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STATUS OF RESEARCH AND FISHERIES - SKIPJACK TUNA (U.S.A.)¹

In 1956, Shimada and Schaefer (1956) showed that the catch of skipjack tuna in the eastern Pacific was not large enough to have a measurable effect on the stock. Since then a number of others have studied the skipjack tuna resource in the Pacific and have reached the same conclusion (Rothschild, 1966; Silliman, 1966; Joseph and Calkins, 1969). Despite evidence that it was possible to greatly increase the annual catch of skipjack tuna on a sustainable basis, the Pacific-wide catches of this species have not increased markedly.

A major reason for the lack of rapid expansion of the fishery is the unpredictable availability of the skipjack tuna to the fishermen. In the central Pacific, where fishing for skipjack tuna is conducted primarily with pole-and-line gear, the availability of live bait has also been a severe limiting factor.

The following sections provide a brief background and status of the U.S.A. fisheries for skipjack tuna in the Pacific Ocean.

EASTERN PACIFIC FISHERY

The eastern Pacific tropical tuna fishery is a complex fishery involving two principal methods of fishing, the pole and line and purse seine, and harvesting two principal species of tunas, the yellowfin and skipjack.

Historical Development

The fishery for skipjack tuna--and yellowfin tuna as well-- in the eastern tropical Pacific is an outgrowth of the California albacore fishery, which began in 1903 (Shimada and Schaefer, 1956). In 1916, when albacore were scarce, small quantities of yellowfin and skipjack tunas, which previously had been overlooked in favor of albacore, were caught and canned.

World War I brought about an increased demand for canned tuna. Albacore alone could not satisfy this demand; therefore, large amounts of yellowfin and skipjack tunas were processed. In 1918, 77% of the pack of canned tuna was composed of yellowfin and skipjack tunas.

Following World War I, as albacore catches continued to be erratic and unpredictable, increasing quantities of yellowfin and skipjack tunas were caught. Whereas fishing was confined to the offshore waters

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of southern California in the early years of the fishery, the increased demand for yellowfin and skipjack tunas triggered an expansion of the fishing grounds to the Baja California region, an area where previous exploration had revealed an abundance of these species.

The expansion of the fishery also introduced the idea of using large refrigerated mother ships. Operating out of Mexican anchorages, the mother ships received the catches from the fleets of small California-based tuna fishing boats. The frozen fish were then transferred to tender ships for transshipment to southern California canneries.

Complications with the Mexican Government's policy concerning customs duties on transshipment of American-caught tuna to California discouraged further expansion of the tender-fleet type of operation. The result was the evolution of the modern high-seas tuna fishing boats which were capable of operating independently and profitably on the high seas. The character of the fishery thus changed from one of small boats dependent on tenders to that of large boats capable of independent operations.

Using pole and line and live bait to fish schools of yellowfin and skipjack tunas, these far-ranging tuna clippers were improved over the years so that they could fish tuna schools more efficiently. Engines were relocated farther forward to give the vessels increased hold capacity. The main house was enlarged. And eventually, a pilothouse was constructed atop the main house (McNeely, 1961).

In the early years, tuna purse seiners were also used in the fishery but were only moderately successful. Their operations, however, were profitable enough so that the fishermen continued using and improving this method of capturing tuna (Green, Perrin, and Petrich, 1971). These early seiners remained largely on local fishing grounds whereas the pole-and-line tuna clippers ventured as far south as Peru and developed familiarity with the distant fishing grounds. By the late 1950's, however, purse seine technology had improved to such an extent that the growing economic crises were all that was needed to bring together all the ingredients for a successful high-seas tuna purse seine fleet (Broadhead and Marshall, 1961).

With the introduction of all-nylon tuna nets used in conjunction with a Puretic "power block," a mechanical device for power hauling of nets, there began a "purse seine revolution" in the tuna fishing industry. McNeely (1961) described the mass conversion of the tuna fleet from predominantly pole-and-line clippers to seiners as an event unparalleled in the history of major U.S. fisheries. Considerable details on the history of both pole-and-line and purse seine fishing for tuna in the eastern Pacific can be found in Godsil (1938), Scofield (1951), Shimada and Schaefer (1956), McNeely (1961), and Green et al. (1971).

Methods of Capture

The present U.S. fleet of tuna fishing boats in the eastern Pacific is essentially dominated by purse seiners, although there still remains a number of small bait boats and trollers. In 1972, the Inter-American Tropical Tuna Commission (IATTC) reported (IATTC, 1973a) that the fleet consisted of 127 seiners and 52 bait boats for a total of 179 tuna fishing boats operating in the Commission Yellowfin Regulatory Area (CYRA). Table 1 gives the number of bait boats and seiners operating in the eastern tropical Pacific tuna fishery in 1950-72.

Table 1.--Long-range California- and Puerto Rico-based vessels fishing in the eastern tropical Pacific tuna fishery, 1950-72.

Year	Bait boats	Purse seiners	Total
1950	204	67	271
1951	228	78	303
1952	202	64	266
1953	190	64	254
1954	182	69	251
1955	172	63	235
1956	175	64	239
1957	170	50	220
1958	159	44	203
1959	140	53	193
1960	70	83	160
1961	44	114	158*
1962	36	103	139
1963	30	111	141
1964	35	111	146
1965	44	111	155
1966	52	102	154
1967	46	101	147
1968	50	104	154
1969	43	114	157
1970	44	121	165
1971	48	124	172
1972	52	127	179

*Does not include about 22 others (mostly under U.S.A. flag) based in Costa Rica, Mexico, and Peru.

