UNITED STATES DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE
BUREAU OF COMMERCIAL FISHERIES

Circular 321
September 1969

Progress in 1967-68 at the Bureau of Commercial Fisheries Biological Laboratory, Honolulu

COVER – Closeup view of decking on Hawaiian fishing vessel, taken by Tamatsu Nakata.

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ABSTRACT

This report deals with research results achieved by the Bureau of Commercial Fisheries Biological Laboratory in Honolulu from January 1, 1967 to June 30, 1968. Described are projects designed to improve the efficiency of the Hawaiian fleet for skipjack tuna; work in immunogenetic analysis that is clarifying the relations of the skipjack tuna subpopulations of the Pacific Ocean; investigation of the shrimp and bottom fish resources of Hawaii; advances in oceanographic research, including discovery of a wake in the lee of Johnston Island, as predicted by theory; the effects of oil spillage on a Pacific island; and the first scientific review of the international CSK (Cooperative Study of the Kuroshio and Adjacent Regions). Publications for the period are listed.

INTRODUCTION

This report deals with research results achieved by the BCF (Bureau of Commercial Fisheries) Biological Laboratory in Honolulu from January 1, 1967 to June 30, 1968.

Highlights of the reporting period include:

1. Attempts to improve the efficiency of the present Hawaiian pole-and-line fleet for skipjack tuna *(Katsuwonus pelamis)*. Skipjack tuna are the basis of by far the largest fishery in Hawaii, but the fleet takes only a minuscule part of the potential annual yield of central Pacific skipjack tuna, which has been estimated as being hundreds of thousands of tons.

2. Experiments aimed at establishing an independent bait-fishing industry. At present the vessels of the fleet seine for their own bait, the preferred species being the nehu, a kind of anchovy. Much time is spent catching bait, when it could be better spent catching tunas.

3. The search for an alternate or supplemental bait. The threadfin shad, a fish introduced into Hawaii as forage for bass, apparently is as effective as the nehu in attracting skipjack tuna.

4. Analytical studies of day-to-day operations of the Hawaiian fleet. These investigations have produced data of kinds and quantities never available before.

5. Use of continuous-transmission, frequency-modulated sonar to study the movements of tunas underwater. The sonar is being used both in the active mode, in which a signal from the ship is reflected by the body of the fish, and the passive, in which a "sonic tag" fed to a fish sends out signals that are detected by the sonar. By both means, fishes underwater can be tracked for periods of hours.

6. Discovery that the skipjack tuna caught in the western Pacific Ocean are genetically distinct from those caught in the eastern and central Pacific. The dividing line between the groups apparently lies far west of Hawaii.

7. Delineation of commercial shrimp resources off the Hawaiian Islands. Several beds of shrimp have been found that might supply a local specialty market, even though a large commercial fishery appears out of the question.

8. Continuing studies of the longline tuna catches of the South Pacific, as they are reflected in the landings at American Samoa. The fishery now extends almost the breadth of the South Pacific Ocean.

9. Confirmation of the theory that the principal changes in the temperature of the waters around Hawaii during the first 7 months of the year are due not to the changing seasons, but to the advection of warm water into the area from the south and southeast. This warm water, less saline than that which prevails during the winter, appears to be associated with the large summer catches of skipjack tuna.

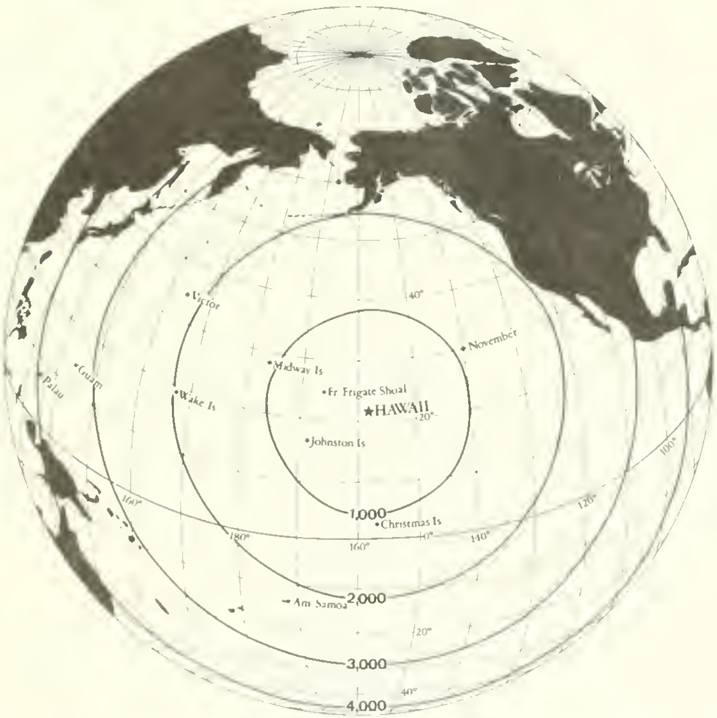
10. Depiction of a pronounced wake effect in the lee of tiny Johnston Island. Predicted by theory, the wake was clearly defined in a cruise made early in 1968. A wake was also found off the island of Hawaii.

11. Investigation of the effects of oil spillage at Wake Island. Such accidents have aroused the concern of authorities throughout the world since the *Torrey Canyon* disaster in the English Channel. At Wake, deleterious effects were relatively slight, owing to a combination of circumstances.

12. Convocation in Honolulu of the first scientific review of the results of the CSK (Cooperative Study of the Kuroshio and Adjacent Regions), an international marine research project in which 11 nations have joined.

A list of publications during the period concludes the report.

THE HAWAII AREA



The Hawaii Area of the Bureau of Commercial Fisheries covers a wide reach of the tropical and subtropical Pacific Ocean (fig. 1). Between Palau in the Trust Territory of the Pacific Islands, where the Hawaii Area maintains a field station, and the Laboratory in Honolulu lie more than 4,000 miles of ocean, a distance about as great as that between New York and Rome, Italy. The second field station, at Pago Pago, American Samoa, south of the Equator, is 5 hours and 10 minutes by jet flight from Hawaii. From Honolulu northwest to Weather Station Victor, 1 of 10 Pacific locations from which the Laboratory maintains continuing data collections, is more than 2,000 nautical miles.

FIGURE 1. Formerly known as POFI (Pacific Oceanic Fishery Investigations), the Hawaii Area of the Bureau of Commercial Fisheries has conducted research on 13 million square miles of the Pacific Ocean since 1949. From its headquarters in Honolulu, it studies tuna fisheries there and through field stations in Pago Pago, American Samoa, and Palau, Trust Territory of the Pacific Islands. It administers research projects under Federal Aid to Commercial Fisheries Research and Development Act (P. L. 88-309) in American Samoa, Guam, and Hawaii. It maintains continuing data collections from Johnston Island, Christmas Island, Vaitogi, Tutuila, American Samoa, Guam, Weather Station Victor, Wake Island, Midway Island, French Frigate Shoal, Weather Station November, and Koko Head (Oahu). Labeled circles show distances from Honolulu in nautical miles.

FIGURE 2. Between January 1950 and December 1966, research vessels of the Hawaii Area sailed about 900,000 nautical miles on oceanography and fishery cruises. Currently, the Hawaii Area operates two ships, the 120-foot CHARLES H. GILBERT and the 158-foot TOWNSEND CROMWELL. Each vessel is at sea more than 230 days of the year. The other vessels that have been operated by the Hawaii Area are the HENRY O'MALLEY, JOHN R. MANNING, and HUGH M. SMITH.

The area under investigation contains about 13 million square miles—a region more than four times the size of that occupied by the contiguous United States. Much of it has been investigated repeatedly during research cruises. Between 1950 and 1966, vessels of the Hawaii Area sailed about 900,000 nautical miles (fig. 2).

A tree-shaded, pink stucco building adjacent to the Manoa Campus of the University of Hawaii is headquarters for the Hawaii Area and site of the Biological Laboratory, Honolulu (fig. 3). There the Laboratory's Chief of Scientific Services, Mary Lynne Godfrey, supervises a data-gathering network that covers almost the entire tropical and subtropical Pacific Ocean. Under her direction is a staff of young, college-trained technicians (fig. 4). Their job is to collect, compile, and process the basic data the Laboratory uses in its studies of the fisheries and oceanography of the Pacific.

Most of the technicians work at the Laboratory unless they are at sea on the two research vessels, *Charles H. Gilbert* and *Townsend Cromwell.* They take turns at manning the two field stations in Palau and American Samoa.

Daily a technician from BCF joins the fish handlers and buyers at Honolulu's two fish auctions and makes measurements and observations on the catches of boats from the Oahu-based 22-vessel longline fleet (fig. 5). The fishery technician rapidly records weights, lengths, and sex of the tunas and billfishes. He may also draw samples of tuna blood or collect eye lenses or stomach contents.

FIGURE 3. The principal building of the Hawaii Area, located adjacent to the campus of the University of Hawaii in Honolulu, houses the Area headquarters and the research staff of the Biological Laboratory. The principal building contains 8 laboratory work areas, 35 offices, a 5,000-volume library, and a seminar room. Behind it is a one-story annex that contains three laboratory work areas, five offices, a duplicating services area, a warehouse, and a garage.

At 5:00 in the afternoon a technician waits at the tuna cannery at Kewalo Basin in Honolulu as the skipjack tuna caught by the pole-and-line fleet are unloaded and trundled in for processing (fig. 6). He too measures and weighs fish and notes their sex, and collects blood samples.

