REEVALUATION OF FISHING EFFORT AND APPARENT ABUNDANCE IN THE HAWAIIAN FISHERY FOR SKIPJACK TUNA, *KATSUWONUS PELAMIS*, 1948-70

RICHARD N. UCHIDA[1]

ABSTRACT

Catch per effective trip, used in 1948-64 as an index of apparent abundance of skipjack tuna, *Katsuwonus pelamis*, in Hawaiian waters, is biased because effective trip, defined as one on which fish were caught, underestimates effort. Catch per day fished, calculated from data collected in 1965-70, is a refined index because effort includes days with or without catches. This paper describes the existence of a linear relationship between catch per effective trip and catch per day fished in 1965-70, and a method of estimating the latter from the former in 1948-64 based on this relationship. Fishing intensity, which was measured by standard effective trips in past studies, is calculated in standard days fished. Changes in catch per standard day fished are not associated with changes in relative fishing intensity. Skipjack tuna abundance in Hawaiian waters, therefore, is fishery independent and is probably influenced by availability and strength of year classes.

In the study of the dynamics of any exploited fish population, data on commercial catch and fishing effort can be interpreted in a number of ways, giving various estimates of apparent abundance. The ultimate objective, however, is to obtain the best possible estimate of apparent abundance.

Prior to 1965, studies on catch and effort statistics in the Hawaiian pole-and-line fishery for skipjack tuna, *Katsuwonus pelamis*, defined fishing effort as a "productive" or "effective" trip, that is, one in which skipjack tuna were caught (Yamashita 1958; Shippen 1961; Uchida 1966, 1967). Effective trip underestimated the actual amount of fishing pressure, but it was used because catch report forms used by the fishermen in 1948-65 provided no spaces for recording zero-catch trips.

Zero-catch trips should be considered as effort expended to catch fish because they include time spent searching for schools of fish. But the relative importance of search and fishing time depends on type of gear used. Gulland (1969) used whaling as an example of a fishery where the important measure was time spent searching, the gear being operational only for a few minutes. The other extreme was bottom trawling, where the important measure was time spent catching fish with the gear on the bottom and searching was minimal. Beverton and Parrish (1956) suggested that where searching *time* is important, the gear may have to be regarded as being engaged in searching for fish but giving no catch until a school is encountered. For pole-and-line fishing, where much time is devoted to searching for schools of fish, Shimada and Schaefer (1956) used the day spent on the grounds as the basic unit of fishing time.

Catch reports of 1965-70 were used to obtain two indices of skipjack tuna apparent abundance: catch per effective trip (*C/ET*), calculated from data on trips with catches, and catch per day fished (*C/DF*), calculated from total days fished including zero-catch fishing days. The purpose of this study is to determine whether a relationship exists between *C/ET* and *C/DF*. The importance of the relationship is that it affords a means of converting *C/ET* to *C/DF* for 1948-64, those years for which no data on *C/DF* exist but for which good *C/ET* information is available. A corrected measure of apparent abundance, derived from standard days fished instead of standard effective trip, is used to estimate the relative fishing intensity in 1948-70.

COLLECTION OF DATA

Data on skipjack tuna catch and fishing effort were obtained from the Hawaii State Division of Fish and Game, which collects fish catch statistics in the Hawaiian Islands. In addition, catch

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[1] Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

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and effort data were also collected routinely at the cannery by personnel of the Honolulu Laboratory, National Marine Fisheries Service. The cannery records, however, were deficient in that they did not provide information on vessels not returning to Kewalo Basin, where the cannery is located, on vessels based on neighboring islands, or on the area of operation.

Catch Reports of 1948-64

The forms for reporting skipjack tuna catch have been revised several times over the years. Essentially, all the different versions used in 1948-64 had spaces for recording the date of landings, the amount of skipjack tuna landed, and the area fished. The date of landing represented an effective trip that may have lasted from one to several days. Because Hawaiian vessels have limited cruising range, a trip usually lasts 1 day. Studies of interview data collected in 1960 showed that of 329 effective trips, 315 or 96% lasted 1 day (Uchida 1967).

Catch Reports of 1965-70

The catch report forms of 1965-70 provided spaces for recording not only the amount of skipjack tuna caught and the area fished, but also the date of each day spent on the fishing ground, a zero catch when no fish was caught, and the number of men aboard per trip. Each entry represented 1 day's fishing. In using data for these years, therefore, days with catches were assumed to be equivalent to effective trips. The sum of days with and without catches was taken as the total number of days fished.

Reporting of Zero-Catch Trips

Review of catch reports and cannery records for 1965-70 showed that some vessels occasionally failed to report zero-catch fishing days. When the number of zero-catch trips recorded in the cannery records exceeded that reported in the catch reports, the difference was assumed to be the number of unreported zero catches. Most vessels reported more zero catches in the catch reports than were recorded in the cannery records; presumably, trips were not recorded at the cannery when a vessel did not return to home port. These catch reports were assumed to be accurate.

Not all unreported zero-catch days were accounted for. In a few cases, vessels failed to indicate a zero catch in the catch report after an unsuccessful day of fishing and also failed to return to Kewalo Basin, site of the cannery and home port of the Honolulu-based fleet. Then, neither the catch report nor the cannery record showed the effort expended.