Source: Data for 1950-69 are from Green et al. (1971). Data for 1970-72 are from Annual Reports of the IATTC for 1970 (1971), 1971 (1972), and 1972 (1973a).

Today's modern tuna seiner has a large carrying capacity and ranges in length from 42.4 m to more than 76 m (Green et al., 1971). While the carrying capacity of the largest seiners prior to 1961 was about 590 metric tons, those built after 1961 averaged 655 metric tons and the largest nearly 830 metric tons. Large seiners of over 1,000 metric tons carrying capacity have joined the fleet in recent years.

Conversion from pole-and-line fishing to seining required completely new types of equipment and gear. Bait tank piping, circulating pumps, fishing racks, and accessory gear were removed. In their place were installed the various components of seine fishing gear. Besides the purse seine and power block, the gear included auxiliary speedboats, masts and booms capable of withstanding the stresses of net hauling, "drying up," and lifting aboard the heavy seine skiff. Seining operations also required heavy-duty winches, hydraulic drive systems, and other deck accessories and installations. McNeely (1961) gives an excellent detailed account of the conversion of vessels from pole-and-line fishing to purse seining.

Details of the purse seine fishing operations may be found in McNeely (1961) and Green et al. (1971). The brief description of the operation given here is taken from both of these reports.

Initially, the operation involves preparation of the purse seine and seine skiff for a set. After the net is stacked properly, the seine skiff is lifted to its position atop the net pile. When fish are sighted and the vessel moves into position for a set, the seine skiff with the net end attached is allowed to drop into the water. The skiff acts as a sea anchor and pulls the first portion of the net over the stern.

A "fishing captain" or airborne observer controls the encircling operation. At the completion of the set, the hauling line is released from the skiff and taken aboard the vessel. The skiff is then free to patrol the open waters or take up its position at the opposite side of the vessel.

The net is pursed until the rings are together. When the rings are out of the water and free, hauling of the net begins. The net is hauled and stacked until the area occupied by the fish is minimal.

Brailing then begins. The brail is guided into the captured fish in the net and takes a full scoop of fish which is then positioned over an unloading hopper on the seiner. Fish unloaded into the hopper are guided to selected brine tanks by a series of metal chutes. After brailing is completed, the net and skiff are prepared for the next set.

The pole-and-line method of tuna fishing used by the eastern Pacific fishery has been described in numerous publications (Godsil, 1938; Shimada and Schaefer, 1956). Briefly, the boat first obtains

bait from the baiting grounds and proceeds to the fishing grounds to scout for schools of tuna. Live bait is the key to this type of operation; therefore, considerable time and effort are expended in locating, capturing, and transporting bait from the baiting to fishing grounds. The amount of bait carried by a bait boat varies; it may be as much as several hundred scoops (a scoop is equivalent to about 3.2 kg of bait) for the eastern Pacific bait boats. The most important bait species in the eastern Pacific fishery is the anchoveta, Cetengraulis mysticetus, a tropical anchovy of wide distribution (Shimada and Schaefer, 1956). Other important bait species are the Galapagos sardine, Sardinops sagax, and the northern anchovy, Engraulis mordax.

On the fishing ground, the fishermen scout for tuna schools and when one is located, the vessel intercepts the school and chums it with live bait. Fishermen stationed in the fishing racks at the stern and along the gunwales near the stern begin fishing as the school is attracted close to the vessel by the chum. While in a state of feeding excitement, the tuna strike at the feathered lures which are cast among the frenzied fish. When hooked, the fish are pulled out of the water and into the boat.

Area and Scope of Operation

In the eastern Pacific, both yellowfin and skipjack tunas occur in the same general fishing grounds. There are, however, some differences in the distribution of these two species. Skipjack tuna may be captured in commercial quantities in waters as cool as 16°C. Yellowfin tuna, on the other hand, are seldom taken in waters colder than 18°C (Broadhead and Orange, 1960). Furthermore, skipjack tuna fishing in the eastern Pacific is concentrated in two areas; the major one occurs between lat 5°N and 10°S, with a secondary area at about the tip of Baja California between lat 20° and 25°N. The Annual Report of the IATTC (1973a) indicates that catch and estimates of abundance in the southern area are usually twice as large as in the northern area.

The advent of a quota system for catching yellowfin tuna within the CYRA resulted in a short fishing season for this species each year, e.g. the 1973 season opened on January 1 and closed on March 8 (IATTC, 1973b). Although skipjack tuna can be taken without restriction within the CYRA, the fleet found itself faced with the alternative of fishing exclusively for skipjack tuna or looking for yellowfin tuna outside the CYRA. While some of the vessels chose to range westward into the high-seas areas outside the traditional fishing grounds of the eastern tropical Pacific, others moved eastward into the Atlantic and have ventured as far as the African coast (Green et al., 1971). Since 1967, there has been a steady increase in the number of vessels that have fished for yellowfin tuna off the west coast of Africa after the closure date for yellowfin tuna season in the eastern tropical Pacific. In fact, many of the new seiners have selected Puerto Rico as their home port, thus beginning a shift away from southern California as the center of U.S. tuna

production. The 1972 listing of the American high-seas tuna fleet shows that of 147 vessels, 37 have selected either San Juan or Mayaguez, Puerto Rico as home port. Roughly half of the fleet, however, continues to operate out of San Diego, California (Anonymous, 1973).