Early or late, whenever and wherever in the Hawaii Area pelagic fish are unloaded in any quantity, the BCF has endeavored to be on hand, collecting data to further its studies. Work starts at 6:00 a.m. for the man stationed in American Samoa, where Japanese, Korean and Chinese

FIGURE 4. Technicians and other specialists constitute the staff of Scientific Services. Here Area Director John C. Marr congratulates Marian Y. Y. Yang, a mathematician in Scientific Services, who is receiving an award for outstanding work.

fishing boats unload their catches at two busy U.S.-owned canneries in Pago Pago.

In April 1965, in cooperation with the Trust Territory of the Pacific Islands and the newly established U.S.-owned fish freezing plant in Koror, Palau Islands, the Laboratory started similar sampling of fish taken in that area of the Western Caroline Islands.

The study of Pacific tuna is intimately linked to knowledge of the environment in which the fish live. With impressive cooperation over the years, agencies with stations all over the Pacific have been assisting in the collection of surface water temperatures and salinity samples for BCF. The collections continue to lead toward a better understanding of the movements of ocean currents and water masses and ultimately of the fish which live in them.

The cooperative program began in late 1953. Working with the District Commissioner of the Line Islands District, Gilbert and Ellice Islands Colony, scientists from the BCF arranged for Gilbertese employees on Christmas Island to gather the desired temperatures and water samples. This important set of records from the equatorial region has continued with few breaks to the present time.

In November 1955, employees of the Laboratory began a twice-weekly collection of water samples at Koko Head on Oahu, for chemical analysis. As is true of all the sampling sites, Koko Head water is characterized by open-ocean conditions.

In early 1957, weekly sampling was begun northwest of Hawaii, on Wake Island, French Frigate Shoal, and Midway Island. Then Johnston Island, to the southwest, was followed

FIGURE 5. The auction market in Honolulu disposes of fresh fish. Most in demand are tunas and billfishes from the longline fishery, which are here shown being examined by buyers. Laboratory technicians attend the auction to collect biological data on a random sample of the fish.

by Manele Point on Lanai and American Samoa in 1961, and Guam in 1962. From each island the Bureau is obtaining these useful sets of data by virtue of the helpful and longstanding cooperation of employees of the Weather Bureau, the Coast Guard, the Navy, the Departments of Agriculture of both Guam and the Government of American Samoa, and the Hawaii Division of Fish and Game.

In addition to data from sampling sites on land, BCF uses material from two ocean weather stations. The Weather Bureau and the Coast Guard have made possible the collection of daily surface water temperatures and weekly water samples from Weather Stations Victor (lat. 34°00'N., long. 164°00' E.) and November (lat. 30°00' N., long. 140°00' W.).

Under Mary Lynne Godfrey's supervision, the millions of items of data collected from this wide area are punched on cards for machine analysis.

These data are used by the Laboratory's scientists to study the resource potentials of the tropical and subtropical Pacific Ocean. The major resources appear to be:

(1) Skipjack tuna.
(2) Shrimp and bottom fish.
(3) Large tunas (bigeye, yellowfin, and albacore) and billfishes taken by longline.

This report deals with results of research on these resources and their environment.

FIGURE 6. The principal fishery in Hawaii is that for skipjack tuna. These fish are caught by pole and line. Most are unloaded at Kewalo Basin in Honolulu for sale to the cannery. Laboratory technicians meet the fishing sampans as they come in and note the weight, length, and sex of samples of the catch.

THE SKIPJACK TUNA RESOURCE

Published studies by the Hawaii Area staff have shown that the skipjack tuna resource of the central Pacific Ocean is capable of sustaining huge harvests over and above present catches. The potential is of the order of hundreds of thousands of tons. A unit of 100,000 tons of skipjack tuna has a value of $25 million to the fishermen. In 1967, the exvessel value of the U.S. shrimp catch was a record $103 million. Two 100,000-ton units of skipjack tuna would thus equal half the present value of that American shrimp catch. Added to the 1967 U.S. tuna catch, these units would bring the tuna total to $94.5 million. These figures are cited to suggest the magnitude of the payoff that would result from expanded skipjack tuna production in the central Pacific.

The Behavior of Tunas

Man has hunted several species of the swift and valuable tunas for thousands of years, but he has accumulated remarkably little reliable knowledge of the behavior of these fish at sea. Only within recent decades has there been a concerted effort to describe precisely how tunas behave in the open ocean.

In 1967 biologist Eugene L. Nakamura summarized the literature on field observations of the tunas for an international conference of fishery experts in Bergen, Norway. Nakamura found that the conditions of fishing have set sharp limits on man's knowledge of the tunas. The most widely used methods of catching the fish require that the tunas be hungry; consequently a substantial part of the body of observations concerns feeding behavior.

Sometimes tunas appear to seek out a single species of small fish as their prey; at other times they do not. Near Hawaii, for example, tunas sometimes appear to prefer the fishes that live at a depth of 1,000 feet or more, rather than the surface-living fishes or baitfishes thrown in the water.

A hungry fish may bite poorly or well. One scientist has found that between the extremes of starvation and satiation, the less food the fish have in their stomachs, the less likely they are to bite well. But others have found that fish with empty stomachs bite very well.

Skipjack tuna, the most plentifully caught of the species in the Pacific Ocean, display vertical bars on their sides during feeding (fig. 7). Scientists have said that the catch will be good when the fish exhibit these bars.

Tunas travel in schools. The size of these schools can vary tremendously, from a few fish to hundreds of thousands. In 1958, near San Benito Island, off the west coast of Baja California, purse seiners took 4,000 tons of bluefin tuna from a single school. This is about 80 per cent as much fish as is caught by the entire Hawaiian skipjack tuna fleet in a whole year.

Almost all species of tunas have been reported in mixed schools of two or more species, Nakamura says. But according to research conducted by Heeny S. H. Yuen at the Laboratory in Honolulu, these "mixed" schools probably

FIGURE 7. Skipjack tuna display pronounced vertical bars on their flanks when they are feeding. These bars interrupt the normally dark longitudinal stripes that characterize the skipjack tuna. These fish were photographed from a viewing port of the Laboratory research vessel CHARLES H. GILBERT. Species related to the skipjack tuna have also displayed such bars during a courting sequence.

are distinct schools of different species of tunas drawn together by a common stimulus, such as food.

In the eastern Pacific Ocean, site of the largest U.S. tuna fishery, skipjack tuna and yellowfin tuna are often caught together in purse seines. Scientists there have found that the excitable skipjack tuna calmed down when they were placed in a baitwell with the less erratic yellowfin tuna.

Schools of tunas usually consist of fish of the same size. The reason probably is that swimming speed varies with size and therefore that fish tend to school with other fish of the same size, which swim at the same rate. Thus even if two or more species are present, they will be approximately the same size.

A Japanese scientist has observed that schools of skipjack tuna that bite well maintain an orderly formation, "like marching troops"; those that bite poorly are "disorderly."

Some tunas school at night. Schooling is thought to be a function of sight; Nakamura thinks that at night the fish can see well enough to school by the light of the moon or the light shed by luminescent organisms. Some fishermen locate schools by watching for the luminescence of planktonic organisms disturbed by the fish.

In the eastern Pacific, purse seining for tuna has been most successful when a shallow upper mixed layer of the sea has been underlain by a pronounced thermocline. That is, the temperature drops off sharply within a few dozen feet. This sharp gradient is widely believed to deter tuna from sounding (diving) and escaping the nets. It may not, however, be temperature alone that causes the fish to avoid the thermocline. The water there is often turbid and sometimes the layer just below the thermocline has perilously little oxygen.

Like many other fishes, tunas appear to seek out floating objects. Some scientists think they use them as "landmarks" in a largely featureless sea. Recently, other scientists have said that the chief function of the floating objects appears to be to offer shelter. In any event, tunas are often found near logs, driftwood, floating vessels, even dead whales. Japanese scientists say that schools may wander as far as 7 or 8 miles from such an object and then return. If this pelagic homing does occur, Nakamura says, it implies that the tunas have some sort of navigational system.

The animal association of the tunas that is most profitable to man is that with birds, although in some fisheries the association with porpoises is more important. In the central Pacific, and in some other areas, fishermen depend almost wholly on sighting bird flocks to locate tuna, Nakamura says. "They even rely on the behavior of the birds to determine certain characteristics of the schools . . . The number and spread of the birds is an indication of school size. If the birds dive and circle fast and erratically, the fish are small. If the birds are seen diving into the water, the tunas have driven their prey to the surface and are feeding actively. If the birds scatter or sit on the sea surface, the fish have sounded."

The tunas are among the swiftest of the fish. Their measured speeds have been as great as 25 m. a second (56 miles per hour).

Nakamura, Chief of the Behavior and Physiology Program at the Laboratory in Honolulu, is interested in the behavior of tunas both at sea and in the laboratory. His group is concentrating on two aspects of the behavior of the fish: their reaction to different species of live bait and their subsurface distribution in the sea.

The Hawaiian Live-Bait Fishery

What the Hawaiians call "nehu" *(Stolephorus purpureus)* is a silver sliver of a fish that is one of the anchovies, much like the kind that come salted and packed in cans (fig. 8). The nehu is sporadically plentiful in Hawaii's dozen or so shallow bays, but probably is not abundant

FIGURE 8. A species of anchovy unique to Hawaii, the nehu is the preferred bait of the pole-and-line fishery for the skipjack tuna. The silvery nehu is found in shallow bays and harbors of all the Hawaiian Islands. At present the fleet spends almost as much time catching nehu as it does the valuable tuna.

FIGURE 9. Nehu not needed after completion of experiments in transporting and holding bait were made available to the Hawaiian fleet. Here a fisherman from one of the sampans places in a bucket nehu supplied by the Laboratory. The bait survived satisfactorily in the baitwells of the fishing vessels.

enough to support a fishery more than a few times the size of the present one; furthermore, the supply is undependable; and, even worse, the nehu is a remarkably fragile fish, prone to die in catastrophic numbers on handling.

