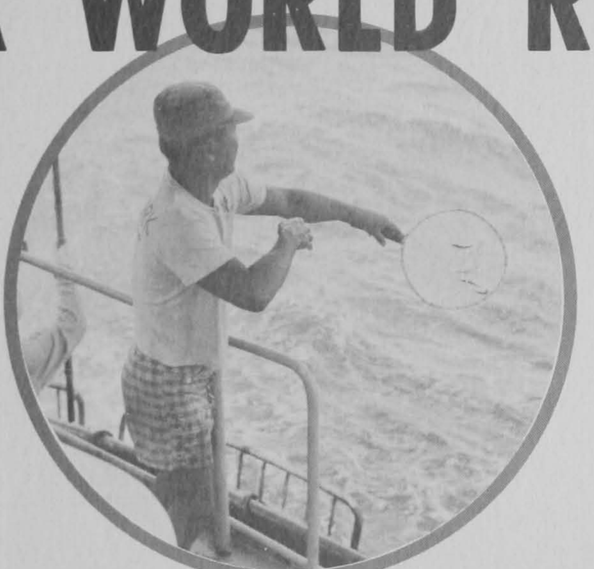
SKIPJACK

A WORLD RESOURCE



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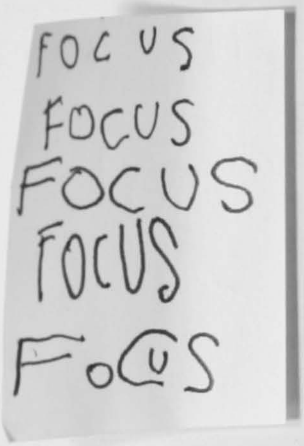
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SKIPJACK-A WORLD RESOURCE

Prepared by Staff of the

BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORIES

AT HONOLULU, SAN DIEGO, AND STANFORD [1]

INTRODUCTION

As perhaps was inevitable, the tuna fishery based in California has finally reached the point at which the fishing pressure on yellowfin tuna in the eastern tropical Pacific has to be relieved, or, if this pressure continues to increase, the result will be an ever-decreasing total catch. In either event, the California fleet must supplement its yellowfin catch by fishing on tuna stocks capable of sustaining greater fishing pressure than is now being imposed on them.

Among the possibilities are yellowfin stocks outside the overfished area, or bluefin tuna and skipjack wherever they may be.

It is known that yellowfin tuna stocks exist outside the presently overfished areas. It is known that the older, larger sizes are found over vast areas of the tropical Pacific. They inhabit the deeper waters of the mixed layer and can be caught on longlines, a method of fishing that is economical only in an economy, such as the Japanese, where manpower can be applied more lavishly than in the American economy. They do not school at the surface and are not caught by the live-bait or purse-seine method. The whereabouts of the younger, smaller sizes needed to recruit the large longline fish remains a mystery. Smaller yellowfin are seen and sometimes caught in the vicinity of tropical mid-Pacific islands. It is not known whether these are the yellowfin that, as they grow older, depart from the islands and descend to deeper waters to become the mainstay of the Japanese longline fishery, but it is doubtful in any case that the younger surface-schooling yellowfin can regularly be found in large enough concentrations around any single archipelago close enough to California or Puerto Rico for U.S. fishermen to catch and land them at a profit.

Bluefin tuna appear near Baja California for a few months each summer and are already an important supplement to the yellowfin and skipjack catch by California fishermen. It is not known where they come from or where they go between their brief seasonal visits to the "local" purse seining grounds. Those caught are practically all immature, and the amounts taken are small compared to the yellowfin and tuna catches. Evidently as they become mature they do not return even seasonally. At present the clues to these mysteries are so scanty that it may take a long time to learn enough about this mystery fish to know whether it represents a large enough stock to support a much greater yield or where to fish for it over additional months of the year. These questions should be, and are being, investigated, but there is no promise of early answers.

The skipjack caught in the eastern Pacific, like the bluefin tuna, are nearly all young and immature. But unlike the bluefin tuna, the catch is large, and fishing extends over a much larger area and through a much longer season. Although the catch is large, its effect on abundance is imperceptible. Indications are that the skipjack would be the most promising of the several possibilities for substantially supplementing the limited yellowfin supplies, if more were known about this fish.

For this reason it seems appropriate to try to bring together in summary form, for the reference of tuna fishermen, such of the information available on skipjack as may be useful in planning future fishing ventures. Several promising lines of research are being pursued to answer critical questions suggested by the imperfect state of our present knowledge.

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[1] The Inter-American Tropical Tuna Commission (IATTC) and the Bureau of Commercial Fisheries Exploratory Fishing and Gear Research Base, Gloucester, made valuable contributions of information to this report.

DISTRIBUTION OF SKIPJACK AND THE SKIPJACK FISHERIES

Skipjack live in the warm upper layer of tropical and subtropical seas, spending their life far from large land masses, their distribution and migrations being related to changing features of the oceanic environment. During the past 15 years or so, broad studies of the distribution of the tunas in relation to their oceanic environment have provided the beginning of understanding of some relationships of these fishes to ocean conditions.

Skipjack are found in quantity only where surface water temperatures are 20° C. (68° F.) or warmer, and occasionally at temperatures as low as 15° C. (59° F.). The world-wide distribution of this species, as we presently know it, is outlined schematically in figure 1. Areas of important commercial fishing, including the pre-World War II Japanese live-bait fishery in Micronesia, are shaded the darkest. Average winter and summer positions of the 20° C. (68° F.) surface isotherms are shown. What is known or inferred about skipjack distribution outside established regions of commercial fishing comes from isolated catches and sightings by commercial craft and research vessels and from the capture of larval specimens by the latter.

Studies of the geographical distribution of catches from logbook records of fishing vessels have demonstrated clearly that skipjack, like other tunas, are not distributed evenly but tend to concentrate in certain specific regions. Although concentrations in these specific, but often vast, regions are remarkably consistent, there are notable year-to-year and season-to-season variations in the location of centers of good fishing. Scientists are making progress in identifying some of the features of the environment which control the distribution of tuna, and continuing research by fishery oceanographers can be expected to define more clearly the movements of tuna in response to changes in their environment. Already in several areas useful relationships between skipjack distribution and sea surface temperatures have been found and are being applied experimentally in short-term forecasting.

Some remarks about the major ocean current systems, depicted in figure 2, will be helpful in understanding the distribution of skipjack, as well as the other tunas, and the application of the more important fishing methods.

In equatorial regions, there is a westward transport of surface water north and south of the Equator by the North and South Equatorial Currents. These currents turn poleward at their western boundaries, transporting large volumes of warm water into temperate latitudes. In the Northern Hemisphere, between 30° and 40° N., these currents leave the shore and flow northeasterly, joining the cold counter-clockwise currents, the Oyashio in the Pacific and the Labrador Current in the Atlantic, and proceed eastward. Processes of mixing and cooling during the eastward flow are such that when the waters reach the western shores, or

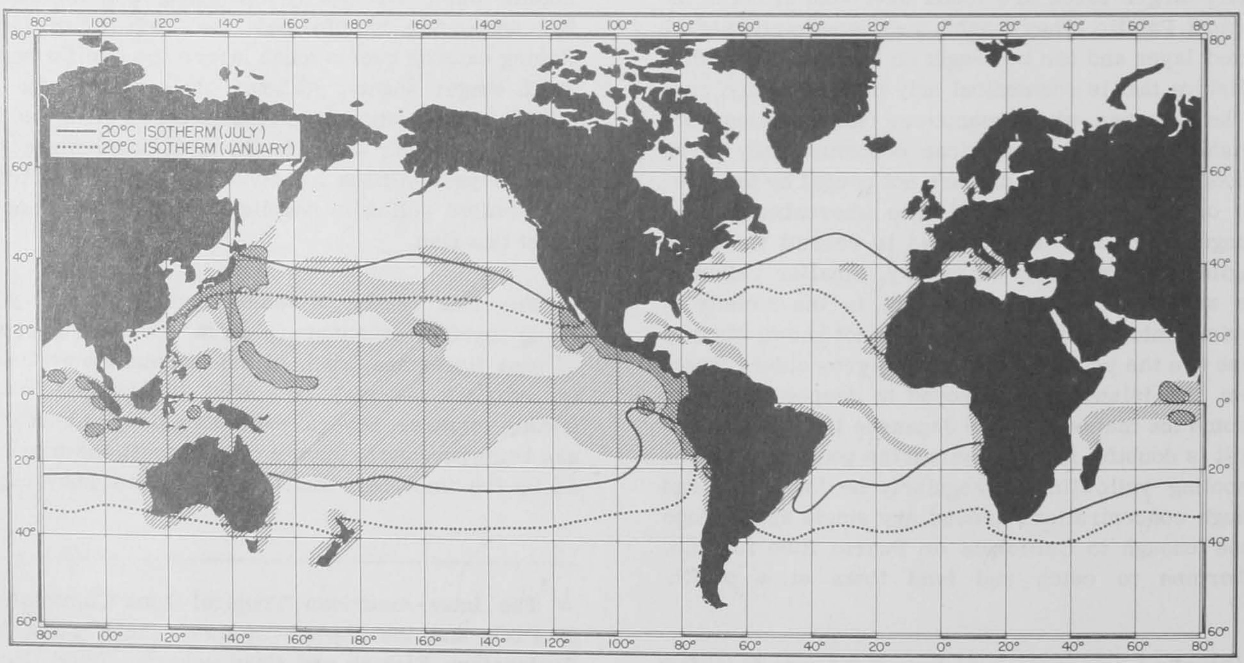

Figure 1.--World distribution of skipjack and skipjack fisheries.

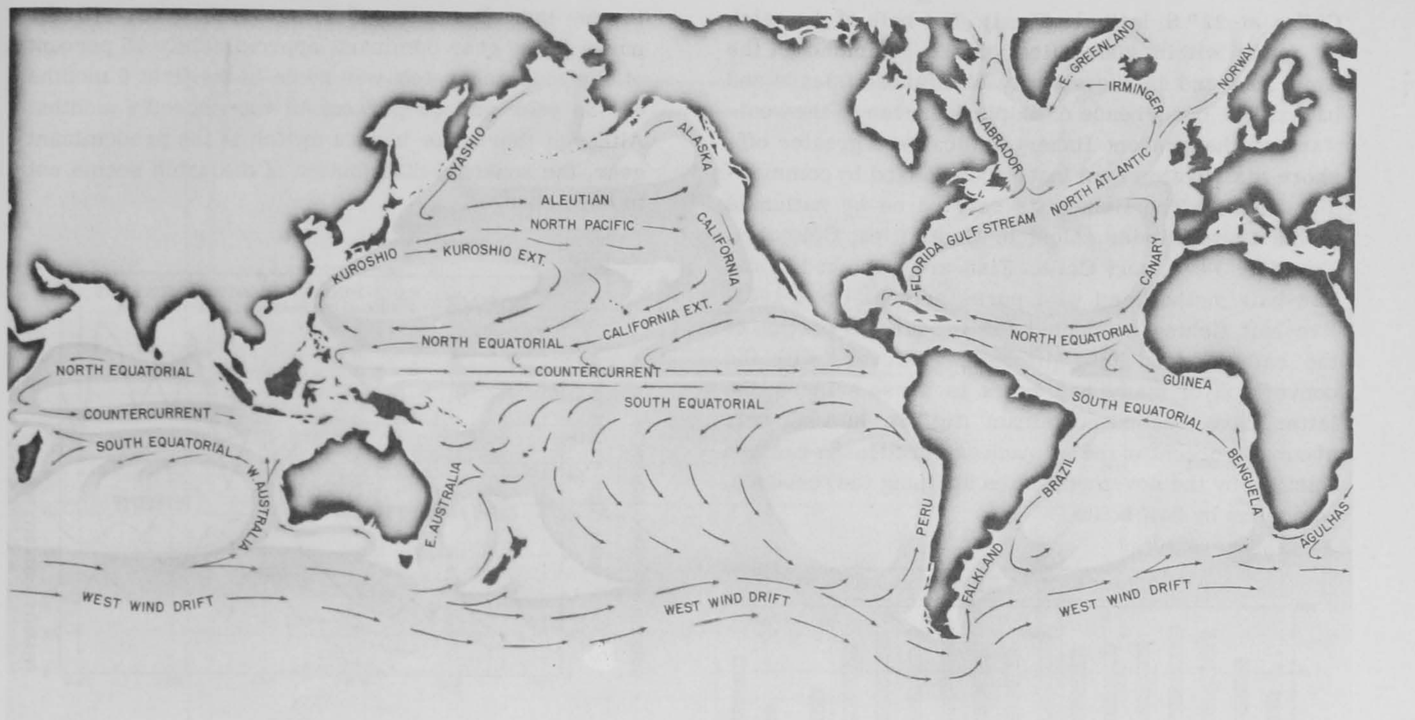

Figure 2.--Major ocean current systems.

eastern side of the ocean, they are no longer tropical. The southward flowing California and Canary Currents transport cool water well into the tropics, where they swing offshore into the equatorial region, completing the circle. There are analogous circulations in the Southern Hemisphere.

The circulation described gives rise to substantially different conditions on the western and eastern sides of the oceans. The western sides have a broad belt of tropical water offshore and a narrow belt of temperate water inshore. Conditions on the eastern sides of the oceans are characteristically the opposite. The tropical ocean, simply stated, is a two-layer system of persistent stability. The upper part is referred to as the mixed layer because it has essentially the same temperature from top to bottom. This is where the tuna live. The mixed layer is warm. It is separated from the cold water of the depths by a strong thermocline, or sharp temperature gradient. The differences described for the eastern and western sides of the oceans profoundly affect the thickness of the warm upper mixed layer. In the eastern portion of the tropical oceans, the mixed layer is thin, from 50 to 200 feet thick; on the western side, it is much thicker, frequently more than 300 feet.

The effectiveness of the principal types of fishing gear for yellowfin and bigeye tuna appears to be related to the depth of the upper mixed layer. The eastern margins of the tropical oceans are the only areas where major live-bait and purse seine fisheries for these species are presently carried on the year around. Live-bait fishing and purse seining depend on the tuna being near the surface. The longline method, which was the basis of the great Japanese expansion in tuna fishing in the 1950's, is the only presently available method which is successful in catching yellowfin and bigeye in the tropics, where the mixed layer is deep. These fishes penetrate the entire range of the deeper mixed layer of the central and western tropical oceans.

Skipjack must behave differently, for so far they have been caught in quantity only by live-bait fishing and purse seining. Catches of skipjack in the areas of the great tropical Japanese longline fisheries for yellowfin and bigeye are so small and so scattered that they only provide evidence of their occurrence. This suggests that skipjack generally ignore baited longline hooks or that they remain close to the surface, whether the mixed layer be deep or shallow. Live-bait fishing might be effective for skipjack in the vast high seas regions of the tropics, but the method appears to be limited by the need for large amounts of small bait fishes usually found in catchable quantities only close to land. Purse seining techniques have not been tried extensively on the fast-moving skipjack schools in the central and western tropical oceans.

