VARIABILITY OF LONGLINE CATCHES OF YELLOWFIN TUNA

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Explanatory Note

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VARIABILITY OF LONGLINE CATCHES OF YELLOWFIN TUNA

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INTRODUCTION

A fundamental problem in inferring the density of a population from a sample or series of samples is the estimation of the magnitude and sources of variability inherent in the samples. Variability may arise from the way the population is distributed in space and from imperfections in the sampling method. The purpose of this paper is to provide a method of estimating the reliability with which longline[1] catches of yellowfin tuna[2] represent the relative abundance of the population.

As a prelude to estimating the variability of the longline catches we will first examine the way in which yellowfin are distributed in space. This will be followed by an empirical examination of the distribution of the catches in order to ascertain a transformation that will permit the application of conventional statistical methods. Finally, the variance will be estimated as a basis for establishing fiducial limits.

SOURCES OF DATA

The catch data used in this study of variability are from two sources: records of Japanese commercial fishing in the western equatorial Pacific in 1950 and 1951, and records of fishing conducted by U. S. Fish and Wildlife Service research vessels in the central Pacific in 1951 and 1952. The principal differences between the two types of data are: (1) The commercial vessels fished around 2,000 hooks along 50 miles of line while the research vessels fished only 240-480 hooks along 5-10 miles of line. (2) The commercial vessels, fishing in fleets, made many sets in particular areas while the research vessels, operating singly, made single sets of gear at stations spaced as much as 90 miles apart. (3) The records of the commercial fishery contain only total catch and total amount of gear for each set, whereas the records of the research operation include these data and other details including the catch of each hook along the line.

1/ The longline is used commercially to catch tunas and marlins in the Pacific Ocean by Japanese fishermen (Shapiro 1950) and by American fishermen in Hawaii (June 1950). It is also used by American fishery research organizations such as the Pacific Oceanic Fishery Investigations of the U. S. Fish and Wildlife Service to ascertain the abundance of deep swimming tunas and marlins in areas not supporting commercial fisheries.

2/ *Neothunnus macropterus* (Temminck and Schlegel)

DISTRIBUTION OF THE YELLOWFIN IN SPACE

The aspect of yellowfin distribution in space that bears on the problem of sampling variability is the presence or absence of aggregation or schooling, for this affects the variability and determines the type of statistical distribution that fits the catches. There is no direct evidence on the social habits of yellowfin when they swim at the depths fished by the longline (200 to 600 feet according to Murphy and Shomura 1953), but they are known to form relatively compact schools at the surface. Our first approach to the problem of schooling or non-schooling involves examination of the location of hooked fish along the line to ascertain whether the catch is randomly distributed or whether it is grouped. The second approach is to compare the relative variability between yellowfin and black marlin catches. This comparison depends on the probability that marlin are not schooled when they swim at subsurface levels because they are generally seen singly at the surface (Nakamura 1949).

Determination of schooling or non-schooling of yellowfin by analysis of the distribution of the catches along the line is analogous to a study of disease in plants that are growing in a row. If the diseased plants are scattered at random the interpretation would be that there is no evidence of contagion (Swed and Eisenhart 1943). Similarly, if the tuna catch is randomly distributed there is no evidence of schooling. An analysis of sequences (Mood 1950) is appropriate to ascertain whether the distribution of hooked yellowfin is random. This involved determining from the total number of hooks and the total catch of yellowfin the most probable number of runs of hooks alike with respect to their bearing or not bearing fish.[3/] If the tuna are schooled, there should be more instances

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3/ A run is defined as consisting of any number of consecutive hooks uniform with respect to occupancy or non-occupancy by fish and bounded at both extremes by changes in this respect. Thus the minimum possible number of runs in a longline set, which is one, would be achieved either by having a fish on every hook, or by having no catch at all. Conversely, the maximum possible number of runs would result from having a fish caught on every alternate hook. In this case the total number of runs would equal the number of hooks in the set, and each of the runs would comprise a single hook.

of two or more fish occupying adjacent hooks than if the tuna were randomly distributed in space, thus reducing the number of runs. A "t" test is used to estimate whether the actual number of runs is significantly different from the most probable number.

The distribution of hooked yellowfin along the line was studied for one cruise (Smith cruise 11)[4/], selected because the mean catch rate was high and also nearly identical in all portions of the line, whereas during most cruises the portion of the line removed from the water last had a higher catch rate than those portions removed earlier. There were 28 fishing stations during Smith cruise 11, but only 15 of these could be used for the anlysis (table 1) because the technique required a minimum catch of 11 yellowfin. Nine of the 15 stations had fewer runs than expected, and 6 had more runs than expected. Of the 9 with fewer runs, 5 had significantly fewer, and in 3 of the 5 the numbers were highly significantly less than was to be expected from a random distribution. In contrast, none of the 6 positive deviations were significant. There is, then, considerable evidence that there were fewer runs than would be expected from a non-schooling population.

The tendency to school is probably greater than this evidence indicates, because the following four factors tended to obscure the manifestation of schooling: (1) About 15 percent of the hooks were occupied by fish other than yellowfin, and if a hook were occupied by some other species before a school of yellowfin chanced on the line, a potential single run might be split into three runs, thus increasing the number of runs by two. (2) There were 60 fathoms between adjacent hooks of two consecutive baskets, whereas hooks within a

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4/ The line used on this cruise was made up of 40 baskets or "skates" of gear essentially as described by Niska (1953), and fished in a manner described by Murphy and Shomura (1953). Briefly, each set consisted of a connected series of 40 main lines supported in the water by a buoy at each connection. Attached to each main line were six evenly spaced hooks. In effect the set of gear in the water resembled a series of 40 catenaries, and since the hook lines were equal in length, the hooks within each basket were fishing at different levels.