The research program at Honolulu in 1967-68 included several studies of the nehu, in which two approaches were used: first, to attempt to improve the present primitive method of collecting, which often requires the ships to quit fishing for tunas and fish for baitfish, most of which are taken during the daylight; and second, to search for other small fishes that could supplement or replace the nehu. It has been calculated that if the fleet did not have to fish for nehu, but could purchase bait, it would have more time for its chief purpose—catching tunas. The Laboratory has experimented with fixed traps and lift nets to take nehu, the object being to develop methods that require less manpower than do present techniques. The results were only slightly encouraging; they emphasized what was already painfully known to the fishermen—that the nehu is a remarkably undependable fish. High catches were sometimes succeeded immediately by a run of dry hauls. This variablility was all the more pronounced because only two to five traps and nets were being used simultaneously. After experiments on catching and holding nehu, surplus fish were given the commercial fleet (fig. 9).

The experiments on the catching and handling of baitfish were carried out under the direction of Richard S. Shomura in Kaneohe Bay, on the island of Oahu. Work there ended in 1968; similar investigations may later be

FIGURE 10. The threadfin shad, a small fish common in the Mississippi Basin, was introduced to Hawaii in the 1950's as a forage fish for largemouth and smallmouth bass. Tests by the Laboratory have conclusively shown it makes a satisfactory substitute for the nehu in catching skipjack tuna.

made in Pearl Harbor, through the cooperation of the U.S. Navy and the State of Hawaii.

Success was achieved in the search for other small fishes that could supplement or replace the nehu. A small clupeid, the threadfin shad *(Dorosoma petenense)*, adaptable to life in fresh or salt water, was introduced into Hawaii in the 1950's and has established itself in fresh water reservoirs (figs. 10 and 11).

In the summer of 1968, under the direction of biologist Robert T. B. Iversen, the *Charles H. Gilbert* tested at sea the relative effectiveness of nehu and threadfin shad as bait for skipjack tuna. This carefully designed experiment showed conclusively that there is no important difference between catches made with threadfin shad and nehu—one takes just as many skipjack tuna as the other. This result is important, for two reasons: the first deals with tradition and prejudice—earlier attempts to locate an alternate bait in Hawaii concentrated on the cichlid, tilapia. The fishermen soon concluded that the tilapia simply was not a good bait for skipjack tuna. The result has been that only exhaustive tests, such as have been made, can now convince them that any other bait will serve to catch fish from the types of schools found in the central Pacific. The second reason the result is important is that the threadfin shad, although delicate, is not as fragile as the nehu; it survives in far higher numbers in the baitwells than does nehu. A higher survival rate means that a skipjack tuna vessel need not bait so often and consequently that fishing trips can be longer. It appears that even in seasons as mediocre as the past two have been, the catch depends largely upon how much time the vessels spend at sea scouting for and catching fish. Threadfin shad is still not the "perfect" bait, if such exists. The Hawaiian supply, which is restricted to a few fresh water reservoirs, may be small in relation to the demands that might be placed on it. Furthermore no one has cultured the animal. Therefore the search for other bait species will continue. The desired species must meet several criteria: it must be small, silvery, active, and capable of being raised in large numbers at a relatively low cost. Several possibilities are being considered.

Other Problems of the Fleet

Although a large resource is known to exist nearby, today the Hawaiian skipjack tuna fleet is a prisoner of its own inadequacies. The vessels are too small to venture far from the islands. Figure 12 shows the most productive areas fished by the fleet in the period 1948-65. None extends very far from shore. The heaviest catches are made within a few miles of bustling metropolitan Honolulu. The catch is highly seasonal; about 53 percent of it is taken in the summer, with a peak in July. These conditions persist in spite of the presence of a cannery in Honolulu that now has to import tuna to keep operating. Thus a ready market exists.

In an effort to diagnose some of the more pressing ailments of the industry, the Laboratory in the summer of 1967 posted seven observers on vessels of the skipjack tuna fleet. These men studied many aspects of the tuna boat operations. Their data afford the first exhaustive quantitative information on how the boats and the fishermen go about their job. This valuable fund of information was collected only through the whole-hearted cooperation of the tuna boat skippers.

At the height of the season, the vessels work a 15.5-hour day, leaving port before daybreak and returning after sunset. They see about six schools of tuna, successfully fish about 2.6 of them. The average catch per school is just short of a ton.

One valuable result of this survey has been the documentation of the very wide variability in some aspects of the operations. A boat with a good catch record takes about

twice as much fish per trip as one with a poor record. It fishes just about as many schools, but the yield per school is higher.

The object of this study is to design new and better fishing strategies and tactics for the Hawaiian fleet. This can be done only after careful analysis of the data. All the 1967 data have been transferred to cards and run through specially devised computer programs. The observational program was repeated in 1968. The resulting data are now being prepared for analysis.

The catch in 1967 was very poor; 1968 was somewhat better, but not much so. Badly needed now are data from a good season, so that operations under varying conditions of yield can be compared.

Preliminary results already provide numerical data where only estimates had been available before, such as the amount of bait taken and how it is used. The seven vessels studied used about 25,000 pounds of nehu as bait during June, July, and August 1967, according to Laboratory scientist Richard N. Uchida. Most of the nehu were used in chumming schools from which fish were caught. About four buckets (approximately 32 pounds) were used, on the average, for each successfully fished school. The skippers spent little bait on schools that could not be fished.

The material shows that in the summer of 1967, which was a poor skipjack tuna season, catches of fewer than 200 fish each were made in about three-fourths of the schools successfully fished.

FIGURE 11 Placid Wahiowa Reservoir, a few miles outside of Honolulu, holds the largest supply of threadfin shad in Hawaii. The fish were seined there and transported by truck to Honolulu for tests at sea.

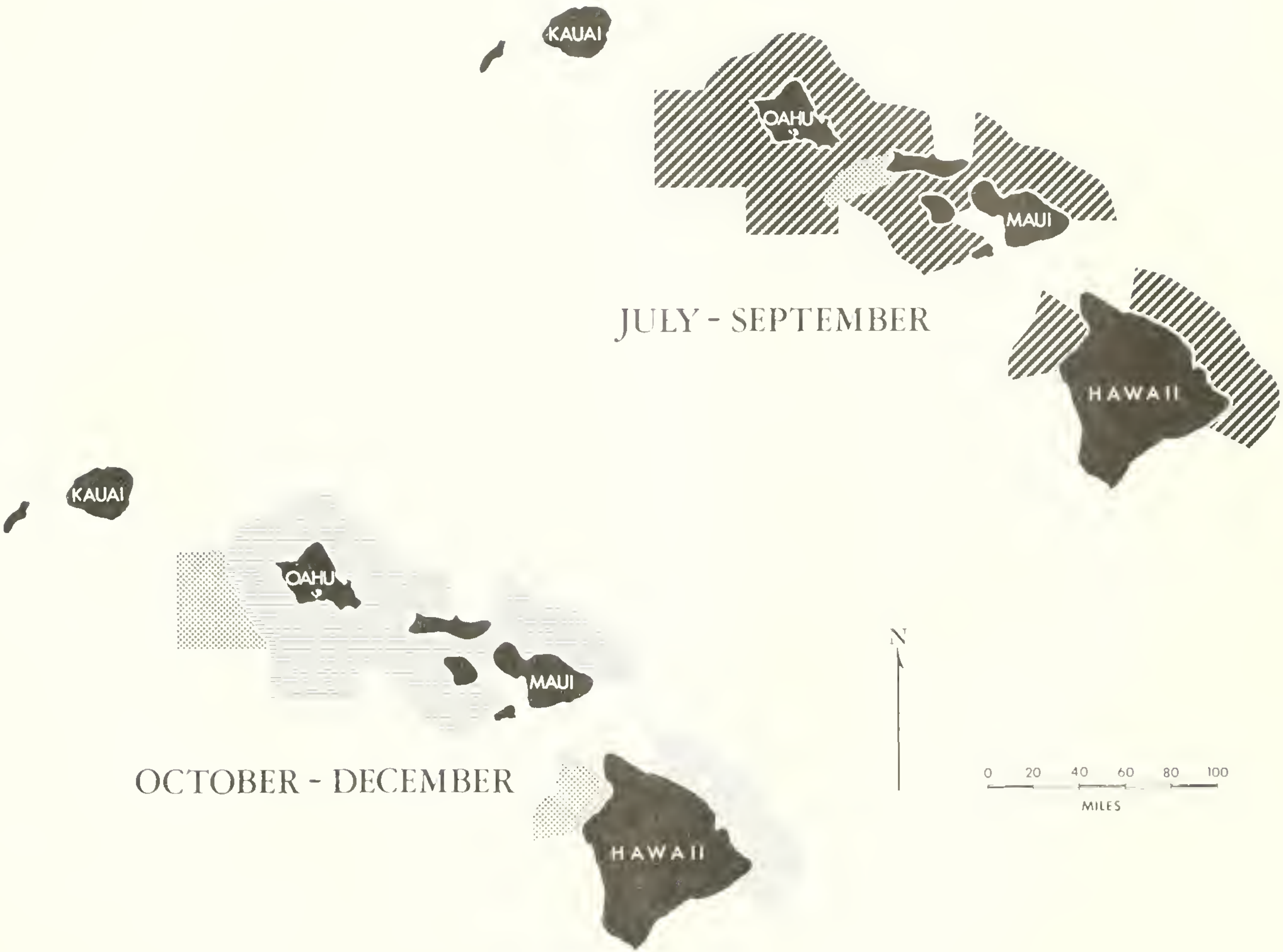
The skipjack tuna appear in schools in which generally all of the fish are about the same size. That is, there are schools of small fish and schools of large fish, but no schools of small and large fish mixed. The boats that fished the schools of small fish got smaller total catches than those that fished large fish. Schools of large fish provided catches as large as 10 tons, as against an average of 1 ton for all the catches.