EASTERN PACIFIC

The skipjack fishery of the eastern Pacific extends for some 4,000 miles on a NW-SE axis between Cedros Island, Mexico, at 28° N. latitude, and northern

Chile, at 22° S. latitude (fig. 1). The bulk of the catch is made within 200 miles of the mainland of the Americas and in the vicinity of offshore islands and banks. The occurrence of skipjack larvae to the westward of the present fishery indicates a greater offshore distribution than that encompassed by commercial fishing. The fishery is carried on by nationals of the United States, Mexico, Costa Rica, Colombia, Ecuador, Peru, and Chile. Fish are captured by the live-bait method and with purse seines. Up to 1961, live-bait fishing accounted for the largest portion of the catch landed in California. However, with the conversion of many bait boats to purse seiners, the latter have become dominant (fig. 3). In 1962 only about 30 percent of the skipjack captured in the eastern Pacific, by the seven countries utilizing the resource, was taken by bait boats.

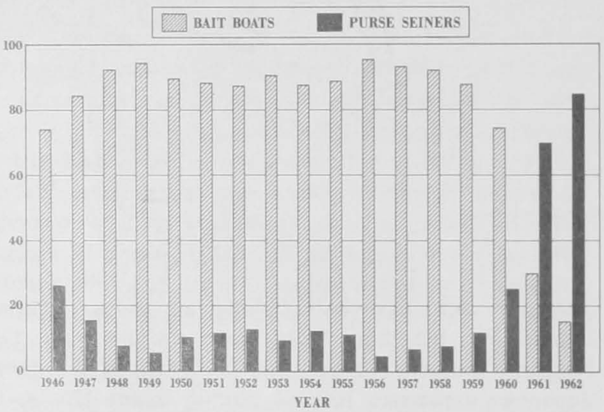

Figure 3.--Percentage of the total annual California landings of skipjack tuna taken by bait boats and purse seiners, 1946-62. (Source: Inter-American Tropical Tuna Commission.)

The amount of fishing has not affected the abundance perceptibly, so it seems that the resource remains under-utilized, at current levels of fishing, and could support a much larger harvest. The eastern Pacific catch and fishing intensity for the years 1934 through 1961 are illustrated in figure 4. The 1962 catch was approximately 159.8 million pounds. Postwar catches have varied between a low of 42.5 million pounds (1946) and a high of 177.6 million (1959). The average during this 17-year period was 120.3 million pounds.

The catch consists for the most part of fish between 18 and 26 inches long (about 4-13 lb.). California State law prevents the landing of fish smaller than 4 pounds; fish over 26 inches and ranging to 30 inches (about 22 lb.) make up the rest of the catch.

Because of their wide, though uneven, distribution in the eastern Pacific, skipjack are taken the year around. In the period 1951-1958, when bait boats were the predominant element in the fleet, about 43 percent of the average annual catch was taken in the first 6 months of the year and approximately 57 percent in the last 6 months of the year. In 1962, with the purse seine gear dominant, approximately 45 percent of the skipjack catch was taken in the first 6 months of the year and 55 percent in the second 6 months. Although there has been a switch in the predominant gear, the seasonal distribution of the catch seems not to have changed.

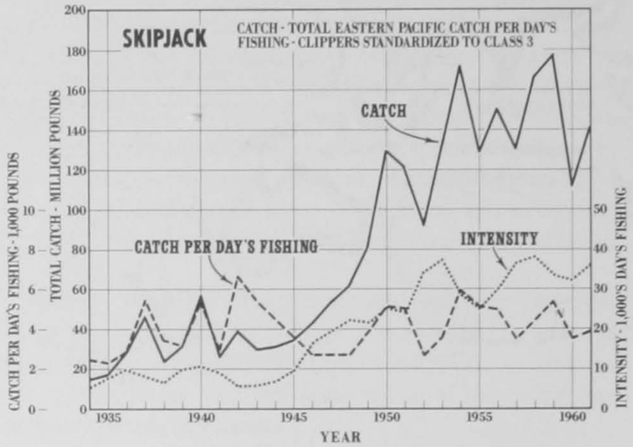

Figure 4.--Total catch, catch per day's fishing, and calculated fishing intensity for skipjack in the eastern Pacific, 1934-61. (Source: Inter-American Tropical Tuna Commission.)

The uneven distribution of skipjack in the eastern Pacific, and the variations that can occur from year to year, are illustrated by the catches of bait boats and purse seiners in 1956 and 1959 (figs. 5-8). The former was a "cold" year and the latter was "warm." Skipjack penetrate farther poleward seasonally at the northern and southern extremes of the fishery in warm years than in cold years, and their penetration coincides with the seasonal march of the 20° C. (68° F.) isotherm.

The absence of skipjack in the middle region, an extensive area off southern Mexico and Guatemala, in 1959 is typical, although somewhat accentuated. This has been the pattern every year since 1951, except in 1956. It has been suggested that surface water temperatures above 82° F. (approximately 28° C.) may be limiting to skipjack in the eastern Pacific, and there were extensive areas with such temperatures in this region during 1959.

If we divide the fishery into two geographical areas north and south of 15° N. latitude, we find a considerable variation in the catch from quarter to quarter within the same year. The catches north of 15° N. latitude come primarily from the vicinity of Baja California. There is a definite migratory cycle in this area which is, as noted above, related to the poleward and anti-poleward movements of the 20° C. (68° F.) isotherm. The sequence of skipjack catches off Baja California indicates a movement into this area in the second and third quarters of the year (April through June and July through September) and

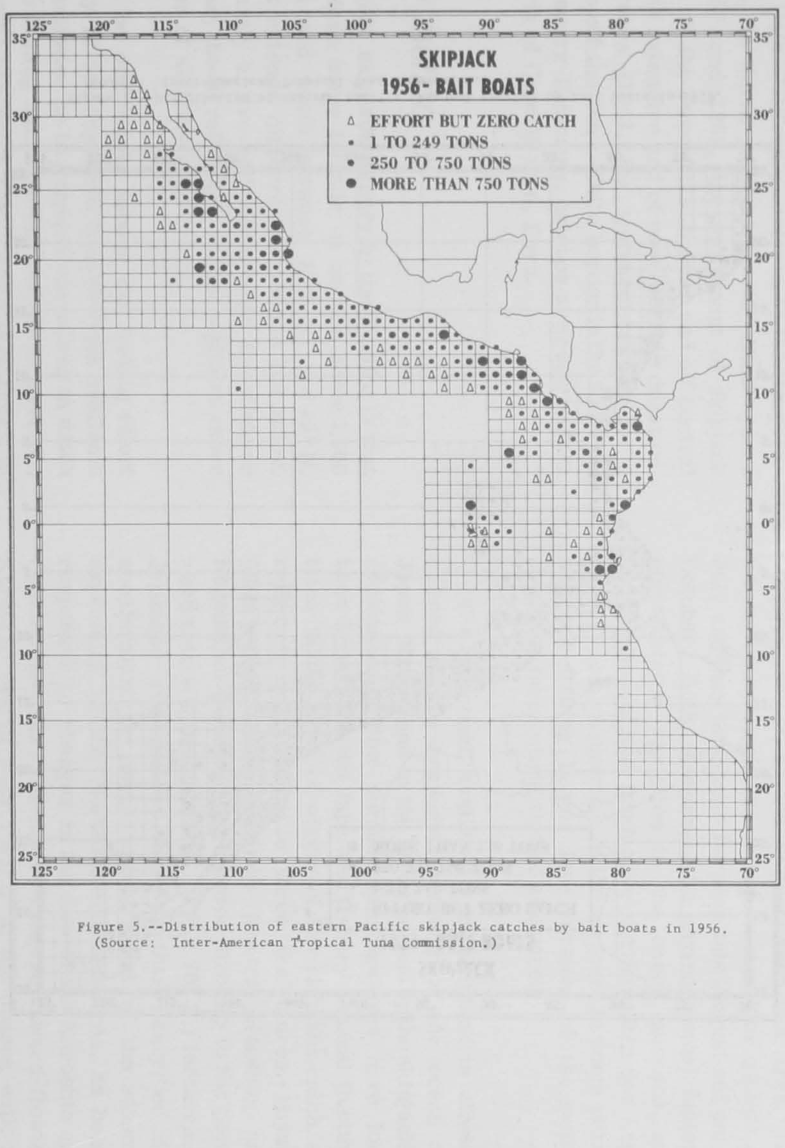

Figure 5.--Distribution of eastern Pacific skipjack catches by bait boats in 1956. (Source: Inter-American Tropical Tuna Commission.)

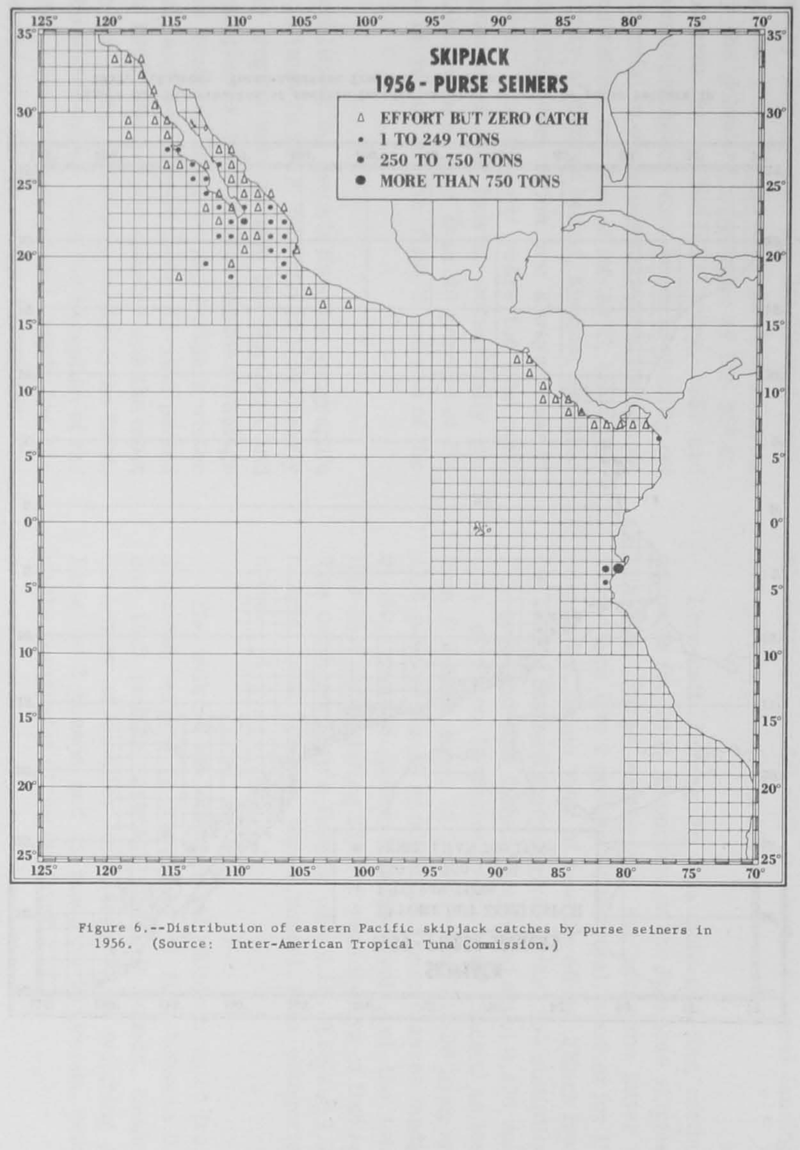

Figure 6.--Distribution of eastern Pacific skipjack catches by purse seiners in 1956. (Source: Inter-American Tropical Tuna Commission.)

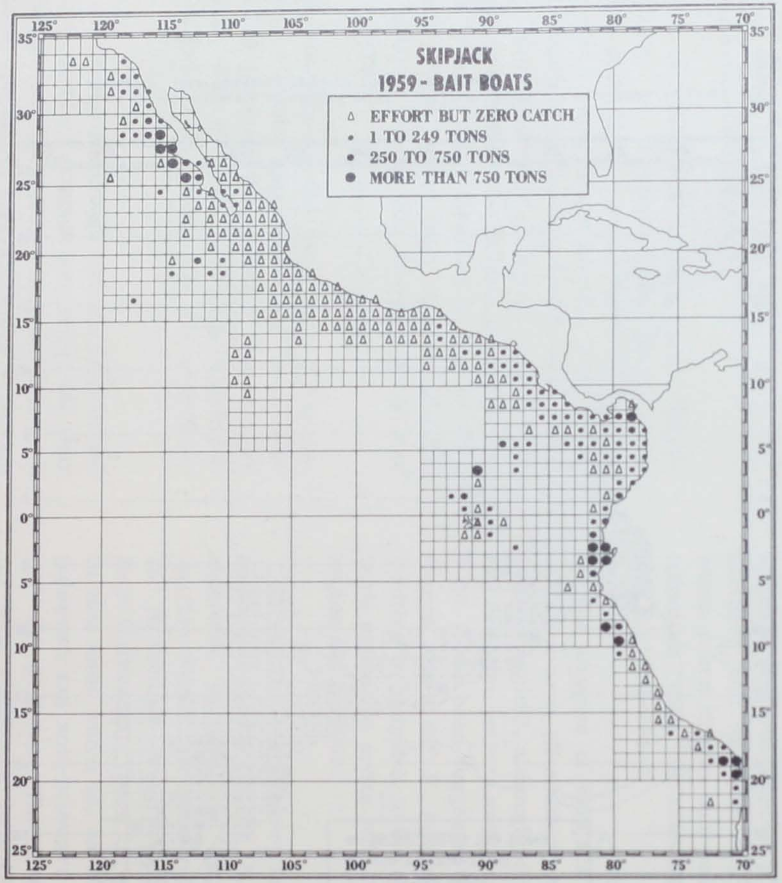

Figure 7.--Distribution of eastern Pacific skipjack catches by bait boats in 1959. (Source: Inter-American Tropical Tuna Commission.)

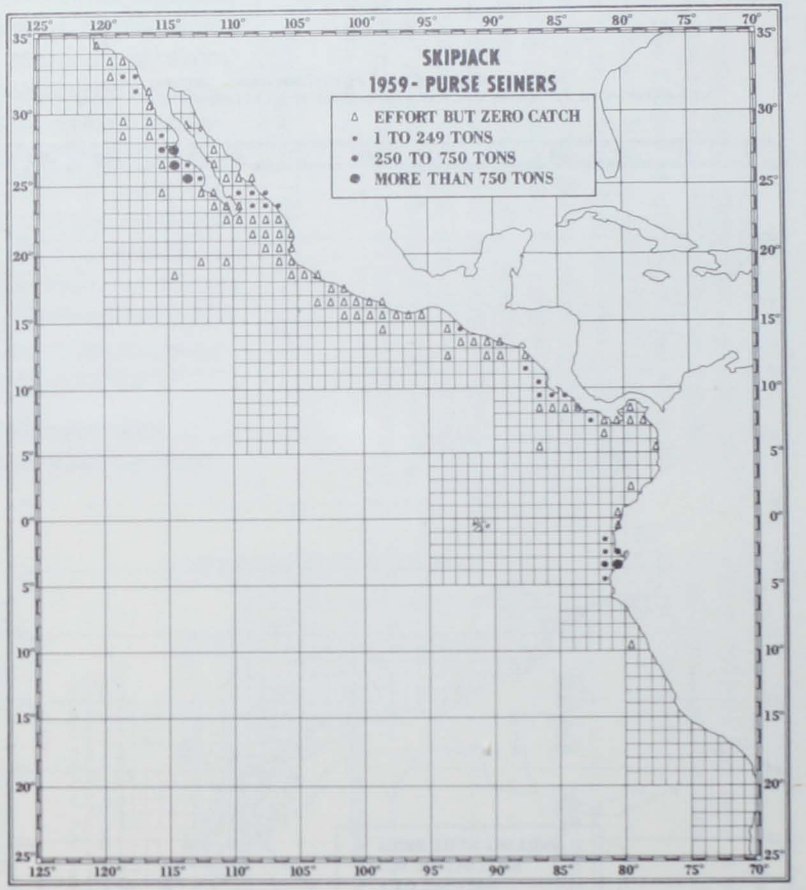

Figure 8.--Distribution of eastern Pacific skipjack catches by purse seiners in 1959. (Source: Inter-American Tropical Tuna Commission.)

a movement out in the fourth quarter (October through December) which is nearly complete by the first quarter (January through March). Northward penetration along the outer coast of Baja California is controlled by the poleward movement of the 20° C. (68° F.) isotherm. In warm-water years, 1957 and 1958 for example, skipjack were taken in quantity off southern California; in more normal years, their most northerly penetration, and that of the 20°C. isotherm, is in the vicinity of Cedros Island, Mexico. The best catches in the northern region are always made in the third quarter, and in most years the next most productive quarter is the fourth, occasionally the second. On the average, less than 25 percent of the annual catch is taken in the first 6 months of the year.