Table 1. Analysis of the number of runs of yellowfin tuna on 240-hook (40-basket) sets of longline gear (Smith cruise 11)

Station	Number of tuna (n_1)	Number of hooks without tuna (n_2)	Total number of hooks 1/ ($n = (n_1 + n_2)$)	Actual number of runs (d)	Most probable number of runs ($2n\alpha\beta$)	$t = \frac{d - 2n\alpha\beta}{2\alpha\beta\sqrt{n}}$
1	23	217	240	29	41.59	-4.690**
2	12	226	238	25	22.79	+1.496
3	38	201	239	63	63.92	-0.222
4	25	215	240	37	44.79	-2.695**
5	19	221	240	35	34.99	+0.004
6	37	201	238	65	62.50	+0.618
7	17	220	237	33	31.56	+0.702
8	42	191	233	65	68.86	-0.855
9	25	200	225	27	44.44	-5.889**
10	11	228	239	19	20.99	-1.463
11	20	218	238	35	36.64	-0.690
12	30	206	236	45	52.37	-2.163*
13	15	221	236	29	28.09	+0.496
14	71	167	238	104	99.64	+0.675
15	31	203	234	47	53.79	-1.930*
Pooled	416	3135	3551	658	706.95	-4.127

1/ Data on variations in the numbers of the original 240 hooks were unobtainable. In the analysis they were treated as nonexistent.

* Significant at .05 level.
** Significant at .01 level.

basket were separated by only 30 fathoms. (3) The hooks were not all fishing at the same depth and this decreases the chance of a school's leaving more than one of its members on the line unless there is a considerable vertical component to the shape of a school. (4) Whenever a tuna or other fish takes a bait without becoming hooked a potential sequence of yellowfin is broken. It seems almost certain that had these four factors been absent the number of runs would have deviated even more from the expected number. This lends qualitative support to the conclusion that the subsurface yellowfin are aggregated rather than randomly distributed in space.

Providing an additional test of schooling or aggregation of yellowfin is a comparison of the variability of black marlin and yellowfin tuna catches made on the same gear at the same time and place. The basis for this comparison is the assumption that the degree of variability of the catch of any species increases with the degree of aggregation of that species. Black marlin are not a schooling species while at the surface, whereas yellowfin are usually aggregated into compact schools. If these contrasting behaviours are retained when the fish occupy deeper levels, there should be a difference in the relative variability of the catches.

A comparison of the variability of black marlin and yellowfin catches is given in figure 1, where each point is based on a catch from the approximately 2,000 hooks comprised in one set of longline gear. It is at once apparent that the yellowfin catches are much more variable than those of the marlin, though the catch rates per 100 hooks are nearly equal.

Numerical expression of this difference in variability has been obtained by testing the frequency distribution of the catches against a Poisson distribution appropriate to the mean catch rates, following the method of Snedecor (1948). The test of the yellowfin catches for the period October 2-10 (selected for relative homogeneity in catch rate), with a catch rate of .454 fish, yielded a chi-square of 47 with a P of less than .000001. On the other hand a similar test of the marlin catches for the period October 2-12, with an average rate of .656, yielded a chi-square of only 11, P of .03. Thus the marlin catches differ only slightly, though significantly, from the Poisson distribution, whereas the yellowfin catches do not even approach conformance with the Poisson, indicating that some factor is introducing great variability.

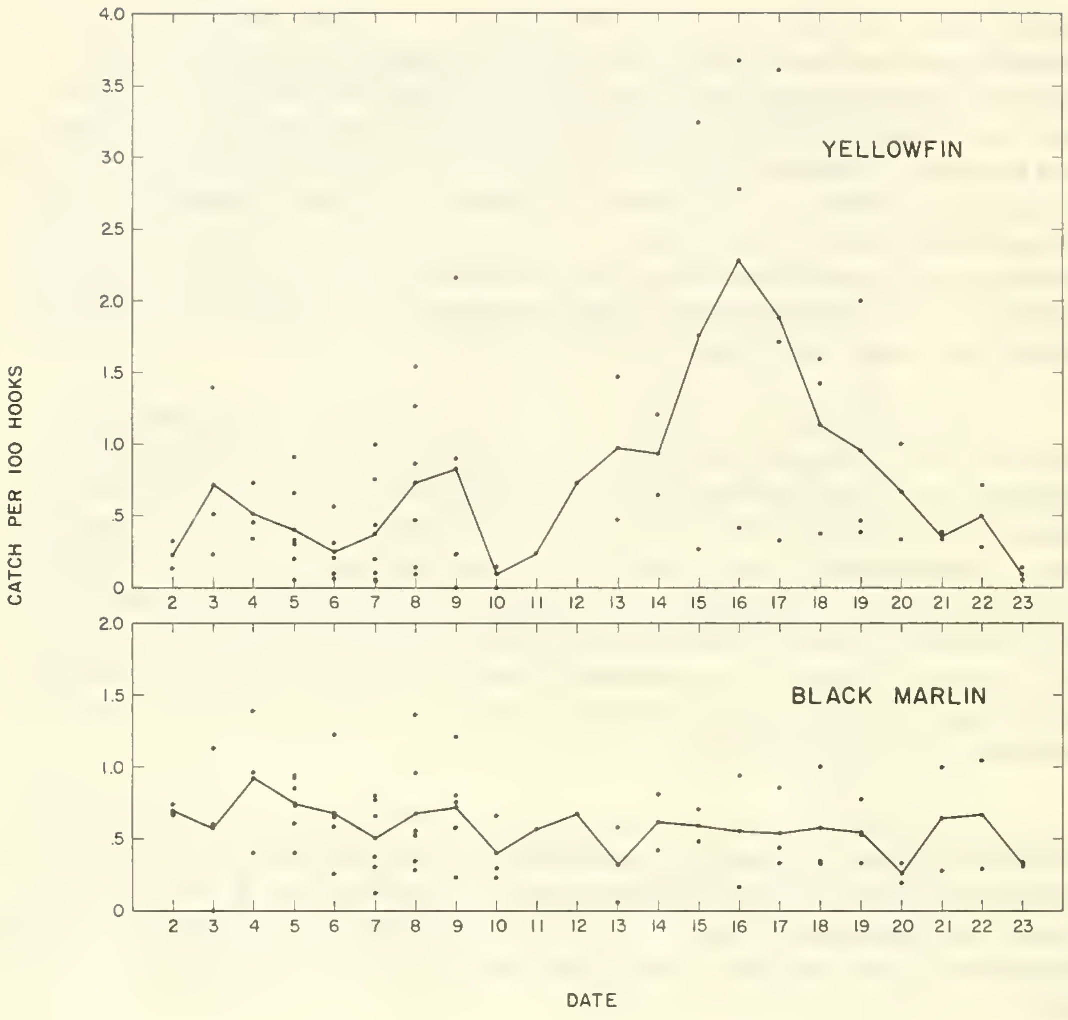

FIG I CATCHES OF BLACK MARLIN AND YELLOWFIN TUNA FROM 6° N LATITUDE, 178° E LONGITUDE DURING OCTOBER 1951. THE CATCH RATES PLOTTED AGAINST THE CORRESPONDING DAY OF THE MONTH ARE BASED ON LONGLINE SETS OF APPROXIMATELY 2,000 HOOKS.