For Honolulu-based vessels, unreported zero-catch days in 1965-70 varied between 0.5 and 3.8% of the estimated annual number of days fished (Table 1). Differences between reported and estimated number of days fished were not significant ($t = 1.020$; df = 5; $P = 0.36$); therefore the few zero-catch days that went unreported should not seriously affect the data in this study.

TABLE 1.—Total days fished as reported, estimated number and percentage of zero-catch days not reported, and estimated total days fished by Honolulu-based Hawaiian skipjack tuna fishing vessels, 1965-70.

Year	Total days fished as reported (Number)	Estimated zero-catch days not reported		Estimated total days fished (Number)
		Number	Percent	
1965	1,938	10	0.5	1,948
1966	1,773	39	2.2	1,812
1967	1,678	67	3.8	1,745
1968	1,923	42	2.1	1,965
1969	1,469	54	3.5	1,523
1970	1,605	51	3.1	1,656

SOURCES OF VARIABILITY IN FISHING POWER AMONG VESSELS

Fishing power is usually calculated on the basis of a physical feature of the vessel such as gross tonnage or engine horsepower. Differences in fishing power, however, are certainly more complicated than a comparison of these physical attributes. Rothschild (1972) stated that "A considerable portion of the variability in fishing power among fishing units can be attributed to variability in skill of the fishing skipper." Fishing skill cannot be measured easily, but its influence on the fishing power of the vessels should be understood.

Variability in crew size from trip to trip also complicates the comparison of fishing power among the vessels. For example, catch reports showed that crew size in 1970 varied between 5 and 11 men per trip. Frequently, small vessels were fully crewed while large vessels operated shorthanded. The result was that some of the small vessels were outperforming the larger ones in some years.

ANALYTICAL PROCEDURES

In the sections that follow, the procedures used in grouping vessels and fishing areas and in treating the data are discussed.

Classes of Vessels

The difficulties that arise from differences in fishing power among the vessels may be reduced by separating them into relatively homogeneous classes, using physical features such as gross tonnage. It is convenient, therefore, to determine which of the physical features of the vessels is, on the average, proportional to fishing power, and to use it to group the vessels into classes.

In a study covering the period 1952-62, the vessels were grouped into two size classes according to their bait-carrying capacities. Class 1 vessels had capacities up to 3,000 liters per baitwell whereas class 2 vessels had capacities greater than that (Uchida 1967). But the ability of class 2 vessels *to catch more fish* than class 1 vessels is not necessarily a permanent characteristic. Although baitwell capacity was a good measure of fishing power in the 1952-62 study, it did not reflect fishing power of the vessels *satisfactorily* after 1962. In 1963-70, some vessels with small bait capacities had catch rates as high as or higher than those with larger capacities. Reevaluation of the data showed that gross tonnage provided a better approximation of vessel performance. *C/ET* and bait capacity were correlated significantly in 8 out of 11 yr in 1952-62, but only in 2 out of 8 yr in 1963-70 (Table 2). Correlation between *C/ET* and gross tonnage, on the other hand, was significant not only in 8 yr in 1952-62, but also in 6 yr in 1963-70. For this study, therefore, vessels of 27 to 44 gross tons were called class 1 and those of 45 to 77 gross tons were called class 2. The selection of the division point between class 1 and class 2 vessels was based on the tendency of *C/ET*, when plotted against gross tonnage, to be closely grouped among class 1 vessels for almost all the years examined. In contrast, *C/ET* of class 2 vessels varied widely in most years.

The relationship of fishing power to vessel age and to bait usage cannot be overlooked. Among 8 class 1 vessels fishing in 1963-70, only 1 was built after World War II whereas 9 out of 12 class 2 vessels fishing in 1963-70 were built after the war. The relative comfort and reliability of most class 2 vessels undoubtedly accentuated the relation between fishing power and tonnage by attracting better captains and fishermen. Also, the difference between vessel classes in the amount of bait used was pronounced. Whereas class 1 vessels used an average of 8.3 buckets of bait per day fished, class 2 vessels averaged 12.3 buckets.

TABLE 2.—Correlation coefficients of *C/ET* on baitwell capacity and on gross tonnage of Hawaiian skipjack tuna fishing vessels, 1952-70. A single asterisk denotes probabilities between 0.05 and 0.01; two asterisks denote probabilities equal to or less than 0.01.

Year	df	Correlation coefficient of *C/ET* on baitwell capacity	Correlation coefficient of *C/ET* on gross tonnage
1952	23	0.326	0.387
1953	23	0.306	0.275
1954	24	0.602**	0.463*
1955	26	0.498**	0.490*
1956	24	0.390*	0.318
1957	23	0.461*	0.457*
1958	21	0.625**	0.678**
1959	18	0.721**	0.669**
1960	19	0.477*	0.464*
1961	19	0.462*	0.499*
1962	17	0.356	0.528*
1963	18	0.703**	0.757**
1964	18	0.403	0.596**
1965	17	0.368	0.327
1966	15	0.400	0.531*
1967	15	0.593*	0.521*
1968	14	0.434	0.529*
1969	13	0.382	0.516*
1970	13	0.510	0.447

Each year in the Hawaiian fishery the same few vessel captains vie for the distinction of being captain of the "top boat." Variability in skill among captains, therefore, complicated the comparison of fishing power among vessels. Furthermore, captains and crew frequently shifted from one vessel to another, taking their fishing skills with them. In 1965-70, for example, a minimum of nine vessels changed captains and the transfer of a highly regarded captain usually involved the transfer of part of his former crew. The shifting of personnel caused some high-producing vessels to become low- or marginal-producers.

