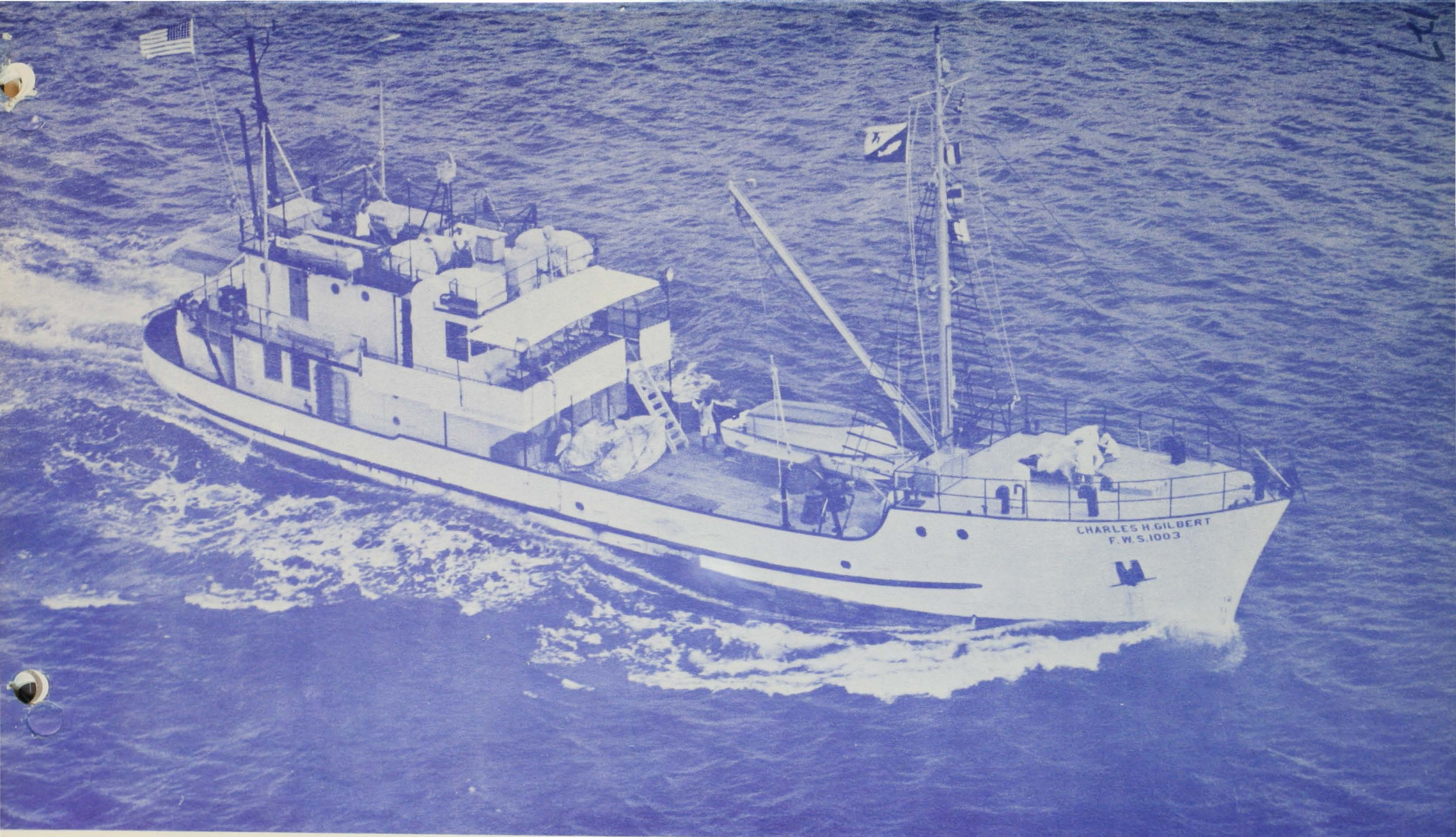


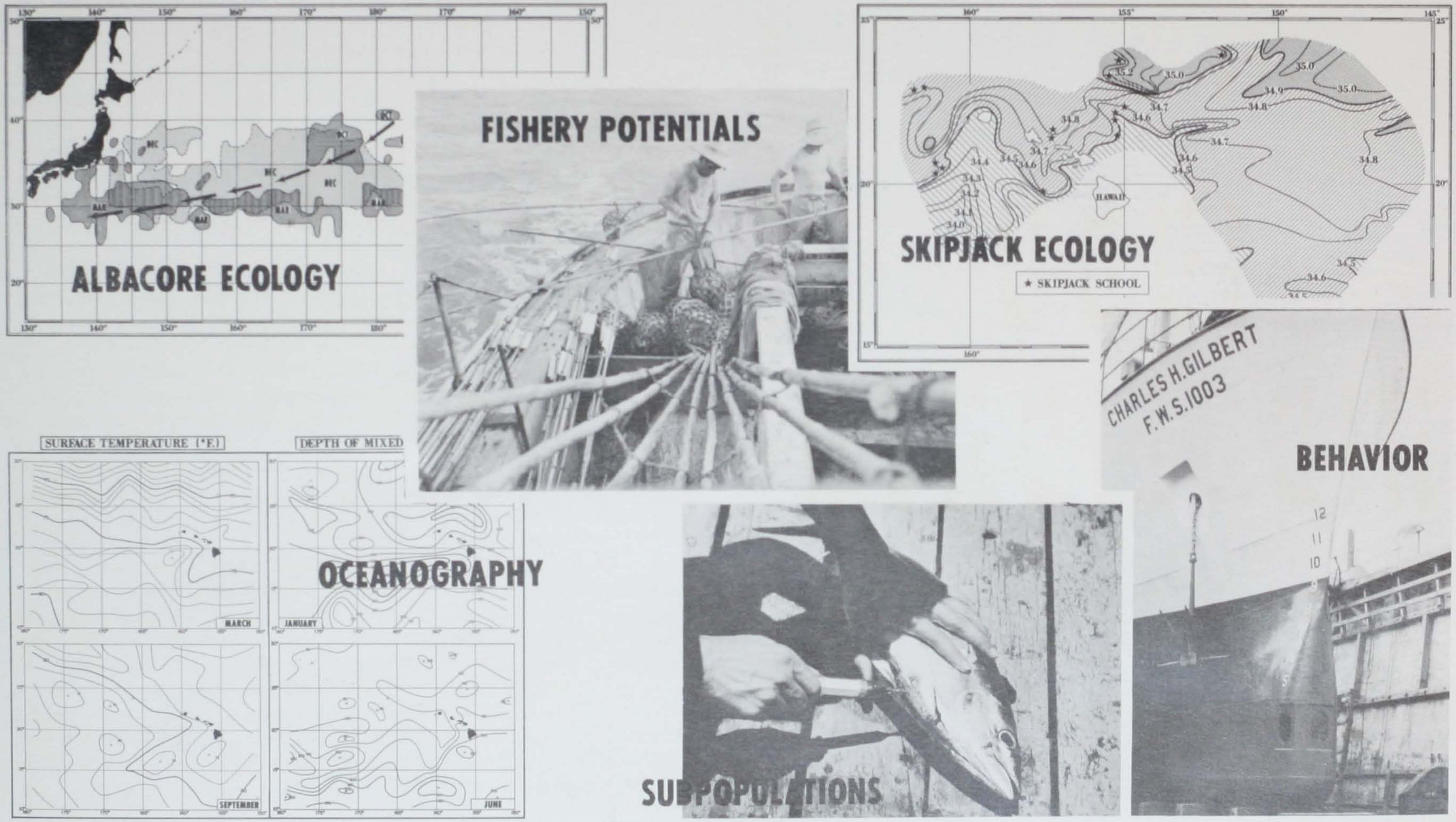
U.S. BUREAU OF COMMERCIAL FISHERIES
HAWAII AREA
BIOLOGICAL LABORATORY
HONOLULU, HAWAII

Mary F

PROGRESS IN 1960

FISH AND WILDLIFE CIRCULAR 127

UNITED STATES DEPARTMENT OF THE INTERIOR, STEWART L. UDALL, SECRETARY
FISH AND WILDLIFE SERVICE, CLARENCE F. PAUTZKE, COMMISSIONER
BUREAU OF COMMERCIAL FISHERIES, DONALD L. McKERNAN, DIRECTOR



Cover: The Laboratory's research ship *Charles H. Gilbert*.

NOVEMBER 1961

1960 HIGHLIGHTS

The oceanographic, marine biological, and fishery research conducted by the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, is authorized by provisions of Public Law 329, 80th Congress (1947). The results of the first 11 years of the Laboratory's research, 1949-1959, were reviewed in last year's annual report (Fish and Wildlife Circular 83). This report summarizes scientific accomplishments for the year 1960 and plans for the future.

The major goals of the Laboratory are to further the understanding of the character, magnitude, and potential yields of the fishery resources of the Pacific, particularly the tunas, and to improve or develop methods for harvesting these resources. Thus, principal research efforts during 1960 were directed towards studies of the tunas and of the pelagic marine environment in which they live.

Among the highlights of the scientific accomplishments, each of which will be subsequently discussed in greater detail, are the following: An atlas of the oceanic climate of the central Pacific, describing the distribution of various chemical and physical oceanographic features, the processes with which each is associated, and variations as related to these processes, was completed. A prediction, issued in March and based on the time of late winter temperature changes in Hawaiian surface waters, that the 1960 skipjack catch by the Hawaiian fishermen would be less than average proved to be valid.

Studies leading to definition of Pacific tuna subpopulations through use of blood group characteristics were started. Excellent progress was made in the development of techniques for preservation of red blood cells of the albacore, bigeye, and yellowfin, and a number of test fluids for the differentiation of the blood group patterns were developed. Studies of the skipjack stocks in the central Pacific showed striking genetic differences between those sampled near the Marquesas and Tuamotu Islands and less clear-cut differences between those from the Hawaiian and Line Islands areas.

Facilities for study of the behavior of tuna were expanded with the addition of an underwater observation chamber in the bow of the Charles H. Gilbert and the construction of new tanks for holding tuna in captivity. The potential utility of the latter was apparent after holding skipjack in a plastic pool for periods up to 6 months.

With available data suggesting that the albacore in the North Pacific are of a single stock and distinct from those in the South Pacific and Indian Oceans, a model was devised to explain the distribution and migration of these tuna in the North Pacific.

Another significant accomplishment was the tentative identification of albacore, bigeye, and two species of bluefin larvae. As skipjack and yellowfin larvae had previously been identified, it is now possible to delineate the time and areas of spawning for all major tuna species.

Analyses of results from cruises made in 1959 suggest that the seasonal movements of skipjack in the central Pacific are associated with certain oceanographic features and that these fish enter Hawaiian waters each spring from the west through southwest.

By means of a deductive approach, hypotheses were developed that schooling of fishes is a protective mechanism and that the degree of schooling by tunas is a function of fish size: the larger the fish the less the tendency to school. Using the Laboratory's longline data, an analysis showed that the smaller yellowfin were more frequently caught on adjacent hooks and that the largest yellowfin were solitary, thus tending to confirm the hypothesis.

In June, a 6-year investigation of albacore in the north central and northeastern Pacific was terminated. From June 1959 through June 1960, the principal efforts in this investigation were concerned with the analyses of data and preparation of reports. Similar efforts were spent in preparation of final reports describing the results of the 2-1/2-year exploratory oceanographic and fishery studies of the waters of French Oceania. The results of both of these investigations have been reported in various publications of the Laboratory and were summarized in the 1959 progress report (Fish and Wildlife Circular No. 83).

As the objectives had been achieved, studies directed toward supplementing the supply of natural bait available to Hawaiian skipjack fishermen were terminated. Reports describing the results of the studies, which were concerned with tilapia, Marquesan sardine, and threadfin shad, were completed.

The Laboratory's research requires the use of more than one ship. In addition to the Charles H. Gilbert, there is need for a vessel specifically designed for long-range operations. As it has been proposed that such a vessel be funded during 1961-1962, preliminary plans were completed during 1960. Requirements considered in the preparation of these plans were a cruising range of 10,000 miles at a speed of 12 knots. Maximum and minimum speeds requested are 14 knots and one-half knot respectively. Design specifications call for space for a crew of approximately 18 and for 12-13 scientists. Working space for the scientists includes oceanographic, biological, and electronic laboratories, a drafting room and a library, and sufficient deck space to accommodate the winches and associated equipment for oceanographic and fishery (longline, trawl, and gill net) operations. Consideration of the above requirements has resulted in plans for a twin-screw vessel, 193 feet long, with a beam of 33 feet, and a 12-foot draft.

In addition to the general facilities mentioned above, detailed specifications include a stern ramp to facilitate handling trawls, underwater observation ports in the bow and stern, a salt water system for use with aquaria in the biological laboratories, recording instruments such as the thermograph, barograph, and echosounder, and refrigerated space for 10 tons of specimens. All berthing and working areas are to be air-conditioned, with facilities for heating as areas of operation require.

With reassignment of personnel from completed investigations and recruitment of new staff members the Laboratory's research staff was reorganized into six investigations. These are Oceanography, Fishery Potentials, Skipjack Ecology, Albacore Ecology, Behavior, and Tuna Subpopulations. The reorganization was to a large extent a matter of administrative convenience, as the research efforts of the investigations are mutually interdependent.

OCEANOGRAPHY: OCEAN-WIDE

As a first step in the compilation of Pacific-wide oceanographic station data, approximately 500,000 IBM cards were received from the U. S. Navy Hydrographic Office. Sorting of this deck was started in order to determine the number of stations available for selected geographical areas for each month. Once all available data are compiled and sorted, analyses, as described below, will be carried out using, in part, the University of Hawaii's IBM 650 electronic computer.

Considerable progress was made during the year in transferring to IBM cards the surface and subsurface oceanographic data collected aboard the Laboratory's vessels during oceanographic and fishery surveys. In order to reduce the time spent ashore in coding the data prior to punching, new forms were designed and printed (fig. 1) for use in the field.

In addition to studies of chemical and physical oceanographic features, studies of both invertebrate and vertebrate plankton and nekton as potential indicator species were begun.

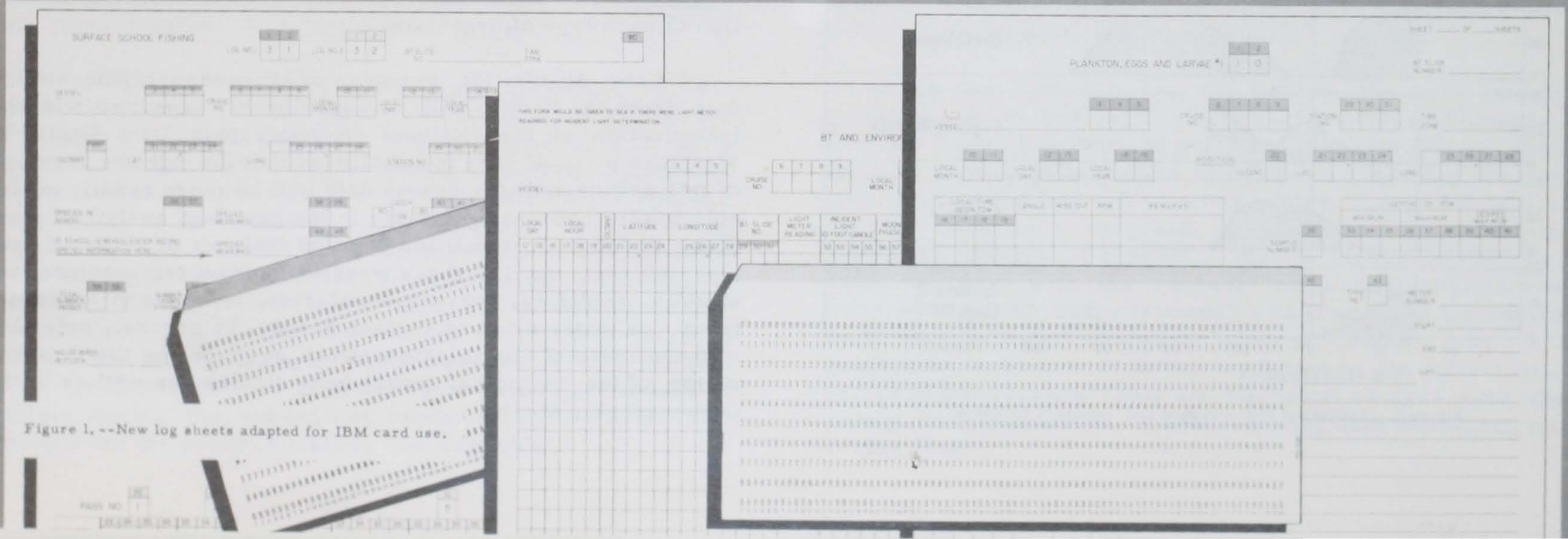


Figure 1.--New log sheets adapted for IBM card use.

Plankton samples collected during both summer and winter by the Laboratory's vessels along longitude 160°W. between latitude 50°N. and 15°S., were examined to determine the distribution and abundance of the calanoid copepods of the genus Candacia. As may be seen from figure 2, the winter distribution of nine species of this genus is discontinuous, with variations in presence or absence and in abundance evident along the transect from subarctic waters south across the Equator into tropical waters of the southern hemisphere. These variations are being examined, along with surface and subsurface variations in the ocean, to determine which of the species may be used as biological indicators of the oceanographic features traversed by the section.

