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

PROGRESS IN 1961-62

CIRCULAR 163

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UNITED STATES DEPARTMENT OF THE INTERIOR, STEWART L. UDALL, SECRETARY
FISH AND WILDLIFE SERVICE, CLARENCE F. PAUTZKE, COMMISSIONER
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Created in 1849, the Department of the Interior--America's Department of Natural Resources--is concerned with the management, conservation, and development of the Nation's water, wildlife, mineral, forest, and park and recreational resources. It also has major responsibilities for Indian and Territorial affairs.

As the Nation's principal conservation agency, the Department works to assure that nonrenewable resources are developed and used wisely, that park and recreational resources are conserved for the future, and that renewable resources make their full contribution to the progress, prosperity, and security of the United States -- now and in the future.

HAWAII AREA
JOHN C. MARR, DIRECTOR
LUCIAN M. SPRAGUE, ASST. DIRECTOR

Cover: Skipjack fishing on a Hawaiian sampan

February 1963

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1961-62 [1/]

HIGHLIGHTS

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In 1961-62 the Biological Laboratory of the Bureau of Commercial Fisheries at Honolulu continued its program of research on the environment, biology, and utilization of the fishery resources of the Pacific. This work, initiated in 1949, has steadily evolved from general exploratory surveys of a vast unknown area toward specialized research on more clearly defined problems.

Oceanographic studies of the tuna environment in 1961-62 led to a refinement of our understanding of the current systems around the Hawaiian Islands through large-scale releases of drift bottles, while development of methods for machine processing of oceanographic data provided increased capability for rapid analysis of the physical conditions prevailing over broad areas of the Pacific. Results of fundamental studies of the forces at work in seasonal changes in the central North Pacific, published as a climatic atlas, were made the basis for designing an intensive experimental study of trade-wind zone oceanography, to be carried out over the next several years.

Again in 1961, as in the previous year, the Laboratory made an accurate preseason prediction of the general level of availability of skipjack to the Hawaiian fishery. An early spring rise in the warming rate of the surface water, as measured at the Laboratory's shore station at Koko Head, Oahu, was followed, as predicted, by a better than average catch in the summer fishing season. The reliability of such monitoring station observations as indications of offshore water mass movements was further strengthened, pointing to the time when the Laboratory's network of shore stations can be used for interpreting large-scale events in the central Pacific Ocean.

Evidence from study of the blood-group characteristics of skipjack, which has shown that there are several subpopulations of that species in the central Pacific, has also revealed that more than one skipjack subpopulation contributes to the Hawaiian fishery. This finding coincided with the results of size and age group analysis, which indicated that different groups of skipjack are intermittently available to the fishery. A key to fuller understanding of these changes in subpopulation availability began to appear with the discovery that different subpopulations of skipjack are probably associated with different types of oceanic surface water.

1/ This report covers the period January 1961 to June 1962.

By tracing the maturation of the ovaries in Hawaiian skipjack biologists found that their spawning activity probably reaches a peak in late spring, with a possible second minor spawning in late summer. The occurrence of larval skipjack corroborated this conclusion. Large skipjack were estimated to spawn nearly 2 million eggs at a time. Progress was made toward defining the temperature limits within which the larvae of skipjack as well as of other tuna species occur.

With a view to raising the productive efficiency of the Hawaiian skipjack fishery, a thorough test was made of methods of fishing skipjack with monofilament nylon gill nets. Skipjack were not taken in commercial quantities, and the conclusion was that the technique is not economically feasible under Hawaiian fishing conditions.

The results of an extensive cruise by the Bureau's research ship Charles H. Gilbert through the area of the South Pacific albacore longline fishery gave support to the theory of independent Northern and Southern Hemisphere populations of albacore, confirming a previous study which indicated a marked difference in the season of peak spawning activity north and south of the Equator.

Living skipjack and other tunas, in captivity and free in the ocean, were studied in specially designed tanks and through the underwater viewing ports of the Charles H. Gilbert, and much was learned about behavior patterns and reactions that may bear on the survival of these fishes and their amenability to fishing. Transient colorations that may serve as signals to the members of a school, responses to various kinds of bait and natural feed, feeding rates and digestion rates, and mixed associations of species were directly observed and recorded on film for analysis. Anatomical studies preliminary to experiments with captive fish indicated that skipjack have a functional sense of smell, and in preparation for tests of their visual powers skipjack were taught to recognize patterns of black lines projected on a screen.

Much work was accomplished outside the scope of the regular research programs. The Laboratory arranged and was host to the Pacific Tuna Biology Conference in August 1961, supplying secretariat and discussion leaders for a week-long meeting of 79 people representing 11 countries. In the line of advisory service, staff members visited American Samoa, Guam, and the Trust Territory of the Pacific Islands and made recommendations for the development of fisheries and fishery administration and research. A review of oceanographic information in the Line Islands area was prepared for the Atomic Energy Commission.

Finally, because the area and scope of the Laboratory's work were reaching the limits of the capability of its one research vessel, plans were made and approved, and funds appropriated, for the construction in the near future of a large, well-equipped oceanographic and fishery research ship to be called the Townsend Cromwell.

Oceanography

PROGRAM CHIEF... RICHARD A. BARKLEY

The oceanographic research program of the Biological Laboratory is concentrated on increasing our knowledge of oceanic circulation systems near Hawaii, on summarizing the information available for the Pacific as a whole, and on performing special investigations, such as a planned analysis of conditions as observed simultaneously over the central North Pacific. The work is aimed at contributing to the general fund of knowledge concerning the oceans, while giving the best possible answers to the immediate oceanographic questions raised by fishery biologists. The results are expected to be of value both to oceanographers and to those who are directly concerned with the problems of finding and catching commercially important ocean fishes.

Our analyses of data collected from the area near the Hawaiian Islands have been summarized in a regional climatic atlas which gives a clear general picture of the seasonal course of events in the surface layers of the ocean. The atlas represents both an end product and a beginning. It is an end product because it provides much of the fundamental information needed to understand what happens in this area of the Pacific, but it is also the point of departure for a more detailed investigation that may answer our questions as to how the tuna respond to seasonal changes in mid-ocean and thus may tell us why our annual empirical prediction of the Hawaiian skipjack catch works.

One of the problems that this more detailed investigation will have to solve is that of measuring the movement of the surface waters over periods of a week or longer. To attack this problem, the Laboratory's oceanographers began a drift-bottle program in January 1961. Figure 1 shows the locations of major drift-bottle releases during that year. Each point represents a position where a group of 10 or 20 bottles was released. About 9,000 bottles have been dropped, with about 600 recoveries reported thus far. Figure 1 also shows the longer range recoveries and the presumed paths of movement of the bottles. Releases near the island of Oahu have been too numerous to be shown on this chart.

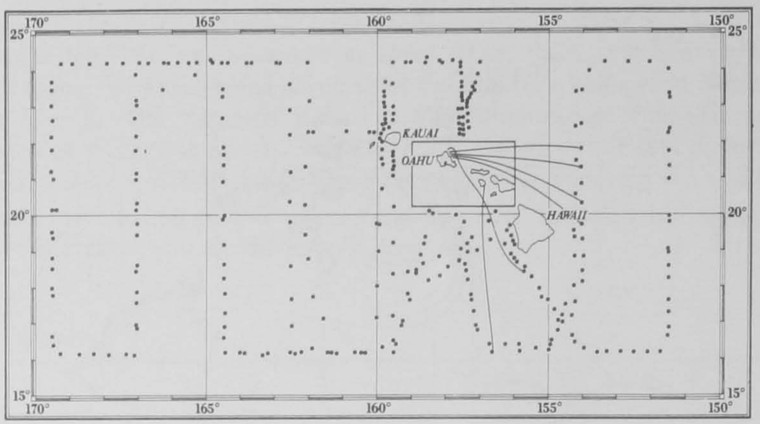


Figure 1.--Drift-bottle releases and long-range recoveries.

Drift-bottle releases and returns from a part of the January-February cruise of the Charles H. Gilbert are shown in figure 2. In working out the pattern of the bottles' movements between the points of release and recovery, it has been assumed that bottles released at about the same time do not cross paths, because in principle streamlines cannot cross one another. The figure points up the fact that the movement of the bottles within the immediate Hawaiian area was generally in a direction opposite to that of the currents prevailing farther away from the Islands.

Bottle releases on a short cruise in May produced the returns plotted in figure 3. In general the indicated current pattern resembles that deduced from the winter recoveries, although a more westerly trend in the drift is evident. One series of releases was made in the channel between Oahu and Molokai. These bottles came to shore in a very regular pattern: those dropped nearest Oahu came ashore near Koko Head, the southernmost tip of the island; bottles released farther to the east were recovered farther north on the windward side of Oahu; the bottles dropped nearest to Molokai either stranded on the northern tip of Oahu or continued on to land on Kauai. It is as if the water had made a flanking movement to the west after passing through the Oahu-Molokai channel.

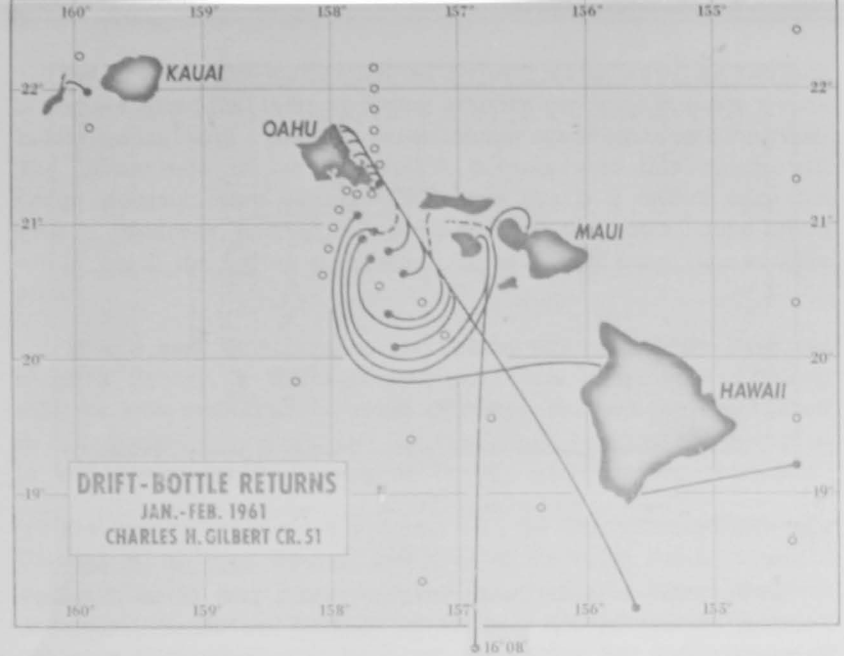


Figure 2.--Drift-bottle returns, January-February 1961. Open circles mark releases which produced no returns, closed circles those from which bottles were recovered.

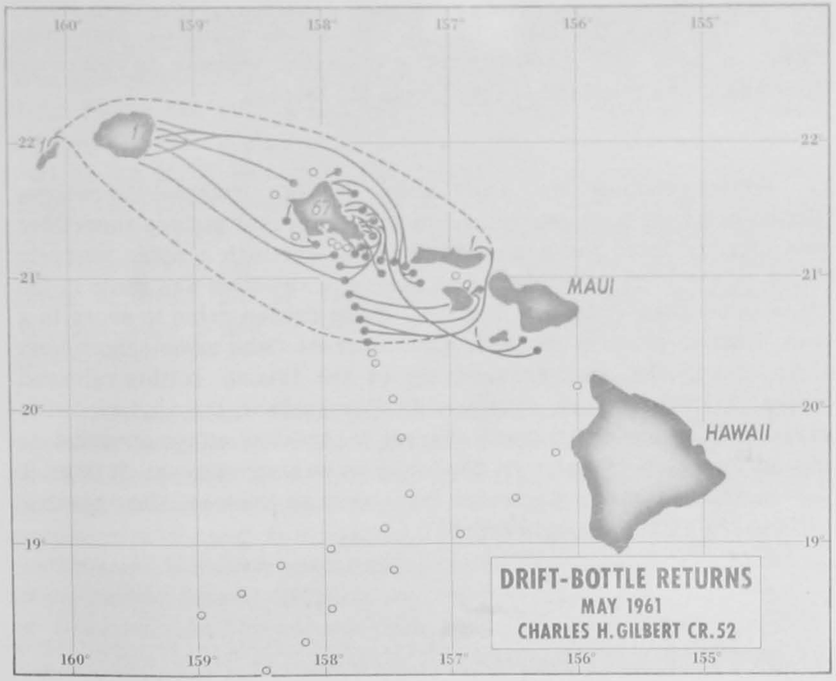


Figure 3.--Drift-bottle returns, May 1961.

The pattern of summer recoveries is shown in figure 4. In the results from this cruise, which was a duplicate of the winter cruise, a pronounced shift in the currents is evident. Whereas bottles released to the east and north of the Islands in winter were not recovered, in summer most of the bottles that were picked up arrived from that direction, and far fewer bottles moved north through the channel between Oahu and Molokai. There is still evidence of drift against the wind to the lee of the Islands, however.