Fishing Areas

After the establishment of the vessel classes, the data within each size class were then grouped into inshore and offshore fishing areas. In the Hawaiian fishery, the deployment of fishing effort and the resulting catches are recorded according to a statistical area system that was established for Hawaiian waters by the Hawaii State Division of Fish and Game in 1947 (Uchida 1970). Basically, three general areas are recognized. The first extends from the coastline to just outside the reef, a distance of about 4 km, and the second extends from 4 to 37 km. Combined and called inshore for this study, these two areas are made up of relatively small statistical areas of unequal sizes. It has been estimated that about 80% of the effort and 75% of the skipjack tuna catch are concentrated within these areas (Uchida 1967). Beyond 37 km is the third area, called offshore here; the statistical divisions within it are large and nearly equal in size.

The inshore fishing ground, restricted to waters within 37 km of the coastline, covered roughly 69,000 km². The offshore ground, on the other hand, was restricted only by the range of the vessels, and varied from year to year. In 1948-65, the vessels covered 111,000 km² in their offshore fishing, but many distant offshore areas were visited in only 1 or 2 yr over this period. The offshore areas visited most frequently totaled roughly 69,600 km².

Comparison of Catch Per Effective Trip and Catch Per Day Fished

The monthly catches of skipjack tuna in 1965-70, separated into inshore and offshore areas within each vessel size class, were divided by two different units of effort. One was the number of days with catches, which was assumed to be equivalent to effective trips; and the index derived was *C/ET*. The other was the total number of days fished, which included days of fishing with and without catches; and the index was *C/DF*. The assumption that days with catches was equivalent to effective trips appears justified; Uchida (1967) showed that 96% of the effective trips lasted 1 day.

Figure 1 illustrates the relationship of the monthly *C/DF* (*Y*) against *C/ET* (*X*) calculated for class 1 and class 2 vessels fishing the inshore and offshore areas in 1965. The least squares regression of *Y* on *X* resulted in a close linear fit with the regression line having an angle of 45°.

A good fit between *C/ET* and *C/DF* can be expected because both indexes are small when fishing is poor and large when fishing is good. In Hawaiian waters, periods of high tuna apparent abundance are characterized by the presence of larger schools and more frequent encounters between vessels and fish schools (Uchida and Sumida 1971).

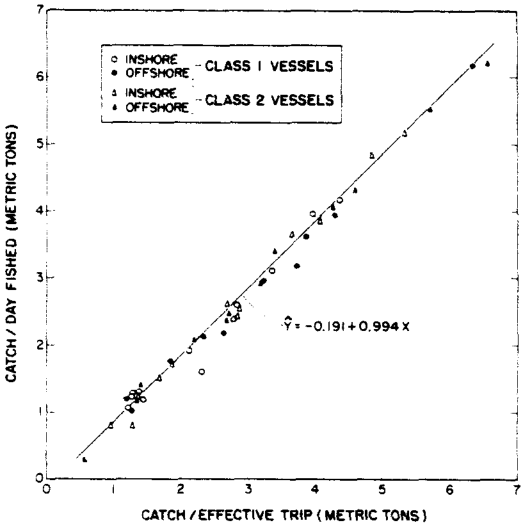

FIGURE 1.—Relationship between catch per effective trip and catch per day fished of Hawaiian skipjack tuna vessels, by areas fished, January-December 1965.

Homogeneity of Data

At the outset of the study, it was decided that one regression equation should be calculated for each area within the size classes. The resulting equations could then be used to estimate *C/DF* from *C/ET* for 1948-64. The decision to calculate one equation for each area by pooling the data for 1965-70 is appropriate, because the data included those years for which skipjack tuna catches from Hawaiian waters were the lowest (1969) and highest (1965) on record. Including data from these 2 yr should provide sufficient low and high values to determine accurately the slope and level of each regression line.

Pooling is appropriate when the samples are homogeneous; therefore, it was necessary to test the hypothesis of homogeneity. Statistical testing of the data, discussed in the following sections, was confined to only one index, *C/ET*, because of the close association between *C/ET* and *C/DF*.

The tests for homogeneity showed that yearly variances of inshore *C/ET* among class 2 vessels differed significantly ($\chi^2 = 11.92$; df = 5; $P<0.05$). A plot of the yearly means and standard deviations, shown in Figure 2A, indicated that they were significantly correlated ($r = 0.883$; df = 22; $P<0.01$). Furthermore, the distribution of *C/ET* was skewed because of many low and few high

