

## PART 1

# REVIEW OF ACTIVITIES

July 1, 1963—June 30, 1966

## REPORT OF THE CALCOFI COMMITTEE

### INTRODUCTION

It has become increasingly apparent that the policy of the CalCOFI has been a valid and valuable one—that the intensive long-term study of the California Current has constituted a nucleus and *raison d'être* of an expanding research and technology of greater depth, field and compass in the North Pacific. The nature of these expanded portions of the program are discussed later in the reports of agencies.

The CalCOFI Committee is deeply involved with its fundamental objectives and with reappraisal of the direction that the CalCOFI should now take. This reappraisal is necessitated by the delineation of unutilized fish resources of the eastern North Pacific and the initiation of a fishery one of these—the anchovy.

The philosophical, scientific, and politico-economic factors pertinent to this reappraisal cannot be competently discussed here. However, the crucial questions can be reasonably well formulated as follows:

Are the long-term needs of the state, society, and mankind best served at this juncture by a concentration of research on the anchovy and its fishery or by a continued expansion of the research into the total environment?

The resolution of this problem depends upon a valid understanding of the evolving position of California; its changing responsibilities to its people and to its challenges and opportunities; and the present and potential contribution of the CalCOFI to the State.

On the one hand, as a result of CalCOFI research, we have the opportunity of reestablishing a reduction fishery of some magnitude. On the other hand, we have the demonstrated, suspected, and as yet unrecognized opportunities and implications of the Pacific and of the expanding research into it, of which the anchovy fishery is an early product.

Clearly the rational solution to these mutually exclusive extremes is an optimum attention to each—a *juste milieu* in which the anchovy fishery is substantially documented and studied and, at the same time, the research continues to be directed toward a broad-scale inquiry into the eastern North Pacific, its oceanography, zoogeography, history and fish populations.

### BACKGROUND

The CalCOFI program, thus, plans a thorough coverage of the California Current system each three

years (1969 next), and a continuing expansion of the several programs, descriptions of which follow.

Early in 1966 the CalCOFI Committee, in a letter to the Chairman of the Marine Research Committee, outlined the history, accomplishments, and status of the CalCOFI research program in simple, brief, factual terms. The 13 points, to which we referred as “a few of the many unshakeable pillars of certainty”, were:

- (1) The CalCOFI program was established as a broad and thoughtful inquiry into the environment and the biology of the California Current system.
- (2) An object of the program was to clarify the nature of the decline of sardine abundance and to understand the nature of the other organisms associated with the sardine in the California Current system.
- (3) Organizationally, the CalCOFI is established as a group of cooperative research programs responsible to these objectives and subject to the review of their progress by the Marine Research Committee, a highly selected group of interested, practical men.
- (4) As will be enumerated below, this arrangement has proven to be extremely successful and rewarding. The rapport between men of scientific and practical bents has, we believe, been unique. There has been neither constraint, on the one hand, nor lack of direction, on the other but rather an almost wholly unprecedented balance between the two where the scientist has been able to work with “responsible freedom” and where he, the MRC and the public have been highly rewarded.
- (5) The oceanography, the biology of the California Current system, and the variations in these are now the best documented and best understood of any oceanic area in the world.
- (6) The understanding of fish populations, biology and resource potential through studies of eggs, larval and adults of pelagic fishes are the most highly advanced of any.
- (7) Wholly new technologies of studies of pelagic fish have been developed and are of far-reaching, world-wide import.
- (8) Entrees into the pre-fishery history of the pelagic fish populations and environments have been developed and are of great local and world-wide significance.
- (9) The populations of a large group of pelagic fish have been determined, studied, and understood to a degree that far surpasses any similar studies in the world.
- (10) The interrelations between competing species of pelagic fishes have been characterized for the first time in history.
- (11) Possibility of a pelagic fishery has been pointed out and the fishery has been established, in which there is a far greater fund of scientific understanding and knowledge available at its outset than for any other pelagic fishery in the history of man.
- (12) A program exists that is ably discharging its full responsibilities both present and future in cooperative research.

- (13) These responsibilities include the study of the effects of the present fishery and the inquiries essential to future development and understanding of other and extensive resources.

The above are overly simplified statements of a part of a large and important program. We believe the results of this program can be characterized by stating that new and important concepts in the uses of our living oceanic resources have been evolved. These, together with the resources at our door, have put California on the threshold of increasing her wealth, and perhaps more importantly, of assuming world leadership in the scientific use of pelagic fish resources. This may, in the long run, be a far more valuable asset to Californians than the economic yield of the resources themselves.

It was on the basis of the research program described in the above letter that we had prepared for the Marine Research Committee, 2 years earlier, an outline of one possible way to enter this new era. This proposal was presented to MRC in March, 1964 by the CalCOFI Committee which at that time was composed of G. I. Murphy, J. D. Isaacs, J. L. Baxter, and E. H. Ahlstrom and appears as Document XII of the minutes of that meeting. It seems appropriate at this time to publish the proposal for all to study, evaluate, and comment upon. In the following it is quoted essentially verbatim.

#### REQUIREMENTS FOR UNDERSTANDING THE IMPACT OF A NEW FISHERY IN THE CALIFORNIA CURRENT SYSTEM

Our philosophical guide in preparing this discussion has been simple. We have asked ourselves, "How should a fishery be conducted, and what investigations should be initiated to give the public guidance of maximum value from marine science?" We would like to regard a new fishery on the sardine-anchovy system as a careful scientific experiment, in which the effect of a controlled harvest of the anchovy and sardine populations is explored. We believe this is a new and stimulating point of departure. While we do not propose it to you as a necessary course of action, we hope you will examine it thoughtfully and decide for yourselves the extent to which the scientific requirements for such an experiment are compatible with the broad needs of society.

#### Background Résumé

The results of over 40 years of study, including 14 years of very intensive inquiry can be succinctly summarized as follows: After many years of intensive selective fishing for sardines, the sardine population declined. This decline was accompanied by a dramatic upsurge of an ecologically similar species, the anchovy. The decline of the sardine was apparently the result of an intensive fishery together with a series of years in which the environmental regime was unfavorable to the sardine. The rise of the anchovy is apparently the result of a series of favorable years for that species, and man's removal of sardines which created more living space for anchovies. The evidence does not allow us to arrive at a consensus as to whether or not the anchovies aggressively drove down the sardine population, but biological interaction between these ecologically similar species is strongly indicated now by the failure of the sardine to respond to a recent spectrum of oceanographic conditions that should have been favorable, and conversely unfavorable to the anchovy.

In any event results of all these studies show that there is now a large unused population of anchovies. They also infer that there is a real chance that simultaneously reducing the pressure on sardines and imposing pressure on anchovies will reverse the present equilibrium and assist in bringing back the more valuable sardine. This constitutes an exciting opportunity for marine science to assist society in meeting its complex needs.

#### Requirements for the Fishery

In developing this section three factors have been paramount.

1. The basis for the suggested experiment while the most complete ever achieved still is not precise enough to foresee exactly how many anchovies and sardines should ultimately be taken. A careful, stepwise, approach such as was used in South Africa is the only defensible experiment.

2. There are time lags in the response of fish populations to new factors. With respect to sardines and anchovies, their life histories suggest that at least 3 years would be required for the responses of the populations to be detected, even in a regime of favorable environments.

3. There are also time lags in scientific analysis, these are especially significant when dealing with a new problem. Thus it is necessary to carry out measurements that can follow events closely, and which will yield results that are readily interpreted. With these factors in mind the approach below is divided into phases. We believe that three years is a minimum for each phase.

*Phase 1.* The objective is to initiate a conservative fishery on anchovies and reduce sardine fishing just sufficiently to produce an observable change in the system, and just enough to improve our preliminary appraisal of the magnitude of the anchovy resource. During this phase a limit of 200,000 tons should be placed on the anchovy fishery and the sardine fishery should be limited to 10,000 tons. Thirty-five percent of both of these limits should be taken off California and 65 percent off Baja California.<sup>1</sup> From the viewpoint of conducting a controlled experiment, it would not be desirable to place a complete moratorium on sardines for two reasons. The fishery is a primary tool for detecting responses in the sardine population. Were the fishery terminated this tool would be lost, and we would have to rely entirely on our surveys. Secondly, a complete moratorium would complicate the experiment by introducing two variables at the same time. The limit suggested for the sardine relieves these problems by keeping our "window" on the sardine population open, and by approximating the average rate of exploitation prevailing over the past years. If both the sardine fishery and competition from anchovies are affecting the sardine population, the chances of bringing back the sardine in the shortest possible time can be maximized by fishing for anchovies and not fishing for sardines. If this is the objective it might be desirable to have a moratorium on sardine fishing. The recommendations of this report are based on the viewpoint of conducting as careful an experiment as possible to determine the factors affecting both sardines and anchovies.

*Phase 2.* The amounts to be removed during Phase 2 and the areal distribution of the limits on each species must await the results of Phase 1. We can hazard a guess that during this Phase the anchovy quota might be raised about 50 percent providing that the results of Phase 1 are not widely different from our preliminary expectations.