Preliminary studies of marine vertebrates as indicator species involved examination of Nanaimo trawl collections (fig. 3) made along a transect from Honolulu to latitude 5°S.

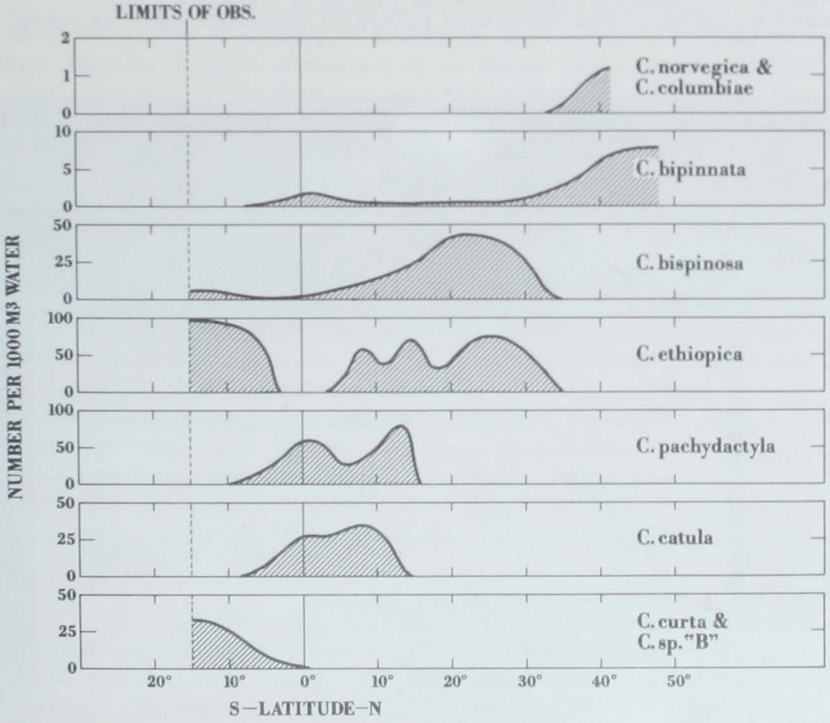


Figure 2.--Latitudinal distribution of nine species of Candacia.

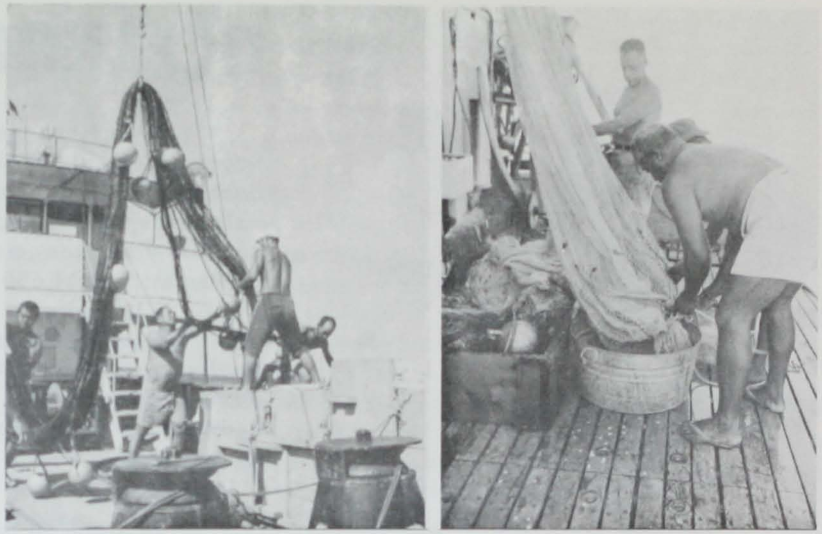


Figure 3.--Recovering and emptying the Nanaimo trawl.

This transect crosses the westerly flowing North Equatorial Current, the easterly Equatorial Countercurrent (10°N. to 5°N.), and extends into the westerly South Equatorial Current. In addition, samples were collected in the region of the equatorial upwelling and from the subsurface, easterly flowing Equatorial Undercurrent. It is anticipated that sampling in such a diversity of ecological situations will result in the discovery of one or more vertebrates which may be used as indicator organisms. Preliminary to the ecological studies, the samples were sorted and progress was made in the identification of each type of organism.

The acquisition of copies of all oceanographic station data from the Pacific will be considerably expedited with the inauguration of the National Oceanographic Data Center in Washington, D. C. It is anticipated that through the services of this new organization these data will be more readily available to this Laboratory for use in the proposed analytical studies. Present plans call for detailed analyses of areas of special interest, such as those where important temperature and salinity gradients, current boundaries, or areas of transition from one water mass to another occur. In general, selection of these areas of special interest will be guided by the requirements of the biological and fishery studies, as well as of the oceanographic studies.

The use of biological indicators to supplement the results of the physical and chemical oceanographic studies will be continued. With the results of the studies of the variations in distribution of the copepod Candacia along longitude 160°W. as a guide, samples from transects in other areas will be selected and the distribution of Candacia similarly analyzed. Other invertebrate indicator species will also be considered.

In the use of marine vertebrates as indicator species, consideration will be given not only to forage fishes captured by trawls, but also to larger predators, such as the sharks and the tunas.

CENTRAL PACIFIC

An atlas describing the oceanic climate of the central Pacific was completed. This study describes, for the area from latitude 30°N. south to the northern boundary of the Countercurrent (10°N.) and from the 180th meridian east to longitude 150°W., the distribution of such features in the surface waters as the depth of the mixed layer, temperature, and salinity. In addition, such processes as evaporation, rainfall, and solar heating were investigated and the variations in the various features were related to these processes (fig. 4). By quantitatively eliminating the effects of rainfall, evaporation, and solar heating, estimates were made of the effects of heat transport by currents (advection). These estimates provided an explanation for the observed seasonal changes in movements of the surface waters in the central Pacific area.

In 1956, a monitoring station was established at Koko Head on the Island of Oahu. Weekly temperature observations and salinity samples were taken. Seasonal changes in the Koko Head data, particularly temperatures, were analyzed during the preparation of the atlas. One result, when considering the rate of change of temperature, was a technique for determining the date, in late winter, when the advection of surface water in a southerly direction past Koko Head reversed to a northerly movement. At the time of this change, the temperatures reversed from cooling to warming. Subsequently, it was observed that the time of this change, between early February and late March, could be related to the total catch of skipjack landed at Honolulu during the subsequent summer. Thus a prediction technique for the skipjack fishery was available.

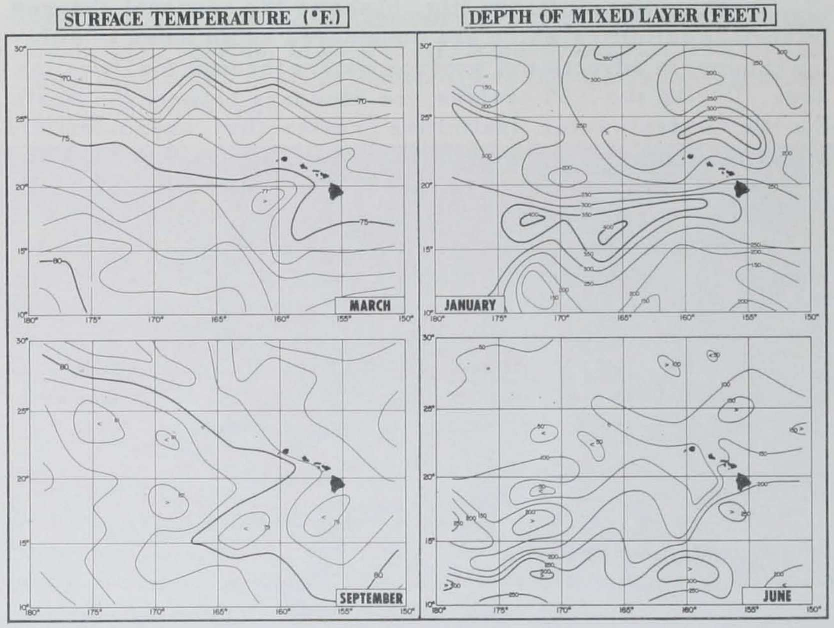


Figure 4. --Sample charts from Atlas.

The prediction for the 1960 total catch was for a poorer-than-average year. Approximately 7,300,000 pounds were landed, as compared with an average catch of 10,000,000 pounds. The 1960 catch will be discussed in greater detail below (Skipjack Ecology Investigation).

In the Hawaiian skipjack fishery, the catch rate generally begins to rise rapidly in April from 200,000 pounds or less per month to 2,000,000 pounds or more in August, thence dropping rapidly in September and October, reaching the minimum rate during late fall or early winter. Large annual fluctuations have been recorded, ranging from a low of about 6,000,000 pounds in 1957 to a high of 14,000,000 pounds in 1954. Because both the seasonal and annual variations are believed to be, in part, associated with changes in the environment, and because of a need to understand the "why" of the prediction technique in order to increase its reliability, a series of five oceanographic and biological cruises were made during 1959. Analyses of the resulting data were completed during 1960.

The adjacent figure (fig. 5) shows the seasonal changes in surface salinities which are considered as an index to similar changes in advection of surface waters through the Hawaiian area. During the 1959 cruises, the boundary between the North Pacific Central water (salinities greater than approximately 35 ‰) and the waters of intermediate salinity (34.5 to 34.9 ‰), designated as those of the California Current Extension, migrated northward until October, then reversed direction. The maximum northerly position of the boundary, latitude 26°N., occurred in July; the southernmost position, 19°N.; in October. The California Current Extension, or intermediate salinity water, which occupied a comparatively restricted area in January (fig. 5A), expanded into an area almost equal to that encompassed by the survey in July (fig. 5B). By October, this water was again restricted to a narrow band.

One objective of these surveys was to correlate the open-ocean observations with those from the Koko Head station, in order that the variations at Koko Head could be more adequately understood with reference to large-scale central Pacific circulation features. It became evident during 1960 that additional stations in the Hawaiian Islands were desirable. Consequently, a survey of the surface salinities around the shoreline of various islands was made, and additional monitoring stations were established on the Islands of Kauai and Lanai (fig. 6).

Studies through 1960 of the variations (both seasonal and year-to-year) in oceanographic features and associated distribution of properties in the central Pacific, and in the distribution of skipjack in both space and time, led to an hypothesis that the 18-20 pound fish which enter the Hawaiian area each spring, the "season fish", are associated with the intermediate salinity water (California Current Extension) and its boundaries. In order to investigate this hypothesis, a series of cruises is planned for 1961: one to study the oceanographic conditions during the winter (January-February), one during the summer (May-June), and a third cruise during the period of change from winter to summer conditions (March-May). In addition to surface temperatures and salinities and temperature-depth observations, various biological samples will be collected

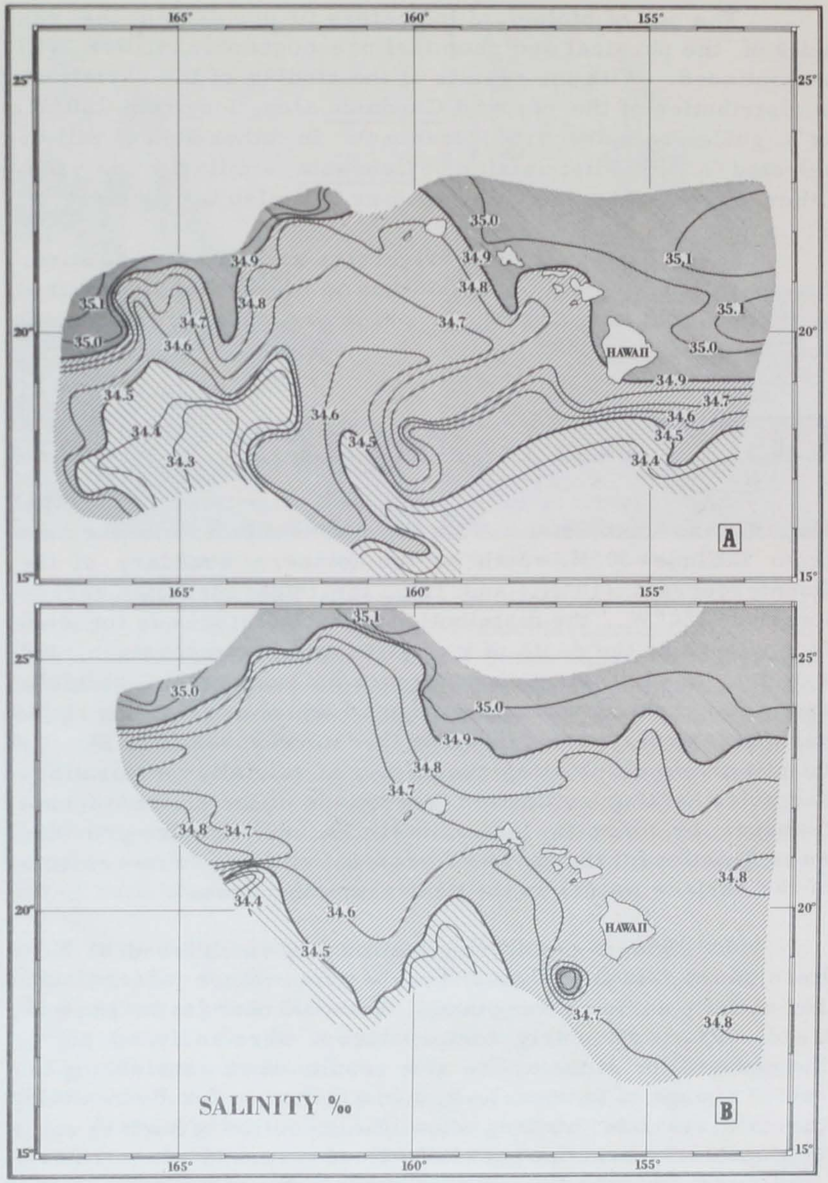


Figure 5.--Hawaiian area surface salinity, 1959: A, January; B, July.

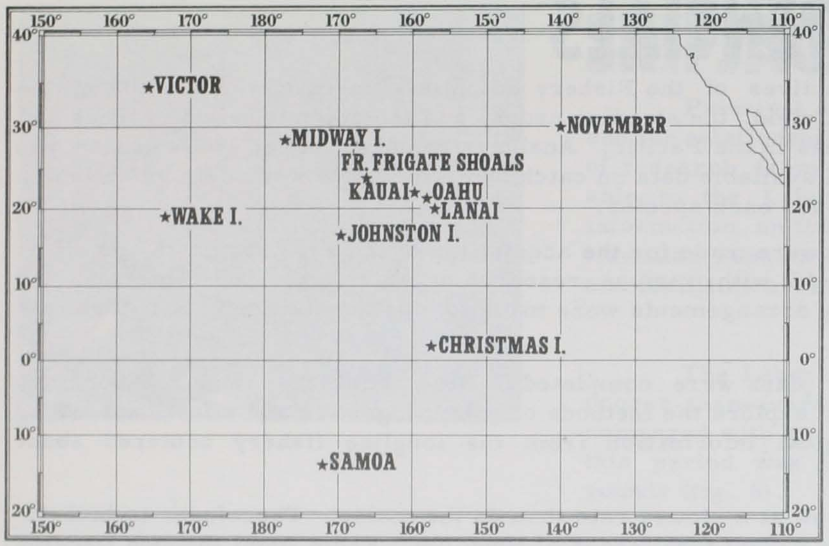
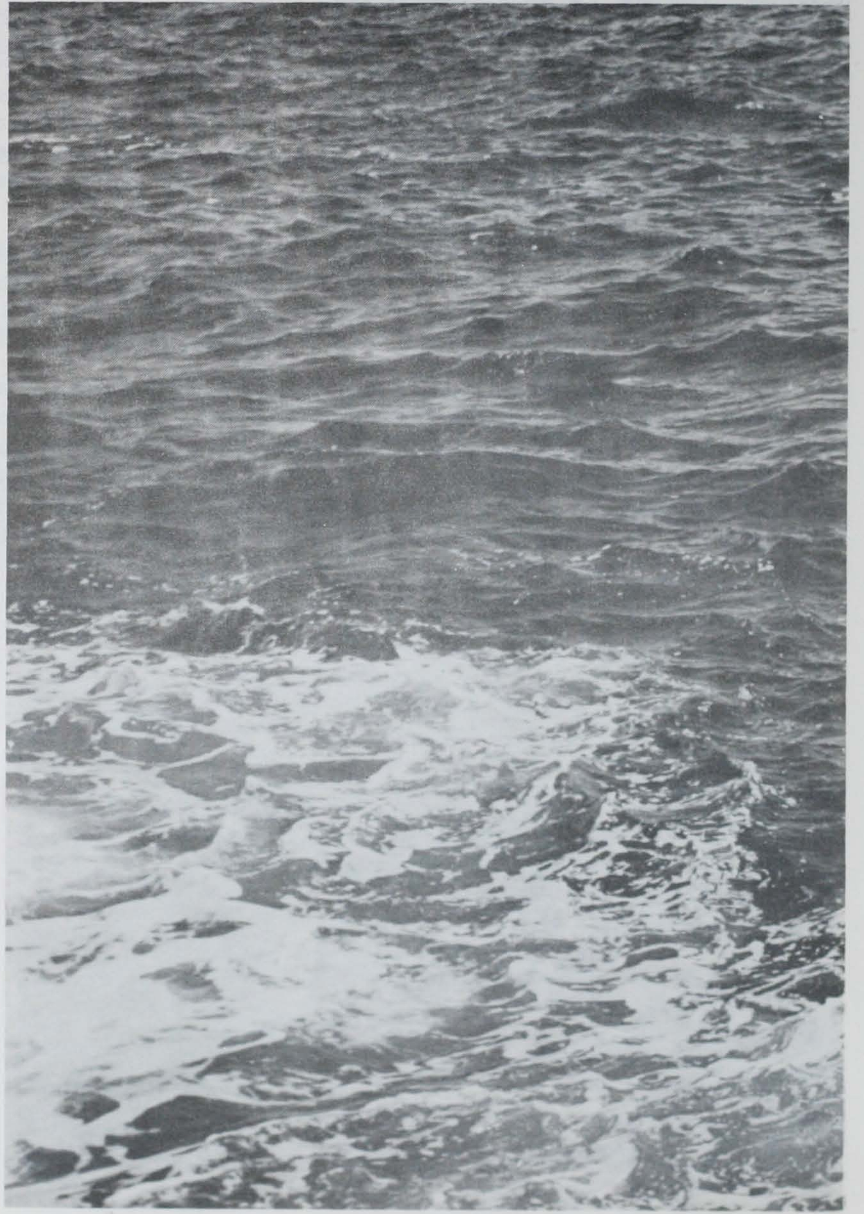


Figure 6. --Location of monitoring stations.