The study shows that the Hawaiian skipjack tuna fleet attempts to fish about 80 percent of the schools sighted, but that only half of the schools sighted yield successful catches. A surprisingly large percentage of the fish are now escaping the fishermen's efforts to catch them, Uchida says.

The Larger Resource

Katsuwonus pelamis, the small tuna that is called skipjack tuna in English, aku in Hawaiian, is caught around the Hawaiian Islands throughout the year. Total catches have varied from 6 million to 16 million pounds a year, but be the year good or poor, the best catches have always been made in the summer. It has thus seemed probable to fishery scientists that in addition to a local population of skipjack tuna, the Hawaiian fishery is drawing upon a migrant population that visits the islands in greatest numbers in summer. Within the past few years, scientists at the Laboratory in Honolulu have concluded that these "season" fish, as the summer migrants are called, are part of a large population resident in the central Pacific Ocean. They hypothesize that one of the main spawning grounds of the skipjack tuna lies to the south and east of Hawaii in the equatorial central Pacific. Fish spawned there migrate to the west coast of Central America and Mexico, where about 70,000 tons of young fish are harvested annually. Within a few months, the hypothesis holds, the skipjack tuna then turn westward again, return-

FIGURE 12. The Hawaiian skipjack tuna fishery is highly seasonal; peak catches are concentrated in July. Most catches are made within 20 miles of the main islands. The data shown here summarize 18 years of the fleet's operations. (Catches off Kauai are not shown because of the unreliability of the data.) The average annual catch is about 5,000 tons. The estimated potential yield of the central Pacific is many times that figure.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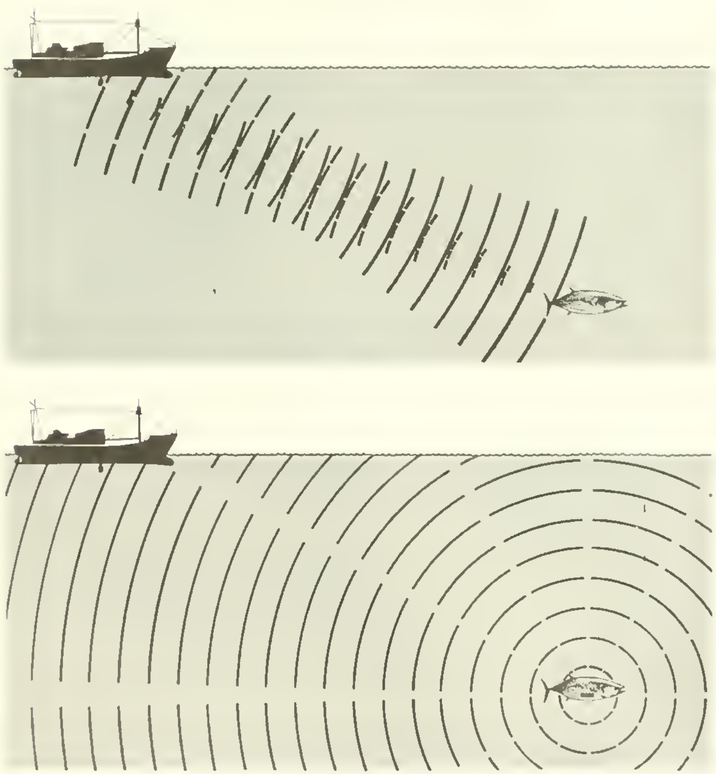
ing to the central Pacific. Several lines of scientific investigation have led to the formulation of this hypothesis. They all point to the probability that there exists in the central Pacific a very large population of skipjack tuna of which the only central Pacific fishery, that in Hawaii, takes a very small amount.



Sonar Investigations

Conducting the basic scientific studies that are required to bring this great resource into production, the Laboratory in Honolulu has equipped one of its research vessels, the *Townsend Cromwell*, with a complex, sensitive, and powerful electronic device, a CTFM (continuous-transmission, frequency-modulated) sonar, to study the movements of tunas in the water. The sonar emits a sound signal whose reflection by a solid object, such as a tuna or a tuna school, indicates to the operator the distance and direction of the object from the ship. In principle, the sonar resembles radar, but where the radar signal is an electromagnetic wave, the sonar uses ultrasonic pressure waves.

Complementing the sonar on the *Townsend Cromwell* is a 14-channel electronic device which records the information provided by the sonar. These data are automatically converted for analysis on large computers. Thus a tuna becomes, in succession, an echo picked up by the sonar (appearing on the sonar screen as a point of light), a number in analog form on magnetic tape, a number in digital form on another magnetic tape, and eventually Arabic numerals on a computer printout.

With information such as this scientists at the Laboratory in Honolulu will be able to determine the ways tunas move about in the ocean. At present, most knowledge depends on sightings of fish when they ascend to the surface in pursuit of prey. How long the central Pacific schools remain at the surface, to what depths they descend, whether they always maintain a schooling formation at

FIGURE 13. When the sonar aboard the TOWNSEND CROMWELL is used in the active mode (above), beams of underwater sound are reflected back to the ship from the body of the fish. When the sonar is used in the passive mode (below), a sound-producing device, which has been fed to the fish, emits a signal every second, and from this signal the movements of the fish can be followed. A combination of the modes will permit gathering more information on fish behavior.

night, how long a school lasts as a school (some scientists believe it may be throughout the lives of the fish), the routes they travel in the central Pacific—all this information, and more, will become available. To date most of the work has been done on schools in Hawaiian waters, as the operators have familiarized themselves with the equipment.

The scientists are using the sonar not only as active equipment but also as passive. In this mode, they listen for a special sound transmitter that is attached (or fed) to a fish (fig. 13). The tag now being used experimentally is 3 inches long and 1 inch in diameter. It broadcasts a sound pulse every second. To date, scientists have used the sonic tag on individual (i.e., nonschooling) tunas and sharks. They were able to track one shark for 18 hours, the tunas for shorter periods. They hope that further development of the sonic tag will enable them to track tuna schools through the depths for longer periods of time.

By determining the behavior of individual tunas and of tuna schools in Hawaii waters, the scientists expect to gain information that will allow them to design specialized gear to make possible the development of this great potential resource, according to Heeny S. H. Yuen, who heads the sonar project.

Skipjack Tuna Subpopulations

In January 1968, Kazuo Fujino of the Laboratory in Honolulu spent 2 weeks fishing for tuna in Tahiti. His object was not food or sport, but to fill small plastic vials with blood drawn from the fish he caught. Fujino is a scientist whose specialty is the population genetics of marine animals, particularly the tunas, and blood samples afford some of the data he needs.

Tuna abound in Tahitian waters. Laboratory research cruises in the 1950's found many schools in the Society and nearby Marquesas Islands. Skipjack tuna are particularly plentiful. It was the skipjack tuna that Fujino flew 2,500 miles to study, for one large gap in scientific knowledge of the skipjack tuna concerns the precise relation of the fish of the central South Pacific to those elsewhere.

History provides incontrovertible proof that man can essentially wipe out a wild species. The buffalo is a spectacular example, as is also the largest of all living creatures, the blue whale. If the animal species of the sea are to be used wisely, they must not be so heavily harvested that they cannot reproduce themselves. In even an elementary economy, the farmer saves seed grain, the rancher does not slaughter all his breeding animals; in the as yet primitive economy of the sea, which is based on hunting, a fishery might risk devastating all of a species, or all of a species in a certain area, if it is not carefully managed.

Therefore scientists consider it essential to understand the relation of the fishes in one area of the ocean to those in another. Is there a single great skipjack tuna population in the Pacific Ocean, for example, so that if catches were increased in the central Pacific there would be enough of the stock left elsewhere to replenish that area? Or are there several smaller populations, or subpopulations, that do not interbreed?

The discipline of population genetics provides some leads to the answers to these questions. Population genetics depends upon the fact that certain characteristics are conveyed from one generation to the next according to rather well-understood laws. In fishes, as in many other animals, some of these characteristics are blood types and the presence of certain proteins in the serum.

Since it deals with populations, this branch of genetics requires large numbers of samples. The blood type of a single fish or a few dozen fish tells little or nothing about the population as a whole. But when hundreds of fish are sampled, the geneticist can draw valid conclusions about the population. The reason is that isolated subpopulations, groups of fish that do not breed with fish from other groups, will display distinct proportions of blood types or other characteristics; these proportions change only very, very slowly with the generations. Thus, in theory, if the fish from the eastern Pacific, say, never breed with fish from off Japan, then in the course of time distinguishable subpopulations would be established.

In practical terms, this would also mean that if the population from off Japan, as an example, were brought to so low a level it could not reproduce itself, the area would not be repopulated by fish from the eastern Pacific, for they might never reach Japan. If, on the other hand, a single great freely intermingling population exists, the depletion of fish in any single area would probably be followed in time by a replenishment of the supply.

To throw light on the subpopulation structure of the tunas, the Laboratory in Honolulu has established a Tuna Blood Group Center. To it come samples from all over the world. In recent months, shipments of skipjack tuna blood, for example, have been received from the Gulf of Guinea (off west Africa), and from the Trust Territory of the Pacific Islands in the western Pacific; and Fujino journeyed to Tahiti and more recently to Ecuador to obtain samples.