*Phase 3.* This cannot be specified at all beyond indicating the ultimate objective. This is to restore the pre-decline balance between sardines and anchovies, and maximize the harvests consistent with all uses, i.e., food, recreation, etc.

*Comment:* It is beyond our scope to determine how such an advanced system of management on an international resource may be achieved. We do feel strongly that conservative managerial flexibility is essential.

#### RECENT DEVELOPMENTS

The 1964 proposal also outlined the basic programs which should be implemented if a fishery were initiated. At that time no fishery for anchovies existed, except for the limited (5,000-6,000 tons) fishery for

<sup>1</sup> At the 21 May, 1964 meeting of the Marine Research Committee, CalCOFI recorded the following emendation: "Our recommendation for Phase 1 included a provision to distribute the catch between Alta and Baja California. For the purposes of this provision we specify 31°N latitude, as this is a natural oceanographic and faunal boundary."

live bait. As a direct result of the CalCOFI proposal, the California Fish and Game Commission authorized an experimental anchovy reduction fishery on November 12, 1965. The 75,000 ton quota allowed is approximately of the magnitude recommended for California waters by CalCOFI. This fishery has continued to the present time (1967).

In March, 1966, with the fishery underway, E. H. Ahlstrom updated the 1964 proposal to point up the breadth and pertinence of CalCOFI research to present and long-range problems. The following is his outline of the programs implemented:

### STUDIES ON THE FISHERY

Important information can be gained from the fishery about the quantity of fish landed, size and age composition of landings, and catch per unit of effort. Other kinds of information that can be derived from systematic sampling include growth rate, age at first maturity, longevity, yield per recruit, mortality estimates, etc. These are "conventional" investigations, involving fairly standardized techniques. A fishery carried out at a low level of intensity furnishes only limited data for determining vital statistics of the population being fished. Such studies are of greatest value in determining vital population parameters when carried out over different levels of fishing intensity.

#### Total Landings by Area

*California Fishery:* Landings statistics now obtained by the State cover tonnage landed, area of capture, and fishing effort. Accurate weights are reported on market and cannery receipts as required by law. Area of catch is determined from fishing logs, required of each boat skipper, whereby each day's fishing is plotted on a map-type log.

*Baja California Fishery:* Plant operators in Baja California cooperate by giving us access to landing records. Our primary source of information about area of capture of fish is personal interview.

#### Size and Age Composition by Area

Data concerning size and age composition are obtained by systematically sampling commercial landings from all ports of landing in California and Baja California. Sampling of commercial landings in California is carried out by the California Department of Fish and Game. Sampling of commercial landings in Baja California is carried out by the Bureau of Commercial Fisheries by means of a contract with the California Academy of Sciences. Samples of whole, adult fish will be retained for unforeseeable research. Age determinations are done cooperatively by California Department of Fish and Game and Bureau of Commercial Fisheries scientists. Cooperative aging of sardines by these two organizations dates from 1941; cooperative aging of anchovies from the early 1950's.

In the past, scales have been "read" to determine the age of both sardines and anchovies. Presently, evaluation is being made of the scale method for determining age versus use of ear bones (otoliths). Anchovy scales are highly deciduous, with the result that it is difficult to obtain adequate scale samples from some loads of fish. Sampling can be carried out more systematically if based on otoliths.

#### Catch Per Unit of Effort by Area

California has instituted a logbook system to obtain information concerning each commercial landings of anchovies. This is in addition to information obtained by interviews, whenever a load of fish is sampled.

It presently is not feasible to try to institute a logbook system for Baja California fishermen. We are able to obtain records of individual deliveries, and to supplement this by interviews.

### STUDIES ON THE POPULATIONS

One of the major reasons for establishing CalCOFI was to obtain information about many aspects of the population dynamics of the sardine that could not be wrung out of catch and effort data. Methods independent of the fishery were developed to determine population size, population structure, factors underlying marked fluctuations in the survival of year-classes, shifts in distribution of the population with respect to the area of the fishery (availability), etc. What was not fully appreciated was the complexity resulting from competition between species of a trophic level (i.e. between sardine and anchovy).

We must continue to investigate the interaction between competing species. This requires more sophisticated research than is possible from studies on the fishery alone.

#### Tagging Experiment—Anchovy

The State has already initiated a tagging experiment in southern California waters. They had tagged about 100,000 anchovies by November, 1966, in areas off northern Baja California, southern California (inshore and offshore) and the Monterey Bay area. Eventually a tagging experiment should permit a determination of the extent of migrations and intermingling of fish from various parts of the anchovies' range—California, Baja California or the Pacific Northwest. Tagging experiments should be combined with genetic studies. Tagging on a broader scale may provide information about population parameters such as population size, fishing mortality, and natural mortality.

One of the initial problems we have to elucidate is the extent and rate of replenishment of stocks from other areas. Will fish move up from Baja California for example, to replenish stocks reduced by fishing off southern California?

A very successful tagging experiment was carried out on the Pacific sardine (1936-41), mostly by the California Department of Fish and Game. The Department will be chiefly responsible for the tagging experiment on the anchovy. The Bureau of Commercial Fisheries is cooperating, especially in developing techniques that will result in low tagging mortality; also in evaluating this mortality.

#### Genetic Studies

These are necessary to determine whether one or several stocks are being fished. We now know, for example, that the sardine fishery off southern California depended upon two genetic stocks (northern and southern subpopulations) with differing availability. Is the anchovy population in the Pacific off California and Baja California similarly made up of several genetically distinct stocks? In point of fact, a tagging experiment would be conducted quite differently if we definitely knew that the anchovy population consisted of a single intermingling stock rather than several genetically distinct stocks.

BCF's genetics program has been working on the problem of "genetic" stocks of anchovies, so far with inconclusive results. The Department of Fish and Game will conduct experiments with eye lens proteins as a means of differentiating possible genetic stocks.

#### Egg and Larva Surveys

To date this has been our prime instrument for evaluating the interaction between the sardine and anchovy populations. These studies furnish information on many other fishes—hake, rockfish, jack mackerel, Pacific mackerel, flatfishes, etc. There is no question about the need of their continuance, although this must be at a more modest scale than in the 1950's. Anchovy population can be adequately monitored with about one-half of the effort (ship time) expended in the 1950's.

We do not have to measure changes in the sardine population with the same degree of precision as changes in the anchovy. We have set a limit of  $\pm 20\%$  as the acceptable level of variability for our estimates of abundance of anchovy larvae. For sardines, an order of magnitude would be acceptable. We are interested in major changes in the abundance of sardines, a small change would have little significance.

### Fish Surveys

Surveys designed to assess the abundance of adult populations of sardines and anchovies should be given high priority. It is hoped that such surveys essentially will become as sensitive a measure of abundance as are the egg and larva censuses.

Both California Fish and Game and the Bureau of Commercial Fisheries have increased their research in this area. The California Department of Fish and Game is utilizing funds obtained under the Commercial Fisheries Research and Development Act (Bartlett Bill) to increase the coverage of their surveys of juvenile and adult fish. Their surveys will investigate fish populations farther to sea and at more frequent intervals than has been possible in the past. The Bureau of Commercial Fisheries has installed a Simrad research sonar on their new vessel, the *David Starr Jordan*. This gear should permit an assay of the distribution and abundance of schools of adult fishes. Cooperative cruises are planned by all three agencies for developing techniques for "Identification of acoustic targets and pelagic fish census."

### ESSENTIAL BACKGROUND STUDIES

These are given in essentially the same form as in the March 1964 proposal.

#### Physical Oceanography

a. Monitoring program through buoys, shore stations, hydrographic cruises as needed, etc. (this should be a burden jointly shared with other interests).

b. Analytical program: Basic studies of dynamic processes affecting the California Current system with particular attention to factors affecting anchovies and sardines and the biota in general.

#### Biological Oceanography

This should be a broadly based background program. The organisms in the California Current system must be examined as an interacting community.

a. Studies of filter feeding fish, trophic level: (Including food habits, predators, natural mortality rates, etc.). This is a huge area, one in which many scientists could lose themselves for many years. Therefore, we recommend that sardines and anchovies be a starting point and that studies radiate out from them! One of the major pragmatic objectives of this program is to test the validity of the two species system. For example, if we lower the anchovy population some species other than the sardine may pop up. Other projects, e.g., the egg surveys, fish surveys, and the historical survey contribute to this study.

b. Historical: Study sediments to ascertain "recent" oceanographic history and changes of major biological components of the California Current system, including fluctuations in sardine-anchovy abundance. This history probably can be developed to cover the last 2,000 years, possibly on a year by year basis.

#### Fishery Biology

a. Age specific fecundity, mortality, etc., of important species, i.e., the biological properties of sardines and anchovies, etc., that underline their inherent rates of increase, and interpretation of egg surveys.

These studies are critical and must receive early emphasis.

b. Adult and larval physiology and behavior: These are essential to achieve understanding of the effects of environmental changes on the dynamics of the community. Initial focus should be on the sardine and anchovy.