(zooplankton, nekton, and tuna blood). Efforts will be made to tag fish to the west and southwest of the area fished by Hawaiian commercial fishermen. It is anticipated that the surface temperature and salinity observations plus the BT data, particularly during the March-May transition period, will be augmented through cooperation of the U. S. Navy and the U. S. Coast and Geodetic Survey.

It is realized that variations in distribution and abundance of the skipjack in the central Pacific are related to a sequence of events--the wind, water, and fish. It is proposed that a large-scale "oceanographic experiment" be conducted in central Pacific waters, to attack the problems raised by the climatic atlas study. A series of oceanographic and meteorological observations will be made over a period of 2 years (1964-1966). From the resulting data, it is anticipated that details of the variations in horizontal and vertical distribution of properties may be described for the period of the survey and that the rates of change and the mechanism involved may be determined. It is further anticipated that the results of this experiment will: (a) provide for a more adequate understanding and increased reliability of the prediction technique, (b) provide data for more detailed studies of the relationships between the marine biota and their environment, and (c) add significantly to the present knowledge of the atmosphere/ocean interaction processes.



FISHERY POTENTIALS

The principal objectives of the Fishery Potentials Investigation are to compile information on the present yield, the standing crops, and the potential yield of tunas and other major predator species in the Pacific. Analyses resulting in such information require the acquisition of all available data on catch and effort and on the determination of growth and mortality rates for each species.

Preliminary efforts were made for the acquisition of the required catch and effort data. Discussions were held with various research organizations, both American and Japanese, and preliminary arrangements were made for the acquisition of selected sets of such data.

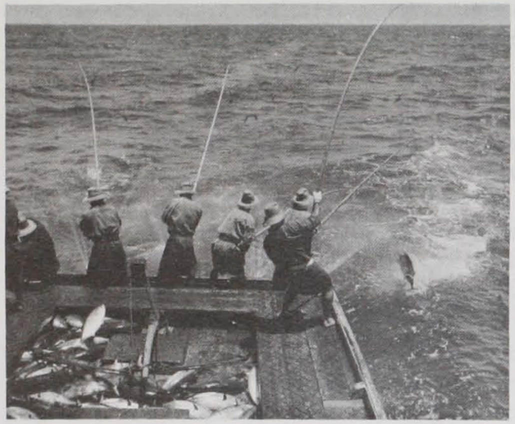
Arrangements and plans were completed in December for sending a Laboratory staff biologist to Samoa to explore the methods of collecting catch and effort data, along with various other biological information from the longline fishery centered about American Samoa.

It was suspected that large female bigeye and yellowfin tuna grow at a slower rate than do the males. Therefore, to investigate this hypothesis, a study was made of the size and sex of longline-caught tuna landed at Honolulu. From April through December 1960, 4,261 bigeye tuna and 1,770 yellowfin tuna were measured and sexed. The hypothesized differences in growth rates were verified. Another interesting fact of importance to the growth studies was revealed from the sex ratios of bigeye. There was a progressive change in the male/female ratio, with a noticeable absence of males in early April 1960, changing to a 50-50 or greater sex ratio (males predominating) in later months. A growth analysis without a separation of the sexes would have shown a rapid, but false, growth rate resulting from the progressively increasing percentage of the larger males in the catch.

Figure 7. --Setting longline from Japanese boat near Samoa.

Continued efforts will be made to acquire catch and effort data for the various tuna fisheries in the Pacific. In addition to the use of these data for estimates of potential yields, they will be charted, on a geographical and temporal basis, to explore the relation of variations in catch per unit of effort and estimates of standing crops to changes in oceanographic conditions.

During early 1961, as mentioned above, the possibilities of obtaining catch and effort data for the longline fishery (fig. 7) in Samoan waters will be investigated. During the acquisition and preliminary analysis of Pacific-wide data, a study will be made of the availability of yellowfin and bigeye data from the Japanese longline fishery. If adequate data are available, even though only from limited areas, estimates of total catch and catch per unit of effort will be made.



SKIPJACK ECOLOGY

Principal emphasis has been on biology, variations in distribution and abundance, and the relationship of these to the environment. As in the past, in addition to the results of research from the Charles H. Gilbert, commercial catch statistics were made available to the Laboratory by the Hawaii Division of Fish and Game. These data provide information on fluctuations in availability of skipjack in Hawaiian waters. Personnel of Hawaiian Tuna Packers, Limited, and the commercial fishermen assisted by making fish and facilities available for various biological studies.

The Laboratory's prediction of the 1960 landings, made in March 1960, was for a poorer-than-average year. The total landings for the year were 7.3 million pounds, as compared with an average of 10.0 million for the past 11 years. The lowest total during this period was for 1957, 6.1 million pounds; the highest was for 1954, 14.0 million pounds (fig. 8).

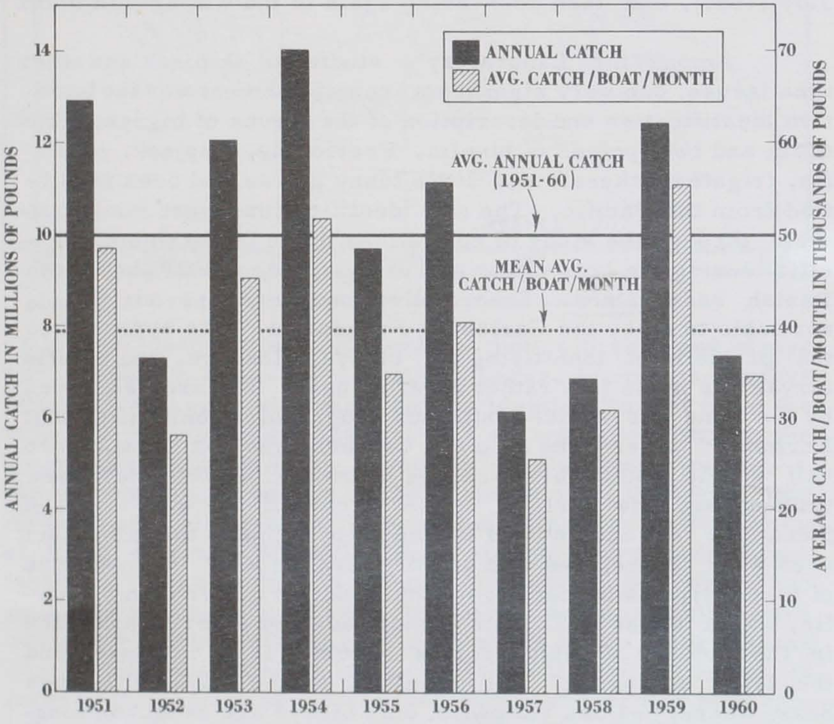


Figure 8. --Annual Hawaiian skipjack landings and average catch/boat/month, 1951-1960.

In figure 9, the average catch/boat/month is shown for 1960, along with the 10-year (1951-1960) average and, for comparison, the averages for 1959 (a good year) and 1957 (a poor year). During most of the 1960 season, the average monthly catch was below the 10-year mean. The average catch per boat (fig. 8) was nearly 5,000 pounds less than the 10-year average (34,500 as compared with 39,500).

A significant feature of the 1960 landings was the sporadic low availability of the season fish, the 18- to 22-pound group that ordinarily contributes greatly to the catch during the summer months. During May and June, 75 percent of the skipjack landings were of fish weighing less than 10 pounds; 25 percent were less than 10 pounds during July, 40 percent during August, and nearly 70 percent during September (fig. 12).

On page 5 of this report, the technique for predicting the total annual catch was discussed. This prediction, based on the late-winter change in surface temperature, is empirical and does not take into account the biology of the skipjack. A prediction, based on oceanographic considerations, might be for a good season, for example. However, failure of a year-class entering the fishery could result in a poor season. Therefore, in order to improve the reliability of the prediction, biological studies of the central Pacific skipjack have been included among the projects in the Skipjack Ecology Investigation. These include primarily studies of spawning, size distribution, and migration.

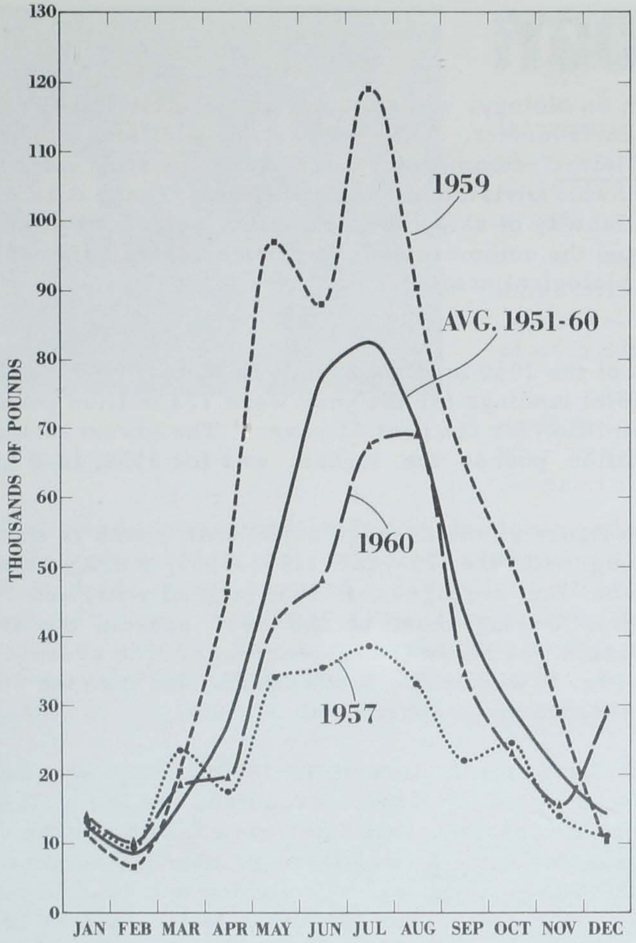


Figure 9.--Average catch/boat/month, 1951-60 and 1957, 1959, and 1960.

Ovary samples were taken from 21 different skipjack schools fished from May to December. These schools may be divided into seven schools of small fish (4 to 6 pounds), six schools of medium-sized fish (18 to 22 pounds), and eight schools of large fish (28 to 30 pounds). Analyses of the ova size distributions for 10 of the schools showed that within samples from separate schools there was very little variation (0 - 0.11 mm.) in the ova diameters of the last modal group. The average variation in this last modal group among fish from different schools was also very small (0 - 0.06 mm.). Of the two modes identified, the smaller was somewhat more difficult to define. However, the variations in ova diameter in the smaller modal group, both within and among schools, were also very slight (0 - 0.05 mm.).

In the summer samples, the male/female ratio for all small fish was 60/40, a significant deviation from equal representation. The ratios within individual schools of small fish conformed to that for the combined total. The ratio for two schools of small fish sampled during the winter months, and for the combined total of the large fish examined, approximated the expected 50/50 ratio.

Seasonal variations of skipjack spawning in Hawaiian waters were shown by preliminary counts of larvae from zooplankton samples collected during two series of cruises in Hawaiian waters, the monthly collections made during the IGY (1957-1958) and five cruises during 1959. Skipjack larvae were few or absent during the winter months, increasing in abundance during spring, reaching a peak during August (IGY) and May-July (1959), and then decreasing again to the winter minimum.

Among the Laboratory's studies of skipjack and other tuna larvae, one very significant accomplishment was the tentative identification and description of the larvae of bigeye, albacore, and two species of bluefin. Previously, skipjack, yellowfin, frigate mackerel, and little tunny larvae had been identified from the Pacific. The new identifications were made possible through the study of collections made in the western Pacific during the late winter and early spring of 1929 aboard the Danish vessel Dana. These collections were generously made available to us by the Carlsberg Foundation. The approach to the problem of identifying the bigeye, albacore, and bluefin larvae was made in a rather novel manner. The area surveyed by the Dana was divided into four geographical units (fig. 10): Formosan waters; the Sulu and Celebes Seas and the southern half of the south China Sea; the waters off northwestern New Guinea; and the eastern Indian Ocean (off the west coast of Sumatra). All unidentified larvae from samples taken in each area were segregated into one or more "types." Comparison of these types with catch records of adults (other than yellowfin, which occur in all four areas) revealed a correspondence in the number of adult species reported from each area and the types of larvae. For example, in the Sulu and Celebes Seas, where, besides yellowfin, only bigeye are caught on longline, one larval type was found in abundance and was designated

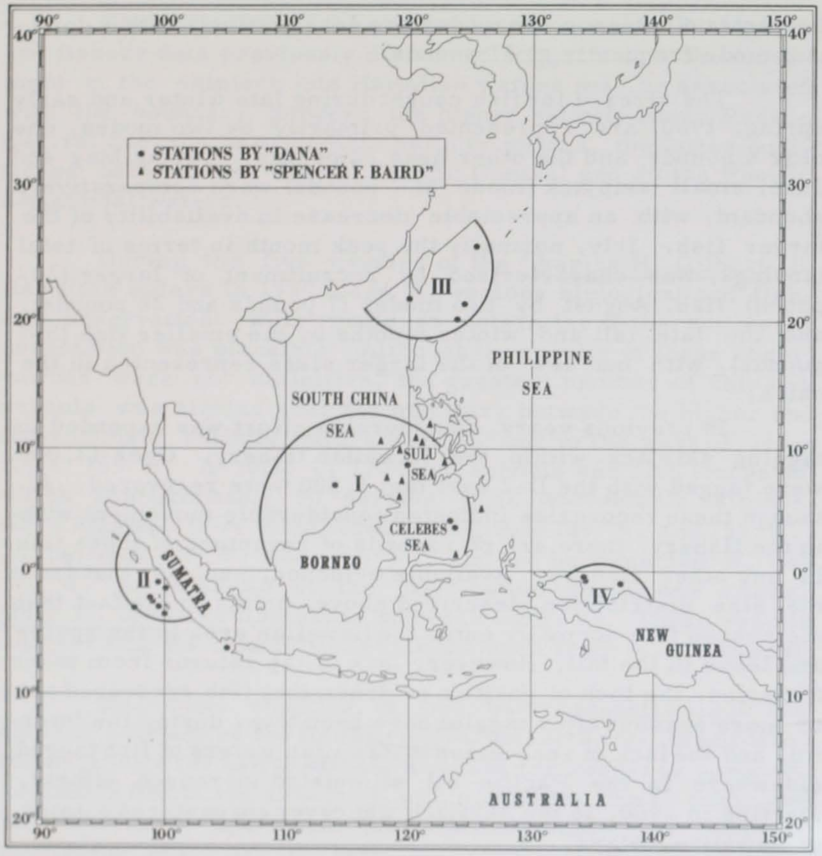


Figure 10. --Areas where Dana collected larval tunas.

as bigeye. In the waters off Sumatra, both albacore and bigeye are regularly taken by longline. Larvae from these waters fell into two general types; one was identical to that from the Sulu and Celebes Seas and thus was designated as bigeye, the other was designated as albacore. In Formosan waters, a similar approach resulted in the segregation of the larvae into three types, albacore, bigeye, and bluefin. For confirmation of these tentative identifications, studies were made of tuna larvae in the Laboratory's samples collected in the central and eastern Pacific. The types of tuna larvae in each sample were compared with the known distribution of the adults of the several species, and the tentative identification of the three species of larvae made through use of the Dana material was thus confirmed. A manuscript describing and figuring the larvae of the albacore, bigeye, and bluefin (fig. 11) was completed.

