CATCH AND ESTIMATES OF FISHING EFFORT AND APPARENT ABUNDANCE IN THE FISHERY FOR SKIPJACK TUNA (*KATSUWONUS PELAMIS*) IN HAWAIIAN WATERS, 1952–62

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ABSTRACT

Detailed data on catch and effort are obtained each year from all vessels that fish full time in the Hawaiian skipjack tuna fleet. These data permit description of the fishery and inferences about the abundance of skipjack. Our past measures of abundance have been stated in terms of total catch and catch per unit of effort calculated in terms of productive trips of all sizes of vessel. This study offers information on changes in the apparent abundance of skipjack in Hawaiian waters calculated from standardized units that will be unaffected by changes in the numbers of small and large vessels in the fishing fleet.

Effort was measured in terms of an "effective" trip, which was defined as a trip in which skipjack were caught. Bias introduced by the lack of data on zero-catch trips is discussed.

The number of men hooking per trip declined in 1950–60; however, those that remained in the fishery increased their catch rate by shifting their emphasis in fishing technique from "grasping and unhooking" each fish to "flipping," a method in which the fisherman swings the fish aboard and by relaxing the tension on the pole, permits the hook to fall clear of the fish's mouth. The higher catch rate from the "flipping" method was one of the factors that offset the effect of the decline in the number of men. Another factor that appeared to increase the catch rate was the reduction in the number of small vessels that did poorly.

The vessels were separated into two size classes: Class 1, with bait-carrying capacities of less than 800 gallons per baitwell; Class 2, with bait capacities of more than 800 gallons per baitwell.

The catch was standardized to Class 2 vessels. The catch per standard effective trip (Y/f) and the total catch fluctuated similarly in all years. The Y/f had no apparent trend and averaged about 5,700 pounds. The Y/f and the relative effective fishing intensity were not correlated significantly over the 11-year period. Year-to-year changes in apparent abundance seem to be independent of changes in fishing effort.

I concluded that variations in the availability and vulnerability of skipjack contribute to fluctuations in landings. The variations in strength of year classes also may have contributed importantly to fluctuations in the landings.

In Hawaii, the skipjack tuna, *Katsuwonus pelamis* (Linnaeus), or aku, as it is called locally, supports the State's most important commercial fishery, contributing about 66 percent by weight to the total Hawaiian marine catch, and accounting for about 40 percent of the total annual ex-vessel value. The fish are caught exclusively by pole and line from schools which are concentrated at the stern of the vessel by chumming with live bait. The fishery is highly seasonal. Landings have ranged from about 29,000 pounds in January, typically a poor month, to about 3.7 million pounds in July, when the catch usually is large. Four- to 5-pound fish usually are caught throughout the year, but between May and September, larger fish, ranging between 13 and 25 pounds, are also taken. The latter contribute a large percentage by weight to the total annual catch. Not only does the catch fluctuate by month but also by year. In 1952–62, the yearly landings ranged between 6.1 and 14.0 million pounds, apparently with changes in the numbers of the larger fish at the islands.

In the past, abundance of skipjack tuna in Hawaiian waters has been measured in terms of total catch and catch per unit of effort calculated in productive trips of all sizes of vessels —uncorrected fishing effort (Yamashita, 1958; Shippen, 1961). In general, total catch is not a dependable measure of abundance, because it is affected seriously by changes in the amount

Published April 1967.

of fishing effort and by weather and sea conditions. Catch per unit of effort calculated in terms of uncorrected fishing effort is also unreliable because it varies from year to year with changes in the fishing fleet. The fleet is made up of vessels of different sizes, and numbers of these change as some enter and some leave the fishery. Both size and number affect the catch per unit of effort. An important phase of this study is the derivation of a measure of abundance of skipjack in Hawaiian waters based on catch per unit of effort in standardized units that are unaffected by changes in the fishing fleet.

SOURCES OF MATERIALS

The basic data for this study were obtained from Fish Catch Reports (January 1952 to June 1954) and Aku Catch Reports (July 1954 to December 1962) submitted by the fishermen to the Hawaii Division of Fish and Game. Catch reports of only those vessels that fished for skipjack tuna full time were used. The report form has undergone several revisions through the years, but all versions have carried spaces for the following information: The date of landing, the pounds of skipjack caught, and the fishing area. Yamashita (1958) described the method of reporting the areas fished by a skipjack vessel. Briefly, a fisherman reports only the code number corresponding to the statistical area where the catch was made. These areas are indicated on the Division of Fish and Game's Fisheries Chart No. 2 (see Yamashita, 1958: fig. 2).

Data on number of men hooking per trip were obtained from Aku Boat Interview Sheets (January 1950 to July 1956), which were collected and checked by the personnel of the Division of Fish and Game, from logbook records (1957–59), and from Sampan Interview Records (August 1959 to June 1961).

DESCRIPTION OF THE FISHERY

The present brief description of the fishery and review of fishing operations is based on June (1951). The number of skipjack tuna sampans fishing full time reached a maximum of 28 in 1951, but since then has declined; in 1963 only 20 vessels were fishing full time for skipjack. The vessels, generally of wooden construction, range from 58.3 to 80.5 feet in registered length and from 27 to 77 in gross tonnage. These vessels carry 6 to 14 men per fishing trip.

The nehu or anchovy, *Stolephorus purpureus* Fowler, makes up about 92 percent of the bait catch; a second bait is the iao or silverside, *Pranesus insularum* (Jordan and Evermann). Each vessel catches its own bait, fishing day and night until a sufficient supply is obtained. All the vessels have six baitwells with screened holes at the bottom through which sea water circulates.

The Hawaiian skipjack tuna fishermen usually confine their fishing and scouting operations to waters within 90 miles of the main islands. Skipjack on the fishing ground are indicated to the fishermen almost exclusively by bird flocks which are often associated with schools of fish. When a school has been sighted the captain attempts to intercept it. Once the head of the school is reached, water sprays are turned on and the "chummer" scatters live bait into the water. If the skipjack bite, the fishermen begin fishing off the stern. Fishing continues until the bait supply is exhausted or until the captain decides that further fishing is not worthwhile. If chumming is unsuccessful, the school is abandoned and scouting is resumed. The sampans may encounter several skipjack tuna schools during the day, but the fish may bite in only about half of them. Scouting and fishing are discontinued as dark approaches, and the vessels usually head for port to unload the day's catch.

TRENDS IN CATCHES OF SKIPJACK TUNA

To show the trends in catches of skipjack tuna from Hawaiian waters, catch statistics were summarized by months and quarters for each year and by two broad geographical areas. Comments on the trends of catches are based on tabulation of data for 1952–62; therefore, the results may not be in complete agreement with those published for 1948–53 by Yamashita (1958).