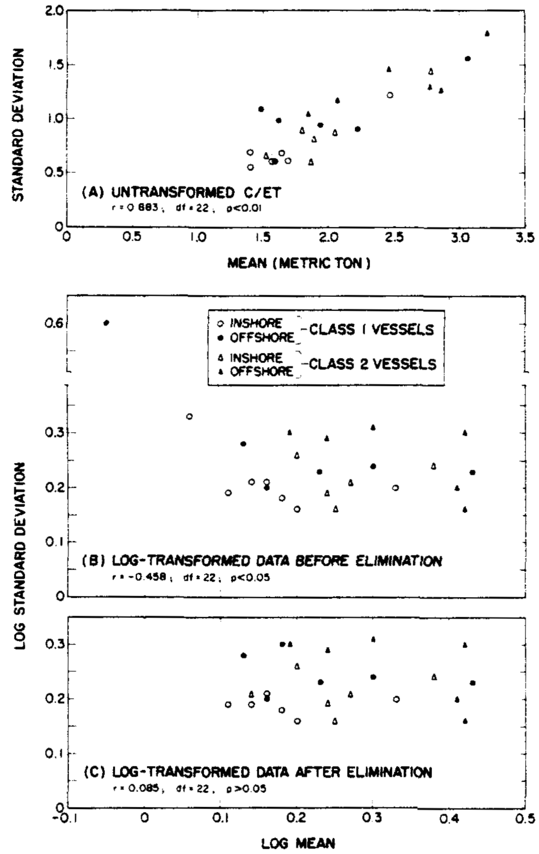

FIGURE 2.—Relationship between mean and standard deviation of catch per effective trip, before and after logarithmic transformation and elimination, by vessel size classes and areas, 1965-70.

values. Because the application of routine statistical procedures requires a normal distribution and independence of the mean and standard deviation, a transformation of the data was required. A logarithmic transformation was selected because the standard deviations tended to be proportional to their means (Figure 2A).

Transformation of the Data

A logarithmic transformation has several theoretical advantages in analyzing catch data (Murphy and Elliott 1954; Gulland 1956). Usually the transformation tends to stabilize the variances and make them independent of the mean. Furthermore, the random components tend to be independently and normally distributed about zero mean and with a common variance.

After the transformation, the means and standard deviations continued to be significantly but negatively correlated ($r = -0.458$; df = 22; $P<0.05$). Examination of the transformed data revealed that there were two points (Figure 2B) that were aberrant and diverged from the cluster of other points. These points represented data for class 1 vessels fishing offshore in 1969 and inshore in 1970. The original monthly catch data showed that the catch rates were affected by very low *C/ET*, all of which were 0.15 MT (metric ton) or less. These catch rates fell close to or beyond $\mu \pm 3\sigma$ and their elimination from subsequent analysis reduced the correlation between the means and standard deviation (Figure 2C) and stabilized the variances ($r = 0.058$; df = 22; $P>0.05$). Tests for homogeneity of variances also indicated that the transformed data for all years could now be grouped by areas within size classes.

Figure 3 shows the frequency distribution and fitted normal curve of the deviations from the mean of log *C/ET* for each area within the size classes. None of the histograms departed significantly from normality when chi-square tests were applied. Therefore, the fit of the normal curve is as good as can be expected (χ^2 ranged from 2.18 to 7.59; $P<0.05$).

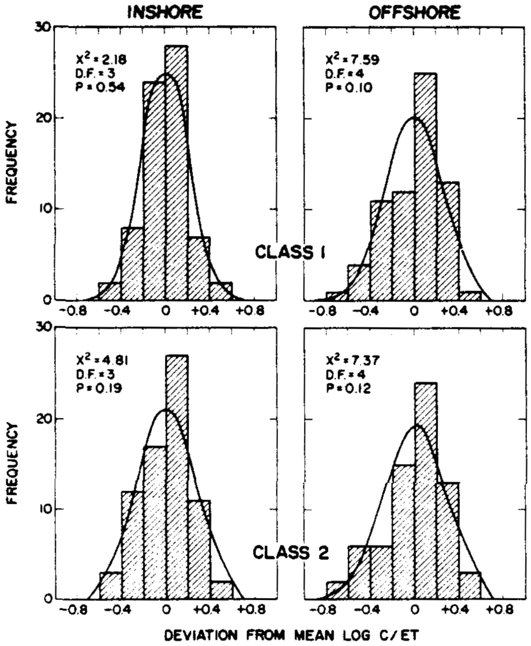

FIGURE 3.—Frequency distribution and fitted normal curve of the deviations from the mean of log C/ET.

Differences in Log Catch Per Effective Trip Between Vessel Classes, Between Areas, and Among Years

A factorial analysis of variance in a randomized complete-block design was used to test whether significant differences occurred in log *C/ET* between vessel classes (blocks), and between areas and among years (main treatment effects). The analysis showed that log *C/ET* with respect to the two vessel classes differed significantly (F = 12.34; df = 1 and 265; $P<0.01$). Significant differences in log *C/ET* also occurred with respect to inshore and offshore areas fished (F = 9.38; df = 1 and 5; $P<0.05$). Furthermore, the results showed significant differences occurred among years fished (F = 9.45; df = 5 and 5; $P<0.05$). A Duncan multiple-range test (Steel and Torrie 1960), with Kramer's (1956) extension of the test, determined that a significant difference in the means occurred primarily between 1965 and 1969, years in which there were considerable differences in fishing conditions.

Relation Between Log Catch Per Day Fished and Log Catch Per Effective Trip

Log *C/DF* increased linearly with log *C/ET* in each of the areas within the size classes. Regression lines, fitted to the data pooled for 1965-70, showed that the scatter about the regression lines was relatively narrow; there were, however, a few observations in each set of data that appeared to have large residuals. To assess the validity or appropriateness of the least-squares fitting of log *C/DF* on log *C/ET*, these residuals were analyzed.

Figure 4 shows the scatter diagrams in which the residuals were plotted against log *C/ET* for the four sets of data. With the exception of a few outliers which can be seen as isolated points with extreme negative ordinates, there were no noticeable peculiarities in the distribution of the residuals. The outliers were rejected at a multiple of the standard deviation using a premium of 2.5% (see Anscombe and Tukey 1963). The overall distribution of the residuals after the rejection procedure appeared in the form of a horizontal band, which indicated that the least-squares analysis of the log transformed data was satisfactory.