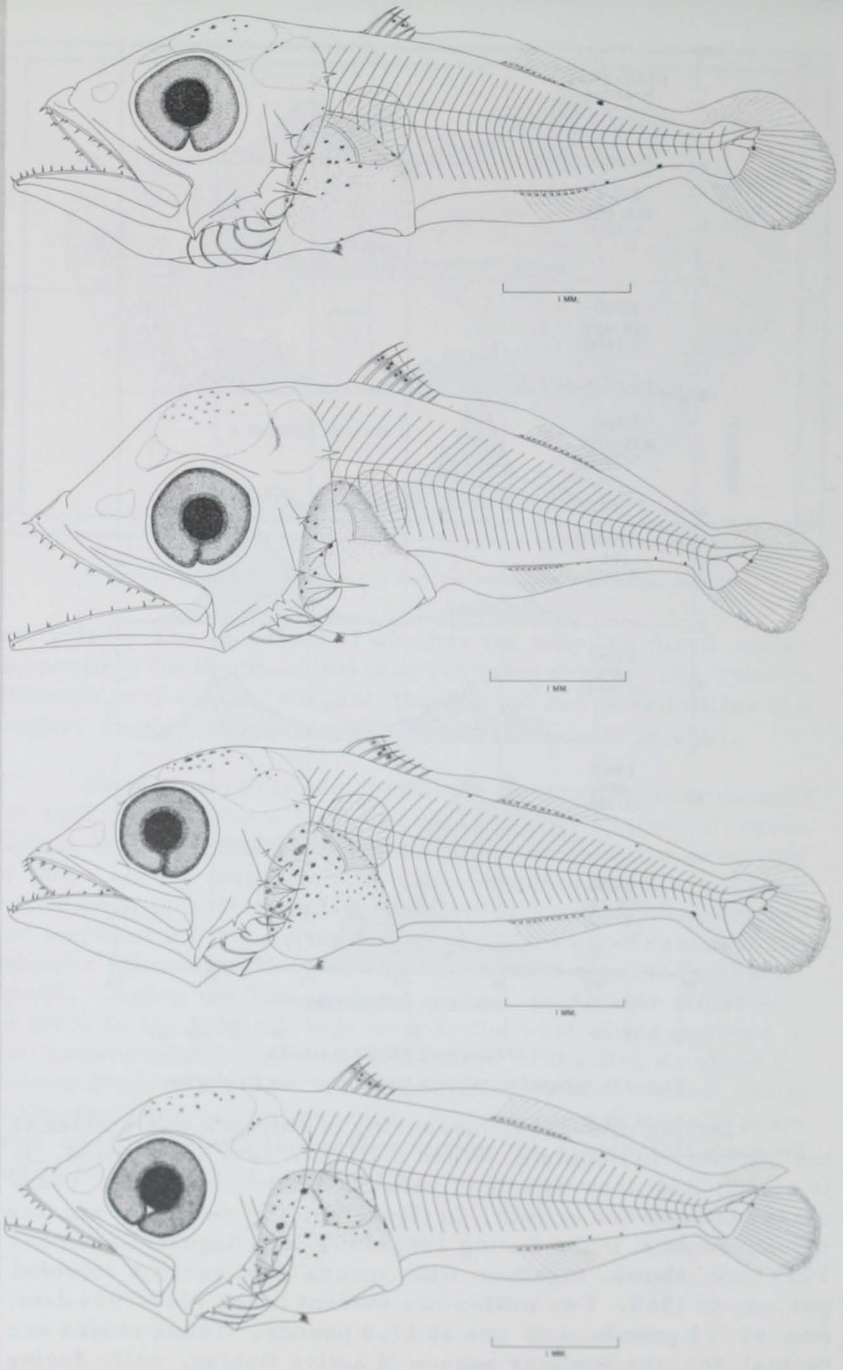


Figure 11. --Larvae of (top to bottom) albacore, bigeye, Australian northern bluefin, and Pacific bluefin.

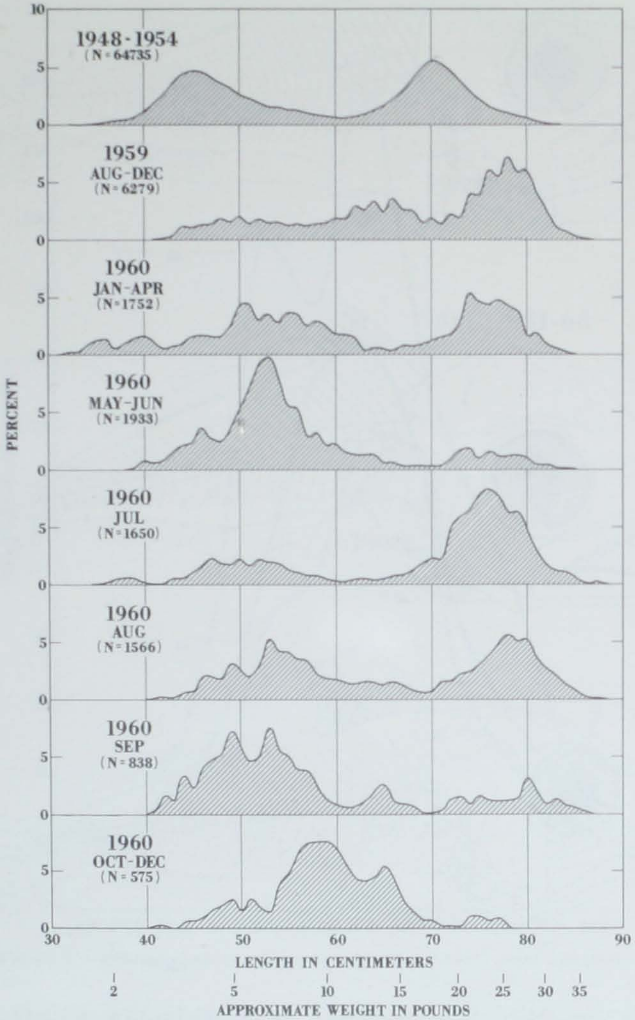


Figure 12. --Hawaiian skipjack length frequency distribution.

During mid-1959, measuring of skipjack was started at the cannery in Honolulu. When sufficient data are at hand, it is anticipated they will be of value in determinations of year-class strength and growth. In figure 12, the means for similar measurements made during 1948-1954 and August-December 1959 are shown, together with means for various selected periods in 1960. Two modes are evident in the 1948-1954 data, one at 4.1 pounds and one at 17.9 pounds. These modes are typical for the summer season of active fishing, while during the winter off-season the modes are less distinct, with a dominant mode frequently at 11 pounds.

The sizes of the fish caught during late winter and early spring, 1960, are represented primarily by two modes, one near 6 pounds and the other near 22 pounds. During May and June, small skipjack (mode at 7 pounds) were comparatively abundant, with an appreciable decrease in availability of the larger fish. July, normally the peak month in terms of total landings, was characterized by recruitment of larger (24-pound) fish, August by two modes (7 pounds and 26 pounds), and the late fall and winter months by the smaller fish (5-7 pounds), with but few of the larger sizes represented in the catch.

In previous years, considerable effort was expended in tagging skipjack within the Hawaiian fishery. Over 13,000 were tagged with the D-2 dart tag; 1,300 were recovered. Although these recoveries indicated considerable movement within the fishery, there are no records of recapture of these fish in any other fishery. Available evidence, such as that from the size distribution described above, points to the fact that the season fish normally enter the Hawaiian area in the spring and leave in the fall. However, lack of tag returns from other fisheries, the lack of positive evidence that fish recovered one or more seasons after tagging have been away during the interim, and the lack of recoveries in Hawaiian waters of fish tagged elsewhere in the Pacific all stimulated increased efforts, starting in 1960, to tag skipjack wherever encountered outside of Hawaiian waters.

In April, 46 skipjack were tagged and released from the Charles H. Gilbert near Roca Partida in the eastern Pacific. Although the results of this limited tagging effort have failed to shed any light on the problems of migration into Hawaiian waters, it is interesting to note that 11 of the tagged tunas (24 percent) were recaptured within 2 months and all but one from the area of the release. All recoveries were reported through the Inter-American Tropical Tuna Commission.

One aspect of an adequate understanding of the causal relationships involved in the seasonal and year-to-year variations in availability of skipjack in Hawaiian waters is a knowledge of why they migrate into Hawaiian waters each spring. Do they come to feed or to spawn or because their migration is related to certain oceanographic features? From where do they come?

Consideration of the various oceanographic, biological, and fishery data previously discussed suggests that the movement of the skipjack into Hawaiian waters may be associated with the boundary between the higher salinity North Pacific Central and the intermediate salinity waters, the latter positioned between the North Pacific Central and North Pacific Equatorial waters.

During the five cruises of the Charles H. Gilbert in Hawaiian waters in 1959 (page 5), various biological and fishery observations were made to determine if the suggested association was plausible. Although the results of these observations were not definitive, the greatest number of skipjack schools was sighted near the boundary between the higher and intermediate salinity waters (fig. 13) and to the west of longitude 155° W. A total of 170 fish schools and bird flocks (of which approximately 80 percent were undoubtedly skipjack) were sighted, 28 of them between longitude 145° W. and 155° W., 76 between 155° W. and 160° W., and 66 between 160° W. and 170° W. An example of the distribution during one cruise, Hugh M. Smith cruise 51, is shown in figure 13. These results suggest that the season fish enter the area from the southwest.

Inadequate supplies of live bait frequently limit the catch of skipjack by the Hawaiian live-bait fishery. In addition, the necessity for bait to sample skipjack for research purposes seriously limits the area from which samples can be taken and the number of specimens available for study. As part of a continuing study to increase the efficiency of the Hawaiian skipjack fishery, and in an effort to provide a means for sampling which is not dependent upon bait, an attempt was made to capture skipjack in Hawaiian waters by means of an encircling gill net. Using a power block for retrieving the net, a 304-fathom-long, 50-fathom-deep gill net was set around four skipjack schools off the leeward shores of the island of Oahu. The schools were small and the fish wild. A few skipjack were caught in the first two sets, none in the second two.

It appeared to observers looking through the underwater viewing ports in the Charles H. Gilbert that the first set surrounded the entire school; no skipjack were seen in the second set and only parts of the schools in the third and fourth. Observers on the surface within the encircled area during the first, third, and fourth sets did not see any fish within the top 10 fathoms, the limit of their vision. These observations suggest the fish escaped before the schools were completely encircled. The question of whether the skipjack dived under the net (into the thermocline) is as yet unanswered. The catches, although very small, suggest the method has possibilities if a longer, deeper net, set from a speedier vessel, is used.

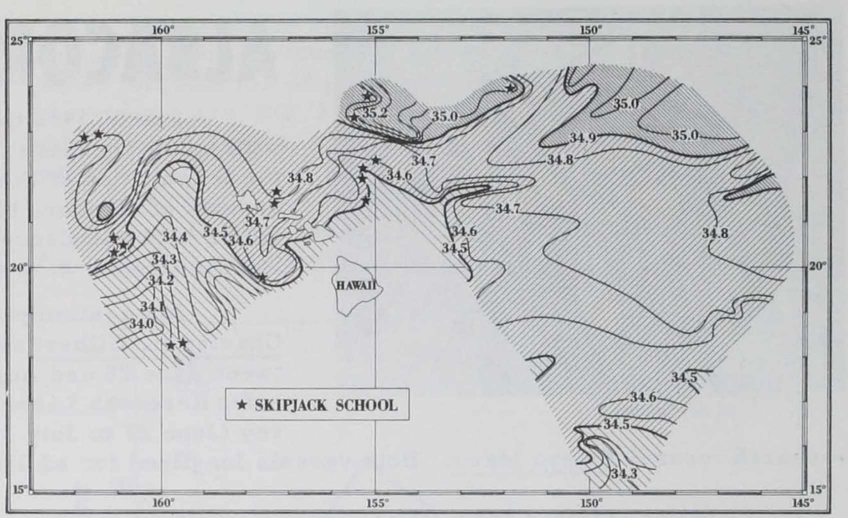


Figure 13. --Skipjack sightings and selected isohalines in Hawaiian waters.

Three cruises in central Pacific waters have been planned for 1961 to study the validity of the previously suggested association of the skipjack with their environment and the direction of their spring migration into the Hawaiian fishery. These cruises will include oceanographic and biological observations and live-bait fishing during the winter (January-February) and summer (June-July) months and the transition period (March-April). During the March-April cruise, particular effort will be made to tag skipjack in waters to the west of the grounds of the commercial fishery to determine if the fish do enter the fishery from this area. In addition, studies of the blood group characteristics will be made for comparison with those of skipjack caught in Hawaiian waters during the winter (off-season) and in other areas of the Pacific.

ALBACORE ECOLOGY

From 1954 to June 1960, the albacore investigations were primarily concerned with studies of these fish in the north central and northeastern Pacific. During 1960, with the termination of this exploratory investigation, efforts were directed to the Pacific-wide aspects of albacore biology. Studies of spawning, age and growth, migration, and distribution and abundance of albacore, in both the northern and southern hemispheres of the Pacific Ocean, were augmented or started.

In an attempt to locate and define North Pacific albacore spawning grounds, the Charles H. Gilbert surveyed the area west of Hawaii to longitude 160°E. (fig. 14), between June 20 and August 28, 1960. A cooperating laboratory, the Nankai Regional Fisheries Research Laboratory of the Japanese Fisheries Agency, carried out a similar survey (June 27 to July 30, 1960) in the western Pacific between 140°E. and 150°E. with its research vessel Shunyo Maru. Both vessels longlined for adults and made net tows for larval and juvenile albacore.

Longline catches from the Charles H. Gilbert were small. Six albacore were captured, five of which were males. The single female possessed ovaries which were well developed but not in spawning condition. The Shunyo Maru took only one albacore, a female, whose ovaries were apparently spent.

Net tows were somewhat more successful in that they resulted in the capture of five larval albacore from the area between 180° and 160°E. The Japanese have not completed examination of their larval tuna collections, but have indicated that they collected about 1,000 "tuna like" larvae. It is possible that the survey from the Charles H. Gilbert may not have extended far enough to the west or that the survey was towards the end of the spawning season. However, part of this question should be resolved once the Japanese complete their examination of the larval tuna collected in the more westerly survey area.

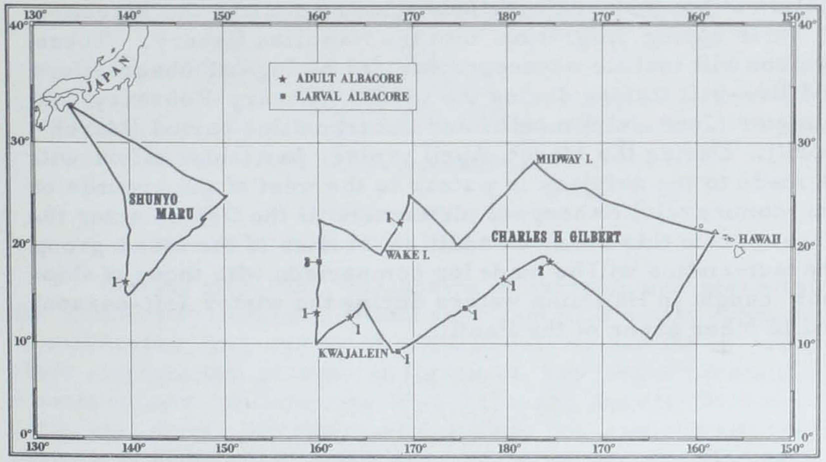


Figure 14.--Track chart of Charles H. Gilbert albacore spawning ground survey.

Preliminary findings from an analysis of albacore length frequency data revealed that the three major fisheries in the North Pacific, the American west coast summer live-bait and troll fishery, the Japanese winter longline fishery, and the Japanese spring live-bait fishery, are exploiting mainly the 3- to 5-year-old fish (fig. 15). These ages are assigned on the assumption that albacore are 2 years old when they first enter the commercial fisheries.

The American fishery takes four age groups ranging from 2- to 5-year-olds. The most heavily fished are generally the 3-year-olds, which constitute roughly 70 percent (by weight) of the total landings. Contributing less, but still present in significant numbers, are the 2- and 4-year-olds, while the 5-year-old albacore constitute an insignificant proportion in the catch.

