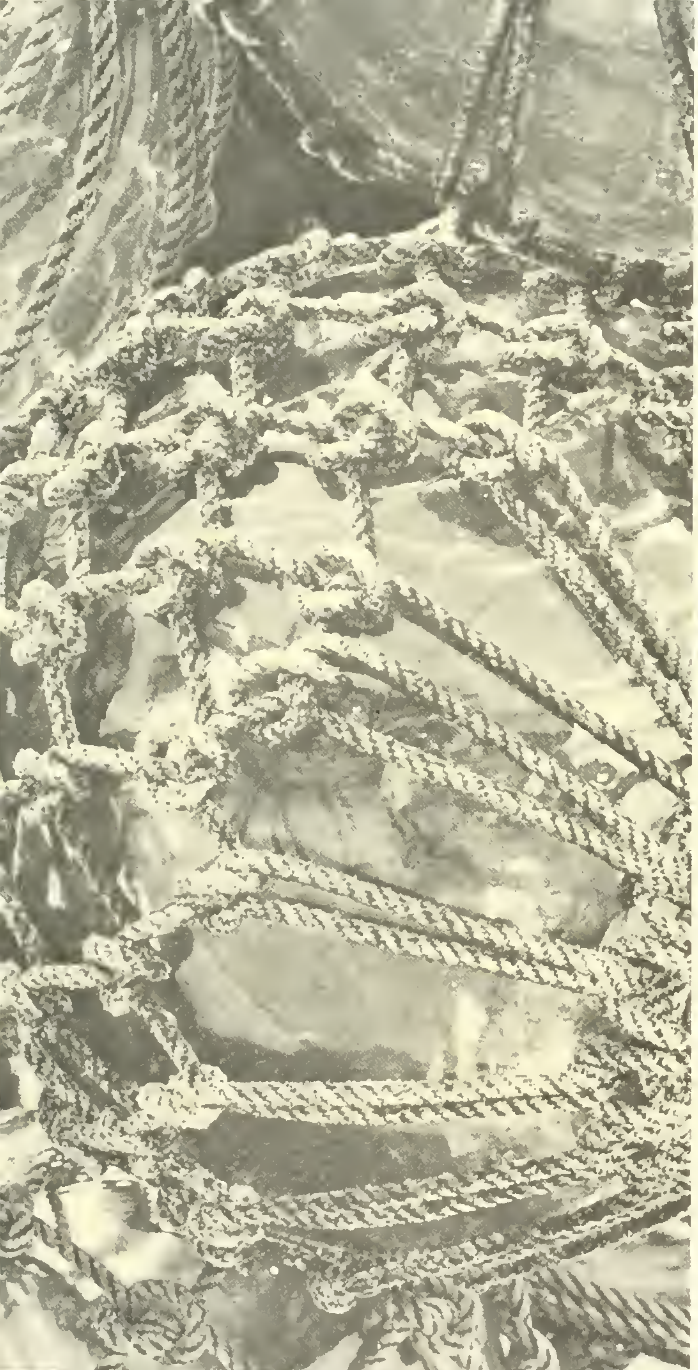

United States Department of the Interior / Fish and Wildlife Service / Bureau of Commercial Fisheries

1965 progress 66 bureau of commercial fisheries biological laboratory, honolulu

August 1967 Circular 274

UNITED STATES DEPARTMENT OF THE INTERIOR

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Progress in 1965-66 at the Bureau of Commercial Fisheries Biological Laboratory, Honolulu

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CONTENTS

ABSTRACT

This report deals with research results achieved by the Bureau of Commercial Fisheries Biological Laboratory in Honolulu from July 1, 1965, to December 31, 1966. Stressed are the studies which have provided the first numerical estimates of the size of the skipjack tuna population of the central Pacific Ocean, an untapped stock of fishes that could hugely increase the U. S. tuna catch. Investigations with a new, sophisticated sonar and a small two-man submarine are also described. Publications issued or in press during the period are listed.

INTRODUCTION

This report deals with research results achieved by the BCF (Bureau of Commercial Fisheries) Biological Laboratory in Honolulu from July 1, 1965, to December 31, 1966.

Highlights of the reporting period include:

1. A conference called by the Governor of the State of Hawaii which resulted in the first numerical estimates of the size of the unfished stock of skipjack tunas of the central Pacific. Estimates arrived at by different methods vary in detail but agree that the present U. S. catch of skipjack tuna (about 70,000 tons a year) could be doubled—or far more than doubled. These findings have lent new impetus to research on methods of improving and expanding the Hawaiian tuna fishery.

2. Firming up of plans for Project Porpoise, a multidisciplinary investigation of the oceanography, meteorology, fishery biology, and ornithology of the central Pacific Ocean from the Equator to lat. 30° N. Field work on the project is scheduled to begin in the fall of 1968.

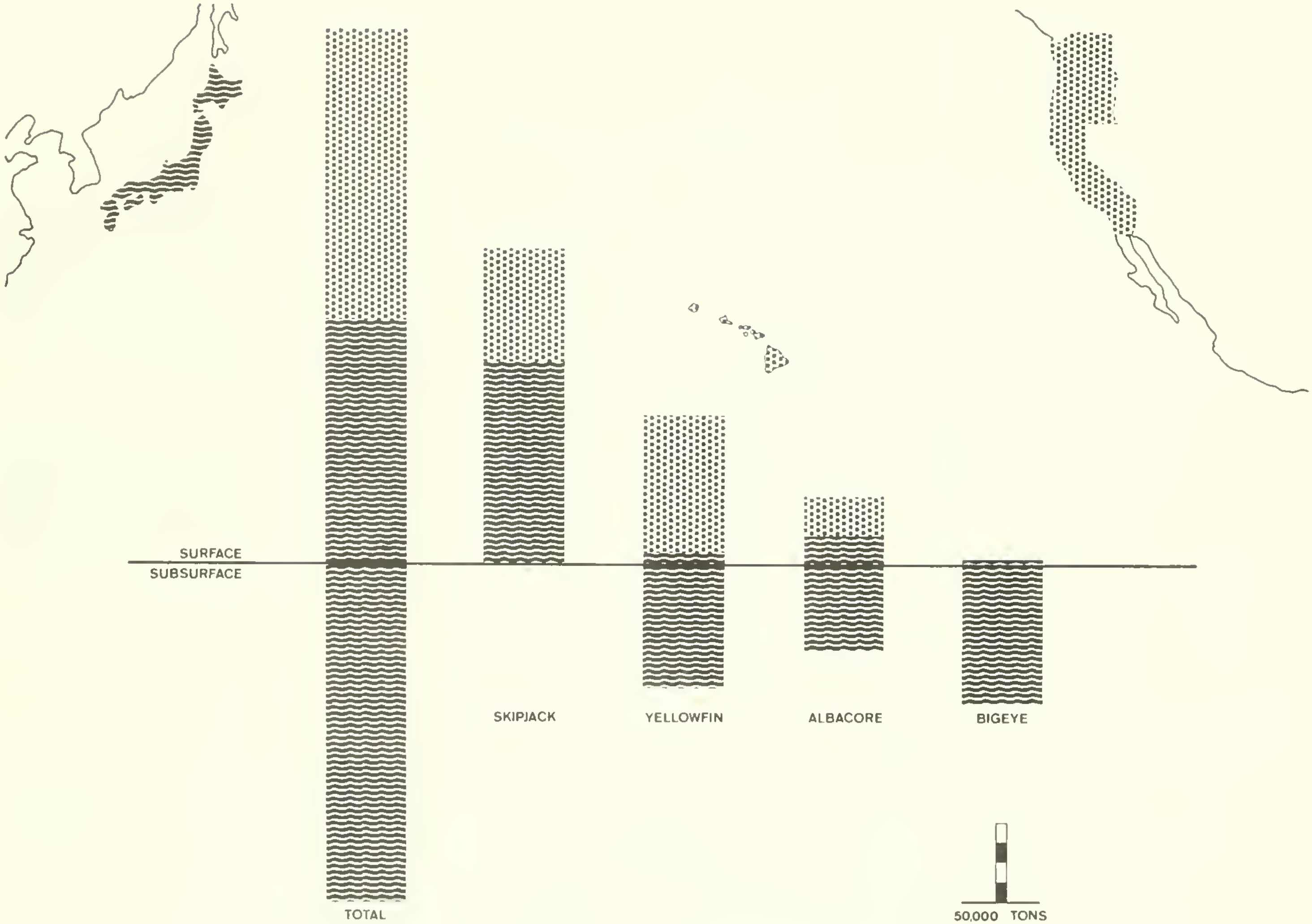
3. Discovery that the apparently chaotic currents off the western coast of the island of Hawaii can be explained in terms of a law of hydrodynamics discovered by the scientist Theodore von Kármán early in this century. This investigation has led to the conjecture that the rich fishing grounds on the coast of Japan may be explained by a similar phenomenon.

4. Use of a two-man submarine, *Asherah*, in pioneering studies off the coast of Oahu. This small vehicle gave fishery biologists an opportunity to observe directly the life of the depths. Among the things they saw were precious red coral growing on the underwater slopes of Oahu, lobsters larger than those now harvested by the Hawaiian fishery, and skipjack tuna feeding at a depth of 500 feet.

5. Investigations of the behavior and subsurface distribution of the tunas of the Hawaiian waters by use of a new continuous-transmission, frequency-modulated sonar aboard the research vessel *Townsend Cromwell*. Scientists have been able to study subsurface tuna schools at considerable distances from the ship—as far as 715 yards, or about half a mile.

6. The first meeting on American soil of the Indo-Pacific Fisheries Council of the Food and Agriculture Organization of the United Nations.

In terms of scientific publications, the period was uncommonly productive. At the end of 1966, members of the staff of the Laboratory in Honolulu had published 56 papers, and 33 more were in press. Two of these publications were books. The Proceedings of the Governor's Conference on Central Pacific Fishery Resources was published late in 1966 by the State of Hawaii. The Oceanographic Atlas of the Pacific Ocean was in press, having been accepted for publication by the University of Hawaii Press.


SURFACE
SUBSURFACE
TOTAL
SKIPJACK
YELLOWFIN
ALBACORE
BIGEYE
50,000 TONS

THE CATCH OF TUNAS

Most of the marine fishes bring the fishermen less than 5 cents a pound. Tunas are an exception. In both of the great tuna-fishing nations—Japan and the United States—tunas on the dock command about 15 cents a pound.

Tunas are relatively scarce. In terms of weight, for example, they amount to only about one-fifteenth of the mass of small herrings, sardines, and anchovies taken annually. In 1965, the total world catch of tuna was 2.6 billion pounds, or less than 1 pound for each inhabitant of the globe. Japan takes about 13 pounds of tuna for each of its citizens, the United States about one-tenth that.

Of the 30,000 fishes known to science, only about 100 species have a worldwide distribution—or rather, circumpolar, since they are taken in every ocean but the Arctic. Among these are some of the tunas. These large, swift, valuable creatures of the open seas have provided food, sport, and puzzlement to man since history began. Aristotle knew and wrote of them. They and their close relatives, smaller creatures that as a group are known as the "tunalike" fishes, constitute a world resource of relatively small size but great value.

The name—"tuna"—has a curious history. Lexicologists tell us we picked it up from our Latin American neighbors, who use the Spanish "atun." The Spaniards got the word from their Moorish conquerors, who in turn had based it on the Latin "thunnus." "Thunnus" is still used in science, and is the parent of the British "tunny." As for the Romans, they borrowed the word from the Greek "thynnos." Where did the Greeks find it? Webster's Unabridged tells us only that it is "not of Indo-European origin," but is akin to the Hebrew "tannin"—serpent, or sea monster. Far, far back in the shadowy past of human history men must first have noticed, and perhaps caught, the tunas.

Three commercially important tunas have names descriptive of their appearance—bigeye tuna, bluefin tuna, and yellowfin tuna. Another, the albacore, has a name whose original Arabic meaning is lost. The name, the skipjack tuna, apparently derives from its characteristic behavior of breaking the sea surface.

The tunas have been fished for thousands of years. The ancient Greeks, for example, knew them well enough to discern the appearance of year classes of varying strength in the bluefin tunas. On the whole, tunas are creatures of the warm seas. At the equatorial latitudes, the Pacific Ocean is somewhat wider than the Atlantic and Indian Oceans combined; probably it should provide a habitat for twice as many tunas as either of the other oceans. Catch statistics suggest that indeed it does. The Japanese longline fishery, the only one that circles the globe, in 1963 caught an estimated 89,700 tons in the Atlantic Ocean, 80,700 tons in the Indian Ocean, and 219,400 tons in the Pacific Ocean.

Between them, Japan and the United States, which hold about one-tenth of the world's population, account for well over half of the world tuna catch. The North Pacific tuna resource, which these countries share, is one of the biological wonders of the world. Five species constitute the bulk of the tuna landings of the North Pacific. These are the

FIGURE 1. Over the past several years, more skipjack tuna have been taken from the Pacific Ocean than any of the other tunas; yellowfin tuna has been a close second. Tuna catches are made at the surface—by pole and line, purse seining, and trolling—and at depth by the longline. Japan, which takes almost the entire longline catch and the western Pacific surface catch, is the leading tuna-producing nation. Skipjack tuna, taken primarily at the surface, heavily dominate surface catches; bigeye tuna lead longline catches. Histograms divide catches by Japan (lower portion of bars) and the United States (upper, checkered portion of bars), but do not denote location of catch.

albacore *(Thunnus alalunga)*, taken by both the United States and Japan; bigeye tuna *(Thunnus obesus)*, heavily fished by Japan and taken in small amounts by the Hawaiian longline fleet; bluefin tuna *(Thunnus thynnus)*, taken by the California purse seine fishery, but more heavily fished by Japan; the skipjack tuna *(Katsuwonus pelamis)*, fished by both countries, with Japan landing about twice as much as the United States; and the yellowfin tuna *(Thunnus albacares)*, also fished by both countries, with the Japanese catch again much larger than that of the United States. In 1965, skipjack tuna made slightly the largest contribution to the catch in weight; the U. S. and Japanese total amounted to 200,200 tons. Yellowfin tuna approached this figure; bluefin tuna, albacore, and bigeye tuna were caught in successively smaller quantities. The bigeye tuna catch, the smallest, and almost exclusively Japanese, amounted to 119,300 tons (fig. 1).