Catch

The catch of skipjack tuna in 1968-72 from the eastern Pacific Ocean is given in Table 2 together with catches made in Hawaii and in the Atlantic Ocean by U.S. tuna fishermen.

Table 2.--Annual skipjack tuna catch in metric tons for the eastern Pacific, Hawaii, and the Atlantic by U.S. fishermen.

Year	Eastern Pacific Ocean ¹	Hawaii ²	Atlantic Ocean ³
1968	70,444	4,227	3,219
1969	58,605	2,705	3,800
1970	50,077	3,334	⁴ 10,736
1971	103,058	6,051	⁴ 16,921
1972	⁴ 31,525	4,952	⁴ 12,167

¹Data for the eastern Pacific are from IATTC (1973a).

²Data for Hawaii are from catch records of the Hawaii Division of Fish and Game.

³Data for the Atlantic are from Miyake and Tibbo (1973).

⁴Preliminary figures.

The catch and abundance of skipjack tuna varies considerably from year to year. Scientists at the IATTC report that this variability does not appear to be related to fishing intensity on the parent stock, but rather to natural factors. Table 2 shows the extent of the high variability in the skipjack tuna landings of the eastern Pacific; the catch in 1971 (103,058 metric tons) is more than double that of 1970 (50,077 metric tons), while the 1972 catch (31,525 metric tons) is down sharply to less than a third of the landings made in the previous year. The record of 122,381 metric tons was made in 1967 with the 1971 catch being the second highest in the history of the fishery.

In the eastern Pacific, fishing tends to be somewhat seasonal at the extremes of the fishing ground (off Baja California and the

regions off South America). In the Central American region, the season is less marked and may persist over a period of 6 months (Waldron, 1963).

HAWAIIAN FISHERY

Unlike the eastern Pacific tropical tuna fishery, the Hawaiian fishery is strictly a one-method, one-species operation. Although small yellowfin tuna and little tunny are taken on occasion by this fishery, the bulk of the annual catch made by the pole-and-line fishery is the skipjack tuna.

Historical Development

The seasonal appearance of skipjack tuna in Hawaii was the basis for a subsistence fishery for the early Hawaiians. Venturing far offshore in outrigger canoes, the Hawaiians sought the schools of skipjack tuna as they entered waters adjacent to the small villages scattered throughout the islands (June, 1951).

Commercial development of the skipjack tuna fishery in Hawaii began about 1900. With the introduction of Japanese fishing sampans and gear, the fishery expanded rapidly. The early sampans were small, usually propelled by a scull or by sail, and crewed by four to six men.

In 1907, gasoline-powered boats were introduced, thus making it possible to expand fishing operations farther offshore. The vessels were gradually improved with the addition of the flying bridge, a pump-spray system, and changes in the hull design to allow greater freeboard forward.

Method of Capture

Prior to 1971, all Hawaiian skipjack tuna sampans were built of wood. Two steel-hulled vessels, originally built for other marine uses, were converted into skipjack tuna fishing sampans in 1947. Today's fleet is comprised of vessels built as early as 1926 and as recently as 1971. The vessels that dominate fishing, however, are the sampans of the immediate post-World War II period. These vessels are characterized by their large bait-carrying capacities (Uchida, 1966).

The newest and most recent addition to the Hawaiian fleet is the steel-hulled Anela built in 1971. It has a cruising speed of 13.8 knots and cruising range of 3,700 km. The registered length is 26.6 m, the beam 7.6 m, and the depth 3.6 m. Gross and net tonnages are 136 and 91 metric tons, respectively (Uchida and Sumida, 1973). The other vessels in the fleet range from 17.8 m to 24.5 m in registered length and from 24.5 to 69.8 metric tons in gross tonnage.

All of the Hawaiian sampans carry 5 to 14 men per fishing trip. The boats have six baitwells arranged on the afterdeck in two parallel rows of three. Varying with the size of the vessel, the bait capacities of these sampans range from about 25 buckets for the small vessels to 130 for the largest one. Emptied of bait during fishing, the baitwells serve as stowage area for the catch. All vessels built prior to 1971 carry ice to refrigerate; the Anela, however, has a pump system to circulate refrigerated seawater.

The method of fishing is basically the same as in the eastern Pacific pole-and-line fishery. Details of the Hawaiian fishing method can be found in June (1951).

Area and Scope of Operation

Hawaiian skipjack tuna sampans are short-ranged vessels and usually operate close to land; seldom venturing more than 170 km from land. The area of fishing operation covers roughly 181,000 sq km. The trips usually last 1 day. Most trips originate between 0200 and 0600 and terminate at 1800 and 2200. An average trip lasts 15.5 hours; of this, 4.8 hours is spent traveling to and from the fishing grounds (Uchida and Sumida, 1971).

Although the small Hawaiian fleet ranges over an extensive area in pursuit of the skipjack tuna, most of the effort is concentrated near shore. Uchida (1967) has estimated that from 60% to 90% of the annual landings of skipjack tuna come from within 37 km of the main islands. Geographically, most vessels fish around the island of Oahu probably because most of the vessels are based there. In 1973, there were 12 boats operating out of Oahu, 2 out of Maui, and 1 out of Hawaii. In 1948-65, 50% of the catch was made off Oahu, 28% off Maui, Molokai, and Lanai, 13% off Hawaii, and 9% off Kauai and Niihau (Rothschild and Uchida, 1968; Uchida, 1970).