TABLE 1.—*Monthly, quarterly, and annual catches of skipjack tuna in Hawaii, 1952–62*

[Thousands of pounds]

Period of time	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	Range	Average
Month:													
January	29	200	271	98	322	524	638	215	242	492	459	29-638	317
February	90	204	185	118	281	133	236	107	179	247	412	90-412	199
March	56	576	359	263	230	454	151	397	327	600	199	56-600	328
April	387	864	759	681	433	331	792	839	411	620	480	331-864	600
May	578	1,240	1,132	1,399	1,375	816	277	1,757	842	930	1,178	277-1,757	1,048
June	818	2,241	2,804	2,197	1,926	812	948	1,679	776	2,721	2,308	776-2,804	1,748
July	1,654	1,510	3,705	1,824	2,321	919	1,405	2,382	1,430	2,288	1,809	919-3,705	1,932
August	1,758	2,142	2,178	1,170	1,586	698	1,191	1,815	1,396	1,359	922	698-2,178	1,474
September	987	1,281	1,049	993	1,055	489	631	1,377	690	705	568	489-1,377	893
October	576	1,199	1,121	440	725	530	186	1,064	439	516	525	186-1,199	666
November	110	218	390	272	635	282	144	626	219	213	170	110-635	298
December	249	384	68	239	243	142	235	155	409	203	385	68-409	246
Quarter:													
First	175	980	815	479	833	1,111	1,025	719	748	1,339	1,070	175-1,339	845
Second	1,783	4,345	4,695	4,277	3,734	1,959	2,017	4,275	2,029	4,271	3,966	1,783-4,695	3,395
Third	4,399	4,933	6,932	3,987	4,962	2,106	3,227	5,574	3,516	4,352	3,299	2,106-6,932	4,299
Fourth	935	1,801	1,579	951	1,603	954	565	1,845	1,067	932	1,080	565-1,844	1,210
Annual	7,292	12,059	14,021	9,694	11,132	6,130	6,834	12,413	7,360	10,894	9,415	6,130-14,021	9,749

MONTHLY, QUARTERLY, AND ANNUAL CATCHES

The seasonal character of the Hawaiian skipjack tuna fishery is shown by the monthly and quarterly catches in 1952–62 (table 1). The catch usually increased gradually from April to a peak in June, July, or August and then declined progressively to a low level in December. Usually February had the smallest catch and July the largest. Also, the catch usually rose in January following the progressive decline from the summer peak to December.

The quarterly catches showed the same trend as the monthly landings. First-quarter catches were usually the smallest and averaged 0.8 million pounds. Second-quarter catches reflected the increased fishing activity during the spring and averaged about 3.4 million pounds. Third-quarter landings were rather consistently the largest and averaged 4.3 million pounds; only in 1955 and 1962 did second-quarter catches exceed those of the third quarter. The fourth-quarter catches declined to an average of 1.2 million pounds.

The variations of the annual catches were large. In 1952–62, there were 4 poor years—1952, 1957, 1958, and 1960—in which the catches were far below the 11-year average of 9.7 million pounds. The catches in 1955 and 1962 were close to the 11-year average, and those of the remaining years were above average. The maximum catch of 14.0 million pounds occurred in 1954; the minimum of 6.1 million pounds was in 1957.

INSHORE AND OFFSHORE CATCHES

For this study, I consider the inshore area to extend from the coastline to 20 miles at sea and the offshore area to include all statistical areas beyond 20 miles from the coastline.

The catch reports used in this study were from vessels that fished for skipjack full time. The total weight landed by these vessels and the effort expended to produce it are hereafter called sample catch and sample effort. In addition to the catches made by these vessels, catches were made by vessels that fished for skipjack tuna only part time. The total weight landed by vessels that fished full time and those that fished part time is hereafter called total catch and the effort expended to produce it is total effort. Data on total catch were obtained from annual summaries of catch issued by the Hawaii Division of Fish and Game.

I obtained the sample catch (all areas) and the sample inshore catch from the catch reports, and from these data, I calculated the percentage of the catch made inshore. The total inshore catch was estimated by applying the percentage of the catch made inshore to the total catch. The estimated annual inshore catches (table 2) are shown in relation to the total catch and the estimated total offshore catch in figure 1.

The percentage of the catch made inshore ranged from 63 percent in 1954 to 90 percent in 1960. During the poor years—1952, 1957, 1958, and 1960—the inshore catch averaged 83 percent of the total catch, whereas in

TABLE 2.—*Estimated total inshore and total offshore catches of skipjack tuna in Hawaiian waters, 1952–62*

Year	Sample catch all areas	Percentage of sample catch inshore	Actual total catch	Estimated inshore catch	Estimated offshore catch
	Thousand pounds	*Percent*	*Thousand pounds*	*Thousand pounds*	*Thousand pounds*
1952	6,277	76	7,292	5,542	1,750
1953	10,543	66	12,059	7,959	4,100
1954	11,229	63	14,021	8,833	5,188
1955	8,257	83	9,694	8,046	1,648
1956	10,937	73	11,132	8,126	3,006
1957	6,075	80	6,130	4,904	1,226
1958	6,494	86	6,834	5,877	957
1959	11,945	83	12,413	10,303	2,110
1960	7,107	90	7,360	6,624	736
1961	10,780	78	10,894	8,497	2,397
1962	9,086	82	9,415	7,720	1,695

average and good years the inshore catch averaged 75 percent.

Yamashita (1958) who examined the 1948–53 catches of skipjack tuna suggested that about 8.0 million pounds may be nearly the maximum that can be obtained in the inshore area. The present study indicates, however, that the inshore catch can be well above this level. The 1959 landings, for example, were 10.3 million pounds and were caught by a fleet of 21 full-time vessels, although in 1949–53 26 to 28 vessels were fishing full time for skipjack.

The offshore catch increased gradually from 1.8 million pounds in 1952 to a peak of about 5.2 million pounds in 1954 (fig. 1). After a sharp decline to about 1.6 million pounds in the following year, the offshore take fluctuated between 0.8 and 3.0 million pounds from 1956 to 1962.

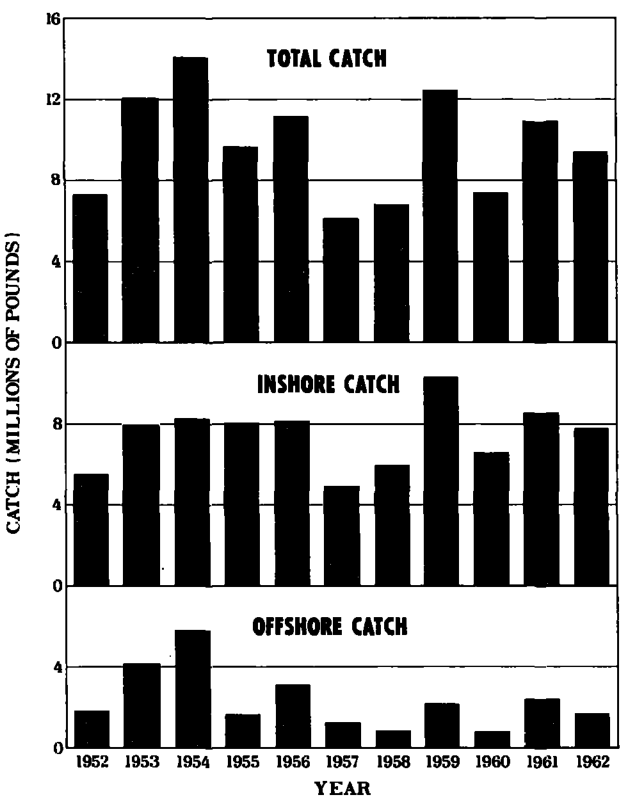

FIGURE 1.—Total catch of skipjack tuna (all areas) and the estimated inshore and offshore catches in the Hawaiian fishery, 1952-62.