In all, 14,000 samples of tuna blood have been analyzed or are waiting for analysis at the Tuna Blood Group Center fig. 14). Because of the importance of the species to the future of tuna fisheries in the central Pacific, more blood samples (12,000) have been taken from skipjack tuna than from any other species, but albacore are represented by 300 samples, bigeye tuna by 500, yellowfin tuna by 700, southern bluefin tuna by 300; and there are still others.

From this storehouse of data, Fujino has drawn the materials for a series of scientific papers for journals in this country and abroad. In a paper published in 1967 he outlined what is known of the subpopulation structure of the skipjack tuna in the Pacific Ocean. Writing in the "Proceedings of the Forty-Seventh Annual Conference of the Western Association of State Game and Fish Commissioners," he reported that the skipjack tuna of the tropical western Pacific, those taken in the waters of the Trust Territory, belong to a subpopulation that does not appear in the Hawaiian fishery. Also different from the Hawaiian fish are those taken in Japanese coastal waters.

The Dividing Line

Seven Japanese fishing vessels operating in the wide and empty reaches of the North Pacific Ocean west of the international date line in the winter of 1967-68 made a catch unexpectedly valuable to science.

The craft were seeking large albacore, a tuna taken by longline fishing. The longlines also caught specimens of skipjack tuna. Smaller than albacore, the skipjack tuna is taken only infrequently on longlines, most of them being caught at the surface.

Through arrangements made by Japanese scientists samples of blood were drawn from 94 of the skipjack tuna at the Japanese port at which they were unloaded. These were then shipped by air to the Tuna Blood Group Center. There the serum was extracted and subjected to electrophoresis.

One of the many constituents of serum is an enzyme called esterase, whose biochemical function is to accelerate the synthesis or breakdown of an ester, a compound of an acid and an alcohol. Like many other proteins, the esterase in serum varies in the amount of electric charge the individual molecule carries. This means that otherwise indistinguishable esterases will move at different rates when they are subjected to an electric field of direct current under certain chemical conditions. In electrophoresis, a few milligrams of a sample of the substance being tested are placed on a plate of starch gel; when current is applied,

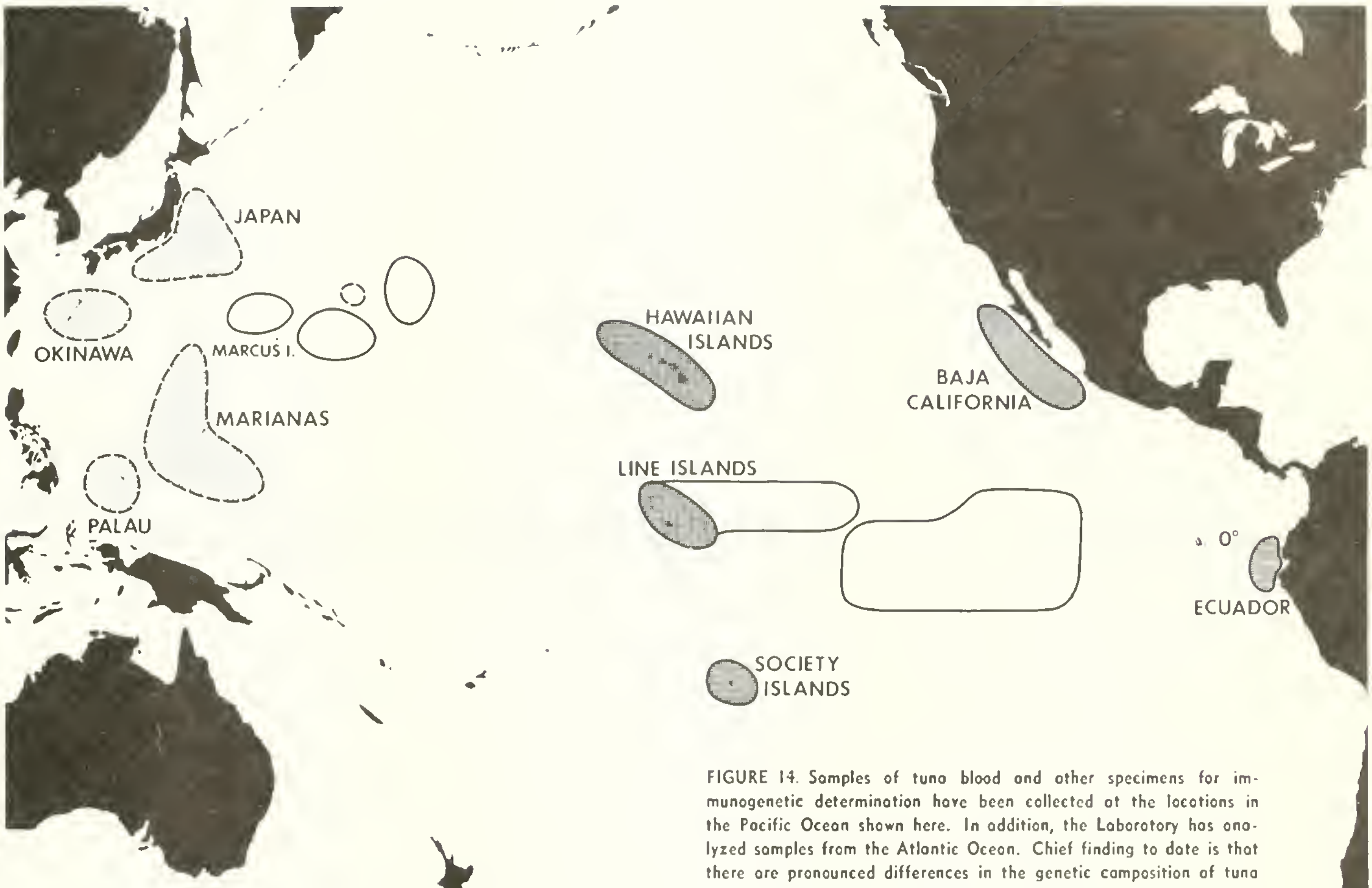


FIGURE 14. Samples of tuna blood and other specimens for immunogenetic determination have been collected at the locations in the Pacific Ocean shown here. In addition, the Laboratory has analyzed samples from the Atlantic Ocean. Chief finding to date is that there are pronounced differences in the genetic composition of tuna populations in the western Pacific (areas enclosed by dashed lines) and those in the central and eastern Pacific (areas enclosed by solid lines). Shading indicates that numerous samples have been taken from the area. The dividing line between the two subpopulations lies, in winter, somewhere near Marcus Island. The western Pacific sample shown to the northeast of Marcus Island was collected in summer.

the protein migrates toward the anode, the positive pole. The different forms of esterase are characterized by their relative mobility, the rate of migration. The samples are strained with a dye so that they appear as brown bands on the plate. Thus after the samples have been treated for a period of a few hours, there will be bands on different parts of the plates.

What the possession of these subtly different types of esterase may mean physiologically to the fish is uncertain, except for the broad biochemical function noted above. The thing that makes serum esterase interesting to fishery biologists is the fact that the distribution of the several forms is genetically controlled. In the serum esterase system in skipjack tuna, six phenotypes commonly occur, resulting from various combinations of three main types of serum esterase. If the proportions of each of these six types in fairly large samples differ consistently between populations, then those populations can be said to be genetically distinct.

On the basis of the serum esterase system, Fujino has found that skipjack tuna in the Pacific Ocean can be split into two populations: one found near the Japanese islands and to the south of them in the Marianas and Palau, and another found off the west coast of Baja California, Tahiti, the Line Islands, and Hawaii. And what made the samples taken by the Japanese fishermen operating between the date line and Japan so important, was that when proportions of six esterase forms are counted these samples proved to be of fish not from the nearby western Pacific group, but indistinguishable from those of the eastern and central Pacific. Thus a possible boundary between the populations lies far to the west of the international date line, a fact not known before.

THE SHRIMP RESOURCE

Recent studies of the shrimp and bottom fish resources of the Hawaiian Islands showed that a possible commercial venture could be initiated for a low volume specialty market. Oceanic islands, such as the main ones in the Hawaiian chain, are characterized by narrow underwater shelves. Water more than a mile deep can be found within 6 miles of the Hawaiian shore. Thus a large resource of animals that live on or near the bottom in shallow water could scarcely be expected in the Hawaiian Islands.

In an early investigation of these demersal resources of the Hawaiian Islands, a study of the fauna to a depth of about 5,000 feet was made in 1902 on the *Albatross*, research vessel of the U.S. Fish Commission (a predecessor of the Bureau of Commercial Fisheries). According to Howard O. Yoshida, Laboratory scientist who headed the trawling surveys in 1967 and 1968, most of the published records of deep-water fishes and invertebrates from Hawaii are based on specimens caught on the *Albatross* survey.

Between October 1967 and May 1968 the Laboratory in Honolulu, in cooperation with the Hawaii Institute of Marine Biology, University of Hawaii, made three exploratory bottom trawling cruises on the *Townsend Cromwell* (fig. 15). The strategy adopted in the surveys was first to locate the most promising areas on the basis of depth data and bottom notations on navigational charts, and then make detailed echo-sounding transects in those areas. Bot-

FIGURE 15. The main Hawaiian Islands, showing the 1,000-fathom (6,000-foot) depth contours. The crosshatching shows the areas surveyed by the TOWNSEND CROMWELL. Darker areas show principal concentrations of shrimp. These large shrimp were the most promising find, from a commercial standpoint. Many small, deep-water flatfishes were also taken.

tom-grab samples were taken to confirm the existence of trawlable bottom as indicated by the echogram. The surveys were restricted to a depth of 3,000 feet or less. About one-tenth of the potential area of this depth was surveyed, and a little less than half of this area was found to be trawlable. The largest trawlable expanse was north of the island of Maui, where drags as long as 4 hours were made. A total of 119 trawl drags was made around the islands. The most promising find, from a commercial standpoint, was a large penaeid shrimp, *Penaeus marginatus* (fig. 16). Other potentially valuable species were deep-water flatfishes about 6 inches long.