After the rejection of large residuals, regression lines were fitted to the data as shown in Figure 5. The dashed lines on either side of the regression lines indicate the 95% confidence limits for the estimates of log *C/DF*. The values of the regression equation and correlation coefficient of log *C/DF* on log *C/ET* are given in Table 3.

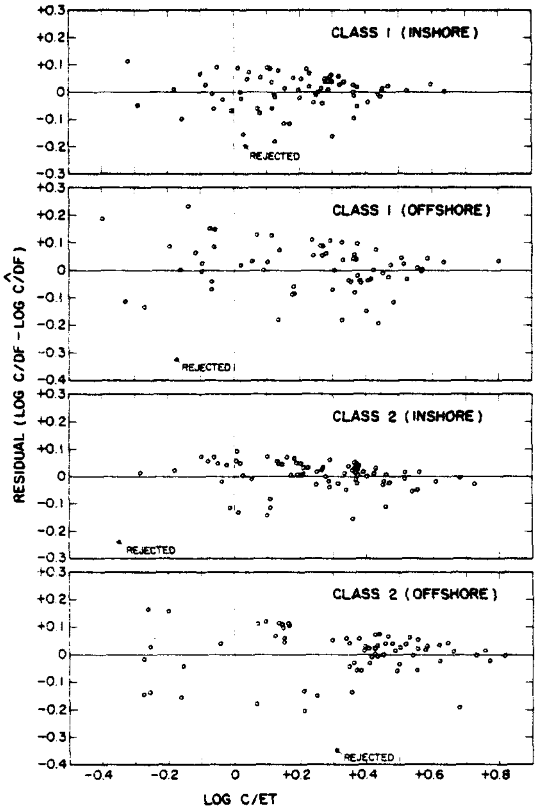

FIGURE 4.—Plots of residuals (log C/DF − log $\widehat{C/DF}$) against log C/ET for class 1 and class 2 vessels fishing inshore and offshore in 1965-70.

Substitution of values of log a and b into the logarithmic equation $\log_{10} C/DF = \log_{10} a + b \log_{10} C/ET$ and solution of the equation provided estimates of *C/DF* from *C/ET*, by month, for

TABLE 3.—Data on the regression and correlation of $\log_{10} C/DF$ on $\log_{10} C/ET$ in the Hawaiian skipjack tuna fishery, by vessel size classes and areas, 1965-70. Two asterisks denote probabilities equal to or less than 0.01.

Vessel size class	Area	$\text{Log}_{10} a$	b	r	df
1	Inshore	−0.11566	1.13915	0.963**	68
	Offshore	−0.12549	1.08370	0.954**	64
2	Inshore	−0.10342	1.13340	0.976**	69
	Offshore	−0.12268	1.13120	0.968**	66