In conclusion, there is considerable evidence that yellowfin tuna are not randomly distributed in space but rather are aggregated. This is indicated by the distribution of hooked yellowfin along a longline, and by the great variability of longline yellowfin catches when contrasted with longline black marlin catches. This apparent tendency to aggregate must be taken into consideration when approaching a statistical treatment of yellowfin tuna catches made by the longline.

TRANSFORMATION OF THE CATCHES FOR ROUTINE STATISTICAL TESTS

In order to apply routine statistical procedures, such as analysis of variance, to enumeration data of the type obtained by longline fishing for yellowfin tuna, several conditions must be met (Barnes 1952). The most important of these are normality of the distribution and independence of the mean and standard deviation. These conditions obtain if the event under study (catching a yellowfin) has a high enough probability of occurrence and a random distribution. The catch rates of yellowfin tuna are of a magnitude to suggest a Poisson distribution, but the presence of schooling or aggregation, previously demonstrated, results in too many extremely low or extremely high values to fit a Poisson distribution (Quenouille 1949, Barnes and Marshall 1951). Under these circumstances a distribution such as the negative binomial more nearly fits the data, and the catches must be transformed prior to the application of statistical tests.

The need for transformation of longline yellowfin catches is indicated graphically in figure 2. These catches show a linear relation between the mean and the standard deviation. In order to overcome this difficulty two seemingly appropriate transformations were tested on these data. The first transformation was based on the assumption that the catch rates fit a negative binomial in which the distribution of schools follows a Poisson form and that of the catches from schools a logarithmic form (Quenouille 1949). Our procedure follows the methods described by Anscombe (1949). This requires estimating a value of k common to the eight distributions by fitting successive values of k into the formula:

$$T = \frac{(N - 1)s^2 - (N - 1 - 1/k)\,\bar{r}(1 + \bar{r}\,1/k)}{(\bar{r} + k)^2}$$

(N = number of items; s^2 = sample variance; $\bar{r}$ = average catch per set). This trial and error process is continued until the sum of T for each of the eight distributions equals or nearly equals zero. For our data a value of 2.24 was selected for k. The data were then transformed[5] by

$$y = \mathrm{Sinh}^{-1} \sqrt{\frac{r + c}{k - 2c}}$$

since we wished the transformation to be applicable to sets of data with low catch rates. For comparison, the much simpler logarithmic transformation commonly used when the standard deviation is proportional to the mean $[y = \log (r + 1)]$ was also applied to the same sets of data.

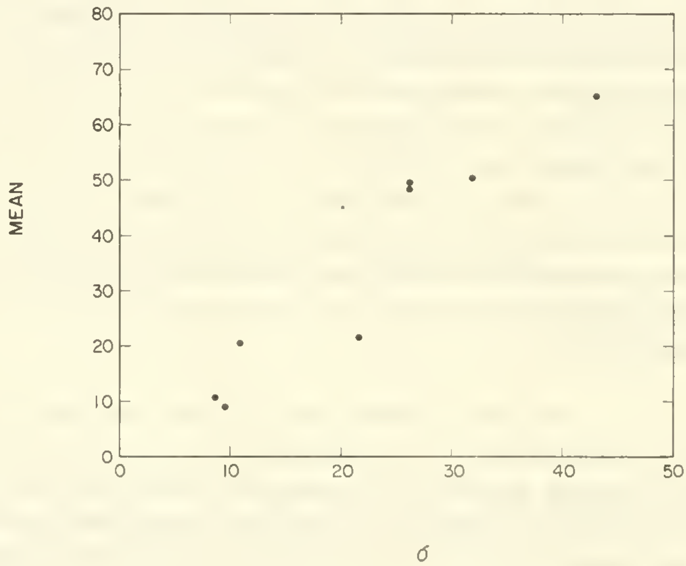

FIG. 2. RELATION BETWEEN MEAN AND σ FOR EIGHT SETS OF UNTRANSFORMED LONGLINE CATCHES. EACH POINT REPRESENTS THE MEAN AND σ FOR A SERIES OF 2,000 HOOK SETS AT ONE LOCALITY IN ONE MONTH.

5/ This follows Anscombe 1949, formula 7. C is given the value of 0.2 conforming with our low value of k; r is the individual catch.

Statistics on the raw data and on the two transformed distributions are given in table 2, and the relations of the means and standard deviations of the two sets of transformed catches are shown graphically in figure 3. It is at once apparent that both transformations have significantly reduced the correlation between the standard deviation and the mean. (For instance, the logarithmic transformation has reduced the correlation coefficient of the mean and standard deviation to -.37, which is not significant.) The normalizing effect of the transformations is indicated in figure 4, in which the raw data distributions are plotted with the distributions of the transformed catches. Both sets of transformed data indicate a tendency to depart from normality, but this does not appear to be serious. Inasmuch as there is little to choose between the two transformations, we will use the less tedious logarithmic transformation in estimating the variance of longline catches of yellowfin tuna.