The seasonality of the catch in the other geographic area (15° N. latitude to 22° S. latitude) is less clearly defined. This region extends into the Northern and Southern Hemispheres, and the fleet has the advantage of fishing the southern summer and northern winter simultaneously and the reverse. In the 11-year period 1951 through 1961, the second quarter was the most productive in six years; the fourth, in three; the first, in two; and the third, in one. With the exception of the second quarter, the average annual catch for the 1951-1961 period was fairly evenly distributed. The average annual catch distribution by quarters 1-4 was 21.9 percent, 32.5 percent, 22.3 percent, and 23.2 percent, respectively. In the southern portion of this area, off Peru and Chile, the skipjack's movements are, as off Baja California, related to the temperature regime. In warm years, i.e., "El Niño" years such as 1957 and 1958, the movement of skipjack into waters off the Peru-Chile border and off central Peru is quite extensive and of considerable duration. In cooler years (1962, for instance), except for a short season off the Peru-Chile border in the southern summer, January-February, catches are restricted to the area north of Cape Blanco, Peru.

WESTERN PACIFIC

The largest skipjack fishery in the Pacific is that of the Japanese home islands. It covers some 1,500 miles north and south between 18° N. and 45° N. latitude, but extends offshore only 200 to 300 miles. It is dominantly a live-bait fishery, so the offshore extension may be a reflection of bait logistics more than a matter of skipjack distribution.

It would be difficult to assess the fishing effort and intensity in the Japanese fishery from available published statistics or to examine variations in catch according to fishing intensity. Between 1935 and 1961, the annual catch reached a low of 39 million pounds in 1945 (a war year) and a high of 368 million pounds in 1959. The average during the 27-year period was 193 million pounds. The skipjack catch from the tropical eastern Pacific during the same period averaged 80 million pounds, with the highest annual landings 178 million pounds, in 1959.

Live-bait fishing by the pole-and-line method accounts for 90 to 95 percent of the Japanese skipjack landings. Purse seines and set nets, the latter of which take 1 to 2 percent of the total, account for the remainder. Some idea of how the effort differs from the United States fishery is given by the 1959 statistics. The pole-and-line fishery employed about 4,490 vessels, of which 76 percent were craft classed as less than 5 metric tons, 12.5 percent as 5 to 50 tons, and 11.5 percent as 50 to 500 tons. These classes landed 5, 20, and 75 percent respectively, of the total live-bait catch during 235,000 vessel-days of fishing. The catch per day's fishing was 0.10, 0.68 and 1.78 metric tons for the three vessel size categories noted.

The bulk of the commercial skipjack catch from Japanese waters is composed of fish between 5.5 and 14.3 pounds, average about 9 pounds. Lesser quantities of smaller and larger fish, weighing as little as 3 pounds and as much as 21 pounds, make up the remainder of the landings.

On the average, over 75 percent of the annual catch is taken during the 4 months from May through September. The greatest variation in the season occurs in the area of the fishery north of about 35° N. latitude, known as the Northeastern Sea Area. The fishery may begin as early as April or as late as July and may terminate between late August and early October. Both economic and environmental factors contribute to variation in the onset, success, and termination of the productive Northeastern Sea Area Fishery. As an example of the former, in some years skipjack fishing begins late because of the availability of large quantities of albacore.

The seasonal availability of skipjack is closely related to the seasonal warming of the ocean off Japan. Variations in the catch caused by the skipjack's avoidance of low surface temperatures have long been known for the Japanese fishery. Annual fluctuations in the area of origin of the skipjack catch, as reflected by landings in three prefectures, Miyagi (northern Honshu), Shizuoka (central Honshu), and Kagoshima (Kyushu), are related directly to the poleward march of the 20° to 21° C. (68° - 70° F.) isotherms. Japanese researchers have further described the acceleration or delay in the onset of the season, especially in the Northeastern Sea Area, as being responses to changes in the flow of the Kuroshio and Oyashio current systems. A strong, northward-flowing Kuroshio (warm water) early in the season will, in general, accelerate the onset of the fishing season. Conversely, a weak Kuroshio, or the late development of a strong Kuroshio, or a strong southward-flowing Oyashio (cold water) will delay the season. Termination of the season is similarly related to the dynamics of these currents.

CENTRAL PACIFIC

HAWAII

The Hawaiian skipjack fishery is seasonal and its operations are confined to waters immediately adjacent to the main islands of the group. The fleet of about 20 wooden "sampans" 60 to 90 feet long normally operates by the day, each crew catching its own live bait, scouting for schools independently, and delivering the unrefrigerated catch each night to the cannery and the fresh fish market in Honolulu. Occasionally the boats shift their base of operations temporarily to one of the other islands, when skipjack or live-bait are more available there.

The Hawaiian fishery produces from 6 to 14 million pounds per year. Monthly landings may range from a low of about 100,000 pounds in December to nearly 2 million pounds in July of the same year. These great annual and monthly variations are not due to fluctuations in effort but to changes in availability of the skipjack. Although skipjack of widely varying sizes are taken at all times of the year, the catch in the summer peak season comprises a higher proportion of 15 to 20-pound fish, the so-called "season aku." This combination of a sharp summer peak in the catch and an accompanying change in the dominant size of fish lends itself to the interpretation that the "season" fish migrate annually into Hawaiian waters from elsewhere, and this is the interpretation that is commonly made.

Intensive tagging experiments in the area of the Hawaiian fishery have produced some information on the movements of skipjack within the island chain, but no clear pattern of migration has emerged. Little is known of the distribution and movements of the fish outside of the present fishing grounds. The commercial boats do not have the cruising range nor adequate bait supplies for scouting to any distance from the Islands, and even if they did, it seems unlikely that they would be able to find much fish once they got beyond the range of the bird flocks on which they depend for spotting the schools. Attempts by research vessels to test various hypotheses about the direction from which the season fish approach the Hawaiian Islands have failed for this reason.

A skipjack fishery based in the Hawaiian Islands could perhaps increase landings over the present level by several methods. One would be to discover areas where skipjack are more available than they are in the present fishing grounds, at least during the winter off-season. If such areas were very far away, more able vessels would be required, and new scouting and fishing techniques would probably have to be developed. Another approach would be to take measures to increase the efficiency of the present fleet operating on its present grounds. The boats now fish on the average about half of the potential working days. They are unable to catch any fish at all from about 50 percent of the schools that they approach, and of the schools which do respond to fishing efforts, only about 25 percent yield substantial catches. Much of the lost fishing time and the low ratio of fishing success can doubtless be blamed on the poor natural supply of bait fish. Attempts are being made to improve operating efficiency by providing a constant supply of hatchery-raised bait (tilapia) and by devising fishing methods other than the traditional pole and line. So far the tilapia have been little used, and fishing gear experiments with gill nets have been unsuccessful. It seems likely that development of a practical means of locating skipjack schools that are unaccompanied by bird flocks would be useful for raising production from the present fishing grounds as well as for exploiting any more distant grounds that might be discovered in the future. Cooperative scouting, with a sharing of information among the boats of the fleet, might well produce a larger total catch than the present highly competitive and secretive individual operations.

The skipjack taken in the Hawaiian fishery range in size from about 35 to 86 cm. (14 to 34 inches, or about 2 to 36 lb.), with very few smaller than 45 cm. (about 4 lb.)(fig. 9). The fishermen in this pole-and-line fishery can and of course do select against the smaller fish, which are wanted neither by the cannery nor the fresh fish trade. Combined samples collected over a period of years show two modal groups centered around 45 cm. (18 inches or 4 lb.) and 71 cm. (28 inches or 19 lb.), with a slightly greater number of fish in the larger modal group.

Monthly samples show three modal groups present in the landings made during the summer. A group of small skipjack is found with great regularity near 45 cm. (18 inches or 4 lb.), as in the combined samples. The second group, made up of large fish, is centered between 63 and 71 cm. (25-28 inches, 15-20 lb.), and the third, a group of very large fish, is centered between 74 and 79 cm. (29-31 inches, 21-26 lb.). The two larger modal groups are present in varying proportions, from almost completely absent to completely dominant. From 1948 to 1954 the group with a mode between 63 and 71 cm. (15-20 lb.) was most important, with few fish in the 74 to 79 cm. group (21-26 lb.) appearing. In 1959-62 the relative importance of these groups was reversed, the latter becoming quite dominant.

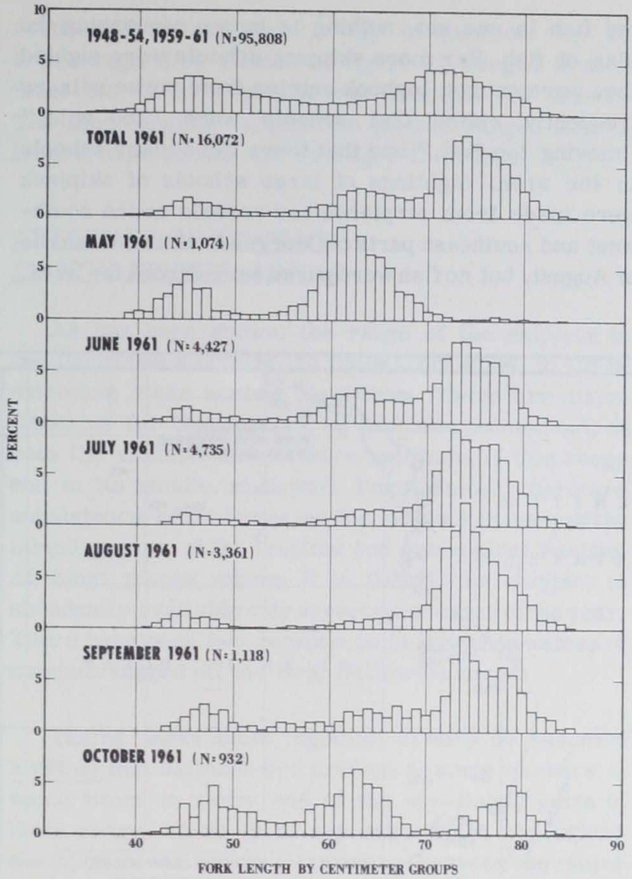

Figure 9.--Hawaiian skipjack length-frequency distributions.

Brock[2] hypothesized that the three modal groups represent three year-classes, the smallest probably being 1-year-olds and the others 2 and 3 years of age. However, the shift in dominance from the 63 to 71-cm. (15-20 lb.) group to the 74 to 79-cm. (21-26 lb.) group poses some as yet unanswered questions.

FRENCH OCEANIA

Throughout French Oceania, as elsewhere in the South Pacific islands, there are subsistence fisheries for skipjack, utilizing for the most part outrigger canoes and the traditional Polynesian pearl-shell lure, without live bait. In Tahiti this type of fishing is done from small motor launches, and landings at the Papeete market have been more than 800,000 pounds in some recent years. The fishery based at Papeete supported the irregular operations of a small cannery for a few years after World War II, the product, canned in coconut oil, being marketed mainly among the islands of the region.

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

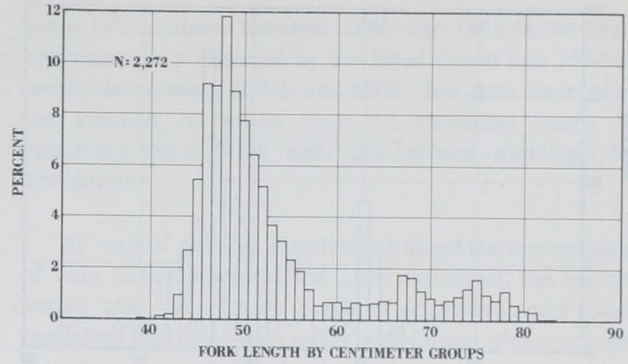

Figure 10.--Marquesan skipjack length-frequency distribution. (Based on Bureau of Commercial Fisheries research vessel catches, 1957-59.)

Exploratory fishing in the Marquesas Islands area produced school sighting rates and catch rates comparable to those recorded for the Hawaiian skipjack fishing grounds, which yield 6 to 14 million pounds annually. The season of greatest availability was found to be January-April. The size frequency distribution of skipjack taken in the Marquesan explorations shows one dominant and possibly two minor modes (fig. 10). The dominant mode is located at 48 cm. (19 inches or 5 lb.) and the two minor modes at 63 cm. (25 inches, 15 lb.) and 76 cm. (30 inches, 25 lb.). If the age analysis worked out by Brock for Hawaiian skipjack can be applied to these fish, there are three age groups available: 1-year-olds at 48 cm. (19 inches), 2-year-olds at 63 cm. (25 inches), and 3-year-olds at 76 cm. (30 inches).

MICRONESIA

Up to the outbreak of World War II there was considerable skipjack fishing in the Japanese-controlled Mariana, Caroline, and Marshall islands. Landings reached a high of slightly over 33,000 metric tons in 1937. The principal bases of the fishery were Palau and Truk, with 30 to 40 small bait boats operating at each place. According to the rather scanty records available, all of the fishing was done close in to the islands, the insufficiency of bait was a constant problem, and production per boat was low. Most of the catch was dried into katsuobushi for the Japanese market. This fishery has never been re-established since the war.

Few data are available on the size of fish taken by the pre-war fishery in Micronesia. Figure 11 shows the size distribution based on small samples recorded from Truk and Yap between 1930 and 1934. The major modes in these samples are centered at 58 cm. (9 lb.) and 64 cm. (13 lb.). Following the type of analysis used for the Hawaiian fishery, there would be only one year-class represented in the Micronesian catch. However, these samples are probably from

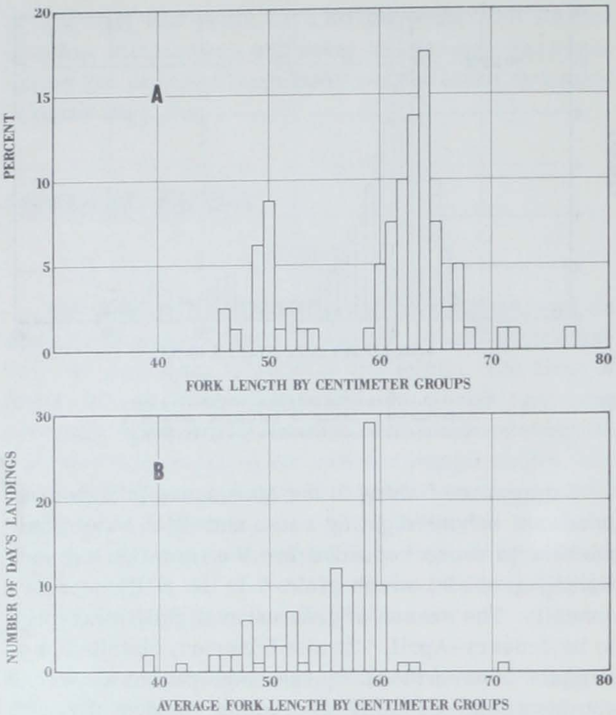

Figure 11.--Sizes of skipjack taken by the pre-war Japanese fishery in Micronesia. A. Length frequency in percentage of a sample of 80 fish taken at Yap Island. B. Estimated average lengths of fish in single day's landings at Truk (converted from Japanese weight units).

limited areas and they may not be fully representative of the skipjack that could be caught in Micronesian waters.