Because of their commercial importance, these species have commanded the interest of fishery scientists for several decades. There are four principal centers for research on Pacific tunas. Two of them, located in San Diego, Calif., are the Inter-American Tropical Tuna Commission and the BCF Tuna Resources Laboratory. Both are concerned primarily with the tunas of the eastern Pacific. In Japan, a nation which has been a leader in fishery research for many years, the work on high-seas resources has recently been consolidated in a new laboratory located in the historic city of Shimizu, famed in Japanese culture for the superb views it affords of Mount Fuji. The staff of the famous Nankai Regional Fisheries Research Laboratory, Japan's chief center for research on tunas of the high seas, will be transferred there.

In the central Pacific is the BCF Biological Laboratory, Honolulu. Founded by Public Law 329, 80th Congress (1947), this Laboratory (formerly called the Pacific Oceanic Fishery Investigations) by statute has as its mission the conduct of studies to ensure the maximum development and utilization of the high-seas fishery resources of the United States in the tropical and subtropical Pacific Ocean. Much of the early work of the Laboratory was dictated by the general lack of knowledge of the tropical Pacific and the main fishery resources—the tunas—of the area. According to John C. Marr, the present Director:

> The work was characterized by the study of the resources in relation to their environment. Results included the discovery of skipjack resources in the Marquesas Islands area (as yet unexploited), the discovery of yellowfin tuna resources in the equatorial Pacific (subsequently exploited by Japanese fishermen, but not by U. S. fishermen, for economic reasons), understanding of the equatorial current systems, including the discovery of the Cromwell Current, description of many features of the biology of the tunas, including establishing the transpacific migrations of North Pacific albacore, and some understanding of the relation between the distribution and abundance of the tunas in relation to the circulation of the Pacific. Progress in the general descriptive studies has led to the identification of more specific problems around which the work of the Laboratory is now oriented.

These more specific problems, during the period July 1, 1965, to December 31, 1966 were: investigations of the oceanography of the Pacific, studies of the ecology of the skipjack and yellowfin tunas and the albacore, research on subpopulations of Pacific tunas, investigations of the behavior and physiology of tunas, inquiries into the use of submersible vehicles for fishery and oceanography research, and—a special mission now drawing to its end—studies of the tunas of the Indian Ocean.

THE TUNAS OF THE CENTRAL PACIFIC

Three fisheries at present harvest the tunas of the central Pacific, that part of the great ocean lying west of about lat. 130° W. and east of the date line. By far the largest catches are made by the Japanese longline fleet, which has operated in the area since the mid-1950's. The other two fisheries are the Hawaiian pole-and-line fishery for the skipjack tuna and the Hawaiian longline fishery for the larger, older tunas of the ocean depths (fig. 2).

On the eastern edge of the Pacific Basin is still another tuna fishery, that conducted along the shores of the Americas by the fleet based in California. This is the richest of American tuna fisheries and one of the largest in the world. Biologists have shown that some of the skipjack tuna caught off the Americas are closely linked to those of Hawaii: the relation between the two fisheries may be very close.

The Hawaiian fishery is small. Eager that it should contribute more strongly to the Hawaiian economy, the State has enthusiastically supported the effort of the BCF Laboratory in Honolulu to estimate the true potential of the central Pacific. This reporting period has brought the first numerical estimates of the resources.

The State of the Hawaiian Fisheries

Hawaiian skipjack tuna landings reached record heights in 1965. More than 8,000 tons were taken, more tuna than the combined pole-and-line and longline fleets usually take in an average year. Fishermen who in ordinary years had to content themselves with an income of about $5,000 made $10,000 and upward in 1965. The bonanza ended in January 1966, as abruptly as if a door had slammed; skipjack tuna landings reached only 68 percent of those in January of the previous year. The summer season of 1966 was disappointing, and the year as a whole was barely average.

On the basis of the change in the rate of warming of the sea surface at Koko Head (fig. 3), southernmost point of the island of Oahu, on which Honolulu is situated, Gunter R. Seckel of the BCF Laboratory in Honolulu was able to warn in April that catches for 1966 would remain at or below average. When the surface water begins its seasonal warming early in the year and when "favorable" water of low salinity bathes the islands during the summer, the aku catch soars. Neither condition prevailed in 1966.

Seckel says, "We have found that two environmental indicators can be related to fishing that is better than average. The first is when the change of winter cooling of the surface water to spring warming occurs in February rather than in March. The second is when waters bathing the islands during the fishing season have a salinity of less than 34.8‰. The first index, since it occurs in February or March, is of predictive value with respect to the main aku season during the summer.

"In 1966 the initial warming took place in March and therefore indicated a fishing season with below average availability of skipjack tuna." This prediction was borne out by the catch.

Some evidence suggests that the island of Hawaii lay in the path of the "favorable" waters during the summer of 1966 and that catches there were above average, but the bulk of the fleet is based to the northwest on the island of Oahu.

Although the skipjack tuna fishery boomed in 1965, and had at least an average year in 1966, Hawaii's other large fishery, that based on the longline, demonstrated no such striking alternations in fortune. In 1965, the longline vessels took about 630 tons of tunas; their catch of billfishes brought their total landings to about 925 tons.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In any long-term view, neither fishery is so profitable as to attract substantial new capital. The ships are small and old. Few young men are entering the fleet. This situation is by no means confined to Hawaii. It seems characteristic of many of our fishing States. In the northwest Atlantic Ocean, for example, the total catch by all nations has increased 41 percent during the last several years, but the U. S. catch has declined 17 percent. The median age for trawler fishermen in Boston is 57 years. Hawaii's fishing industry has few if any problems that are unique.

Legislators of the State of Hawaii have expressed much concern over the condition of the fisheries. In 1965 this interest took the form of a resolution requesting Governor John A. Burns to convene a conference of fishery experts to review research on the fishery resources of the central Pacific and to assess their potential, with a view toward taking measures that would pump new life into Hawaii's fisheries.

The conference met in Honolulu and Hilo from February 28 to March 12, 1966. By design, it was restricted at first to a small group of scientists who reviewed current knowledge of the chief central Pacific fishery resource, the tunas. Later, when the deliberations of this group had been consolidated into reports, conclusions were discussed with government officials and members of the fishing industry. On the final day of the conference, the results were presented at a public meeting.

FIGURE 2. The "aku"—Hawaiian for skipjack tuna—vessel BUCCANEER returns to Kewalo Basin, Honolulu, from a fishing trip. At the dock is one of the vessels of the longline fleet. Vessels, gear, and techniques of both fleets are scaled-down adaptations of Japanese models. Together the pole-and-line and longline fisheries land about 6,000 tons of tuna a year. The skipjack tuna catch is by far the largest in the State and provides Hawaii with its only marine product for export to mainland markets.

FIGURE 3. Twice weekly, technicians collect water samples from Koko Head, southernmost point of Oahu. The advent of spring warming at Koko Head helps forecast the skipjack tuna catch for the summer season. The technician wears a safety belt while working on this rocky, wave-washed shore. The water sample is returned to the BCF Laboratory in Honolulu for chemical analysis.

The BCF Laboratory in Honolulu was the site of the first portion of the conference. Several of the members of the staff participated, as did representatives of the University of Hawaii, the Hawaii Division of Fish and Game, and scientists from the mainland United States.

The Hawaiian Aku Fishery

Two-thirds of the present population of Hawaii had not been born when the first of the still-operating aku boats entered the fleet. This craft, the sturdy old *Sunfish*, was contructed in 1926, says Richard N. Uchida. And more than 20 percent of the population of Honolulu has been born since the most recent aku boat, the *Angel*, was built in 1955. The *Sunfish* and most of the other vessels built before World War II are relatively small. Uchida chooses as the dividing line between small and large vessels a value of 800-gallon baitwell capacity, for the ships able to carry more bait are able to catch more fish. In those terms, only 3 of the 17 prewar vessels can be classified as large; 11 of the 13 constructed since World War II are large.

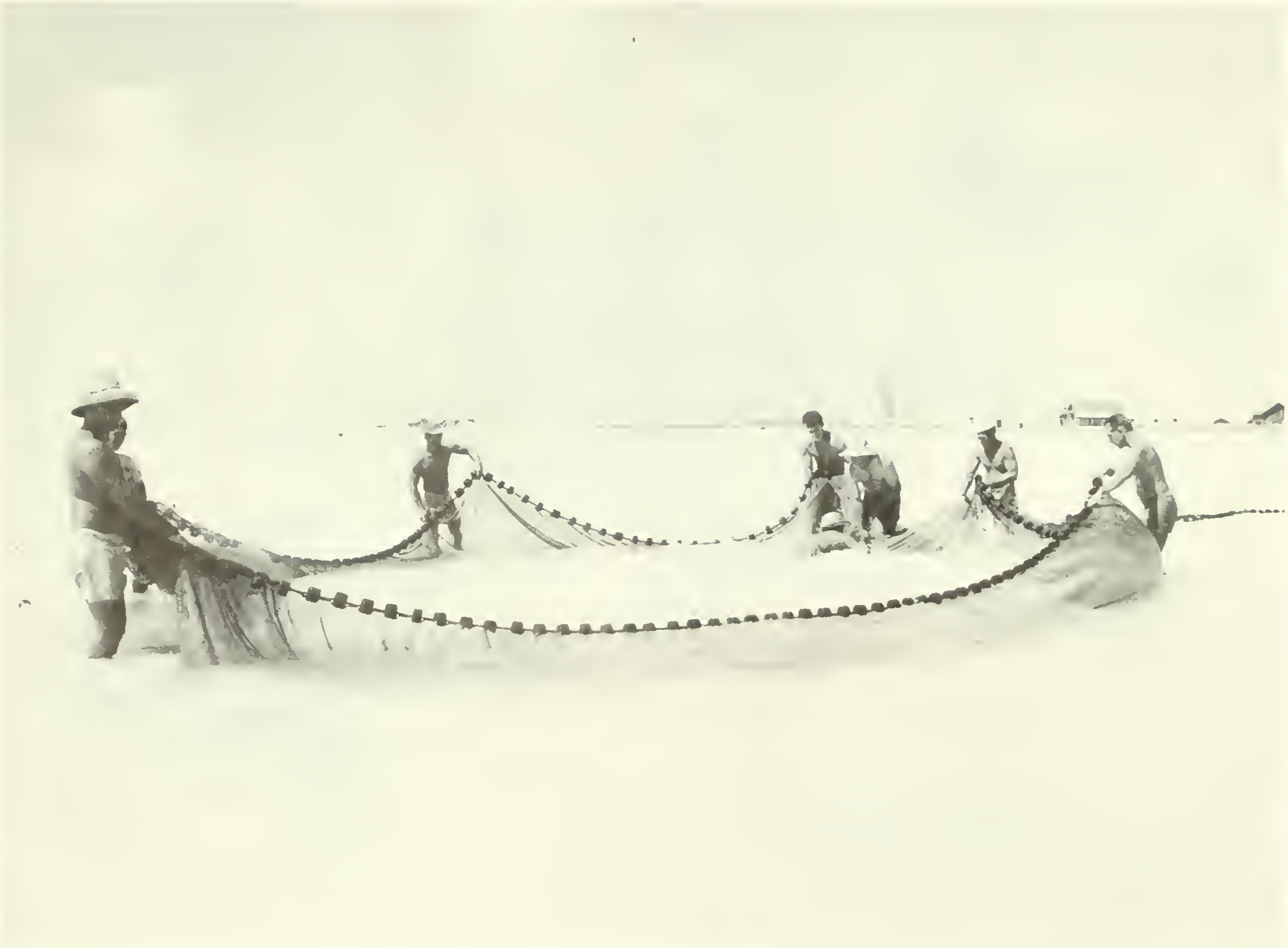
Statistics on the Hawaiian skipjack tuna catch go back to 1928, but those acquired since 1948 appear to be the most trustworthy; Uchida has used them in his various studies of the industry. They show wide fluctuations in the catch, from about 3,000 tons in 1957 to 8,000 in 1965. Monthly averages, on the other hand, very less. In any year, good or bad, the largest catches were made in the summer, and in only 5 years from 1952 to 1964 did July fail to bring the peak catch. In those few exceptional years, the top month was either June or August.

The skipjack tuna catch usually is about 60 percent in weight and 40 percent in value of the State's annual landings of fish and shellfish. Only the skipjack tuna catch provides Hawaii with a marine product of any consequence for export to the mainland; this is an important consideration in the thinking of business and government in considering how the State's marine resources are to be utilized. If the skipjack tuna industry can be expanded, a ready market exists for the product; the same does not now hold true for the other fisheries.

About 75 percent of the skipjack tuna are taken within 20 miles of the main islands, principally Oahu, Uchida says (fig. 4). In a good fishing year, such as 1959, this inshore area alone will produce as much fish as can be caught both inshore and offshore in ordinary years. There are several reasons for the predominance of, and reliance on, the inshore area. Some reasons are biological, some economic, and one, at least, a matter of topography. The biological reason is that the preferred baitfish, the tiny silver nehu, upon which the fishery heavily depends, is a frail and short-lived creature when it is taken from its brackish water habitat and transported to the open sea. Dead bait is no good in a live-bait fishery; the vessel is at a disadvantage if it does not use up the bait close to the baiting grounds (fig. 5). Economically, it obviously costs more to keep the vessels at sea long enough to reach the offshore areas; increased catches may be offset by higher running costs. Finally, in Pearl Harbor and Kaneohe Bay, the island of Oahu simply has baiting grounds more productive than those of the other islands. Kauai, for example, has no baiting ground as reliable as either of those on Oahu.

For their data on the effectiveness of fishing trips, scientists rely on returns made by the skippers to the Hawaii Division of Fish and Game. These reports divide the inshore and offshore grounds into numbered statistical areas. The skipper enters the amount of fish he caught in a particular area (the area is always large enough, by the way, to prevent his competitors from actually pinpointing his fishing ground). For some years, the Division did not request the skippers to note the trips on which they failed to catch fish; this important statistic will be available in the future, for the forms have been revised. Uchida says that these

FIGURE 4 Most of the fish landed in Hawaii are caught within about 20 miles of the islands. This map shows the geographical extent of the Hawaiian fishing industry in 1964. Landings of several species are included. Darkly shaded ocean areas show where the heaviest catches were made. By far the most productive area is that lying off the western shore of Oahu and within a few miles of downtown Honolulu. This region, which constituted about one-sixtieth of the area fished, contributed one-sixth of the entire Hawaiian catch. Other productive areas lie off the northeast coast of Hawaii and near Molokai and Lanai



"zero-catch" trips decrease as catch increases, as might be expected. From the sketchy data at hand, it appears that, in a good year, they may account for about 10 percent of the trips made. In a poor year, such as 1957, the ships may catch fish on only two trips out of three.