VARIATION OF THE YELLOWFIN CATCH OF A SINGLE SET OF LONGLINE GEAR

Having selected a logarithmic transformation as the most practical way to overcome the effect of schooling of yellowfin on the variability of longline catches of that species, we now consider the problem of estimating the variance of catches made by the longline gear used by POFI. Estimation of the variance of the results of any sampling technique is best effected by consideration of replicate samples. These were not available, and as a substitute individual sets of gear were subdivided into 2 or 4 subsets, each subset consisting either of the sum of the catches of alternate baskets or of every fourth basket. This scheme was adopted in order to avoid bias due to the longer time that one end of a series of baskets was fished.[6]

The variance of a single subset was estimated by applying a standard analysis of variance (Snedecor 1948) to the logarithmically

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6/ The subdivision of sets into subsets by combining alternate baskets raises the question of disturbing the relation between σ and the mean by breaking up runs of fish that might include the ends of two adjacent baskets. This does not appear serious as the double distance between the end hooks of adjacent baskets, as pointed out, considerably reduces the probability of disturbing a run, i.e., the runs are already broken up in the field before the application of the analysis.

Table 2. Comparison of three treatments of the eight sets of longline yellowfin catches shown in figure 2.

Set No.	N	Raw data			Logarithmic transformation (N+1)			Hyperbolic transformation		
		Mean	σ^2	σ	Mean	σ^2	σ	Mean	σ^2	σ
1	45	50.23	911.26	31.87	1.600	.1012	.3181	2.260	.1344	.3666
2	40	9.23	90.98	9.54	0.839	.1107	.3337	1.347	.2172	.4661
3	28	21.67	461.82	21.49	1.224	.1672	.4089	1.748	.2159	.4646
4	45	10.77	77.98	8.83	0.937	.1010	.3178	1.492	.1502	.3876
5	25	20.88	118.62	10.89	1.295	.0402	.2005	1.882	.0525	.2290
6	27	49.37	683.95	26.15	1.482	.0570	.2387	2.312	.0791	.2813
7	98	48.25	682.79	26.13	1.626	.0596	.2443	2.272	.0512	.2262
8	102	65.21	1856.94	43.092	1.729	.0856	.2925	2.379	.1144	.3382

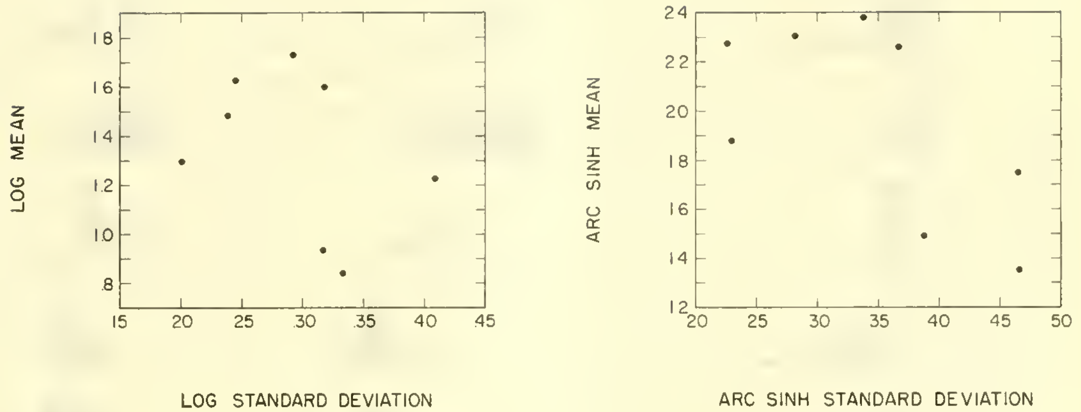

FIG. 3. RELATION OF MEAN AND STANDARD DEVIATION OF TRANSFORMED YELLOWFIN CATCHES.