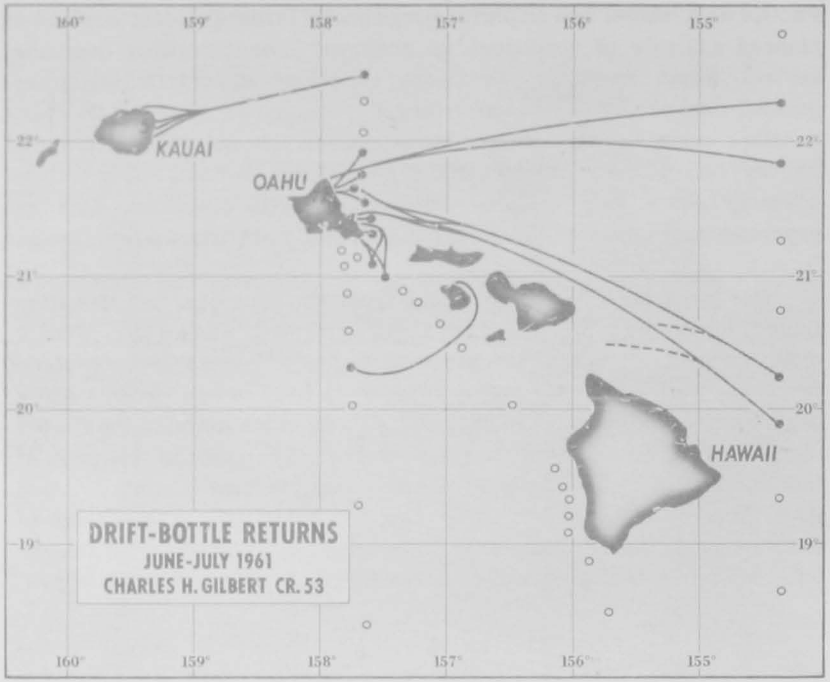


Figure 4.--Drift-bottle returns, June-July 1961.

This apparent seasonal shift in the currents is in general agreement with the currents as calculated from heat-budget computations in the climatic atlas. The bottles furnish more detail than was previously available and help us to understand the seasonal changes in surface temperature and salinity near the Islands. In figure 5 are the surface salinity charts for the winters of 1959 and 1961. The effects of northward drift in the lee of the Islands are evident in the low salinities found there. In figure 6 the summer salinity chart shows a broad band of water of intermediate salinity in the center of the figure; this agrees with the drift-bottle results, which suggest that in summer the water is carried to the Islands from the east rather than the southeast.

One byproduct of the studies embodied in the climatic atlas was a technique for predicting the relative level of the annual catch in the Hawaiian skipjack fishery. The prediction is based on the time when the sea surface temperature trend changes from the cooling portion of the annual cycle to the beginning of warming. The upper panel of figure 7 shows the monthly mean surface temperatures for Hawaiian waters for 1961, as measured at Koko Head, Oahu. The lower panel expresses the same trend as rates of temperature change, in degrees per month. The adjusted mean rate of temperature change over a period of 8 years is shown in figure 8, with the curve for 1961 in dotted lines, for comparison. It is clear that the same warming and cooling trends that turn up year after year also appeared in 1961, but they were generally about one month earlier than usual.

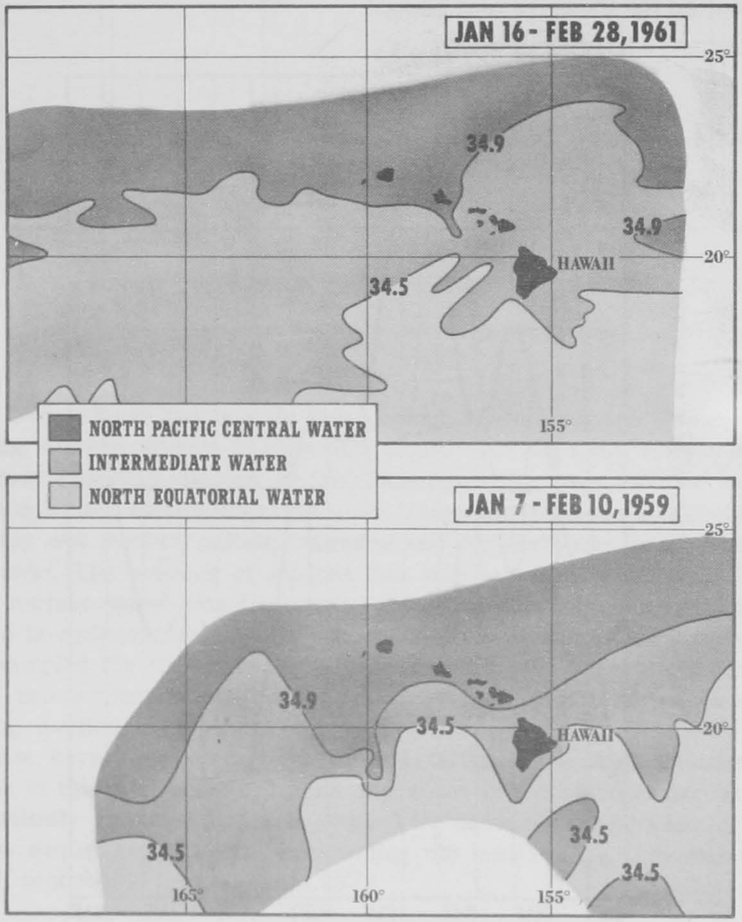


Figure 5.--Winter surface salinity, central North Pacific, 1959 and 1961.

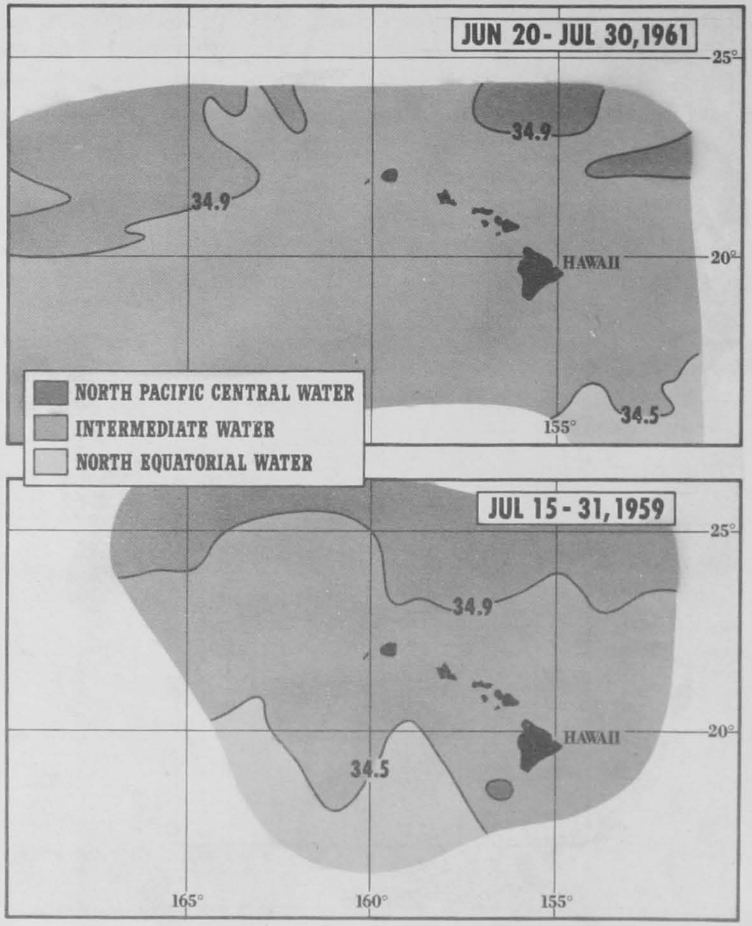


Figure 6.--Summer surface salinity, central North Pacific, 1959 and 1961.

In figure 9 the catch statistics for the Hawaiian skipjack fishery for a number of years are plotted against the time when the rate of temperature change became zero; that is, the time when warming began in the spring. The Laboratory predicted that skipjack fishing in 1961 would be better than average, as it had been in other years when warming began early. However, in 1961 the beginning of warming was earlier than ever before recorded, and the ocean was obviously behaving in an unusual way, so some concern was felt over the validity of the prediction.

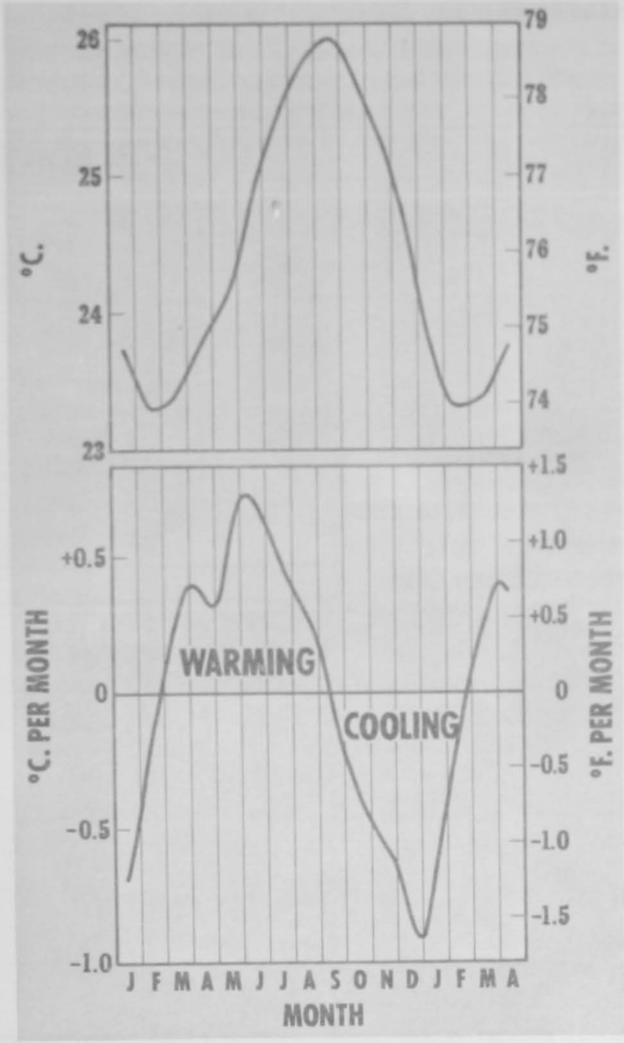


Figure 7.--Monthly sea surface temperature and rate of temperature change at Koko Head, Oahu.

It turned out that 1961 was in fact a better than average year, with a catch of 10.9 million pounds, comparable to that of 1956. However, one of the effects of the early seasonal change was an unusually early start to the summer fishery, followed by an abrupt and equally early end, when the large fish disappeared from local waters in mid-July instead of in August, as normally happens. Events such as these are what we must try to understand in our studies of the ocean and the fisheries near Hawaii.

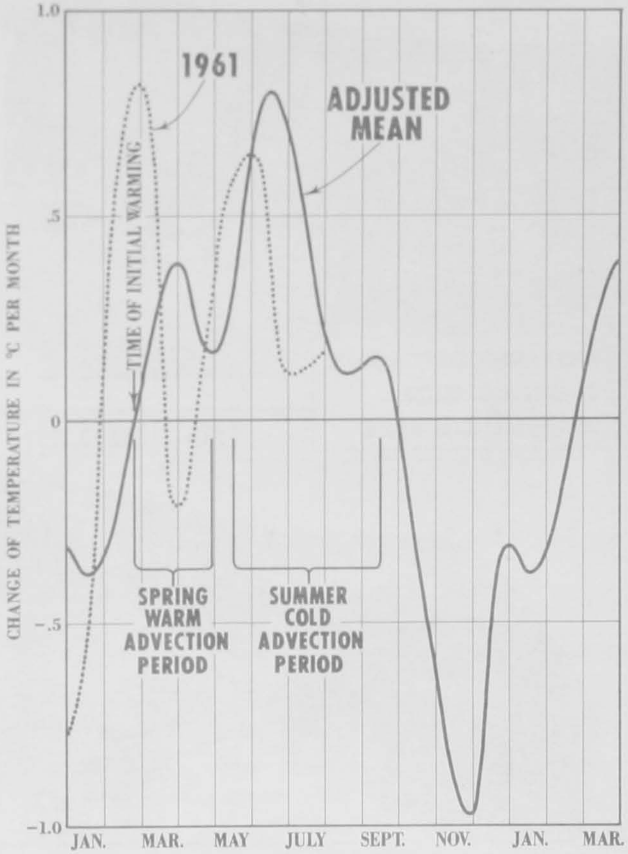


Figure 8.--Mean and 1961 rates of surface temperature change at Koko Head, Oahu.

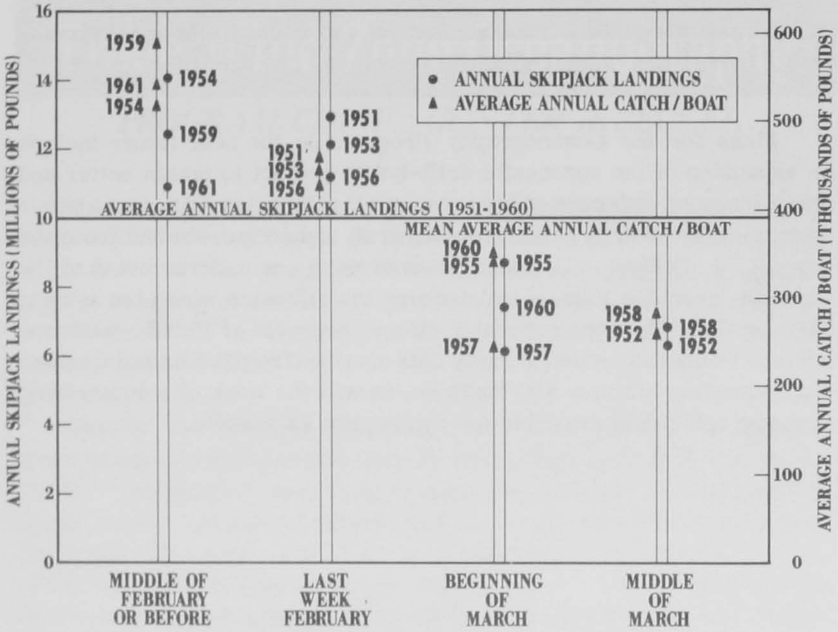


Figure 9.--Annual skipjack landings and catch per boat vs. time of onset of sea surface warming.

Events near the Islands also depend on what happens elsewhere in the Pacific. Figure 10 shows the locations of the Laboratory's sea surface sampling stations on islands and weather ships, with the year in which each station began its work. These stations send to Honolulu weekly sea surface salinity samples and surface water temperature records. The network of stations thus acts as a system for sampling the surface water simultaneously, providing data analogous to those used in meteorology. In addition, a line between Samoa and Honolulu is sampled for the Laboratory by Matson liners at intervals of about one month. An example of the ways in which these station data are being studied is given in figure 11, where monthly mean salinity values have been plotted for seven stations. The point of interest here is the progression in time and space of the seasonal decrease in salinity at the stations. In general the decrease appears in clockwise sequence at points surrounding the mid-Pacific high-salinity cell, centered at about latitude 25°N.

