing that survival will be good. Thus the problem of food supply, or as it is expressed technically, productivity, becomes one of our major problems. What are the conditions that favor a plentiful food supply?

For the sardine larvae to have a plentiful food supply, the animals they feed upon must have adequate plant food. The plants in turn must have adequate nutrient materials: marine plants need fertilizers for good growth just as do land plants. These nutrients are supplied to a great extent by vertical currents in the sea. Let us consider this problem of productivity in some detail.

In the ocean, as on the land, the primary producers of foodstuffs are plants. In the ocean these are principally minute, free-floating organisms known as diatoms. They manufacture foodstuffs, as do any plants, through the process of photosynthesis. Sunlight is necessary for this process, hence the diatoms are confined to a surface layer seldom deeper than 300 feet. Chemical raw materials are needed in the manufacture of foodstuffs, particularly such substances as carbon dioxide, compounds of nitrogen (ammonia, nitrites, and nitrates), phosphates, silicates, sulfur, as well as traces of certain metals such as copper, iron and manganese. The animal populations of the ocean are completely dependent upon the marine plants for their foodstuffs. Of course, not all animals feed directly on the diatoms. But whatever the source of food of a marine animal, whether it be fish or squid or crustacea or the numerous, small free-floating animals known collectively as zooplankton - through some chain of events it may be traced back to the primary producers of organic material, the marine plants. The sardine is a plankton feeder during all stages of its life history. Marine plants enter into its diet directly, but of greater importance as food for the sardine are small plankton animals - particularly such groups as copepods and euphausiids.

Some of the raw materials needed by marine plants for the manufacture of organic matter are present in the surface layers in very small concentration only. This is particularly true of such essential nutrient materials as nitrates, phosphates and iron. If the supply of these "fertilizers" was not being constantly replenished in the euphotic zone (the zone of plant growth), depletion would soon result and no further growth of diatoms would be possible. The replenishment comes about, in part, as a product of the metabolism of plants and animals while living, or by being released through the action of bacterial decay after their death. However, much of the latter process takes place below the euphotic zone, and inasmuch as the nutrients are not ordinarily utilized in the deeper water, they tend to accumulate there. Hence the return of nutrient substances to the euphotic zone must come about by some process of vertical circulation of the water and/or by upward diffusion.

We may speak of the return of these essential plant foods to the surface layer as "enrichment". The most important method by which this is effected off our coast is through a process of vertical water movement known as "upwelling". One of our major problems is the determination of the whereabouts, extent and time of occurrence of such "upwelling" of deeper water, and its dispersion to adjacent water masses by horizontal currents and mixing processes. The determination of the rate of upwelling is not a simple task. We cannot go to sea and actually measure the rate at which nutrients are being raised to the surface, for the vertical currents are so very slow that their direct measurement is impossible, being only of the magnitude of something like 100 feet vertical ascent per month. Hence we must use indirect means to estimate the currents. There are several approaches to the problem. One approach is to study, through indirect techniques developed by physical oceanographers, the processes involved in the vertical circulation of the ocean in order to measure the rate, extent, and amount of the upwelling. Another method is to examine the effects of the vertical currents on the temperature, salinity, oxygen content and phosphate content of the water, and from these estimate its extent. Another and quite different method is to get at the causal factors behind the upwelling and associated processes. These approaches are not mutually exclusive, rather they should be considered complementary, since an evaluation of causal factors requires a knowledge of the mechanisms of water movements and of the effects resulting from the upwelling.

It has been shown by H. U. Sverdrup, Director Emeritus of Scripps Institution of Oceanography, and others that the wind is the principal driving force which maintains the major circulation in the ocean and also produces upwelling. It is only the higher wind velocities, those above 13 knots, which are important in the generation of currents, and, of course, their effect will depend upon their direction, duration, and force, which will vary with the season off the west coast of North America.

The winds off the coast of California are characterized by a rather distinct annual cycle, and progression from one season to another follows a similar pattern each year. However, the winds are influenced by long period trends which causes a certain amount of year to year variation in the cycle. It may be well to examine the average annual characteristics of winds and currents off the coast of California in indicating how the process of upwelling occurs or is suppressed.

The winter period is characterized by storms, with periods of calm or variable winds occurring between storms. Just prior to a passage of a storm, south winds occur which in an indirect way favor the development of a north-flowing current along the California coast. As a storm moves onto the coast, however, a strong wind blows from the northwest and north favoring the development of a south-flowing current. A calm or variable wind such as occurs between storms develops no current at all. In general, the north-flowing counter-current is stronger during the months of November through February than at any other time of the year and is located between the coast and 40 to 100 miles offshore. The south-flowing California current, located outside the counter-current is usually rather weak during this season of the year.