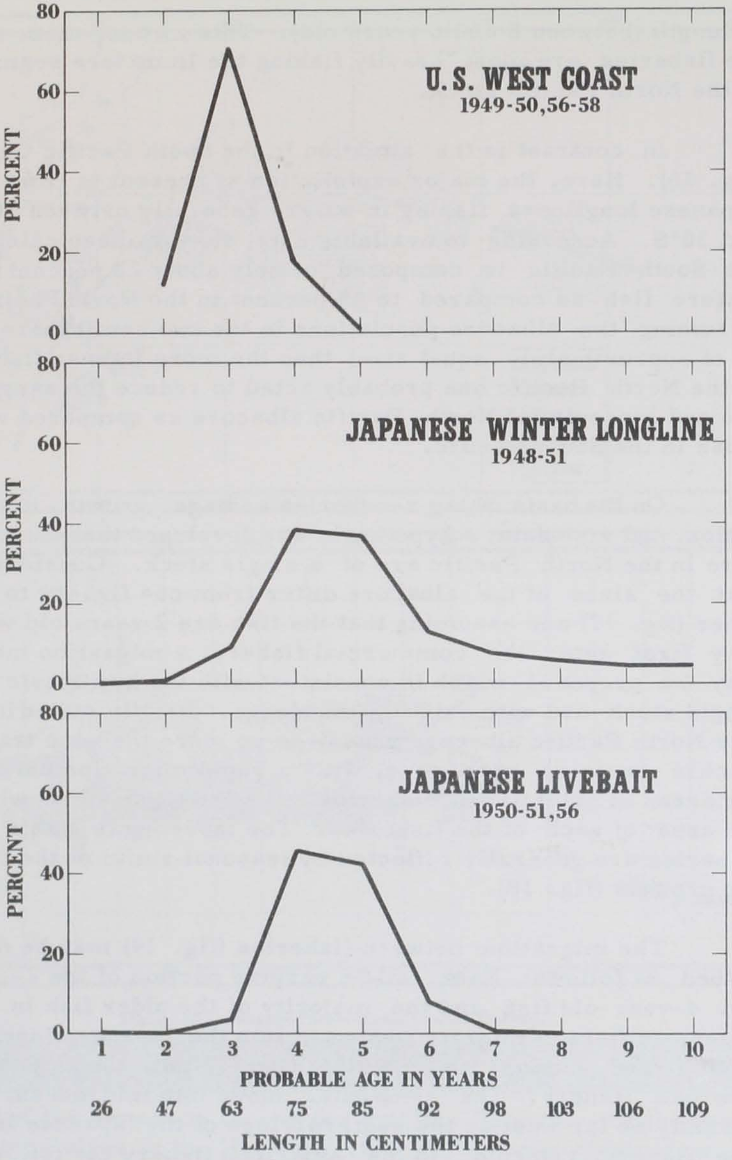


Figure 15. --Size and age composition of catch in U. S. and Japanese albacore fisheries.

The 4- and 5-year-olds are the major groups taken by the Japanese winter longline fishery, with the 4-year-olds accounting for about 29 percent of the landings and the 5-year-olds about 27 percent. The 3-, 6-, and 7-year-olds make up 29 percent, while older fish contribute smaller amounts.

The Japanese spring live-bait fishery also has a major part of its catch composed of 4- and 5-year-old fish, which together account for 88 percent of its total landings. Next in importance are the 3- and 6-year-olds (about 12 percent), while fish of ages 2, 7, and 8 comprise a small portion of the catch.

Considering the total North Pacific albacore landings (fig. 16), it is estimated that the most heavily fished age group,

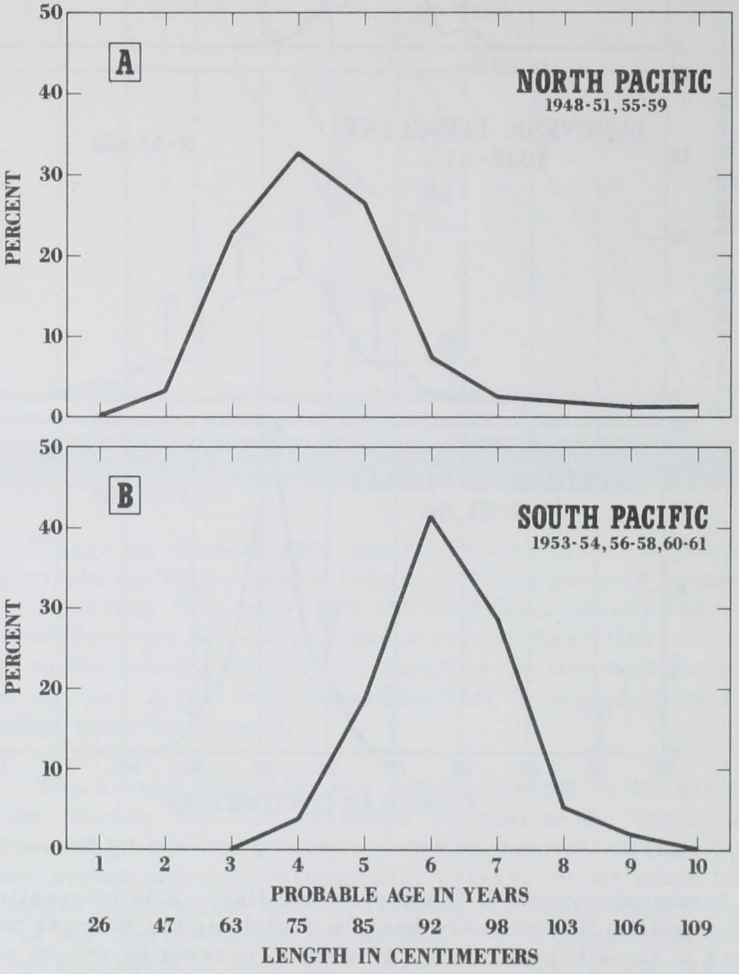


Figure 16. --Size and age composition of North and South Pacific albacore catches.

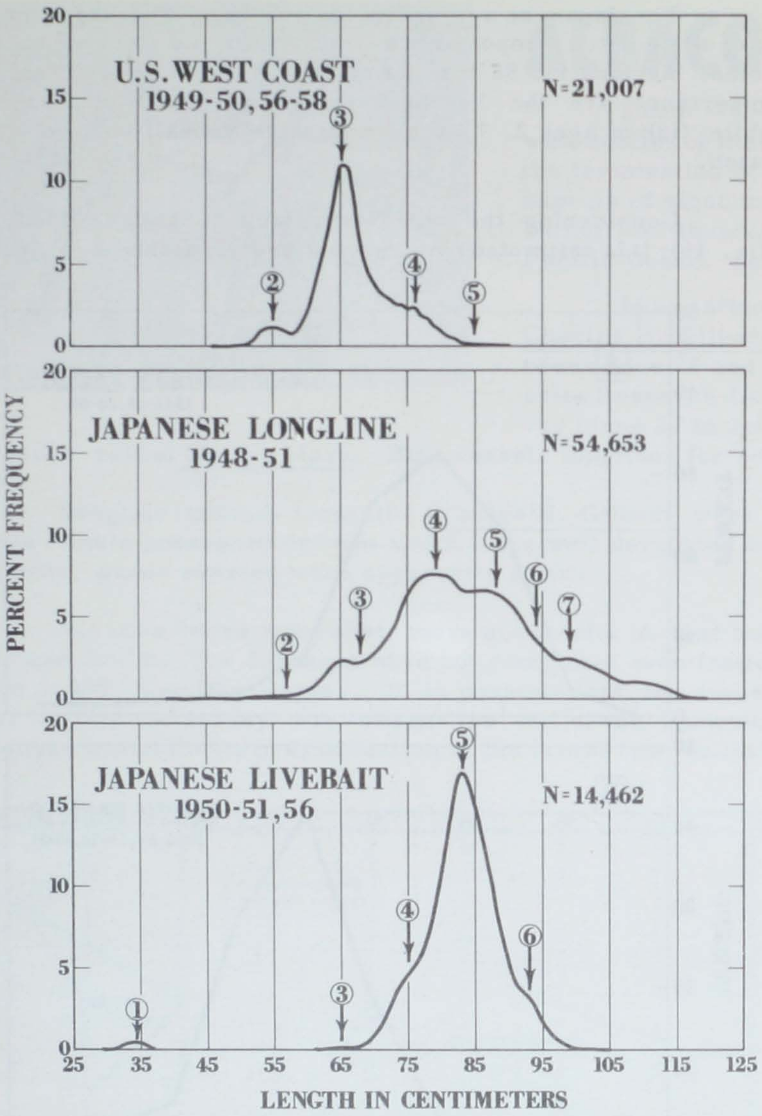


Figure 17.--Albacore length frequency distributions in North Pacific fisheries.

in terms of weight, is the 4-year-old fish. It is interesting to note that the fisheries are heavily exploiting the younger members of the albacore stock. Nearly 85 percent by weight of the total North Pacific landings are of fish 5 years old or younger. Spawning studies have shown that albacore attain sexual maturity and spawn for the first time when they reach about 90 cm. in length (between 5 and 6 years old). This means, then, that the fisheries are most heavily fishing the immature segment of the North Pacific stock.

In contrast is the situation in the South Pacific Ocean (fig. 16). Here, the major exploitation at present is from the Japanese longliners fishing in waters generally between 10°S. and 30°S. According to available data, the Japanese catch in the South Pacific is composed of only about 22 percent immature fish as compared to 85 percent in the North Pacific. Assuming the albacore populations in the two hemispheres to be of approximately equal size, then the more intense fishery in the North Pacific has probably acted to reduce the average age and longevity of North Pacific albacore as compared with those in the South Pacific.

On the basis of tag recoveries and age, growth, distribution, and size data, a hypothesis was developed that the albacore in the North Pacific are of a single stock. Considering that the sizes of the albacore differ from one fishery to another (fig. 17) and assuming that the fish are 2 years old when they first enter the commercial fishery, a migration model may be proposed which is consistent with the hypothesis of a single stock and with existing knowledge. Briefly stated it is: The North Pacific albacore undertake no more than one trans-Pacific crossing each year, with a rapid migration between the areas of established fisheries and a slow movement within the area of each of the fisheries. The movements within the fisheries are generally reflected by seasonal shifts of the fishing grounds (fig. 18).

The migration between fisheries (fig. 19) may be described as follows: Each fall, a varying portion of the 2-, 3-, and 4-year-old fish and the majority of the older fish in the American fishery migrate westward into the Japanese longline fishery and, during the following spring, into the Japanese live-bait fishery. The remainder move into mid-ocean, or possibly as far west as the eastern fringe of the Japanese longline fishery, returning to the American fishery the following summer. Consequently, some of the fish may be available to the American fishery for as many as 4 or 5 successive seasons.

The Japanese live-bait fishery is notably lacking in 2- and 3-year-old fish. When present, these small albacore may migrate eastward into the American fishery after spending a

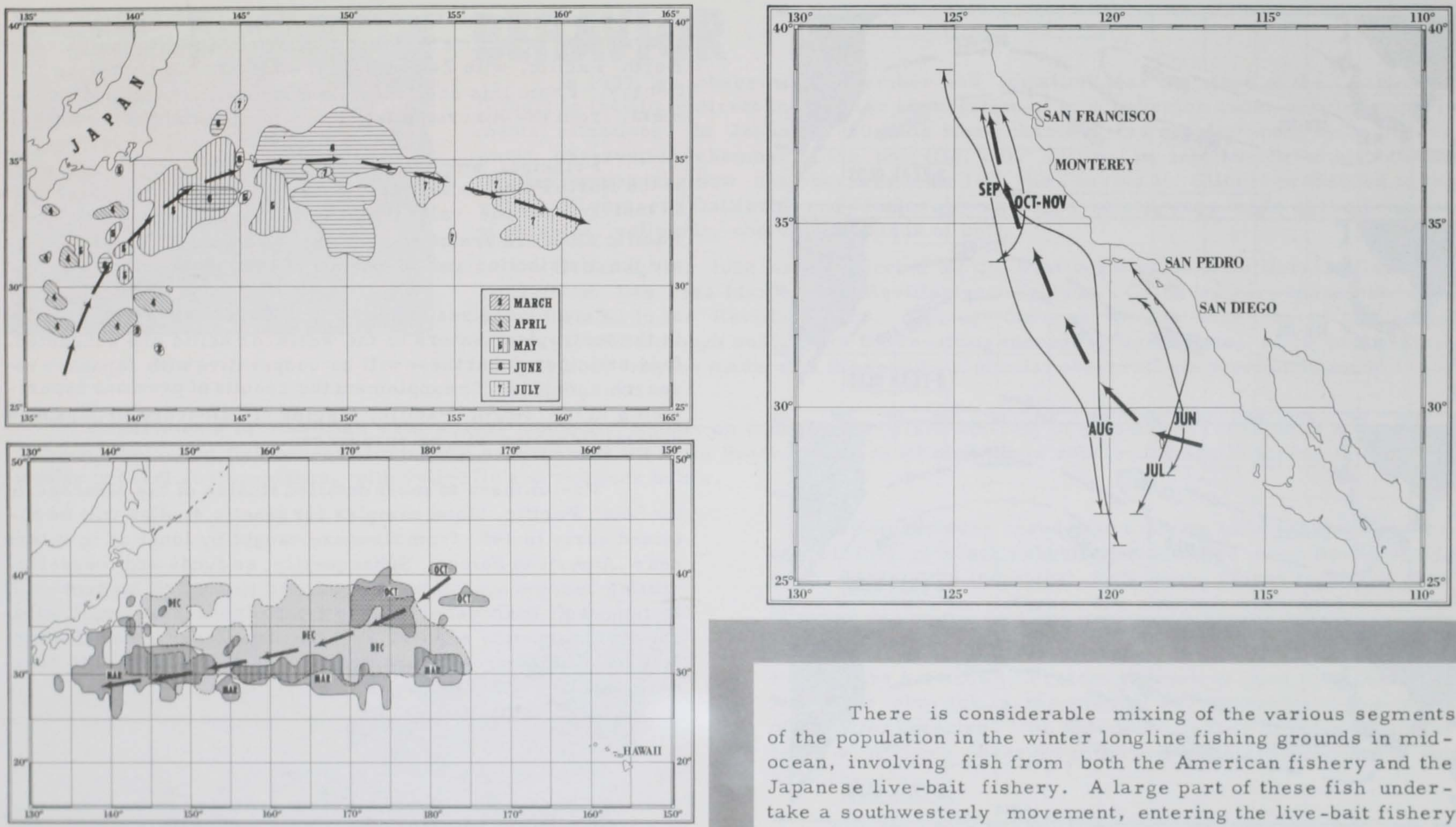


Figure 18. --Albacore movements in each fishery.

part of the season in the winter longline fishery. Of the more common sizes in the live-bait fishery, comparatively few of the 4- and 5-year-old groups migrate eastward during the following summer into the American fishery. This is evident from the small proportion of these size groups in the American catch. The bulk of the albacore from the Japanese live-bait fishery migrate into the longline fishery and then return to the live-bait fishery the following spring.

There is considerable mixing of the various segments of the population in the winter longline fishing grounds in mid-ocean, involving fish from both the American fishery and the Japanese live-bait fishery. A large part of these fish undertake a southwesterly movement, entering the live-bait fishery in the spring. A few may depart earlier to migrate into the American summer fishery.

The 6-year and older age groups present in the winter longline fishery are not available to either of the other two fisheries (fig. 17). A portion of these larger fish, having reached sexual maturity in temperate waters, moves south into subtropical and tropical waters, forming the reproductive segment of the North Pacific population. Since these older fish are always present in the winter longline fishery, it is apparent that a portion moves back north in the spring, possibly to areas not included in the Japanese live-bait fishery.

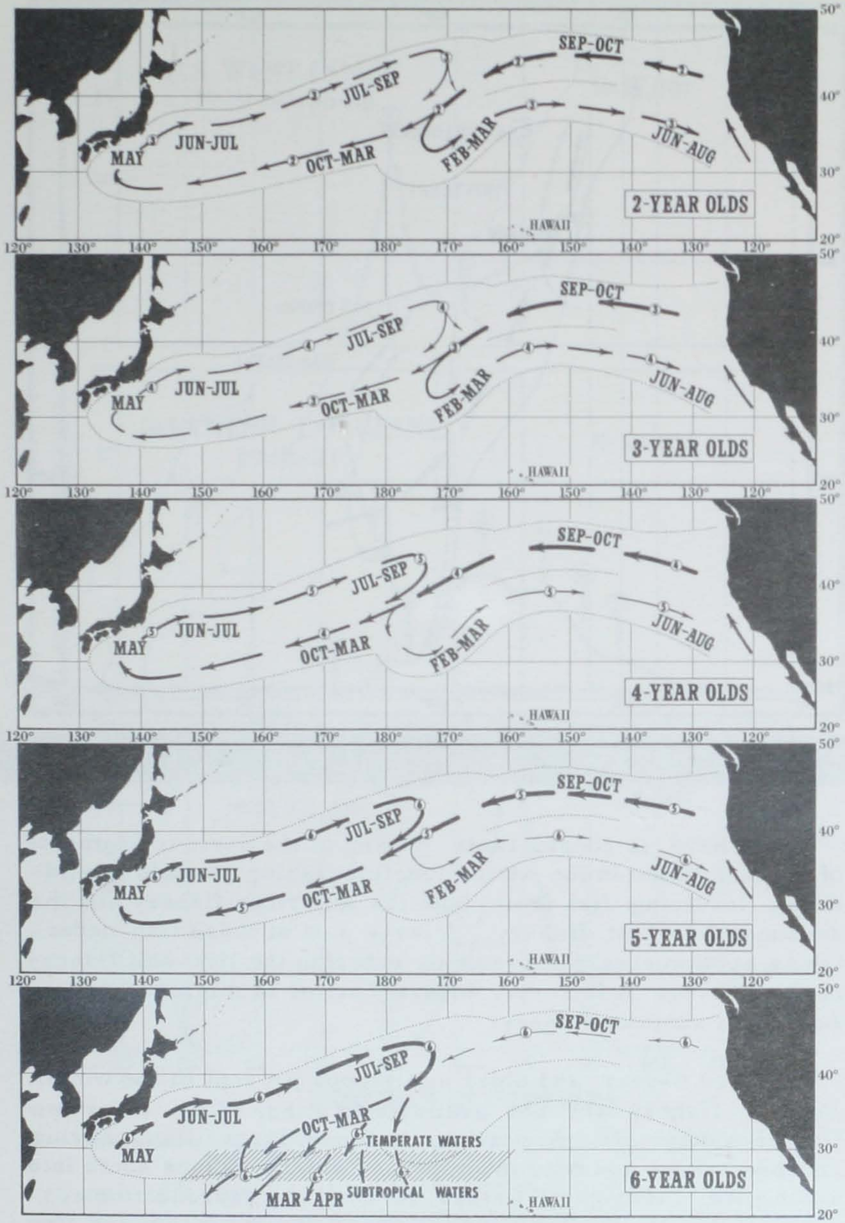


Figure 19. --Scheme of trans-Pacific migrations of albacore.