WESTERN ATLANTIC

Skipjack are found off the east coast of the Americas from New England to southern Brazil. The resource in this vast region has been virtually untapped and nothing is known of its magnitude. Prior to 1962, the only commercial fishery exploiting the resource was that carried on around the western tip of Cuba by small bait boats, capacity 5,000-18,000 pounds, fishing for skipjack and blackfin tuna (Thunnus atlanticus). Between 1954 and 1959, inclusively, the combined catch of both species totaled 19.2 million pounds, of which approximately 30 percent was skipjack. The fishery takes small skipjack, for the most part 2 to 6 pounds, although individuals up to 20 pounds have been recorded.

In July 1962, United States west coast purse seiners initiated the only other commercial fishery for skipjack in the western Atlantic. Fishing east of Long Island and inside the 100-fathom contour between July 30 and August 26, the seiners caught 480 tons of skipjack in 17 successful sets (fig. 12). The surface water temperatures at which fish were captured ranged between 69° and 78° F. With the exception of one log entry which indicated an average size of 10 pounds for the fish in one set, nothing is known concerning the size of fish. Far more skipjack schools were sighted than were caught; logbook entries from purse seiners frequently stated that schools were "too wild," "moving too fast," and that there were many schools in the area. Sightings of large schools of skipjack were made from airplanes and vessels on the southwest and southeast parts of Georges Bank in the middle of August, but no fish were purse seined from the area.

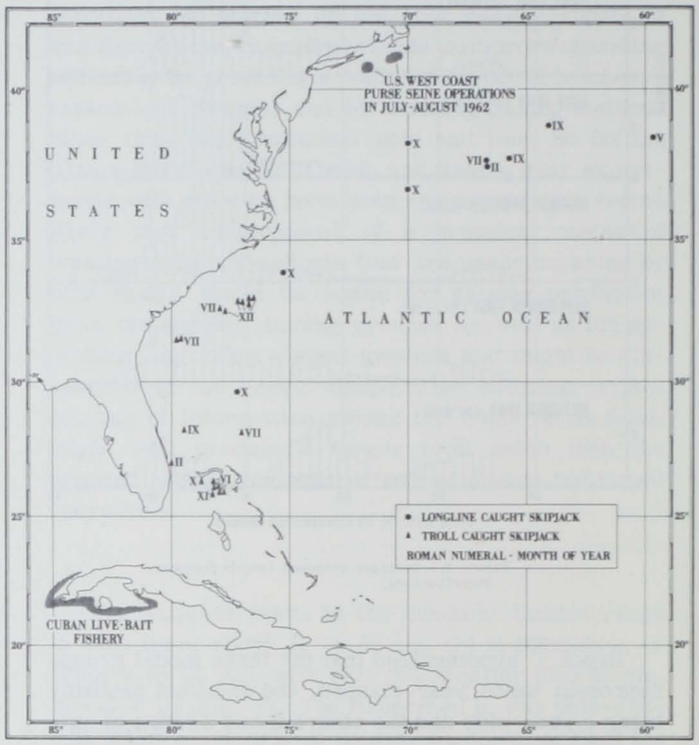

Figure 12.--Locations of skipjack catches in the western Atlantic.

Although the number of successful sets (17) is far too small to support any concrete conclusions, it should be noted that the catch per successful set, 28.17 tons, was relatively high. In the eastern Pacific skipjack fishery, the catches per successful set north and south of the Gulf of Tehuantepec in 1960 were 10.46 and 26.25 tons, respectively.

In figure 12 there are plotted, in addition to the areas of operation of the Cuban live-bait fishery and the United States purse seiners, records of troll-caught and longline-caught skipjack. The records, though few in number, do indicate a wide distribution for the species off the Atlantic States. Two areas of troll-caught fish are of some interest: The first approximately 150 miles east of Charleston, South Carolina, and the second about 130 miles east of Miami, Florida. In the former area, five fish were captured within a distance of 60 miles during the course of 1 day; and in the latter, six fish were taken within 30 miles in 1 day. The catches could be construed as indicative of appreciable quantities of fish, in their respective areas, for the day in question. The 20 troll-caught fish plotted in figure 12 ranged in size from 3.5 to 17.0 pounds and averaged 9.6 pounds. The nine longline-caught fish plotted ranged in size from 2 to 39 pounds and averaged 13 pounds.

EVIDENCE OF SKIPJACK IN NON-FISHED AREAS

As has been shown, the range of the skipjack in the Pacific is a broad band from about 40° N. to 40° S. extending clear across the Ocean. There are major fisheries for the species, as has been pointed out, at both the eastern and western extremes of this range and in its middle, at Hawaii. Furthermore, there are subsistence-scale fisheries for skipjack in many of the island groups of the tropical and subtropical Pacific. At most places where it is fished, the skipjack is abundantly available only at certain seasons of the year. There have been two recaptures in Hawaiian waters of skipjack tagged off the Baja California coast.

Taking these facts together, it may be assumed a priori that skipjack are present in some numbers at some times in every one of the non-fished parts of their range, which is to say essentially, throughout the open ocean areas intervening between the major fishing grounds. To these open ocean areas may be added, as non-fished areas, the waters off certain islands where, though skipjack may be taken regularly, their occurrence and abundance are not documented in enough detail for scientific study or industrial planning.

Documented evidence of skipjack occurrence in non-fished areas of the open ocean consists of sightings of schools; occasional catches, usually by trolling or longlining, neither of which is an effective method of fishing for skipjack; and the presence of larvae and juveniles in night-light, plankton net, and trawl collections. Such evidence is almost exclusively the product of research vessel operations and so is available only for the parts of the open ocean through which such vessels have passed. Somewhat more detailed documentation of the occurrence of skipjack is available for some of the "non-fished" areas around islands where research ships have made live-bait fishing surveys, as in the Marquesas and Tuamotu, or where there were formerly commercial fisheries that have now ceased, as in the Caroline, Marshall, and Mariana islands.

SIGHTINGS AND OCCASIONAL CAPTURES

A summary has recently been made of the records of skipjack school sightings from vessels of the Bureau of Commercial Fisheries Biological Laboratory, Honolulu. This summary, which is scheduled for publication as a Special Scientific Report, covers data from 177 cruises between 1950 and 1961 in the area approximately bounded by the West Coast and 165° E. longitude between 20° S. and 52° N. The data represent the results of more than 23 thousand hours of recording bird flock and tuna school sightings by helmsmen.

By way of general conclusions about the occurrence of tuna schools within the area surveyed, the report states the ". . . high rates of sightings were most prevalent in time-area units containing island groups . . . there were distinct seasonal changes in the rates of sighting . . . the rate of sighting in the general Marquesas area was much higher than for any other area of similar size."

"Surface schools of fish and bird flocks were almost completely absent between 25° N. and 30° N., except near Midway Islands. To the east of the Hawaiian Islands flocks and schools were also scarce, and a definite band of low abundance could be noted between the Hawaiian and the Line Islands in the vicinity of latitudes 10° N. - 15° N."

High sighting rates in the Hawaiian area were in the June-August quarter. In the Marquesas area the highest rates were in the December-February quarter. Figures 13 and 14 show the number of sightings of bird flocks and surface schools per 10 hours of scouting for 5-degree squares for the months of June to August.

Interpretations of sighting data should be made with caution, since a lack of sightings in an area does not necessarily mean that skipjack are absent from that area. It may mean either that skipjack are absent or that they are not active on the surface. Furthermore, it should be recognized that birds are an important visual aid for finding schools and that birds are not commonly numerous at great distances from land. In areas far from land, skipjack schools could well be at the surface but be extremely difficult to detect because they are not accompanied by working bird flocks. In any case, studies of skipjack scouting in Hawaiian waters have shown that in that area bird flocks cannot usually be seen farther than 4 miles and that 66 percent of the flocks spotted were less than 1 mile from the vessel. If sonic equipment can be made effective for detecting skipjack schools, it may substantially enhance the efficiency of scouting, particularly for deep-swimming schools, though it should be noted that techniques of fishing such schools are still to be worked out.

In general, skipjack are found in the tropical and subtropical waters of all oceans. The problem is whether they occur in sufficient numbers at any particular place to support commercial ventures. For example, on cruise 33 of the research vessel John R. Manning seven skipjack were caught just south

BIRD FLOCKS

JUNE TO AUGUST

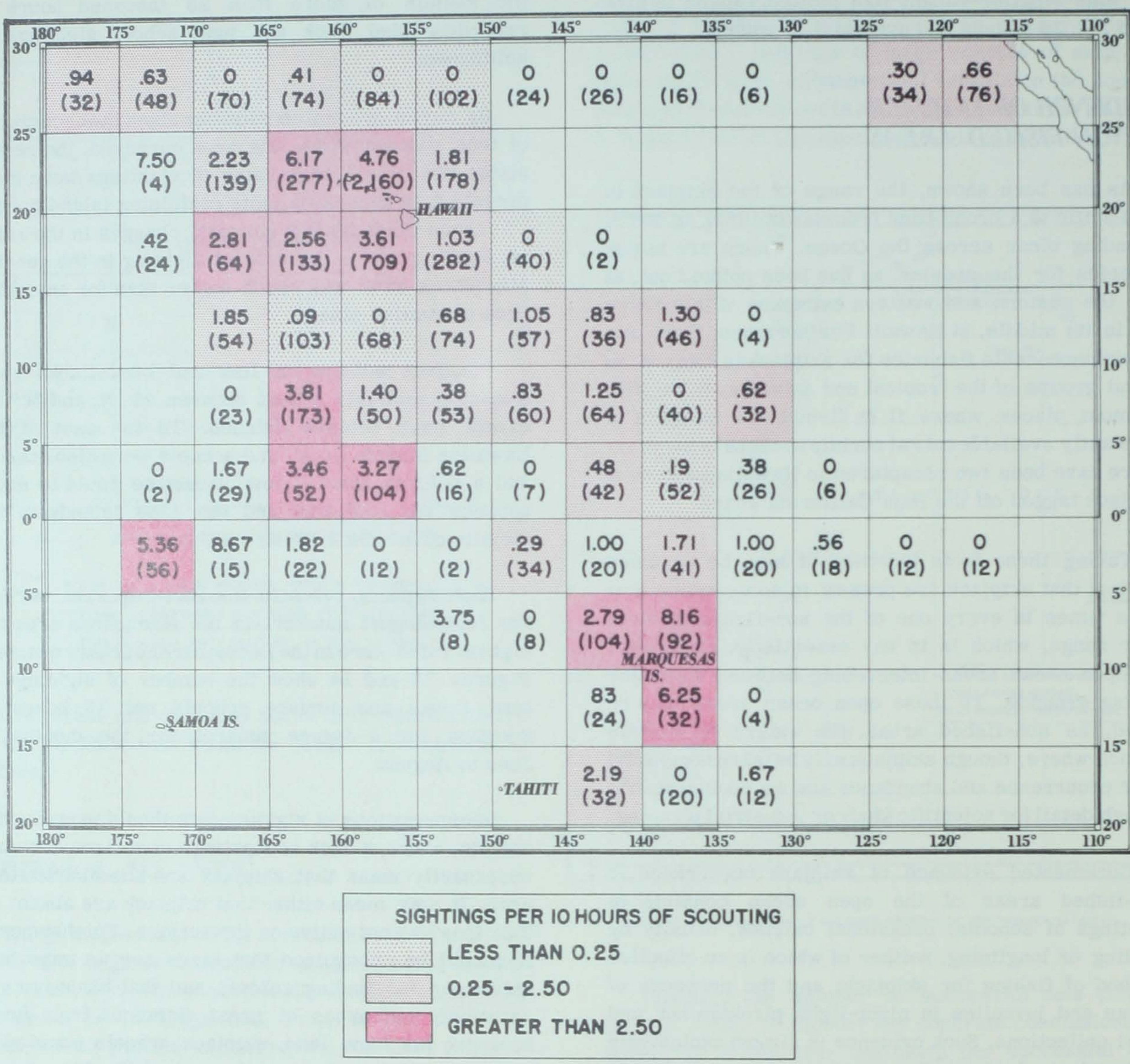

Figure 13.--Distribution of sightings of bird flocks in the central Pacific for the months of June to August.

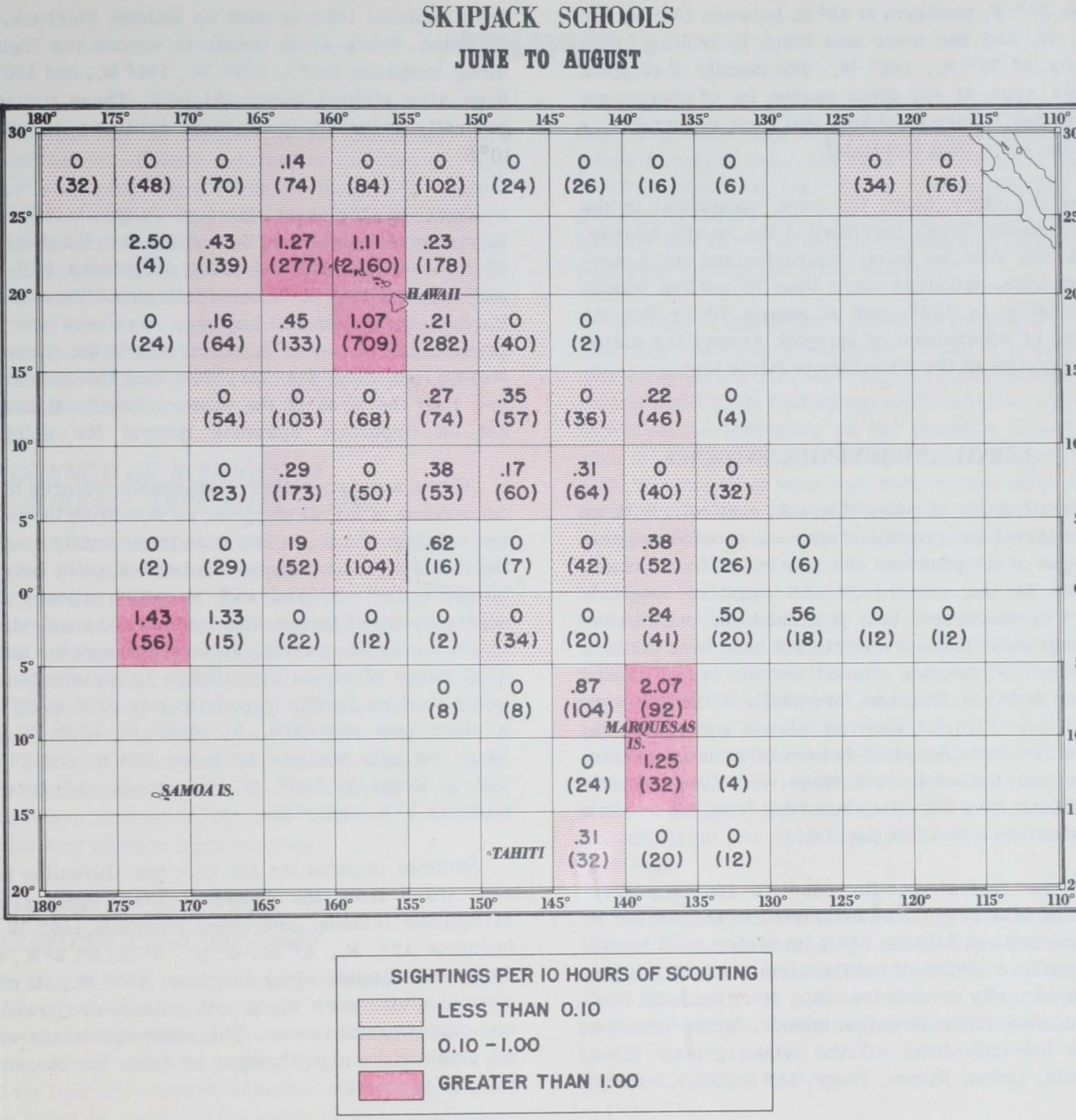

Figure 14.--Distribution of sightings of surface schools in the central Pacific for the months of June to August.

of the 57° F. isotherm at 40° N. between 135° W. and 150° W. and one more was taken by trolling in the vicinity of 38° N., 142° W. The density of skipjack in this area at any given season is, of course, not known, but it seems unlikely that their occurrence is anything more than incidental.