As has been mentioned, fewer and fewer young men are entering the fishing industry. Some of the active fishermen quit and seek shoreside employment; others become too old for the hard seafaring life. The problem of attrition is acute, if expansion of the industry is considered. In 1959, Uchida says, the small vessels averaged 8.4 men hooking per trip; by 1960 the average had sunk to 6.9. Large vessels presented the same picture. In 1959 they had an average of 10.4 men hooking per trip; by 1960 the average was down to 7.4. Interestingly, this decrease in manpower was not directly reflected in the catch rate, for during that period the fishermen switched to a more productive fishing technique. Formerly, the man swung a skipjack tuna aboard and caught it beneath his arm to release the hook. In the 1950's most fishermen changed to a more rapid, but far more tiring, method of fishing: they flipped the fish aboard and let the line go momentarily slack so that the writhing fish shook itself free, and then tossed the line back in the water. The work is backbreaking. Since unbruised fish command a premium in the fresh fish market, some skipjack tuna are still landed by the older method, but most are not. However it is done, pole-and-line fishing (fig. 6) is hard. It is a craft that is often passed down through the generations, from father to son.

FIGURE 5. The location and capture of small baitfishes take much of the time of the Hawaiian skipjack tuna fishermen. The most successful bait is the nehu, a local anchovy. Here crew members on an experimental fishing expedition to the Leeward Islands seine the shallow waters of a lagoon for bait. The Leeward Islands, consisting of atolls and isolated rocks, extend northwestward from Hawaii in a long arc reaching almost to the international date line.

FIGURE 6. Fishermen aboard the research vessel CHARLES H. GILBERT bring in skipjack tuna for experimental studies ashore. Their techniques are essentially those of the Hawaiian skipjack tuna industry. The number of skilled pole-and-line fishermen in Hawaii has declined drastically during recent decades.

The skipjack tuna vessels spend almost as much of their time at sea in catching bait as they do in scouting and fishing for tuna. They do not go to sea daily. In 1960-65, the small vessels averaged about 100 trips per year; large vessels made fewer trips. Weather plays an important part in determining whether the boats fish; a stormy period can keep them tied up for days on end.

The number of fish present in a body of water larger than a small fishbowl can rarely be counted exactly. The most readily available indicator of the number in the ocean consists of statistics from the catch. These records must be refined, however, before the scientist can estimate availability and abundance. As a first step toward an estimate of apparent abundance, Uchida converted all his catch and effort data to a standard term, a single 1-day trip by a large vessel. These figures suggest that during 1952-64, the years of his study, availability varied considerably in the Hawaiian area, from a low of about 5,000 pounds per trip in 1958 to a high of more than 7,000 pounds in the next season. Standard fishing trips declined slightly in the early years and leveled off at about 1,600 trips in 1959-64. From his figures, Uchida concluded that the skipjack tuna fishery itself is not seriously affecting the abundance of the species in Hawaiian waters: Changes in abundance are due to variation in the availability and behavior of the fish on the fishing grounds; the strength of the various year classes may also be important. In his most recent study, Uchida has scrutinized the striking differences between offshore and inshore catches. He has been able to document the fact that the offshore grounds are the more productive. Larger and faster biting skipjack tuna were found farther from the islands, and these profitable fish stayed near the vessel longer, allowing larger catches. Whether the Hawaiian skipjack tuna fleet would profit by attempting to spend more time offshore poses economic problems, however.

The Hawaiian Longline Fishery

The last weeks of December see a striking upsurge in fish landings in Honolulu. Sashimi—sliced raw fish—is a favorite holiday delicacy in Hawaii, and the fishermen work long hours attempting to satisfy the market. Retail prices for the tuna shoot up; the best fresh fish sell for considerably more than filet mignon.

Most of this fish is supplied by the longline fleet (fig. 7). Two species provide the bulk of the tuna catch by longline—the bigeye tuna and yellowfin tuna. December is the peak month for the bigeye tuna catch. A sharp slump in January possibly is induced by the long early-January holiday that is traditional in the longline fleet. And in December, yellowfin tuna catches are higher than at any other time of the year except the very peak of the season, June and July.

In an average year, the longline fleet lands between 900 and 2,200 tons of tunas and billfishes (average yield of the pole-and-line fishery for skipjack tuna is about 5,000 tons, it will be remembered). In terms of dollars to the fishermen, however, the longline fishery means more than is evident from the figures of the catch, for it takes premium fish. Thus in the 15 years 1950-64, the auction price of bigeye tuna was never lower than 30 cents a pound and rose to almost 60 cents in 1964; this latter is 4 times the average United States-Japan price for tuna and 12 times the average world price for marine fish. Yellowfin tuna prices rose also, though not as spectacularly, going from about 30 cents to about 38, said Thomas S. Hida, who prepared an analysis of the longline fishery for the Governor's Conference. Skipjack tuna prices in Hawaii have stayed at about 10 to 12 cents a pound for fish sold to the cannery; prices for fish sold in the fresh fish market are higher.

It was a Japanese immigrant named Imose who introduced the Japanese method of longline fishing to the Hawaiian Islands in 1917. Fishing a few miles from Honolulu, he was so successful that his technique was rapidly adopted by other fishermen. Although from the beginning the most important species caught have been the yellowfin and bigeye tunas, some albacore and several of the billfishes are also taken. The tunas and most of the billfishes are consumed fresh. Some of the larger Pacific blue marlin, however, are used in the manufacture of "kamaboko" (fishcake).

Like the aku fleet, the longline fleet is suffering from attrition. There were 59 vessels in 1948, but only 30 in 1966. The number of fishermen has declined from 190 to 87.

Although their trips may last several days, most of the longliners fish within sight of the islands. The Laboratory in Honolulu has provided instruction and advice in navigation to some of the skippers to encourage them to try their hand at longer trips. These few vessels, fishing several hundred miles from the islands, have had encouragingly high catch rates.

But the bulk of the fishery, near the islands, is not doing well. The years 1954-65, Hida said, saw a steady decline in the number of bigeye tuna landed; as the yellowfin tuna catch remained almost steady, this drop has meant that total landings of the tunas have decreased, and rather sharply.

The fish taken by the longlines are large. Average weights of bigeye and yellowfin tuna landed in the Hawaiian area have fluctuated between 135 and 170 pounds. Bigeye tuna are caught most plentifully in winter and spring, yellowfin tuna in summer. The most heavily fished areas are those close to the principal ports.

Fishes other than tunas are taken commercially in Hawaiian waters, of course, but these fish are essentially near shore resources. The tunas constitute the only high-seas resource harvested at present. Of the tunas, the skipjack, is taken in the greatest numbers and in the greatest tonnage.

The high seas around the Hawaiian Islands have apparently provided excellent fishing grounds for the Japanese longline fleet but have been fished rarely by American ves-

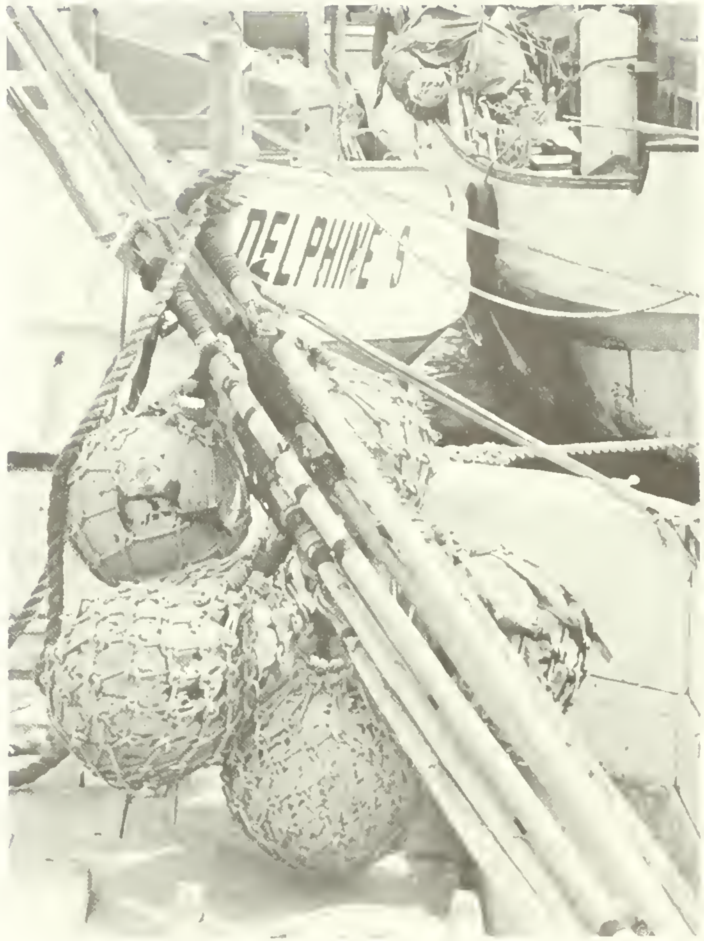


FIGURE 7. Characteristic of the Hawaiian longline fleet are the glass fishing floats which buoy the lines and the stout bamboo poles which mark the junction of two of the lines. Topped with flags, these poles help locate the line; the longline fleet in Hawaii is sometimes called the "flagline" fleet.

FIGURE 8. The great California-based tuna fleet depends mostly on surface-caught yellowfin and skipjack tunas taken along the coasts of the Americas as far south as northern Chile (darker shading). A recent development has been fishing by Japanese longliners for yellowfin and bigeye tunas in the eastern Pacific (lighter shading).

sels. With current techniques and gear, longlines have proved the only effective method of harvest and longlines cost more in manpower than is profitable with present American wage scales.

This situation presents some obvious questions; the one of chief interest in Hawaii is this: Is the skipjack tuna fishery capable of expansion? The Governor's Conference sifted the scientific evidence concerning this matter. The conference took the view that the potential of the central Pacific resource could not be correctly assessed unless it were viewed in the context of the tuna populations of the entire Pacific. Material was presented that dealt with the large surface fishery in the eastern Pacific Ocean and with the Pacific-wide Japanese longline catch.

The Eastern Pacific Tuna Fishery

Sailing from San Pedro and San Diego, the California fishing fleet seeks tunas as far as northern Chile (fig. 8). Today most of the vessels are purse seiners (in 1964 the United States had 111 purse seiners and 35 bait boats) and are mostly between 100 and 200 tons. Walter M. Matsumoto charted the growth of this fishery for the Governor's Conference.

The fishery dates back to the early years of the century; about 400 tons of albacore were taken in 1911. From this small start, the fishery rose rapidly, so that by 1920, landings were 19,600 tons. The largest constituent of the catch remained albacore, but yellowfin tuna, skipjack tuna, and bluefin tuna were also taken. By 1930, the catch was near 50,000 tons. The beginning of the depression saw catches waver, but by the mid-1930's, the total had climbed above 60,000 tons, with yellowfin tuna contributing the most. The industry had its first 100,000-ton year in 1940. After World War II, this record was soon doubled; a catch of 200,000 tons was achieved for the first time in 1960. From 1960 through 1965, the annual catch remained between 150,000 and

200,000 tons. Yellowfin tuna, which became the most important element in the fishery in 1928, continued to dominate the catch. Some years in the 1960's have seen catches of 100,000 tons of yellowfin tuna alone—as much as all species combined a generation ago. Except for the catch of the Japanese longline fleet, which has extended its operations to the eastern Pacific within the decade, all of the tunas in the eastern Pacific are taken at the surface and mostly by nets (fig. 9).

The statistics on the total catch tend to mask important trends that become apparent only when the catch of each species is examined. Scientists of the Inter-American Tropical Tuna Commission have used catch statistics to estimate the impact of the fishery on the yellowfin tuna stock. Reviewing the record of the catch for the past several decades, they have concluded that the yellowfin tuna population is below the level at which maximum yield can be sustained. They recommended a limitation of the catch to 79,300 tons in 1966. Similar studies on the companion species, skipjack tuna, failed to show a corresponding link between increased fishing pressure and the size of the stock. Several years ago the scientists suggested that the skipjack tuna stock could withstand a much higher level of fishing effort and greater catches.

In the past, albacore was one of the chief elements of the eastern Pacific fish catch. It ceased to be so in the 1930's and has never yielded the tonnage that yellowfin and skipjack tuna do now. In 1963, the albacore catch was at its peak figure, about 30,000 tons. Most of the albacore are caught off the coast of California, Oregon, and Washington. The season usually lasts from June through October.

Fishing for albacore begins off Baja California and moves northward as the season progresses. The catch is subject to drastic fluctuations, Matsumoto says. In 1926, it plummeted to a tenth of its 1925 total of 11,000 tons and remained at well under 1,000 tons for a decade, rising abruptly to its

FIGURE 9. There is a Japanese saying: "Net—rich man; pole and line—beggar." The development of purse seining in the eastern Pacific Ocean resulted in greatly increased catches.

former level in 1938. Scientists say the reason is that the distance from shore of the major part of the albacore's path of seasonal migration along the coast varied considerably within and among seasons and that the fleet of the 1930's was not equipped to operate far offshore, as it is today.

Although bluefin tuna is much in demand in Japan, it has never played much of a part in the United States Pacific fishery. About 10,000 tons are taken annually. The year 1966 seems to have set a new high, about 17,000 tons landed in California.

Bigeye tuna, again one of the most important species in the Japanese catch, is taken only in insignificant quantities in the eastern Pacific, according to Matsumoto.

The Japanese Longline Fleet in the Pacific

The Japanese longline fleet alone has more than 1,000 vessels. (The U. S. tuna fleet has about 200.) Until the early 1950's such ships (fig. 10) confined their fishing activities to the Pacific Ocean and largely to the western part of it. Beginning in 1952, they started to range far afield, first to the Indian Ocean, and then in 1955, to the Atlantic Ocean. Meanwhile, year by year their operations swept across the wide Pacific, until by 1960 they were fishing all the warm seas of the world coast to coast. The catch is sold in many nations (fig. 11).