It is possible for the Anela to operate in other areas of the Pacific Ocean. This vessel has the capability of traveling to distant ports throughout the central and western Pacific to conduct pole-and-line fishing operations. In early 1972, while under charter to the National Marine Fisheries Service (NMFS), Southwest Fisheries Center, Honolulu Laboratory, the Anela sailed to the Marshall Islands and American Samoa, two areas that have been under consideration as potential bases for commercial skipjack tuna fishery development by the Pacific Islands Development Commission (Uchida and Sumida, 1973). The results of this exploratory cruise disclosed that the availability of skipjack tuna in waters of the Marshall Islands and American Samoa was impressive. Live bait was plentiful in the Marshall Islands, but scarce in American and Western Samoa. To conduct fishing trials in American Samoa, therefore, the vessel caught bait in Fiji and transported it back to American Samoa. At Fiji, the Anela found both tuna and live bait in abundance.

Catch

The Hawaiian skipjack tuna fishery is highly seasonal. Catches are usually lowest early in the year then increase gradually from about April to a peak in June, July, and August (Figure 1). After the northern summer season the catches decline progressively to a low level in December. About three-fourths of the annual landings are made in May-September.

In 1968-72, the skipjack tuna catches from Hawaiian waters averaged 4,254 metric tons and ranged between 2,705 metric tons in 1969 and 6,051 metric tons in 1971 (Table 2). The record catch of 7,329 metric tons was made in 1965 whereas the lowest catch was made in 1969.

The size of skipjack tuna available in Hawaiian waters ranges from small fish (less than 4.8 kg) to large skipjack tuna weighing over 12.6 kg. The bulk of the catch during the height of the fishing season is made up of fish averaging 8.1 kg (Figure 2).

PROBLEMS

Although skipjack tuna catches are not regulated in the eastern Pacific, it is essential that fishery scientists understand the natural variability in skipjack tuna catch and abundance. For example, does variability in the catch represent changes in real abundance of the entire stock or merely reflect changes in availability of part of the stock? Proper management of the stock cannot be undertaken without an understanding of this variability and its effect on the catch.

At the World Scientific Meeting on the Biology of Tunas and Related Species, Chapman (1963) brought out the importance of the application of ocean research to the increased production of tuna from the sea. He said:

"Essentially what is wanted is to relate the circulation of the lower atmosphere with the circulation of the upper ocean, relate the circulation of the upper ocean with the aggregation of tuna in space and time, and relate the behavior of tuna to oceanic conditions, all to the end that the fishermen can locate, catch and land a load of tuna in the quickest time possible, with the highest reliability of being able to do it again, and with the lowest possible cost per ton of production. What is aimed at is reliable prediction of tuna aggregation in time and space from parameters of ocean or air conditions readily and customarily measured."

Attempts at finding such relationships between the occurrence of skipjack tuna and the environmental conditions have been discussed by Seckel (1963, 1972). He has suggested that the current system in the North Pacific is an important cause of variations in the availability