FISHING INTENSITY

Fishing intensity is the total amount of effort expended in catching fish. Effort changes with time in different ways. For example, in a fishery where a trip is considered a unit of fishing effort, an increase in the duration of trips or an increase in the fishing power of vessels alters the unit of effort. These changes complicate the analysis of catch and effort data; therefore it becomes necessary to obtain and examine information on size of vessels, on modification of or improvement to fishing gear, and on changes in fishing time.

SIZE CLASSES OF VESSELS

It may be expected that size of a vessel influences its potential efficiency as a fishing unit in a pole-and-line fishery because the larger crews give the larger vessels greater fishing power. One measure of effort is the number of men aboard per trip; this number may vary among vessels and with the years. The interview records for 1950–56 indicated that the number of men aboard per trip varied between 6 and 14.

The effects of this crew variability were reduced by separating the vessels arbitrarily into two size classes according to their bait-carrying capacities. The bait-carrying capacity was a good measure of the vessel's fish capacity, because on the return to port the empty baitwells were used to store the catch. The vessels with large bait capacities were the large ones that usually carried more men. Data on the bait capacity of most of the vessels in the fleet were given by Yamashita (1958; appendix table 1).

The bait capacity of a vessel is stated in terms of the average effective volume in gallons per baitwell and is derived from the length of the baitwell, its width, and its depth up to the water level.

The size classes of vessels used in this study are as follows:

Class 1.—Bait capacity up to 800 gallons per baitwell; registered length, 58.3 to 71.9 feet; gross tonnage, 27 to 54 tons; engine, 110 to 450 horsepower. Their number ranged from 8 to 16 in 1952–62.

Class 2.—Bait capacity more than 800 gallons per baitwell; registered length, 65.0 to 80.5 feet; gross tonnage, 45 to 77 tons; engine, 160 to 600 horsepower. Their number ranged from 11 to 14 in 1952–62.

It was necessary to estimate the bait-carrying capacity of four vessels for which Yamashita (1958) gave no records. To determine the most dependable procedure, characteristics such as gross tonnage, net tonnage, registered length, and engine horsepower, were examined in relation to average effective volume of baitwells. The regression of average effective volume per baitwell (Y) on gross tonnage (X) (fig. 2) proved to have the smallest error of estimate. This relation was used therefore, to estimate the average effective volume of the four vessels.

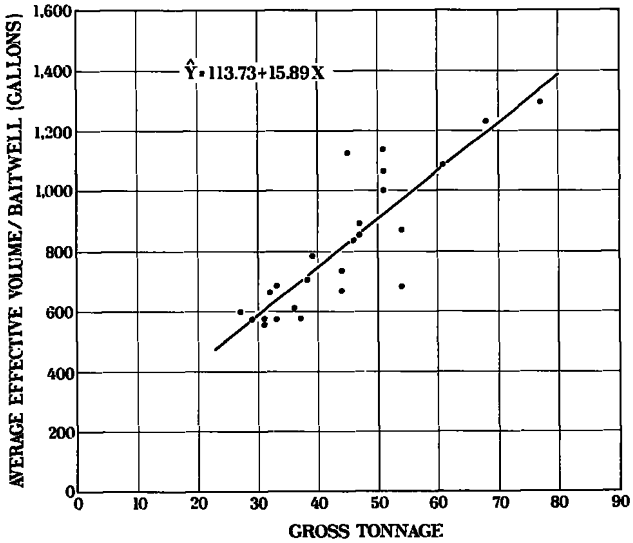

FIGURE 2.—Regression of average effective volume per baitwell on gross tonnage of Hawaiian skipjack tuna vessels.

THE EFFECTIVE TRIP AS A MEASURE OF EFFORT

The records used carried three types of statistics from which one might estimate effort: The number of men hooking per trip, the number of men aboard per trip, and the number of trips. The number of men hooking per trip and the number of men aboard per trip were not consistently entered; therefore, I selected the number of fishing trips as the unit of effort. The catch reports showed all trips on which a catch was made, but gave no indication of zero-catch trips. For this study I define effort as an effective trip (a trip on which skipjack tuna were caught).

Because zero-catch trips were not recorded, effort always is underestimated. The extent of the underestimate may not be serious in some years, because zero-catch trips are fewer when fishing is good (Shippen, 1961). This source of error can weigh heavily, however, in a year of poor fishing, when zero-catch trips become numerous.

ESTIMATES OF ZERO-CATCH TRIPS

Because only the number of effective trips is known from the catch reports, estimates of catch per effective trip (Y/g) are larger than if total effort had been used, assuming that zero-catch trips occur from time to time. (The notation Y refers to the total weight of fish in the catch and g to the fishing effort or effective trip as recorded. In a later section of this paper the notation f is used to refer to fishing effort expressed in standard effective trips.) A measure of effort, however, should reflect zero-catch trips as well as those on which fish were caught.

Logbook records available for a few vessels in 1957–59 provided some data on zero-catch trips (table 3). Five vessels kept logbooks in 1957, seven in 1958 and five in 1959; the vessels represented 20, 29, and 24 percent of the fleet.

TABLE 3.—*The total catch, number of Class 1 and Class 2 vessels sampled, their total recorded trips, and number and percentage of zero-catch trips, Hawaii, 1957–59*

Year	Total catch	Class 1				Class 2			
		Vessels	Trips	Zero-catch trips		Vessels	Trips	Zero-catch trips	
	Thousand pounds	*Number*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Number*	*Percent*
1957	6,130	2	181	51	28	3	357	136	38
1958	6,834	2	145	31	21	5	482	131	27
1959	12,413	1	93	2	2	4	336	32	10

Because no additional data are available, I assumed that this sample represents the fleet's activities for these years.

Zero-catch trips were more frequent among Class 2 than among Class 1 vessels (table 3). The higher rate of occurrence in poor years (1957–58) than in the good year (1959) indicates that the percentage of zero-catch trips tends to decrease as total catch increases. The apparent negative correlation between these variables is supported to some extent by Shippen (1961: table 2) who analyzed the logbooks of two vessels. (The original records show that these were Class 2 vessels.) He found that in a poor year (1952), zero-catch trips accounted for 10 percent of the total trips made by Boat A and 14 percent of those made by Boat B. In a good year (1953), zero-catch trips were 8 and 10 percent for Boat A and Boat B, respectively.

The numbers of effective trips and zero-catch trips were used to estimate the total effort for 1957–59. For example, in 1957, the total number of zero-catch trips among Class 1 vessels was estimated by simple proportion to be 262. The estimated total effort for both size classes for 1957–59 is given in table 4.