Because of the way in which the statistics were presented —until those for 1963 appeared—it was difficult to tell what percentage of the total Japanese longline effort was expended in each of the three oceans and how successfully. Yet estimates of the total Pacific catch and effort are vital to the assessment of Pacific tuna stocks. Tamio Otsu and Ray F. Sumida prepared an estimate of the catch and effort for

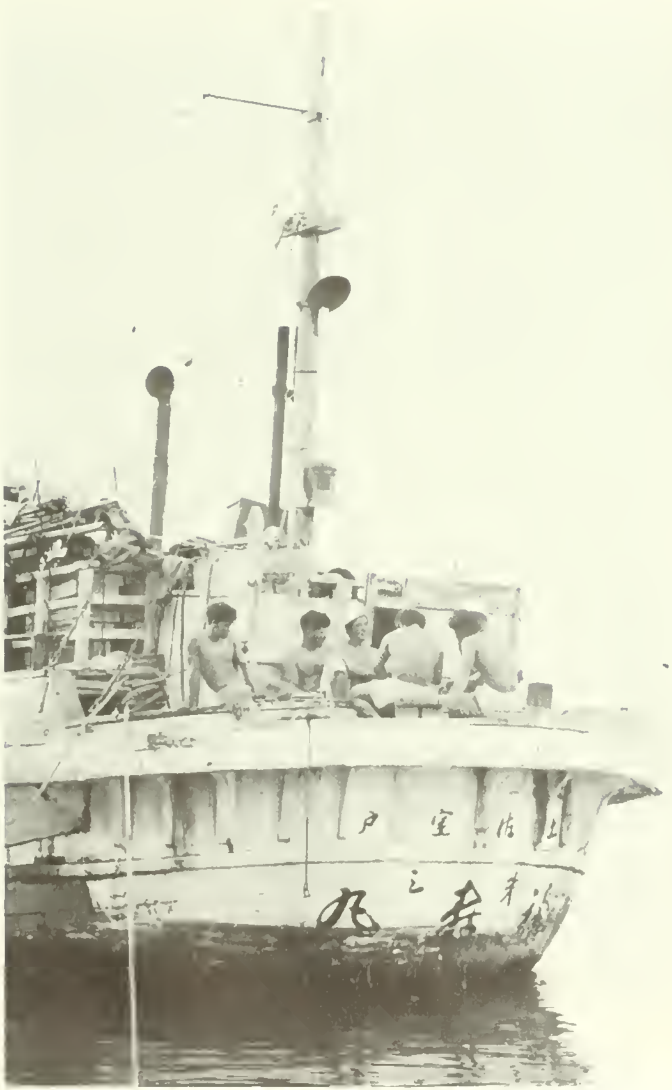


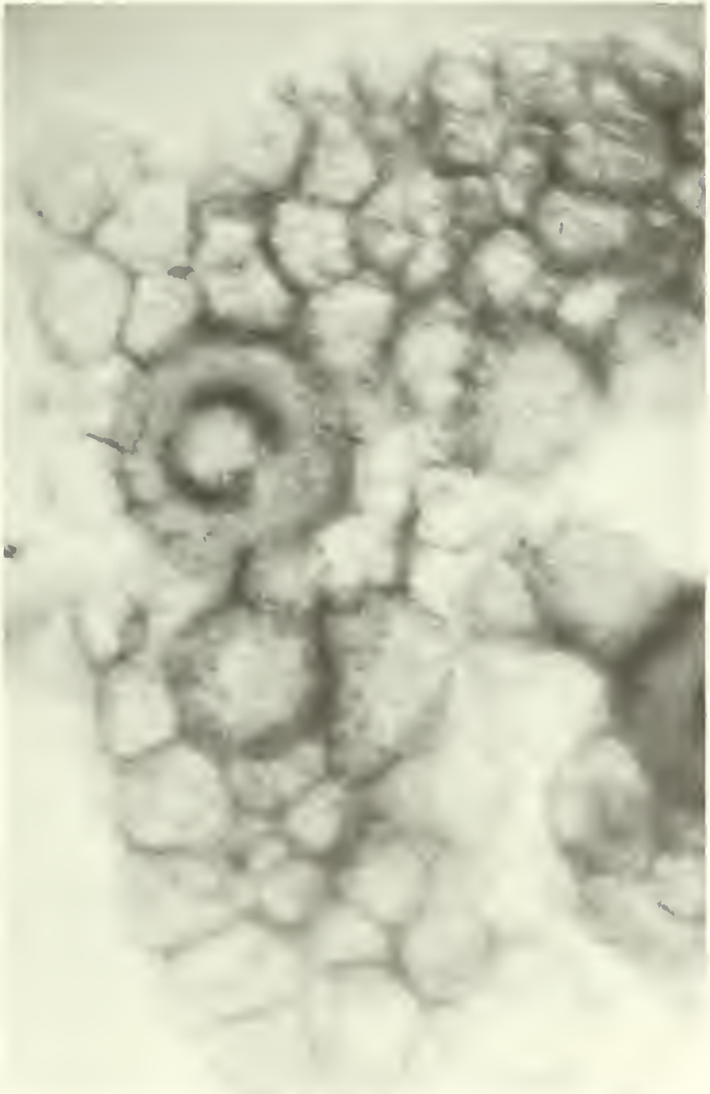
FIGURE 10. Within a decade, the vessels of the Japanese longline fleet have become a familiar sight in almost every warm water part in the world as their tuna fishery has circled the globe. The FUKUJU ("Good Fortune") MARU, photographed in American Samoa, is a wooden longliner whose home port is Murota, Kochi Prefecture, Japan.

the years 1953-63 for the Governor's Conference. These estimates show that although the contributions of the other oceans have been rising, the Pacific has continued to supply well over half the catch. Not until 1962 did either of the other oceans exceed the Pacific catch of any one of the tuna species. Then, and in 1963 as well, several thousand more tons of bluefin tuna were taken from the Indian Ocean than the Pacific, as the fishery pushed far into the Southern Hemisphere.

Otsu and Sumida's estimates clearly show the impact made by the resurgence of the Japanese fleet upon the tuna resource in the Pacific Ocean. They disclose that the longliners took a total of 2.4 million tons of tunas from the Pacific Ocean in the 11 years, 1953-64. This figure seems enormous until one compares it with the catch of that small corner of the Pacific Ocean fished by the far fewer vessels of the eastern Pacific fleet. There the total catch during the same period was 2.3 million tons. In other words, for the longline fleet, the fish are still relatively few and far between. The numbers cited by Otsu and Sumida suggest that in 1953 the Japanese longliners caught one tuna for every 30 hooks they put out and that by 1963 they were catching only one for every 40, or, to put it more conventionally, the catch of tunas per 100 hooks had declined from about three to about two. Longlining is hard and often profitless. It has never been adopted in the United States (except in the small Hawaiian fishery) and, unless it can be mechanized more thoroughly than at present (or prices go up several times), seems little likely to be so.

The Japanese longline fleet has more than declining catch per unit of effort to worry about. The South Koreans and Chinese are building new vessels and pitting them against the Japanese fleet. In the fishery based in American Samoa in the South Pacific, for example, the Japanese vessels had no competitors until 1962, when the Koreans arrived. The Chinese followed in 1964, and by the last quar-

FIGURE 11. Some tunas caught by Japanese longliners based in the South Pacific are transshipped to the United States Here frozen tuna are being unloaded in Honolulu.



ter of 1965 the fishery was shared by 62 vessels from Japan, 30 from Korea, and 13 from Taiwan.

Tuna Larvae and Young

If all the eggs spawned by a single female yellowfin tuna in one season were to survive the vicissitudes of life in the sea, at maturity they alone would provide a catch of about half a million tons of fish. Most fishes have this prodigal reproductive potential: It is the mechanism that maintains the breed.

It would be useful if tuna eggs (fig. 12) could be identified as to species, but they cannot be. All tunas except the albacore can be identified at the next stage of their life, the larval. The distribution of larvae pictures the areas and time of spawning of the tunas. For the Governor's Conference, Walter M. Matsumoto reviewed all available evidence on the occurrence of tuna larvae in the Pacific.

The most intensively investigated sector of the Pacific is that narrow strip along the west coast of North America which is the site of the field studies of the California Cooperative Oceanic Fisheries Investigations. Almost 16,000 plankton samples were taken there in 1951-60. This area, however, is nearly barren of tuna larvae. Far more productive of larvae have been the region west of Central America, sampled mostly by the Inter-American Tropical Tuna Commission, and the central Pacific, where the Laboratory in Honolulu has made several thousand plankton tows.

Matsumoto found that skipjack tuna larvae were remarkably sparse in the eastern Pacific (fig. 13). They have been captured widely and often in the central Pacific from lat. 30° N. to 20° S., and presumably (data are very sketchy) are frequently taken in the western Pacific, where their

FIGURE 12. Immature eggs taken from a female skipjack tuna. Most of those in this photomicrograph are about one one-hundredth of an inch in diameter. The larger circles are eggs that are further developed than the others.

north-south range is considerably greater—from the coast of Japan to that of Australia.

The distribution of yellowfin tuna larvae is very different. They have been taken in many localities in the eastern Pacific, from Baja California to Panama, and throughout the central and western Pacific.

As for the other tuna species, data are scarce indeed. Some bigeye tuna larvae have been caught in the eastern and central Pacific, often very far at sea, and near the Philippines. Bluefin tuna larvae have been reported only from around Taiwan. Very young albacore have been caught near Hawaii, to the east of the Philippines, and to the east and west of Samoa; Matsumoto assumes that the chief spawning grounds are not too far from the two latter sites.

The material on the larvae allows the depiction of spawning season. In higher latitudes, skipjack tuna spawn mainly from late spring to early fall, according to Matsumoto, but in the equatorial region they spawn the year around.

One of the most interesting aspects of Matsumoto's work is his effort to determine the relative abundance of larvae of skipjack and yellowfin tuna. Because data were few from the western Pacific, he limited himself to that part of the ocean east of the international date line. In a north-south direction, toward the northern end of the range there were far more skipjack tuna larvae at the height of the spawning season than were found near the Equator, where spawning takes place throughout the year. Yellowfin tuna showed no such pronounced variation.

Skipjack tuna larvae became less and less frequent from west to east. The highest catches per tow, indeed, were made only a few degrees east of the international date line. Beyond long. 130° W., that is, within the area of the eastern Pacific fishery for skipjack tuna, almost no skipjack tuna larvae were found.

Although yellowfin tuna larvae were also more abundant at the date line they were also found in considerable quanti-

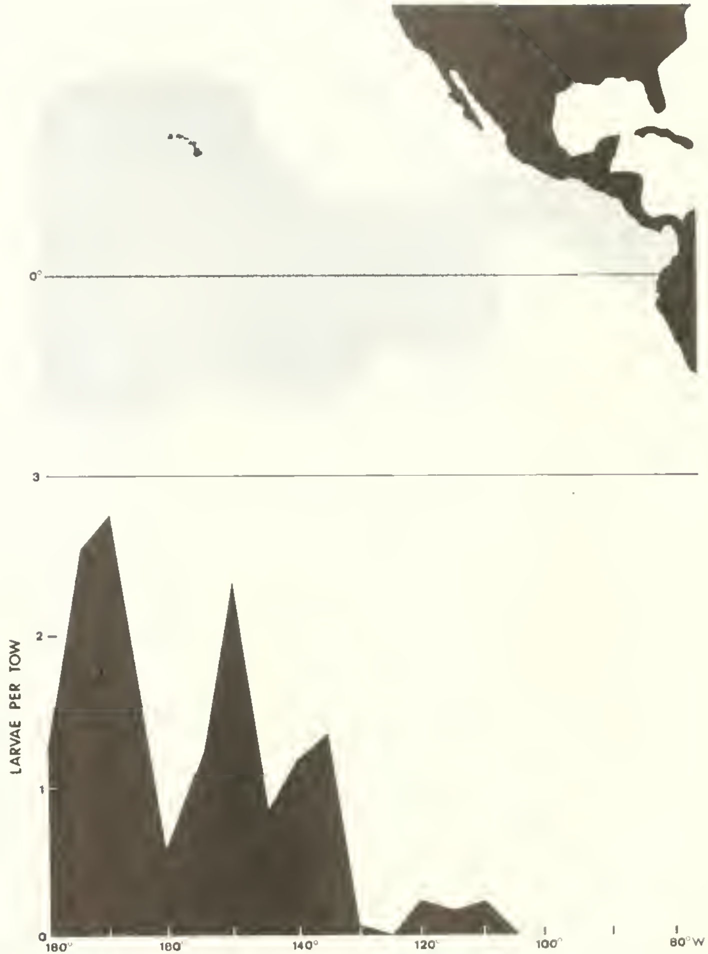


FIGURE 13. Plankton tows show that skipjack tuna larvae are widespread and plentiful in the central Pacific, sparse in the eastern Pacific. The top part of the figure shows the distribution of skipjack tuna larvae. The bottom part shows the average number of larvae per tow taken over several years of sampling.

ties all the way across the breadth of the Pacific Ocean, including the site of the rich eastern Pacific yellowfin tuna fishery.

Matsumoto thinks that the tropical Pacific has large skipjack tuna resources to the west of the 180th meridian. This area is at present fished only very lightly by the fleet based in the Trust Territory of the Pacific Islands. Before World War II, it supplied Japan with a substantial catch of skipjack tuna in those islands.

The feeble larvae are caught by plankton nets; but when the tunas enter the next stages of their lives, as juveniles able to dart about under their own power, they become elusive indeed. Tens of thousands of larvae have been taken on research cruises; captures of juvenile tunas can be numbered in the hundreds, says Bruce E. Higgins, who reviewed the data on juveniles for the 12th Session of the Indo-Pacific Fisheries Council.

Higgins' findings complement Matsumoto's. Juvenile yellowfin tuna are more common than skipjack tuna in the eastern tropical Pacific, but have been reported from fewer locations in the central and western Pacific. Skipjack tuna juveniles were by far the most plentiful, accounting for well over half the total of all juveniles.

Were they not eaten by larger fishes, juvenile tunas would be almost unknown to science. No net used today—particularly the standard 1-m. net (fig. 14) that is used to sample the plankton—catches them as often as do larger tunas and billfishes. This fact is strikingly shown when locations of capture are mapped. Almost all the small tunas are recovered at fishing ports, that is, are found in the stomachs of larger fishes landed there. Distribution maps thus prob-

FIGURE 14 The 1-m. net is the standard collecting device used to sample the drifting plants and animals of the sea, the plankton. "One meter" refers to the diameter of the mouth of the net. Drifting specimens are taken by the net, but very few of the active juvenile forms of the tunas have ever been taken in plankton tows.

FIGURE 15. A new type of net will be used by the Laboratory in Honolulu in an attempt to capture juvenile tunas at sea. This large trawl, with a mouth opening of about 65 feet, is designed to be towed at a specified depth in the water. The mesh is so small that the juveniles, which are no more than a few inches long, cannot escape.

ably misrepresent the actual distribution of juveniles in the ocean.

Seeking a better method for the collection of the fish, Higgins consulted with the Bureau's Exploratory Fishing and Gear Research Base, Seattle, which supervised the design and construction of a new type of net (fig. 15). It is very large, with a mouth which when open is big enough to engulf a six-story building. The mesh is small, so that the juveniles cannot escape. It can be towed at middepths. This new trawl net will be tested on cruises of the research vessel *Townsend Cromwell* during 1967.