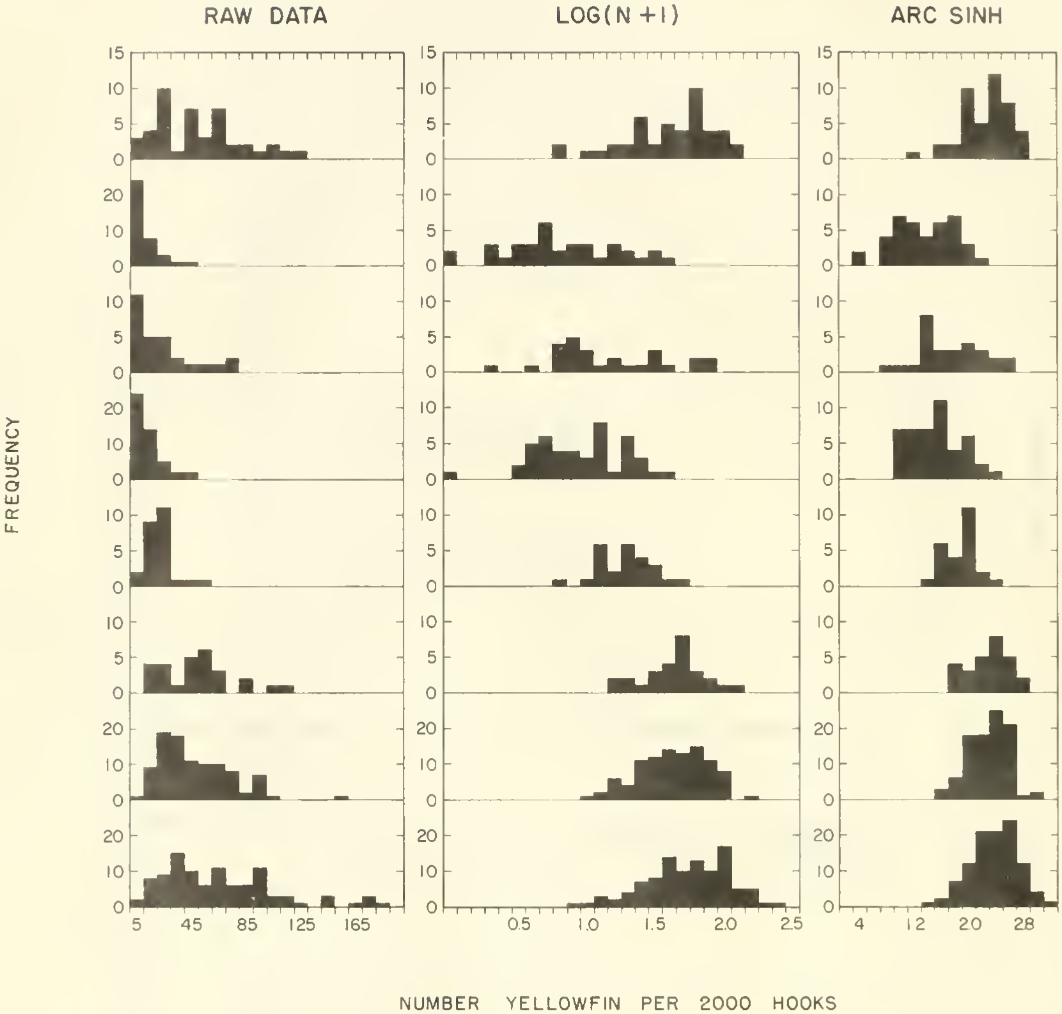

FIG 4 ORIGINAL YELLOWFIN TUNA CATCHES, LOGARITHMICALLY TRANSFORMED CATCHES, AND CATCHES TRANSFORMED BY THE ARC SINH FORMULA THE DATA CORRESPOND TO THOSE USED IN TABLE 2.

transformed paired catches, and then interpreting the "discrepance" as an estimate of the variance of a single subset. The only deviation from the usual computational technique was the rejection of sets of paired data of which one member was a zero. This was done because the effect of this alteration was less serious than the effects of the more commonly used adjustments for zero values. It resulted in rejection of as much as one-sixth of the data from one set, probably reduced the variance slightly, and of course limits the analysis to catch rates of more than one fish per 100 hooks.

The first series of fishing stations subjected to analysis of variance furnished estimates for 18-, 37-, and 74-basket sets of longline gear. The actual amount of gear fished during these stations varied from 60 to 84 baskets, 80 being the most typical number. Replicate fishing stations were obtained as follows: First, each station's set was divided into four subsets by combining the catches of every fourth basket, yielding 104 subsamples from 26 stations. (Equal numbers of baskets were obtained in each subset by discarding the last one, two or three baskets of a station when necessary). The 104 subsamples were formed into a series of 52 paired subsamples by pairing those derived from adjacent baskets, and two pairs were rejected because they contained a zero value. The mean number of baskets in this series was 18. Next, each of the 26 stations was divided into paired subsamples by pooling the catches of alternate baskets, again discarding superfluous baskets at the end of the set of gear. The mean number of baskets in this series was 37. Finally, each station was regarded as a unit, and stations occurring on consecutive days were paired yielding 14 pairs with a mean of 74 baskets.[7]

Analyses of variance[8] of these sets of catch records (table 3) indicate a substantial reduction in the estimated σ with increasing

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7/ During the collection of these data the geographical distance between any two consecutive stations was slight, and certainly did not involve movement to another zone of the ocean. There is, then, *a priori* reason to regard the catch on a succeeding day as a replicate. Two additional stations were used in this series which could not be used previously because only the total catch was recorded.

8/ In the computation the logarithms of the catches shown in table 8 (see appendix) were utilized. Since unequal amounts of effort are involved in some pairs in the 74-basket series, a simple ratio adjustment was applied to all members so as to equate the catches to those to be expected had there been 80 baskets in each pair. The use of the less tedious 80 basket adjustment is mathematically justified because of the use of the logarithms of the variates.

numbers of sampling units (baskets). This reduction is almost exactly proportional to the reduction to be expected from the theoretical relationship between σ and the number of sampling units (fig. 5).

The near identity of the empirical reduction in σ with the reduction calculated from the σ of the 18-basket subsets indicate that no substantial new sources of variation were introduced when 2 consecutive days of fishing in the same area were considered as replicates. Perhaps the close approximation also serves as a measure of the suitability of the logarithmic transformation for this type of longline catch.

In addition to the estimate of σ for an 18-basket subset that can be derived from the previous analysis, values were calculated from three other series of 20-basket subsets. These latter were from 40-basket stations fished as much as 90 miles apart, and were obtained by pooling the catches of alternate baskets. The analysis of these data is shown in table 4. Considering the 20-basket value derived from table 3 with the three values from table 4, the range of the logarithmic σ of a 20-basket set (.191-.248) appears to represent sampling variation. It follows that the best estimate of the σ of a 20-basket set of longline gear is obtained by averaging the four empirically obtained variances and extracting the square root of the mean variance, yielding a mean value of .229.

It does not follow that the estimate of σ obtained from our carefully controlled experimental fishing can be applied to other types of longline fishing, such as Japanese commercial fishing, in which such variables as the length of time the gear is in the water vary considerably from day to day. As a test, two trial calculations were made on series of data derived from Japanese commercial fishing in which the sampling unit was about 2,000 hooks fished per day instead of the 240-400 hooks fished by POFI. The first series was obtained by pairing consecutive days' fishing by one vessel. The second series was obtained by selecting a block of ocean 60 miles square and pairing catches that occurred in that block on the same date without regard to vessel identity. As may be seen from table 5, these two methods furnished nearly identical estimates of σ, but they are larger than that obtained from our own fishing.

Considering hook or basket number only, extrapolation of the estimated σ of our experimental fishing (.229 for a 20-basket set) to

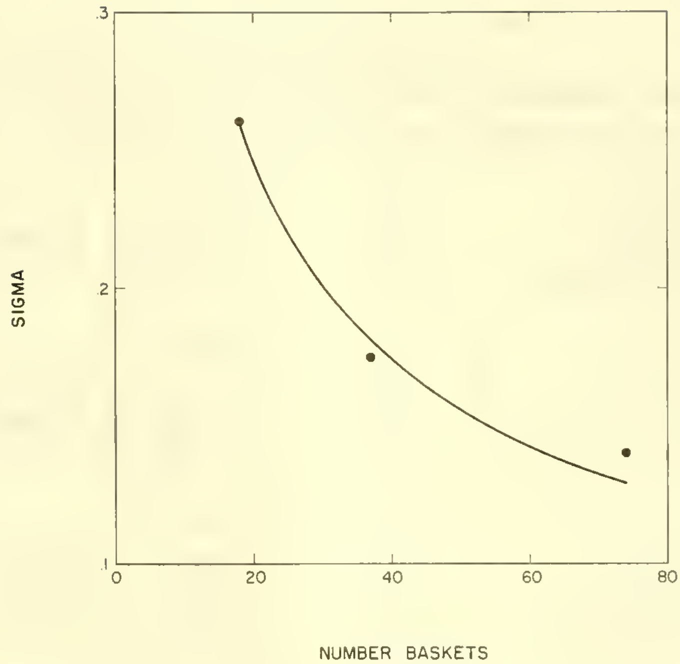

FIG. 5. σ (EQUAL TO SQUARE ROOT OF DISCREPANCE MEAN SQUARE) PLOTTED AGAINST NUMBER OF BASKETS IN THE SAMPLING UNIT. CURVE CALCULATED FROM THE σ OF THE 18-BASKET SUBSETS.