On the other hand, the area comprised in the United States Trust Territory of the Pacific Islands, which can now be fairly characterized as a non-fished area, produced more than 70 million pounds of skipjack in 1937, and it seems likely that the density of occurrence of skipjack around the major island groups of the Territory is fairly high.

LARVAL AND JUVENILE EVIDENCE

Identification of young skipjack, particularly those in the larval and juvenile stages can provide valuable evidence of the presence of adults in non-fished areas. Insofar as the western Pacific (west of longitude 180°) is concerned, both published and unpublished records show that larval skipjack have been taken at one time or another around various island groups (Palau, Mariana, Caroline, Marshall, Gilbert, Loyalty, Ellice, and Fiji), at isolated islands such as Wake, and at midoceanic sites betwen Marcus and Wake, Wake and Eniwetok, and Wake and Kure islands. Specimens have also been recorded from the western and southern Coral Sea (fig. 15).

In the central Pacific (180° to 150° W.) larval skipjack have been taken as far north as latitude 30° N. in summer and latitude 25° N. in winter, well beyond the northern limits of the Hawaiian skipjack fishery, which normally extends less than 60 miles from land. To the south of the Hawaiian Islands, larvae have been taken not only from all the island groups (Line, Phoenix, Union, Samoa, Tonga, and Society), but also from isolated islands such as Malden, Starbuck, and Johnston. North-south transects across the Equator along longitude 180° , 170° W., 155° W., and 150° W. have also yielded larval skipjack. These transects generally extended from about latitudes 15° N. to 10° S.

Over to the east (east of longitude 150° W.) larvae have been taken throughout the Tuamotu and Marquesas Islands, and along longitudes 140° W., 130° W., and 120° W. between latitudes 6° N. and 8° S. Farther east scattered captures have been recorded between 15° N. and 2° S. all the way to the American coasts, but they are very few and the indications are that the area of the eastern Pacific fishery is not an important spawning ground for skipjack.

There are two rather remarkable features of the occurrence of larval skipjack, as seen from the plankton catches. First, in the area immediately south of the Hawaiian Islands there is a band of water between latitudes 15° N. and 18° N. which appears to be nearly devoid of larvae. How far east this zone extends is not known at present. Second, although the latitudinal range of larval distribution is quite extensive in the western Pacific (approximately 30° N. to 30° S.), it decreases eastward. At longitude 150° W. the range extends between latitudes 15° N. and 20° S., and at longitude 120° W. it extends only between latitudes 7° N. and 8° S.

Records of juveniles are very few. Juveniles have been taken from the Caroline, Line, Phoenix, and Marquesas islands, and along longitude 150° W. at latitudes 12° N., 8° N., 6° N., 3° N., 0°, 2° S., and 5° S. The catches along longitude 150° W., all midoceanic sites, were made with a midwater trawl on one experimental cruise. The other specimens were all obtained by night-lighting or from the stomachs of large predators.

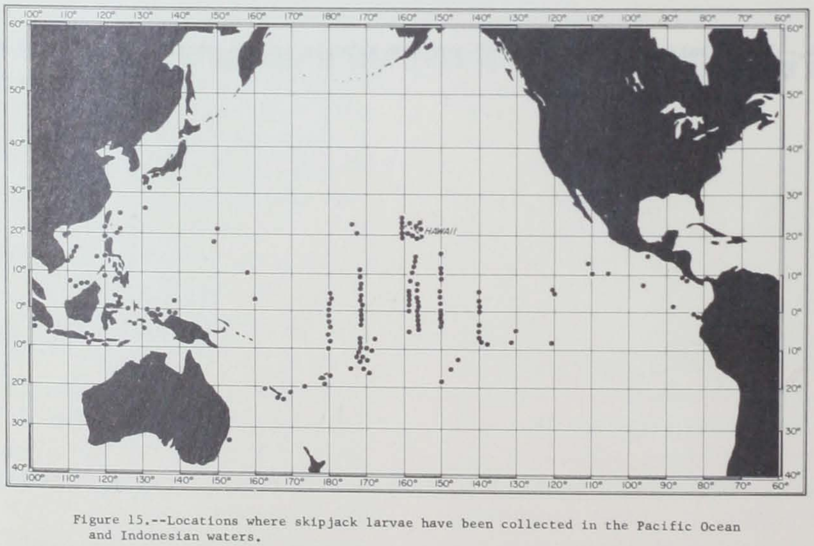

Figure 15.--Locations where skipjack larvae have been collected in the Pacific Ocean and Indonesian waters.

BEHAVIOR

The behavior of skipjack is an exceedingly important aspect of their relation to the fishery. Behavior is a factor that governs the skipjack's appearance at the surface and thus signals its presence to the birds and indirectly to the fisherman. It is not enough that the skipjack become sightable, it must also be catchable, and here too behavior plays an important role. The behavior of skipjack is being studied both in connection with their response to environmental cues and more broadly from the standpoint of their occurrence at the surface.

FREQUENCY OF SCHOOLS AT THE SURFACE AROUND ISLANDS

As indicated earlier, schools of skipjack appear to be more frequent around islands. It is possible that the density of skipjack distribution is really higher around islands, but is also possible that they only appear with greater frequency at the surface in the vicinity of islands. There is the further possibility that skipjack may not come to the surface with any greater frequency around islands than they do in the open sea but that the greater abundance of birds near land increases the frequency with which surface schools are sighted there. Two or all three of these factors may operate simultaneously.

BEHAVIOR OF SCHOOLS AROUND OCEANIC ISLANDS

It is commonly said that skipjack around oceanic islands go in small schools and that their behavior is "wild," that is, the schools move fast and erratically, frequently will not respond to bait, and cannot be held for long in the vicinity of the boat. Such judgements often seem to imply that skipjack schools are larger and less wild in the major fishing grounds off large land masses, but few quantitative data seem to be available for making comparisons between areas and seasons for these practically important aspects of skipjack behavior.

Such scattered and not strictly comparable data as we do have appear to support the common view. Thus, it has been reported that purse seine sets on skipjack schools in the eastern tropical Pacific have produced on the average about 14 tons of fish. The largest of the few seine captures of supposedly complete schools in Hawaiian waters yielded only about 3-1/2 tons. Similarly, Hawaiian live-bait boats take on the average only about 1 ton from each school fished, while the clippers of the eastern Pacific averaged 2.8 tons. In the Japanese skipjack fishery, where the number of poles in operation from each boat is greater than elsewhere, a figure of 1,000 kan (about 4 tons) of catch has been taken as the criterion dividing good from poor biting schools. The few data we have on the pre-war Japanese fishery in Micronesia indicate that there, as in Hawaii, most schools afforded only brief fishing and small catches.

In these fragmentary indices the factors of school size and behavior ("wildness") are of course inextricably mixed with other factors related to environmental conditions, fishing methods, and so on. Perhaps more purely indicative of the behavior aspect are data on the percentage of schools sighted which respond to chumming with live bait. In one study of the Hawaiian fishery it was found that 52 percent of a sample of 92 schools produced no catch. A Japanese researcher has written that in the Japanese skipjack fishery a boat may encounter more than 100 schools in one trip but be able to make catches from "only a few" of them. In another study of the Japanese fishery it is reported that of a sample of 132 schools from which some skipjack were taken, 67 produced 1,000 or more fish. The same study, in which the schools are classified by their association with birds, drift logs, et cetera, indicates that in Japanese waters bird-associated schools are less likely to yield large catches than are schools associated with banks or drift logs.

In experimental live-bait fishing in the Marquesas Islands area the percentage of schools which did not respond to bait and the distribution of catch rates were found to be quite similar to data from the Hawaiian fishery, indicating that the skipjack around these two groups of oceanic islands are of a like degree of "wildness."

POSSIBILITY THAT LARGE SKIPJACK SWIM DEEP

It has been suggested that large skipjack keep to greater depths than small fish. The fact that longline captures of the species are usually big fish supports this idea, although the large size of the hooks and bait on tuna longlines may be a factor. If large skipjack, like large individuals of other tuna species, do tend to stay deep, and if there is a higher proportion of large skipjack in the open sea areas than in the coastal fishing grounds, the conventional scouting method of looking for bird flocks associated with surface schools may provide a poorer estimate of skipjack abundance in the open ocean than it does in coastal or island waters.

THE STOCKS

EASTERN PACIFIC

The Inter-American Tropical Tuna Commission has reported that the catches of skipjack by the commercial fishery in the eastern Pacific fall into two distinct geographical groups. A northern fishing area extends along the coast of Baja California and offshore to the Revillagigedo Islands and Shimada Bank. This area is separated from a southern fishing area by a region extending 500-1,000 miles along the Mexican coast where few skipjack are captured. The southern fishery extends from below the Gulf of Tehuantepec south to northern Chíle and offshore around the Galapagos Islands. The gap in landings between these two areas is most noticeable during years of warm water temperatures, such as 1959 (figs. 5-8).

Figure 16 shows diagrammatically some of the major migrations of marked skipjack released in the eastern Pacific and recovered in the central and eastern Pacific areas. These data suggest that there is considerable mixing of skipjack among the major fishing areas in the north and among the major fishing areas in the south but little direct movement of skipjack between the northern and southern groups, at least within the region of the commercial fishery of the eastern Pacific. Two tagged skipjack released by the IATTC in 1960 on the northern fishing grounds of the eastern Pacific were recaptured in 1962 in the Hawaiian commercial fishery. The seasonal distribution of the catch on the northern ground suggests an inshore-offshore movement.

Skipjack taken by the commercial fishery in the northern areas of the eastern Pacific are for the most part small, immature fish. Skipjack taken around the

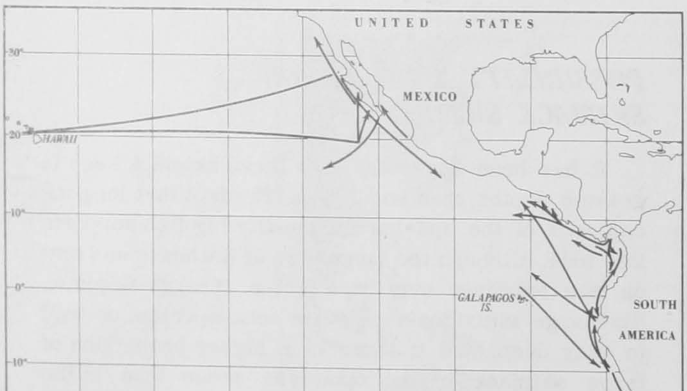

Figure 16.--Diagram of skipjack migrations in the eastern Pacific, based on results of tagging by the Inter-American Tropical Tuna Commission.

offshore islands tend to be larger than those taken closer to the continent but are, on the average, smaller than the large skipjack taken in the central Pacific. Similarly, in the south there is an increasing percentage of larger skipjack in the more offshore parts of the fishing grounds.

Very few larval or juvenile skipjack have been captured in the eastern Pacific despite extensive sampling, and examination of the gonad development of the adults also suggests that spawning occurs outside the range of the commercial fishery.

Results of blood typing by the Inter-American Tropical Tuna Commission of skipjack taken in the eastern Pacific do not yet serve to differentiate the eastern Pacific stocks nor to differentiate them from those of the region near Hawaii.

In 1956 a record quantity of about 30,000 tons of skipjack was taken on the northern grounds of the eastern Pacific fishery. The average annual landings during the period 1951-62 ran about 18,000 tons. According to the Inter-American Tropical Tuna Commission there is no evidence of overfishing.

In recent years the catch of skipjack from the southern grounds of the eastern Pacific has approached 70,000 tons. The average catch from this area during the period 1951-1962 was about 51,000 tons. The abundance is highly variable from year to year but averages considerably greater than the abundance on the northern grounds. The Inter-American Tropical Tuna Commission has stated that the southern grounds are capable of supplying a larger average harvest of skipjack. Until there is more information about the offshore skipjack resource, any expansion of the eastern Pacific fishery will probably be most feasible in this southern area.

CENTRAL PACIFIC

Skipjack are known to be distributed throughout the tropical Pacific to the westward of presently fished areas in the eastern Pacific. The wide distribution of skipjack larvae, the findings of Bureau of Commercial Fisheries surveys in the Marquesas Islands, the character of the Hawaiian fishery, the scale of the pre-World War II Japanese fishery in the area of the Trust Territory of the Pacific Islands, and the present Japanese fishery off the Bonin Islands and southern Japan point to the existence of very large skipjack resources, only some of which are being exploited. Various problems, some economic and some biological, have slowed the exploitation of some available stocks. In offshore areas the absence of large bird flocks, possible differences in feeding behavior, and the absence of large schools of surface bait fish suggest that suitable sonar gear will need to be developed to assist in searching for skipjack, as well as possible modifications in fishing methods to catch schools which behave differently.

Blood-group studies by the Biological Laboratory at Honolulu of skipjack from various locations in the central and western Pacific indicate that skipjack are separated into a number of subpopulations. In figure 17 Roman numerals show the subpopulations which have been recognized by serological methods. Seven subpopulations have so far been indicated, and it is expected that quite a few more will be identified as more samples become available. A new and promising aspect of these studies is the idea that skipjack subpopulations in the central Pacific may be uniquely associated with recognizable features of the major oceanic circulation systems.

Tagging results in the eastern Pacific suggest that at least two subpopulations occur in that area. In the central Pacific about 13,000 tagged skipjack have been released near Hawaii, and 1,311 tags have been recovered, all from the Hawaiian fishery. None of the few (2,195) skipjack tagged in the Marquesas were ever recovered.