TABLE 4.—*Number of effective trips and estimated number of zero-catch trips of Class 1 and Class 2 vessels, Hawaii, 1957–59*

Year	Vessels	Class 1			Class 2		
		Effective trips	Estimated zero-catch trips	Estimated total trips	Effective trips	Estimated zero-catch trips	Estimated total trips
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1957	25	668	262	930	910	560	1,470
1958	24	659	179	838	865	323	1,188
1959	21	779	17	796	1,055	111	1,166

The number of zero-catch trips was large in 1957 and 1958. In 1957 the estimated total number of unreported zero-catch trips was 822, or an average of about 33 per vessel; in 1958 the estimated number was 502 or about 21 per vessel. In 1959, a good year in the fishery, the estimated number of zero-catch trips for the fleet was only 128—about 6 per vessel.

The results indicate that catch per effective trip should be regarded with caution. Effective effort is a biased measure of fishing pressure, but it has been used because information on zero-catch trips was not available from the catch reports used. This condition has been remedied; in July 1964, the Hawaii Division of Fish and Game issued revised catch-report forms which have spaces for recording zero-catch trips.

DURATION OF AN EFFECTIVE TRIP

Most of the vessels in the fleet made short runs. They left for the fishing grounds in the early morning and returned to port in the evening. On occasion, however, trips of 2, 3, or 4 days have been recorded. Only a small proportion of the day was devoted to actual fishing; the greater part was spent scouting for bird flocks that follow schools of skipjack tuna.

To judge the possible effects of longer trips, the frequency of occurrence of 1- and multiple-day trips (2 or more days per trip) was determined from 1960 interview records for 16 vessels (table 5). Records for a total of 329 trips showed 315 of 1 day (95.7 percent), 13 of 2 days (4.0 percent), and 1 of 3 days (0.3 percent). Of the thirteen 2-day trips, 9 had catches during both days at sea, but each of the

TABLE 5.—*Number and percentage of 1-, 2-, and 3-day trips, total catch, catch per effective trip, and range of catches of 16 Hawaiian skipjack tuna vessels in 1960*

Days per trip	Effective trips		Catch		
			Total	Per effective trip	Range
Number	*Number*	*Percent*	*Pounds*	*Pounds*	*Pounds*
1	315	95.7	1,636,185	5,194	375–30,553
2	13	4.0	121,462	9,343	2,000–17,000
3	1	.3	35,000	35,000	
Totals	329		1,792,647		

remaining 4 had only 1 day in which skipjack tuna were caught. We may conclude that a trip usually represents 1 day's fishing.

AVERAGE NUMBER OF MEN HOOKING PER EFFECTIVE TRIP

The number of hooks fishing on a Hawaiian skipjack tuna vessel depends on the number of fishermen that take fishing positions along the stern during the fishing operation, since each man fishes a single pole to which a line and feathered jig is attached. Yuen (1959), in a study of the response of skipjack tuna to live bait, pointed out that the number of men hooking was one of the factors that affect the catch per school. The catch per effective trip is also related to the number of men hooking; it is important, therefore, to examine the year-to-year variation in this number. Data on the number of men hooking were available only from records collected between 1950 and 1960; those for 1950–56 and 1960 were from interview records and those for 1957–59 were from logbooks. These data were used to calculate monthly and annual averages by size classes of vessels (table 6).

TABLE 6.—*The monthly and annual average of the number of men hooking per effective trip on Class 1 and Class 2 Hawaiian skipjack tuna vessels, 1950–60*

Month and class		1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
Jan.	1	-----	-----	-----	-----	-----	-----	6.0	6.0	7.1	-----	7.0
	2	-----	-----	-----	-----	-----	11.0	8.3	7.2	7.2	-----	7.9
Feb.	1	-----	-----	-----	-----	-----	8.0	6.0	5.7	6.7	-----	8.2
	2	-----	-----	-----	-----	-----	-----	8.3	6.3	6.8	-----	7.9
Mar.	1	-----	-----	-----	8.8	9.9	9.3	-----	6.8	6.9	-----	7.1
	2	-----	-----	-----	9.6	10.0	10.3	10.0	6.6	7.3	-----	7.4
Apr.	1	-----	-----	-----	9.5	9.3	9.2	7.3	6.5	7.1	7.4	6.7
	2	-----	-----	-----	9.3	9.7	9.6	10.0	7.2	7.7	7.1	7.0
May	1	8.4	8.2	9.3	9.3	9.4	9.2	7.2	6.7	6.0	6.8	6.6
	2	10.6	10.0	9.0	9.4	10.5	9.7	-----	8.1	8.2	8.0	7.0
June	1	8.8	8.0	8.0	8.8	9.2	9.3	7.1	6.7	7.1	8.6	7.4
	2	10.2	10.7	9.7	9.4	9.7	-----	-----	8.2	8.7	7.8	7.3
July	1	8.8	7.9	8.2	8.0	8.5	8.8	7.7	7.0	8.9	8.9	6.8
	2	9.7	8.5	9.7	9.8	9.5	9.2	-----	8.2	8.7	7.3	7.7
Aug.	1	8.6	8.7	8.5	8.6	8.4	8.2	-----	6.3	7.9	8.4	6.5
	2	10.8	9.7	9.1	10.3	10.1	8.3	-----	7.4	8.5	7.2	7.6
Sept.	1	7.4	8.8	9.1	6.5	9.5	7.5	-----	5.5	5.7	7.5	6.5
	2	10.7	9.1	9.1	10.2	9.4	7.4	-----	7.8	7.8	6.9	6.8
Oct.	1	-----	6.2	7.8	7.9	8.5	8.0	-----	7.2	6.1	6.9	7.3
	2	-----	8.7	8.6	-----	9.4	7.0	-----	6.7	8.0	6.6	6.7
Nov.	1	-----	-----	8.7	9.9	10.0	8.0	-----	7.3	6.4	6.2	5.0
	2	-----	7.0	7.0	9.9	11.9	6.0	-----	6.5	8.3	6.9	5.0
Dec.	1	-----	-----	-----	-----	-----	-----	-----	8.0	6.6	7.0	6.5
	2	-----	-----	-----	9.3	11.0	6.1	-----	6.8	7.9	6.7	6.4
Annual average	1	8.4	8.2	8.4	8.6	9.2	8.9	7.1	6.7	7.1	7.6	6.9
	2	10.4	9.6	9.2	9.7	9.8	8.3	8.7	7.4	8.1	7.2	7.4

I expected that the number of men hooking per effective trip would be greater during the season months (May to September) than during the off-season months (Shippen, 1961). Despite the incompleteness of the data for some years, the trend of change, discernible from the data for those years where information was adequate, indicates no pronounced increase in the number of men hooking in May to September (fig. 3). More men fished per effective trip in Class 2 than in Class 1 vessels, although the 1959–60 data indicate that the differences between the two classes were small.