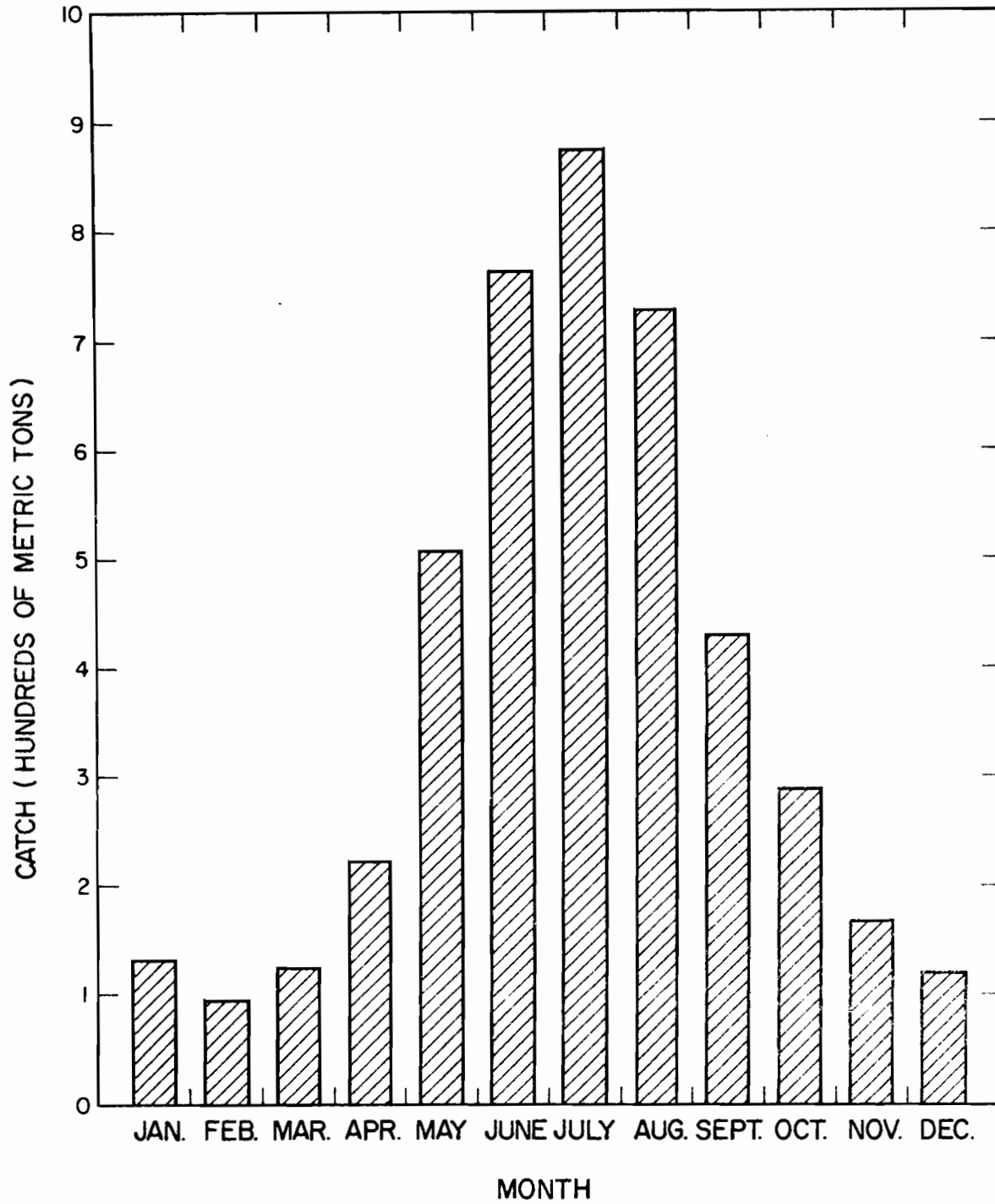


Figure 1.--Average monthly catch of skipjack tuna from Hawaiian waters, 1948-72.

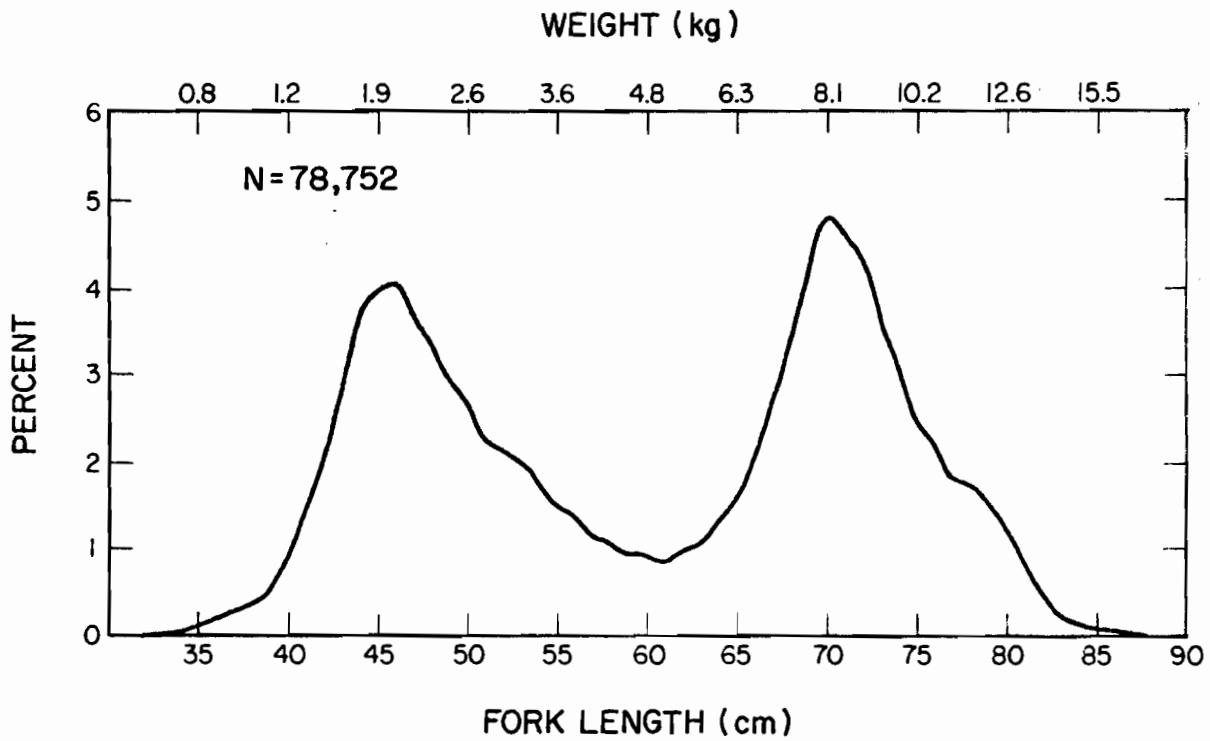


Figure 2.--Size composition of the commercial landings of skipjack tuna in the Hawaiian fishery (from data files, Bureau of Commercial Fisheries Biological Laboratory, Honolulu) (from Waldron, 1963).

of skipjack tuna in Hawaiian waters. A numerical drift model was used to investigate the contribution of currents to the travel of skipjack tuna from the eastern North Pacific to Hawaii. But models require verification before they can be used effectively to predict the catch.