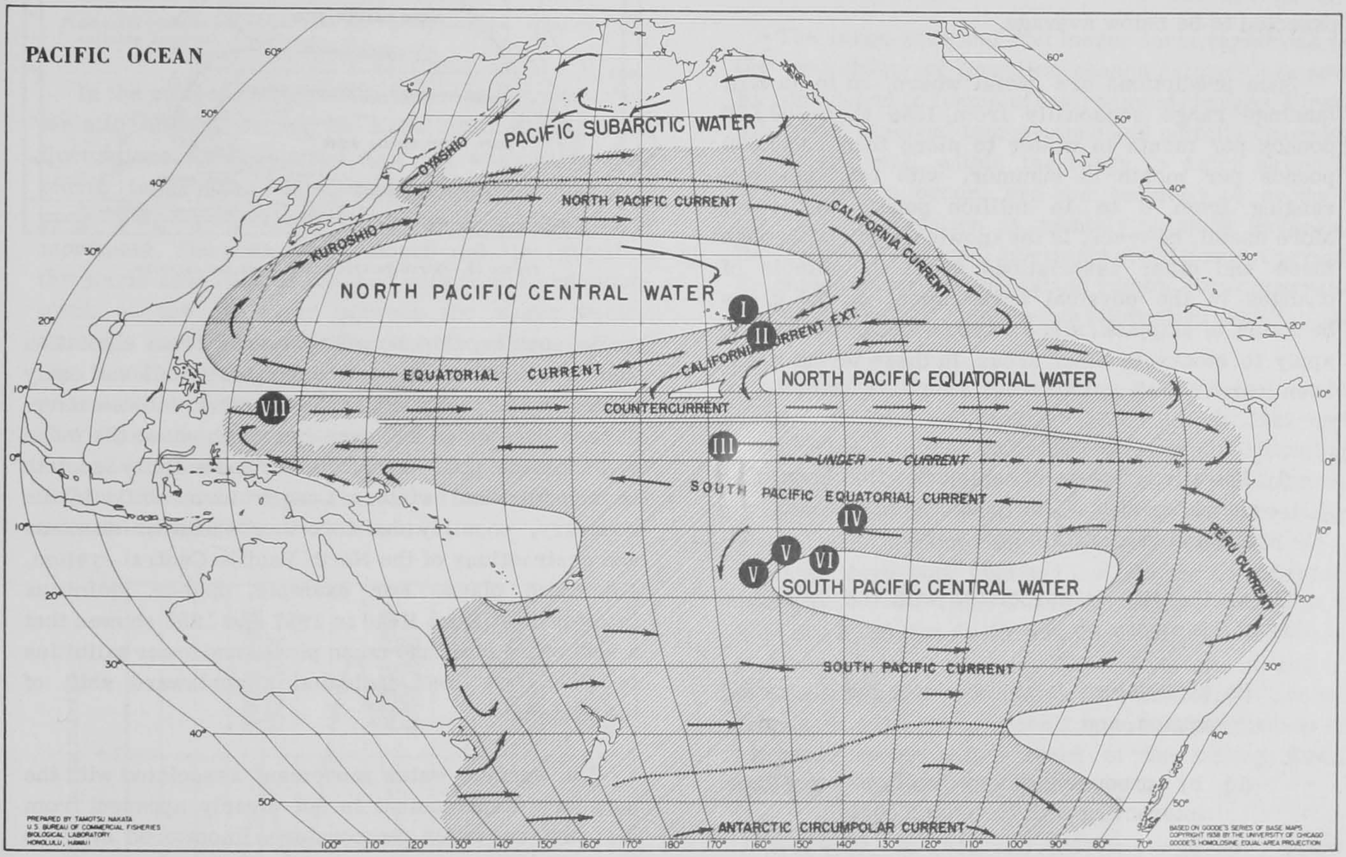

Figure 17.--Skipjack subpopulations in relation to major circulation features of the Pacific Ocean.

THE SEA, WEATHER, AND SKIPJACK

THE HAWAIIAN OCEANOGRAPHIC CLIMATE AND THE HAWAIIAN SKIPJACK FISHERY

Since 1959 the Bureau of Commercial Fisheries Biological Laboratory at Honolulu has predicted good or bad fishing years in Hawaii on the basis of an empirical relationship established between the time of initial heating of sea water near Koko Head on the island of Oahu and the annual skipjack landings. Whenever initial heating occurs before the end of February, annual landings are expected to be average or above, and when it occurs in March, they are expected to be below average.

Such predictions are useful where, as in Hawaii, landings range seasonally from less than 200,000 pounds per month in winter to more than 2,000,000 pounds per month in summer, with total landings ranging from 6 to 14 million pounds per year. More useful, however, is the knowledge gained through these and other associations about the effects of changes in the physical environment on the gross behavior of skipjack, since this knowledge would also apply to stocks in other areas. In these terms it has been learned that:

(1) Hawaiian "season" skipjack (the large fish characteristic of the peak fishing season) are at home in a certain type water.

(2) Availability is associated with the dynamics of the system:

(a) by bringing favorable water into the island region, and

(b) by producing favorable flow conditions interacting with the island chain.

(3) Favorable dynamic conditions are in part predictable.

THE HAWAIIAN OCEANOGRAPHIC CLIMATE

In the Hawaiian area both meteorological and oceanographic properties show little apparent seasonal variation. Sea-surface temperatures range from 73° to 78° F., with small year-to-year changes. The average surface salinity ranges seasonally from 34.8 to 35.1 ‰. In contrast to the temperatures, however, year-to-year variations are large, so that in some years the seasonal salinity change is not clearly apparent and in others it may be more than 0.5 ‰. Other, more subtle, changes take place every year.

The schematic representation of North Pacific water types and currents (fig. 18) shows the Hawaiian Islands to be located near the boundary separating the North Pacific Central water from the California Current Extension water. The salinity in the former is greater than 35 ‰ and in the latter less than 34.8 ‰. The boundary, therefore, can be identified by a relatively small and narrow salinity gradient.

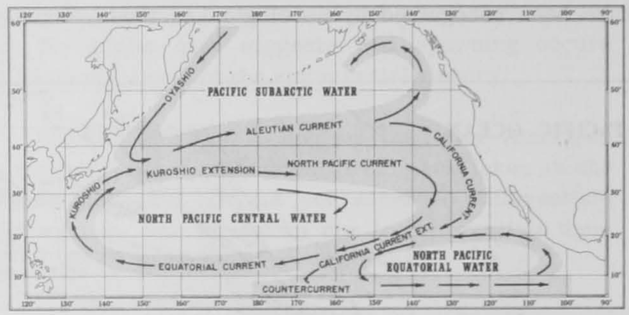

Figure 18.--North Pacific water types and currents.

Seasonally, this boundary moves from a position just south of the Islands during late fall and early winter to one just north of the Islands in late summer. This is illustrated in figure 19, which shows the mean and extreme positions of the 35 ‰ salinity isopleth in summer and winter. Longer term shifts in the boundary, possibly due to either shifts or dilations and contractions of the North Pacific Central system, also take place. For example, higher salinities monitored at Koko Head in 1957 and 1958 showed that a southward shift had taken place, and lower salinities in 1960 and 1961 indicated a northward shift of the system.

The surface water movement associated with the boundary displacement is not clearly apparent from the surface water temperatures monitored at Koko Head. However, the rate of change of temperature per month reflects both the seasonal boundary displacement and changes in the mean speed of flow through the Islands. Although seasonal heating and cooling of the sea water near Hawaii is basically determined by the net heat exchange across the sea surface (solar radiation, back radiation, evaporation), the temperature is also modified by water movement (advection). For example, when warmer water moves into an area, the rate of temperature rise during a warming cycle would increase, or the rate of temperature decrease during a cooling cycle would be reduced. Conversely, colder water flowing into an area during a warming cycle would decrease the rate of temperature rise or increase the temperature decline during a cooling cycle.

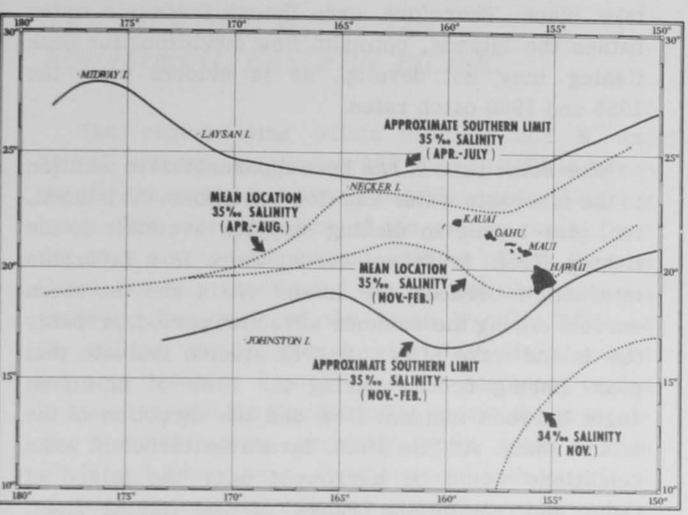

Figure 19.--Summer and winter mean and extreme positions of the 35 ‰ salinity isopleth.

In the rate of change of temperature curve (characteristic heating curve) for Koko Head (fig. 20), the fluctuations superimposed upon the seasonal heating (curve is positive) and cooling (curve is negative) cycle can be identified in terms of surface water movement. The peak during March and April signifies the warm advection associated with northward movement of the boundary between the North Pacific Central and California Current Extension waters. The November-December dip signifies cold advection associated with the southward retreat of the boundary. The dip in the heating curve due to the summer cold advection reaching a maximum during July and August reflects increased flow associated with the summer intensification of the trade winds.

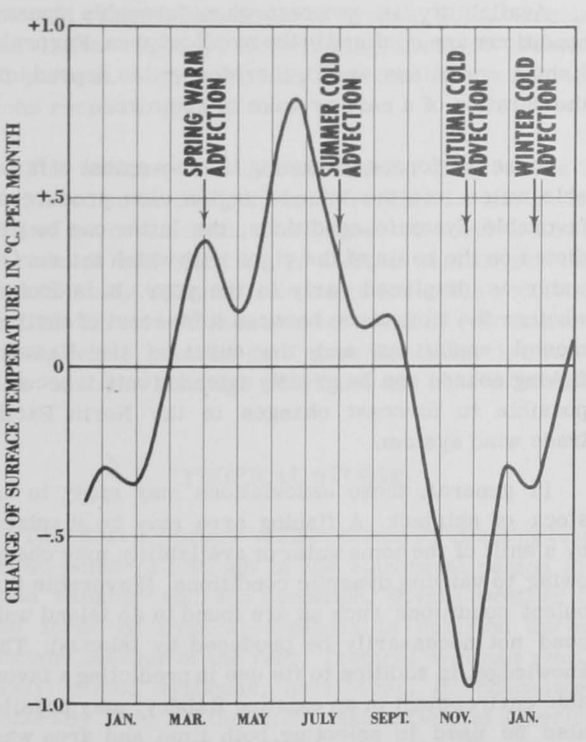

Figure 20.--Characteristic heating curve of the surface water at Koko Head, Oahu.

The fluctuations of the heating curve indicate accelerations which in turn reflect the changing forces acting on the system. In Hawaii, early heating and pronounced fluctuations mean vigorous displacement of the boundary and intensified flow conditions. Late initial heating, usually accompanied by a change in the shape of the heating curve, may mean displacement of the North Pacific Central system or a change in the mean flow through the Islands. Thus, the seasonal and longer term displacement of the salinity boundary is linked to the dynamics of the ocean system.

HAWAIIAN SEASON SKIPJACK AND THE OCEANOGRAPHIC CLIMATE

The large seasonal and longer term variations in the availability of Hawaiian season skipjack can now be considered in terms of environment changes. First, the small seasonal temperature and salinity changes, which are well within the range in which skipjack are known to occur, are not believed to produce the tenfold variation in monthly skipjack landings. However, the seasonal movement of California Current Extension water into the Island region, coinciding with the fishing season, provides an interesting association.

Figure 21 shows the relation between the annual catch per boat and summer salinities. In 1952 and 1957, when summer salinities were high, indicating that North Pacific Central water bathed the Islands, skipjack landings were low. During the remaining years, when summer salinities were below 35 ‰, landings were both high and low. During two of these years, 1958 and 1962, summer salinities below 34.8 ‰ indicated that California Current Extension water was near but not at Koko Head. If the occurrence of season skipjack is associated with California Current Extension water, then depending on the distribution of favorable water within reach of the fishing fleet, landings could be either good or bad.

However, in 1955 and 1960 landings were below average even though the Islands were within California Current Extension water. This indicates that other factors besides a favorable type of water are important for successful fishing.

It has been stated that the occurrence of California Current Extension water within the Hawaiian Islands is associated with the dynamics of the ocean system, which is also reflected in the fluctuations of the heating curve. Examination of landings in terms of the dynamics of the system, as reflected in the heating curve for the years 1951 through 1962, shows that fishing success is associated with the time of initial heating, and that peak fishing occurs during the summer cold advection period, the time of highest rate of flow past the Islands.

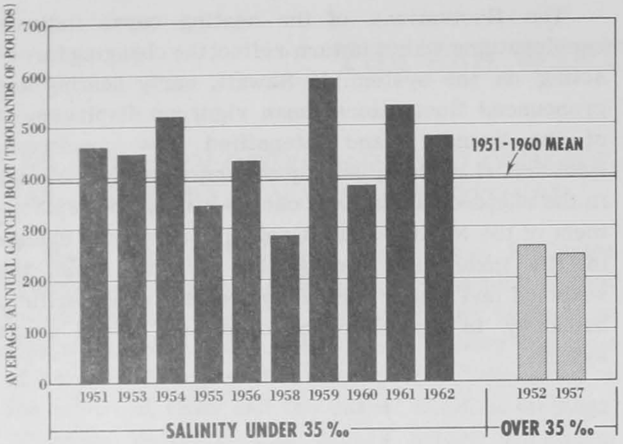

Figure 21.--Average annual catch per boat in the Hawaiian skipjack fishery in relation to summer ocean salinity.

Figure 22 illustrates the association between time of initial heating and annual landings per boat. Landings were above average if initial heating took place at the end of February or earlier, and below average (excepting 1962) when it took place in March. The best catch rates occurred in 1954, 1959, and 1961, years with early initial heating and pronounced heating curve fluctuations, indicating vigorous boundary displacement and intensified flow conditions. The poorest landings occurred in 1952, 1957, and 1958 when not only was unfavorable North Pacific Central water present, but late initial heating and a lack of pronounced heating curve fluctuations indicated weak flow conditions.

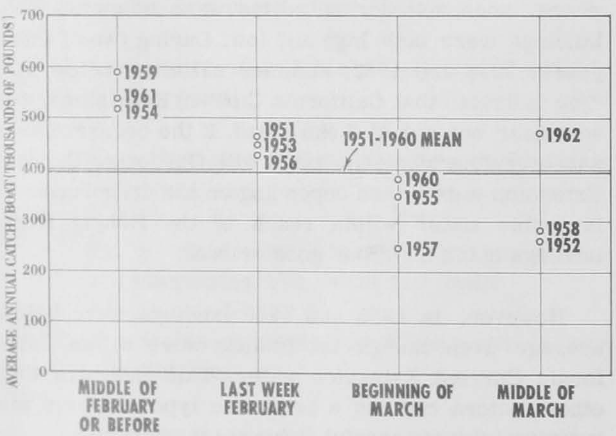

Figure 22.--Average annual catch per boat in the Hawaiian skipjack fishery in relation to the time of initial ocean warming.