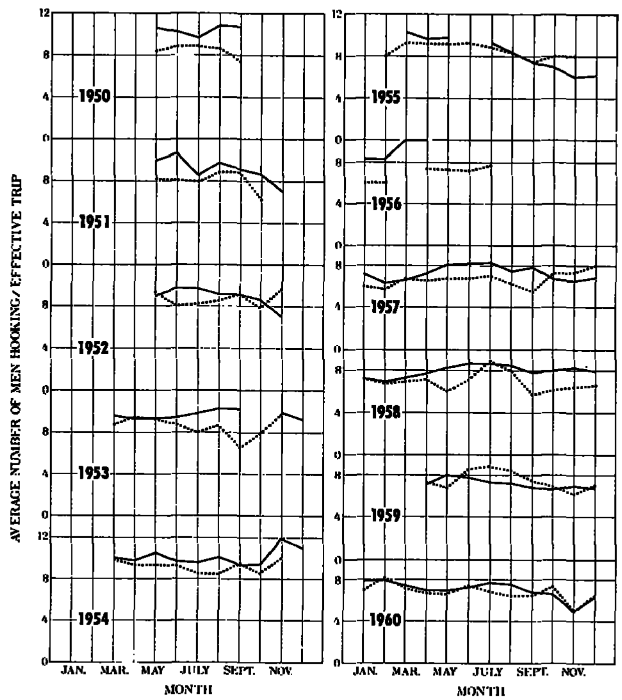

FIGURE 3.—Monthly averages of number of men hooking per effective trip on Class 1 and Class 2 Hawaiian skipjack tuna vessels, 1950–60. Class 1 vessels, broken line; Class 2 vessels, solid line.

Figure 4 illustrates the decline in the annual average. The average number of men hooking per effective trip on Class 1 vessels was fairly steady from 1950 to 1955, then dropped and remained at a lower level in 1956–60. The average for Class 2 vessels declined almost steadily from 1950 to 1960. This decrease in the number of men hooking from 1950 to 1960 was not, however, accompanied by a decline in the catch per effective trip. An explanation is given in the section on Apparent Abundance.

after 1953 (fig. 5). The percentage of effective inshore trips did not differ greatly between Class 1 and Class 2 vessels. For Class 1 vessels, the percentage of inshore trips, on the average, was 81 percent, whereas for Class 2 vessels, the average was 83 percent over the 11 years.

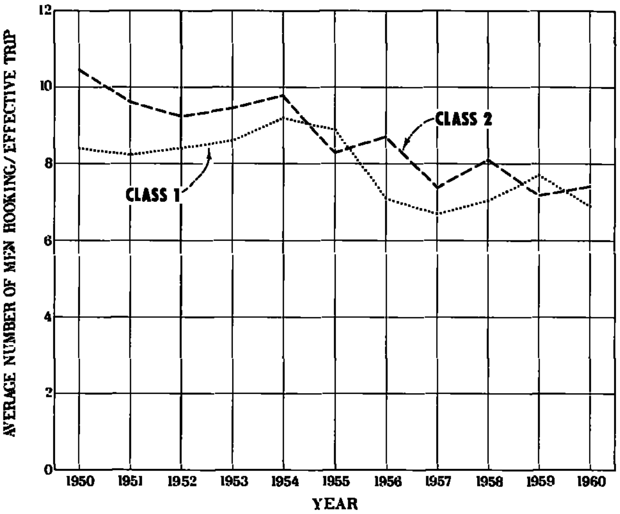

FIGURE 4.— Annual averages of number of men hooking per effective trip on Class 1 and Class 2 Hawaiian skipjack tuna vessels, 1950–60.

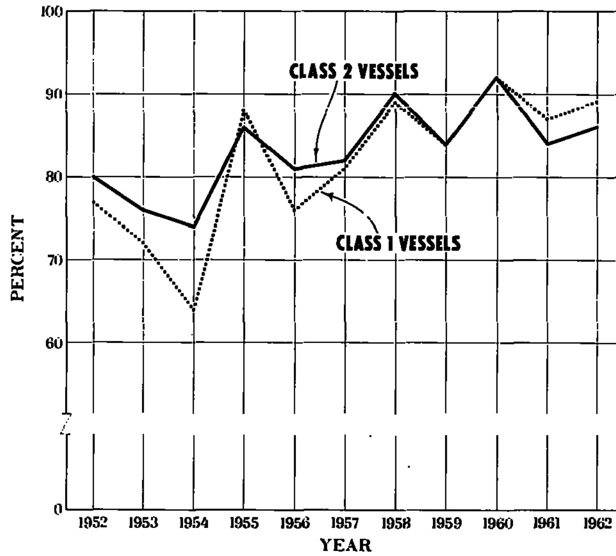

FIGURE 5.—Percentage of effective trips inshore by Class 1 and Class 2 Hawaiian skipjack tuna vessels, 1952–62.

DISTRIBUTION OF EFFORT BY AREA

About 80 percent of the effective trips during any given year were in the inshore area (table 7). The percentage of effective inshore trips for both classes of vessels declined from 1952 to 1953. Class 1 vessels showed a further decline in 1954, then a gradual increase, whereas Class 2 vessels showed a gradual increase

TABLE 7.—*The number and (in parentheses) percentage of effective trips by Class 1 and Class 2 Hawaiian skipjack tuna vessels in inshore and offshore areas, 1952–62*

Year	Effective trips							
	Class 1 vessels				Class 2 vessels			
	Inshore		Offshore		Inshore		Offshore	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
1952	658	(77)	197	(23)	555	(80)	137	(20)
1953	799	(72)	308	(28)	738	(76)	232	(24)
1954	696	(70)	291	(30)	690	(77)	209	(23)
1955	817	(88)	116	(12)	748	(86)	124	(14)
1956	709	(76)	222	(24)	772	(81)	184	(19)
1957	540	(81)	128	(19)	742	(82)	168	(18)
1958	587	(89)	72	(11)	783	(90)	82	(10)
1959	658	(84)	121	(16)	884	(84)	171	(16)
1960	563	(92)	51	(8)	858	(92)	73	(8)
1961	608	(87)	88	(13)	939	(84)	179	(16)
1962	646	(89)	80	(11)	804	(86)	131	(14)
Average [1]	662	(81)	152	(19)	774	(83)	154	(17)

[1] Percentages were computed from the average annual numbers of effective trips.

A summary of effective trips by areas for each size class of vessels with respect to poor years and average and good years showed that in poor years, the percentage of effective inshore trips by Class 1 vessels was 84 percent; in average and good years, it was 81 percent. For Class 2 vessels, the values were 86 percent in poor years and 82 percent in average and good years.

One may wonder if skipjack tuna are more abundant inshore, since a larger percentage of the total trips is made within 20 miles from land. Observations of skipjack schools in Hawaiian waters in 1953 indicated that sightings of tuna schools were equally numerous offshore and inshore except for sectors to the northeast and southwest of Oahu (Royce and Otsu, 1955).

If schools are equally abundant offshore and inshore, the question arises as to why effort has been concentrated in the inshore grounds. There are several possible answers. Fishermen reduce costs by remaining close to port as long as they can make profitable catches. The concentration of effort inshore also may be dictated by the quality and quantity of live bait. Even though it may occasionally survive as long as a week, the delicate nehu may die within a few hours. The fishermen logically would fish inshore to use the bait quickly before mortality becomes heavy. Furthermore, the need to replenish live-bait supplies to some extent restricts trips to the distant offshore grounds, where live bait is unavailable.