Judging from the size composition of the catch, it appears that recruitment takes place primarily in the eastern North Pacific, with 2- and 3-year-old albacore entering the fishery. From this area there is a generally westward movement, from the American into the Japanese fisheries.

Principal emphasis during 1961 will be given to studies of the North Pacific albacore. These will include genetic studies to test further the validity of the hypothesis that the North Pacific albacore are of one subpopulation and studies to delineate the distribution and abundance of the larvae.

Further cruises to define the albacore spawning grounds in the subtropical waters of the western Pacific are scheduled. It is anticipated that these will be cooperative with Japanese research agencies. To supplement the results of previous experiments in the North Pacific, tagging of albacore in Japanese coastal fisheries will be encouraged.

Preliminary to more detailed studies of the albacore in the South Pacific, blood samples for genetic studies will be obtained early in 1961 from albacore caught by longline in waters near American Samoa. Subsequently, as funds and vessel facilities become available, it is planned that small albacore will be tagged off the coast of Chile to determine if these small albacore subsequently support the longline fishery near Samoa. Studies of blood group characteristics of the South Pacific albacore will be augmented.

BEHAVIOR

In 1959, an observation chamber was installed near the stern of the *Charles H. Gilbert* to facilitate direct underwater observation of tuna behavior under varying experimental situations. In January 1960, this stern chamber was supplemented by an underwater observation chamber in the bow (fig. 20). Sailing in late March from Portland, Oregon, where the bow chamber was installed, the *Charles H. Gilbert* proceeded to the waters off southern California and Mexico, where observations were made of the behavior of skipjack, yellowfin, and various kinds of bait.

Scouting for tuna was conducted off the west coast of Baja California, Cape San Lucas, and Las Tres Marias and Revillagigedo Islands. Catches were made only near Roca Partida in the Revillagigedos. Although the observations were limited to a period of 4 days, and although analysis of the resulting records is incomplete, some preliminary comparisons may be made with the results of similar observations previously made in the central Pacific.

Experiments in Hawaiian waters were conducted mostly on schools comprised entirely of skipjack. There were a minimum of three species of fish present during the experiments off Roca Partida. A school of rainbow runners (*Elagatis bipinnulatus*) was usually present at the surface, with yellowfin and skipjack below.

Figure 20.--Underwater observation chamber in bow of *Charles H. Gilbert*.

Comparisons based primarily on field observations revealed that skipjack schools encountered near Roca Partida were denser (the individual fish were closer together) than those in Hawaiian waters. The skipjack were not held to the stern by the chum, but approached the vessel, moved off, and returned at intervals. In contrast, the skipjack in the central Pacific are not known to return to the boat once the school has left. The skipjack in the eastern Pacific schooled at a depth of 6 feet or greater, with individual dashes to the surface for bait, while those observed in Hawaiian waters schooled at the surface.

In the eastern Pacific, the apparently mixed schools of yellowfin and skipjack of approximately the same size were, in reality, separate schools. When observed from the underwater chamber, the distinction was obvious as the separate schools of each species moved to and from the area of chumming.

Direct observations suggested that the eastern Pacific tuna did not exhibit any differences in behavior whether water sprays were on or off. These tentative conclusions may be subject to revision after analysis of the motion picture records. In experiments in the central Pacific, it is apparent that

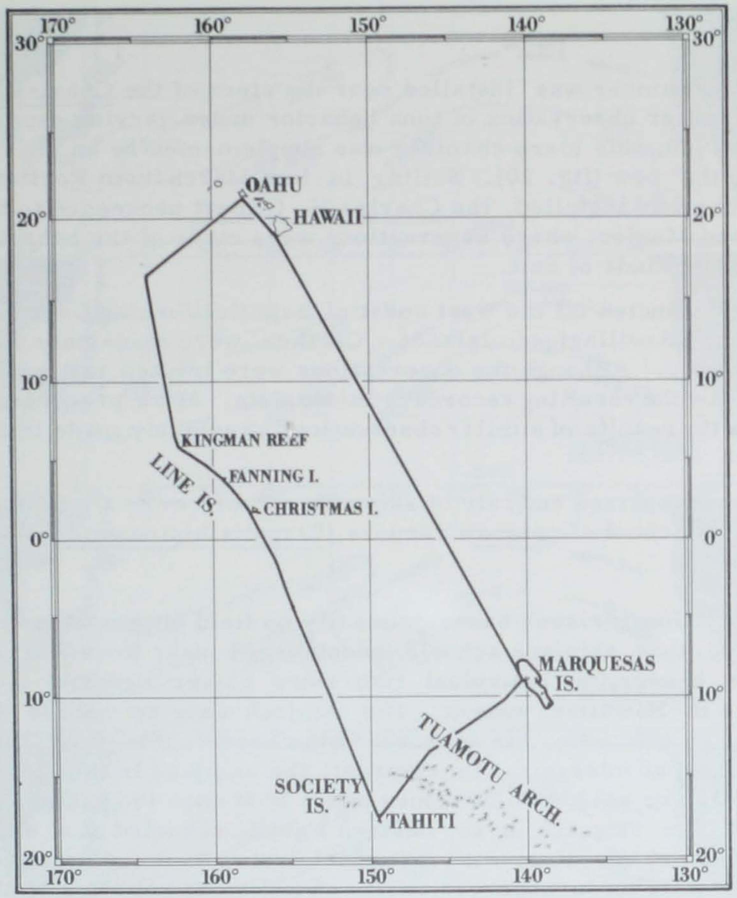


Figure 21.--Track chart of Charles H. Gilbert cruise 50 to Line, Marquesas, and Society Islands.

differences in behavior of the skipjack, with sprays on or off, are related to the type of bait used in the experiment. For example, with nehu (Stolephorus purpureus) as bait, there is an evident increase in excitement of the fish and in the catch rate, when the sprays are on. With mullet (Mugil longimanus), goatfish (Mulloidychthys samoensis), or iao (Pranesus insularum), no increase in either excitement or catch rate was observed with the sprays on, while with aholehole (Kuhlia sandvicensis) and tilapia (Tilapia mossambica), there was an increase in catch rate, but no observed increase in excitement.

During the spring cruise of the Charles H. Gilbert there were opportunities to observe both the response of the tuna to different types of bait and the behavior of the bait. Northern anchovy (Engraulis mordax) were obtained at San Diego and thread herring (Opisthonena libertate) and anchovy were caught in Banderas, Santiago, and Manzanillo Bays. The most pronounced excitement was induced in the tuna by the most elusive bait, the thread herring. Northern anchovy sounded immediately and, upon sighting the tuna, reversed direction and swam to the surface. The two other species of anchovy (both of the genus Anchoa) assembled into schools and moved away from the vessel. The thread herring sounded, but, unlike the northern anchovy, exhibited considerable evasive activity as they sounded, luring the tuna away from the surface and the vessel.

In order to extend the studies of comparative behavior of tuna in different geographical areas, observations were made on the behavior of fish in seven skipjack schools and two mixed schools of yellowfin and skipjack during a mid-winter cruise of the Charles H. Gilbert to the Line, Marquesas, Tuamotu, and Society Islands. One school of skipjack was studied near the Line Islands and the remaining eight near the Marquesas (fig. 21).

In addition to the observations of variations in tuna and bait behavior under experimental conditions, similar to those mentioned above, a new study was started during this cruise. Underwater sounds associated with the fishing operations were recorded, and various sounds were transmitted into the water in order to observe the behavior of the fish in the presence of these sounds. The equipment used for these experiments was a towed, free-flooding, plastic housing containing a U. S. Navy sonobuoy hydrophone (fig. 22). This instrument towed well at

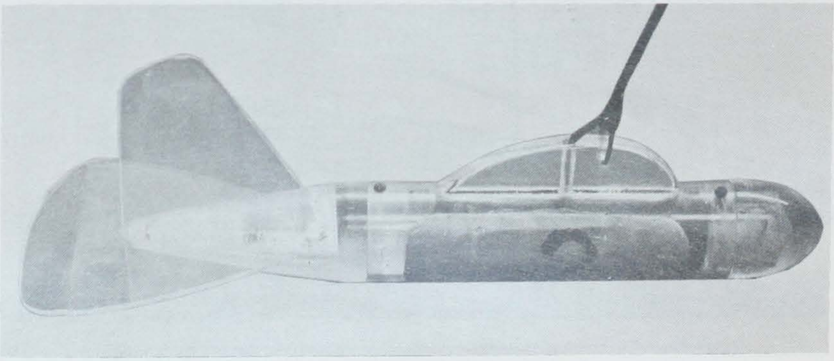


Figure 22.--Experimental sound transducer.

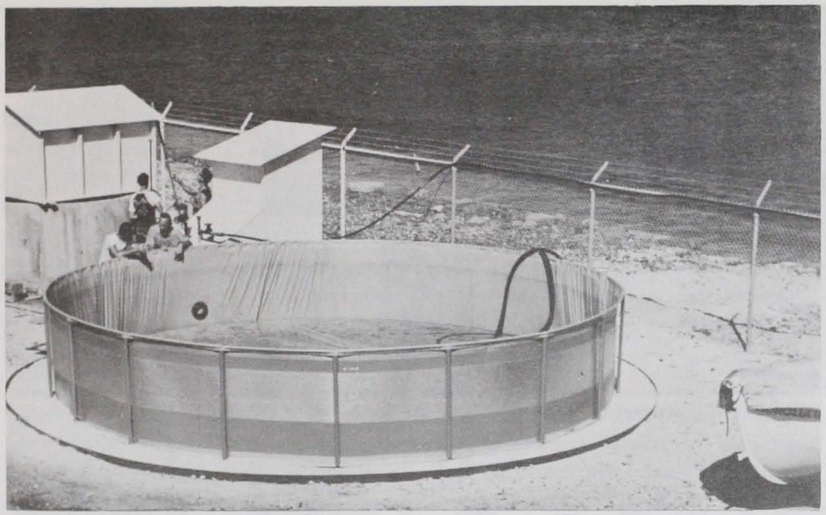


Figure 23. --Plastic pool in which skipjack were held.

speeds of up to 9 knots. On one fishing station, porpoise (a predator) and squid (forage) noises were transmitted into the water. Although the observers did not note any significant change in behavior of the tuna when the sound was introduced, the final results must await analyses of the film and tapes.

Although various aspects of the behavior of skipjack have been successfully studied by the Biological Laboratory, Honolulu, from the underwater observation chamber of the *Charles H. Gilbert*, only limited control over the fish is possible in their natural environment. As a first step toward meeting the need for holding skipjack in captivity, where they can be studied under more controlled conditions, 35 skipjack captured by live-bait fishing in late 1959 were placed in a pool at the Kewalo Basin Laboratory (fig. 23). All died within 1 to 1-1/2 days. Various methods of handling were tried with other skipjack, but none lived in captivity for more than 50 hours. Then, in February 1960, a way was found to eliminate manual handling of the fish. Skipjack captured and introduced into the pool in the manner described below lived for nearly 6 months. Caught by pole and line, with a barbless hook, they were lowered into a specially constructed tank (fig. 24) carried on the stern of the fishing boat (fig. 24a). The line was slacked to allow the fish to shed the hook. During transport to Kewalo Basin, water was continually circulated within the tank. When the vessel reached shore, the tank was lifted from the stern and immersed in the pool (fig. 24b). The hatch on the side of the tank was opened, and the skipjack were allowed to swim out.

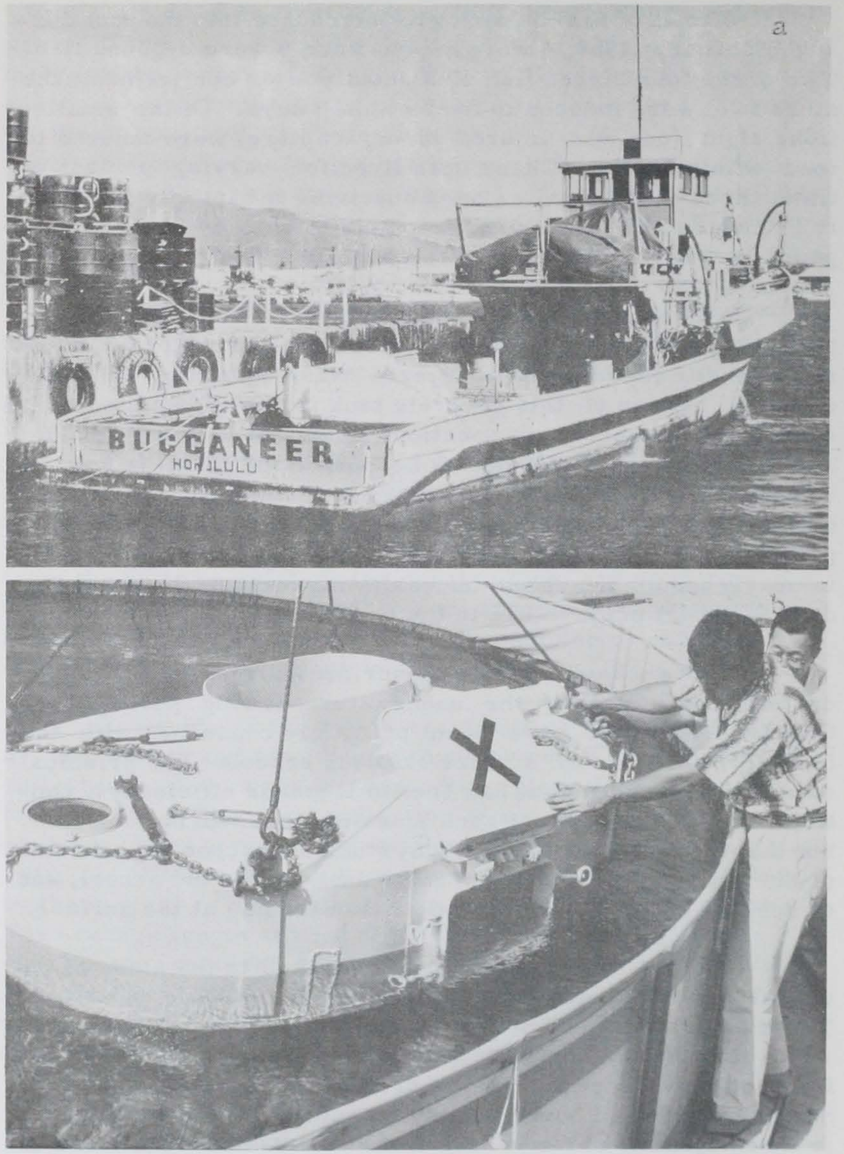


Figure 24. --Portable skipjack tank on sampan and in pool.

A total of 13 skipjack were introduced into the pool during February 1960; 4 were 6-pound and 9 were 2-pound fish. Two of the four larger fish died shortly after confinement; the other two were induced to feed within 9 days. Of the smaller fish, eight (one was injured during capture) were induced to feed within 3 days. These fish lived for varying periods of time, three of the smaller ones surviving in captivity for nearly 6 months. At the end of 5 months, each had gained about 1 pound in weight. Their food was mainly pieces of frozen shrimp.

With the successful development of a technique for establishing skipjack in captivity, construction of a tank more suitable for experimental purposes was begun (fig. 25). The circular portion of this concrete tank is 15 feet in diameter; each of the two rectangular sections is 35 feet long, 6 feet wide, and 4 feet deep. The water to be used in the tank, as was the case in the pool (fig. 23), is pumped from an adjacent well. It differs from ocean water in that it is less saline (32 ‰ as compared to 34.5 - 35.0 ‰) and more acidic (pH 7.6 vs. 8.2), and is nearly devoid of oxygen, necessitating aeration (by cascading down a tower) prior to use in the tank.

Those behavior studies described above which were conducted through use of the underwater viewing ports in the *Charles H. Gilbert* have been primarily concerned with the feeding reactions of surface skipjack schools. The principal objective of these studies has been to increase efficiency of capture. It is planned that such investigations will be continued, but that they will be augmented by studies of schooling behavior of the tuna, of the behavior of individuals within the school, and of schools under conditions other than feeding at the surface.

When a surface school is chummed to the stern of the vessel, only a portion of the school is available for study. There is, at present, no way to determine the size of the school or to observe the activity of the fish which are not within the field of view from the window of the observation chamber. Similar problems, considerably magnified, are to be expected in investigations of the behavior of sub-surface schools and of surface schools under conditions other than feeding. New types of instruments are needed, both for detection and for observations of fish behavior. Sonar equipment, presently available or to be developed, will undoubtedly facilitate detection of both surface and sub-surface schools from surface vessels. Under ideal conditions, such equipment will make possible some tracking of the schools and estimation of their horizontal and vertical distribution. Underwater television, to a very limited extent, may be used for the direct observation of fish behavior (as contrasted with the indirect observations through use of sonar). In view of these limitations to studies of fish behavior from surface vessels, an investigation into the feasibility of constructing a small, maneuverable, high-speed submarine is planned. If such a submarine proves feasible, its use will eliminate many of the present limitations imposed by use of surface vessels for direct observations of the behavior of both surface and sub-surface fish schools.