The spring period is characterized by prevailing northerly and northwesterly winds nearly parallel in direction to the coast of central California. The northerly winds, when blowing parallel to the coast at velocities exceeding 13 knots for a period of several days or longer, set up a current pattern which brings about upwelling. The sequence of events is about as follows. The first effect of the drag of the wind on the sea surface is to set up motion in the surface layers in the direction of the wind. This pure wind drift current soon veers to the right due to acceleration associated with the earth's rotation, so that the resultant water transport in the surface layers has a component offshore. As a result, the light surface water adjacent to the coast will be transported away from the coast and will cause the surface to slope up to the west. Eventually, however, a steady state is reached in which the depleted water must be replaced near the coast by heavier subsurface water, thus "upwelling" along with it the nutrients.

If we stopped at this point in the description of the effects of the northerly winds it would not be clear how this same chain of events also brings about an intensification of the California current. The upwelling leads to changes in the distribution of mass, with the denser upwelled water accumulating along the coast and the light surface water being transported away from the coast. This altered distribution of density is reflected in the surface topography, in that the ocean surface now slopes downward toward the shore and due to this slope, force of gravity will tend to cause the surface water offshore to flow downhill toward the coast. As soon as such flow begins, however, the acceleration due to the effect of the earth's rotation turns the water toward the right, and when equilibrium is reached the water flows toward the south. This process of the altered distribution of density giving rise to a current which flows in the direction of the wind is thus a secondary effect of the wind in producing ocean currents. It is this indirect effect that is shown in charts of dynamic heights, such as the charts issued in the Scripps Institution physical and chemical data reports. As shown by these charts, the final result of northerly and northwesterly wind is to cause the California current to become intensified and extend nearly to the coast. The counter-current, on the other hand, is weak or obliterated in the surface layer of the ocean although it may still be present at a depth. Upwelling continues as long as the winds are favorable. Enriched water is transported and diffused both along shore and offshore from the area of upwelling, thus dispersing the nutrients over a considerable area.

Upwelling does not occur simultaneously along the length of our coast, but begins in the south and gradually moves northward. It seems to be definitely associated with the northward migration of an extensive region of atmospheric high pressure. This semi-permanent high pressure area moves from the vicinity of Cedros Island in perhaps February and March to Cape Mendocino in September, and has associated with it northerly winds in the region near the coast. Off Pt. Conception, for example, upwelling occurs during the spring and early summer months, but ceases or becomes less apparent during the late summer. Off Cape Mendocino, on the other hand, upwelling is most intense during the late summer months.

In fall, as the semi-permanent high pressure cell weakens and moves rapidly southward, the region is subjected to the passage of storms at increasingly frequent intervals and the wind distribution is changed so that southerly winds are more predominant. This results in a weakening of the California current and the reestablishment of the counter-current along the coast. The annual cycle is then completed.

Deeper water that is brought into the zone of plant growth by upwelling has different characteristics than surface water. In our routine analysis of physical and chemical characteristics of the water we concern ourselves primarily with four measurements: temperature, salinity, dissolved oxygen content and phosphate content. We have indicated that the zone of plant growth (the euphotic zone) is about 100 meters deep ordinarily. It so happens that this is also the maximum depth to which the water is homogenized by the action of waves, currents, and instability associated with evaporation. In this mixed layer the temperature is nearly uniform, but below it the temperature drops sharply as the depth increases. The oxygen content also decreases sharply with depth below the mixed zone. Within the upper 100 meters depth the water is usually nearly saturated with oxygen, but at 800 meters depth the saturation may be as low as 5%. On the other hand, both salt content and phosphate content increase with depth below the mixed layer. Hence water upwelled from some depth will be colder, more saline, of higher phosphate content and of lower oxygen content than ordinary surface water.

It should be possible, by observing the extent of the reduction in temperature or increase in salinity of surface waters in regions of upwelling, to estimate the extent of the upwelling. However, this estimation requires a knowledge of average conditions, otherwise there is no standard by which to gauge the reduction in temperature or increase in salinity. Hence this is a fairly long term project.

Our primary interest in upwelling is in the enrichment of the surface waters resulting therefrom. The abundance of marine plants (diatoms) undoubtedly depends to a large extent on the quantity of inorganic nutrients available for their growth and multiplication. Hence the size of the "crop" of marine plants produced during a given year may be directly related to the intensity of upwelling during that year.