To produce a series of charts, sections, and other types of summary information the Laboratory is analyzing all available oceanographic station data for the entire Pacific. This undertaking was prompted by the fact that every study of conditions in a given area of the ocean runs into problems related to changes in the "upstream" environment. The analysis is performed as much as possible by machine methods, only the final plotting and contouring being done by hand. Use of machines makes it possible to interpolate observed data from 300 stations, edit the results, average the results by areas of 2 degrees of latitude by 10 degrees of longitude, and be ready to plot the final values in less than 3 hours. The same work would take approximately 350 man-hours if done by hand methods. A sample of such analysis is given in figure 12, which shows the values obtained from 300 stations in the area between 130° W. and the Date Line, from 20° S. to 10° N., in the form of five north-south salinity sections. The high-salinity water at the subsurface maximum in the south can be traced to its surface origin in the southeast, near 20° S., 135° W. in the figure.

The very slight subsurface salinity maximum and minimum in the North Pacific are shown as persisting almost to the Equator. The values of salinity near this minimum and maximum differ so slightly

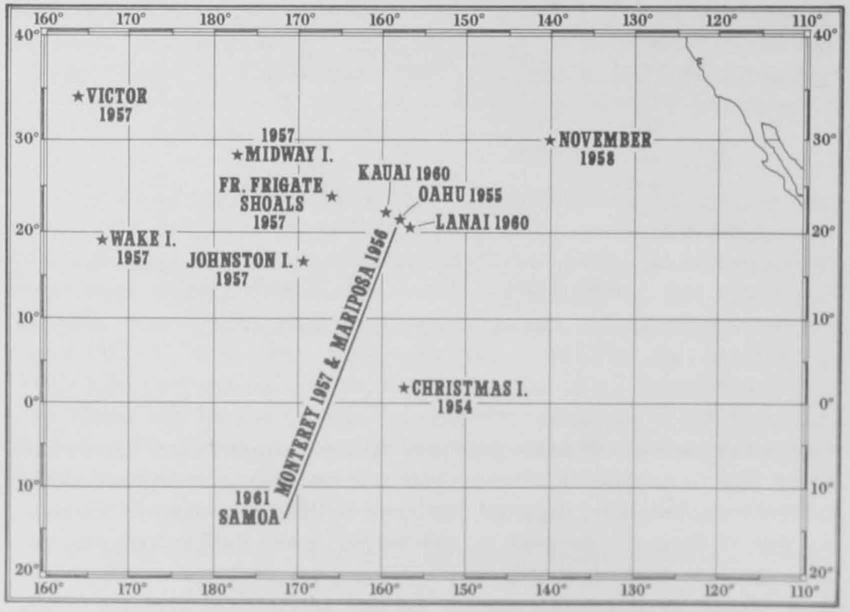


Figure 10.--Sea surface sampling locations, with dates when sampling began.

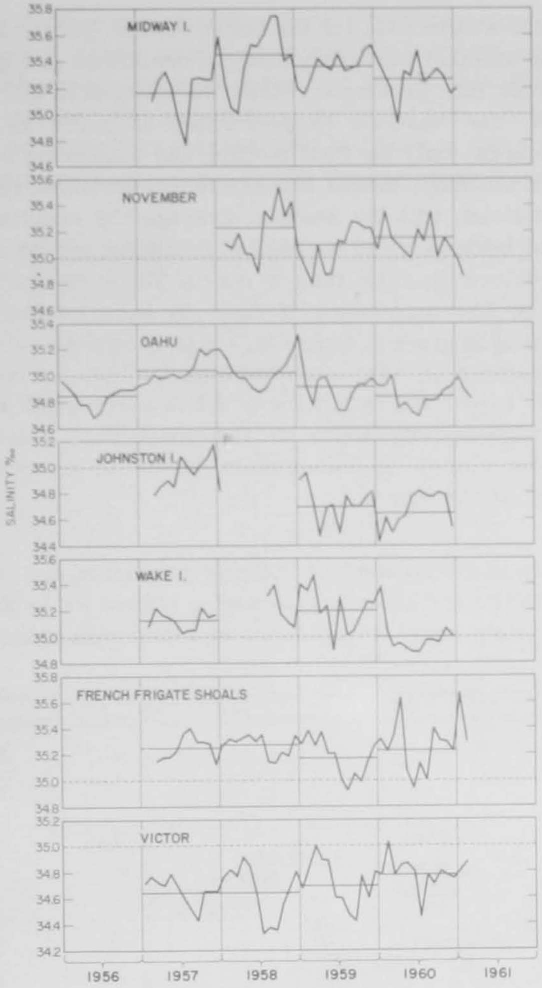


Figure 11.--Monthly mean sea surface salinities at seven stations.

that in the case of single stations they have sometimes been ignored as being due to analytical errors. The interpolation system used at the Laboratory, however, does not introduce artificial maxima or minima, so that if they are present in any degree in the final output, one can be confident that they are most likely real features. Sections like that shown in figure 12 are of evident value in determining where to sample during future research cruises.

Early in 1962 a detailed analysis of an area near Christmas Island was prepared at the request of the Atomic Energy Commission, using the same methods employed in preparing figure 12.

Plans for the Oceanography Program in the near future include an expansion of the successful drift-bottle project to obtain better and more frequent coverage of the area near the Hawaiian Islands, together with releases of drift cards from aircraft and drogue studies from the Charles H. Gilbert, all aimed at improving our understanding of the currents near the Islands and defining the influence which the Islands have on the mid-ocean current systems. Analysis of Pacific-wide sea surface temperature and salinity data obtained from island and weather ship sampling stations will continue, as will the work of summarizing oceanographic data available for the Pacific as a whole.

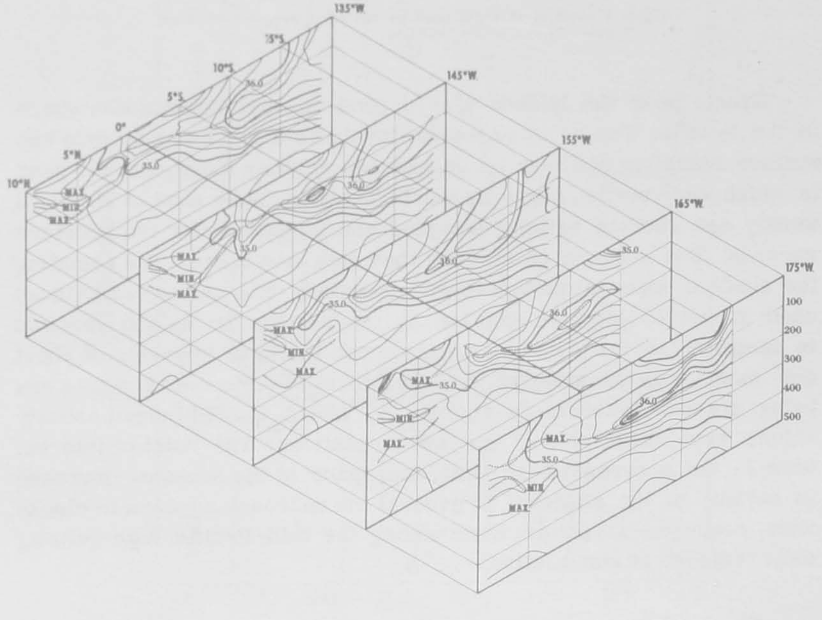


Figure 12.--Salinity distribution in the central Pacific Ocean.

Trade Wind Zone Oceanography

PROGRAM CHIEF... GUNTER R. SECKEL

This newly organized program of oceanographic research has been initiated as a result of previous studies of the oceanographic climate of the Hawaiian Islands region, carried out by the Oceanography Program of the Biological Laboratory, Honolulu, and reported in the form of a climatic atlas (U.S. Fish and Wildlife Service, Fishery Bulletin 193).

Briefly, the findings embodied in the atlas showed that changes in the oceanographic climate of the Hawaiian region, as reflected in the surface temperature and salinity distributions, can be explained in terms of heat and salt advection (that is, the movement into and out of the region of waters with different temperature and salinity characteristics), the net heat exchange across the sea surface between the ocean and the atmosphere, and the balance of precipitation and evaporation within the region.

Fluctuations in advection result from seasonal north-south displacements of the boundary between North Pacific Central water and California Current Extension water and from seasonal changes in the flow of the California Current Extension in the vicinity of the Hawaiian Islands. These processes are directly reflected in fluctuations of the heating curves (the monthly rate of change of temperature plotted versus time) based on data obtained from monitoring stations like that at Koko Head, Oahu. It has been found that the shape and fluctuations of such a heating curve are characteristic for its location and can in turn be used to monitor the oceanographic climate of an area.

Thus, the Koko Head heating curve indicated a southward displacement of the oceanographic climate in Hawaiian waters in 1957 and a northward displacement in 1955, 1960, and 1962. It also revealed that years with pronounced fluctuations in the heating rate early in the year, such as 1954, 1959, and 1961, were followed by years which showed a northward displacement of the oceanographic climate.

Recently an association between the Hawaiian oceanographic climate and the trade-wind system, namely the dependence of the climate upon the location, movement, and strength of the center of wind action, has been discovered. We are thus provided with both a qualitative model of a part of the North Pacific "heat engine" and a method of pursuing its study further. The new investigation has, therefore, been planned for the trade-wind zone, which is one of the most important energy-transfer regions of the North Pacific. The investigation is to be an experiment both to verify the qualitative model and to measure the seasonally changing processes which govern the distribution of surface water properties.

As a result of the investigation it will be possible, for example, to compute the amount of heat stored in the low-latitude waters of the North Pacific, to be later transported northward and released to the atmosphere in higher latitudes. It will also become possible to monitor quantitatively the heat-engine processes in the trade-wind energy transfer region by measuring selected properties at key island or buoy stations.

In the atmosphere, the climate of a region touches virtually every phase of human activity and plant and animal life. In the hydrosphere, the climate of a region plays a similar role. The effect of changes in the oceanographic climate of the Hawaiian Islands region has already been demonstrated. As the scope of marine activities broadens it is anticipated that the understanding of climatic processes in the sea to be gained from this investigation will find increasing numbers of applications and may eventually lead to forecasting of climatic trends both in the ocean and the atmosphere.

The experiment will have three phases: (1) the design and planning phase, (2) the field phase, and (3) the evaluation phase. The design and planning phase is expected to take several years. It encompasses theoretical studies to determine the type, frequency, and spacing of samples to satisfy the requirements of heat, salt, and momentum budget equations. It will deal with sampling problems and processing techniques in preparation for the field phase of the experiment. The field phase will be a three-dimensional time sequence of observations as determined during phase 1 and will take 18 months to 2 years. Finally, phase 3 will be the evaluation of the results.

Initially, during 1963 and 1964, the new program will be concerned with phase 1: designing an experiment to verify the climatic model which has been deduced for the trade-wind zone from studies carried on over the past 4 years.

Subpopulations

ACTING PROGRAM CHIEF... LUCIAN M. SPRAGUE

Studies of inherited substances on the red blood cells of skipjack, yellowfin, bigeye, and albacore tuna have shown that they provide a useful basis for defining subpopulations of the tunas.

While the blood characteristics of all of the species mentioned have been investigated, there have been differences of emphasis and approach, because the species differ as regards the availability of samples from different geographical areas and technical problems of preserving and studying their blood.

Results of blood-group studies of skipjack tuna sampled at several locations in the Pacific Ocean indicate that this species is broken up into a number of subpopulations. Samples have been obtained from waters around the Hawaiian Islands, Christmas Island, the Marquesas and Tuamotu archipelagoes, the Society Islands and the western Carolines. A new and promising aspect of these studies is the developing concept that skipjack subpopulations may be uniquely associated with dynamic features of the major oceanic circulation systems. The emphasis of our skipjack studies has been placed on recognizing subpopulations and more recently on the relationships between the several skipjack subpopulations now recognized and physical features of the oceanic circulation system.

In the bigeye, albacore, and yellowfin tuna, emphasis has been on developing additional knowledge about blood-group systems in order to provide materials suitable for a sophisticated analysis of population data as they are accumulated.