EFFECTIVE TRIPS BY SIZE CLASSES OF VESSELS

The average number of effective trips per vessel per year fluctuated widely in 1952–62 (table 8). The average number of effective trips per Class 1 vessel per year (fig. 6)

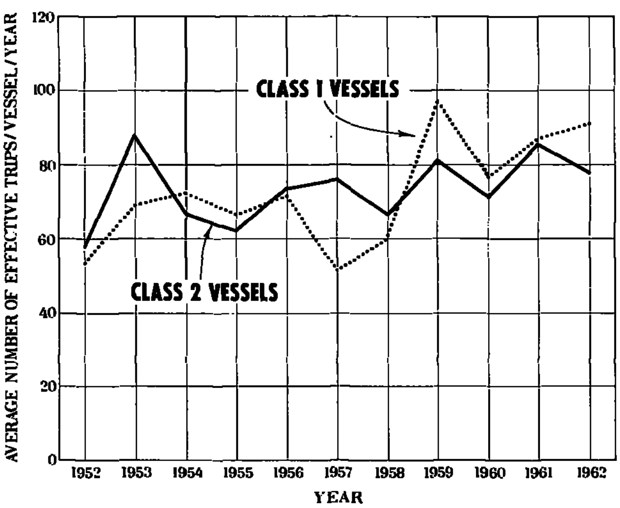

FIGURE 6.—Average number of effective trips per vessel per year by Class 1 and Class 2 Hawaiian skipjack tuna vessels, 1952–62.

fluctuated between 51 and 72 in 1952–58, rose sharply to 97 in 1959, and ranged between 77 and 91 in 1960–62. For Class 2 vessels, the average rose very sharply from 58 to 88 in 1952–53, then declined to 75 in 1954 and to 62 in 1955. After 1955 the average appeared to increase gradually. The reason for the increase in the number of effective trips, particularly the sharp increase since 1959 among Class 1 vessels, is not known.

TABLE 8.—*The total number of effective trips and the average number of effective trips per vessel by Class 1 and Class 2 Hawaiian skipjack tuna vessels, 1952–62*

Year	lass 1 vessels			Class 2 vessels		
	Vessels fished	Total	Average per vessel	Vessels fished	Total	Average per vessel
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
1952	16	855	53	12	692	58
1953	16	1,107	69	11	970	88
1954	15	987	66	12	899	75
1955	14	933	67	14	872	62
1956	13	931	72	13	956	74
1957	13	668	51	12	910	76
1958	11	659	60	13	865	66
1959	8	779	97	13	1,055	81
1960	8	614	77	13	931	72
1961	8	696	87	13	1,118	86
1962	8	726	91	12	935	78

APPARENT ABUNDANCE

The catch per unit of effort does not provide estimates of true abundance but of apparent abundance, since it is affected by availability[1] and vulnerability[2] to the fishing gear. In the section that follows, I discuss the catch per effective trip, the factors affecting it, and the method used to obtain a standard unit of effort.

CATCH PER EFFECTIVE TRIP BY SIZE CLASSES OF VESSELS AND AREAS

Data on Y/g (catch per effective trip) by size classes of vessels and areas are given in table 9 and plotted in figure 7. The inshore Y/g for Class 1 vessels fluctuated within a relatively narrow range, whereas that for offshore fishing fluctuated more widely. The curves for Class 1 vessels offshore and Class 2 vessels inshore were similar. Catches of Class 1 vessels that fished offshore fluctuated widely and followed the curve for the total catch. The inshore and offshore Y/g for Class 1 vessels and total catch were significantly correlated ($r = 0.675$; $df = 9$; $p = 0.03$ and $r = 0.923$; $df = 9$; $p < 0.001$, respectively). A similar comparison of data for Class 2 vessels showed that both the inshore and offshore Y/g were sig-

[1] "Availability is the portion (a percentage) of the recruited population that is physically within the geographic range of the fishery during the fishing season." (Ahlstrom, 1960: p. 1361.)

[2] "Vulnerability is the accessibility of the fish within the geographic range of the fishery to the efforts of a fishery." (Ahlstrom, 1960: p. 1361.)

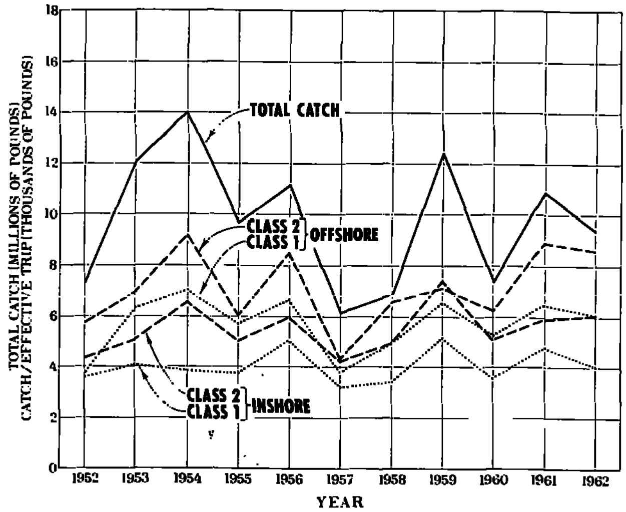

FIGURE 7.—Total catch and catch per effective trip by areas for Class 1 and Class 2 Hawaiian skipjack tuna vessels, 1952–62.

nificantly correlated with the total catch (r = 0.762; df = 9; p<0.01, and r = 0.697; df = 9; p = 0.02, respectively).

FACTORS AFFECTING ESTIMATES OF THE CATCH PER EFFECTIVE TRIP

Proper interpretation of statistics on catch and effort requires information about factors that contribute to variations in catch per unit of effort. For the skipjack tuna fishery in Hawaii, a number of factors have been isolated as causes of variation in catch per effective trip. Some of these are discussed here.

Changes in the Availability of Skipjack Tuna

In a study on the oceanography and skipjack fishery in the Hawaiian region, Seckel and Waldron (1960) pointed out that the time of initial warming of the surface water at Koko Head, Oahu, appears to be related to the annual skipjack landings. When the initial warming occurred in February, this implied that the California Current System was well developed and average or better-than-average fishing years occurred. When the initial warming occurred in March, fishing was poor.

The relation between the time of initial warming and skipjack landings later in the season appeared to have some predictive value concerning the availability of skipjack tuna. According to Seckel (1963: fig. 4), the initial warming occurred in March in 1952, 1955, 1957, 1958, and 1960; skipjack availability should be low during these years. As was pointed out earlier, however, the catch in 1955 was close to the average catch of 9.7 million pounds for 1952–62 (table 1) and was considered an average year for the purpose of this report. The forecasts made from 1959 to 1962 were dependable, but the prediction of favorable fishing conditions and catch levels could not be made with assurance because only partial understanding of the relation has been achieved. At present, variations in skipjack availability appear to be one of the most important factors causing fluctuations in the total catch of skipjack in the Hawaiian fishery.