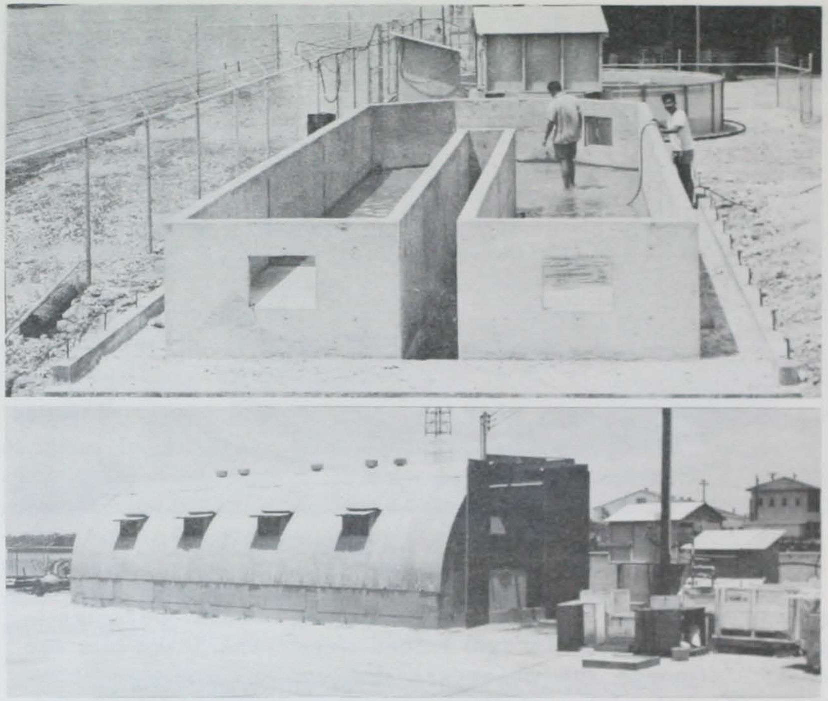


Figure 25. --Skipjack behavior study tank with and without quonset hut mounted.

During 1961, the first experiments to study the behavior of captive skipjack, under controlled conditions, will be made in the new tanks at Kewalo Basin. These experiments will include studies of color, size, shape, and odor discrimination and other experiments designed to test the response of skipjack to various stimuli. Supplementary studies of the morphology of the sensory organs, such as the olfactory capsule, will be made.

BAIT SUPPLEMENTS

A series of studies, begun in 1952, to determine the feasibility of supplementing the supply of natural bait to Hawaiian commercial skipjack fishermen, was brought to successful completion in 1960. These studies included investigations of the use of artificial baits, introduction of Marquesan sardines (Harengula vittata) into Hawaiian waters, the introduction of tilapia and threadfin shad (Dorosoma petenensis) into various ponds and reservoirs in the State, and studies of the methodology and economics of rearing tilapia by hatchery methods.

The principal bait used in the Hawaiian live-bait skipjack fishery is the nehu, a small anchovy. Not only are the nehu frequently in short supply, thus limiting total landings, but they are comparatively delicate fish, and it is estimated that 30 percent of those caught are lost through mortality. This not only limits the total amount of nehu available for chum, but also reduces the time the bait may be maintained in the wells aboard the vessels. It has been estimated that if bait were not limiting, the Hawaiian skipjack landings would be increased by at least 50 percent (from an annual average total of 10 million to 15 million pounds).

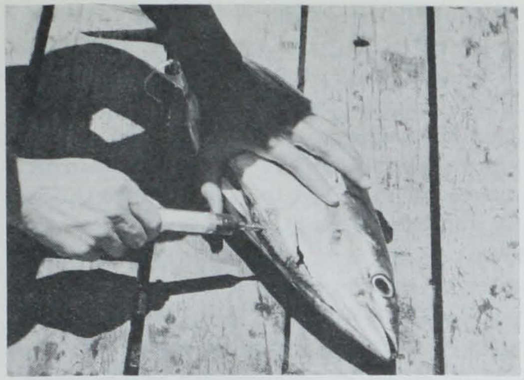
The results of investigations of the use of artificial baits were generally negative or inconclusive. Skipjack showed little or no response to the use to both edible (agar, fish flesh) and inedible (aluminum foil, mica flakes) materials as chum, and the study was terminated in 1953.

The Marquesan sardine proved to be excellent live-bait during the Laboratory's skipjack investigations in waters of French Oceania, and this potential bait supplement was introduced into Hawaiian waters in late 1955. Additional releases were made in 1956, 1957, and 1958. By September 1960, adults in spawning condition and young sardines had been captured from waters near six of the eight Hawaiian Islands. State restrictions on the capture of these fish, pending their establishment in Hawaii, were lifted during 1960, thus permitting Hawaiian fishermen to capture and use them as livebait. A total of 14 reports of capture of Marquesan sardines by commercial fishermen were received during 1960.

Tilapia were first brought to Hawaii in 1951. Sea tests proved these fish to be an effective bait for skipjack, particularly for the larger (18-24 pound) tuna. Investigations into the economics and methodology of rearing tilapia were first made by the Laboratory at a small hatchery on Oahu in 1956 and were continued at a larger hatchery on the island of Maui in 1957-1959. Experiments were carried out to discover methods for inducing early spawning and the optimal salinity, sex ratios, brood stock concentrations, feed, and rate of feeding. The Maui plant produced slightly over one million fry annually in 1958 and 1959. Bait-size tilapia from the Maui plant yielded on the average 46-50 pounds of skipjack per pound of tilapia. Comparable figures for nehu were 50-57 pounds of skipjack per pound of bait.

The favorable results of the Laboratory's tilapia investigation, both as to the economics of their rearing by hatchery methods and their success as a livebait, encouraged the Hawaii State Board of Agriculture and Forestry to request funds from the State Legislature for construction and operation of a tilapia hatchery. The funds were appropriated, site was selected, and plans for construction completed. The plant is expected to be in operation in 1961.

Threadfin shad, which are prolific, can tolerate fresh or sea water, and have been proven by sea tests to be an excellent bait fish, were introduced into Hawaii by the Laboratory in 1959. The first indication of successful spawning was reported from a reservoir on the island of Oahu during May 1960. In June, additional evidence of spawning was provided by the capture of shad from a reservoir on the island of Maui. The average length at time of planting in August 1959 was 9.5 cm. Those captured in June 1960 were as small as 1.9 cm. With the successful introduction of the threadfin shad into Hawaiian waters, this supplemental bait species is now potentially available to the Hawaiian skipjack fishermen.



SUBPOPULATIONS

Studies of the composition of Pacific tuna stocks were started, using as "natural tags" the inherited characteristics detectable as individual differences between red blood cells of different natural population units or subpopulations. The principal efforts during 1960 were directed towards definition of the stocks of skipjack in the subtropical and tropical waters of the central Pacific. Such definition, not only for the tunas but also for other climax predators, will result in a better understanding of growth and rates of recruitment and mortality, which may be unique to different racial or genetic stocks within each species.

Before beginning to compile data, at least partial solutions to two technical problems were needed: development (1) of methods for preservation of fresh red blood cells for considerable lengths of time and (2) of a battery of testing fluids. Excellent progress was made toward the solution of both. Methods were developed which permit keeping albacore, bigeye, and yellowfin bloods for several months. No such success has been achieved, as yet, with skipjack bloods, and thus analyses must be made within 10-14 days, which means that frequently they have to be made at sea.

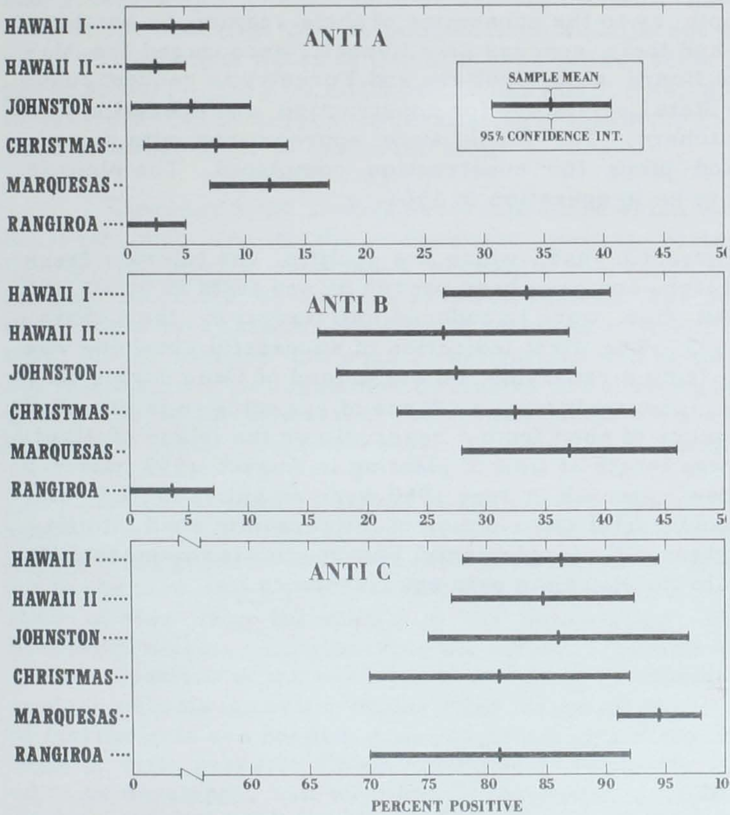


Figure 26. --Differences in reactions of skipjack blood from various areas.

Fifty-eight yellowfin samples were screened with a number of testing fluids, of which one revealed consistent individual differences. Samples from 115 albacore, 65 fresh and 50 frozen, were collected. The 65 fresh samples were screened with 38 fluids, of which 25 were bean extracts. From these, five fluids, two animal sera and three bean fluids, were selected as reagents or potential reagents. Although only 24 bigeye blood samples were tested, at least eight reagents were found which differentiated more than six different blood-group patterns.

In the investigation of skipjack stocks in the central subtropical and tropical Pacific, 154 skipjack blood samples from Hawaiian waters and 325 from the Line, Marquesan, and Tuamotu areas were tested. The results showed qualitative and quantitative discontinuities among the stocks. Of particular interest (see fig. 26), is the sharp demarcation evident between samples from skipjack caught near the island of Rangiroa in the Tuamotus and those from fish caught near the Marquesas, separated by a distance of only approximately 600 miles. The data suggest that these two stocks do not interbreed. On the other hand, samples from near Christmas Island and from Hawaiian waters (separated by nearly 1,200 miles) do not show such differences.

The study of natural populations of pelagic fishes does not permit use of the technique of individual crosses in order to investigate the inheritance of particular characters. There is need for fundamental studies of blood group inheritance in fishes. Thus, a study of blood group inheritance in tilapia was initiated. Facilities for holding these fish were constructed at the Biological Laboratory, Honolulu, and the tanks were stocked in preparation for making the necessary crosses, both brother-sister and among species.

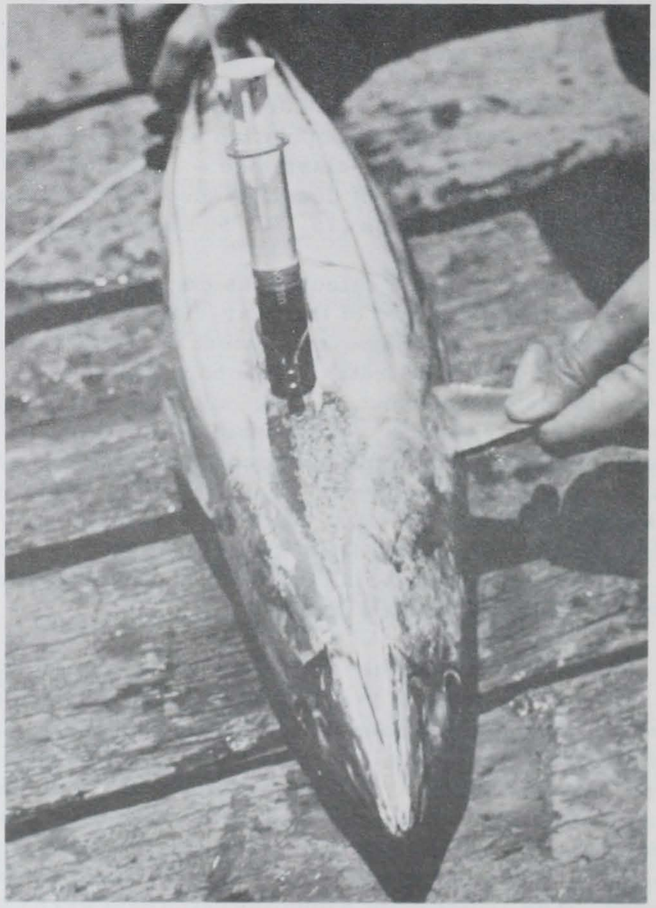
Although particular emphasis during 1961 will be devoted to use of blood groups in the identification of subpopulations of the Pacific skipjack and albacore, such studies will be made for all major species of tuna, and other climax predators, as samples become available. Simultaneously, the improvement of methods of preserving red blood cells, particularly from skipjack, and development of additional testing reagents will be continued.

Blood samples will be collected from skipjack in central Pacific waters, from the Charles H. Gilbert (three cruises, January through July) and from commercial sampans. Also, additional samples will be collected from waters near the Line, Marquesas, Tuamotu, and Society Islands in the fall.

Previous investigations by the Biological Laboratory, Honolulu, and by other laboratories suggest that the albacore of the North Pacific are members of a single subpopulation and, largely by inference, that those of the South Pacific belong to a distinct subpopulation. Albacore blood samples will be collected, as practicable, from both the American and Japanese fisheries. Further, samples will be collected by a biologist of the Honolulu Laboratory from albacore caught by Japanese longline fishermen in southern hemisphere waters around American Samoa. The results of analyses of these samples should considerably expand our knowledge of the degree of heterogeneity of the Pacific albacore stocks.

Subsequent to 1961, along with studies of the blood group systems of skipjack and albacore in various areas of the Pacific (and possibly the Indian Ocean), increasing effort will be devoted to such systems in the yellowfin and bigeye and in other climax predators. Samples will be collected from fish caught from the Laboratory's vessels, those of other research organizations, and from commercial fishing boats.

As adequate knowledge of the blood group systems of the various species becomes available, the distribution of the various subpopulations in both space and time will be compared to the oceanography of the Pacific, in order to determine if there are obvious features which may be natural barriers between subpopulations.



MODEL STUDIES

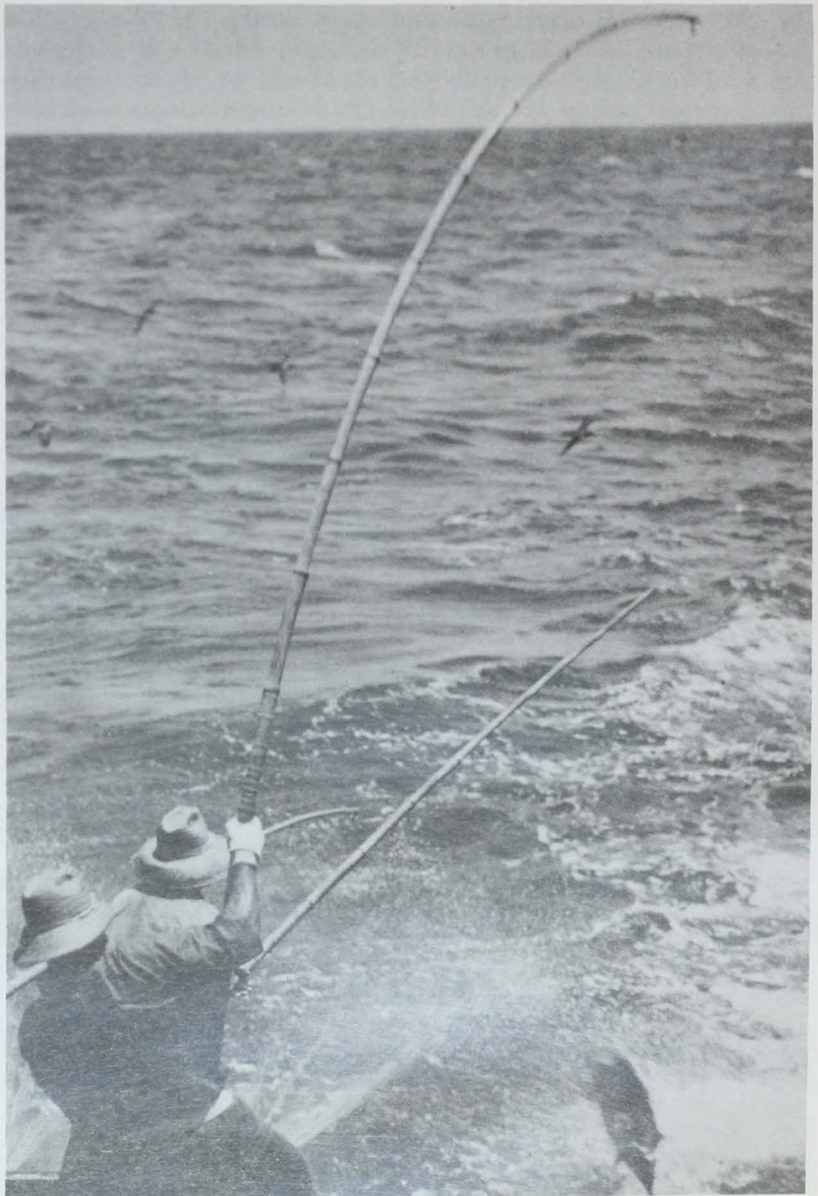
In addition to studies involving various types of oceanographic, biological, and fishery data, various model studies were undertaken. Verification of these models (or hypotheses) was, where practicable, done by testing with data collected during the course of the Laboratory's various investigations.