Large amounts of statistics on the tunas become available only after the fish enter the commercial catch. The several fisheries of the Pacific draw on the tunas at different stages of their life. Statistics from the catch allow fishery scientists to determine what elements of the population support which fisheries. Sharp differences appear: Off Japan, for example, the bigeye tuna taken by the longlines are shorter (and presumably younger) than those taken in equatorial waters. Bruce E. Higgins, who has reviewed the records of lengths of fish in the several fisheries, says the sizes also change markedly from west to east. The larger bigeye tuna are caught in the east. Albacore taken near Japan are mostly 20 to 30 inches long; those near Hawaii, much longer. Yellowfin tuna in the western Pacific are 30 to 40 inches long, and those of the open seas slightly larger than those caught closer to land. In the eastern Pacific, where the yellowfin tuna are the object of a large surface fishery, smaller fish are caught; the average length is about 23 inches, but the deep-swimming yellowfin tuna caught by longlines are very large. Skipjack tuna in the eastern Pacific are small and young. In the central Pacific, several size groups are present. Larger fish (more than 20 inches long) are invariably the preponderant type in the peak summer catches in Hawaii.

Age and Growth of Tunas

From data obtained by the Laboratory in Honolulu, Eugene L. Nakamura and James H. Uchiyama calculated curves of average weight against length. Their data show that skipjack tuna have a maximum length of about 27 inches and weight of 37 pounds.

As has long been known, yellowfin tuna grow much larger than the skipjack tuna. The Honolulu data show that they attain a length of about 5 feet and a weight of more than 250 pounds. Bigeye tuna are larger yet, reaching a length of almost 6 feet and a weight of about 330 pounds. Albacore are smaller. The largest are about 4 feet long and weigh under 100 pounds.

Richard S. Shomura prepared a study of age and growth of the Pacific tunas for the Governor's Conference. He found the greatest discrepancies of reported age and growth in the several studies that have been made on the growth of albacore. Workers are uncertain whether the young albacore enter the fisheries at 1 or 2 years of age. Usually these fish are about 18 inches long, although some are as short as 12 inches.

Few studies have been made of the age and growth of skipjack tuna, Shomura found. The most recent, made by Brian J. Rothschild, indicates that the skipjack tuna in Hawaiian waters are about a year old and 12 inches long when they enter the fishery. Fish 2 years old and about 20 inches long form a considerable part of the Hawaiian skipjack tuna catch.

Most of the evidence on the yellowfin tuna suggests that it grows rapidly during its early life, about 14 inches to almost 20 from its first to its second year. Bigeye tuna display much the same growth pattern.

Estimates of Tuna Abundance

The studies just cited summarize what is known of the distribution of the commercially caught tunas in the central Pacific Ocean. The chief business of the Governor's Conference was to evaluate the evidence to see whether the central Pacific catches might be increased. The conferees found that for the yellowfin tuna and the skipjack tuna, substantial increases should be possible.

After reviewing the material on the yellowfin tuna, the working group estimated an increased yield of about 30,000 to 50,000 tons per year from the central and western Pacific if yellowfin tuna smaller than those now taken by the Japanese longline fleet could be caught.

The estimate for bigeye tuna was made by Ralph P. Silliman. He used data from the Japanese longline fishery to arrive at an estimate of a maximum sustainable yield of about 80,000 tons a year. The fishery is already far more than this; Silliman believes, therefore, no significant increase in the catch of the large bigeye tuna is possible.

Silliman also estimated the potential catch of skipjack tuna. Here his basic data came from the eastern Pacific fishery. He estimated a maximum yield of 225,000 tons, or about three times the amount now being taken.

Also using data from the eastern Pacific fishery, Brian J. Rothschild treated his material somewhat differently from Silliman and arrived at a different estimate. He set the potential yield at between 2 and 17 times the current 70,000 tons a year. (His higher figure would make the central Pacific skipjack tuna stock provide almost as much fish as the present catch of tuna for the entire world.)

Rothschild points out that his estimate of yield ignores the skipjack tuna stocks of the South Pacific, which may be vast.

Underlying both Silliman's and Rothschild's calculations is the assumption that the hypotheses concerning spawning and migration of the skipjack tuna advanced by Rothschild

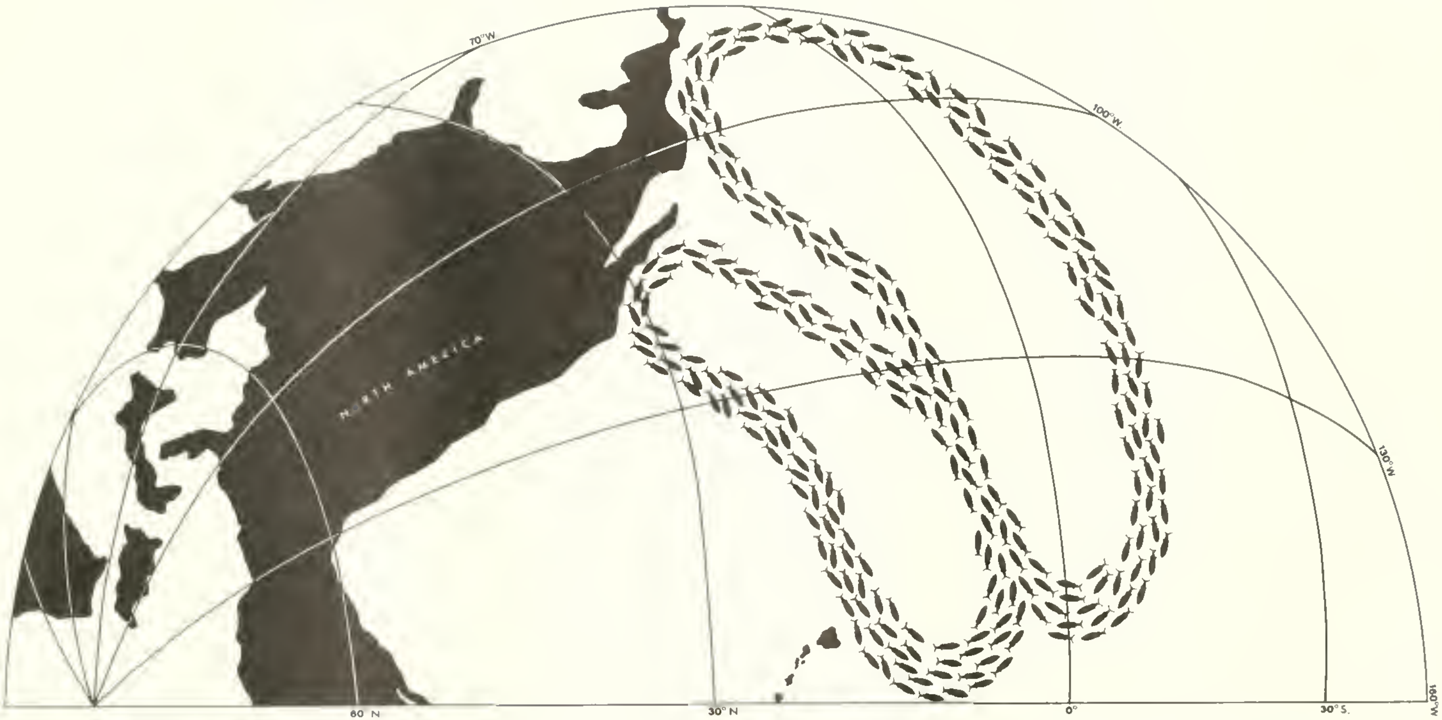


FIGURE 16. Brian J. Rothschild of the BCF Laboratory in Honolulu has hypothesized that the skipjack tuna of the eastern Pacific are spawned in equatorial waters of the central Pacific. They enter the eastern Pacific fishery at an age of about 1 year but remain there only a few months. Those that are not caught return to the central Pacific and spawn. This older stock is not substantially fished at present. Rothschild sees a similar movement of the fish in the Southern Hemisphere.

are correct (fig. 16). Very briefly, these hypotheses said that the eastern Pacific stock of skipjack tuna is spawned somewhere in the central Pacific, that the fish enter the eastern Pacific at about 1 year old but remain there no more than a few months, that at about 18 months they return to spawn in the central equatorial Pacific, and that most of them are never caught in any fishery. Evidence to support the main points of these hypotheses is plentiful, but direct proof is lacking and will remain so until more is known about certain aspects of the life history of the fish.

One of these aspects is tied into the probability of the existence of several subpopulations of skipjack tuna. It has now been shown, through the work of the Laboratory in Honolulu, that subpopulations of skipjack tuna are detectable and that several exist in the central Pacific. These groups of skipjack tuna do not interbreed. Lucian M. Sprague and Kazuo Fujino have discovered a number of methods to identify genetic differences of several groups of skipjack tuna.

There exist, then, large, potentially harvestable stocks of tunas in the central Pacific Ocean. But where in that vast region are they to be found? Some evidence suggests that the Hawaiians may not have to search very far to locate these fish. The adjacent waters are very productive of big tunas. Heavy catches of yellowfin tuna are made by the Japanese longliners within a few hundred miles of Hawaii.

In the most exhaustive review of the Japanese longline fishery in the Pacific printed to date, Brian J. Rothschild drew upon the data printed in the Japanese journal Tuna Fishing to depict the expansion of the longline fleet in time and space from 1953 through 1963. He was interested in changes in large areas from year to year. He divided the Pacific Ocean into 20° quadrangles, an area about 1,200 nautical miles to the side, and investigated the fishing history of each. Most of his data deal with the yellowfin and bigeye tunas, which dominate the Pacific longline catches.

Rothschild documented the rapid spread to the east and south of the center of longline fishing effort in the Pacific. In 1953 it lay off the home islands of Japan; the farthest east effort extended was a tentative probe to the northeast of the Hawaiian Islands. In 1954 the Japanese fleet went farther into the central Pacific. By 1955 it was fishing not far from Baja California, and the following years saw effort being expended from the coast of Asia to that of South America, as interest in the fishery moved south of the Equator. By 1963, the principal center of effort of the Japanese longline fleet lay nowhere near Japan, but in a high-seas quadrangle in the eastern Pacific just south of the Equator, a shift of several thousand miles in a decade.

When compared with reported tuna catches and converted into an index of abundance, these effort figures suggest that throughout these years the big yellowfin tuna caught by the longline have remained most abundant in the southwestern Pacific, but that bigeye tuna have been more abundant in the central and eastern Pacific; Rothschild says that the eastward expansion of the fishing was stimulated by the high apparent abundance of bigeye tuna in the east. Is this expansion paying off? Some scientists think it is not, pointing out the greater cost of catching bigeye tuna in the eastern Pacific than to the west (because the distances to home ports are longer). Rothschild believes that a constriction of the longline activities looms ahead. He sees the concentration of effort falling back westward to the vicinity of Hawaii.

The four quadrangles which join near the Hawaiian Islands have apparently provided a substantial share of the Japanese longline catch for the past several years. The southern pair of quadrangles has usually exceeded the Pacific-wide average for the yellowfin tuna catch.

Thus substantial tuna resources are available in the central Pacific to one of the two standard techniques of capture. The question is: Where are the fish that are not taken by this method?

THE WATERS OF THE CENTRAL PACIFIC

Within the vast area of the central Pacific are some locations at which fish are more likely to be found than at others. Some of these locations are semipermanent and relatively well-known features of the current patterns of the Pacific Ocean. Others are only beginning to be discovered. Most of what is known of the oceanography of the area is based on work of the BCF Laboratory in Honolulu. Now this Laboratory is planning to conduct its most extensive oceanographic project.

Project Porpoise

In the year 1838, the United States Government embarked on an enterprise with goals that seem modern. One object of the U. S. Exploring Expedition was to attempt to link the distribution of the rich and heavily exploited whale stocks to the oceanography of the South Seas. The enterprise involved sending a fleet of small wooden sailing ships through lands still fabulous, including an area then probably more remote, in a sense, than the moon is to us today. This was Antarctica, whose very existence as a continent was then debated. There Yankee sailors in tarred hats chased penguins and planted the 26-starred American flag on a peak in what is still known as Wilkes Land, after the commander of the expedition.

Large-scale oceanographic-biological expeditions are not common even today. When the Laboratory in Honolulu decided to spearhead a multiship cooperative investigation of the biology and oceanography of a wide area of the central Pacific, it fittingly looked back more than a century and chose for the project a name associated with this pioneer American effort to relate marine biology and oceanography.

The name is Project Porpoise. It comes from the 240-ton gun brig, *Porpoise*, which staunchly withstood the perils of Cape Horn and the Antarctic and the languors of the South Seas, to circumnavigate the globe and in 1842 to sail into New York Harbor as the field phase of the expedition came to an end.

Project Porpoise has grown out of the interest of oceanographers, meteorologists, fishery biologists, and ornithologists in the factors that are associated with the weather, the current, the fishes, and the birds of the trade wind zone of the North Pacific. It stems directly from the Trade Wind Zone Oceanography Pilot Study, conducted by the Laboratory in Honolulu in 1964-65 under the leadership of Gunter R. Seckel.

During the pilot study the research vessel *Townsend Cromwell* made cruises near the Hawaiian Islands each month for 16 months, covering a fixed pattern that was as broad as time allowed. The field studies ended early in July 1965. Since that time, the data have been processed and are now ready for publication; descriptive studies of the region also are being prepared.

These studies have yielded two principal findings. The first is that around the Hawaiian Islands, the waters above the 3,000-foot depth are layered like a cake, each layer having distinctive physical and chemical characteristics traceable over hundreds or even thousands of miles. The other finding relates to oceanic fronts. During World War I, Scandinavian meteorologists found that many changes in the weather could be accounted for by the meeting of air masses of contrasting physical properties, one cool and dry, the other warm and wet, for example. For this phenomenon they chose the word, "front," by analogy with the contested frontlines in the current war. Later, "fronts" between cool and warm water were found at sea. They are well documented for the shallower layers and can account for sharp differences in the distribution of commercial fishes. In the equatorial Pacific, for example, yellowfin tuna are often caught in considerable quantities near surface fronts. The Trade Wind Zone Oceanography Pilot Study offered further

FIGURE 17. Birds compete with tunas for prey. Fishing vessels maintain lookouts for the wheeling, diving flocks of sea birds. The Smithsonian Institution, which has a Pacific-wide study of marine birds, will cooperate in Project Porpoise.

evidence that such discontinuities can also be identified in deeper waters. Even at several hundred feet beneath the surface, there can be, as there are in the atmosphere and at the sea surface, pronounced changes within a very few miles.