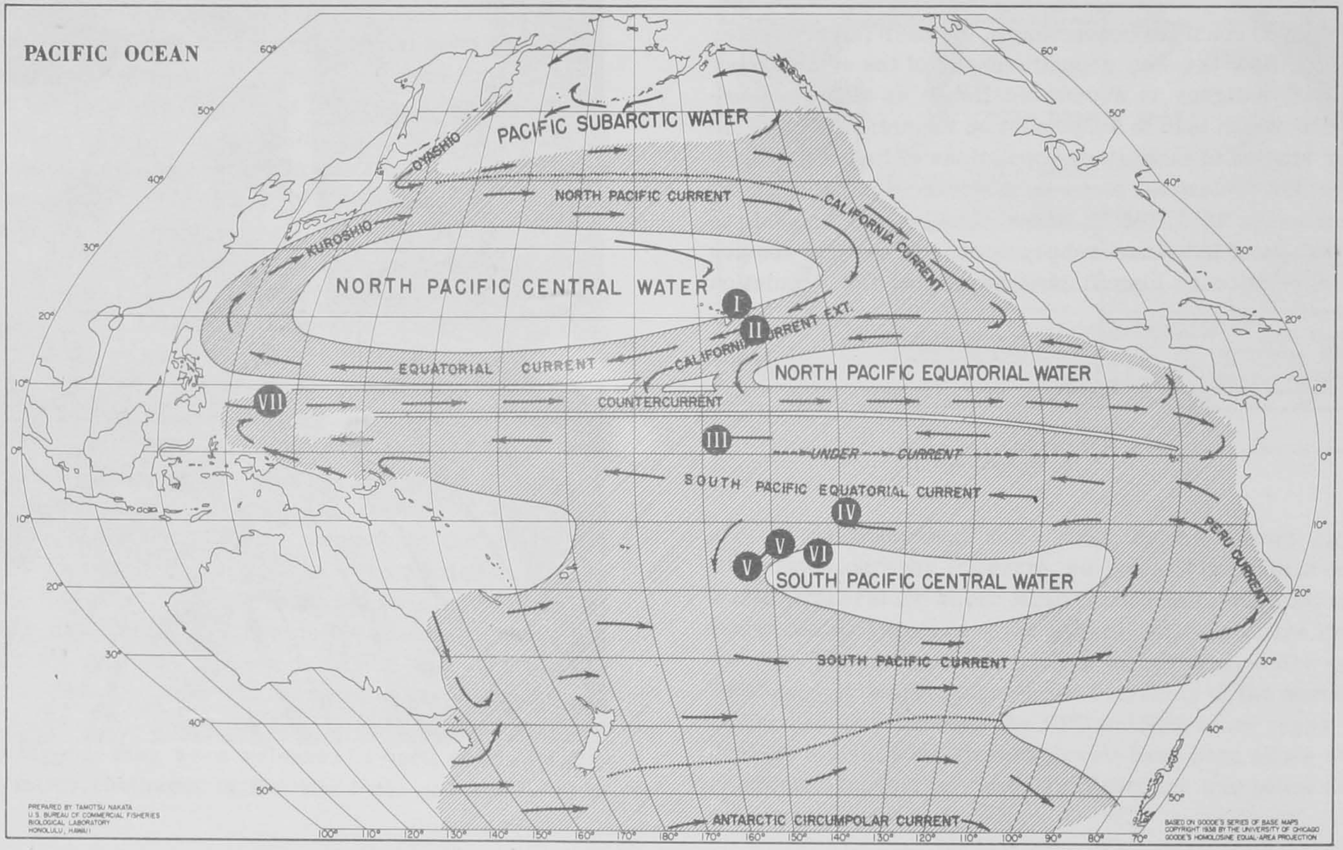
The availability of large or "season" skipjack in Hawaiian waters is correlated with the dynamic features of the ocean circulation systems near Hawaii. It has been shown by studies in the Oceanography Program that the rate of change of the ocean's warming in the early spring provides an indication of the relative degree to which large skipjack will enter the fishery. During 1962, a year which resembled 1955 and 1960 in its dynamic features and which was an average year in the abundance of fish landed, two kinds of information of importance to understanding the relationship between skipjack abundance and the oceanic climate were obtained. One was the finding by commercial skipjack fishermen in Hawaii of tagged skipjack released by the Inter-American Tropical Tuna Commission near Baja California in 1960. The other was evidence, obtained from data on blood groups, that two genetically separable subpopulations entered the Hawaiian commercial skipjack fishery in 1962. One of these subpopulations (II of fig. 13) was represented in part by very large fish of the size (26 lb.) of those from which the tags were recovered. It is postulated that these fish had their origin in the eastern Pacific, within the California Current regime. The other subpopulation (I of fig. 13) was represented by two size groups, large fish (about 15-25 lb.) and small fish (2-4 lb.), and samples were obtained throughout the sampling period, which began early in January 1962, before the advent of so-called "season" fish.

These findings, taken together with the better known association between dynamic conditions in the ocean near the Hawaiian Islands and skipjack abundance, suggest a means of studying the relationship between water masses and skipjack subpopulations.

Figure 13 shows a schematic representation of the major surface features of the circulation systems of the Pacific Ocean. Our data suggest, by the fact that in each case different subpopulations, denoted by Roman numerals, lie within well-defined differences in water types, that the subpopulation unit is related to a specific portion of the circulation system or to a mass of oceanographically definable water. For an understanding of the skipjack resource, it is essential that the nature of the mechanisms that reproductively isolate one skipjack population from another be understood. If it is true, and at this point it seems a likely possibility, that the ecological boundaries of a given subpopulation coincide with definable features of the circulation system, our understanding of the relationship between physical processes in the ocean and biological organisms will be greatly increased. The utility of being able to analyze the sources of fishery recruitment and the effects of ocean dynamics upon population isolation, as demonstrated by the skipjack findings, cannot be overstressed.

Serological studies have been carried out on other tuna species as well. In each case slightly different problems have been met, but, a general pattern of similarity has been found between blood group systems of the yellowfin, albacore, and bigeye tuna. Our aim in the development of reagents in these species has been to discover antigens which form blood-group systems directly amenable to genetic analysis. An example is the A-B-O system of bigeye. In bigeye two blood factors, A and B, occur and form groups with the blood types A, B, AB, and O. Analyses of the relative proportions of these four groups agree with a hypothesis that the blood-group system is determined by the inheritance pattern of three alternate genes. The importance of these findings lies in the fact that analysis of the expected and observed proportions of these four blood-type groups in a population sample will reveal whether the sample has been drawn from an isolated breeding stock or from a heterogeneous population. Such inferences can only be drawn from blood-group systems in which all the blood types can be recognized and can be clearly shown to occur in conformity with mathematical expectations.

Our studies of the yellowfin are now at the point where representative sampling in geographically distant localities would be useful for the purpose of identifying the nature and extent of subpopulations in this species. To date, 1,345 samples of yellowfin blood have been examined. Owing to the generalized nature of the material available for testing this species, until recently only data of serological interest have been obtained. Last summer we succeeded in increasing to 12 the number of test materials suitable for use on yellowfin, and 6 of these materials appear to detect factors in the C-system. These tools should enable us to carry out yellowfin population studies when suitable samples become available.



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BASED ON GOODE'S SERIES OF BASE MAPS
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GOODE'S HOMOLOSINE EQUAL-AREA PROJECTION

Figure 13.--Skipjack subpopulations in relation to major circulation features of the Pacific Ocean.

Our studies of the Pacific albacore are at a less sophisticated level than those of the other tuna species mentioned and will be given considerable attention in 1963. The receipt of rabbit antialbacore immune sera from commercial sources provides materials that should be of great assistance in the rapid development of this program. Thus far, 1,044 albacore bloods have been examined; as with yellowfin, the data are mainly of serological interest.

New studies are planned, among them an extension of the present sampling of tuna bloods into the Indian Ocean in connection with the International Indian Ocean Expedition and the initiation of studies of additional species of tuna and related species, probably beginning with a study of the bluefin tunas.

We should begin to consider conducting in the near future studies on the rate of gene flow between populations and of the evolutionary history of individual antigens in scombroid fishes as aids to understanding the events which lead to subpopulation formation. We should also increase our studies of laboratory populations of fishes to determine whether or not selection plays a major role in determining blood-group frequencies in fishes. It will in time be very valuable to study the relationships of individual subpopulations of several species taken together in relation to identifiable features of the circulation system.

* * *

Skipjack Ecology

PROGRAM CHIEF... BRIAN J. ROTHSCHILD

Studies in skipjack ecology are concerned with defining the relation between skipjack and their environment. Work during the year included studies of the distribution of skipjack and environmental variables in a large area around the Hawaiian Islands, of catch changes in the Hawaiian fishery relative to changes in temperature and salinity at the Laboratory's Koko Head monitoring station, and of the distribution of larval tuna relative to temperature and salinity. Migrations of large skipjack in and out of the Hawaiian fishery were inferred from changes in the size composition of the commercial landings and the results of subpopulation studies. Estimates of fecundity and the maturity stages of skipjack from the same and from different schools were made on the basis of ovary examination. Results of these studies have added to our basic knowledge of skipjack ecology and will provide a basis for increasing the efficiency of harvesting this valuable resource.

Our investigations of relations between skipjack distribution and seasonal movements of the boundary between North Pacific Central (NPC) and North Pacific Equatorial (NPE) water types (fig. 14) were continued during 1961. Three cruises--January to February, April to May, and June to July--were made within the area bounded by latitudes 15° and 25° N. and longitudes 150° and 170° W. The results of scouting during 1961 indicated that, as in 1959, skipjack were most abundant in the zone of intermediate-salinity water to the south and west of the Islands before the appearance of large skipjack in the area of the fishery. On the 1959 and 1961 cruises, schools were sighted in greater numbers west of longitude 155° W. than to the east of that line. Occurrence of this distribution pattern in 1959 had suggested that skipjack move into the Hawaiian fishery from the west or south. To test this hypothesis, plans were laid for releasing large numbers of tagged skipjack to the southwest of the Islands. In 1961 only 248 skipjack could be tagged; they were released in April near Johnston Island, some 750 miles southwest of Hawaii. None of these fish has been recovered.

A skipjack tagged by Inter-American Tropical Tuna Commission biologists and released 20 miles west-southwest of Turtle Bay, Baja California, in September 1960 was recaptured in June 1962 by Hawaiian fishermen. This skipjack, which weighed 25-3/4 pounds when recovered, provided the first record of skipjack migration between the eastern and central Pacific fisheries and indicated that some skipjack taken in the Hawaiian fishery are eastern Pacific emigrants.

In 1961, as during the 1959 cruises, water of intermediate salinity (34.5 - 34.9 $^{o}/oo$) covered more of the Hawaiian area in summer than in winter. In the summer of 1961, NPC water covered only a small area to the east of longitude 164° W., and NPE water covered less area than in 1959. Salinity gradients across the boundary between NPC and NPE water types were sharpest during the winter months.

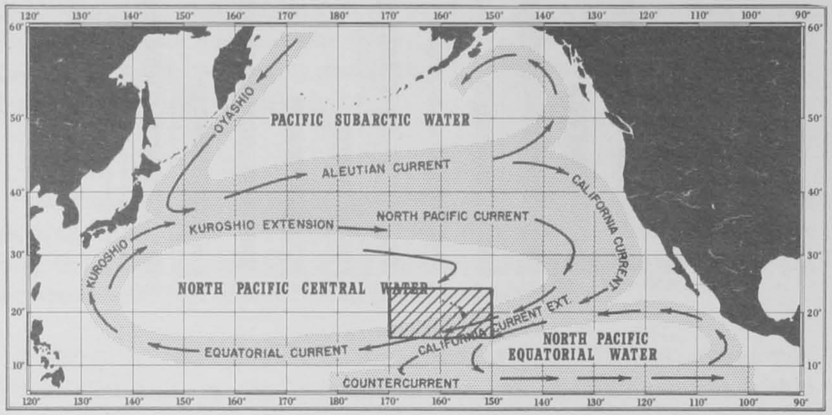

Figure 14.--Location of the water type boundary in the Hawaiian area.

As is described more fully in the report on the Trade-Wind Zone Oceanography Program, analysis of the rate of change of surface water temperature at our Koko Head monitoring station has produced a technique for predicting the general success of the Hawaiian skipjack fishery. The change from cooling to warming, which usually occurs in February or March, signals the beginning of the northward movement of the boundary between the NPC and NPE water types. During the past decade, skipjack landings in Hawaii have been above average when the northward movement began in February and below average when the movement began in March.

The prediction made to the fishing industry in March 1961 was that landings of skipjack for the year would be above average. This prediction was based on a change from decreasing to increasing surface water temperatures at Koko Head very early in February. Landings of 10.9 million pounds substantiated the validity of this prediction (fig. 15). While total landings for 1961 were only slightly above average, the catch per boat per month of 47,000 pounds placed 1961 second only to the peak catches of 1959 and well above the 1950 to 1960 average.

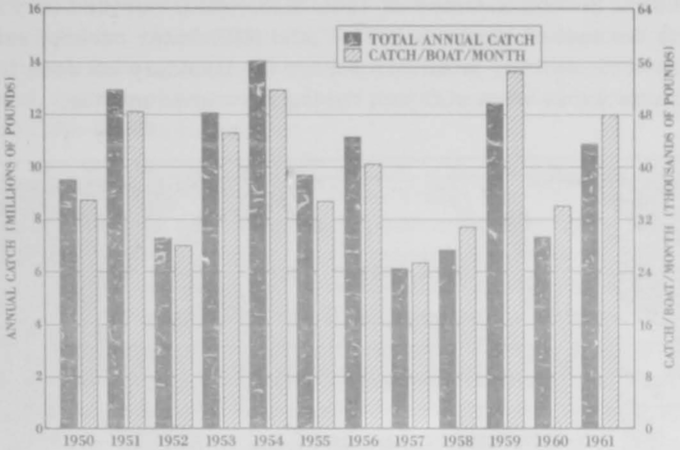

Figure 15.--Average catch per boat per month and total annual landings in the Hawaiian skipjack fishery.

Usually catches increase abruptly between May and June, with high catches in June, peak catches in July, high catches in August, and a sharp decline in landings during September or October. In 1961, catches increased in June as usual, but the peak catches were in June, followed by a slight decrease in July and an abrupt decrease in August, resulting in an early and short season. Effort, in terms of number of deliveries, was high for the year as a whole, and the catch per trip was also high, exceeded only in June and July of 1954. Had it not been for the shortness of the period of high catches, the total landings might have been considerably greater (fig. 16).

Changes in oceanographic conditions during 1961, as measured by the Koko Head temperature and salinity observations, were such as might have been expected to result in an early peak and decline of the fishing season. Examination of the Koko Head heating curve (fig. 8) shows that peak heating as well as initial warming occurred earlier than usual, and the period of summer cold advection and peak fishing season coincided.

Small (less than 8 lb.) and medium (8-15 lb.) skipjack were predominant in the landings from January through May, with length modes of these groups at 42-45 cm. (16-18 inches) and 62-64 cm. (24-25 inches), respectively. In June there was a marked change to a catch composed mostly of large (more than 15 lb.) skipjack, with their mode at 73 cm. (29 inches), and this group continued to dominate the landings through September. October landings were, as in the early months of the year, composed mostly of medium-sized skipjack with a mode at 63 cm. (24 inches).