Table 3. Analyses of variance of yellowfin catches of paired 18-, 37-, and 74-basket sets (6 hooks to a basket). The values used are the logarithms of the catches in table 8 (appendix).

Number of baskets	Source of variation	Degrees of freedom	Sum of squares	Mean squares	σ
18	Total	99	8.5969		
	Subsets	1	0.0219	0.0219	
	Stations	49	5.2342	0.1068	
	Discrepance	49	3.3408	0.0682	0.261
37	Total	51	3.2085		
	Subsets	1	0.0212	0.0212	
	Stations	25	2.4188	0.0968	
	Discrepance	25	0.7685	0.0307	0.175
74	Total	27	1.2881		
	Subsets	1	0.0212	0.0212	
	Stations	13	1.0087	0.0776	
	Discrepance	13	0.2582	0.0199	0.141

Table 4. Analyses of variance of yellowfin catches for three sets of 40-basket stations. Each set was subdivided into two duplicate sets for analysis. The values used are the logarithms of the catches in table 9 (appendix).

Set number	Source of variation	Degrees of freedom	Sum of squares	Mean squares	σ
1	Total	51	5.6903		
	Subsets	1	0.1562	0.1562	
	Stations	25	4.0752	0.1630	
	Discrepance	25	1.4589	0.0584	.242
2	Total	39	6.5611		
	Subsets	1	0.0138	0.0138	
	Stations	19	5.8517	0.3080	
	Discrepance	19	0.6956	0.0366	.191
3	Total	35	3.3816		
	Subsets	1	0.0200	0.0200	
	Stations	17	2.4518	0.1442	
	Discrepance	17	0.9098	0.0535	.231

Table 5. Analyses of variance of series of Japanese commercial fishing longline yellowfin catches (about 2,000 hooks or 350 baskets per set). The values used are the logarithms of the catches in table 10 (appendix).

Set number	Source of variation	Degrees of freedom	Sum of squares	Mean squares	σ
1 1/	Total	43	4.6779		
	Samples	1	0.0539	0.0539	
	Stations	21	3.6408	0.734	
	Discrepance	21	0.9832	0.0468	0.216
2 2/	Total	77	6.1943		
	Samples	1	0.0005	0.0005	
	Stations	38	4.5656	0.1201	
	Discrepance	38	1.6282	0.0429	0.207

1/ This series is based on all the fishing in a block bounded by 1°-2° N. latitude and 160°-161° E. longitude during May 1951. A pair was formed from two consecutive sets as they appeared in a tabulation by days. The maximum time interval between the members of any pair is therefore 1 day.

2/ This series is based on the fishing of two catcher vessels. A pair consists of two consecutive days' fishing by one vessel. If there was a break in time of more than 1 day or in distance of more than 1 degree, the pair was rejected.

the 350 baskets yield a value of .055, considerably smaller than the value of .212 obtained by averaging the two values for commercial fishing. Very likely this difference was largely caused by failure to rigidly control the conduct of each fishing operation in the instance of the commercial fishing, thus increasing the variability of the catches. This probably arose in part because commercial operators would have no particular reason to fish in an identical manner each day, and furthermore precise control would probably be more difficult when fishing 350 units of gear than with 40-80 units of gear. Differences in gear design and differences in the spatial distribution of the fish between the central Pacific, where the POFI fishing was carried out, and the western Pacific, where the commercial fishing was done, may also have introduced additional variability.

The demonstration that the same estimate of variability cannot be applied to situations as widely different as small experimental sets of fishing gear and large commercial sets indicates that our results will not be valid elsewhere unless the general conduct of the fishing is reasonably identical. The general method of determining the variability does, however, appear to have wide application, even though the specific numerical results obtained apply only to the fishing carried out by POFI.

SETTING FIDUCIAL LIMITS ON THE CATCHES

The average σ (.229) of the 20-basket POFI longline sets derived in the previous section appears to represent the best basis for setting fiducial limits on the catches of this type of gear when it is used in the same manner. From this estimated σ fiducial limits can be estimated for any station based on 20 to 80 baskets of gear.

If it is desired to set 95-percent confidence limits on a catch based on 20 baskets of gear, the 2 σ limits ($\pm$ .458) are converted to ratios by using the antilogs, giving fiducial limits of 35 percent (100 x 1/2.87) to 287 percent (100 x 2.87). Applied to a catch of 10 fish per 100 hooks, the 95-percent confidence limits would be 3.5 to 28.7 fish per 100 hooks. To estimate the fiducial limits of a set of a number of baskets different from 20 it is only necessary to follow the above procedure after adjusting the value of 2 σ by the formula where N is the

$$\frac{.458}{\sqrt{N/20}}$$

number of baskets in the set. This has been done for numbers of baskets between 20 and 80 as shown in table 6.

In order to compute the 95-percent limits of the average of several fishing stations it must be assumed that the stations share a common variance. This assumption appears to be met within the central Pacific area, but might not apply between the central Pacific and other areas, where such factors as the schooling habits of the fish might differ. Following this assumption, it is only necessary to sum the number of baskets involved and calculated a new 2 σ based on the relationship of the number of baskets involved to the number used in calculating the basic σ (.458 for 20 baskets).9/

Table 6. Two sigma (95-percent) limits for catches of yellowfin tuna made on the gear used by Pacific Oceanic Fisheries Investigations.