This study of subsurface fronts may have many implications in the distribution of fishes. As yet, it has been possible to test the biological yield of subsurface fronts on only one fishing expedition. In April 1966, the Laboratory in Honolulu enlisted the cooperation of three Honolulu-based longline vessels, the *Kaku*, *Pulpo*, and *Aukai*, in a joint venture. The commercial vessels were to fish in the open seas about 350 miles from Honolulu. The *Townsend Cromwell* sailed farther south until she located a subsurface front. Her longlines, fishing at a depth of about 300 to 500 feet, straddled the front.

The *Townsend Cromwell* catches were compared with those of the commercial longliners. Catch rates of tunas did not vary greatly. On the other hand, the *Townsend Cromwell* in the frontal area took more sharks and more mahimahi (dolphin fish). The results thus suggested that the frontal area might be richer, in terms of total fish production, if not in tunas alone, than the other area.

From the beginning of the Trade Wind Zone Oceanography Pilot Study, the participation of other research laboratories whose programs could complement the oceanographic work has been sought. At the time of writing, it appears that the Meteorology Department of the University of Hawaii may undertake the investigations of the meteorology of the zone, and the Smithsonian Institution, which participated in the pilot study and which has a Pacific-wide investigation of sea birds, plans to join Project Porpoise.

Relying not only upon shipboard observations, but on such sources as data from satellites, the meteorologists would seek new insights on tropical and winter storms, on the transformations of air masses, and on the as yet little understood meteorology of the equatorial region.

Bird flocks are one of the best signs of the presence of tuna schools (fig. 17). Presumably these birds are competing with the big fish for the little fish near the surface. On Project Porpoise cruises the Smithsonian Institution would observe and collect the sea birds. By July 1967, the Institution will have already banded about 1.5 million birds on islands in the trade wind zone. It hopes now to study their distribution away from the breeding islands. It will study the development, composition, and behavior of bird flocks in relation to tuna schools, information that would be of immense value to the fishermen. One project calls for a comparison of stomach contents of birds and of tunas feeding in the same area.

Field work is now scheduled to begin in the fall of 1968. The next several months will be devoted to more detailed planning and to an effort to broaden the list of participants so that the venture can give the great scientific return.

Wakes in Lee of Islands

Another study in oceanography at the Laboratory in Honolulu has defined an area in the central Pacific where semipermanent features in the oceanic circulation may provide conditions conducive to the aggregation of fishes, including tunas.

The island of Hawaii, a volcanic mass whose 4,021 square miles make it about the size of the State of Connecticut, stands in the path of the westward-moving currents of the central Pacific Ocean like a stone in a sluggish stream. Bathed during most of the year by the highly saline waters of the north central Pacific, the island in summer frequently lies within the less saline waters of the California Current Extension. When these waters reach as far north as the island of Oahu, the State's skipjack tuna catch (a full third of which is taken no more than 20 miles off Oahu) is usually good.

As these currents diverge around the volcanic mass of Hawaii, says oceanographer Richard A. Barkley, they estab-

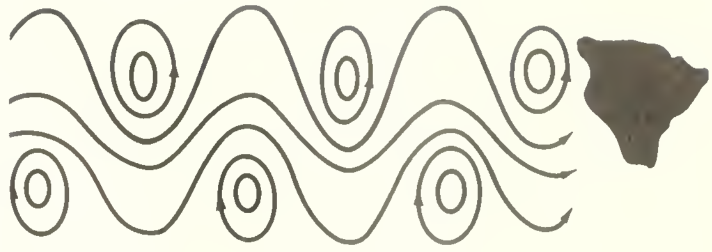


FIGURE 18. In the top drawing, all of the islands of the State of Hawaii have been obliterated except the "big island," Hawaii itself. Extending westward from Hawaii is a theoretical von Kármán wake, generated by the flow of a generally west-moving current (not shown) around the gigantic volcanic obstruction of the island. In the bottom drawing, the remaining islands of the State have been restored to their normal position and an actual current pattern, observed in March 1953, drawn in. As in the theory, clockwise and counterclockwise eddies appear downstream from the islands. Such eddies may profoundly influence fish distribution.

lish patterns of movement that can be traced far to sea and possibly may have profound biological effects. These patterns take the form of great circling wheels of water. They appear as a result of the same physical process that causes a flag to flutter in the breeze. The technical name for this phenomenon is the von Kármán wake (fig. 18). It is named after Theodore von Kármán (1881-1963), the hydrodynamicist whose studies in 1911-12 led to an understanding of it. Von Kármán wakes had not been observed in large-scale flow until the space age began. Then cloud patterns photographed by weather satellites identified them in the atmosphere.

The water flow to the west of Hawaii at first appeared to be a random system of turbulence, Barkley says. But as data accumulated, a regular pattern of movement was discerned. Like lazy whorls of smoke, eddies form at the northwestern and southwestern tips of Hawaii. The eddy to the northwest rotates counterclockwise, that to the southwest clockwise. As the eddies grow, the main stream rips them from the island tips, like soap bubbles torn from the pipe, and they drift westward. But they maintain their identity as far to sea (500 miles) as the Laboratory's research vessels have attempted to trace them. Usually, one grows more rapidly than the other, so that a large counterclockwise eddy on the northwest will expand until its dimensions are about those of the island, that is, about 60 miles in diameter. Then it drifts away and a clockwise eddy from the southwest takes its place. The lee of the island can hold a train of these eddies for hundreds of miles to sea. It consists of a stream about 90 miles wide, having a "wavelength" (the distance between successive eddies of the same type) of about 120 miles. The entire train of eddies which make up the wake moves westward about 6 miles a day, or about 75 percent of the speed of the current which generates it.

What this water movement may mean biologically is interesting: The counterclockwise eddies bring cool water and nutrients such as phosphate and nitrate for ocean plants up from the depths to near the surface. In the center of the counterclockwise eddy, relatively cool water can be found at a depth of 150 feet or less. Eighty miles away, in the center of a clockwise eddy cool water is more than 600 feet beneath the surface.

Barkley thinks it takes the eddies about 10 to 15 days to form and move away from the island, which would mean that the western coast of Hawaii would be bathed by waters of different types every 2 weeks during fall and winter, when the eddies have been most often observed. He thinks also that the differences between the northern and southern eddies in such properties as temperature, plant nutrients, and perhaps salinity, might possibly be reflected in the amount of food present for fishes to eat, and thus in fish abundance.

Although the significance of the large downstream eddies was noted only within the past few months, it had been described as early as 1949, when the research vessel *Hugh M. Smith* made one of the first oceanographic cruises in Hawaiian waters. The area has been visited since then, upon occasion, but not enough cruises have been made to determine whether the eddies prevail throughout the year or appear only during the fall and winter. Sometimes the currents from the east may be too weak to set an eddy moving westward from the island. Or the currents may be so strong that they break up the pattern shortly after it forms. Barkley suggests that the total annual productivity of the area may depend upon the number of divergent, cyclonic, counterclockwise eddies that form each year.

Barkley's principal task at the Laboratory in Honolulu has been the preparation of an oceanographic atlas of the Pacific Ocean, which will be published by the University of Hawaii Press; in it are summarized all oceanographic observations in the Pacific Ocean from 1917 through 1964. While preparing the charts for the atlas, Barkley recognized that the

FIGURE 19. The wake system in the meeting of the Kuroshio and Oyashio off Japan finds warm, highly saline water from the south meeting cold, dilute water from the north. In the top drawing, the temperature pattern is traced. Note that directly off the northern coast of Honshu, the chief island of Japan, the water temperature at a depth of 600 feet rises about 16° F. in about 100 miles. Measurements were made in July through September, 1961. In the lower figure is a theoretical analysis of the double wake—or vortex street—system

wake system he had discovered off the island of Hawaii had a larger counterpart in the western Pacific.

The meeting of the Kuroshio and Oyashio, the great warm and cold currents that join off the coast of Japan, is one of the most interesting features of the Pacific Ocean. It is a boundary where the warm, saline waters of the south meet the cold, dilute waters of the north, and the site of major ocean fisheries.

Barkley's studies of the wake system downstream from Hawaii have yielded a clue which promises to bring order out of the apparent chaos of the front between the Kuroshio and the Oyashio. For there, too, he finds a wake system (fig. 19), but one wider and much more complex than that off the island of Hawaii. The wake off Japan differs from that off Hawaii in at least three respects: It consists of not one, but two von Kármán-type systems, side by side; it is considerably more intense, with much larger eddies; and it appears to remain stationary instead of moving downstream. There is one other difference, too. The area west of Hawaii has been fished too little to show definitely if the wake has an effect upon the abundance of commercially important fish. Off Japan, Barkley believes that the much stronger gradients of the Kuroshio-Oyashio system influence the fisheries.

"The discovery that the Kuroshio-Oyashio front is a rather well-ordered system may have important implications to the men who fish the Gulf Stream and in other areas where it is possible that von Kármán wake phenomena may be found, now that we know what to look for," Barkley says.

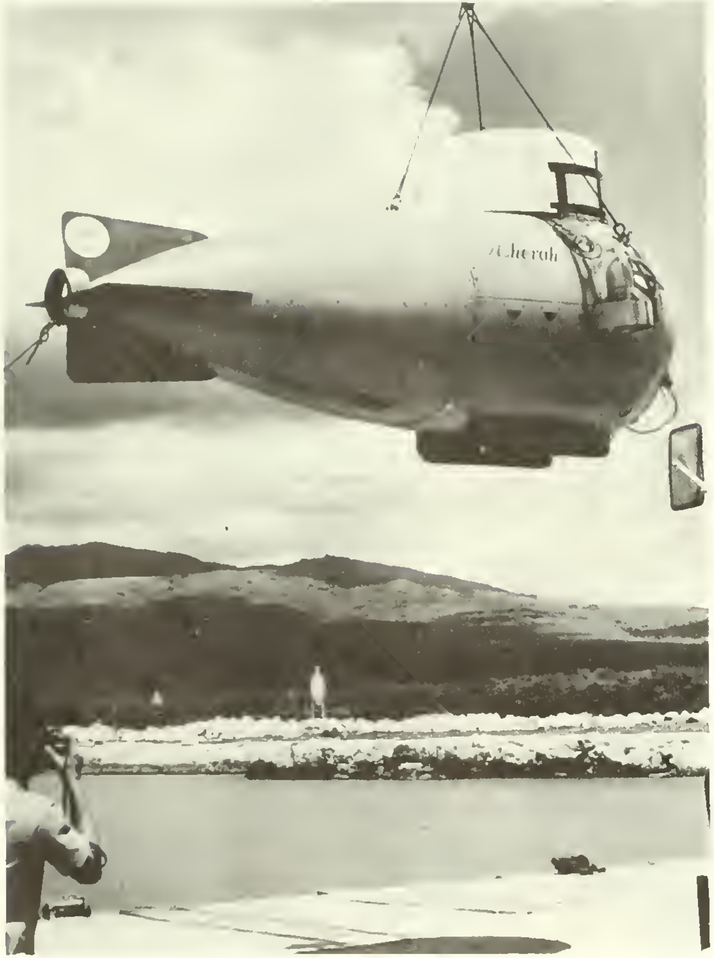


FIGURE 20. The research submersible, ASHERAH shown here being lowered from the dock into the water, is 16 feet long and carries a pilot and observer. Her name comes from that of a Phoenician goddess of the sea. ASHERAH was chartered by the Laboratory in Honolulu for a month's underwater studies off the leeward coast of Oahu.

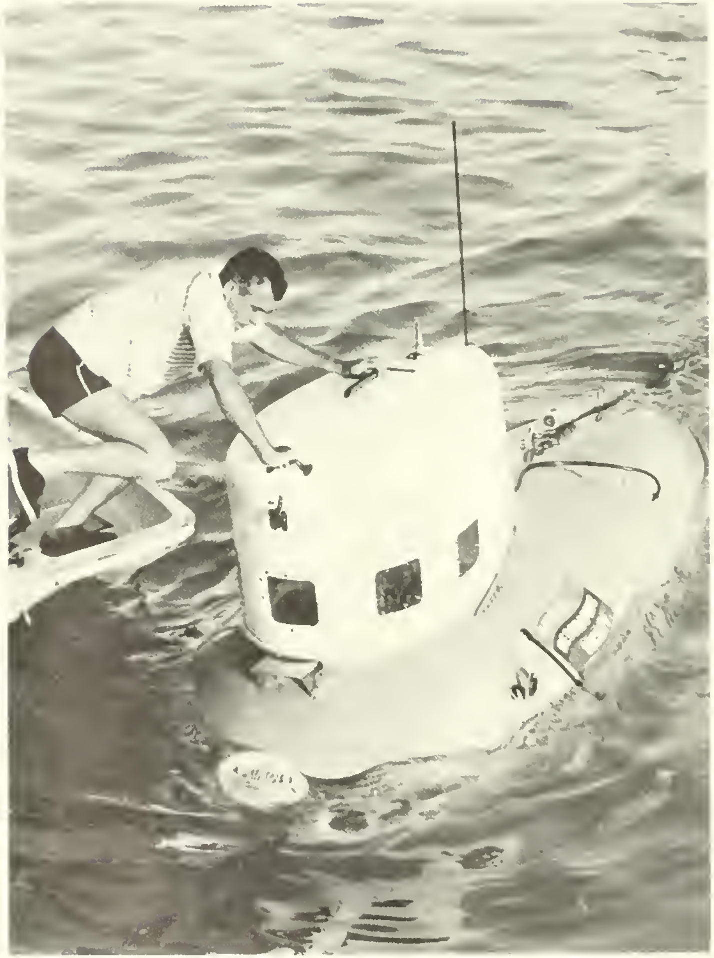


FIGURE 21. Boarding ASHERAH could be a tricky business, particularly in rough seas. The craft has a maximum operating depth of 650 feet. Scientists in ASHERAH made a number of fresh and significant observations of life underwater and discovered firsthand some of the potentials of submersibles in fishery and oceanography research

A SEA GODDESS

Christmas shoppers in Honolulu in 1966 were offered a novelty available nowhere else in the United States—locally produced jewelry fashioned from coral of a pale, luminous pink that was called by the sellers "angelskin coral." It had been harvested only a few weeks before from the uneven floor of the sea between the islands of Oahu and Molokai. As any visitor knows, Hawaii already possesses a thriving industry in black coral, which is harvested from relatively shallow waters by scuba divers. But the vastly more valuable red coral, taken by tangle gear from depths too great for divers, is new on the Hawaiian market.

Of about 2,500 known species of coral, only 1 or 2 are considered of gem quality. As a youth, the great American geologist James D. Dana served as a member of the scientific party aboard the U. S. Exploring Expedition. His studies there, indeed, laid the foundation for his later worldwide reputation. In his classic book, Corals and Coral Islands, he mentioned that when he visited the Hawaiian Islands in 1840 he obtained a sample of precious coral, and he pictured it in his scientific report on the expedition, published in 1850. Reports of later expeditions have scattered references to the findings of precious coral.