Marine plants are the first link in the organic food chain. They are directly used as food by many marine animals. These animals that graze upon marine plants are spoken of as herbivores. An increase in abundance of plants would not be immediately reflected in an increased number of herbivores. There must be a time lag. Undoubtedly a portion of the marine plants disappear into the depths and are not available as food. Most marine plants are denser than sea water and tend to sink downwards to depths where growth is impossible. Two processes act to prevent the whole population from disappearing in this way. The first is population increase: the plants within the euphotic zone are growing and dividing so that new plants are always being added. The other process: vertical stirring of the mixed layer by wind and waves. The proportion of plants that are "lost" from the euphotic zone may be a variable one, with the result that the relation between enrichment and the size of the herbivore population may not be as clear cut as in the case of the plant population. Carry the organic chain one step further along - to the carnivores that feed upon the herbivores (the sardine is in this group since its principal food consists of plankton animals rather than plants) and the relation may be more obscured.

It may be asked of us - "But why are you concerned with all this? What relation can the sinking of diatoms possibly have to the sardine?"

Our concern arises from the fact that we do not want to do any unnecessary work. We want to find short cuts. Now, if the food chain were sufficiently direct - if a given amount of enrichment would always result in a diatom population of predictable size - and these were always equally available as food for animals - so that we could predict from the diatom population the size of the herbivore population - then it would be possible to bypass these intermediate steps in the cycle and predict directly from the amount of enrichment what the effect would be on the survival of sardine larvae. This we would like very much to be able to do. In fact, we would prefer to take it one step further back still, and predict from the strength and duration of winds favorable for upwelling what the effect would be on the success of sardine recruitment. In that way we could let the meteorologists collect our data for us. But if this relation becomes obscured along the food chain - if a variable fraction of the diatom population is available as food, for example - we may not be able to bypass the intermediate steps in the chain, but will have to study it link by link. Much more information is required before the proper short-cuts can be selected.

However, Walford (1946) has obtained results that encourage us in the belief that much of this work can eventually be bypassed. He obtained a definite correlation between the strength of year classes (as determined from their contribution to the commercial catch) and the intensity of upwelling during the season of their origin. He used the only data then available - salinity observations of the surface waters as measured at Scripps pier - for assessing the intensity of upwelling. It is now clear that one factor, such as salinity of the water, should not be used alone as an index of upwelling, since higher salt content may result from causes other than upwelling of deeper waters. However, if used in conjunction with other characteristics of upwelled water (temperature, oxygen content, phosphate content) it should be a satisfactory index. Much better data on upwelling will be available from the current surveys.

We have gone into this problem of productivity in considerable detail, because it seems to us to be the center of our whole investigation. Even so, we have barely scratched the surface of many phases of it.

The extent of the sardine spawning area may be of considerable importance in the problem of food supply for the sardine larvae. When spawning is widespread, the larvae would be put into contact with a larger food supply - there would be less competition between the larvae for food, with the result that chances for survival would be enhanced. When the spawning area is restricted, competition between individuals would be greater with the result that survival might be much poorer. Hence, we are interested in those conditions that cause variations in the extent of spawning. There is considerable evidence that the extent of the spawning area may be directly dependent upon physical features such as temperature. All spawning during the 1949 season occurred in water between 13.30°C and 16.20°C (temperature at 15 meters depth). The northward progression of spawning during the season was definitely associated with the northward progression of favorable spawning temperatures, while the gradual elimination of spawning from the southern part of the survey area coincided with the rise in temperature above the favorable range.

One other problem concerning the food supply may be mentioned briefly. We are obtaining quantitative data on the larvae of a number of species of fish that undoubtedly compete with the young sardine for food - such fish as anchovies, sauries, jack mackerel, to mention only a few of the more important. This competition may have a considerable effect on the success or failure of year classes of sardines.

Although fluctuations in food supply seems to us to be the most important factor behind the success or failure of year broods of sardines, we cannot overlook the possibility that other causes of mortality may be of considerable or even prime importance. Especially we cannot overlook the effects of predation. It has already been pointed out that the young sardine larvae have a formidable array of predators - including many ubiquitous and exceedingly abundant members of the plankton community. The abundance of these organisms can be determined from the plankton collections. Hence, a study can be made to determine what relationship if any exists between the abundance of such predators as arrow-worms and the survival rate of the young sardines. Another form of predation may be more difficult to investigate - the predation of disease-producing organisms. The possible role of diseases in effecting the present decline in sardine abundance has not been given due consideration. For one thing, the decline in abundance of the California sardine is not unique - there seems to be a world wide decline in sardine abundance. The decline in the Japanese fishery for sardines has been even more precipitous than our own. The Atlantic pilchard is also suffering a similar decline - Portugal, for example, is very concerned over the decline in her sardine fishery. Could the simultaneous decline in abundance in these several fisheries be just a matter of chance coincidence? Or is there some factor - such as an epidemic among sardines - common to all three? For example, there has been an epidemic among the Atlantic coast herring population during the past few years that has seriously crippled the fishery. The sardine is a close relative of the herring. Hence it is likely that it could be similarly affected by disease-producing organisms. This possibility needs to be given serious consideration.