In the eastern Pacific, scientists at IATTC are investigating the relationship between sea-surface temperatures in the spawning areas and skipjack tuna abundance in the fishing areas (IATTC, 1973b). The reasoning is that since the number of skipjack tuna larvae increases with temperature, warm years in the central Pacific spawning areas may result in higher indices of apparent abundance in the fisheries of the eastern Pacific. The recruits entering the eastern Pacific are believed to be 1 to 2 years old; therefore, variations in spawning or survival of larvae may be reflected in the fishing in about one and a half years.

Correlation between various indices of skipjack tuna abundance and those of sea-surface temperature and atmospheric pressure one and a half years earlier were significant in 28 out of 31 tests. The results indicated that there is a relationship between skipjack tuna abundance in the eastern Pacific and sea-surface temperature in the central equatorial Pacific. But because temperature may not be the single causal factor, but merely reflecting fluctuations in oceanographic conditions, other environmental factors have been examined.

In 1973, IATTC scientists estimated the apparent abundance and catch for 1973 and 1974, using the Darwin, Australia barometric pressure anomalies (IATTC, 1973b). They estimated the total skipjack tuna catch for 1973 to be 44,450 metric tons (49,000 short tons) which approximated the actual catch of roughly 43,540 metric tons (48,000 short tons). For 1974, their estimate is 120,650 metric tons (133,000 short tons).

Beginning in 1969, tuna tagging experiments also received considerable emphasis. With fishing effort expanding rapidly 1,000 to 3,000 km offshore, there was an urgent need to know more about the extent of mixing among the fish of various inshore and offshore areas (IATTC, 1973a). Although yellowfin tuna tagging experiments have received much more emphasis because of the heavy exploitation of this species, large numbers of skipjack tuna have also been tagged. Almost equal numbers of skipjack and yellowfin tunas were tagged in the eastern Pacific in 1973. The IATTC (1973b) reported that in 1973, 1,938 skipjack tuna and 1,927 yellowfin tuna were tagged. Recapture totaled 464 skipjack tuna and 115 yellowfin tuna.

In an effort to determine whether it is possible to induce formation of permanent marks in bones and scales of tuna, IATTC scientists are also conducting live-tank experiments on Pacific mackerel, Scomber japonicus (IATTC, 1973b). By this method, it is hoped that growth rates and age can be estimated. Pacific mackerel, tagged and injected intramuscularly with various dosages of tetracycline, were autopsied after

removal from the live tank and were found with tetracycline deposited in bones, scales, and other body organs. The smallest dosage used, 10 mg/kg of fish, was readily detected under ultraviolet light. These experiments are continuing.

Because the two-species tuna fishery of the eastern tropical Pacific depends on skipjack tuna as well as yellowfin tuna, it is difficult to separate the problems encountered by the fishermen in capturing yellowfin tuna from those encountered while fishing for skipjack tuna. One of the most pressing problems today is the mortalities among two species of porpoise, Stenella graffmani and S. longirostris, both of which are found in close association with schools of yellowfin. About half of the yellowfin tuna caught by seiners is taken from schools associated with porpoise (Green et al., 1971).

In making a set around a yellowfin tuna school associated with porpoise, the problem is then to separate unwanted porpoise from the valuable tuna. To accomplish the separation with the least possible mortality to the porpoise, the fishermen have developed a method called "backing down." The purpose is to allow the porpoise to spill over the corkline of the net and at the same time retain the yellowfin tuna. Despite this operation to save the porpoise, some are inadvertently entangled in the net and drown. The NMFS, Southwest Fisheries Center, La Jolla Laboratory has, in recent years, initiated programs to research and develop improved fishing methods and gear that would reduce porpoise mortality as required by the Marine Mammal Protection Act of 1972. Data are also being collected for a study of the dynamics of the porpoise population.

To be competitive with foreign tuna fisheries, U.S. fishermen must also constantly seek ways to improve the efficiency of harvesting the skipjack tuna resource. Green et al. (1971) cite a number of areas in which the tuna fleet could upgrade its efficiency to cope with rising costs and competition with low-cost foreign tuna producers. Improved refrigeration and partial processing at sea may increase the value of the catch. Transferring of the catch from the net to the boat should become more mechanized to reduce time lost in these operations on the fishing grounds. Furthermore, reduction of off-loading time should reduce turn-around time for the boats.

Other improvement could be made in the vessel's power plant, in net handling, in the deck equipment for handling the catch, in the net itself, and in scouting for fish schools (Green et al., 1971).

The key to the establishment and expansion of pole-and-line fisheries for skipjack tuna is the availability of live bait; this problem is particularly acute in the Hawaiian Islands. The availability of the native baitfish, nehu, varies widely and there is usually a shortage of baitfish from May through September when fishing for skipjack tuna becomes very intense. Most vessels expend much time and effort in

capturing sufficient bait to fish skipjack tuna. In recent years, the time spent in day baiting was about 40% of the total daytime activity of the fleet. Obviously, a reduction in the time spent day baiting would provide more time for fishing. An increase in fishing effort should increase the landings of skipjack tuna proportionately.

The problem of providing supplemental bait to the skipjack tuna fishing boats has a history that goes back at least two decades. In November 1953-October 1954, an early baitfish research program of the Hawaii Division of Fish and Game evaluated the suitability of Tilapia mossambica, a freshwater cichlid, as live bait for the fishery. The results of the field trials indicated that tilapia was suitable for skipjack tuna fishing and was subsequently cultivated on a large scale (Brock and Takata, 1955; King and Wilson, 1957; Hida, Harada, and King, 1962; Uchida and King, 1962). The failure of tilapia as a viable supplemental baitfish was attributed to the reluctance among the fishermen to purchase tilapia consistently.