Four such models were considered during 1960. They were concerned with: (1) the relationship between spawning-stock size and year-class size; (2) the schooling behavior of tuna; (3) the efficiency of longline gear for schooling and non-schooling tuna; and (4) the effects of modifying the abundance of a particular organism upon its biological associates. Preliminary results from two of these studies are as follows:

One model study involves an examination of the effects, through 215 generations, on population size and on year-class size of five different year-class size — spawning-stock size relationships, a single set of density-independent factors, and four different survival rates (15, 30, 50 and 70 percent).

The results of the calculations demonstrated that populations resulting from two of the year-class — spawning-stock size relationships either became extinct or infinitely large at any but middling survival rates. The populations from a third relationship became extinct at low survival rates. It thus seems unlikely that such relationships could exist in nature. Populations from a fourth did not become extinct nor infinitely large; however, characteristics of year-class sizes did not correspond to available data on year-class sizes in nature. The latter did not differ from those of a fifth population, in which all of the variation in year-class size resulted from density-independent random factors.

In the second model, an equation was developed which would express the ratio of the encounter rates between a given number of prey and schooled or scattered predators. Since a set of longline gear with its baited hooks could be regarded as a given number of prey, it was hypothesized that the large tunas are selectively taken by this gear because they are either scattered or in small schools, while the smaller fish are schooled to a greater degree and thus less likely to encounter the hooks. The Laboratory's longline catch data were examined to see if fish caught on adjacent hooks, and thus more likely to have been hooked from a school, were smaller than those that were not so caught. The analyses disclosed that the most numerous and largest fish were solitary. Next in abundance and size were fish hooked in pairs. Three fish on adjacent hooks were less abundant and smaller, while runs of four were both the rarest and the yellowfin thus caught were the smallest of all.



REPORTS, PUBLISHED AND IN PREPARATION

In the following list are the papers of the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, published, in press, or in preparation during 1960. In addition to publications describing research undertaken by the members of the Laboratory staff, a number of translations of oceanographic and fishery research papers, particularly Japanese to English, were prepared.

AKANA, ALBERT K. JR., HERBERT J. MANN, and ROBERT E. K. D. LEE

1960. Research vessel is fitted for underwater observation of fish. Pacific Fisherman, vol. 58, no. 8, p. 8-10.

AUSTIN, THOMAS S.

1960. Oceanography of the east central equatorial Pacific as observed during Expedition EASTROPIC. U. S. Fish and Wildlife Service, Fishery Bulletin, vol. 60, no. 168, p. 257-282.

1960. Summary, 1955-1957 ocean temperatures, central equatorial Pacific. California Co-operative Oceanic Fisheries Investigations Reports 7, p. 52-55.

BROCK, VERNON E.

1960. Fisheries and the future. Proceedings of the Hawaiian Academy of Science. 35th Annual Meeting 1959-60. p. 3-5.

The introduction of aquatic animals into Hawaiian waters. Internationale Revue der Gesamten Hydrobiologie. (in press)

On the nature of the selective fishing action of longline gear. (in preparation)

———, and ROBERT H. RIFFENBURGH

1960. Fish schooling: a possible factor in reducing predation. Journal du Conseil Permanent International pour l'Exploration de la Mer. vol. 25, no. 3, p. 307-317.

BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, HONOLULU

1960. Past (1949-1958), Present (1959), Future (1960-). U. S. Fish and Wildlife Service Circular 83, 62 p.

GRAHAM, JOSEPH J.

The macroecology of the albacore tuna *Thunnus germo* (Lacépède), in the central North Pacific Ocean. (in preparation)

Observations and hypotheses on the ecology of the lancet fish, *Alepisaurus borealis* Gill, in the central and eastern North Pacific. (in preparation)

———, and WILLIAM L. CRAIG

Oceanographic observations made during a 1959 albacore (*Thunnus germo*) survey off the North American West Coast. (in preparation)

———, and JAMES W. MC GARY

Investigations of the potential albacore resource of the central North Pacific. (in preparation)

GRICE, GEORGE D.

Calanoid copepods from equatorial waters of the Pacific Ocean. MS. No. 1008, U. S. Fish and Wildlife Service, Fishery Bulletin. (in press)

———, and EVERET C. JONES

1960. Two new species of *Candacia* (Copepoda: Calanoida) from the central Pacific with notes on two other species. Pacific Science, vol. 14, no. 3, p. 280-291.

HIDA, THOMAS S., JOSEPH R. HARADA and JOSEPH E. KING
Rearing of tilapia for tuna bait, 1958-59. (in preparation)

_______, and ROBERT A. MORRIS
Preliminary report on the Marquesan sardine in Hawaii. (in preparation)

_______, and DONALD A. THOMSON
Introduction of threadfin shad to Hawaii. (in preparation)

IVERSEN, ROBERT T. B.
Food of albacore tuna, *Thunnus germo* (Lacépède) in the central and northeastern Pacific. (in preparation)

KING, JOSEPH E., and ROBERT T. B. IVERSEN
Midwater trawling for forage organisms in the central Pacific. (in preparation)

MARR, JOHN C.
1960. The causes of major variations in the catch of the Pacific sardine, *Sardinops caerulea* (Girard). Proceedings of the Hawaiian Academy of Science. 35th Annual Meeting, 1959-60. p. 24 (Abstract).

The causes of major variations in the catch of the Pacific sardine, *Sardinops caerulea* (Girard). Proceedings of FAO World Conference on Sardine Biology. (in press)

The Honolulu Biological Laboratory. (in preparation)

Note on the recovery rate of tagged skipjack, *Katsuwonus pelamis*, and the effects of handling. (in preparation)

_______, and LUCIAN M. SPRAGUE
The use of blood group characteristics in studying subpopulations of fishes. (in preparation)

MATSUMOTO, WALTER M.
1960. The application of paper chromatography in identifying tuna larvae. U. S. Fish and Wildlife Service, Special Scientific Report--Fisheries 337, 9 p.

1960. Notes on the Hawaiian frigate mackerel of the genus Auxis. Pacific Science, vol. 14, no. 2, p. 173-177.

Collections and descriptions of juvenile tunas from the central Pacific. Deep-Sea Research. (in press)

Identification of larvae of four species of tuna from the Indo-Pacific region. I. (in preparation)

MC GARY, JAMES W.
1960. IGY oceanographic program and the development concerning the Pacific Equatorial Undercurrent. Proceedings of the Hawaiian Academy of Science. 35th Annual Meeting, 1959-60. p. 22 (Abstract).

1960. Surface temperature anomalies in the central North Pacific, January-May 1958. California Co-operative Oceanic Fisheries Investigations Reports 7, p. 47-51.

_______, and JOSEPH J. GRAHAM
1960. Biological and oceanographic observations in the central North Pacific, July-September 1958. U. S. Fish and Wildlife Service, Special Scientific Report--Fisheries 358, 107 p.

_______, _______, and TAMIO OTSU
Oceanography and North Pacific albacore. California Co-operative Fisheries Investigations Reports. (in press)

MURPHY, GARTH I.
1960. Introduction of the Marquesan sardine, *Harengula vittata* (Cuvier and Valenciennes), to Hawaiian waters. Pacific Science, vol. 14, no. 2, p. 185-187.

_______, and RICHARD S. SHOMURA
The distribution and abundance of tunas in the central equatorial Pacific. (in preparation)

MURPHY, GARTH I., KENNETH D. WALDRON, and GUNTER R. SECKEL

1960. The oceanographic situation in the vicinity of the Hawaiian Islands during 1957 with comparisons with other years. California Co-operative Oceanic Fisheries Investigations Reports 7, p. 56-59.

NAKAMURA, EUGENE L.

1960. Confinement of skipjack in a pond. Proceedings of the Hawaiian Academy of Science. 35th Annual Meeting, 1959-60. p. 24 (Abstract).

The establishment and behavior of skipjack tuna *Katsuwonus pelamis* in captivity. (in preparation)

_______, and ROBERT C. WILSON

The distribution and biology of the Marquesan sardine. (in preparation)

_______, and HEENY S. H. YUEN

Comparative incidence of the giant trematode *Hirudinella marina* Garcin, in skipjack, *Katsuwonus pelamis* (Linnaeus), from Marquesan and Hawaiian waters. (in preparation)

OTSU, TAMIO

1960. Albacore migration and growth in the North Pacific Ocean as estimated from tag recoveries. Pacific Science, vol. 14, no. 3, p. 257-266.

_______, and RICHARD J. HANSEN

Sexual maturity and spawning of the albacore in the central South Pacific Ocean. (in preparation)

RIFFENBURGH, ROBERT H.

1960. A new method for estimating parameters of the Gompertz growth curve. Journal du Conseil Permanent International pour l'Exploration de la Mer, vol. 25, no. 3, p. 285-293.

1960. A system analysis of the marine ecology. International Statistical Institute. 32nd Session held June 5-9, 1960 in Tokyo, 9 p.

RIFFENBURGH, ROBERT H.

Growth curve determination using parametric extremers. Growth. (in press)

A quasi-normal distribution with finite range. (in preparation)

ROYCE, WILLIAM F.

A morphometric study of yellowfin tuna *Thunnus albacares* (Bonnaterre). (in preparation)

SCHANER, EVERETT, and KENNETH SHERMAN

1960. Observations on the fecundity of the tomcod, *Microgadus tomcod* (Walbaum). Copeia, 1960, no. 4, p. 347-348.

SECKEL, GUNTER R.

1960. Advection - a climatic character in the mid-Pacific. California Co-operative Oceanic Fisheries Investigations Reports 7, p. 60-65.

An atlas of the oceanographic climate of the Hawaiian Islands region. MS. No. 1042. U. S. Fish and Wildlife Service, Fishery Bulletin. (in press)

_______, and KENNETH D. WALDRON

1960. Oceanography and the Hawaiian skipjack fishery. Pacific Fisherman, vol. 58, no. 3, p. 11-13.

SHERMAN, KENNETH

Occurrence of early developmental stages of the oblong ocean sunfish *Ranzania laevis* (Pennant) in the central North Pacific. (in preparation)

_______, and ROBERT P. BROWN

Oceanographic and biological data, Hawaiian waters, 1959. (in preparation)

SHIPPEN, HERBERT S.

Distribution and abundance of skipjack in the Hawaiian fishery, 1952-1953. (in preparation)

SHOMURA, RICHARD S., and EUGENE L. NAKAMURA
Temporal variations in marine zooplankton from Hawaiian waters. (in preparation)

SPRAGUE, LUCIAN M., and ANDREW M. VROOMAN
A racial analysis of the Pacific sardine (*Sardinops caerulea*) based on studies of erythrocyte antigens. (in preparation)

STRASBURG, DONALD W.
1960. A new Hawaiian engraulid fish. Pacific Science, vol. 14, no. 4, p. 395-399.

1960. Estimates of larval tuna abundance in the central Pacific. U. S. Fish and Wildlife Service, Fishery Bulletin, vol. 60, no. 167, p. 231-255.

Diving behaviour of Hawaiian skipjack tuna. Journal du Conseil Permanent International pour l'Exploration de la Mer. (in press)

Some aspects of the feeding behavior of *Remora remora*. (in preparation)

An aerating device for salt well water. (in preparation)

_______, and JOHN C. MARR
Banded color phases of two pelagic fishes, *Coryphaena hippurus* and *Katsuwonus pelamis*. Copeia. (in press)

_______, and HEENY S. H. YUEN
1960. Progress in observing tuna underwater at sea. Journal du Conseil Permanent International pour l'Exploration de la Mer, vol. 26, no. 1, p. 80-93.

Preliminary results of underwater observations of tuna schools and practical applications of these results. Indo-Pacific Fisheries Council, 8th Session. (in press)

SUMIDA, CHARLOTTE (student assistant)
Observations on the fecundity of the threadfin shad (*Dorosoma petenense*). "Tomorrow's Scientist" section of Science World. (in press)

UCHIDA, RICHARD N.
Hermaphroditic skipjack. Pacific Science. (in press)

_______, and JOSEPH E. KING
Tank culture of tilapia. MS. No. 1022. Fishery Bulletin. (in press)

VAN CAMPEN, WILVAN G.
1960. Japanese summer fishery for albacore (*Germo alalunga*). U. S. Fish and Wildlife Service, Research Report no. 52, 29 p.

VAN LANDINGHAM, JOHN W.
1960. A note on a stabilized starch indicator for use in iodometric and iodimetric determinations. Limnology and Oceanography, vol. 5, no. 3, p. 343-345.

WALDRON, KENNETH D.
Changes in the catch of skipjack and in their environment, Hawaiian waters, 1955-1957. (in preparation)

YAMASHITA, DANIEL T.
Results of Hawaiian skipjack tagging, 1957-58. (in preparation)

YOSHIDA, HOWARD O.
1960. Marquesas area fishery and environmental data, January-March 1959. U. S. Fish and Wildlife Service, Special Scientific Report--Fisheries 348, 37 p.

Longline fishing for deep-swimming tunas in the Marquesas Islands and adjacent areas. (in preparation)

YUEN, HEENY S. H.
Bow wave riding of dolphins. (in preparation)

TRANSLATIONS (UNPUBLISHED)

HASHIMOTO, TOMIJU and YOSHINOBU MANIWA
Noise of creatures in sea in region of ultrasound. Japan Fisheries Agency. Technical Report of Fishing Boat 12, p. 99-114. 1958. (Translation from the Japanese by Grace Y. Beard).

_______, MINORU NISHIMURA, and YOSHINOBU MANIWA
An experiment on the detection of fish schools by sonobuoy. Bulletin of the Japanese Society of Scientific Fisheries, vol. 26, no. 3, p. 245-249. (Translation from the Japanese by Grace Y. Beard).

KITOU, MASATAKA
Offshore distribution of plankton produced in coastal water. Plankton Society of Japan. Information Bulletin of Planktology in Japan 5, p. 7-8. 1957. (Translation from the Japanese by Grace Y. Beard).

KOGA, SIGEYUKI
On the difference of the stomach contents of tuna and black marlin in the South Equatorial Pacific Ocean. Bulletin of the Faculty of Fisheries, Nagasaki University 7, p. 31-40. November 1958. (Translation from the Japanese by Grace Y. Beard).

On the stomach contents of tuna in the West Indian Ocean. Bulletin of the Faculty of Fisheries, Nagasaki University, no. 6, p. 85-92. 1958. (Translation from the Japanese by Grace Y. Beard).

LOZANO CABO, FERNANDO
The use of echo-sounders in the study of the migration of tuna. F. A. O. General Fisheries Council for the Mediterranean. Proceedings and Technical Papers no. 5, p. 101-104. 1959. (Translation from the French by Donald A. Thomson).

Critical study of echo-sounders used for tuna detection. F. A. O. General Fisheries Council for the Mediterranean. Proceedings and Technical Papers no. 5, p. 91-99. 1959. (Translation from the French by Donald A. Thomson).

MATSUDAIRA, CHIKAYOSHI
Culturing of a Copepoda, *Sinocalanus tenellus*. Plankton Society of Japan. Information Bulletin on Planktology in Japan 5, p. 1-6. 1957. (Translation from the Japanese by Grace Y. Beard).

NANKAI REGIONAL FISHERIES RESEARCH LABORATORY (ed.)
Average year's fishing condition of tuna long-line fisheries, 1958 edition. Tokyo Federation of Japan Tuna Fishermen's Co-operative Associations, 1959. Two volumes - Text and Atlas. General comments by Hiroshi Nakamura. (Translation from the Japanese by Grace Y. Beard).

SAKŌ, NOBORU
On the gill-rakers of *Sardinia melanosticta* (Temminck and Schlegel). Bulletin of the Japanese Society of Scientific Fisheries 7, p. 237-238. 1938. (Translation from the Japanese by Grace Y. Beard).

SUYEHIRO, YASUO
The study of finding the reasons why the bonito does not take to the angling-baits. Journal of the Imperial Fisheries Experimental Station (Tokyo) 9, p. 87-102. 1938. (Translation from the Japanese by Grace Y. Beard).

ZAITSEV, V. P. and V. G. AZHAZHA
Underwater scientific expeditions on the *Severyanka*. From Rybnoe Khoziaistvo, July 1959, p. 7-16 (vol. 35, no. 7). (Translation from the Russian by Wilvan G. Van Campen).