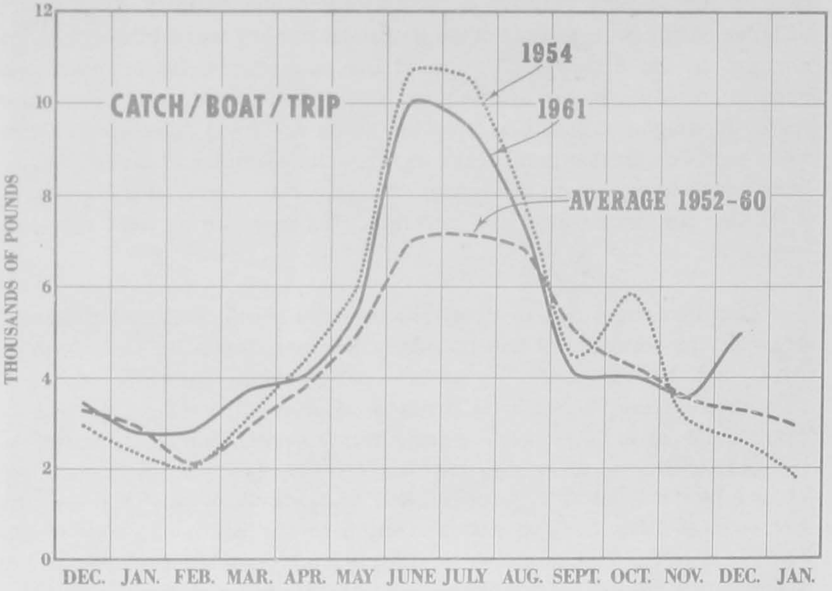

Figure 16.--Average catch per trip by months for 1952-60, 1954, and 1961.

Examination of the size distribution within the group of large skipjack present during the summer suggests that it was composed of two groups, with modes at about 72-74 cm. (29-30 inches) (19.6-21.5 lb.) and 76-78 cm. (30-31 inches) (23.6-25.7 lb.); for purposes of discussion these will be referred to as the small and large groups, respectively. In July and September the modes of the small and large groups are evident (fig. 17), while in June and August they can be deduced from the shape of the frequency distributions, which are skewed to the left. In October only the large group is present, with a modal length of 79 cm. (about 31 inches).

The combined small and large groups entered the fishery in June and remained available until September. There were, however, changes in the relative amounts of these two groups in the landings. In October the small group disappeared from the fishery, leaving only the large group. By February 1962, when the next samples were obtained, this large group had also disappeared.

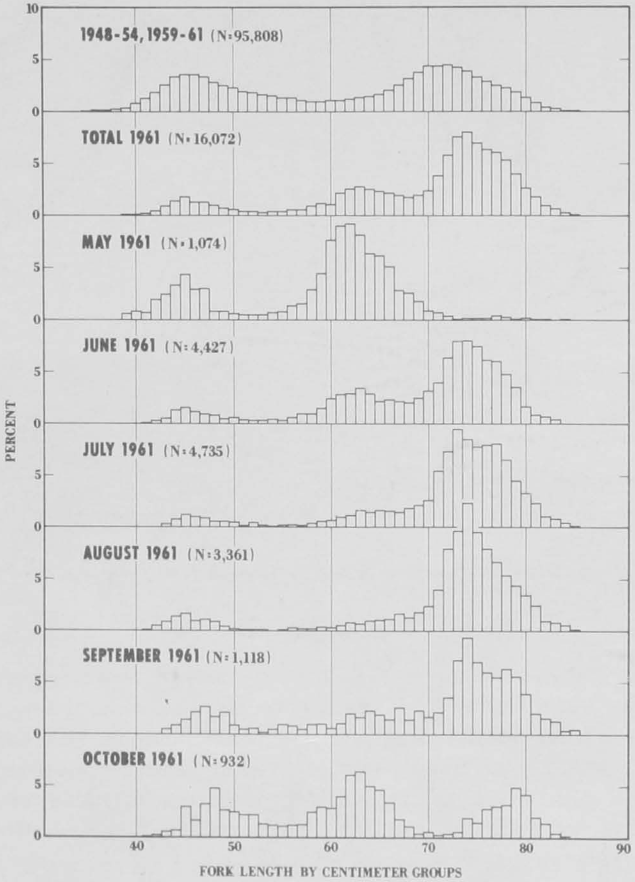

Figure 17.--Hawaiian skipjack length-frequency distributions.

Growth of Hawaiian skipjack was determined by Brock[2/] on the basis of the positions of modes in length-frequency distributions. The growth curve constructed by Brock can be used to trace the history, i.e. the presence in the fishery, of certain modal groups over a period of time. During 1961 the observed growth of the group of large skipjack from June to October was in agreement with expected growth. It was necessary, however, to go back to April 1960 to find a modal group which could be considered the predecessor of the large group. Such a group was present in the fishery from January to April, although not always as a dominant group.

Growth of the small group from June to September was also about that expected on the basis of Brock's estimate of growth. The history of the small group differs from that of the large group in that we can find its probable predecessor in our data for the period of February to December 1960. The small group does not appear to have been present from January through May 1961.

It appears from these observations that discrete groups of skipjack may be present in the fishery at irregular intervals. They may in fact be absent during one season, only to appear as a dominant or semi-dominant group during the following season.

Skipjack ovaries were sampled during 1960 and 1961. There was little variation in the position of the ova diameter modes within samples taken from single schools during the summer. Preliminary analysis shows, however, that there are significant differences between samples taken from different schools. By September skipjack taken from single schools had ovaries in the immature, mature, and spent stages of development.

The occurrence of residual ova increases from 1 percent in April to 80 percent in August. The weight of the gonad relative to body weight is at its highest in August. These phenomena may be associated with a peak in spawning in late spring, followed by a secondary spawning in late summer.

[2/] Brock, Vernon E. 1954. Some aspects of the biology of the aku, Katsuwonus pelamis, in the Hawaiian Islands. Pacific Science, vol. 8, no. 1, p. 94-104.

Larval skipjack collected during the 1959 survey cruises were most abundant in May and June, with few collected during January, March, and September. Thus, larval studies support the theory of late-spring spawning, but samples were not obtained which could be used to delineate a late-summer spawning.

The number of eggs released at one spawning was estimated from the number in the most developed group in the ovary. For fish of 44, 77, and 87 cm. (17, 30, and 34 inches) fork length the estimates were 280,000 ova, 1,300,000 ova, and 1,900,000 ova, respectively. Total number spawned in a year would, of course, be greater if a second modal group continued to develop and was spawned.

Following the tentative identification in 1960 of tuna larvae collected by the Dana during her round-the-world cruise in 1928-30, larval tuna distribution or occurrence was examined in terms of salinity and temperature. Preliminary findings indicate no apparent relation between larval occurrence and salinity of surface water. Skipjack larvae were collected in waters with a wide range of salinity values, from 32.0 to 36.0 °/oo, representing nearly the extremes for Pacific and Indian Ocean waters (fig. 18). Similar results were obtained for larvae of yellowfin and bigeye.

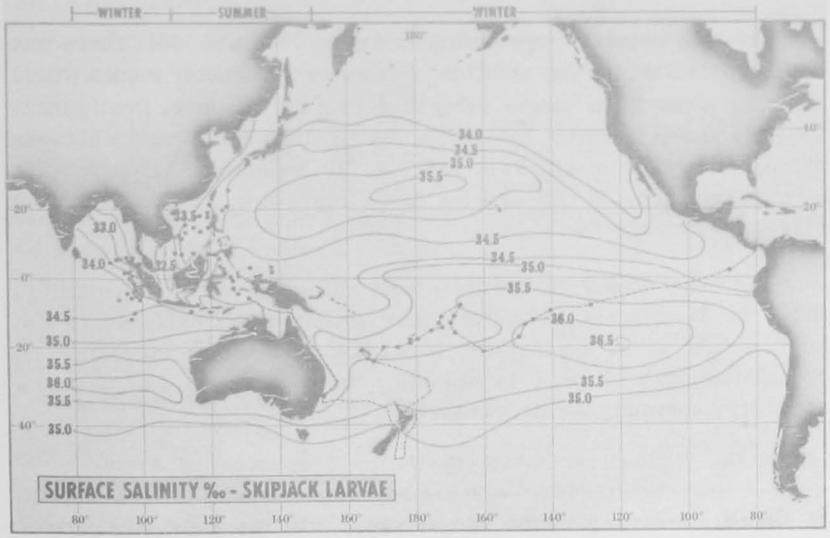

Figure 18.--Occurrence of skipjack larvae in relation to salinity.

The relation between larval tuna occurrence and surface water temperatures appeared more distinct. Skipjack larvae in the Dana collections were not taken in waters cooler than 75° F. (fig. 19). Data from Hawaiian waters show 72° F. as the lowest water temperature in which skipjack larvae have been found. Consequently, the actual temperature limit for larval skipjack occurrence could be in the neighborhood of 70°-72° F. Yellowfin and bigeye larvae occurred in waters warmer than 74.8° F. and 75.0° F., respectively. The lower temperature limits of larvae of these two species have not yet been determined exactly.

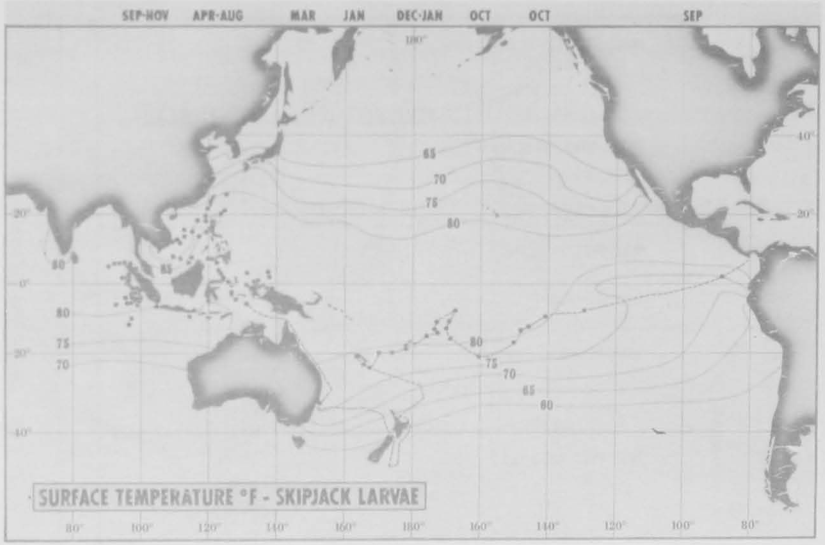

Figure 19.--Occurrence of skipjack larvae in relation to water temperature.

Tuna larvae taken in plankton hauls from waters around New Caledonia were identified. These samples were obtained through the courtesy of the Institut Français d'Océanie, Noumea, New Caledonia. The collection had mostly skipjack (173) and a small number of yellowfin (37). No albacore were recognized. Included among the specimens were three tuna larvae with unusual pigmentation. They had a single row of five or six closely spaced chromatophores along the base of the second dorsal fin; the rest of the trunk, excluding the abdominal sac, lacked any pigmentation. The number of myomeres appeared to be similar to that of skipjack, but there were about 17 ossicles representing the bases of spines in the first dorsal fin, and the second dorsal fin originated on the 19 myomere. These characters resemble those of the rare "slender tunny," Allothunnus fallai, but since they could not be observed very clearly, no definite identification was made.

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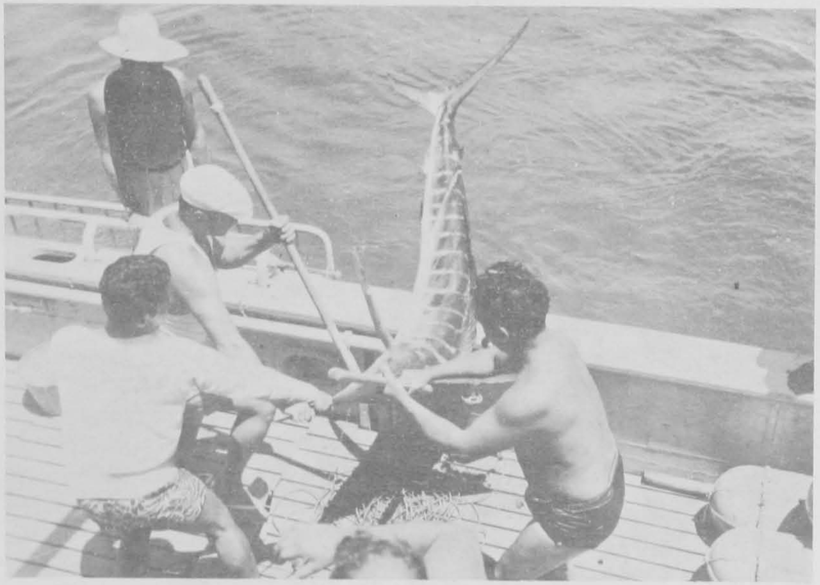


Fishery Potentials

PROGRAM CHIEF... RICHARD S. SHOMURA

The Fishery Potentials Program was organized in 1959 to evaluate the pelagic fish resources of the Pacific Ocean. Recent evidence that the albacore and possibly other tunas undertake extensive migrations made it necessary to conduct the program on a Pacific-wide basis. Basically, the types of data required to assess a population are catch and effort data for the fisheries and estimates of reproduction, growth, and mortality rates. The greatest potential source of such data for the Pacific tuna populations is, of course, the extensive Japanese high-seas fishery. To date, however, detailed catch and effort data for that fishery have not been made available, and consequently the scope of the Program has been limited to the more modest goals of (1) documenting the Hawaiian and Samoan longline fisheries and (2) undertaking studies on some of the vital statistics of the commercially important fish species.

A Laboratory staff biologist went to Samoa early in 1961 to ascertain whether basic catch and effort data could be obtained on a continuing basis from the Samoan longline fishery. This fishery was begun in 1954 and is carried on at present by about 40 Japanese and a few Korean longline vessels. These longliners are based at Pago Pago, American Samoa, and make a total of about 300 trips annually. Their operations cover an area exceeding 3 million square miles.