Other species have also been tried. Marquesan sardine, Sardinella marquesensis, was introduced into Hawaiian waters, but this species never became established in quantity (Hida and Morris, 1963). Threadfin shad, Dorosoma petenense, a freshwater fish with excellent qualities as tuna bait, was also introduced into freshwater reservoirs around the islands (Hida and Thomson, 1962). This species became well established in one reservoir on Oahu and the production from it was sufficient for comprehensive field trials by vessels of the NMFS and the skipjack tuna fleet (Iversen, 1971). But unlike tilapia, shad was not cultured in captivity. Capturing and transporting shad from the reservoir to the docks, and acclimating them to seawater before transfer to the baitwells were problems that eventually proved too costly for an economically feasible operation. Work has also been done with sharpnosed molly, Poecilia sphenops, as skipjack tuna bait (Herrick, unpublished²; Baldwin, 1974).

Another approach to the solution of the acute bait shortages during the summer is to transport bait from areas where it is readily available. In 1973, a proposal to transport the northern anchovy, Engraulis mordax, from California to Hawaii met with enthusiastic support from the fishermen. The northern anchovy has been brought to Hawaii in the past on several occasions. All indications were that this species was hardier than nehu and also acceptable to the local fishermen. Acceptability was shown by a willingness of fishermen to purchase such

²Herrick, S. F., Jr. 1972. Economic analysis of commercial molly (Poecilia sphenops) baitfish aquaculture. 11 p. and attachments. Hawaii Institute of Marine Biology, University of Hawaii, Kaneohe, HI 96744.

bait. Consequently, the NMFS, Southwest Fisheries Center, Honolulu Laboratory initiated a program to transport the northern anchovy into Hawaii. They provided the expertise to carry out a study to determine the feasibility of transporting live anchovy in a 19,000-liter (5,000 gallons) aircraft refueling trailer that was modified to haul fish. The system included a self-contained, life-support system. The transport vehicle will use to its advantage the roll-on/roll-off cargo handling system developed by the U.S. maritime industry to move bulk cargo. At present, the work on this project is progressing at a satisfactory rate.

Although providing supplemental bait may be a partial solution to the bait shortages experienced by the Hawaiian skipjack tuna fishermen, it is not the only means of increasing the supply of usable bait. Nehu is notoriously vulnerable to mortality from handling; therefore, about a third of the nehu caught in Hawaiian waters do not survive long enough to be used as bait for fishing. Brock and Uchida (1968) estimated that 25% or more of the bait may die within 24 hours after capture. Baldwin, Struhsaker, and Akiyama (1972), therefore, evaluated survival of baitfish in the sampan's baitwells and developed equipment and techniques to avoid some of the causes of nehu mortalities.

Acute temporary shortages and high mortalities of nehu are not the only problems faced by the skipjack tuna fishermen. Another problem that arises from time to time is that of competition between commercial skipjack tuna fishermen and other users of baitfish species.

LITERATURE CITED

Anonymous.

1973. American high seas tuna fleet. In Pacific Packers Report
1973. Suppl. Natl. Fish. 53(12):29, 31, 33.

Baldwin, Wayne J.

1974. Raising mollies for skipjack bait may eliminate use of frail nehu. Natl. Fish. 54(9):7C.

Baldwin, W. J., J. W. Struhsaker, and G. S. Akiyama.

1972. Longer life for nehu. [In English and Japanese.] Univ. Hawaii Sea Grant Program MS-71-01 A, 24 p.

Broadhead, Gordon C., and Arthur R. Marshall.

1961. New methods of purse seining for tuna in the eastern Pacific Ocean. Proc. Gulf Caribb. Fish. Inst., 13 Annu. Sess., p. 67-73.

- Broadhead, Gordon C., and Craig J. Orange.
1960. Species and size relationships within schools of yellowfin and skipjack tuna, as indicated by catches in the eastern tropical Pacific Ocean. Bull. Inter-Am. Trop. Tuna Comm. 4:447-492.
- Brock, Vernon E., and Michio Takata.
1955. Contribution to the problems of bait fish capture and mortality together with experiments in the use of tilapia as live bait. Territory of Hawaii, Industrial Research Advisory Council Grant 49, Final Report, 39 p.
- Brock, Vernon E., and Richard N. Uchida.
1968. Some operational aspects of the Hawaiian live-bait fishery for skipjack tuna (Katsuwonus pelamis). U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 574, 9 p.
- Chapman, Wilbert M.
1963. World-wide tuna research planning. In H. Rosa, Jr. (editor), Proc. World Sci. Meet. Biol. Tunas Related Species. FAO (Food Agric. Organ. U.N.) Fish. Rep. 6:1097-1107.
- Godsil, H. C.
1938. The high seas tuna fishery of California. Calif. Dep. Fish Game, Fish Bull. 51, 41 p.
- Green, R. E., W. F. Perrin, and B. P. Petrich.
1971. The American tuna purse seine fishery. In Hilmar Kristjonnsson (editor), Modern fishing gear of the world 3:182-194. Fish. News (Books) Lond.
- Hida, Thomas S., Joseph R. Harada, and Joseph E. King.
1962. Rearing tilapia for tuna bait. U.S. Fish Wildl. Serv., Fish. Bull. 62:1-20.
- Hida, Thomas S., and Robert A. Morris.
1963. Preliminary report on the Marquesan sardine, Harengula vittata, in Hawaii. Pac. Sci. 17:431-437.
- Hida, Thomas S., and Donald A. Thomson.
1962. Introduction of the threadfin shad to Hawaii. Prog. Fish-Cult. 24:159-163.
- Inter-American Tropical Tuna Commission.
1971. Annual report of the Inter-American Tropical Tuna Commission, 1970. La Jolla, Calif., 127 p.
1972. Annual report of the Inter-American Tropical Tuna Commission, 1971. La Jolla, Calif., 129 p.