#### Final Comment

Obviously this list is not complete (for example, the basic productivity studies underway are quite pertinent). We believe it incorporates the most essential investigations that offer attainable goals. It is impossible to foresee what will seem essential and attainable in the future. The only thing that can be done about this is to foster a group of scientists who are responsible with respect to vital and

attainable goals, and who are also responsive to new problems, new opportunities, and to advances in the marine sciences generally.

On February 27, 1967, the CalCOFI Committee updated the recommendations to the Marine Research Committee on the development of the experimental anchovy fishery. It finds that the basic rationale expressed in that document remains valid. However, the values expressed in Phase 1 of the proposed experimental fishery have been revised on the basis of data for eggs and larvae in the additional years.

Phase 1 had as its objective "to initiate a conservative fishery on anchovies and reduce sardine fishing just sufficiently to produce an observable change in the system, and just enough to improve our preliminary appraisal of the magnitude of the anchovy resource." This called for a 200,000 ton annual quota, 35% of which was to be taken off "California" (north of 31°N. lat.) and the balance off Mexico (south of 31°). It called for a concurrent sardine fishery at a 10,000 ton level. The anchovy quota was based on egg and larva data for the years 1951-59 which indicated a total anchovy biomass of about 2,000,000 tons. Since that time, egg and larva data through 1965 have been analyzed and considerable information is available for 1966. These data show that the population level for the period 1962-66 was two to two and one-half times as great as it was in 1958-59. At the same time, the center of distribution of the population has altered, so that about half is now found north of 31°N.

Using the conservative 2x increase and taking note of the northward change of the population center, the total quota becomes 400,000 tons, with an approximate take north of 31° of 200,000 tons. The total anchovy biomass is now of the order of 4-5 million tons. The recommended take, 10% of the minimum, is extremely conservative but is sufficient to serve the purpose of Phase 1.

CalCOFI now recommends a complete moratorium for at least 2 years on the take of sardines because of the extremely low population level. We believe that a moratorium will not have an adverse effect on the experiment. A moratorium was not originally recommended for two reasons: (1) So that conditions of only one component of the experiment (i.e. the anchovy) were changed and (2) so that appropriate samples of the adult sardine were obtained for study. However, the continued reduction of the sardine population already constitutes a significant and inescapable alteration of the conditions, and sufficient samples of sardines can be obtained from mixed catches, lift net samples, etc. Thus, neither of these earlier objections to a moratorium on the sardine remains valid and a moratorium is now recommended.

The CalCOFI Committee believes that the program should now progress in the following manner:

1. The anchovy and sardine populations should be carefully monitored and studied, following, in general, our previous recommendations for research on such a fishery. Research should include

the appropriate egg and larva studies, catch records, tagging, fecundity, and food studies, etc.

2. Data should be analyzed and published with all possible expedition. Back data should be given high priority.
3. The populations, distribution and biology of the total pelagic fishes of the eastern north Pacific must be much better quantified. The areas of limited biological knowledge for each important species must be clearly delineated and resolved.

Examples for such limitations are:

Jack mackerel—area of distribution—population size—fecundity.

Hake—distribution of adults, food.

Squid—population size, distribution, food.

These are conspicuous deficiencies of the previous data. In addition, the previous data that are pertinent to the problem must be further studied and analyzed for the important and necessary insight they provide into the population of these and other pelagic fishes.

4. The nature and mechanisms of oceanographic and marine biological variation must be extended further into the source waters of the California Current. New methods and new programs will now allow us to do this.

## DISCUSSION OF RECOMMENDATIONS

Clearly the direction of research that CalCOFI recommends is far from a singleminded inquiry into the anchovy. We believe that we would be serving neither science nor the state were we to adopt the anchovy fishery as a single object of study. Rather we are recommending an adequate continuing and defensible study of the anchovy and sardine and an expansion of the broad studies of the pelagic environment, which have paid off so handsomely. In this we believe that we are choosing a multilane highway into the future, which not only coincides with the scientific objectives, but serves the statutory objectives of the State and the MRC, in manifold ways.

For example, if (or, perhaps, when) the State is called upon to defend its high seas fishery resources against the encroachment of foreign fleets, it would indeed present a sorry argument were it to possess a plethora of data on the anchovy and negligible quantitative data on the saury, hake, jack mackerel and squid, for these species also are in great abundance and clearly attractive to international exploitation.

This has been pointed out before, along with other reasons to broaden the program at this time. For example, a monolithic approach to the anchovy could, of course, result in a *cul-de-sac* of empty answers were the anchovy fishery to fail for economic or statutory reasons.—*E. H. Ahlstrom, J. L. Baxter, J. D. Isaacs, and P. M. Roedel.*

## AGENCY ACTIVITIES

### *California Academy of Sciences*

The experimental studies of responses of the northern anchovy (*Engraulis mordax*) to light stimuli were

extended into 1964 for additional tests with application of ultra-violet and infrared radiation, and concluded by the end of the same year. These studies revealed a few important factors that are related to behavior. These are as follows:

1. The anchovy is a phototactic animal.
2. It is capable of discriminating qualitatively between monochromatic (green, blue, red) and white lights.
3. It is able to distinguish green light from blue.
4. It shows a preference for the green and blue lights over white.
5. It proved to be strongly negative in reaction to red light (however, the fish tolerated this type of illumination as an alternative to total darkness).
6. It is capable of reacting differently to different intensities of white light.

The results of these studies were published in the Proceedings of the California Academy of Sciences on January 15, 1965 (Vol. XXXI, No. 24, pp. 631–692) under the title "Behavior and Natural Reactions of the Northern Anchovy, *Engraulis mordax* Girard, Under the Influence of Light of Different Wave Lengths and Intensities and Total Darkness," by Anatole S. Loukashkin and Norman Grant.

The investigation of food habits and feeding behavior of the northern anchovy in California and Mexican waters was initiated on July 1, 1965, and continued in 1966. By the end of the 1965–66 fiscal year, 592 anchovy stomachs had been collected in Baja California, southern and central California, mostly by Anatole S. Loukashkin. Preliminary analysis of the stomach contents shows that the northern anchovy is an omnivorous feeder. It feeds on both zooplankton and phytoplankton. From the scant material at hand it is difficult to determine the degree of preference for one type of food over the other. It seems that the anchovy feeds on the available supply, regardless of kind. The stomachs collected contained either zooplankton exclusively or phytoplanktonic ones, or both. However, the bulk of food found in the stomachs was zooplanktonic organisms, such as euphausiids, copepods and amphipods. The euphausiids were the dominant food item. Among the diatoms consumed by the anchovy, *Chaetoceros* was found to be a dominant form. In some cases it contributed to 99% of the contents in bulging stomachs (Monterey Bay).

As to the method of feeding, the anchovy is both a filter feeder, and a particulate feeder. During the reported period field observations under natural conditions were carried on during routine cruises of the California Fish and Game M/V ALASKA by Anatole S. Loukashkin. These observations include records of school patterns, feeding behavior, school maneuverability, and reactions to artificial light sources and fishing gear, of the sardine, anchovy, mackerels and other pelagic fishes.

**California Department of Fish and Game  
Pelagic Fish Investigations**

The Department's portion of the CalCOFI Program is conducted by its Pelagic Fish Investigations. The primary responsibilities are: (i) basic monitoring of the pelagic wet fisheries, particularly Pacific sardine, Pacific mackerel, jack mackerel, and northern anchovy, and (ii) conducting research vessel surveys of the pelagic and bathypelagic fishery resources of the California Current system.

Studies of the wet fisheries include: (i) sampling of commercial and live-bait catches to determine the age and length composition; sardine and anchovy age determinations are made in cooperation with the U.S. Bureau of Commercial Fisheries; (ii) interviewing fishermen and collecting logbook data to measure fishing effort and determine catch localities; and (iii) determining the amounts of fish landed and insuring the accuracy of source documents in cooperation with the Department's biostatistical unit.

Good progress was made with respect to the large backlog of age composition and fishery data on jack mackerel. This information, some dating back to 1947, has been processed and the analysis of data and preparation of manuscripts is in progress. The analysis should reveal whether the jack mackerel fishery depends upon highly available year-classes and, if such is the case, possibly explain fluctuations in fishing success experienced in recent years.

High priority is being placed on analysing all age composition and fishery data relating to Pacific mackerel with the objective of determining various aspects of the population dynamics of the species. Such information has been only partially presented in the past and this work will aid materially in understanding recent changes in the status of Pacific mackerel.

In November, 1965, the California Fish and Game Commission authorized an experimental anchovy fishery for reduction with a quota of 75,000 tons. To do the research required to monitor the effects of the fishery, an expanded anchovy research project was established by the Department. Concurrent with the inception of a reduction fishery new or revised sampling and monitoring procedures were needed. Previously the anchovy fishery was quite small and sampling consisted of 50-fish samples, selected at random and as convenient, and skipper interviews. This sampling procedure continued through the 1965-66 season.