After the surveys, Yoshida concluded that although the Hawaiian waters do offer the possibility for establishing a commercial shrimp fishery, the resource is too small to supply anything but a minor, specialty market.

THE LONGLINE RESOURCE

The tuna populations of the various parts of the Pacific Ocean may or may not be interrelated biologically, but economically the fisheries most certainly are. A substantial portion of the American demand for tuna has for years been supplied by Japanese vessels operating in the Pacific, Indian, and Atlantic Oceans. Several studies, some of them by the Laboratory in Honolulu, suggest that the longline fleet is finding the tunas of the Pacific less plentiful than in the past.

What is happening to the fishery for the tunas is exemplified in an American possession, American Samoa. The principal element in the private economy of American Samoa is the fish business (fig. 17). The two canneries there, which are American-owned, provide jobs for about 1,130 American Samoans (of a total population of about 20,000 persons, over half of whom are children), and have payrolls estimated in 1964 by a French observer, F. Doumenge, at $2 million (in 1968 the figure would be higher). The canneries depend for their supply upon foreign vessels that fish almost across the breadth of the South Pacific Ocean (fig. 18). About 70 percent of the catch consists of albacore.

The Laboratory in Honolulu has carefully watched the fishery from its inception in 1954 and since 1963 has maintained a field station in Pago Pago. Analyses of the catch by biologist Tamio Otsu and his associates are beginning to suggest that the vessels will continue to find the albacore less profitable to catch. A declining albacore fishery would be a serious threat to the island's economy. The Laboratory is continuing its studies and is preparing detailed scientific analyses of the catches.

THE OCEANIC ENVIRONMENT

Oceanographic studies at the Laboratory in Honolulu are designed to provide environmental information in the areas of interest affecting the distribution of tunas. This is being done through (1) Pacificwide studies of the vertical and horizontal distribution of water properties, water masses, and field of motion through the analysis of a historic stockpile of oceanographic station data, (2) studies of the oceanographic climate in the trade wind zone of the North Pacific, and (3) studies of island wake systems. The Pacificwide studies form the basis of an "Oceanographic atlas of the Pacific Ocean," by Richard A. Barkley, published by the University of Hawaii Press late in 1968. The other two investigations will be discussed below.

FIGURE 16. Large shrimp akin to those that provide the bulk of the fishery elsewhere in the world were located on the ocean floor off Hawaii. Although they run as large as eight to the pound (heads on) —shrimp of good commercial size—it appears that the resource is limited and can support no more than a small, local, specialty market.

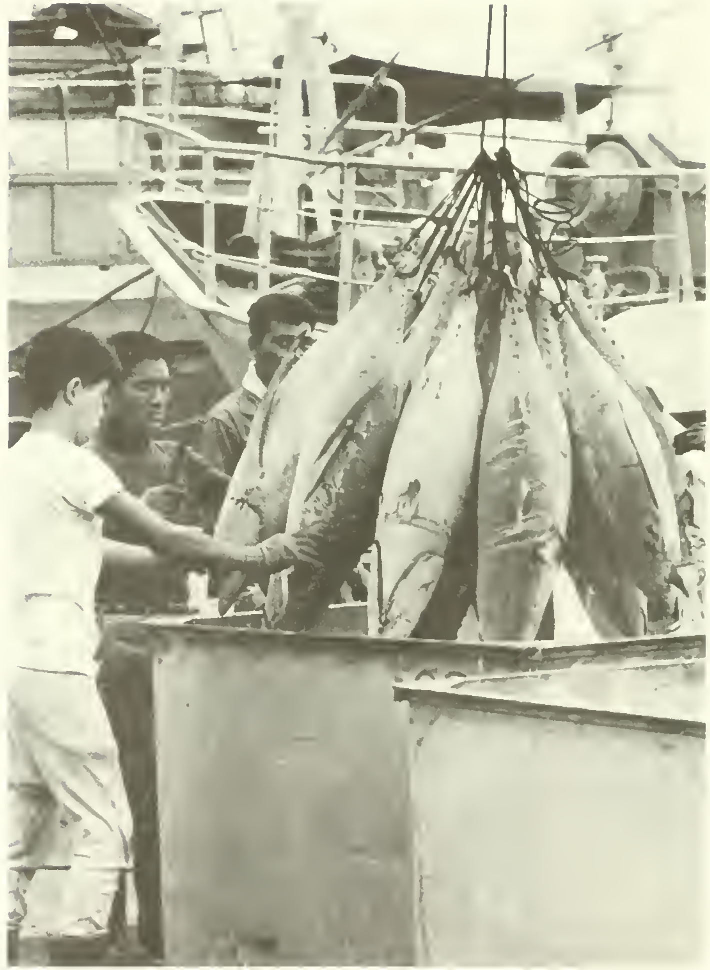


FIGURE 17. Fishing in American Samoa runs the gamut from the subsistence level to an industrialized operation that employs a substantial percentage of the citizens of American Samoa. Left, women and children search the reef for mollusks. They eat the animals, use the shells for the manufacture of curios. Right, frozen albacore caught in the South Pacific Ocean are unloaded for canning at one of the two American-owned canneries in American Samoa.

Fish and the Weather

In his Trade Wind Zone Oceanography Pilot Study of 1964-65, oceanographer Gunter R. Seckel compiled 18 months of data on oceanographic changes in the vicinity of the Hawaiian Islands. He is now seeking to relate these changes to conditions in the atmosphere. He has computed heat exchange between the sea and atmosphere from the Equator to lat. 35° N., and between long. 30° and 170° W. This is a region dominated by the trade winds. He has found that because of the prevalence of the trade winds, the Hawaiian area is chiefly one in which heat is lost from the ocean by the process of evaporation. Thus when the ocean waters warm significantly, they do so not primarily because of seasonal atmospheric changes in the immediate area but because of advection—warmer waters have entered the area from the south and southeast.

The scale of this advection is related to the intensity of the trade winds and the location of their center, he says. These vary from season to season and from year to year.

For the 12-month periods July 1963 to June 1964 and July 1964 to June 1965, there were net heat losses from the sea surface in the trade wind zone, although these losses were different for the 2 years. Since the amount of radiation from the sun and sky varies little from year to year, the differences were due primarily to differences in the rates of evaporation and these, in turn, were primarily due to differences in wind speed.

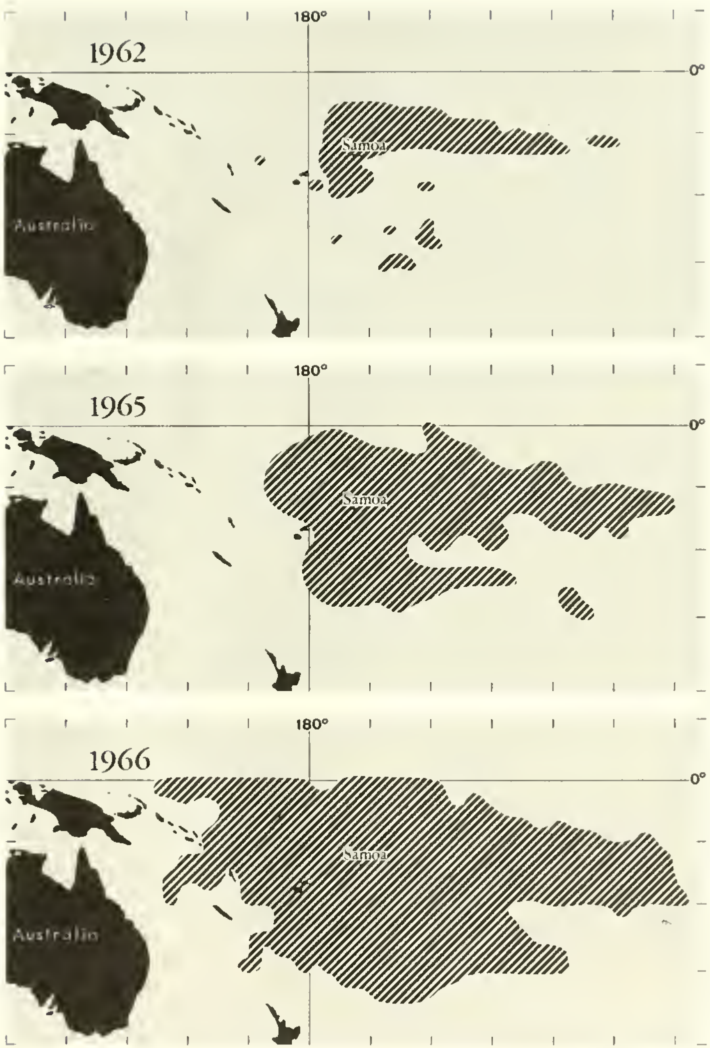


FIGURE 18. The albacore fishery based in American Samoa has grown rapidly and spread over a vast area in the South Pacific Ocean. Catch per unit of effort, however, is declining. This decrease, which is appearing in other major tuna fisheries, makes it all the more imperative that the central Pacific skipjack tuna resource be brought into production.

Advection is clearly shown by the fact that the heat exchange equations for Koko Head from February to September 1964 disclosed a net loss during this period. Yet there was a substantial increase in the temperature of the surface waters. This increase was due to the northward transport of water by currents.

Seckel has presented evidence that the appearance of the season tuna in the island area is closely correlated with changes in oceanographic conditions, and particularly the presence of warm water of relatively low salinity that flows into the area from the south and southeast.