Inter-American Tropical Tuna Commission.

1973a. Annual report of the Inter-American Tropical Tuna Commission, 1972. La Jolla, Calif., 166 p.

1973b. The bi-monthly report of the Inter-American Tropical Tuna Commission. [1973 bi-monthly reports for January-February, March-April, May-June, July-August, September-October, November-December.] La Jolla, Calif.

Iversen, Robert T. B.

1971. Use of threadfin shad, Dorosoma petenense, as live bait during experimental pole-and-line fishing for skipjack tuna, Katsuwonus pelamis, in Hawaii. U.S. Dep. Commer., NOAA Tech. Rep. NMFS SSRF-641, 10 p.

Joseph, James, and Thomas P. Calkins.

1969. Population dynamics of the skipjack tuna (Katsuwonus pelamis) of the eastern Pacific Ocean. Bull. Inter-Am. Trop. Tuna Comm. 13:1-273.

June, Fred C.

1951. Preliminary fisheries survey of the Hawaiian-Line Islands area. Part III - The live-bait skipjack fishery of the Hawaiian Islands. Commer. Fish. Rev. 13(2):1-18.

King, Joseph E., and Peter T. Wilson.

1957. Studies on tilapia as skipjack bait. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 225, 8 p.

McNeely, Richard L.

1961. The purse seine revolution in tuna fishing. Pac. Fish. 59: 27-58.

Miyake, Makoto P., and C. Gail Tibbo (compilers).

1973. Statistical bulletin of the International Commission for the Conservation of Atlantic Tunas. Stat. Bull. 3.

Rothschild, Brian J.

1966. Preliminary assessment of the yield potential of the skipjack tuna in the central Pacific Ocean. In Thomas A. Manar (editor), Proc. Governor's Conference on Central Pacific Fishery Resources, State of Hawaii, p. 251-258.

Rothschild, Brian J., and Richard N. Uchida.

1968. The tuna resources of the oceanic regions of the Pacific Ocean. In DeWitt Gilbert (editor), The future of the fishing industry of the United States, p. 19-51. Univ. Wash., Publ. Fish. N.S. 4.

Scofield, W. L.

1951. Purse seines and other roundhaul nets in California. Calif. Dep. Fish Game, Fish Bull. 81, 83 p.

Seckel, Gunter R.

1963. Climatic parameters and the Hawaiian skipjack fishery. In H. Rosa, Jr. (editor), Proc. World Sci. Meet. Biol. Tunas Related Species. FAO (Food Agric. Organ. U.N.) Fish. Rep. 6:1201-1208.

1972. Hawaiian-caught skipjack tuna and their physical environment. Fish. Bull., U.S. 70:763-787.

Shimada, Bell M., and Milner B. Schaefer.

1956. A study of changes in fishing effort, abundance, and yield for yellowfin and skipjack tuna in the eastern tropical Pacific Ocean. Bull. Inter-Am. Trop. Tuna Comm. 1:347-469.

Silliman, Ralph P.

1966. Estimates of yield for Pacific skipjack and bigeye tunas. In Thomas A. Manar (editor), Proc. Governor's Conference on Central Pacific Fishery Resources, State of Hawaii, p. 243-249.

Uchida, Richard N.

1966. The skipjack tuna fishery in Hawaii. In Thomas A. Manar (editor), Proc. Governor's Conference on Central Pacific Fishery Resources, State of Hawaii, p. 147-159.

1967. Catch and estimates of fishing effort and apparent abundance in the fishery for skipjack tuna (Katsuwonus pelamis) in Hawaiian waters, 1952-62. U.S. Fish Wildl. Serv., Fish. Bull. 66:181-194.

1970. Distribution of fishing effort and catches of skipjack tuna, Katsuwonus pelamis, in Hawaiian waters, by quarters of the year, 1948-65. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 615, 37 p.

Uchida, Richard N., and Joseph E. King.

1962. Tank culture of tilapia. U.S. Fish Wildl. Serv., Fish. Bull. 62:21-52.

Uchida, Richard N., and Ray F. Sumida.

1971. Analysis of the operations of seven Hawaiian skipjack tuna fishing vessels, June-August 1967. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Spec. Sci. Rep. Fish. 629, 25 p.

1973. Tuna: Pole-and-line fishing trials in central and western Pacific. Mar. Fish. Rev. 35(1-2):31-41. (Also Mar. Fish. Rev. reprint No. 962.)

Waldron, K. D.

1963. Synopsis of biological data on skipjack Katsuwonus pelamis (Linnaeus) 1758 (Pacific Ocean). In H. Rosa, Jr. (editor), Proc. World Sci. Meet. Biol. Tunas Related Species. FAO (Food Agric. Organ. U.N.) Fish. Rep. 6:695-748.