Beginning November, 1965, a logbook system was inaugurated to obtain catch, effort, gear and fishing area data. The chart-type logbook devised prior to the 1965-66 reduction season proved successful in fulfilling its intended purpose and with minor modification will continue to be used. Initial problems with the logbooks were lack of consistency among fishermen in recording scouting time and inaccuracy of the fishermen's estimate of catch size. Both problems decreased as the fishermen gained experience. Data recorded in these logbooks are coded, key punched, and machine processed to facilitate analysis.

At the start of the second anchovy reduction season, sampling procedures were changed rather extensively.

Changes were based on the knowledge gained during the first season and will probably be modified as the fishery increases and as we increase sampling efficiency. Briefly our southern California sampling plan required obtaining 20 random samples for every 5,000 tons of fish landed. The ton (within the 5,000) to be sampled is determined from a table of random numbers as is the port and the load to be sampled. Samples are by weight and consist of two 1-pound clusters. Each cluster is divided into equal parts. All the fish in one part are measured only, from the remainder we obtain length, weight, sex, maturity, and scales and otoliths for age determination. Maturity is determined by a method defined by Hjort.<sup>2</sup>

Central California sampling procedures differ from those in southern California in that one 4-pound sample is taken each day from alternate reduction plants in Monterey Bay. The sample is divided into two parts,  $\frac{2}{3}$  are measured and the remainder of the sample is processed as in southern California.

As part of the expanded anchovy research program, the Department has tagged more than 100,000 northern anchovies since March, 1966. These fish have been tagged and released in areas along the coast from Cape Colnett, Baja California to San Francisco Bay. The tagging method is that developed by Vrooman, Paloma, and Jordán,<sup>3</sup> in which an internal stainless-steel-alloy tag is used. Numerous problems were encountered and solved during the past months of tagging. The most serious potential problem was predation on tagged fish at the time of release. To avoid this problem all the fish tagged (3,000-4,000) during 1 day are released as a group. These fish were mixed with a greater number of untagged fish and released over an anchovy school whenever possible.

By February, 1967, about 350 tags had been recovered by magnets in the meal lines of the processing plants. Preliminary returns have shown movements of anchovies from southern California to Ensenada, Baja California, and to Monterey, California. Fish have also moved between inshore waters and offshore waters around the southern California Channel Islands. The large majority of the returns came from near the area which the tagged fish were released.

With funds obtained through Public Law 88-309, the Federal Aid for Commercial Fisheries Research and Development Act (Bartlett Bill), the Department has greatly expanded its oceanic surveys of adult and juvenile fishery resources. The scope of the surveys was changed from a survey of the inshore area during the fall months to a year-around survey of all pelagic and bathypelagic fishery resources. The survey covers the area from Oregon to Magdalena Bay, Baja California.

A calendar-year survey consists of 10 cruises each of 20 days duration. Eight are echo-sounder surveys, one each to southern Baja California and northern California and three each to central and southern

<sup>2</sup> Hjort, Johan. 1910. Report on herring investigations until January, 1910. *Cons. Perm. Int. Explor. Mer., Publ. Circumstance*, (53): 35.

<sup>3</sup> Vrooman, Andrew M., Pedro A. Paloma, and Romulo Jordán. 1966. Experimental tagging of the northern anchovy, *Engraulis mordax*. *Calif. Fish and Game*, 52(4): 228-239.

California including northern Baja California. Followup cruises in southern and central California serve as both gear research cruises and intensive sampling surveys.

The first phase of the expanded survey, in fiscal 1965-66, was designed to provide continuity with cruises conducted during the past and to develop the following survey techniques, which have been in effect since June, 1966. An echo sounder is operated continuously during the day over predetermined transect lines that extend perpendicularly from shore for at least 35 miles or until the 1000-fathom depth contour is reached. These lines are spaced 15-30 miles apart and average about 50 miles in length. Hourly fixes are obtained and the number of schools appearing on the echo sounder are recorded for each hour of running time. Identification of species is accomplished by echo trace characteristics and by fishing a small, 30-foot midwater trawl. The trawl is also fished at regular 10-mile intervals during the night as the vessel returns inshore over the outbound transect lines. A record is kept of all visually observed surface schools and indications of fish during both day and night. Catch records include species, numbers, sizes and sex. Scale or otolith samples are obtained from the important species for determining age composition. Limited oceanographic observations pertaining to fish distribution are regularly obtained. These include bathythermograph casts, water turbidities, temperatures, and weather conditions.

We have now completed five cruises of this new type; two to central California, two off southern California which includes northern Baja California and one in southern Baja California. Anchovies have been the dominant species in all areas. Since these surveys were initiated some important seasonal distribution and behavioral aspects have been determined for anchovies. During spring the anchovy population was composed of thousands of very small schools distributed over large areas extending at least 50 to 80 miles offshore. These schools were located near the surface in clear, deep water and normally contained less than 2 tons of fish. All were adults in advanced spawning stages. Large compact schools, suitable for purse-seine fishing, were scarce and found only in a few localized areas. Juvenile fish were generally found close to shore in water shallower than 50 fathoms. During summer and fall all sizes of anchovies were found much closer to shore, at greater depths, and in larger but fewer schools. Decreases in school numbers from spring to fall in the southern California area exceeded 80 percent. These results indicate that, in general, the fish spread over a large area in spring to spawn and concentrate in small coastal areas during summer and fall. The most opportune time to estimate population size appears to be spring. With the large number of schools and extensive distribution, echo sounding surveying is much more effective. Schools size and identification are also more easily determined. Fall and summer distributions, with fewer and large schools, decrease the effectiveness of the echo sounder in probability of de-

tection, species identification and school size determination. This type of distribution and behavior should be more favorable for commercial fishing.

School types and behavior patterns were also observed. Small numbers of horizontal-layer school types 80 to 100 fathoms below the surface and more numerous plumes located 20-50 fathoms deep were the predominant schools in northern Baja California and central California. The southern California region contained these types plus plume-type schools at shallower depths. At nightfall all school types came to the surface where almost all dispersed into surface scatter or loose detached school segments. Only a very few remained compact enough to be visible as a bioluminescent spot or register as an echo trace.

The night behavior of anchovies appears closely associated with the upper extremity of the scattering layer that comes toward the surface after dark. The after dark rise and surface dispersal of schools suggests a feeding behavior as evidenced by the large numbers of recently ingested food organisms observed in stomachs of night-caught fish. A very high percentage of these organisms were euphausiids, which are an important constituent of the upper scattering layer.

Quantities of sardines were present only in the southern part of Sebastian Vizcaino Bay. Adults of the fall spawning sub-population overwhelmingly predominated the samples taken. This group is now apparently the strongest remnant of the whole population. Incoming juvenile year-classes were practically nil. Other species surveyed were minor in importance compared to anchovies. Juvenile jack mackerel, mostly of the 1966 year-class, were widely distributed in small scattered schools. Trawl catches usually ranged from 1 to 50 individuals, they rarely exceeded 100 specimens.

Hake were locally abundant in July off San Francisco. Many schools were found associated with white-bait smelt. Both species were in close association with each other, the hake were 1 to 3 fathoms off the bottom with the smelt 3-4 fathoms above them. The hake appeared as small groups, 20 to 50 yards apart. A series of these groups was counted as a school. One such school was over a mile across. Those sampled were large adults, 20-25 inches. Only minor traces of hake were noted in southern California in October and no concentrations were seen in November off central California.

The Department continued to issue data reports on past-year cruises (since 1950). The material is coded onto IBM cards, organized into tables by an electronic computer, and printed directly by a photographic process. The data are printed in the California Cooperative Oceanic Fisheries Investigations (CalCOFI) Data Report series.

Eight reports, covering the 9 years from 1950 through 1958, were printed and distributed while two more reports (9 and 10) for 1959 and 1960 were completed and ready for printing. Data for the several additional years were partially processed and will be printed as they are ready.



### ***Hopkins Marine Station***

The Hopkins Marine Station of Stanford University at Pacific Grove, California, conducts studies on the environment and organisms of the coastal waters of central California. Under the CalCOFI Program the marine station monitors the marine climate and phytoplankton of Monterey Bay. Approximately weekly cruises to six stations are made on Monterey Bay, and daily shore temperatures are reported from Pacific Grove and Santa Cruz. The data collected are compiled and distributed to interested agencies and individuals in the form of mimeographed quarterly and annual reports. A short paper summarizing some of the results obtained appears elsewhere in this report.

### ***Scripps Institution of Oceanography Marine Life Research Program***

The Marine Life Research Program includes that portion of the research of the California Cooperative Fisheries Investigation that is conducted by the Scripps Institution of the University of California. This program has been principally concerned with the ecology of the California Current system—that is, its currents and countercurrents, temperatures and temperature fluctuations, and its chemistry, plankton, climatology, etc.

The Marine Life Research Program (MLRP) has also expanded its scope considerably through a series of contracts and grants from the Office of Naval Research, the Atomic Energy Commission, the National Science Foundation, The Marine Research Committee and others. It also has expanded by informal cooperation with the Navy, the Coast and Geodetic Survey, other research programs of the University, etc.