In the fall of 1965, Donald W. Strasburg from the BCF Laboratory in Honolulu became the first man to see this rare and valuable substance growing in Hawaiian seas. He was an observer aboard the research submarine *Asherah*, which was operating on the leeward side of Oahu. Several weeks later scientists from the University of Hawaii located beds of precious coral in the channel between Oahu and Molokai, and the first harvest has now been made.

Asherah was the ocean goddess of history's first recorded seafarers, the Phoenicians. The research submarine *Asherah* (figs. 20 and 21) is a tadpole-shaped, 16-foot submersible built by Electric Boat Division of General Dynamics Corporation. Launched in 1964, she first saw use in archeological studies in the Aegean Sea.

For several years, the BCF Laboratory in Honolulu has made theoretical investigations of the research potential of submarines in fishery and oceanographic research. Only the Russian fishery scientists have such a craft at their command, and it is a refitted military submarine. What the scientists in Honolulu have had in mind is a more sophisticated ship, one designed for her specific purpose. These investigations have reached the stage of the first designs. The plans call for a nuclear-powered submarine 163.5 feet long and carrying a scientific party of 7 and a crew of 24—a vessel swift and maneuverable enough to follow the movements of fishes, so outfitted that a host of biological and oceanographic studies could be made aboard her. This ideal vehicle remains far in the future. Before it is built, scientists will need to use smaller research submersibles to extend their work farther and farther underwater. Therefore in the fall of 1965, the Laboratory in Honolulu chartered *Asherah* for a month's work off Oahu.

Asherah carried a pilot and an observer, and made 50 dives off Barbers Point on the sheltered leeward side of Oahu. Donald W. Strasburg supervised the work.

The maximum operating depth of *Asherah* is 650 feet. The Hawaiian Islands slope so sharply to the abyss that such depths are found close to shore. *Asherah* thus operated within a few hundred yards of the familiar beaches, cane fields, and steep green slopes of Oahu. The underwater terrain she covered constituted essentially a continuation of that landscape. It consisted of a sloping sandy plain, interrupted by rocky ledges 10 to 60 feet high and ending with an abrupt cliff that swept nearly vertically downward far deeper than the range of the little research craft.

FIGURE 22. Little PSENES CYANOPHRYS, the speckled driftfish, are sometimes eaten by tunas. These fishes are about 2 inches long They often aggregate under drifting material at sea. They have the faculty of changing their color to match that of their background. Observers on ASHERAH saw great shoals of such small fishes.

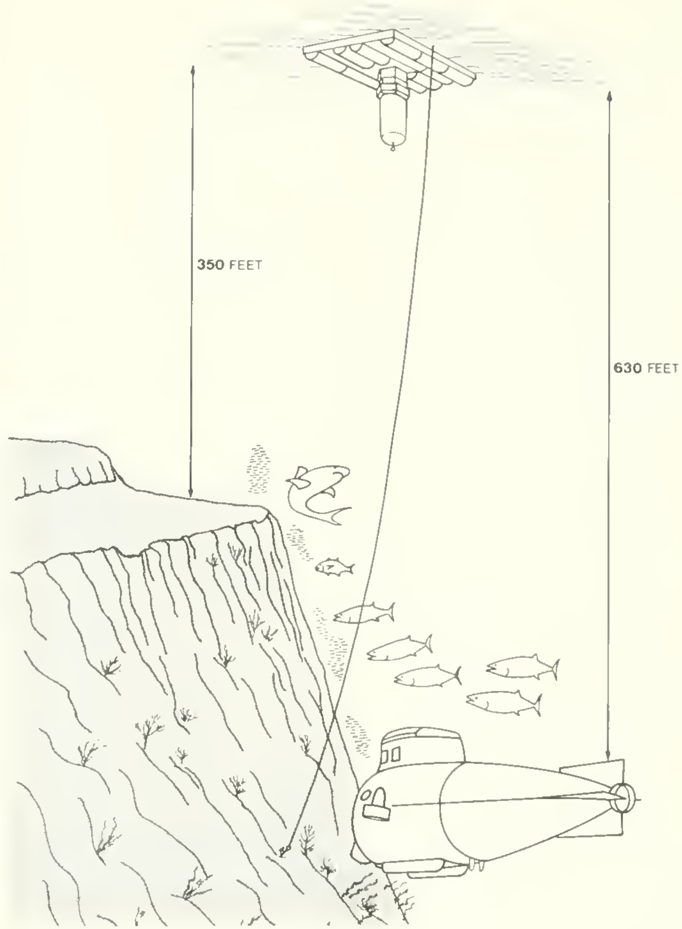


FIGURE 23. Along the face of the steep underwater cliff off Oahu, scientists aboard ASHERAH found skipjack tuna feeding at a depth of about 500 feet. It had not been known before that the skipjack tuna had so great a depth range. The raft NENUE was anchored overhead during most of the dives.

The scientists from the Laboratory in Honolulu who made the dives aboard the *Asherah* write of their observations with a cool dispassion; they speak of them with excitement, for what they saw has been seen by very, very few men. They found the sloping sandy plain featureless and almost barren of life, except where it was dotted by coral growth or rocky rubble: There hosts of creatures congregated. The rocky ledges 10 to 60 feet high that interrupted the plain were surrounded by clouds of colorful fishes. Above these bottom-dwelling species swam schools of fishes of the mid-depths.

Wherever the steep face of the limestone underwater cliff afforded a foothold, things were growing, and small feeding fishes were swarming around them like bees about a blossoming tree. It was at this considerable depth, about 500 feet, that a scientist aboard the *Asherah* made what was perhaps the single most important observation of the dives. There he saw skipjack tuna feeding on fishes an inch or so long. The depth to which the skipjack tuna traveled had never been known before. The fish are known almost entirely from their brief visits to the surface in pursuit of prey. It was at a depth of more than 500 feet, also, that the precious red coral was seen. In crevices and ledges along the cliff face were seen spiny lobsters of a size rarely caught in Hawaii. Like the skipjack tuna, other fishes such as snapper, amberjack, and wahoo patrolled the cliff. In all, more than 100 species of fish were seen on the *Asherah* dives. There were literally millions of the small forage fish upon which the larger, commercially important species feed (figs. 22 and 23).

These fishes were observed near the shores of Oahu. Whether the same conditions obtain in the open sea is not known; hence the interest in the use of larger submersibles and a sensitive sonar in fishery studies.

FISHES AND GEAR

Once the subsurface stocks of skipjack tuna are located the next step will be to harvest them. The only subsurface tuna stocks yet taken are those which the Japanese and the Hawaiians catch on their longlines. Under the direction of John J. Magnuson, a group of scientists at the Laboratory in Honolulu has spent several years studying facets of the behavior of tunas (fig. 24). From these studies may come the clues necessary to the construction of new types of fishing gear, and shifts to new methods.

Fishes of the open sea have been most successfully caught by the longline, an item of gear which does not actively seek the fish, but which the fish themselves find. According to Magnuson, it is possible that the best future gear for the subsurface tunas will be designed on this principle. The gear could be an adaptation of the longline, or it could be a drifting net or trap. Along the coast of Europe, long nets are used to intercept the regular migrations of the bluefin tuna. If the routes used by the Pacific tunas could be determined, gear might be devised to catch these fish during their migrations. Information on how well tunas see, hear, smell, may afford new insights as to new types of gear and methods.

The Governor's Conference pointed to the existence in the central Pacific of a tremendously large stock of tunas and examined the problems of locating and catching them. The solution of these problems is a long-term project. The conference also had more immediate results. It suggested several ways in which the catches of the present Hawaiian fisheries could be improved—by easing the bait problem and thus allowing the fishermen to spend more time fishing for tunas; by encouraging offshore fishing; by testing methods successful elsewhere but untried in Hawaii, notably the use of a light-weight synthetic purse seine developed by the

Norwegians for their bluefin tuna fishery. After the conference, a group of interested legislators and scientists formed a committee to draw up a concrete program for the encouragement of the Hawaiian fishing industry. The Laboratory in Honolulu is represented on this committee and will make some of the scientific studies required for the revitalization of the Hawaiian fisheries.

It was pointed out at the Governor's Conference how fishing vessels and techniques have evolved in response to different aspects of the behavior of the tuna species. Japan, Howard O. Yoshida said, has several types of vessels, several types of gear, each rather narrowly specialized to catch certain species behaving characteristically at certain stages of their life history. A large part of the Japanese tuna catch is taken by the longliners. In a generation, the longline fleet has grown to encompass the globe. The Japanese longline fleet alone accounted for a substantial share (31.4 percent) of the world tuna catch in 1963. Two types of vessels are used by the longliner. One is a special longline vessel, the other a combination boat built for pole-and-line fishing but adaptable to longline operations. Most of the longliners are relatively small, 250 to 350 gross tons. A few, however, are much larger.

Longline gear is enumerated in baskets, the term coming from the fact that in the old days the coiled lines were actually stored in bamboo baskets (fig. 25). A ship of 250 to 350 tons will fish about 400 baskets. When the lines are tied together and cast overboard, they form a single continuous mainline about 50 miles long. Attached to the mainline are branch lines that terminate in baited hooks.

FIGURE 24. Little tunny, or kawakawa, attacks a school of nehu in a research tank. Scientists at the Laboratory in Honolulu are studying aspects of the behavior of tunas and of their prey. The kawakawa is often used in such studies because it is sturdy and plentiful. Bait studies will be given further emphasis at the Laboratory during the coming year.

FIGURE 25. Japanese longline fishermen work on their gear. Long liners set as many as 400 baskets of the gear, forming a continuous mainline about 50 miles long. Dropper lines with baited hooks fish for large tunas and billfishes several hundred feet beneath the surface. The glass floats mark the junction of two lines.

FIGURE 26. A crewman aboard a research vessel fishes for tuna during an experimental cruise. Bird flocks are a sign of the presence of fish. Water is sprayed on the sea surface during fishing.

These hooks fish far beneath the surface of the sea, at 500 feet or more. The mainline is buoyed up by glass or plastic floats. The fishermen begin setting the lines at about 3:00 a.m. The operation requires about 4 strenuous hours of work as the hooks are baited and one basket put overboard every 30 seconds. Then the vessel either drifts or steams back to the head of the set. The arduous task of bringing in the longlines begins about noon and continues without cease until midnight or later; the fish are removed and stowed in ice.

Longline fishing depends for its success, of course, on the fact that the larger and older tunas of some species, notably bigeye tuna and yellowfin tuna, are found several hundred feet beneath the surface, not near it. The reason for this distribution is not known. The *Townsend Cromwell* sonar may eventually provide clues.

Longline skippers are reputed to locate their fishing grounds partly on the basis of past experience, partly as a result of scientific studies of the ocean which have suggested that the presence of some of the subsurface tunas is related to certain oceanographic features. The catch is truly oceanic, bearing no particular relation to the nearness of land.

The Hawaiian longline fleet is a scaled-down version of the Japanese. The vessels evolved from the Japanese sampan. They have a high narrow bow and moderate to low freeboard aft. They are about half as long as the most widely used Japanese versions. Where the Japanese may fish 400 baskets a set, the Hawaiian longliners fish no more than 70. Hawaiian fishermen get up later, beginning their set about 5:30 a.m. Hauling commences later in the day, about 4:00 p.m., and takes about 3 hours. The Japanese vessels are at sea for months on end; the Hawaiian vessels, which lack mechanical refrigeration, average about 9 days at sea and most of their trips are made within sight of land. A Japanese longliner has a crew of 30 men, a Hawaiian vessel 4.

In Japan, major fisheries for skipjack tuna and albacore depend on the pole-and-line method. The boats have a long, high bowsprit, Yoshida says, and carry fishing racks along one or both sides, around the stern, and along the bowsprit. As a group, they are smaller than the longline vessels; the largest is no more than 180 gross tons. The skippers locate fish schools by various means. Lookouts watch for bird flocks, floating timbers, and other indicators of the likely presence of fish. Most vessels have a full-time radio operator whose principal duty it is to obtain and relay reports on how fishing is going.

When a school is sighted, live bait is thrown overboard to concentrate the school near the vessels. On the fishing racks, the young, skilled fishermen are stationed along the bowsprit where the lift is highest (and the work hardest) and the older or less skilled fishermen around the stern and sides. The Japanese obtain their bait by purchasing it from dealers. At the peak of the season they are supplied on the fishing grounds by special bait-carrying craft.

The Japanese mode of pole-and-line fishing was introduced into Hawaii around 1900. It has been somewhat modified to suit local conditions. A distinct type of vessel has evolved, at 50 to 80 feet long much smaller than the Japanese ships and lacking the distinctive fishing racks of the Japanese vessels. Most fishing is done from the stern (fig. 26). The crew is smaller. The vessel moves ahead at low speed while fishing, whereas the Japanese vessels lie "dead" in the water. Another difference between the Japanese and Hawaiian techniques appears in the method of obtaining bait. In Hawaii, each vessel seines for its own bait, usually the nehu. Some spend almost two-thirds as much time fishing for bait as fishing for tuna.

For several decades, surface schools of skipjack and yellowfin tunas near the shores of the Americas in the eastern Pacific were fished by pole-and-line vessels. The schools there are relatively compact, with many individuals in each. They are thus susceptible to purse seining. Beginning in the late 1950's, many of the famous tuna clippers of the California coast were converted to, or replaced by, modern purse seiners. Technological innovations—notably the development of nets of light, tough synthetic fibers and of mechanical devices for power handling of the seines—triggered the conversions. In purse seining, a great net, about half a mile long and 300 feet deep, is set in a circle to entrap a school of tunas. As the net is drawn to the ship, the fish are confined to a smaller and increasingly smaller portion of the net, until the squirming mass of living treasure can be hauled aboard. Both purse seiners and tuna clippers depend on visual methods to locate fish. The Californians have one refinement: They often use small aircraft to do some of their spotting for them and report the location of schools by radio.

The principal tuna catches of the Pacific are made by these methods. The small catch of albacore off the U. S. coast is taken as well by still another technique. Small vessels are fitted with as many as 11 troll lines, which fish the near-surface waters behind the ship. One of these troll lines, by the way, is called the "whiskey line," for by tradition the fish it catches are sold to buy liquor for the crew.