Number of baskets	Lower limit in percent	Upper limit in percent
20	35	287
30	42	237
40	47	211
50	51	195
60	55	183
70	57	176
80	59	170

9/ Actually, this procedure is valid only for geometric means, but it is a useful approximation if the catches do not range through orders of magnitude. If these conditions are not met, the method developed by Sette and Ahlstrom (1948) for setting fiducial limits on logarithmically transformed data appears more appropriate.

For convenience in estimating the limits of catches of several stations or single stations (up to 80 baskets in size of set) figure 6 has been prepared, following the procedures outlined in this section. Although it is primarily designed to furnish a guide to the 95-percent limits of catches made by POFI vessels, it can serve as a rough estimate of these limits for other similar exploratory longline investigations, provided the construction and method of handling the gear are not too dissimilar.

SUMMARY

A study of the variability of longline catches of yellowfin tuna was conducted (1) to establish a means of estimating the variance of catches made with different amounts of gear in a single set or station, and (2) to suggest a method of estimating the variance of a catch rate derived from the average catches of several stations. Pursuant to this, the existence of schooling was investigated, and the suitability of two transformations was tested empirically.

The evidence for schooling of subsurface yellowfin is from two sources: (1) An analysis of runs indicating that they are clumped or grouped on the line; and (2) the markedly greater day-to-day variation in yellowfin catches as compared with the catches of a non-schooling fish, the black marlin.

The skewness of the data and the linear relation of the mean and σ occurring in the catch data make it desirable that they be transformed before applying statistical analysis. A logarithmic transformation appears to be the most appropriate.

The variances of 18-, 37-, and 74-basket sets were investigated by analysis of variance on the logarithmically transformed catches. The square root of the discrepance, interpreted as σ, was found to be inversely proportional to the square root of the number of baskets in the sampling unit, when the construction of gear and method of operation were held constant. Analysis of two groups of Japanese commercial fishing catches, based on 350-basket sets, gave estimates of σ considerably larger than would be expected if the σ calculated from the smaller sets were adjusted to the 350-basket level. This suggests that there was a lack of standardization in the conduct of the commercial fishing.

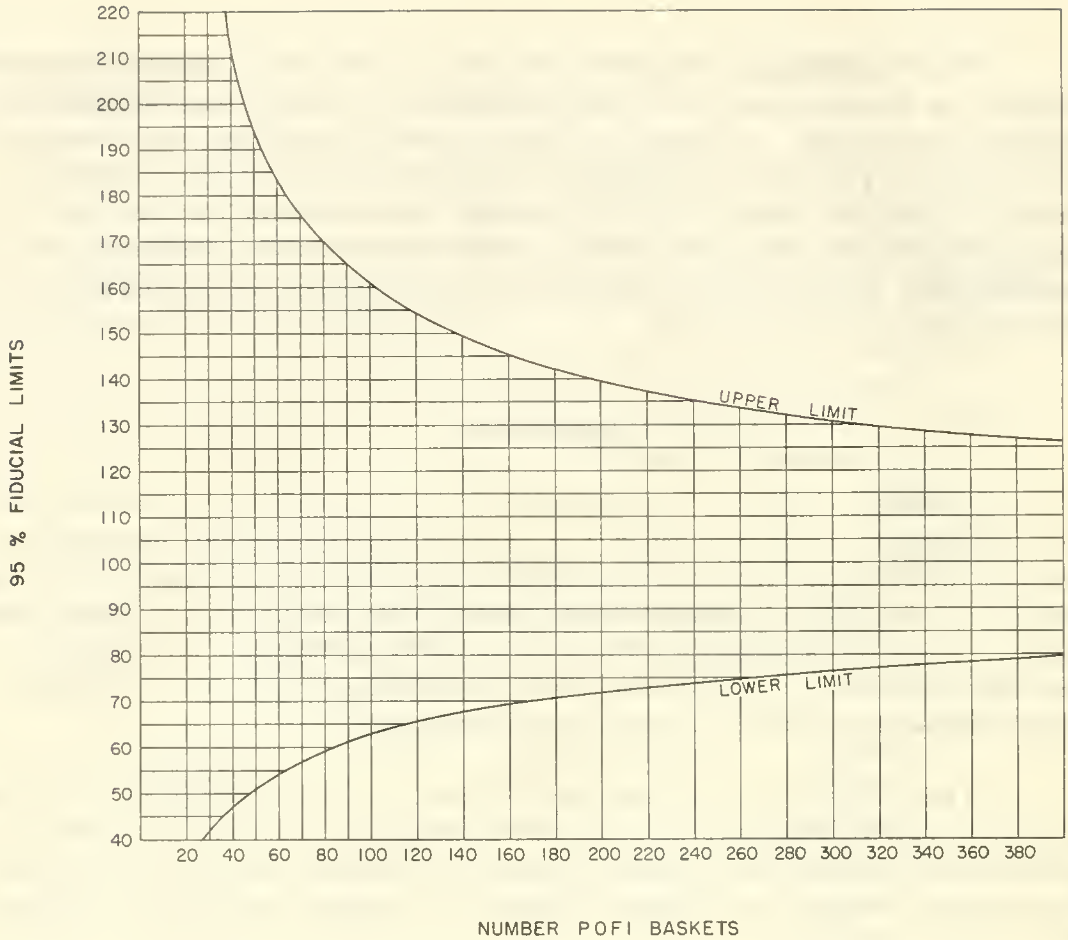

FIG 6. NINETY-FIVE-PERCENT FIDUCIAL LIMITS FOR CATCHES OF YELLOWFIN TUNA MADE WITH THE TYPE OF LONGLINE GEAR DESCRIBED BY NISKA (1953). THIS GRAPH MAY BE USED TO ESTIMATE THE 95-PERCENT (2σ) LIMITS FOR THE CATCH OF ANY STATION OF 20-80 BASKETS OR ANY COMBINATION OF SUCH STATIONS. FOR A COMBINATION OF STATIONS THE APPROPRIATE LIMITS ARE READ BY ENTERING AT THE TOTAL NUMBER OF BASKETS INVOLVED, AS IN THE INSTANCE OF A SINGLE STATION. FOR INSTANCE A CATCH OF 10 YELLOWFIN/100 HOOKS BASED ON 120 BASKETS (e.g. 3, 40 BASKET STATIONS) HAS LIMITS OF 6.5/100 15.5/100 HOOKS.