In addition to the broadened research into the eastern North Pacific, the MLR also is carrying on its responsibilities for the monitoring of the California Current and the anchovy fishery, as discussed in the CalCOFI Statement.

The MLRP thus plans a thorough coverage of the California Current System each three years (1969 next), and a continuing expansion of the several programs, descriptions of which follow.

*Atlases.* The reduction of the load of routine data collections, has allowed an acceleration of the analysis and publication of the data taken over the period of intense inquiry. The last several years have thus seen the publication of a number of atlases on the distribution and distributional changes of the principal planktonic organisms of the eastern North Pacific. The atlases now published or in press include the Copepods of the California Current, Vol. I; the Euphausiids; the Dynamic Heights; and 10 Meter Temperatures. Other atlases in late stages of preparation are: Copepods, Vol. II; Biomass of Zooplankton (see below); Chaetognaths; Molluscs; Anchovy Larvae.

Within the next year there thus will be in published form the most extensive biological and physical oceanographic documentation of any oceanic region on earth. The atlases are published with particular attention to the requirements of an interdisciplinary cooperative program, so that scholars in a number of

different disciplines can compare distributions and check their hypotheses of interaction and dependency. The atlases are thus precursors of much added discovery.

*Biomass Analysis.* In the last several years the problems of arriving at a meaningful measure of zooplankton have been resolved. The purpose of the biomass analysis was to develop a measure and methodology for the zooplankton that would typify it as a functional component of the organic milieu. This is in distinction from a strict taxonomic breakdown. The nineteen functional groups are measured in volume in each sample. Thus the data from each cruise can be presented as the actual organic component of the water represented by each of the groups. The variations between years is striking and is related to the varying oceanographic conditions.

As the zooplankton are the vital food for most of the small pelagic fishes, these fluctuations are particularly important to the CalCOFI objectives.

Biomass analysis of the zooplankton have now been completed for a number of years and the first atlas will soon be published.

*Varved Sediment Study.* As previously reported, the sediments in certain basins are apparently laid down in annual layers and subsequently undisturbed. These sediments thus contain a "record" of almost annual resolution of the oceanographic and marine biological conditions of the overlying waters for at least the last several thousand years.

We are thus able to reconstruct the range of conditions to which the region has been subjected with a greatly enhanced insight. The conditions during recent studies can be placed in an extremely important perspective.

Sediments of this type have now been found in about six locations along the Pacific Coast from southern California to central Peru.

Fish scales are abundant and extremely well preserved in these sediments. The initial findings in southern California sediments are that the sardine scales are only twice abundant in these sediments. The recent period of about seventy years was a period of abundance and there was a similar period about eight hundred years ago. At other times sardine scales are rare. On the other hand the scales of the anchovy and the hake are in high abundance throughout the entire period except for short periods of time. Anchovy scales were rare in the recent period. The recent period appears to be typified by a weak California Current.

The importance of the local and world-wide implications of this sediment work can scarcely be exaggerated. It is an unexpected, unprecedented and potentially powerful entree into a very broad understanding of the distribution and variations of pelagic fishes and the related oceanographic conditions.

*Sediment Collections.* Not unrelated to the findings of the sediments, the MLRP has recently developed a collector that can be placed on the bottom of the deep ocean, and which will collect coarse particles of sediment that are precipitating from the water



column. Although only a few experimental sets have been made, from the data collected have been made the first direct estimates of the natural generation time of some planktonic marine organisms. It may be that this approach can yield much fundamental understanding of the economy of the sea that has avoided other efforts.

**Planetary Food Potential.** Included in the MLR program is a continuing study of the position of marine productivity in the food potential of this planet. This study is, of course, highly approximate. Nevertheless it aids in placing fishery development in perspective. Figure 1 compares the productivity of the land and sea and the related harvest by man. The potential harvest of the sea is seen to be several orders of magnitude greater than the present, or enough animal protein for more than 60 billion people. It is clear from this study that such a harvest can be achieved only by the capture of rather primitively feeding fish, such as the anchovies and sardines.

In addition, the probable efficacy of such interventions as artificial upwelling can be evaluated in such a perspective matrix. It appears that the heat rejection required to produce the world's power requirement from atomic sources can incidentally increase the ocean productivity in an amount approximately sufficient to supply a quarter of the needed protein.

Details of these and other such considerations can be found in several of the listed publications.

**Sardine Parasites.** An investigation into the stomach contents of sardines indicates that the sardine population off California was increasingly parasitized by two species of trematodes during the period 1925 to 1955. In later years the infestations were very heavy. There is even some evidence of competition between the two species of trematodes within the sardine stomachs. Such competition would be almost certain evidence that the infestation was damaging to the sardine.

Neither the sardine below Sebastian Viscaïno nor the anchovy were subject to such infestations.

Whether or not this infection contributed to the decrease of sardine stocks cannot be definitely ascertained.

**Sea Surface Temperature Anomalies.** The Years of Change 1957-58, brought to our attention the fact that variations in oceanic conditions were not of local origin but rather involve the entire North Pacific, if not the entire planet. We now know that non-periodic departures from normal sea surface temperatures are common throughout the oceans. In the North Pacific these anomalous conditions are often large scale and of long persistence (ca.  $\frac{1}{4}$  the width of the Pacific and of 2 years duration). These anomalies are associated with changes in weather conditions, the distribution of marine organisms, circulation, etc. We are now planning a large-scale study of these anomalies and their associated conditions utilizing a large number of unmanned instrument stations over a major part of the North Pacific.

In preparation for this research, a pilot study has been carried out. This study has revealed a number of high intriguing characteristics of these events that will require explanation. Among these findings are: A dependency of anomalies on the local spatial temperature gradient over one-half of the year; a relatively smaller variation in spatial and temporal temperature gradients in the regions of high anomalies than in the regions of "normal" conditions; an anisotropy of the heating-cooling cycle; and others.

In addition, the first long-term records from unmanned stations have been obtained. These have shown several important features including astronomic periodicities of temperature fluctuations.

This planned study of the North Pacific should result in better insight and input into North hemispheric meteorological and oceanographic prediction.

Some of these deep moored stations will be installed in the CalCOFI area and will result in almost continuous offshore data.

**Deep Benthic Conditions.** The oceanographic studies of the eastern North Pacific have been extended into deep water. The findings have been most significant.

Many of the conditions of the deep ocean bottom are virtually unexplored. The near-bottom currents are very poorly known, and little is known of the active creatures of the deep ocean floor. The development of autonomous instruments at Scripps has allowed

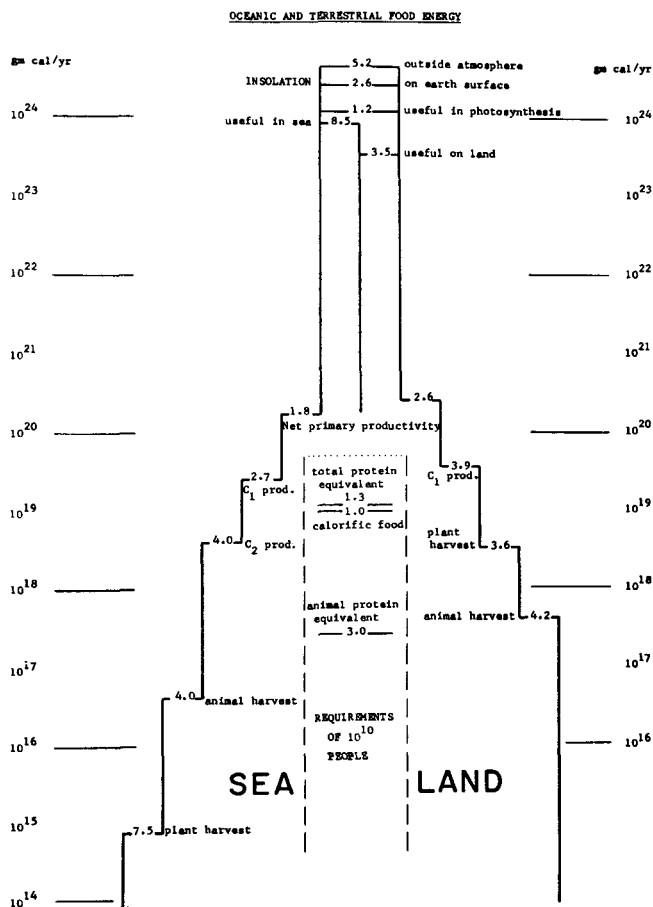


FIGURE 1. Diagram of total energy cascade into the food of the marine and terrestrial realms.—prepared by W. Schmitt.

us to add some insight into these conditions. Deep currents in the eastern North Pacific have been found to be low but of somewhat higher velocity than anticipated (ca. 3 cm/sec), and the fluctuating component has been found to result principally from the lunar semi-diurnal surface tide. We have also demonstrated the presence of unexpectedly large fish populations (see Figure 3) including very large climax predators, whose presence on the deep ocean bottom is an environmental condition of importance.