Changes in the Number of Men Hooking and in Fishing Technique

Since the average number of men hooking per effective trip declined between 1950 and 1960, I examined the data to see if the Y/g showed a similar decline. The results (table 9 and fig. 7) showed that Y/g did not decline during 1952–62. For example, if the poor years of 1952, 1957, 1958, and 1960 are omitted to simplify the comparison, Y/g for the remaining years appears to be approximately the same before and after 1955, that is, no indication exists of a decline in Y/g. An excellent 2-year comparison is provided by the data of both size classes in 1954 and 1959, in which years

TABLE 9.—*The catch per effective trip of Class 1 and Class 2 Hawaiian skipjack tuna vessels in inshore and offshore areas, 1952–62*

Year	Catch per effective trip			
	Class 1		Class 2	
	Inshore	Offshore	Inshore	Offshore
	Pounds	*Pounds*	*Pounds*	*Pounds*
1952	3,586	3,728	4,323	5,722
1953	4,055	6,337	5,069	6,943
1954	3,867	7,758	6,312	9,210
1955	3,762	5,704	5,048	6,023
1956	4,914	6,338	5,871	8,228
1957	3,219	3,790	4,210	4,333
1958	3,238	4,928	4,723	6,593
1959	5,133	6,551	7,416	7,129
1960	3,573	5,283	5,093	6,244
1961	4,775	6,490	5,891	9,909
1962	4,019	6,071	6,066	8,602

oceanographic conditions were similar. In both years the water in the Hawaiian Islands area warmed early (Seckel and Waldron, 1960); the total catch was above average; and Y/g was also large (table 9) even though the average number of men hooking per effective trip (both classes of vessels) was 9.6 in 1954 and 7.3 in 1959.

Richard S. Shomura (personal communication) has suggested that failure of this decline in Y/g to appear may have been the result of a change in the fishing techniques necessitated by a decrease in the number of skilled fishermen. In the past, when a fisherman caught a fish, he grasped it under his arm so that he could remove the barbless hook; he then dropped the fish on the deck. (Among local fishermen, the method is called "catch" or its Japanese equivalent "daku" which means to hold in one's arm.) A considerable amount of practice and experience is required before one develops the skill necessary to fish by this method. Another method used only occasionally in the past was "flipping," in which the fisherman swings the fish aboard and suddenly relaxes the tension of the pole to permit the hook to fall clear of the fish's mouth before it drops on the deck. (This method is sometimes called "mochikomu" which in Japanese means to bring in.) Interviews with fishermen indicated that flipping allows them to catch fish faster and does not require the same degree of skill as "catching fish under the arm," but the fishermen tire more rapidly. The shift in emphasis from catching under the arm to flipping permitted a short-handed crew of limited experience to equal or better the catch of a larger and more experienced group of fishermen. Because flipping bruises the fish, some fishermen still catch under the arm when fishing large skipjack, which bring a premium price on the fresh-fish market. Damaged fish bring lower prices.

Changes in the Efficiency of Class 1 Vessels

Fishing efficiency per vessel also increases when vessels that do poorly in the fishery are forced to stop fishing. In 1952–62, the number of Class 1 vessels actively fishing decreased from 16 to 8 (2 were wrecked and 6 stopped fishing). When Class 1 vessels were ranked according to the total catch of each vessel, the results showed that the eight vessels fishing in 1962 were usually among those that were ranked high in previous years. Because those that did poorly stopped fishing, the fishing efficiency (as measured by the average catch per effective trip) of all the remaining vessels increased. This increase in fishing efficiency also may have offset the effect of the decline in the number of men hooking per trip.

The number of Class 2 vessels reached a maximum of 14 in 1955 and declined to 12 in 1962 (1 was wrecked and 1 stopped fishing). Since only one vessel in this size class has stopped fishing, the efficiency of the class could not be expected to change markedly.

Amount of Bait Used per Effective Trip

Bait supply as well as the number of men hooking per effective trip may affect catch. It is important, then, to determine whether the larger vessels do carry and use more bait than the smaller ones. Data on bait catch (table 10) permitted investigation of this problem.

TABLE 10.—*Total buckets of bait used and amount used per effective trip by Class 1 and Class 2 Hawaiian skipjack tuna vessels, 1952–62*

Year	Class 1			Class 1		
	Total buckets of bait used	Effective trips	Buckets used per effective trip	Total buckets of bait used	Effective trips	Buckets used per effective trip
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
1952	12,202	855	14.3	11,319	692	16.4
1953	12,932	1,107	11.7	14,163	970	14.6
1954	12,592	987	12.8	15,503	899	17.2
1955	13,144	933	14.1	16,092	872	18.4
1956	12,092	931	13.0	14,588	956	15.2
1957	8,187	668	12.2	13,497	910	14.8
1958	5,721	659	8.7	10,966	865	12.7
1959	10,233	779	13.1	17,961	1,055	17.0
1960	5,748	614	9.4	10,593	931	11.4
1961	9,462	696	13.6	18,051	1,118	16.1
1962	9,315	726	12.8	14,733	935	15.8
Average	10,148	814	12.3	14,315	928	15.4

Class 2 vessels used more bait per effective trip in all years for which there were records. The 11-year unweighted averages indicated that Class 1 vessels used 12.3 buckets per effective trip compared with 15.4 buckets per effective trip by Class 2 vessels. The difference in the average number of buckets of bait used per effective trip between class 1 and Class 2 vessels was statistically significant

($t = -11.31$; $df = 10$; $p < 0.001$). We can conclude, therefore, that the amount of bait used in fishing contributed to the larger catch per effective trip among Class 2 vessels.

STANDARDIZATION OF CATCH PER EFFECTIVE TRIP

Differences between the large and the small vessels in numbers of men and in quantity of bait and hence in catching ability can complicate the estimation of apparent abundance. Rather than analyze data for the two classes of vessels separately, I have employed only one index, based on a "standard" unit of fishing effort. This unit is derived from a set of conversion factors which translate unequal fishing practices and capacities into a standard unit. For example, under conditions of equal abundance, when a small vessel makes a smaller catch than a large vessel, standardization of the effort units takes into account the differences in their fishing power. A general discussion of the problems in standardizing fishing effort may be found in Gulland (1955, 1956), in Shimada and Schaefer (1956), and in Schaefer (1963).

Efficiency Factors

The yearly Y/g of the two classes of vessels by areas permits the calculation of efficiency factors (Shimada and Schaefer, 1956). For each area the ratio of the yearly Y/g of Class 1 to that of Class 2 was computed. For example, from table 9, values of Y/g for 1952 were as follows:

Class 1: Inshore —3,586 pounds/effective trip
Offshore—3,728 pounds/effective trip
Class 2: Inshore —4,323 pounds/effective trip
Offshore—5,722 pounds/effective trip

For Class 1 vessels, the efficiency factor for inshore was 3,586/4,323 = 0.83; for offshore, it was 3,728/5,722 = 0.65. The efficiency factors for Class 2 vessels are fixed at 1.00 for all years. The mean efficiency factor for the year is the geometric mean of the inshore and offshore values. The geometric mean is appropriate for averaging ratios.