Arrangements were made to place logbooks prepared by the Biological Laboratory on the Japanese longline vessels. In May 1961, 40 logbooks were sent to Samoa and distributed to the captains of the fishing boats. The returns have been data from 16 boats representing 36 trips. It does not appear that a logbook program administered from Honolulu can be expected to produce an adequate sample of operational data from the Samoan fishery.

In addition to distributing the logbooks the biologist made one trip aboard the Japanese longliner Yuki Maru, a typical small tuna boat of 74 gross tons, with a crew of 19 men. The trip extended over a 1-month period, and the longlines were fished at 22 locations (fig. 20). On an average day fishing commenced at about 5:00 a.m. and 380 baskets of gear were set. On a linear basis this represents about 80 miles of mainline, however, because the gear is set slack, the actual length of the set ranged from 20 to 25 miles. The setting operation was usually completed by 8:30 a.m., and the gear was then left to fish until noon. Hauling of the gear commenced at noon and took 12 to 13 hours. Albacore tuna dominated the catch, 1,666 (79 percent) of approximately 2,100 fish caught on the cruise being of that species. These fish averaged about 40 pounds each.

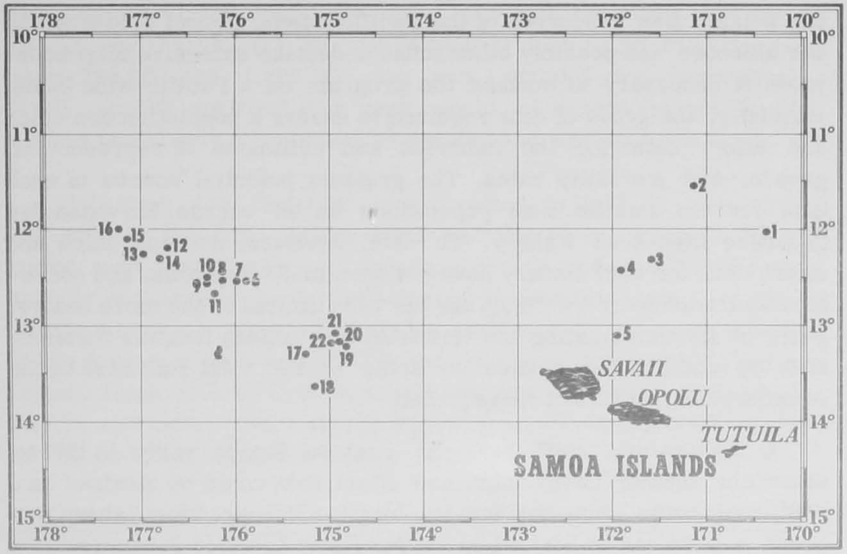


Figure 20.--Positions of _Yuki Maru_'s longline sets.

In April 1960 an intensive sampling program was initiated to collect detailed catch and effort data from the Hawaiian longline fishery. In addition to the number of fish by species, the size and sex of more than 90 percent of the catch were recorded. On an annual basis this represents about 5,000 bigeye tuna, 5,000 yellowfin tuna, 1,500 striped marlin, and 500 blue marlin.

Although the data collected thus far are inadequate for a definitive study of the vital statistics of these populations, a preliminary study was carried out with the bigeye tuna data to determine the adequacy of the data and to see whether male and female bigeye grow at the same rate. It is a widely recognized phenomenon that the size distributions by sex of longline-caught bigeye tuna are not similar: the males invariably predominate in the larger size group. A hypothesis of sexual difference in growth rates was formulated, and a preliminary test was made using data collected from April 1960 to March 1961. The results showed that differential growth does exist for this species. Both sexes grow at about the same rate up to 100 pounds, when they are at an estimated age of 3 years; thereafter the females grow at a slower rate than the males.

The sampling program in the Hawaiian longline fishery is being continued, and further measures are being planned for collecting detailed catch and effort data from the Samoan fishery.

Special Studies

EXPERIMENTAL GILL NET FISHING FOR SKIPJACK

PROJECT LEADER ... RICHARD S. SHOMURA

Today, despite the generally vigorous growth of Hawaii's economy, the Hawaiian skipjack fishery gives indications of slow deterioration. From a modest start in the early 1900's this fishery increased in importance until in recent years the skipjack landings have made up 50 to 70 percent of the total fish landings in the State of Hawaii. Since 1948 from 6.1 to 14.0 million pounds of skipjack have been landed annually. Total landings do not, however, reveal the serious conditions facing the fishery as well as does a survey of the size and age of the fishing fleet.

The history of the fishery in the post-World War II period shows an initial flurry of activity, born of optimism, which led to the construction of nine new boats between 1946 and 1949. Between 1950 and 1960 only one new vessel was added to the fleet. With the retirement of a number of the older boats from the active fleet in recent years, and in the absence of any new construction, the fleet has dwindled from 32 boats in 1948 to its present level of 20 boats. Even after the withdrawal of some of the older boats the fleet may still be considered old; of the 20 boats fishing today, 7 were built between 1926 and 1931.

The factors responsible for this decline in the fishery are complex but are basically related to the wide fluctuations in the catch from year to year and to a method of fishing, with pole and line and live bait, which has remained virtually unchanged since the beginning of the fishery. This unchanging level of fishing efficiency, against a background of constantly rising operational costs, has sapped the industry's strength, particularly during poor seasons.

The essential solution to the problem of restoring the Hawaiian skipjack fishery to a condition of healthy growth is to increase the level of fishing efficiency, either by improving the present pole-and-line method, or by introducing a different mode of fishing. The latter approach has been attempted in our program of testing monofilament nylon gill nets as gear for catching skipjack tuna in commercial quantities. This program was carried out in 1961 and 1962 by personnel of the Biological Laboratory and was jointly financed by the State of Hawaii and the Bureau of Commercial Fisheries, with cooperation of the industry.

In recent years the use of monofilament nylon fiber for gill nets has spread widely throughout the world's fisheries. The special attribute of the monofilament form of nylon fiber is its high transparency in water, which gives it an advantage in catching efficiency over other synthetic or natural fibers. Monofilament gill nets have proven so efficient in catching salmon that the States of Oregon, Washington, and Alaska have banned their use.

The gill nets used for experimental skipjack fishing were of three mesh sizes. By the simple test of passing skipjack of various sizes through meshes of different dimensions, a mesh of 5-1/2 inches stretched measure was selected for attempts to capture skipjack of 4 to 10 pounds. The fiber was of the size commercially designated 22 MF (approximately 22-pound test line). For fishing skipjack larger than 10 pounds, which make up the bulk of the Hawaiian season's catch, web of 7-3/4-inch and 9-inch (stretched measure) mesh were chosen. These larger meshed nets were made up of 35 MF fiber (approximately 35-pound test line) and 45 MF fiber (45-pound test line), respectively.

For the 1961 field work each unit of gill net measured 100 fathoms along the cork line and 102 fathoms along the lead line. The net was hung at the rate of 200 fathoms of webbing to the 100 fathoms of cork line. All of the units made up were 10 fathoms deep. Because of difficulties encountered in handling nets of these dimensions, the length of each unit was reduced to 50 fathoms for the 1962 tests. Results of the 1961 trials had shown that most of the skipjack taken were in the upper one-fourth of the nets, so in 1962 the depth of the nets was decreased to 5 fathoms.

In 1961 and 1962 various methods of using monofilament gill nets to capture skipjack were tried. Except for some trials of passive fishing done at night, all of the methods used were variations of the active gill net fishing strategy developed early in 1961. This involved locating a skipjack school by sighting a "working" bird flock and, as in the standard pole-and-line method, chumming the school to the stern of the boat with live bait. After the size of the fish had been determined, either by sighting them at the surface or by catching a few on pole and line, nets of the appropriate mesh size were set. Heavy chumming was continued during the setting operation. After the net had been set, fishing with pole and line was usually continued near the nets. The net was hauled in with a gill net powerblock after the fish stopped biting or when signs of the school's activity ceased. Variations of tactics tried in active fishing included running the boat across the net through a "gate" in the center of the set, setting the nets below the surface, and setting several joined shackles of net in a curve partially surrounding the school.

The 1961 field work was carried out mostly with small-meshed nets, as large skipjack were scarce in Hawaiian waters at the time, so in 1962 efforts were concentrated on trying to catch the larger fish. The results of straight surface sets appear to show a progressive loss in fishing efficiency with increasing mesh size. From surface observations it seemed that the larger skipjack were more deliberate in their feeding behavior and could not be brought to as intense a feeding frenzy as could be induced in small skipjack by chumming live bait. Thus, only 2 out of 23 sets with the 5-1/2-inch mesh failed to take any skipjack, whereas 10 out of 17 sets of the 7-3/4-inch mesh and 6 out of 9 sets of the 9-inch mesh caught no fish.

Although these experiments demonstrated that skipjack could be taken by surface gill nets, the catches were too small to be of commercial significance, especially in view of the heavy use of live bait that was required. Our fishermen were of the opinion that for the same amount of bait fish chummed the pole-and-line method would have taken several times more skipjack than was caught in the nets. In fact, when pole-and-line fishing was tried near the gill net set, it usually produced a greater catch than the gill nets did.

The gilling and entangling of skipjack in the nets occurs only while the nets are being set. Attempts to lead additional fish into the net by crossing it through a "gate" while continuing to chum bait produced no noticeable improvement in the catch. To observers on the vessel during the passage across the net it appeared that the skipjack avoided the web by either veering off or sounding.

Because it was difficult to take the boat through the "gate" in rough seas, and because the skipjack seemed to see and avoid the nets so readily at the surface, subsurface nets were tried in 1962. The floats on these nets were small enough to allow them to sink. The net was then supported at a depth of 12 feet by lines attached to large rubber floats. Results of eight trials were negative. The skipjack simply followed the vessel over the net.

The fourth method of active gill net fishing was an attempt to encircle the school while keeping the fish at one side of the boat by chumming live bait. Four trials were made using 3 or 4 shackles of gear, but in no case were we successful in completing the circle. Aside from the indicated ability of skipjack to see the monofilament net, the encircling method involved hauling in the gear with the vessel lying in the trough of the sea part of the time. In rough water the rolling of the vessel made the operation both difficult and hazardous.

Passive gill net fishing at night was carried out in July and August 1962. The usual procedure was to set the nets at sunset, allow the gear to fish through the night, and haul in the nets at daybreak. Fourteen such random night sets were made. Although the catches were varied and of academic interest, only one skipjack was captured.

Our conclusion from the field trials carried out in 1961 and 1962 is that monofilament nylon gill nets cannot catch skipjack in commercial quantities in Hawaiian waters and that their employment with live bait represents a less efficient use of bait than the pole-and-line method.

The failure of the gill nets to capture large Hawaiian skipjack can be attributed to the great clarity of the waters around the Hawaiian Islands and the apparently high visual acuity of the skipjack.

✡

Albacore Ecology

PROGRAM CHIEF...TAMIO OTSU

A number of recaptures by Japanese fishermen of albacore tuna tagged on the American side of the North Pacific have established the fact that the albacore, at least in its younger years, performs migrations of great scope. The study of other aspects of the life of this species, the highest priced of the tunas, has been hampered by our inability to distinguish its larval and juvenile stages from those of other closely related tuna species. This obstacle has now been overcome with publication by the Laboratory of descriptions of the larvae of four species, including the albacore. It will now be possible to use studies of the geographical and seasonal distribution of newly hatched specimens to refine our understanding of the Pacific albacore spawning pattern, which is known to us at present only from studies of the ovaries of mature fish and the distribution of the young albacore occasionally found in the stomachs of large predators.

Along with spawning studies, a major subject of investigation by the Albacore Ecology Program is the relation between the albacore of the North and South Pacific. It is not known with certainty whether the albacore exploited by American and Japanese fishermen in the North Pacific represent the younger elements of a stock which extends across the Equator and supports the Japanese longline fishery of the South Pacific with its older age groups, or whether the Southern Hemisphere population is a separate one, of which the younger and presumably more abundant portion is as yet relatively unexploited. A first approach to this problem has been made through comparison of the spawning habits of albacore north and south of the Equator. Preliminary to beginning extensive field work, a study was made of albacore ovaries collected at the cannery in American Samoa. The results indicated that the spawning season of South Pacific albacore is in the southern summer, approximately half a year apart from the spawning of the North Pacific fish, which are also reproductively most active in the warm season.

This indication of two separate spawning populations was followed up by an extensive field investigation between January 15 and April 5, 1962, when the Charles H. Gilbert was sent to the southwest Pacific for a survey around the New Hebrides, New Caledonia, Fiji, the Ellice Islands, Tonga, and Samoa (fig. 21). This investigation, which was designated by the Hawaiian name for the albacore AHIPALAHA I, was carried out in cooperation with the Institut Français d'Océanie, of Noumea, New Caledonia. The Institut's research vessel Orsom III concentrated its efforts in the waters of the New Hebrides and New Caledonia while the Charles H. Gilbert worked in the more eastern areas. Both parties used comparable methods in longlining to collect adult spawners and hauling plankton nets and midwater trawls to sample larval and juvenile albacore.