*Instrument Development.* Recent instrument development in the MLRP has been remarkably successful. All recent deep moorings have remained in operation at least six months in the open sea and one remained for 23 months. Long period records are now available that greatly increase our understanding of ocean conditions and are allowing the greatly increased program.

The autonomous instruments are valuable for research of the deep bottom.

The new Isaacs-Brown Opening-Closing Midwater Trawl is yielding much needed data on the vertical distribution of marine organisms.

New instruments under development include new sensors for deep moored stations, an acoustic release for autonomous instruments, isotherm following floats, etc.

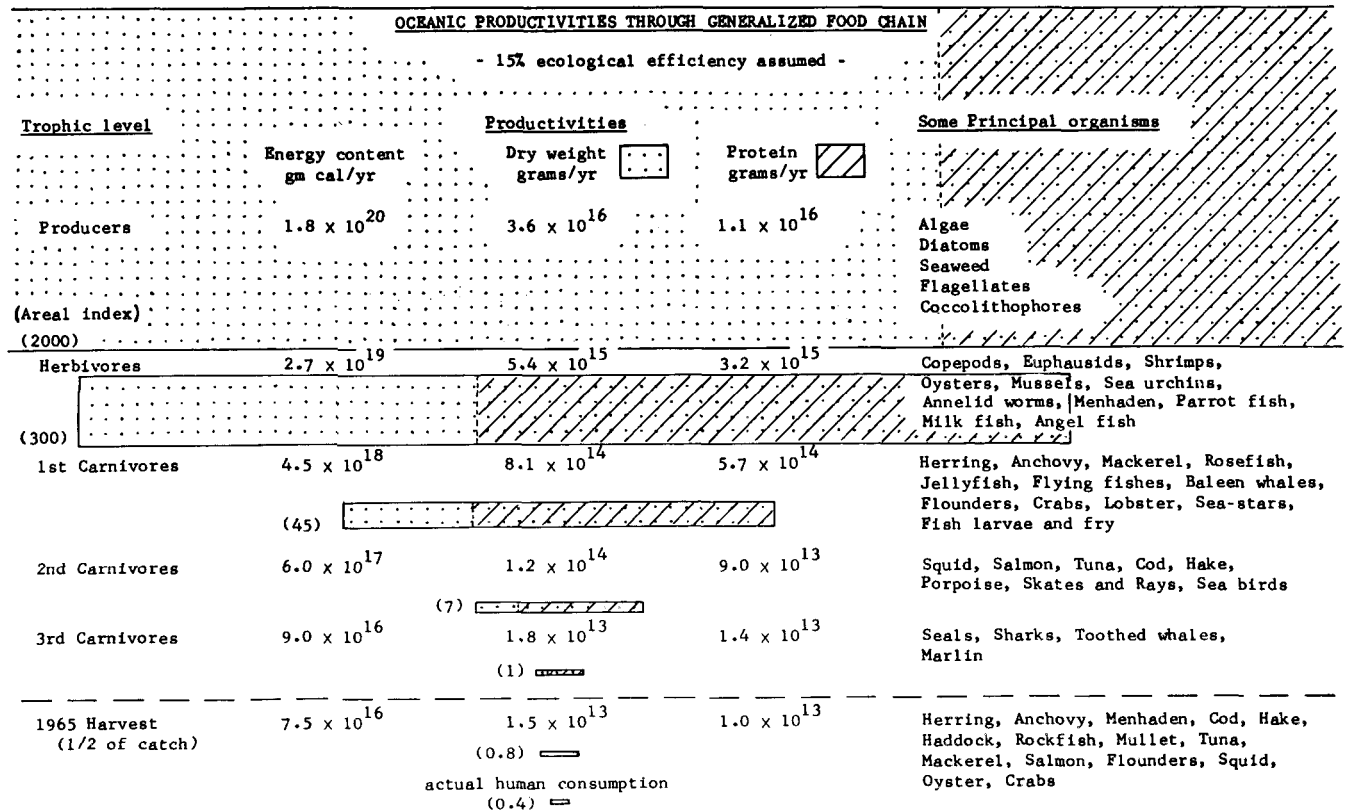
*Special Cruises.* The special cruises of the MLRP have been directed toward: (1) instrument development, (2) exploration of deep benthic conditions including the varved sediments, (3) cruises to explore and further delineate biological and oceanographic conditions in the North Pacific. Three such cruises were carried out in the period.

*Summary.* In summary, the MLR program over the recent period has greatly expanded its competency, range of interest, and findings. This expansion has been spatially into the North Pacific, vertically to the sea bottom, and temporally into the past range of conditions of the California Current.

This expansion is dependent upon and additive to the knowledge and insight that the CalCOFI program has created which is serving as a precious foundation for an expansion of research and the opportunities of California—and vindicating the prediction of the generators of the CalCOFI program that the Pacific can represent a freedom to the State of California rather than a barrier.

**U.S. Bureau of Commercial Fisheries  
California Current Resources Laboratory**

The former La Jolla Biological Laboratory, the oldest Bureau of Commercial Fisheries Laboratory in California, was renamed the California Current Re-



Note: The food chain should more accurately be thought of as a food web, in which most organisms feed on more than one trophic level, changing diet with their age (especially when young) and the availability of food.

FIGURE 2. Diagram showing the total marine food web. Hatched areas show total food and total protein food at each step.—prepared by W. Schmitt.



FIGURE 3. Grenadiers, hagfish, migrating tube worms and other creatures attracted to a bait and photographed by an untethered automatic camera at 1200 fathoms off Baja California.—(field view is about 9' x 12').

sources Laboratory in 1964, and in September of that year moved from the old, frame building on the Scripps campus, where it had been housed since 1954, to the newly built Fishery-Oceanography Center on a cliff site overlooking the ocean,  $\frac{1}{2}$ -mile north of the old location.

The Center is a strikingly modern laboratory, built of prestressed concrete and includes four multi-story buildings around a center courtyard. Noteworthy features of the Center are research laboratories grouped into functional complexes for studies of physiology, fish taxonomy, behavior, culturing of marine organisms, radiobiology, population ecology, and chemical and physical oceanography. An experimental seawater aquarium which delivers 200 gallons per minute, via epoxy-lined asbestos concrete and polyvinyl pipe lines from the Scripps Institution of Oceanography pier, is the focus for rearing and behavior experiments and physiological studies on fish and other marine organisms. These excellent facilities have made possible some of the results discussed later, as for example, the successful rearing of pelagic marine fish larvae and the maintenance of euphausiid shrimp in captivity.

The California Current Resources Laboratory carries out a broadly based research program, emphasizing

the study of pelagic fishes, exclusive of the temperate tunas, in the California Current region. The ocean survey program is carried out cooperatively with the Scripps Institution of Oceanography's Marine Life Research Group. With the California Department of Fish and Game, the California Current Resources Laboratory investigates the age and size composition of commercial landings of sardines and anchovies, and contracts with the California Academy of Sciences to sample the sardine and anchovy fisheries of Baja California.

We have tried to achieve a balance in the California Current Resources Laboratory between basic and applied research. The laboratory has pioneered in several important areas of ocean research, including the taxonomy of pelagic marine fish eggs and larvae, the use of systematic egg and larva surveys of oceanic areas for evaluating fish resources, the use of blood genetics for establishing the existence of genetic stocks (subpopulations) within the Pacific sardine populations, the rearing of pelagic fishes from eggs through larval stages to juveniles, and the gaining of an understanding of the hydrodynamics and performance of plankton sampling gear.

*Bio-oceanographic Surveys.* Sixteen bio-oceanographic surveys were made on the CalCOFI pattern

from July 1963 through June 1966. Coverage was on a quarterly basis through 1965 and then on a monthly basis in 1966.

The research vessel, *Black Douglas*, which was used almost exclusively for CalCOFI surveys, was retired after the last cruise in 1965 and replaced by the new research vessel, *David Starr Jordan*, which began its work in January, 1966. *Jordan* was designed specifically for oceanographic and biological research. It is of steel construction, 171 feet long, with a cruising speed of 12 knots, fuel capacity for 40 days, and a range of 12,000 miles. Special features include a bow thruster, underwater observation ports, biological, chemical, and hydrographic laboratories, research sonar, radar and navigational equipment.

Certain changes were made in coverage and methods of sampling during these years. In January and July 1964, a special grid of 80+ stations was occupied off Pt. Arguello to determine more fully the areal distribution and seasonal changes in abundance of fish larvae in that area. In all of the 1965 cruises, two samples were taken at most stations, one with the standard 1-m net and the other with a fine mesh (0.27 mm) 1-m net hauled together with or consecutively after the standard net. This was done in order to obtain information regarding the kind and degree of undersampling by the standard net of anchovy eggs and of very small fish larvae. In 1966 almost all collections with the standard net were made in assembly with a newly-designed  $\frac{1}{2}$ -m "anchovy egg net" (0.33 mm mesh).