Wakes in the Lee of Islands

Skipjack tuna of the eastern and central Pacific are found over a range of about 6,000 miles. As a rule they are caught, as is obvious from figure 12, no more than a few miles from the islands in Hawaii, and in the eastern Pacific as far as a few hundred miles offshore. If these very small needles in a very wet haystack are to be located, our knowledge of the mechanisms that concentrate them, i.e., oceanographic conditions, needs expansion.

The very first oceanographic cruise conducted by the Laboratory in Honolulu in 1949 located a natural phenomenon the implications of which are only now being explored. To the west of the great island of Hawaii a wide counterclockwise eddy was found. On a subsequent fishery exploration cruise in the area, skipjack tuna schools were found to be more plentiful near the eddy (350 miles from land) than near the shores of the Hawaiian Islands. Later, in 1962, E. C. Jones, a Laboratory scientist, studied the "island effect" on the zooplankton (which make up part of the tuna's food) near the Marquesas Islands in the central South Pacific Ocean. He found inshore forms of zooplankton organisms much farther to sea (80-100 miles) than could be explained by the operation of pure chance.

Thus the presence of islands in the ocean might alter the productivity of the waters considerably beyond the immediate shores.

A mechanism that could explain the presence of nearshore copepods far to sea and the presence of tuna concentrations hundreds of miles from the nearest islands has now been advanced by Richard A. Barkley, an oceanographer at the Laboratory in Honolulu. He has postulated that an island standing in the path of an ocean current would set up what is known as a von Kármán wake, a disturbance in the stream that results in the regular formation of eddies that move downstream some distance from the island (the distance depending on the island's size and the strength of the current). To test this theory, the *Townsend Cromwell* and *Charles H. Gilbert* went to sea in January and February 1968 to study the structure of the current downstream from the large island of Hawaii (diameter about 80 miles) and tiny Johnston Island (diameter about 10 miles). At Johnston they found a wake that neatly fitted the theory (fig. 19). Eddies rotating clockwise and counterclockwise formed alternately in the lee of the island. They took about 2 days to form and grow to full size. When they reached maturity, they began to migrate downstream (northwest) at a rate of about 2.2 miles a day. The eddies were about 50 miles across. The picture off Hawaii was more complex, owing to interference from other nearby islands, but eddies of the expected size and speed were found.

Since the counterclockwise eddies are divergent, bringing cool, enriched water near the surface, they should be more productive than adjacent waters and consequently provide more forage for fishes, including tunas. The eddies also would explain the non-random dispersion of nearshore forms far to sea observed by Jones.

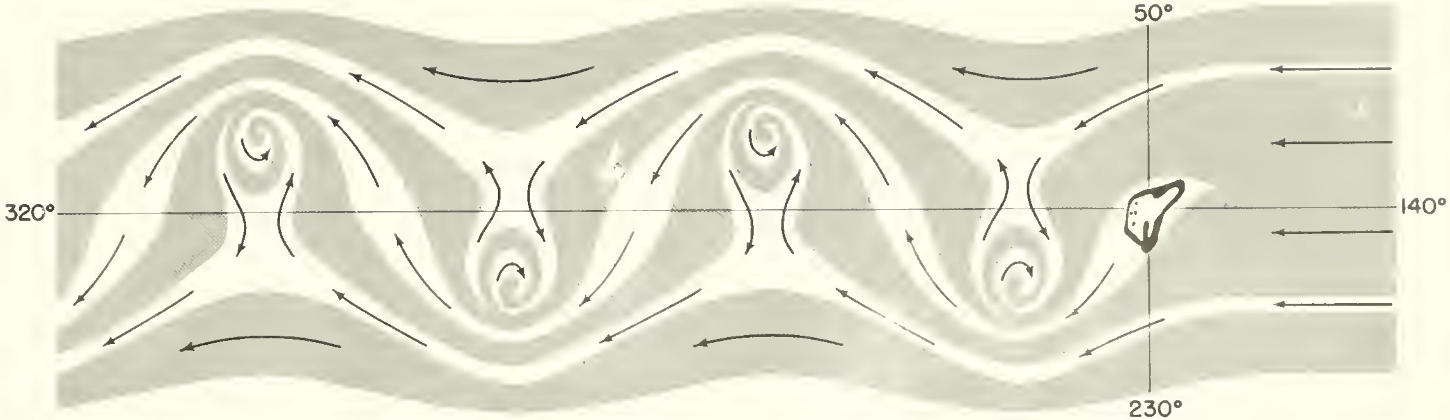


FIGURE 19. Off tiny Johnston Island, 820 miles southwest of Honolulu, oceanographers from the Laboratory found a wake set up on the downstream side of the island. Remarkably regular in pattern, a series of eddies was found in the lee of the island, rotating clockwise and counterclockwise alternately, and moving downstream. Compass directions are given.

Off the island of Hawaii, Laboratory scientists have found counterclockwise eddies several times. They are much larger than off Johnston Island, and more persistent (fig. 20).

Explanation of the wake phenomenon might explain many heretofore puzzling observations. Practically, it could allow fishery scientists to pinpoint areas in which concentrations of valuable fishes might reasonably be found.

THE MENACE OF OIL SPILLAGE

Wake Island, a tiny atoll halfway between Hawaii and Guam, is a refueling point on some Honolulu-Tokyo flights. In September 1967 it was the site of two disasters, one of which essentially cancelled the effects of the other.

Early in the month, the 18,000-ton tanker, *R. C. Stoner*, which was loaded with jet fuel, aviation gas, and a small amount of bunker oil, ran aground on the reef about 600 feet outside the entrance to the boat harbor at Wake. As her cargo leaked out, it spread over the small harbor and washed ashore on the adjacent beaches. Damage to marine life was fortunately very slight. Two Bureau staff members were sent to Wake to assess possible damage and to gain experience which would be useful in case a similar disaster occurred elsewhere in the Hawaii Area.

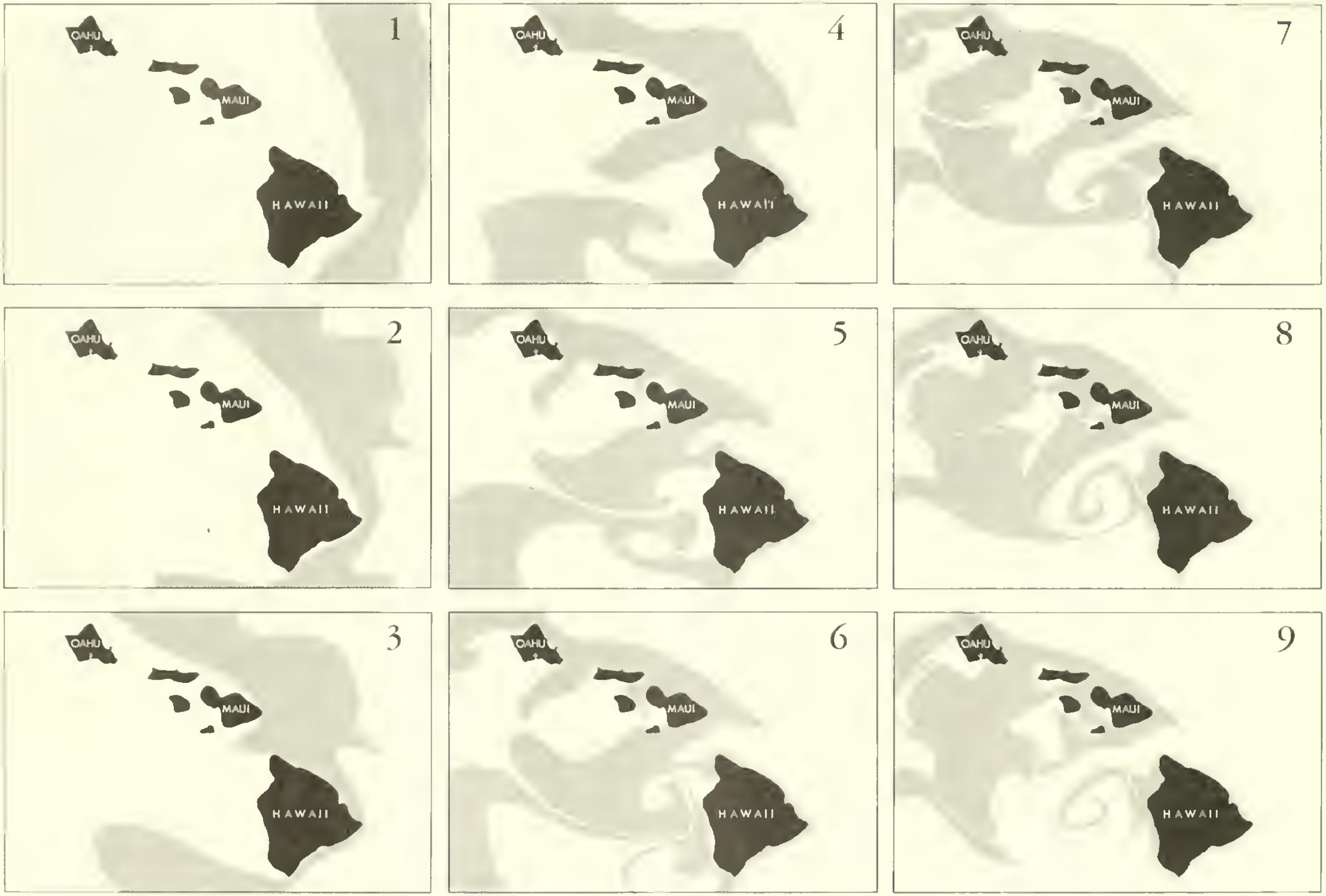


FIGURE 20. The 363,000 square miles of the Hawaiian area have been shrunk to the size of a large pool table in a three-dimensional scale model at the Laboratory in Honolulu. By injecting dye into the water, scientists can study the development of eddies in the lee of the islands. Here is an artist's rendering of one such experiment, showing the effects of a flow of water from the northwest (typical summer conditions). As the current moves around the islands, large persistent eddies are formed in their wake. The experiments shown here represent about a month of steady northeasterly flow.