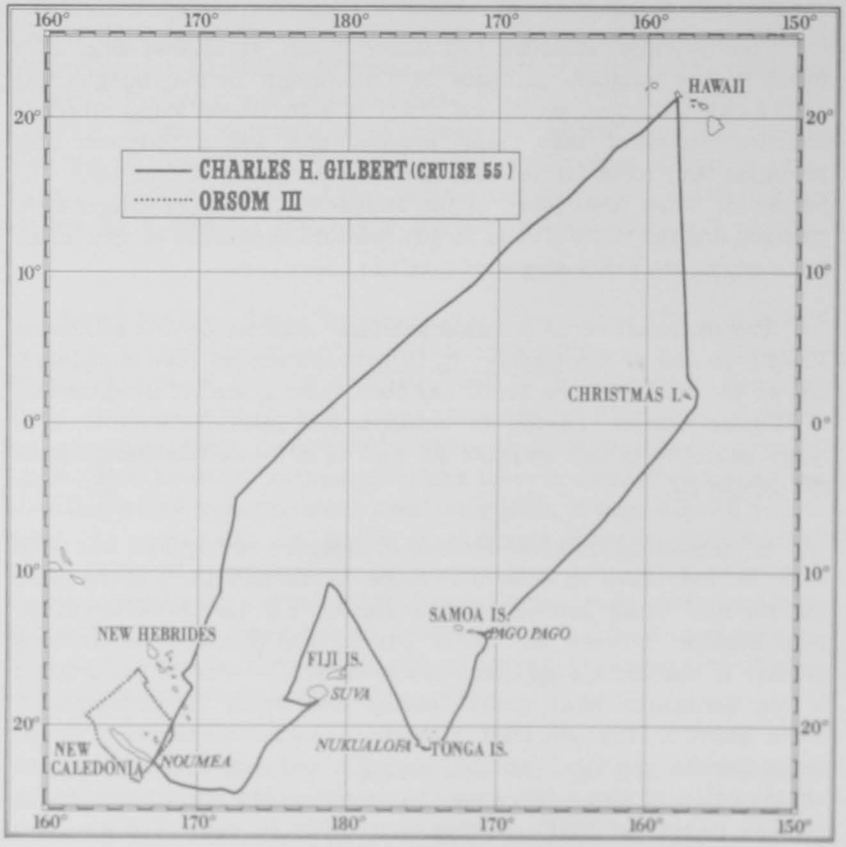


Figure 21.--Cruise tracks of AHIPALAHA I, the Charles H. Gilbert's South Pacific albacore survey, and of the Orsom III.

Longline fishing from the Charles H. Gilbert yielded 49 albacore, 53 yellowfin and other tunas, 17 spearfishes, 46 sharks, and 51 miscellaneous specimens. The albacore were all large, mature fish, the smallest being about 34 inches long. Of the females collected, about half had recently spawned and the ovaries of the others were unripe. The Orsom III reported the capture of 70 albacore, 51 other tunas, 9 spearfishes, 27 sharks, and 65 miscellaneous fish on the longlines. The biologists of the Institut Français d'Océanie considered that the condition of the ovaries of their female albacore specimens indicated that they had all spawned recently. Thus the results of observations on both vessels were in agreement in showing that the timing of the survey had been too late to catch the peak of the South Pacific albacore spawning season.

Five juvenile albacore, all under 10 cm. (4 inches) long, were found in the stomach contents of fish caught by longlining during AHIPALAHA I. The predators that had eaten these young albacore included yellowfin tuna, blue marlin, and wahoo. Skipjack tuna juveniles and other as yet unidentified tuna young (either bigeye or yellowfin) were also found in the stomachs of longline-caught fish, emphasizing the value of these large predators as sources of specimens for studying the early stages of tuna life history.

The examination of plankton samples collected on this southwest Pacific cruise of the Charles H. Gilbert has not yet been completed, but so far one albacore larva has been found in the 107 samples that have been sorted. Larvae of skipjack and yellowfin were found in large numbers in our samples as well as in the collections made on the Orsom III.

In connection with our studies of albacore ecology, all available data on the sizes of albacore taken in various parts of the South Pacific are being assembled and studied for further clues to the relationships between the North Pacific and Southern Hemisphere stocks. It has become apparent that small albacore of the sizes found in the American West Coast fishery also occur in the temperate South Pacific. The smallest albacore landed commercially in the South Pacific are taken around Australia and New Zealand; they are estimated to be 2 to 3 years old. Three-year-olds predominate in the coastal fishery of Chile, making up roughly 70 percent of the catch (fig. 22). Australia and Chile, however, account for only a minor part of the albacore catch from the South Pacific Ocean.

The only major fishery for albacore in the South Pacific is the Japanese longline fishery. The Japanese longliners, many of them based in American Samoa or attached to mothership fleets, fish albacore between the Equator and latitude 30° S. The predominant age group in their catch is the 6-year-olds, which make up 42 percent of the total.

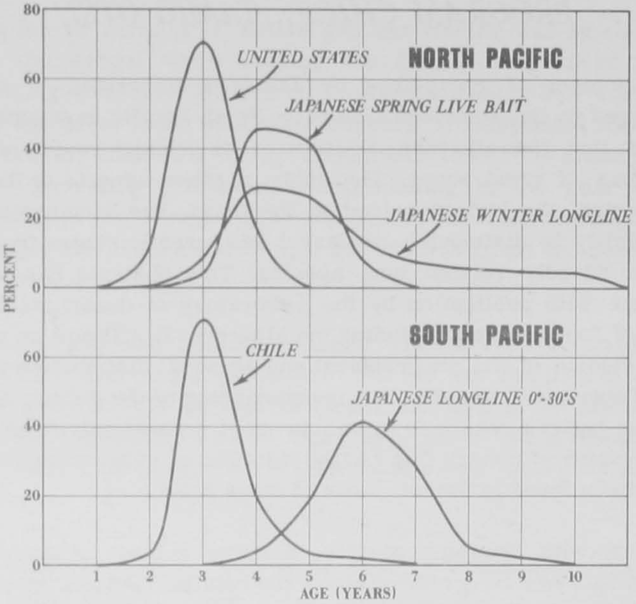
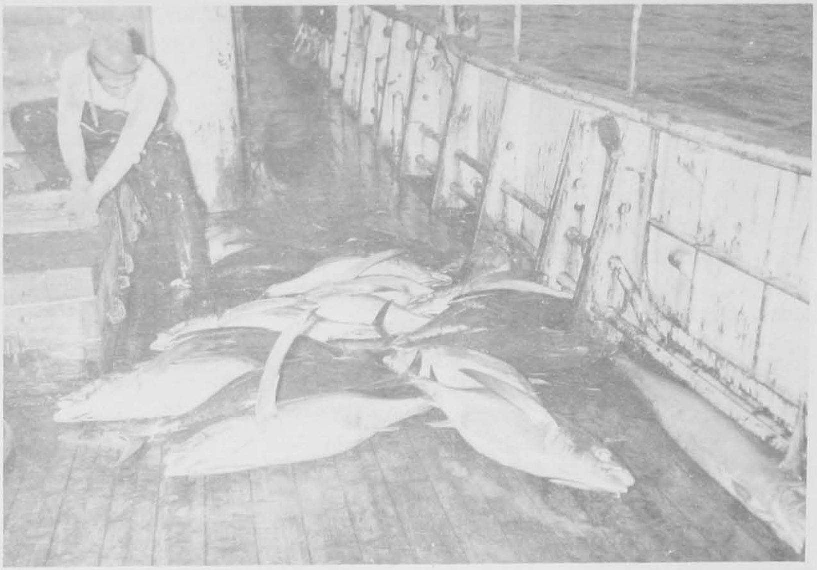


Figure 22.--Weight of various albacore age groups in landings of the Pacific fisheries.



Comparison of the North Pacific and South Pacific albacore landings shows that 93 percent of the fish taken in the northern fisheries are immatures less than 5 years old, while only 35 percent of the albacore caught in the Southern Hemisphere fishery are considered to be immature fish (fig. 23).

More cruises to the albacore latitudes of the South Pacific are being planned with the objective of more sharply defining the spawning grounds of the Southern Hemisphere albacore. In the light of the results of AHIPALAHA I, the next such cruise will be scheduled earlier in the year in an effort to catch the peak of the spawning season. Once again principal emphasis will be on longline fishing for ripe adults, plankton tows to collect larvae and juveniles, and night-light fishing and examination of stomach contents for larger juveniles.

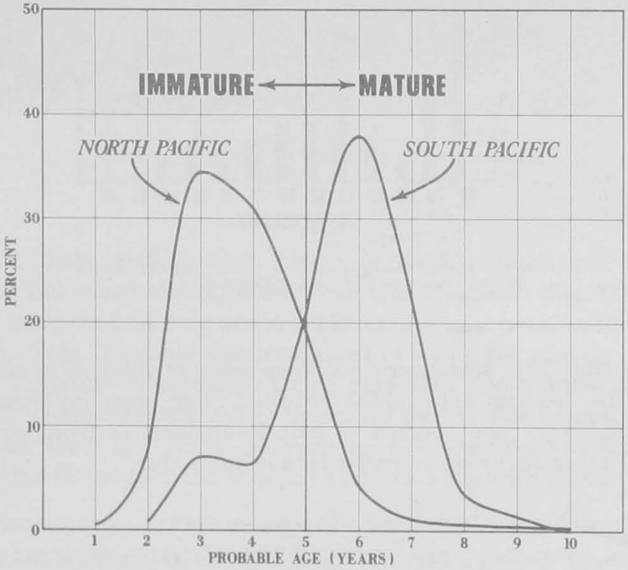


Figure 23.--Age composition of North and South Pacific albacore landings.

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Behavior

PROGRAM CHIEF... JOHN J. MAGNUSON

Behavior studies at the Biological Laboratory are concerned with the sensory abilities of tuna and with their behavior in response to their environment. These studies are conducted both at sea from underwater viewing ports in research vessels and on shore in specially constructed tanks. Technical problems in studying the fast-moving tuna of the open sea have made it necessary to pioneer new methods of observing and handling specimens. Information which comes from the Behavior Program is providing an understanding of the individual tuna's reaction to the multitude of environmental stimuli and this understanding is expected to be useful in the development of fishing gear, in predicting the location of tuna in time and space, and evaluating the influences of behavior patterns on the survival and abundance of tuna.

Every species of fish is characterized by quite specific anatomical features, and in most cases these structures are functional. Likewise, every species of fish is characterized by quite specific behavior characteristics, and in most cases these too are functional. Skipjack for example, swim continuously and with their mouths continually agape. This constant swimming brings them in contact with prey and also flushes oxygenated water over their gills. If they stopped swimming they would suffocate. During short bursts of speed while chasing prey, skipjack approximately 24 inches long swim at speeds up to 12 body lengths per second (23 ft./sec.). During these short bursts of speed, the tail fin may make nine sweeps back and forth each second. This high swimming speed functions, of course, in the capture of prey and probably in the avoidance of predators.

Skipjack are normally marked with four or five dark stripes running from the tail towards the head. When a hungry skipjack is presented with food, sections of these stripes fade, leaving a pattern of dark and light vertical bars. These vertical bars slowly fade only to return suddenly when another food stimulus is presented. A skipjack which has been fed until it will take no more food will not assume the feeding color pattern. This barred pattern may be what behaviorists call a "social releaser," that is, a characteristic of one animal which stimulates a specific response in another animal. At the present time we do not know the behavioristic significance, if any, of these color changes.

Other noticeable colorations of the skipjack which may turn out to be related to behavior are the silvery tongue, the white leading edge of the first dorsal and pectoral fins, a series of iridescent blue streaks on the back just in front of the tail fin, and a light spot on top of the head marking the location of the pineal window (fig. 24).

Figure 24.--Color features of living skipjack.

When fed as much as they would take once a day, skipjack in the laboratory tanks ate 1.6 ounces of squid and shrimp per pound of their own body weight per day, but when fed 13 times a day, this increased to 3.2 ounces per pound per day. Food consumption was greatest at the first feedings, early in the day, and smaller amounts were eaten through the remainder of the day (fig. 25). Shrimp exoskeletons began to appear in the feces about 1.5 hours after a meal. Skipjack ate little or nothing after dark and would not take food particles from the bottom of the pool. The size of the food particles they would eat decreased as feeding progressed.

Experiments were conducted at sea from the <u>Charles H. Gilbert</u> in the waters of Hawaii and the Line Islands to determine the influence of different species of bait and artificial feeding stimuli on the feeding behavior of skipjack. The fishing techniques of the Hawaiian sampan fleet were used: skipjack were found by looking for bird flocks and were attracted to the vessel by chumming and then caught on pole and line (fig. 26). Measurements were made of changes in catch rate and in the feeding rate which resulted from changing from live to dead bait, from one species of bait to another, or from turning off and on a water spray over the surface of the water.

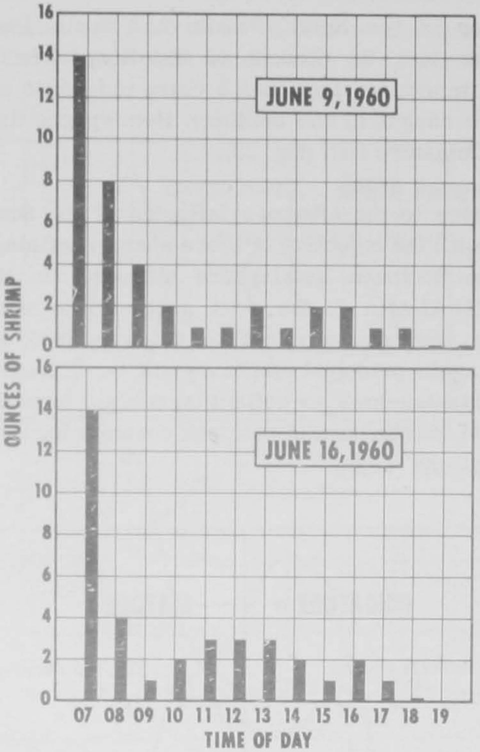

Figure 25.--Amount of food eaten at hourly intervals during daylight hours by four 3-pound skipjack.

The catch rate increased when water sprays were turned on and decreased when they were turned off (fig. 27). This occurred not only when such nondiving bait species as anchovy, silversides, and mullet were used, but also with diving species such as goatfish, tilapia, and mountain bass. Although this appears to be true for diving and nondiving bait as a whole, evidence is not sufficient to draw conclusions about individual bait species. However, the feeding rate of skipjack on the chum was higher when sprays were on only when a nondiving bait was chummed (fig. 27). Water sprays increase the feeding attack rate on bait or hooks that are near the surface.

Figure 26.--Pole-and-line fishing for skipjack in Hawaii.