In calendar 1966, monthly coverage, the first since 1960, was re-instituted in order to obtain data for a base year for studies of the anchovy population, in keeping with the opening of an experimental reduction fishery. Adequate coverage of the pattern from San Francisco to southern Baja California usually requires at least two ships. Since it was not always possible to have two for each month, surveys for one ship were planned always to include the pattern off southern California from Point Conception to San Diego and either to work north to San Francisco or south near Magdalena Bay.

The monthly surveys of 1966 will permit us to obtain current estimates of abundance of other important fishery resources in the CalCOFI area in addition to the northern anchovy—particularly Pacific hake, jack mackerel, sardine, and rockfishes.

*Cooperative Hake Surveys.* During the period of this report, three cooperative hake cruises were made, usually employing the *Black Douglas* of this laboratory and the *John N. Cobb* of the Exploratory Fishing and Gear Research Base, Seattle, Washington. The purpose of the cooperative cruise was to determine the location and extent of spawning concentrations of adult hake off California and Baja California and the quantities that could be captured per hour of trawling. All of the cruises were made in February-March, the months of peak spawning of hake.

In order to locate concentrations of spawning hake, the *Black Douglas* scouted for high concentrations of newly-spawned hake eggs by means of a systematic

program of plankton sampling and examination of samples immediately after collection. When high concentrations of eggs were found, the information was radioed to the *Cobb*, which moved to the area, located the position of spawning adults with its echo-sounding equipment and then lowered its large pelagic trawl to appropriate depths. Using this method a direct relation was found between areas of high egg concentration and the presence of spawning adults. Several such areas of adult hake abundance were surveyed off southern California and northern Baja California. One of the concentrations was estimated to extend over 23 square miles. The largest catches were obtained offshore from San Diego (in the vicinity of CalCOFI station 97.35). A catch of 20,000 pounds was obtained in one of the 1-hour sets. The location of spawning concentrations changed from year to year. Hake were encountered at depths of 80 to 225 fathoms with the fish occupying the shallower depths at night.

Males predominated in most catches, often contributing 90 to 95 percent of the fish caught. Males appeared to be more permanent residents of spawning schools than the females. The latter appeared to enter the spawning schools for a brief period, spawn their eggs, and then leave.

Anchovies were taken in more than half the trawl hauls made by the *Cobb* during the cooperative cruise of 1964. The most interesting phenomenon relating to these fish was their consistent occurrence during the day at depths of about 125 fathoms, and on one occasion at a depth of 185 fathoms. At dusk the echograms showed the schools rising to the surface.

*Distribution of Schooling Fish as Determined by Sonar.* With the commissioning of the *David Starr Jordan* in January 1966, the Behavior program started a field study of the distribution, movements and abundance of schools of anchovies and other pelagic species. The Simrad sonar installation will be the primary tool in this project. To date four surveys have been carried out in conjunction with monthly egg and larva cruises. Analysis of the sonar records has revealed that a few large aggregations of fish schools occurred on each cruise. In half a dozen cases the peak counts were higher than 100 schools per 10 miles and in one case as high as 200. These aggregations, furthermore, were extended over distances of 20 to 40 miles, some along the coast and some on station lines extending offshore, and a number of them were identified as anchovies by underwater observation. Targets of a biological nature also occur frequently in the outer portions of the survey pattern but so far these have been scattered and usually weak in signal strength. Trawling gear, which will be used to obtain samples for identification and life history information, has been tested but not yet used routinely.

The potential of sonar for ecological surveys and resource evaluation is evident not only in the high rate of target registration, but also in the way the limited sonar data already taken relates to other kinds of information collected. A major shift in distribution of anchovy concentrations within a period of 4

weeks, for instance, appeared to be associated with a marked shift in surface temperature distribution. Also, simultaneous depth sounder records indicate that some of the variation in distances at which school groups are detected from the vessel is probably related to the depth of the groups. On one occasion schools were observed to move vertically in close coordination with the deep scattering layer. The accumulation of such information, along with studies based on tracking schools, an operation already attempted with moderate success, should provide valuable field information for understanding the behavior of these fishes in relation to features of their environment, and perhaps also for estimating their seasonal and regional abundance, at least in a relative sense.

*Resource Evaluation.* Perhaps the prime accomplishment of the California Current Resources Laboratory has been the demonstration that systematic surveys of fish eggs and larvae constitute one of the best means available for evaluating fish resources. These surveys have shown that there are a number of important fish resources in the California Current region that are underutilized or not fished at all. The most abundant of these is the anchovy, which has shown a 10-fold increase during the 16 years of CalCOFI surveys. Second only in abundance to anchovy larvae are those of the Pacific hake. Jack mackerel larvae are less abundant in the area surveyed but more widely distributed. This species spawns throughout the CalCOFI area, but eggs and larvae are more

common in the outer half of the CalCOFI pattern; the offshore extent of spawning of jack mackerel seldom is completely delimited by CalCOFI surveys.

Of more importance is the documentation of the interaction between the sardine and anchovy populations. The anchovy population increased in abundance as the sardine decreased. Competition, coupled with a selective fishery for the sardine, gradually allowed the anchovy to become predominant in its trophic level. We are vitally interested in whether the action is reversible. Can the abundance of the sardine population gradually be increased by applying differential fishing pressure to the anchovy resource?

*Rearing Pelagic Marine Fishes.* The program for rearing pelagic marine fish larvae has the basic objective of developing techniques and equipment by which marine fishes may be cultured under laboratory conditions from the egg stage through the larval and metamorphic stages to the juvenile and eventually adult stage. Many scientists have attempted to rear pelagic marine fishes during the past century because of the wide scientific and commercial applications inherent in this accomplishment. Rearing pelagic fish larvae under laboratory conditions opens many avenues of scientific inquiry and provides new areas of specific studies on larval fish survival, taxonomy, embryology, physiology, and behavior.

Progress during the past 3 years of experiments in rearing pelagic fish larvae at this laboratory has culminated in outstanding success in multiple rearings



FIGURE 4. School of Pacific mackerel, reared from eggs by Dr. George Schumann.—photo by George Mattson.

of northern anchovy, Pacific sardine, and Pacific mackerel. Many hundreds of individuals of these valuable commercial species were reared from their eggs to the juvenile stage in the laboratory. At the same time approximately 18 other species of marine fish were successfully carried from hatching through metamorphosis to the juvenile form.

Success in rearing may have resulted from the combination of a suitable environment and a good food supply. Observations on newly-hatched larvae indicated the need for large volumes of sea water because of its stability of temperature, salinity, and biotic factors. Large aquaria provide room for swimming without frequent contact of walls, one of the major causes of mortality of laboratory-reared fishes.

At first feeding, sardine and anchovy larvae require high densities of food in their immediate environment. Live plankton has been provided, which has been obtained by filtering large volumes of sea water to obtain sufficient numbers of minute plankton organisms of sizes that can be ingested by newly-feeding larvae (organisms no larger than 0.08 mm in diameter). As the larvae grew, larger food organisms were supplied in high densities.

Sardine and anchovy larvae, at first feeding, can swim only limited distances. Their swimming ability requires that the entire volume of a 500-gallon aquarium must contain uniform distribution of food organisms at a density not less than 4 per cubic centimeter of water, regardless of whether only one larvae or a thousand are being cultured. This problem was solved by restricting the space for the larvae with use of thin-walled plastic bags floated in the aquarium. The thin plastic permitted gas exchange to take place between the waters inside and outside of the bag, while the soft material offered very little resistance when struck by a swimming larva. When larvae become able to hunt food over greater distances, the bags were silt open and the growing fish allowed the freedom of the larger container.

*Life History Studies of Rockfish.* A major goal of the Life History and Taxonomy program is to prepare complete descriptions of the life history stages of the fishes that contribute eggs and larvae to the plankton of the California Current region. A major study is being made of rockfishes (*Sebastes* spp.).

The large number of rockfish species (more than 50) pose an immense problem in attempting to identify rockfish larvae collected in plankton. The problem is simplified by the fact that rockfish are live bearers that retain their young to the larval stage. Such early larvae of 17 species have been obtained from identified females and have served as a means for identifying the later larval stages in our collections.

The complete series of developmental stages from the developing embryo to the adult, have been described for *Sebastes paucispinis*. It was found that young of this rockfish species spend the first several months of their life as epipelagic larvae and transform into juveniles at 30 mm length. Juveniles are found in shallow coastal waters over rocky bottoms in association with algae (*Macrocystis*, *Laminaria*, and

*Egregia*) or over sand bottom in association with eel grass (*Zostera*). Juveniles remain in waters shallower than 20 meters during their first year of life, then move into deeper water. Most of the adults collected were found in depths of 80 to 300 meters during the investigation.

*Plankton Dynamics.* Since the start of the work on quantitative sampling of fish eggs and larvae in 1939, the California Current Resources Laboratory has been involved in problems of quality control of plankton collection. In 1963 the diverse plankton-sampling studies were united under one program. The work of the Plankton Dynamics program is divided into four areas: plankton sampler design and operation, plankton behavior, microdistribution, and measures of amount of zooplankton (biomass).