Scientists say that the specialized vessels and techniques now in use may have to be radically changed if the full potential of the central Pacific tuna resources is realized. It seems undeniable that the subsurface behavior of the tunas themselves will help write the specifications the new craft and new gear must meet. How the fish behave when they are away from the surface is now being studied at the Laboratory in Honolulu by the use of a CTFM (continuous-transmission, frequency-modulated) sonar to study the distribution and behavior of fish schools at sea (fig. 27). The sonar (the word is an acronym for "sound navigating and ranging") was installed on the research vessel *Townsend Cromwell* in 1966. Scientists have now obtained information

on the sonar's effective range, its ability to determine the depth and movement of fish, and the likelihood that the sonar targets can be specifically identified.

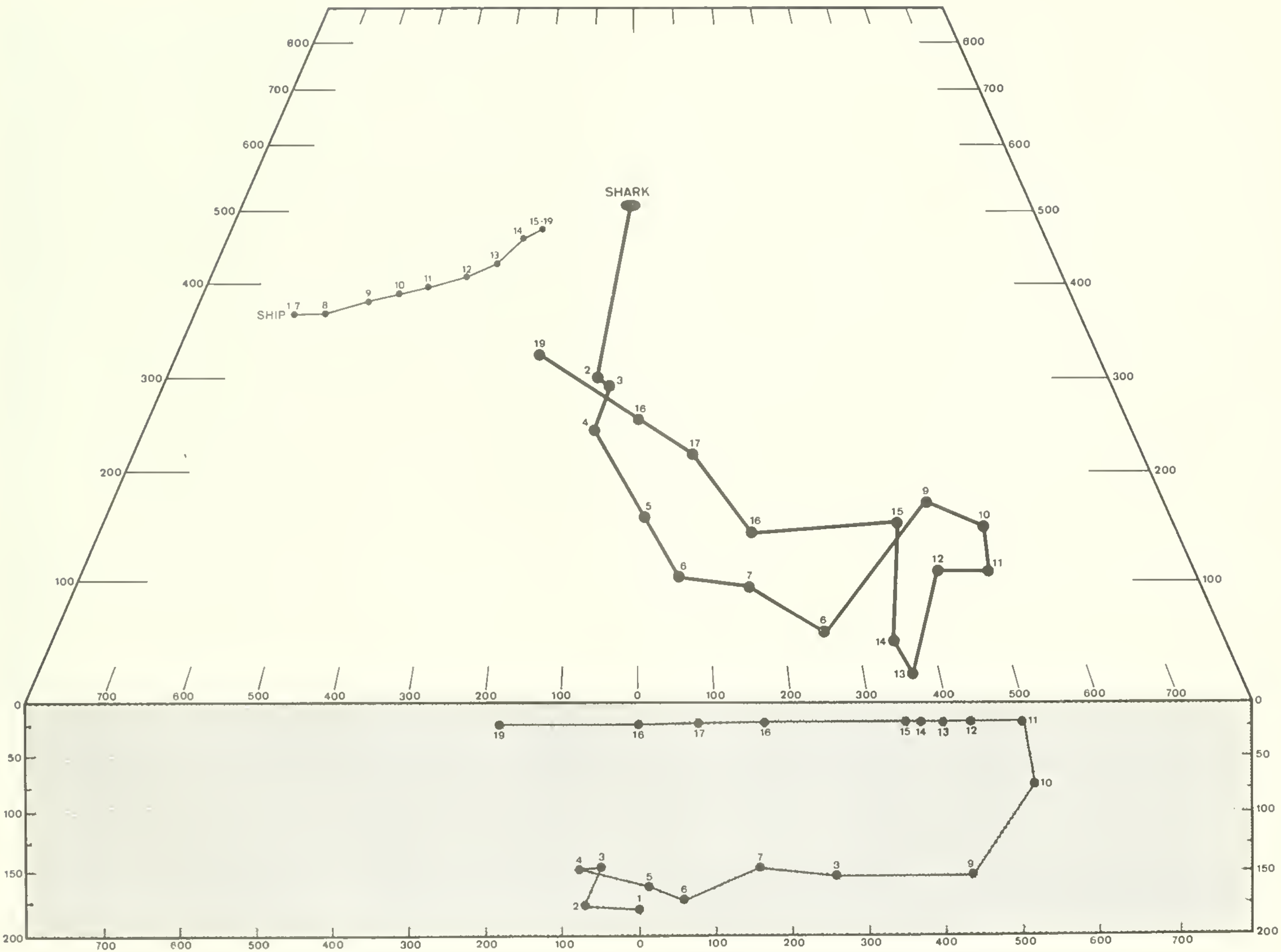
The sonar emits a beam of inaudible high-frequency sound in a specified direction. A target such as a fish reflects a portion of that sound to transducers aboard the ship. The signal is translated in two forms: as an audible sound and as a moving point of light on the face of the cathode-ray screen (fig. 28). The sonar operates in two modes, a "search" mode of 52 to 32 kilocycles per second for distant targets (about a mile away) and a narrower and more intense "classify" mode of 290 to 260 kilocycles per second for closer examination of nearby targets.

Throughout the summer and fall of 1966, the *Townsend Cromwell* coursed the waters of the Hawaiian Islands to test the equipment and train operators. During much of the period the sonar was operating 24 hours a day. It will take several months and a thorough reflective scrutiny of the material before the scientists will be able to say with confidence all they have discovered.

One positive gain of the cruises, says Heeny S. H. Yuen, who supervised the sonar studies, has been confidence in the equipment and its potentialities. For years the *Townsend Cromwell* and *Charles H. Gilbert* have been equipped with underwater viewing ports. Maximum visibility has been 20 yards and not always that. With the sonar, a single skipjack tuna 20 inches long, hung beneath a buoy, could be observed from 258 yards. Schools of skipjack tuna could be observed as far as 440 yards—and on one occasion, 715

FIGURE 27. The new CTFM sonar aboard the TOWNSEND CROMWELL allows scientists to track individual fish and fish schools beneath the surface of the water. High-frequency sound emitted by the transducers is reflected by the fish back to the ship. Each return appears as a point of light on a cathode-ray screen (center). The sonar is kept on target by means of a joy stick, which can be seen on the console beneath the cathode-ray screen.

FIGURE 28. This sector of the cathode-ray screen shows sonar returns made by fishes to the port of the ship (note bearings). The large circle is a cursor of light which the technician uses to isolate a target.


SHARK
SHIP

yards. The maximum sonar range varied considerably among schools, owing to differences in fish size and the height of the waves. Maximum range (880 yards) was attained not on a school of fish, but on porpoises.

The sonar has high resolution and a high information rate. It can rapidly search a complete underwater hemisphere. The high resolution makes it possible to determine accurately the position of a fish relative to the ship. The high information rate makes it possible to note the fish's position as often as every 30 seconds. Consequently, the biologists can obtain data on the swimming speed and course of a fish over short periods of time. For example, an unidentified subsurface target was found to be swimming at 2 knots at a depth of 175 feet (fig. 29). It was tracked as it surfaced, turned, and swam back to the ship. There it was identified as a whitetip shark about 5 feet long.

Much of the early work with the sonar was concerned with known targets. These were either dead fish suspended at a known range or skipjack tuna schools that had been sighted from the bridge. Occasionally schools could be seen at the surface that could not be picked up on sonar. The cause seems to be that signals vary according to the size of the fish and also the sea state. Target strengths were much lower for smaller fish and in high seas, where more sound-reflecting air bubbles were mixed in the water.

The sonar in effect makes the whole upper layer of the sea transparent. During the cruises there might be no signs of fish schools at the surface, but the sonar would locate numerous schools below the surface. Most of the fish were in the upper 30 feet, but a second concentration was at about 150 feet, and a third at about 400 feet. Once a skipjack tuna school that had been identified at the surface was tracked to a depth of 120 feet. Again, a mixed group of skipjack and yellowfin tunas was tracked to 420 feet.

Efforts to stay with targets were fairly successful. Once contact was maintained with a school of large skipjack tuna for almost an hour, and for 3 hours with a group of mixed skipjack and yellowfin tunas.

As yet, species identification by sonar alone has not been possible, although a painstaking review of the data may offer clues. Porpoises can be distinguished from fishes, but the individual species of fish cannot be determined from the sonar scope. The identification of porpoises (as a group, not species) is particularly easy, of course, for these animals emit sounds that are detectable on the sonar. The fish apparently do not, although this "passive" phase of sonar—listening for fish sounds—remains to be investigated more thoroughly. Previous research by Robert T. B. Iversen at the BCF Laboratory in Honolulu has shown that yellowfin tuna can hear (they can be trained to respond to underwater sounds) and that they themselves emit rudimentary sounds, whose biological purpose is as yet unknown and which have not been heard at sea.

FIGURE 29. How fish behavior underwater is studied. Here a target later identified as a whitetip shark was spotted at a depth of 175 feet and almost directly ahead of the ship. The shark swam away from the ship for several hundred yards, then rose to the surface and returned. The actual track shows that he followed an irregular course on his trip away from the ship and his return. Distances are in feet.

FIGURE 30. The 18 nations of the Indo-Pacific Fisheries Council represent well over one-third of the world's population. In some of the countries, fish is the primary source of animal protein. Yet experts think only a few are deriving the full potential of the protein resources of the adjacent seas. The Council met for the first time on American soil in Honolulu in 1966.

FISHERIES FOR THE FUTURE

Although it lies closer to the shores of the Americas than those of Asia, Hawaii is a part of the Indo-Pacific region, so far as its fauna is concerned. Its fishes are more like those of Indonesia than of Mexico. In October 1966 Honolulu played host to a meeting of scientists concerned with the fish resources of the Indo-Pacific region.

This meeting took place at the East-West Center at the University of Hawaii from October 3 to 16. The U. S. delegate to the conference was John C. Marr, Director, Hawaii Area, Bureau of Commercial Fisheries. His alternate was John A. Dassow from the Bureau's Technological Laboratory in Seattle.

The Indo-Pacific Fisheries Council (fig. 30) was initiated under an agreement signed at Baguio, Philippines, in 1948 and established under the auspices of the Food and Agriculture Organization of the United Nations in the same year. Its objectives are "the development and proper utilization of the living aquatic resources of the Indo-Pacific area," and "attainment of these ends through international cooperation." The member countries are Australia, Burma, Cambodia, Ceylon, France, India, Indonesia, Japan, South Korea, Malaysia, Netherlands, New Zealand, Pakistan, Philippines, Thailand, United Kingdom, United States, and South Vietnam.

The home of more than one-third of the world's population, the Indo-Pacific is the site of some of the largest fisheries in existence. In some of these countries the culture of fishes for food, an art which dates back more than 2,500 years, contributes substantially to the diet of the people. Extensive research on fish culture is conducted in the field. At the 12th IPFC (Indo-Pacific Fisheries Council) Session there was considerable interest in reports from several nations on their experiments in breeding completely new kinds of fishes. In India even intergeneric hybrids have been bred. As one of the delegates to the Council put it, the limits of the production of cultured fish is "just what man chooses to make it." He suggested that the future might see such fish far more important than marine fish, in terms of food.

The seas of the Indo-Pacific region are far from being fully utilized. Few of the nations are approaching the potential of the areas immediately adjacent to their coasts. Almost all, and notably Thailand and South Korea, are making determined and increasingly successful efforts to increase their share of food from the sea.

As a part of the American share of the International Indian Ocean Expedition, Richard S. Shomura of the Laboratory in Honolulu headed the studies of the U. S. fisheries of the Indian Ocean. Two papers resulting from this research were presented to IPFC. One, by Shomura, described the pelagic catches made on two fishery cruises. Over half the fishes caught were tunas. Most plentiful was the yellowfin tuna; bigeye tuna, albacore, and skipjack tuna appeared in decreasing order. Shomura and Frederic S. Osell of the Laboratory in Honolulu and Shoji Kikawa of Nankai Regional Fisheries Research Laboratory, Japan, are now preparing an exhaustive study of the longline catches (with the addition of data from the active Japanese longline fleet) and oceanographic conditions in the Indian Ocean.

The same fishing cruises provided material for Kikawa, who visited the Laboratory in Honolulu for several months in 1966, and Maria G. Ferraro to investigate the maturation and spawning of tunas in the Indian Ocean. They found that albacore spawned below lat. 10° S., yellowfin tuna from slightly north of the Equator to lat. 10°-20° S.

One of the chief features of the IPFC meeting was a 2-day symposium on Fisheries Education and Training. Systems from around the world were described, including those in Australia, Canada, Fiji, Hong Kong, India, Israel, Japan (which has by far the largest training program), Papua-New Guinea, Philippines, Taiwan, Thailand, and the United States. Three U. S. programs were discussed. One was a since-terminated program to train men for the aku fleet in Hawaii. Another was a small program in which Micronesians come to Hawaii for on-the-job training with the fleet; this has proved successful. The third program was one being established by the University of Rhode Island specifically aimed at educating potential fishing vessel skippers.

One result of the symposium was the recommendation that one or more educational centers be established in the Indo-Pacific region to train extension officers and others who could then train fishermen directly and to prepare audio-visual aids and texts to be used in fishery training. The Council agreed that there were certain unique skills required in fisheries, not only at sea but also in some activities on land, and that the trade required special training not usually available in a country's general educational program—as Hawaii and Rhode Island among the United States have recognized.

Discussed at the 12th Session were the fishery studies to be conducted under the international CSK (Cooperative Study of the Kuroshio and Adjacent Areas). CSK is sponsored by the United Nations Educational, Scientific, and Cultural Organization. Marr serves as Assistant International Coordinator for Fisheries. IPFC agreed that studies be made on some fishery resources common to two or more of the CSK countries: chub mackerel, goldenthread, lizardfish, saury, skipjack tuna, spanish mackerel, and yellow croaker. The Council supported CSK work on the bottom resources of the South China Sea, an area whose fishery potential is as yet little realized.

At the Governor's Conference, where the talk had been mostly of how to increase catches, a member of the audience rose and said: "I want to ask a question in favor of the fish. I imagine sooner or later man will learn how to catch them as fast as he wants to. Is any effort being made to conserve or replace fish in the ocean?" Marr, who was Chairman of the conference, replied by pointing out that the interest of the conference was in maximum sustainable yield, "which means you would be harvesting them at a rate that could be continued forever."

This same concern with the long-term view seemed apparent at the meeting of IPFC, where men of diverse cultures met with sober awareness of the double-edged need to improve the diet of the teeming millions of the world and, at the same time, to see that great living resources are not destroyed. About 2 billion of the 3 billion people on earth suffer from protein malnutrition. This number includes 50 to 70 percent of preschool children. This type of malnutrition can produce mental retardation in children; even ordinary childhood diseases may be fatal to those who suffer from it.

This great dual problem—how to help people live better and still not irreparably damage the element that supplies their food—is, in the words used by President Lyndon B. Johnson in a telegram welcoming the IPFC to the United States, "one of the principal items on the agenda of mankind."

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