The mean efficiency factors for Class 1 vessels and the average for the 11-year period not only demonstrate the greater capability of Class 2 vessels, but also the variability of the factor (table 11). For example, if the Y/g of Class 1 vessels were some constant proportion of that for Class 2 vessels, one would expect an almost constant efficiency factor. The efficiency factors of Class 1 vessels, however, were as high as 0.86 and as low as 0.68. These values show no trend, and apparently are not related to good and poor years.

TABLE 11.—*Values of efficiency factors for Class 1 Hawaiian skipjack tuna vessels in terms of a fixed value of 1.00 for Class 2 vessels*

[These factors were used to standardize the unit of effort in 1952-62]

Year	Class 1	Year	Class 1
1952	0.74	1958	0.72
1953	.86	1959	.80
1954	.72	1960	.77
1955	.84	1961	.73
1956	.80	1962	.68
1957	.82	Average	.77

The efficiency factors by area (computed in terms of a fixed value of 1.00 for Class 2 vessels, offshore) for each vessel class (table 12) show that the values for both Class 1 and Class 2 were almost consistently smaller for inshore than for offshore fishing. The average for the 11-year period indicates that the offshore values of efficiency factors are higher than their respective inshore values. Furthermore, the mean efficiency factor for Class 1 offshore is slightly larger than that for Class 2 inshore. This result was not unexpected because efficiency factors do not take into account the ability of a vessel to visit distant areas where fish density may be higher. Al-

TABLE 12.—*Values of efficiency factors for Class 1 Hawaiian skipjack tuna vessels inshore and offshore and for Class 2 vessels inshore in terms of a fixed value of 1.00 for Class 2 vessels offshore*

Year	Class 1		Class 2
	Inshore	Offshore	Inshore
1952	0.63	0.65	0.76
1953	.58	.91	.73
1954	.42	.84	.68
1955	.62	.95	.84
1956	.60	.77	.71
1957	.74	.87	.97
1958	.49	.75	.72
1959	.72	.92	1.04
1960	.57	.85	.82
1961	.48	.65	.59
1962	.47	.70	.70
Average	.57	.80	.78

though it may appear from the values of efficiency factors in table 11 that Class 2 vessels always have better results than Class 1 vessels, the data indicate that, on the average, the offshore catches of Class 1 vessels are likely to be larger than those of Class 2 vessels fishing in inshore waters.

Catch per Standard Effective Trip

The efficiency factors, given in table 11, were used in calculating the standard unit of effort. For example, in 1952 there were 855 effective trips by Class 1 vessels and 692 by Class 2 vessels. The standard effective trip is the sum of the products of the mean efficiency factor and total number of effective trips of the size classes:

$0.74(855) + 1.00(692) = 1{,}325$ standard effective trips. The catch per standard effective trip (Y/f; the notation f refers to fishing effort expressed in standard effective trips) is found by dividing the sample catch by the standard effective trips:

$\frac{6{,}277{,}046}{1{,}325} = 4{,}737$ pounds per standard effective trip; and the fishing intensity is obtained from the total catch and Y/f:

$\frac{7{,}291{,}851}{4{,}737} = 1{,}539$ standard effective trips.

The Y/f reflects only apparent abundance based on the trips on which fish were caught. The total catch of skipjack tuna in pounds, Y/f, and relative effective fishing intensity per Class 2 trip are presented in table 13 and the index curves are illustrated in figure 8.

TABLE 13.—*Total landings of skipjack tuna in Hawaii, catch per standard effective trip, and relative effective fishing intensity, 1952–62*

Year	Total catch	Catch per standard effective trip (Class 2 trip)	Relative effectivefishing intensity (In Class 2 trips)
	Thousand pounds	*Pounds*	*Trips*
1952	7,292	4,737	1,539
1953	12,059	5,486	2,198
1954	14,021	6,983	2,008
1955	9,694	4,986	1,944
1956	11,132	6,430	1,731
1957	6,130	4,166	1,471
1958	6,834	4,850	1,409
1959	12,413	7,119	1,744
1960	7,360	5,062	1,454
1961	10,894	6,629	1,643
1962	9,415	6,358	1,481

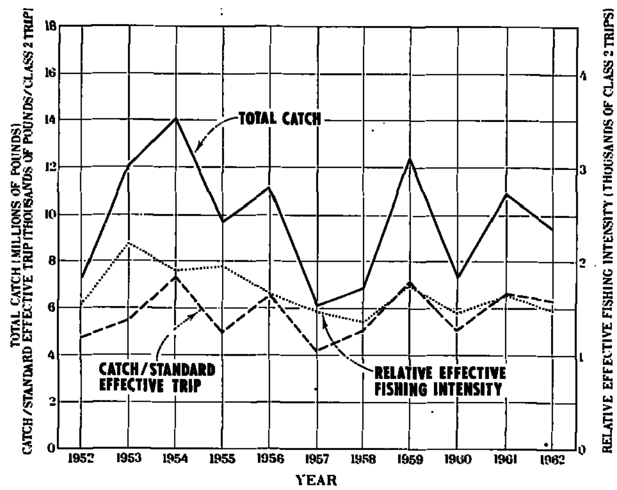

FIGURE 8.—Total catch, catch per standard effective trip, and the relative effective fishing intensity for skipjack tuna in Hawaii, 1952–62.

The curve for Y/f was at 4,737 pounds in 1952, rose in 1953 and again in 1954 to reach a peak of 6,983 pounds, then dropped to about the 1952 level in 1955. Another peak in 1956 was followed by a decline to its lowest level in 1957. The Y/f reached another peak in 1959, surpassing that of 1954. The Y/f had no trend; rather, the values varied around an average of about 5,700 pounds per standard or Class 2 trip. The relative effective fishing intensity exhibited a slight decreasing trend from about 1953 to 1958 and leveled off at about 1,600 standard trips in 1959–62.

INTERRELATION OF TOTAL CATCH, FISHING INTENSITY, AND APPARENT ABUNDANCE

The catch per standard effective trip (Y/f) and the total catch fluctuated in a similar fashion in 1952–62 ($r = 0.851$; $df = 9$; $p < 0.001$). For the 11-year period, then, the total catch may be used as an index of apparent abundance, but it should by no means be considered an appropriate index in other years. The situation may change in other years, because of the sensitivity of the total landings to various influences such as weather, sea conditions, the amount of effort expended, and the market for skipjack tuna.

The Y/f and the relative effective fishing intensity were not correlated significantly over the 11-year period ($r=0.343$; $df=9$; $p = 0.32$). The lack of correlation suggested that changes in the size of the Y/f were not influenced by changes in the amount of fishing, but by other fishery-independent factors, such as variation in availability and vulnerability; the strength of year classes also may be important (Rothschild, 1965). The effective fishing intensity tended to decline over the years under study, largely because of a decrease in the number of vessels in the fleet.

ACKNOWLEDGMENTS

Two Hawaii State Government agencies assisted in the preparation of this paper: The Division of Fish and Game of the Department of Land and Natural Resources made available all its catch statistics and interview records and the Division of Archives of the Department of Accounting and General Services permitted the use of its facilities. The Computing Center of the University of Hawaii provided technical assistance. Robert R. Parker reviewed the manuscript.

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