Of interest are the years 1955, 1960, and 1962, when the shape of the heating curve and the winter salinities indicated northward displacement of the North Pacific Central system in the vicinity of Hawaii. It appears reasonable that such years should follow years of intensified flow past the Islands. During these years, initial heating occurred in March and pronounced fluctuations (except in 1962) did not take place. Therefore, even though favorable water bathes the Islands, optimum flow conditions for peak fishing may not develop, as is evident from the 1955 and 1960 catch rates.

For some time it has been apparent that in addition to the favorable water and flow conditions, the Islands, too, play a role in making skipjack available to the fishing fleet. In other words, there is a favorable interaction between the island chain and the mean current during the summer advection period, probably the island wake effect. Recent studies indicate that peak fishing occurs during the time of minimum angle between incident flow and the direction of the island chain. At this time, favorable turbulent wake conditions would be narrowest near the Island of Oahu and within the range of the fishing fleet.

The associations described can mean that the Hawaiian season skipjack lives in a home water, the California Current Extension, and becomes available to the Hawaiian fishing fleet only when this water enters the Islands region.

The associations also may indicate that Hawaiian skipjack are not uniformly distributed in their home water, as far as appearance at the sea surface is concerned, or alternatively, that their normal habitat is, in fact, not at the sea surface. In either case,the preferred location for fishing them appears to be in the wake of the Hawaiian Islands. Should dynamic conditions favorable to the formation of the island wake not develop, then the season skipjack will not become available to the fishery.

Availability is greatest when favorable dynamic conditions are confined to the smallest area. Favorable fishing conditions would, therefore, also depend upon the duration of a narrow wake in summer.

Since the forces producing the movement of favorable water into the Islands region also produce the favorable dynamic conditions, the latter can be predicted on the basis of the vigor with which the surface water is displaced early in the year. It is doubtful whether the time lapse between a forecast of environmental conditions and the onset of the Hawaiian fishing season can be greatly extended until it becomes possible to forecast changes in the North Pacific trade wind system.

In general, these associations may apply to any stock of skipjack. A fishing area may be displaced by a shift of the home water or availability may change owing to varying dynamic conditions. (Favorable turbulent conditions such as are found in an island wake need not necessarily be produced by islands). This knowledge, in addition to its use in predicting a favorable environment in an existing fishery, may possibly also be used in selecting both time and area when searching for new skipjack resources.

WEATHER AND SEA IN THE EQUATORIAL EASTERN PACIFIC

The region lying within latitudes 30° N. and 20° S. between longitudes 80° W. and 180° is infrequently traversed by vessels outside regular shipping lanes. The disappearance of the sailing vessel from the seas and the concurrent opening of the Panama Canal literally terminated the bulk of observational coverage for much of the South Pacific. Whereas the sailing vessel, after turning Cape Horn, sought out the "roaring forties" and the southeast trades to speed across the Pacific to the Orient, the present-day steamship very carefully avoids areas of high winds and heavy seas. Furthermore, with the advent of fully operational synoptic computer-programmed "optimum track" ship routing techniques, much or even all rough weather can be avoided by major shipping interests to prevent schedule delays and costly equipment damage. As a consequence, marine weather data for this area are so scarce as to pose a major problem in formulating accurate, representative summaries of climatological information.

Published information concerning the equatorial eastern Pacific is limited to three major sources: The U.S. Weather Bureau's "Atlas of Climatic Charts of the Oceans" (1938), the U.S. Navy's "Marine Climatic Atlas of the World, Volume V, South Pacific Ocean" (1959), and the British Admiralty's "Monthly Meteorological Charts of the Eastern Pacific Ocean" (reprinted 1956). Of the three sources, the U.S. Navy publication has perhaps the most complete and up-to-date coverage. It utilizes information collected over the past century by vessels of British, U. S., German, and Dutch registry, contributing about 67 percent, 20 percent, 8 percent, and 5 percent of all observations respectively.

The tendency for current marine observations to be biased toward conditions favorable for navigation cannot be overlooked. The degree of error which it introduces into analyses of marine weather records is extremely difficult to evaluate for areas receiving as little travel as that outlined above. It is recommended, therefore, that the data presented below be treated with caution, although they are the best available.

TROPICAL STORMS

The most important weather elements affecting tuna purse-seine operations in the equatorial region are wind velocity and sea condition. Severe weather in the form of tropical cyclones is common during certain seasons of the year. Tropical cyclones (variously named typhoons, hurricanes, or chubascos) generally form off the west coast of Central America and west of longitude 180° near the Equator. As these storms move to the westward, they sometimes recurve to the north early in the period of storm development, and at other times proceed westward for long distances before recurving and dissipating. Storm tracks are often erratic and difficult to forecast.

Northern Hemisphere storms in the eastern Pacific (locally termed chubascos or cordonazos off Mexico and Central America) generally originate in the zone bounded by latitudes 5° and 15° N. Early-season vortex development often takes place in the vicinity of Clipperton Island during May-June, whereas late-summer and fall storms originate right off the Mexico-Nicaragua coast. September is the month of maximum frequency.

Tropical cyclones traverse the South Pacific Ocean from the vicinity of the Marquesas (about 140° W.) to the east coast of Australia. Most of the storms of record have occurred in the period December-April; January and March have accounted for about 50 percent of all storms observed. Although a few storms have been reported to occur during the months May-September, the probability of encountering one is rather small. The major tropical storm paths in the eastern tropical Pacific are outlined in figure 23.

Since ships' weather reports are sparse or completely absent for some South Pacific regions, many storms develop and dissipate without ever being charted. The recent reference on Southern Hemisphere tropical storms, "Proceedings of the Tropical Cyclone Symposium," [3] contains the most comprehensive summary available.

The advent of the United States TIROS meteorological observation satellite program has made it feasible to issue tropical storm advisories as soon as incipient vortices are picked up by the satellite's cameras, often well in advance of the first indications from weather reports by surface shipping. The potential usefulness of the satellite program will be realized soon in more timely, accurate reporting of tropical storms in both hemispheres. The tuna fleet can monitor high-seas weather advisories on a regular basis when operating in this region. Frequencies, broadcast schedules, and other specific information about plain-language marine forecasts and warnings are given in U.S. Navy Hydrographic Office publication No. 206 and 207, "Radio Weather Aids."

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[3] Proceedings of the Tropical Cyclone Symposium, Brisbane, Australia, December 1956. Issued by the Director of Meteorology, Australian Bureau of Meteorology, Melbourne; Wilke and Company, Publishers: pp. i-x, 1-436.

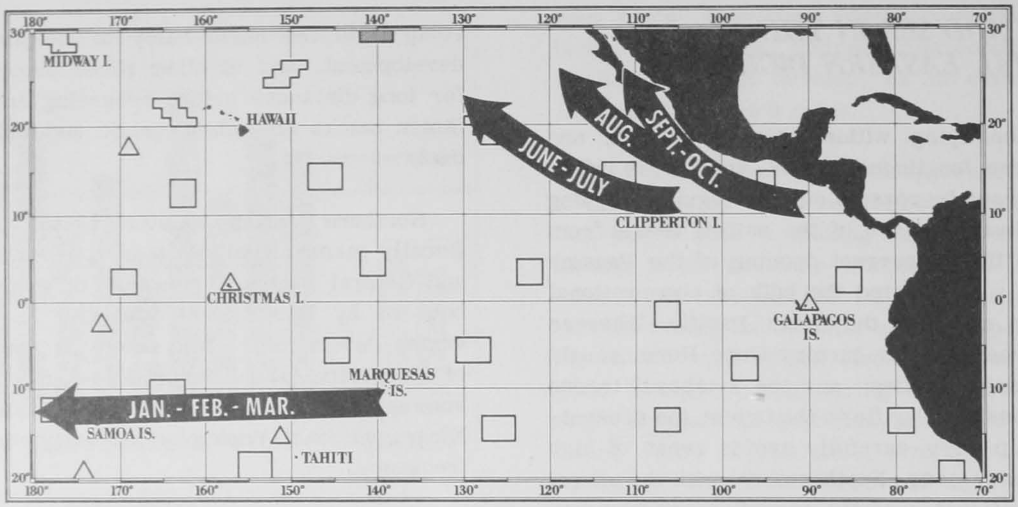


Figure 23.--Tropical storm paths and wind data source areas in the eastern tropical Pacific. Months of maximum storm frequency are indicated within the arrows. Blocks indicate ocean area data sources; triangles indicate island stations; hatched block indicates Weather Ship Station November.

GALES

Gale-force winds not associated with tropical storms are seldom recorded in the equatorial region of the Pacific. The frequency of observed winds greater than 34 knots is less than 1-2 percent, except for the Gulf of Tehuantepec area off the southern Mexico coast, where gale-force winds occur about 5-10 percent of the time in November and December. "Tehuantepec" (north) winds occur during January and February, but the frequency is lower than in the preceding months.

VISIBILITY

Visibility conditions for tuna scouting are favorable more than 90 percent of the time in all areas of the equatorial eastern Pacific. Occasional reductions in visibility occur during rain squalls and in areas under the influence of tropical storms.

PRECIPITATION

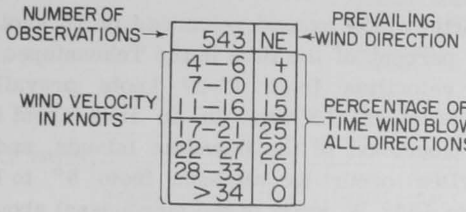
A major precipitation belt persists north of the Equator the year around. The center of maximum precipitation fluctuates between latitudes 4° and 9° N. and longitudes 110° and 170° W., according to the season of the year. All precipitation is of convective, non-frontal origin. Exceptions may occur in latitudes 20° -30° N., when well-developed frontal systems penetrate farther to the south than usual in wintertime. Periods of precipitation are short, except in close proximity to tropical storms. Then, precipitation is moderate to heavy, and duration depends upon distance from the storm center and direction of storm movement.

Precipitation occurs from 5-15 percent of the time over most of the region. The January precipitation maximum along latitudes 5° -7° N. occurs more than 35 but less than 40 percent of the time. The July-August frequency of precipitation drops to 20-30 percent in this same region.

WIND AND SEA CONDITIONS

Tuna purse seiners operating in the equatorial region may experience periods when fishing is not possible because of wind and sea conditions not accompanied by severe weather. The weakening and strengthening of the easterly trade winds associated with the north and south movement of the intertropical convergence zone will frequently cause sustained wind velocities of 20 to 30 knots.

Certain charts taken from the U.S. Navy's "Marine Climatic Atlas of the World, vol. V. South Pacific Ocean" (1959) have been selected and condensed in figures 24 to 27 to provide a picture of wind and sea conditions. The months of January, April, July, and October were selected as being representative of each of the four seasons. In figures 24-27 each set of data is connected with a line to the block or triangle representing the area where the observations were made. Blocks stand for areas where observations were made at sea, triangles for island stations. The hatched block indicates Weather Ship Station November. In each set of data, the figure in the upper left is the number of observations. At upper right the prevailing wind direction is given. At the left are wind velocity ranges in knots, at the right the percentage of the time the winds, from whatever direction, are within the indicated velocity range. For example:



Percentage frequencies of winds of 0-4 knots are omitted; wind frequencies of less than 1/2 percent are indicated by a plus sign. The data on winds greater than 17 knots are set off by a line to indicate the proportion of the time that tuna boat operators may anticipate, on the basis of available records, wind and sea conditions that might preclude purse-seine operations. The sea-keeping characteristics of the particular vessel, of course, determine the wind velocities that actually limit its fishing operations.

January winds (fig. 24)

Fresh to strong winds occur in several areas, mainly between latitudes 10° and 30° N. The area between Hawaii and longitude 130° W. experiences strong easterly and northeasterly winds about 30-40 percent of the time. The Tehuantepec region has experienced winds up to gale force about 30 percent of the time; gale-force winds (> 34 knots) occur about 6 percent of the time. Other areas to the south of the Equator and westward have reported strong tradewinds (> 16 knots) averaging about 20 percent of the time.

April winds (fig. 25)

Winds limiting fishing operations may be encountered in the Gulf of Tehuantepec about 6 percent of the time. Strong winds may also occur about

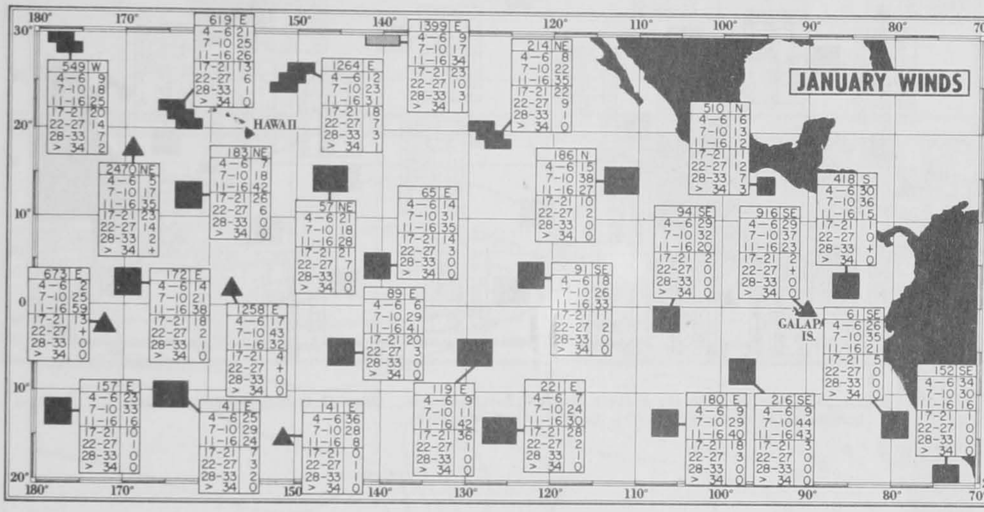


Figure 24.--January winds in the eastern tropical Pacific Ocean. (Adapted from U. S. Navy, Marine Climatic Atlas of the World, vol. V, 1956: chart no. 2.)

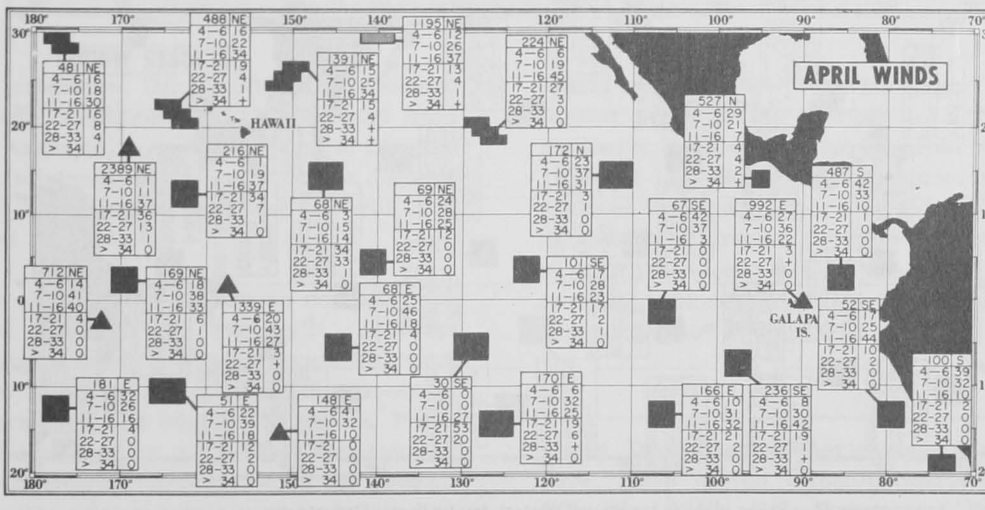


Figure 25.--April winds in the eastern tropical Pacific Ocean. (Adapted from U. S. Navy, Marine Climatic Atlas of the World, vol. V, 1956: chart no. 38.)