One measure of the success of recruitment can be obtained from estimates of survival during the larval period. Another measure of the success of year broods can be obtained from surveys of juvenile sardines made on the nursery grounds. The California Division of Fish and Game plans on surveying the abundance of juvenile sardines, four to six months old, on the nursery grounds. If the greatest mortality does occur during the first few weeks or months of life, the abundance of juvenile fish on the nursery grounds may reflect the relative strength of year classes. The problem of surveying juvenile sardines is a difficult one. The nursery grounds are extensive, and, as yet, imperfectly known. Also techniques for locating and sampling juvenile fish quantitatively have to be perfected. However, if the difficulties can be surmounted, the surveys of juvenile sardines should be of great value in assessing the strength of year classes in advance of their entry into the commercial fishery.

The Problem of Availability

Why are adult sardines more available to the fishery during some years than others? What are the environmental conditions that affect the distribution of the adult sardines? This problem of considerable importance to the sardine fishery is being investigated by the California Division of Fish and Game. In working on this problem they are using their new research vessel the MV "Yellowfin" on nearly a full time basis.

The object of the research is to correlate physical and biological oceanographic conditions with sardine distribution to determine the effects of these conditions upon the availability of sardines within the fishing area. In doing this it will be possible to utilize as basic data the oceanographic observations being collected by the Scripps Institution and the Fish and Wildlife Service, a number of aspects of which have been discussed in the preceding pages. To correlate their findings with these data the California Division of Fish and Game is taking a limited amount of oceanographic data at the spots where sardine schools are found - temperature observations (using a bathythermograph), samples of salinity at several depths, samples to determine diatom abundance, and samples of plankton.

In carrying out this program it is necessary to develop ways to locate schools of fish rapidly and to determine the kinds and sizes of fish in the schools. The "Yellowfin" is equipped with sonar and a recording fathometer, and it has already been demonstrated that these are efficient tools for finding fish schools. The schools on the surface can be satisfactorily sampled with small concussion grenades, but those at depths of over 20 feet are more difficult to sample and methods for doing so are still being perfected. Experimental work with gill nets and a mid-depth trawl is being carried out in an attempt to solve this problem. The investigation will not be confined to the fishing grounds, but study will be made of the distribution of sardines in other areas as well.

The sampling of the schools gives valuable information on several points. The sex, size and age distribution of the sardines in the school are determined by the same methods used in sampling the commercial catch. Stomach samples are obtained to study the kinds of food eaten by sardines and by comparison with plankton samples made at the localities of capture to determine whether the sardine selects certain types of food and ignores others. It has been shown that herring in the North Sea avoid heavy concentrations of plant food, but are likely to occur where animal food, particularly copepods, is abundant. One of the problems of the present study is to find out whether there is a similar relation between the distribution of sardines and the type of food in the area.

In addition, information is being obtained on the relationship of the sardine to other species - for many of the schools sampled to date have contained a mixture of several species in addition to the sardine - particularly Pacific mackerel, jack mackerel and anchovies.

Another aspect of the work involves a study of sardine behavior and schooling habits. This problem is being investigated experimentally under laboratory conditions by the California Academy of Sciences. At sea, by means of sonar and fathometer, it should be possible to follow the movements of fish schools and study their behavior in schooling under natural conditions. In this connection there are many problems on which we need information. Practically nothing is known of the schooling habits of sardines during the spawning season. Because they are more widely dispersed during this period, it has been assumed that they break up into quite small schools. This may or may not be so. The relation of schooling behavior to environmental conditions, especially temperature, needs investigation. Studies on sardine behavior being conducted at the California Academy of Sciences have shown that temperature appears to be important in the schooling behavior of sardines.

The two major problems being investigated under the expanded sardine research program, recruitment and availability, have this in common: in both we are studying the sardine "at home". In the preceding pages we have attempted to present some of the features, biological and physical, that influence the living conditions of the sardine. To date, little more than a good beginning has been made on the study of these environmental conditions. Yet it is rather certain that before we can hope to predict fluctuations in abundance of the sardine fishery we must first investigate the environment thoroughly enough to understand the effects of physical and biological processes on the sardine population.