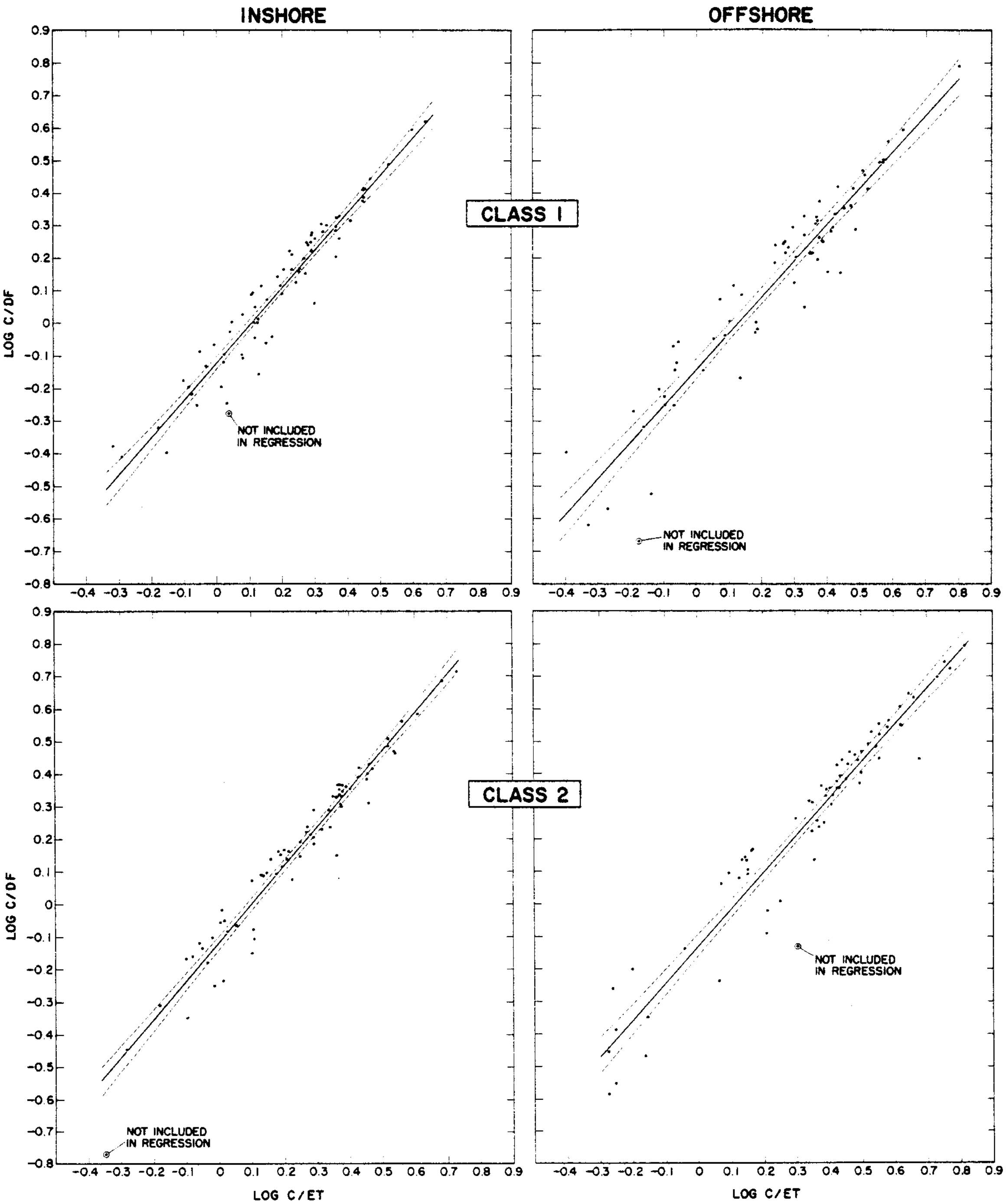

FIGURE 5.—Regression of log C/DF on log C/ET for class 1 and class 2 vessels fishing inshore and offshore in 1965-70.

TABLE 4.—Estimating the number of days fished among class 1 vessels fishing in the inshore area, January-December 1948.

Month	Catch (MT)	Effective trips (No.)	C/ET (MT)	$\log_{10} C/ET$	$\log_{10} C/DF$	Calculated C/DF (MT)	Estimated days fished (No.)
January	205.48	77	2.66857	0.42627	0.36993	2.34388	88
February	108.87	73	1.49137	0.17358	0.08207	1.20803	90
March	59.33	72	0.82403	−0.08405	−0.21141	0.61458	96
April	76.91	99	0.77687	−0.10965	−0.24057	0.57468	134
May	133.94	119	1.12555	0.05136	−0.05714	0.87669	153
June	285.80	154	1.85584	0.26854	0.19024	1.54970	184
July	352.30	147	2.39660	0.37959	0.31675	2.07374	170
August	239.72	120	1.99767	0.30052	0.22668	1.68531	142
September	191.07	104	1.83721	0.26415	0.18525	1.53199	125
October	101.31	81	1.25074	0.09716	−0.00497	0.98861	102
November	49.59	44	1.12704	0.05194	−0.05649	0.87802	56
December	19.26	25	0.77040	−0.11328	−0.24470	0.56923	34
Total	1,823.58	1,115					1,374

1948-64. For example, Table 4 shows the data used in the computations and the results obtained among class 1 vessels fishing the inshore area in 1948. C/ET was derived from the equation,

$$C/ET \text{ (col. 3)} = \frac{\text{Monthly catch (col. 1)}}{\text{Number of effective trips (col. 2)}}$$

and converted to logarithms (col. 4). Log C/DF (col. 5) was derived from the equation,

$$\log C/DF = \log a + b \log C/ET$$

and converted to C/DF (col. 6). Days fished were estimated from the equation,

$$\text{Days fished (col. 7)} = \frac{\text{Monthly catch (col. 1)}}{C/DF \text{ (col. 6)}}.$$

Standardization of Catch Per Day Fished

A method of standardizing effort of different size classes of vessel has been discussed by Shimada and Schaefer (1956) for the eastern Pacific yellowfin and skipjack tuna fishery. I used a similar method to estimate relative fishing power of class 1 vessels in the Hawaiian fishery so that their unit of effort was comparable to that of class 2 vessels, which were selected as the standard size class (Uchida 1966, 1967). Briefly, the method involves the use of correction or efficiency factors that are calculated from C/DF of the vessel size classes. Efficiency factors adjust the fishing effort of one size class to that of a standard class. For example, under conditions of equal abundance, the class 1 vessels can be expected to produce a smaller catch than the class 2 vessels. From the catches of the two classes, the fishing power of class 1 vessels can be determined relative to class 2, the standard class, for a given fishing area.

To illustrate the calculation of efficiency factors and the standard unit of effort, the annual C/DF given in Table 5 by vessel size classes and areas were used. In 1948, the efficiency factor for class 1 vessels fishing inshore was 1.33/1.78 = 0.747 and for offshore was 2.07/3.46 = 0.598. The efficiency factors for class 2 vessels were fixed at 1.000 for all years. The mean efficiency factor, 0.668, is the geometric mean of the inshore and offshore values. The geometric mean is appropriate for averaging ratios.

Varying from 0.59 to 0.82 (rounded) and averaging 0.71 in 1948-70, the efficiency factors demonstrated not only the greater capability of class 2 vessels, but also the wide variability of the factors from year to year. There was no evidence that the efficiency of class 1 vessels increased or decreased relative to class 2 vessels. Therefore, neither the efficiency of the standard class nor that of class 1 vessels has been altered by the loss of the less efficient or marginal vessels.