600-900 miles southeast of the Hawaiian Islands about 68 percent of the time. High easterly and southeasterly trade wind velocities also occur in the region of 0° -15° S. near 130° W.; here velocities in excess of 16 knots occur from 25-73 percent of the time.

July winds (fig. 26)

The maximum trade wind zones noted in April change very little, except for an eastward extension of strong winds to include the region near 10° S. and 110° W. Here easterly and southeasterly trades blow above 16 knots from 16-30 percent of the time. Increased easterly wind velocities are observed also in the Phoenix-Samoa-Tokelau Islands area.

October winds (fig. 27)

North winds exceed velocities of 16 knots about 24-25 percent of the time in the Tehuantepec region. Wind velocities from 17-27 knots prevail about 48 percent of the time in an area about 600-900 miles southeast of the Hawaiian Islands, and strong easterlies occur in an area from 5° to 15° S. at 100° to 130° W. (east of the Marquesas) about 33-35 percent of the time.

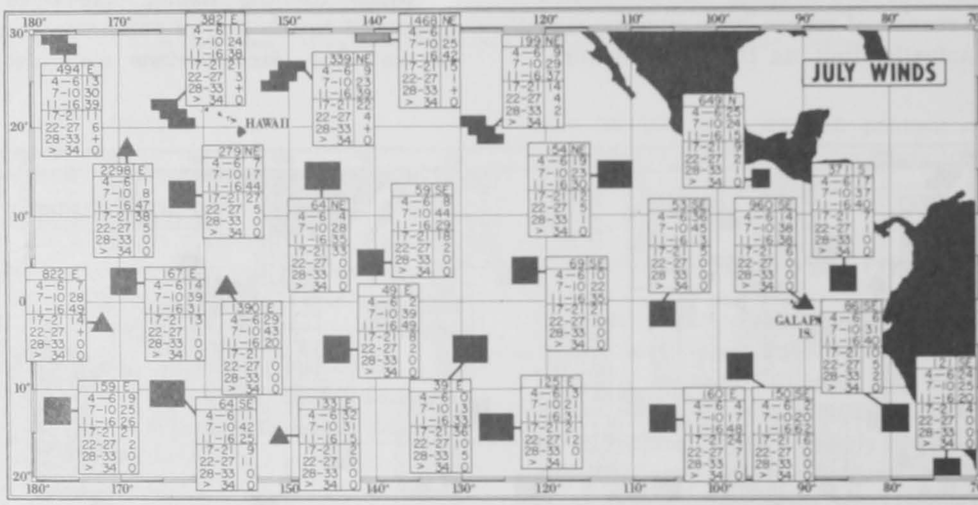


Figure 26.--July winds in the eastern tropical Pacific Ocean. (Adapted from U. S. Navy, Marine Climatic Atlas of the World, vol. V, 1956: chart no. 74.)

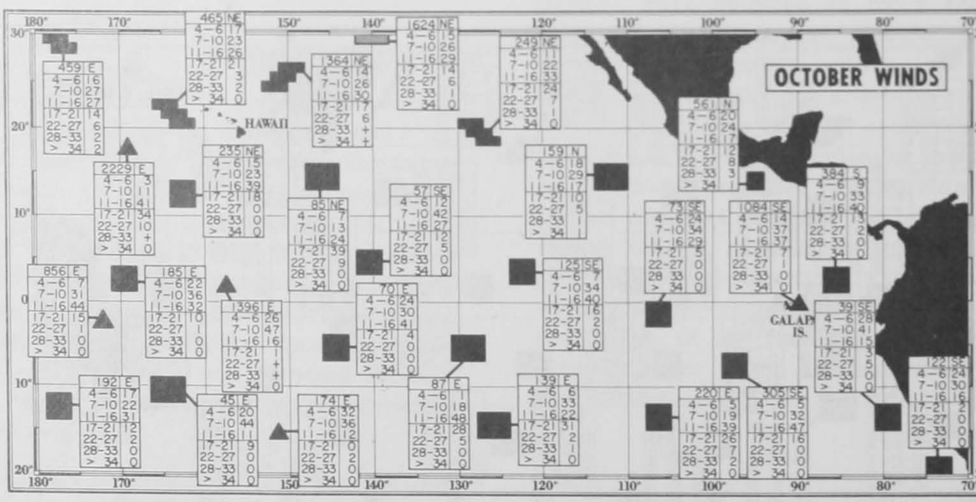


Figure 27.--October winds in the eastern tropical Pacific Ocean. (Adapted from U. S. Navy, Marine Climatic Atlas of the World, vol. V, 1956: chart no. 110.)

Table 1.--Minimum time and fetch required for winds to produce waves of a given height, and length of the resulting waves. (Adapted from McGary, James W., 1957. Wind Atlas of the North Pacific. U.S. Fish and Wildlife Service, Special Scientific Report - Fisheries 243, pp. 2-3).

TO PRODUCE WAVES	WIND VELOCITY														
	20 KNOTS			25 KNOTS			30 KNOTS			35 KNOTS			40 KNOTS		
	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)
4 FEET HIGH	3.2	11	40	2.0	7	43	1.3	< 5	46	1.0	< 5	49	0.9	< 5	50
8 FEET HIGH	19.0	120	155	6.2	26	86	4.0	18	82	3.0	14	86	2.2	11	86
12 FEET HIGH				20.0	745	216	8.0	48	133	5.4	31	123	4.0	22	125
16 FEET HIGH							16.2	125	237	8.9	59	172	6.3	42	166
20 FEET HIGH										14.0	120	258	9.1	67	216
24 FEET HIGH										31.0	320	462	13.4	115	288
28 FEET HIGH													20.9	210	406
32 FEET HIGH													36.5	440	620

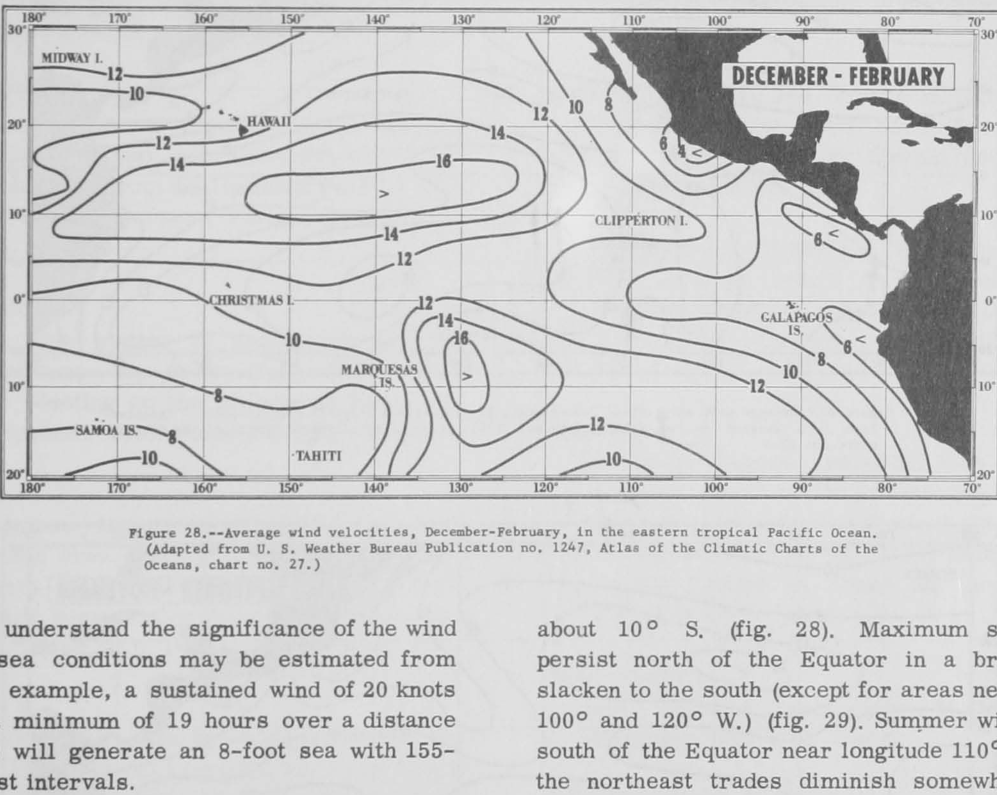


Figure 28.--Average wind velocities, December-February, in the eastern tropical Pacific Ocean. (Adapted from U. S. Weather Bureau Publication no. 1247, Atlas of the Climatic Charts of the Oceans, chart no. 27.)

To better understand the significance of the wind summaries, sea conditions may be estimated from table 1. For example, a sustained wind of 20 knots blowing for a minimum of 19 hours over a distance of 120 miles will generate an 8-foot sea with 155-foot wave crest intervals.

Average wind velocities have been computed for the equatorial region of the Pacific.[4] Although the charts summarize winds irrespective of direction, they do serve to emphasize the shifting areas of maximum prevailing wind velocity by season. These charts can also be used for comparison with average wind conditions usually encountered in the present fishing areas. The winter maxima occur in two distinct belts, one about latitude 10° N. and the other about 10° S. (fig. 28). Maximum spring trades persist north of the Equator in a broad belt, but slacken to the south (except for areas near longitudes 100° and 120° W.) (fig. 29). Summer winds increase south of the Equator near longitude 110° W., whereas the northeast trades diminish somewhat (fig. 30). Fall wind velocities are somewhat higher in the southern latitudes over an extended area from longitude 90° to 140° W. (fig. 31).

[4] U.S. Department of Agriculture, Weather Bureau. 1938. Atlas of the Climatic Charts of the Oceans, WB. No. 1247. U.S. Government Printing Office, Washington, D. C. p. I-VI, 130 charts.

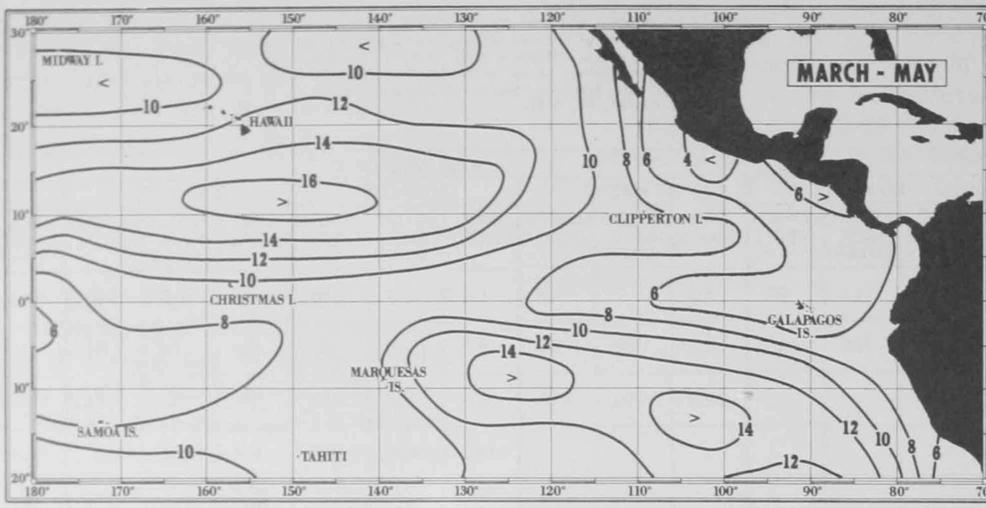


Figure 29.--Average wind velocities, March-May, in the eastern tropical Pacific Ocean. (Adapted from U. S. Weather Bureau Publication no. 1247, Atlas of the Climatic Charts of the Oceans, chart no. 28.)

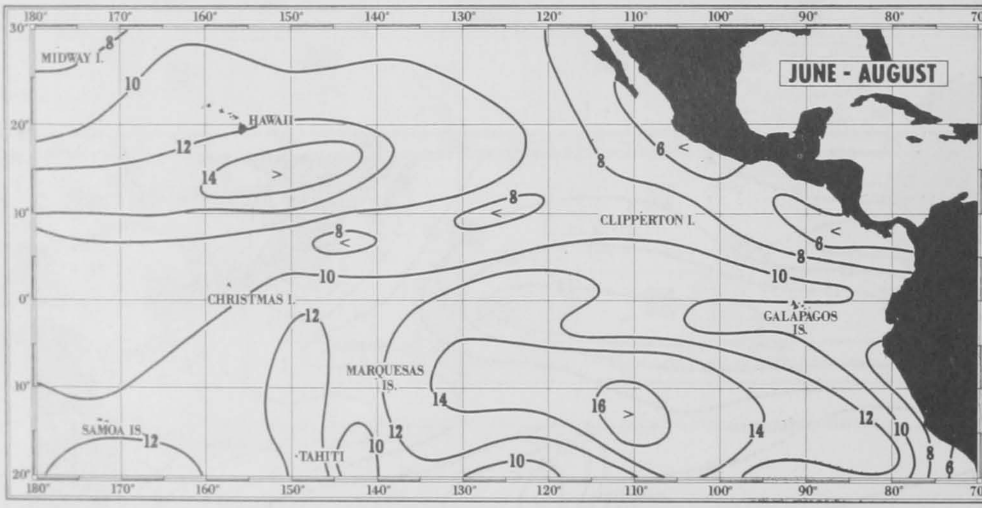


Figure 30.--Average wind velocities, June-August, in the eastern tropical Pacific Ocean. (Adapted from U. S. Weather Bureau Publication no. 1247, Atlas of the Climatic Charts of the Oceans, chart no. 29.)

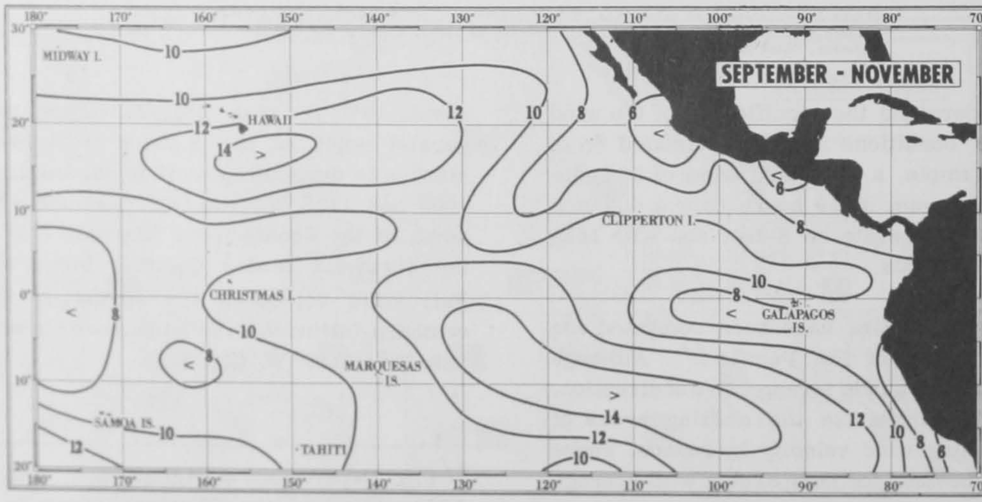


Figure 31.--Average wind velocities, September-November, in the eastern tropical Pacific Ocean. (Adapted from U. S. Weather Bureau Publication no. 1247, Atlas of the Climatic Charts of the Oceans, chart no. 30.)

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