FIGURE 21. The 18,000-ton tanker R. C. STONER lies at the mercy of the sea on the reef off the entrance to the small-boat harbor at Wake Island (upper left). Fuel leaked from the damaged tanker and washed ashore (upper right). Oil in the adjacent small-boat harbor reached a depth of about 3 to 4 inches. This was pumped off to a nearby pit and burned (lower left). Some fishes of the reef were killed (lower right); however, a fishery biologist from the Laboratory in Honolulu found a plentiful and apparently unaffected fish population when he made dives not far from the polluted beaches.

The two Bureau staff members, Reginald M. Gooding, fishery biologist, and Ollie Custer, physical science technician, flew to Wake on September 13 and made several surveys of the beaches and the waters just offshore. Both are skilled divers.

The jet fuel mixed with the water and gave it a straw color. Diving near the tanker, Gooding and Custer found that contaminated water irritated their skin. They observed schools of fish swimming normally in it, apparently unharmed.

According to Gooding and Custer, damage to the marine life of the atoll was confined to the boat harbor and to a narrow strip of water along about 2 miles of beach. They estimated that perhaps 3 tons or more fish and other animals washed up on the beach, killed by the deadly seepage (fig. 21). Over 90 percent of these consisted of typical fishes of tropical reefs, such as parrotfish, squirrelfish, and grouper.

On September 17, the 140-mile-an-hour winds of typhoon Sarah struck Wake, causing great damage to buildings and other structures. It blew away all the oil, however, and even partially scoured the oil fouled rocky banks of the boat harbor. After the typhoon, the water had returned to its usually clear turquoise color.

Several circumstances combined to keep the fish kill at a minimum, Gooding says. The two most important of these were (1) the cargo was not primarily bunker oil and (2) the coastal terrain was such that much of the fuel accumulated in a small-boat harbor and none was able to enter the shallow lagoon.

INTERNATIONAL ACTIVITIES

The Hawaii Area, BCF, because of its scientific interests, because of the presence on its staff of recognized authorities in fisheries research, and, to some degree, because of its geographic location, is deeply involved in international activities. Some of these are described here.

At the request of the Department of State, John C. Marr, Hawaii Area Director, has served for several years as U.S. delegate on the Indo-Pacific Fisheries Council, the oldest of the regional councils sponsored by FAO (Food and Agriculture Organization of the United Nations); he is currently serving as Vice-Chairman; in 1966, the Hawaii Area played host to the 12th Session of the Council. The Director, Hawaii Area, serves as a member of the Fisheries Advisory Committee of the South Pacific Commission.

In May 1968, at the invitation of the U.S. Civil Administration of the Ryukyu Islands and the Government of the Ryukyu Islands, three members of the Hawaii Area staff conducted a fisheries workshop in the Ryukyus.

At the request of the Department of State, the Director, Hawaii Area, serves as U.S. National Coordinator for CSK (the Cooperative Study of the Kuroshio and Adjacent Regions); by election among the National Coordinators, he also serves as Assistant International Coordinator for Fisheries; in April-May 1968, he served as Convenor of a Symposium on the Results of the CSK, which was held in Hawaii, and participated in the subsequent Fifth Meeting of the International Coordinating Group. The Kuroshio (literally, "Black Stream") is a warm oceanic current of variable width, depth, and intensity that sweeps from

FIGURE 22. These characters are for the Kuroshio, literally "Black Stream." Originating in the tropical and subtropical waters of the western Pacific, the great warm stream sweeps along much of the east coast of Japan before turning eastword. Associated with it are some of the richest fisheries in the world.

the tropical latitudes of the western Pacific Ocean along the Pacific shore of Japan as far north as northern Honshu and then veers to the east-northeast (fig. 22). It loses its identity as a distinct current near long. 160° E., where it merges into the great east-flowing North Pacific Current which dominates the circulation in midlatitudes east of the international date line.

Some of the great fisheries of Japan are located in or near the Kuroshio. Partly as a result of this circumstance, the Kuroshio system has been under intensive study since the late 19th century. Immense amounts of data have been collected over the years, but oceanographers have long recognized that there continued to be rather wide gaps in their knowledge of this interesting and productive region.

In the early 1960's a group of marine scientists conceived the idea of a broad-scale international study to fill in some of these gaps. CSK was established under the auspices of the United Nations Educational, Scientific, and Cultural Organization (UNESCO). Fishery aspects of the investigation were coordinated by FAO.

Eleven nations have agreed to cooperate in the study: the Republic of China, Indonesia, Japan, the Republic of Korea, the Republic of the Philippines, Singapore, Thailand, the United Kingdom (Hong Kong), the United States, the U.S.S.R., and South Viet Nam. The directing body of CSK is an International Coordinating Group, whose members are the National Coordinators and Assistant National Coordinators of the various nations. These officials are selected by their governments.

The scientists who planned CSK recognized that the origins of the great current must lie far to the south of Japan and that the Kuroshio influences and is influenced by oceanographic and meteorological conditions over a very wide sector of the western Pacific (hence the "adjacent regions" of the title). The area nominally under investiga-

FIGURE 23. Eleven nations have joined in the study of the Kuroshio and adjacent regions, which have been defined, as shown here, as extending from long. 160° E. to the Asian Continent, and from New Guinea to northern Japan. Included in the area is the Trust Territory of the Pacific Islands, which the United States administers.

tion reaches from long. 160° E. (a few hundred miles from Wake Island) to the shores of Asia, and from Hokkaido in the north to New Guinea in the south (fig. 23). It thus embraces about 6 million square miles, or an area two-thirds the size of the North American Continent.

Field work under CSK began in 1965. By 1968, a total of 98 oceanographic cruises had been completed. At times as many as 19 vessels of several nations were working simultaneously in the region and under a coordinated plan of operation—probably something of a record in the history of oceanography. An oceanographic data center had been established in Japan and a plankton sorting center in Singapore. These centers process data from the cruises of the several nations and issue reports synthesizing information obtained. Several such reports had appeared, and a scant handful of analytical papers had been published in the scientific journals, but until May 1968 in Hawaii, there had been no opportunity for general review of the scientific results of this massive oceanographic enterprise.

That opportunity came at the Symposium on the results of the CSK, held at the East-West Center, University of Hawaii, April 29 to May 2, 1968. The symposium was attended by representatives of all the CSK nations except Indonesia and Viet Nam. There were 14 participants from the United States, 7 from Japan, 5 from China, 4 from Thailand, 3 each from Hong Kong, Korea, and the U.S.S.R., 2 from Singapore, and 1 from the Philippines; observers attended from UNESCO, FAO, the World Meteorological Organization, the Indo-Pacific Fisheries Council, and the Pacific Science Association.

Immediately after the Symposium, on May 3 and 4, the International Coordinating Group held its fifth meeting, at which National Coordinators reviewed the findings of the Symposium and charted the future course of CSK.

Many new findings were discussed at the Symposium. Some were interesting because they were unexpected: For example, aggregation of fishes around drifting objects has aroused much speculation; at the Symposium Motoo Inoue and his colleagues of Japan reported that tunas cluster around drifting logs only if those are infested with particular species of burrowing animals that the tunas find tasty. Some papers suggested that the authors had discovered basic principles of how the physical world behaves: Kozo Yoshida of Japan and other scientists have found what may be a global phenomenon never described before—narrow, persistent bands of eastward flowing waters in the subtropics. Richard A. Barkley of the Laboratory in Honolulu presented a refinement of his model of the Kuroshio-Oyashio front, which he sees as a pair of von Kármán vortex streets arranged side by side. Some papers resolved previous speculation: Kazuo Fujino of the Laboratory in Honolulu showed that—as has been discussed—the skipjack tuna of the western Pacific clearly differ genetically from those of the central and eastern Pacific Ocean. Other papers possessed an interest that transcended the narrowly scientific: The group of Thai biologists led by Deb Menasveta reported on the bottom fish resources of the Gulf of Thailand and the Sunda Shelf. Already the basis of a rapidly growing fishery, these resources might contribute strongly to feeding the inhabitants of a very populous and often hungry part of the world if present catches can be sustained and similar catches made in other shallow areas in the South China Sea.

It was readily apparent at the meeting that the bulk of the work had been done in the northern sector of the CSK region. One of the strongest recommendations of the International Coordinating Group was that work be intensified in the South China Sea, an area which has been largely neglected scientifically. The International Coordinating Group agreed that synoptic surveys in the Pacific Ocean (i. e., to the east and south of Japan) should end in 1970, but stressed that no closing date can yet be established on the work in the South China Sea. Thus the next few years are likely to see intensified cooperative work in that area; this decision was one of the prime results of the meeting.

Another recommendation was that a second CSK Symposium be scheduled for 1970. The group also recommended that the results of this first Symposium be reported in two volumes under the editorship of John C. Marr.

The CSK meeting was the third in a series of meetings on fisheries and oceanography that have been arranged by the Laboratory in Honolulu and held at the East-West Center in the past few years, the first being the 12th Session of the Indo-Pacific Fisheries Council in 1966, the second the meeting of the planning committee for a conference on the role of fisheries and oceanography in the economic development of the Pacific Basin in February 1968.

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