MEASURES OF APPARENT ABUNDANCE AND FISHING INTENSITY

Estimate of the apparent abundance of skipjack tuna on the fishing grounds, expressed as catch per standard day fished (C/SDF), can be calculated from efficiency factors and the total number of days fished for each of the two classes of vessels. For example, in 1948 there were an estimated 1,444 fishing days among class 1 vessels and 829 days among class 2 vessels. The standard days fished is the sum of the products of the mean efficiency factor and the total number of fishing days of the size classes. C/SDF is found by,

TABLE 5.—Catch per day fished inshore and offshore among class 1 and class 2 vessels, class 1 efficiency factors, and their geometric mean, 1948-70.

	Inshore			Offshore			
Year	Class 1	Class 2	Efficiency factors	Class 1	Class 2	Efficiency factors	Geometric mean
1948	1.33	1.78	0.747	2.07	3.46	0.598	0.668
1949	1.56	2.24	0.696	2.54	4.12	0.616	0.655
1950	1.34	1.74	0.770	2.10	3.38	0.621	0.692
1951	1.64	2.59	0.633	2.60	3.58	0.726	0.678
1952	1.31	1.66	0.789	1.31	2.19	0.598	0.687
1953	1.53	1.98	0.773	2.37	2.69	0.881	0.825
1954	1.36	2.54	0.535	2.89	3.80	0.760	0.638
1955	1.39	1.99	0.698	2.08	2.32	0.896	0.791
1956	1.90	2.36	0.805	2.30	3.27	0.703	0.752
1957	1.18	1.63	0.724	1.28	1.61	0.795	0.759
1958	1.17	1.87	0.626	1.79	2.36	0.758	0.689
1959	1.97	3.03	0.650	2.37	2.91	0.814	0.728
1960	1.32	2.02	0.653	1.94	2.40	0.803	0.727
1961	1.82	2.37	0.768	2.42	4.05	0.598	0.677
1962	1.49	2.45	0.608	2.22	3.43	0.647	0.627
1963	1.17	1.77	0.661	1.87	3.55	0.527	0.590
1964	1.40	1.69	0.828	2.07	2.90	0.714	0.769
1965	2.39	2.90	0.824	3.32	4.01	0.828	0.826
1966	1.54	1.82	0.846	1.93	2.91	0.663	0.749
1967	1.47	1.84	0.799	1.65	2.31	0.714	0.755
1968	1.57	1.68	0.934	2.04	2.93	0.696	0.807
1969	1.12	1.43	0.783	1.58	2.26	0.699	0.740
1970	1.32	1.74	0.759	1.30	2.36	0.551	0.646

$$C/SDF = \frac{TC_1 + TC_2}{(EF)\,(DF_1) + DF_2}$$

where TC_1 = total catch of class 1 vessels,
TC_2 = total catch of class 2 vessels,
EF = efficiency factor,
DF_1 = days fished among class 1 vessels, and
DF_2 = days fished among class 2 vessels.

In 1948-70, C/SDF of skipjack tuna in Hawaiian waters ranged from a low of 1.61 MT in 1957 to a high of 3.29 MT in 1965, but no trend with time was discernible (Table 6; Figure 6).

Relative fishing intensity is estimated from C/SDF and the total state catch, which includes catches of part-time as well as full-time vessels:

$$\text{Relative fishing intensity} = \frac{TC_s}{C/SDF}$$

where TC_s = total state catch.

When examined over the 23-yr period, fishing intensity did not decrease appreciably despite a gradual decrease in the number of vessels fishing from a maximum of 28 in 1951 to 15 in 1970. With a reduction in the fleet, which occurred primarily among the older class 1 vessels, fishing intensity would be expected to decline, but it did not. The reason was that the average days fished per vessel per year increased. Class 1 vessels fished an average of 86.1 days per vessel in 1948-58 when their numbers declined from 15 to 10 vessels and 121.2 days in 1959-70 when their numbers further decreased from 8 to 4 vessels (Figure 7). Class 2 vessels have not decreased in number drastically, declining from 14 in 1955 to 11 in 1970. Averaging 86.9 days fished prior to 1964, class 2 vessels subsequently averaged 119.8 days per year.

INTERRELATION OF TOTAL CATCH, FISHING INTENSITY, AND APPARENT ABUNDANCE

The total catch of skipjack tuna, given in Table 6 and shown in Figure 6, fluctuated with C/SDF in a similar fashion in 1948-70 (r = 0.902; df = 21; $P<0.01$). For the years studied, then, total catch may be satisfactory as a gross index of changing apparent abundance but may not be suitable in future years because it is obviously sensitive to changes in demand or fishing effort, competition from other fisheries, and economic constraints upon the fishery.

Changes in C/SDF are not associated with changes in fishing intensity (r = 0.302; df = 21; $P>0.05$); therefore, the apparent abundance of skipjack tuna in Hawaiian waters is not influenced by changes in the amount of fishing effort expended, but by fishery-independent factors such as variations in availability, which in turn is related to changes in the fishes' habits or

TABLE 6.—Total landings in metric tons (MT) of skipjack tuna in Hawaii, catch per standard day fished, relative fishing intensity, catch per standard effective trip, and relative effective fishing intensity, 1948-70.