It was our judgment in starting the plankton program that two major problems were inhibiting the improvement of precision and accuracy in quantitative zooplankton sampling. One problem area was that of plankton behavior, of the responses of organisms to sampling gear. The other was an inadequate understanding of the operation of plankton sampling gear. As anticipated, the description of the performance of sampling gear has proceeded at a faster pace than the study of the biological problems.

Comprehensive tests of hydrodynamics of plankton sampling devices were carried out at the David Taylor Model Basin near Washington, D.C. Eighteen persons participated in or were actively associated with these tests, including personnel from five BCF laboratories and from several university and industry groups.

The tests showed that in "clean" water at the model basin, the amount of effective straining area rather than the size of the mesh apertures was the predominant consideration. As long as the ratio of mesh aperture area to mouth area was at least 4 to 1, little difference was observed in filtering efficiencies of fine or coarse-meshed Nitex nets in "clean" water at towing speeds of 1½ to 3 knots. All had filtering efficiencies of 90 percent or more when new (less if the net previously had been used at sea).

The tests also showed that bridles and tow cables cause major accelerations and turbulence in the water ahead of nets. Although these disturbances have little effect upon the actual filtering efficiencies of large nets, they provide cues to which animals may respond to avoid capture.

Following the studies of plankton net performance under controlled model basin conditions, the nets were taken to sea, in order to study the effects of clogging on plankton net performance. The telemetering flow measuring devices used for the model basin tests were adapted for use at sea. Clogging was monitored in several phytoplankton rich areas, usually near shore, as well as in clear waters, 250 miles seaward of Pt. Conception. The rate of clogging was found to be markedly dependent upon the composition of the plankton community. When a series of nets were tested in plankton-rich waters at the same locality, the rate of clogging was found to be affected by mesh aperture size, mesh aperture amount and net form



(whether cylindrical, conical, or cylindrical-conical)—listed in order of importance.

Mesh aperture sizes markedly affected the rate of clogging. The smaller mesh sizes clogged at a rate which was related to the area of the individual mesh aperture. We concluded that the finest mesh practical for the usual survey tows should be 0.3 mm mesh aperture width but that even in such a net the combined areas of the apertures would have to be at least 8 times the mouth area to get sustained filtration for 15 minutes at 2 knots.

It was found that mesh aperture amount also affected clogging strongly. For instance, in a given body of water a 20 percent increase in reserve filtering area would allow a net to filter twice the amount of water before filtration efficiency was adversely affected. Our studies of the effect of net form on clogging rate showed that cylindercone nets clog more slowly than conical nets.

An important finding of the research on plankton gear is that the basic filtration characteristics of a towed plankton net in the field may be effectively predicted by establishing the proportions of mesh aperture area necessary for each size of plankton mesh. We have applied these data to the design of a small mesh net to retain the eggs of the northern anchovy. Since January, 1966, this net has performed with the predicted efficiency in more than 1,000 tows in all areas of the survey region of the California coast.

*Experimental Tagging of Anchovies.* Before the beginning of the anchovy fishery, it was understood that a tagging program would be needed to aid in the studies of the population structure, movements, and abundance of these fish, as well as to measure the effects of fishing pressures. Anchovies are extremely delicate and susceptible to injury when handled, therefore experiments were made to determine whether tagging was feasible and practical.

Since tags were to be recovered from magnets in fish canneries, steel internal tags were chosen for marking the fish. It was found that the same type of internal tag (13 x 3 x  $\frac{1}{2}$  mm), used successfully on the Pacific sardine, herring, mackerel, and anchoveta, could also be used on the anchovy. Mortality was decreased by coating the tags with 5 percent tetracycline paste and inserting them posteriorly through an incision cut just dorsal to the tip of the pectoral fin. Contrary to expectations, greater mortality was found to occur among fish that had been anesthetized before tagging than among those tagged without anesthetic. Better survival occurred in freshly-caught anchovies than in fish that had been held in live bait tanks for several days.

The California Department of Fish and Game has successfully used these methods to tag many thousands of anchovies off the coasts of California and Baja California during 1966.

Since the metal internal tag is not visible and even the incision scar is completely indiscernible after 2 or 3 weeks, we have been unable to get tag returns from the bait fishery. Several methods of externally

marking the tagged fish have been tested. The most promising mark is created by injecting a red fluorescent pigment just under the skin of the opercle. This mark is readily visible in live or dead fish, is not injurious to the fish, and, when properly injected, does not fade.

*Genetic Studies.* Serology, which was successfully employed in distinguishing the three subpopulations of sardines, is also being applied in the search for northern anchovy subpopulations. In order to find blood groups that may be used in characterizing anchovy subpopulations, it was necessary to produce new blood-typing reagents. We have developed some new techniques that have enabled us to collect relatively large volumes of high titer reagents from immunized fish. These reagents produced in fish show a greater degree of specificity than reagents that were formerly produced in warm-blooded animals.

Electrophoresis of tissue proteins from anchovies has also been tried. The electrophoretic patterns produced in polyacrylamide gel from the soluble proteins of the eye lenses showed no differences in anchovies sampled from southern Baja California to San Francisco. The most promising proteins now appear to be the transferrins, a specific group of iron-carrying proteins found in the blood sera. Transferrins labeled with radioactive iron and electrophoresed on starch gel show polymorphism, which appears to be controlled by a 3-allele genetic system. The frequency of occurrence of these genes in anchovies taken from various areas can be used in looking for subpopulations.

*Behavior Studies on Anchovies.* One of the major endeavors of the Behavior Program during the past several years has been to develop a quantitative description of anchovy feeding: to discover what its food preferences are, how it captures different kinds of organisms, and how the rate at which it removes food from the water depends on the amount present, the size of the fish and its state of hunger.

Experiments have shown that predation is by filtering on organisms less than 1 mm in length and by particulate biting on organisms a few mm or more in length. It has been shown also that the larger organisms are preferred, but that the filtering attack directed at the smaller organisms is not abandoned in favor of biting unless the larger organisms are abundant enough to provide a greater rate of caloric intake.

Other experiments have shown that the rate of intake on both sizes of food organisms, when they are present in surplus quantity, increases with growth of the fish up to a weight of about 4.0 grams, beyond which it tapers off steadily toward an asymptotic level. Though this relation between size and feeding rate has the same pattern for the two sizes of food organisms, the rates are higher for the larger items, indicating that an anchovy at any size is able to consume more in weight and hence in calories of the large organisms than of the small organisms. Another set of experiments has shown that for an anchovy of any



given size the rate of intake by weight on small food organisms is constant for as long as 1 hour after the start of feeding, whereas the rate of intake on large organisms starts at a much higher level and declines rapidly. In less than an hour it is at a lower level than the constant rate on small organisms. Such information, along with the answers to a number of related questions, the effect of light intensity and temperature on feeding rates, for example, will lead to an understanding of what variations in plankton abundance means to the fish in terms of food availability.

*Feeding, Growth, Respiration, and Carbon Utilization of Euphausiid Shrimp.* An experimental study was made of the biology of the euphausiid shrimp, *Euphausia pacifica*, describing growth, feeding, respiration, molting, and the efficiency with which it incorporates carbon from its food into body tissue.

Among planktonic organisms in the food web of the oceans, euphausiid crustaceans rank high in abundance and importance. They are food for a variety of fishes, ranging from sardine and jack mackerel to tunas and salmon, and are the chief food of baleen whales.

The experimental studies were dependent upon successful maintenance of euphausiids in the laboratory. Techniques were developed that permitted normal growth and development of euphausiids in the laboratory; some experimental animals were kept for over one year.

The euphausiid shrimp studied, *E. pacifica*, is an omnivorous feeder, utilizing both algae and small zooplankton animals. In the laboratory, crustacean nauplii seemed to be preferred food over unicellular algae, but both were eaten when available.

Growth in euphausiids, as in all crustaceans, is accompanied by molting. Euphausiids kept in the laboratory at temperatures similar to those at which the animal lives in the sea (9–15°C) were observed to molt on the average every 5 days. The dry weight of each molt is approximately 10 percent (range 4–14 percent) of the dry weight of the animal which produced it. Molts contained approximately 46 percent ash, 17 percent organic carbon, and 2.5 percent organic nitrogen. Each molt contained about 4 percent of the organism's carbon, 2 percent of its nitrogen.

Assimilation of ingested carbon (digestion) appeared to be high, usually over 80 percent, as judged from tracer experiments with carbon-14. Respiration accounted for the major portion of the assimilated carbon—62 to 87 percent. The long term loss of carbon due to molting ranged from 6 to 11 percent. The fraction of assimilated carbon calculated to appear in eggs was 9 percent. In young individuals with rapid growth, incorporation of assimilated carbon into body tissue was as high as 30 percent, in older individuals with slower growth it was as low as 6 percent. Calculations from an oceanic population gave 9 percent as level of incorporation of organic carbon into tissue (excluding eggs and molts) over the life span of the animal.