Catch rate and feeding rate increased when living bait was chummed and decreased when dead bait was chummed (fig. 28), showing that the dead bait does not provide as intense food stimuli as does live bait. This indicates that movement is one of the stimuli inducing feeding behavior in skipjack. Catch rate also drops when dead bait is used, because whereas living anchovies tend to swim along with the boat when they are being pursued by skipjack, dead anchovy drift away behind the vessel and take the skipjack away with them.

In a comparison of different bait species, anchovy increased the catch rate when alternated with silversides and topminnow, silversides decreased the catch rate when alternated with anchovy and jack, and mullet increased the catch rate when alternated with tilapia (fig. 29). Because the number of schools involved in these comparisons was small, the conclusions should be considered tentative.

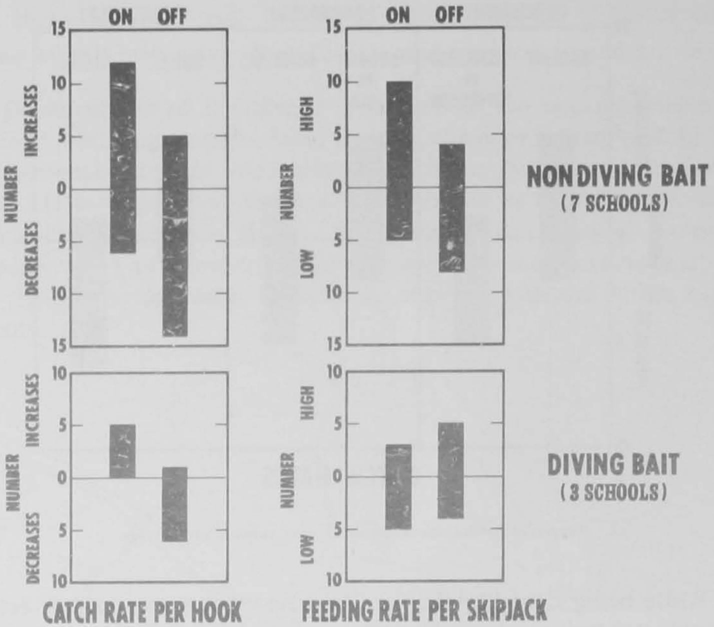

Figure 27.--Changes in catch and feeding rate with water sprays on and off.

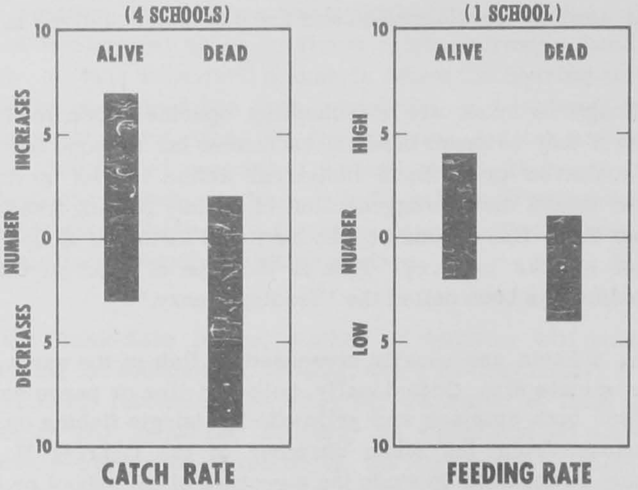

Figure 28.--Catch and feeding rates with live and dead bait.

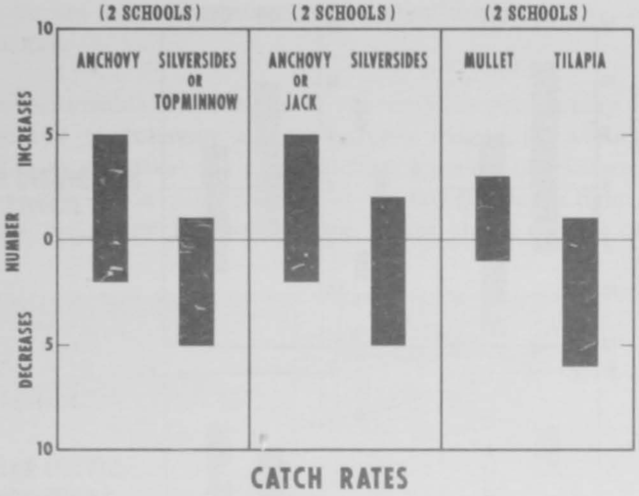

Figure 29.--Skipjack catch rates with various bait fishes.

While being fished by the pole-and-line technique, surface schools of skipjack characteristically dive or sound, returning to the surface seconds or as long as 28 minutes later. Zero to eight dives were observed per school in Hawaiian waters (fig. 30), and the frequency of diving was found to be associated with the occurrence of two species, lizardfish and squirrelfish, in the stomach contents of the skipjack. We hypothesized that these two species were more attractive than the live bait used by the fishermen and that the skipjack dived in pursuit of them.

Although skipjack are a schooling species, when food stimuli are present they no longer orient on each other but respond individually to the scattered prey. Such individual action breaks up the highly organized school and an aggregation of rapidly feeding fish forms in its place. Each fish swims rapidly back and forth and up and down in individual attacks on prey. This is the type of behavior that, when very intense, has been called the "feeding frenzy."

Tuna schools are usually composed of fish of the same species and approximate size. Occasionally, pole-and-line or purse seine tuna boats catch both skipjack and yellowfin in a single fishing operation. Observations from the stern chamber of the Charles H. Gilbert have made it possible to study the structure of the school or schools from which such mixed catches are made. When underwater movie sequences of such schools were analyzed, it was obvious that each species tended to school with its own kind even though fish of the other species were near. A higher frequency of groups of a single species was observed than would have been expected if the fish schooled indiscriminately with the other species (fig. 31).

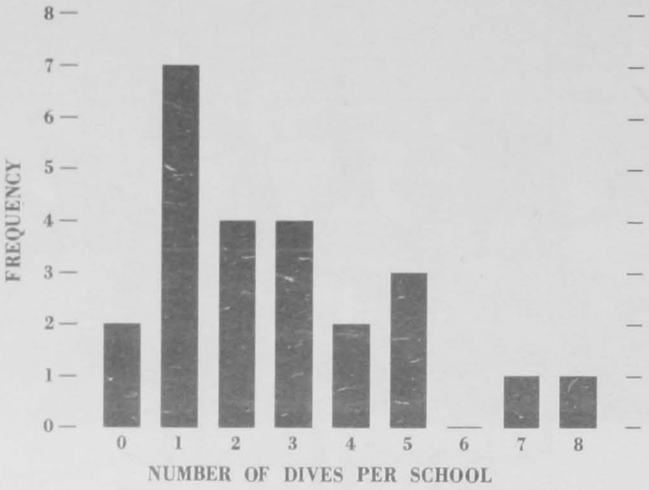

Figure 30.--Diving frequency of Hawaiian skipjack schools.

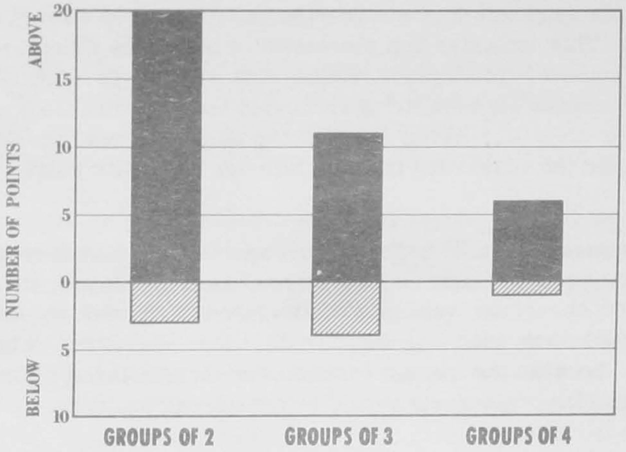

Figure 31.--Distribution of observed percentages of homogeneous groups above and below those expected by chance.

Recent studies have demonstrated that skipjack have a functional olfactory organ and that certain jaw movements might be involved when the sense of smell is being used.

A tank for use in measuring visual acuity was completed, necessary instruments were installed, and measurement techniques were perfected preliminary to the experiments. Visual acuity was measured after training skipjack to discriminate between vertically and horizontally striped squares. These patterns were projected onto a frosted glass plate at a window located at the end of an experimental trough. Response to the vertically striped pattern was rewarded with food, while movement toward the horizontally striped square brought an electric shock. After two weeks of training, the fish associated one with food and the other with punishment. Visual acuity experiments were then begun. Skipjack, swimming down the experimental trough toward the window with the projected patterns, accelerated when they approached close enough to perceive the vertical bars (reward) and decelerated when they approached close enough to perceive the horizontal bars (punishment). The distance between this point of discrimination and the projected patterns is used, with the width of the projected bars, to calculate visual acuity at different light intensities.

The three underwater viewing ports in the bow of the Charles H. Gilbert have been used to observe tuna, porpoise, flyingfishes, and some of the larger forms of drifting sea-life. Most small fish dart rapidly away from the moving ship, but tuna and porpoise swim within view of the bow windows for prolonged periods of time.

Very loose schools of skipjack have been observed, with 7 to 18 yards between fish. These schools, 3 to 6 feet beneath the surface, were only one fish deep. During periods of observation when small numbers of natural prey were sighted by the skipjack, the vertical color pattern appeared on the skipjack, and two or three of the fish nearest the prey organisms converged on them and fed. We have not yet succeeded in observing tuna in a feeding frenzy with natural prey concentrations although we have attempted to do so by heading the vessel through areas marked by the surface splashes of feeding fish. Although the tuna were sighted by the underwater observer, they dove immediately and were not visible for prolonged periods.

The bow viewing ports made it possible to observe in detail the behavior of porpoise when riding the bow wave. The postures of these free riders (fig. 32) demonstrated that they use their bodies rather than their upturned tail flukes to take advantage of the propellent forces of the bow wave. The flukes appeared to be used for control.

Observations of the larger members of the oceanic community of small, drifting animals from the bow chamber by day and, by their luminescence, at night were interesting but hard to record in numerical terms. It is hoped that the bow chamber can be used to estimate the abundance of surface fishes, but perhaps its greatest value will continue to be as a tool for making observations on marine mammals and fishes as the ship is actually moving with and within surface schools.

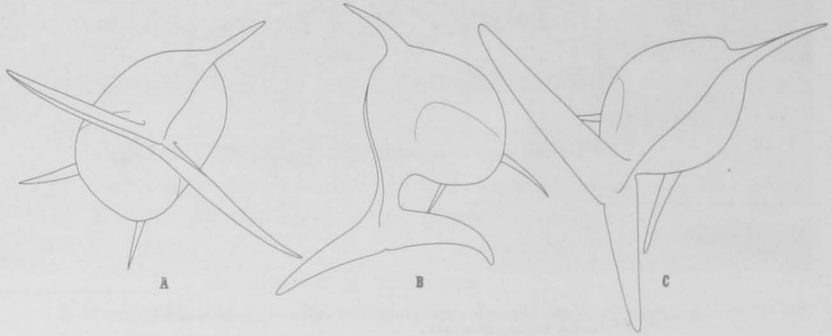

Figure 32.--Postures of the porpoise Tursiops sp. while riding a bow wave.

Our relative success in maintaining skipjack in large laboratory tanks has encouraged us to construct more shoreside facilities for the study of tuna behavior. A tank in which the hearing abilities of tuna will be measured has been completed. A complex of six tanks is under construction (fig. 33) for studying feeding and schooling behavior. This facility consists of 6 plastic pools, 24 feet in diameter and 4 feet deep, each serviced with 75 gallons of aerated salt well water per minute. Observation facilities permit both overhead viewing and viewing from beneath the water surface.

In the immediate future, studies of behavior will concentrate on describing the locomotory, feeding, and schooling behavior of tuna, on determining factors responsible for the effect of time of day on the feeding and schooling behavior of tuna, and on determining behavioristic responses involved in the formation of floating log communities. Studies of sensory abilities will determine visual acuity under various lighting conditions, the properties of color

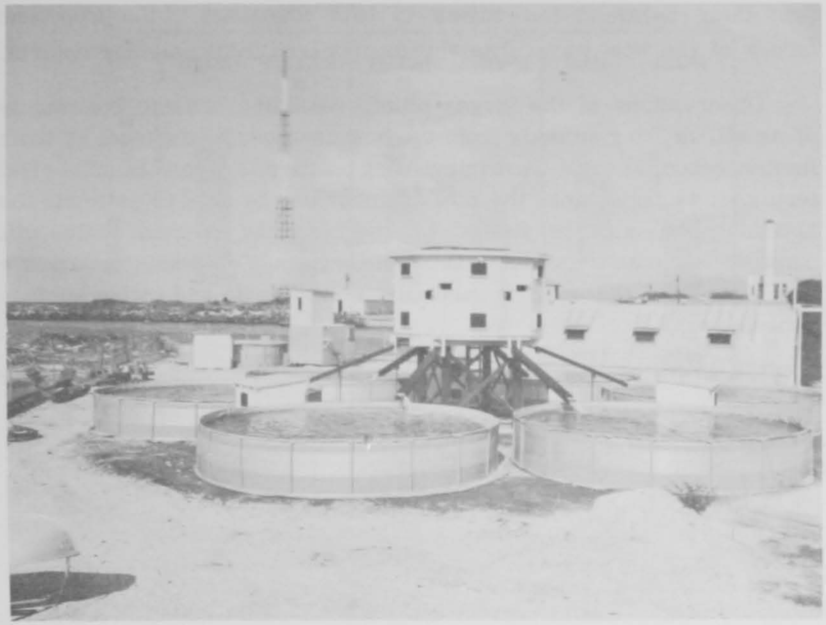

Figure 33.--New shoreside facilities for observing tuna behavior at Kewalo Basin, Honolulu.

vision in tuna, and the characteristics of the tuna's hearing ability. Skipjack will be used in most of these studies, but other species will be utilized where necessary. All studies will be aimed at description and understanding of the behavior and the sensory capacities of tuna, with the goal of predicting how a tuna will respond to both natural and artificial stimuli in the oceanic environment.

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