Year	Total catch (MT)	Catch per standard day fished (MT)	Relative fishing intensity (Class 2 days)	Catch per standard effective trip (MT)	Relative effective fishing intensity (Class 2 trips)
1948	3,802.96	2.01	1,891	2.30	1,653
1949	4,488.23	2.53	1,773	2.85	1,575
1950	4,314.38	1.99	2,161	2.31	1,868
1951	5,863.37	2.93	2,001	3.28	1,788
1952	3,307.58	1.83	1,806	2.15	1,538
1953	5,470.15	2.14	2,552	2.46	2,224
1954	6,360.13	2.81	2,256	3.16	2,013
1955	4,397.43	1.95	2,248	2.26	1,946
1956	5,049.58	2.59	1,946	2.91	1,735
1957	2,780.66	1.61	1,726	1.90	1,464
1958	3,100.15	1.87	1,652	2.18	1,422
1959	5,630.65	2.93	1,919	3.26	1,727
1960	3,338.46	1.99	1,673	2.30	1,452
1961	4,941.66	2.69	1,835	3.01	1,642
1962	4,270.81	2.56	1,665	2.88	1,483
1963	3,673.86	2.15	1,712	2.48	1,481
1964	4,093.10	1.98	2,065	2.29	1,787
1965	7,328.96	3.29	2,221	3.54	2,070
1966	4,256.82	2.24	1,896	2.52	1,689
1967	3,646.80	1.99	1,832	2.30	1,586
1968	4,227.41	2.04	2,067	2.32	1,822
1969	2,704.94	1.63	1,658	2.02	1,339
1970	3,334.46	1.89	1,760	2.19	1,523

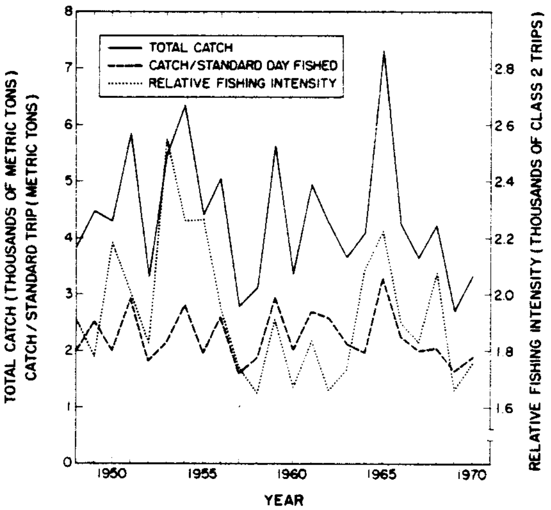

FIGURE 6.—Total catch, catch per standard day fished, and the relative fishing intensity for skipjack tuna in Hawaii, 1948-70.

in the environment, and to the strength of the year classes.

Catch per standard effective trip (*C/SET*) and relative effective fishing intensity, the two indices used in previous studies (Uchida 1966, 1967, 1970), are also given in Table 6. As expected, both *C/SDF* and *C/SET* fluctuated similarly in 1948-70 (r = 0.998; df = 21; P<0.01). Likewise the correlation between relative fishing intensity and relative effective fishing intensity was significant, indicating that changes in one paralleled changes in the other (r = 0.982; df = 21; P<0.01). It can be concluded that although the use of effective trips in previous studies produced biased results, which deviated from more precise estimates calculated from days fished, its use did

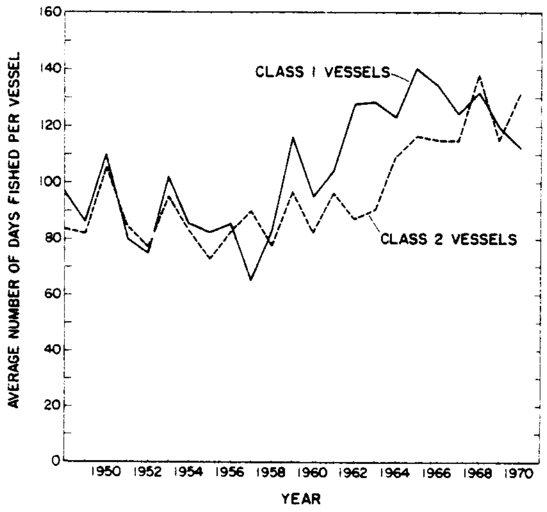

FIGURE 7.—Average number of days fished per vessel per year among class 1 and class 2 Hawaiian skipjack tuna vessels, 1948-70.

not lead to faulty conclusions about the status of the Hawaiian skipjack tuna fishery. The only serious bias appears to be that fluctuations in the *C/SET* were slightly exaggerated and those in effective fishing intensity were dampened.

SUMMARY

The existence of a linear relationship between catch per effective trip and catch per day fished in 1965-70 was described. Based on this relationship, catch per day fished was estimated from catch per effective trip for 1948-64.

Efficiency factors were used to standardize fishing effort of class 1 vessels to that of class 2. The data showed that in 1948-70, efficiency factors for class 1 vessels remained constant relative to class 2 vessels. Fishing intensity, calculated in standard days fished, did not decline over the 23-yr period despite the gradual decrease in the number of vessels fishing. Data from the catch reports showed that in the face of this decline in fleet size, the remaining vessels increased effort by fishing more frequently.

Total catch correlated significantly with *C/SDF*; therefore, it was a good gross indicator of skipjack tuna apparent abundance. Evidence supported the conclusion that in Hawaiian waters, skipjack tuna apparent abundance was not influenced by changes in the amount of fishing effort expended but by fishery-independent factors. And although effective trips as a measure of fishing pressure in previous studies underestimated effort and, therefore, provided a biased estimate of skipjack tuna apparent abundance in the Hawaiian fishery, its use did not lead to faulty conclusions.

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