The quadratic mean σ of four sets of transformed data is used as the best estimate to apply to longline catches made by POFI. By appropriate application this σ can be used to estimate confidence limits for the yellowfin catches of single stations, or groups of stations, provided certain limitations are taken into account.

Table 7. Eight sets of Japanese commercial yellowfin catches (catch per 2,000 hooks) on which table 2 is based. Each figure represents one day's fishing. The catches were made in the western equatorial Pacific in 1951.

May 1^{o}N. L., 160^{o}E. L.	October 2-10 6^{o}N. L., 178^{o}E. L.	October 11-23 6^{o}N. L., 178^{o}E. L.	October 6^{o}N. L., 177^{o}E. L.	August 6^{o}N. L. 173^{o}E. L.
12.00	6.48	7.78	4.32	54.38
20.40	0.00	55.55	2.67	12.58
5.96	30.84	8.42	9.52	14.70
27.38	1.26	6.67	19.80	22.50
26.67	6.84	6.67	11.90	20.00
4.62	4.56	73.44	3.80	20.00
26.67	6.16	5.72	5.40	30.48
60.74	4.70	7.62	6.00	12.98
41.33	9.42	4.76	5.26	21.11
28.89	4.10	20.00	6.67	11.42
73.33	8.82	34.28	8.82	11.67
16.00	27.94	14.28	8.82	25.00
57.34	14.56	6.67	10.48	29.17
19.84	20.00	32.00	12.12	14.17
39.68	2.06	2.86	16.67	10.83
107.66	11.30	7.62	18.62	25.00
38.10	1.08	64.98	23.52	9.70
45.33	25.26	40.00	43.00	44.32
8.89	4.04	28.58	19.00	20.00
26.67	2.02	9.66	4.00	18.28
26.67	43.16	14.50	2.83	20.83
61.48	1.16	9.52	4.00	27.46
74.44	16.18	72.18	2.67	6.67
54.54	14.16	29.42	25.33	26.67
64.00	6.60	24.22	16.20	12.22
55.22	6.00	1.06	6.16	
95.24	2.86	5.40	4.70	
81.33	1.86	12.98	0.00	
67.62	13.24		4.52	
24.00	4.50		5.64	
55.96	2.67		10.78	
124.44	4.00		10.58	
118.52	17.18		18.00	
42.22	2.86		2.50	
62.56	0.00		20.54	
39.82	1.02		2.16	
102.67	10.18		6.48	
86.67	9.10		12.41	
61.84	18.18		10.67	
24.24	2.82		3.88	
76.67			26.67	
53.18			3.04	
60.00			2.90	
16.30			30.67	
43.33			12.38	

Table 7. Eight sets of Japanese commercial yellowfin catches (catch per 2,000 hooks) on which table 2 is based. Each figure represents one day's fishing. The catches were made in the western equatorial Pacific in 1951. (Continued)

August 4°N. L., 158°E. L.	August 1°N. L., 156°E. L.		August 1°N. L., 157°E. L.		
29.33	50.48	27.36	24.21	66.67	115.29
43.81	24.00	49.48	43.43	24.12	58.89
19.04	16.41	57.00	12.94	103.53	
17.14	67.02	29.33	67.06	82.41	
13.72	55.18	73.33	74.12	93.47	
86.67	41.14	23.00	178.82	148.00	
55.60	28.58	32.00	47.06	78.32	
28.70	33.33	85.00	37.33	18.63	
40.00	94.66	46.50	76.71	45.71	
28.89	37.94	58.78	113.97	93.33	
69.33	60.52	51.76	82.00	52.38	
37.90	32.39	35.30	89.77	94.44	
54.74	70.52	31.11	38.95	102.67	
41.67	36.92	14.74	86.49	32.00	
51.86	29.41	75.56	68.24	117.33	
23.00	61.33	23.81	52.00	172.00	
80.00	52.22	30.20	46.46	25.92	
66.67	61.54	34.66	30.48	12.97	
50.67	81.00	12.00	95.45	35.35	
114.82	33.52	20.42	21.05	39.39	
45.33	60.96	68.72	40.00	44.76	
40.74	24.76	46.16	38.92	9.14	
107.82	53.33	47.00	35.09	11.58	
64.00	22.86	71.00	54.39	26.67	
15.24	35.36	25.94	94.12	30.67	
55.33	93.33	16.96	90.59	64.86	
53.70	14.28	49.50	82.41	19.30	
	35.24	22.10	36.67	14.91	
	39.04	24.00	7.84	73.68	
	92.64	99.00	32.38	25.55	
	28.10	45.00	73.33	142.10	
	70.40	38.88	25.21	93.00	
	49.00	37.90	30.68	95.55	
	62.00	55.38	80.00	40.00	
	53.68	96.84	56.00	96.89	
	10.81	25.94	171.14	246.00	
	68.42	37.84	61.00	66.67	
	21.02	47.36	92.50	32.88	
	8.89	26.67	37.89	108.27	
	34.00	152.38	62.11	63.81	
	37.00	47.72	162.10	38.89	
	69.00	72.72	27.03	44.00	
	93.00	16.22	22.70	125.00	
	59.00	85.00	70.27	145.00	
	40.00	73.00	91.14	60.95	
	61.62	97.14	16.47	90.59	
	15.15	75.55	43.43	63.81	
	15.91	23.80	38.67	19.05	
	105.68		40.00	50.00	
	23.16		28.95	60.23	

Table 8. POFI longline catches from Cavalieri cruise 1 arranged in pairs for the analyses in table 3.

20-basket catches			40-basket catches			80-basket catches			
Number baskets	Number yf		Number baskets	Number yf		Number baskets	Number yf	Number baskets	Number yf
15	5	1	30	8	10	60	24 [1]	60	44 [1]
15	14	2	30	23	10	60	44	68	58
15	13	2	30	21	11	68	14	68	26
17	12	16	34	19	30	68	29	76	36
17	3	6	34	4	8	68	15	76	20
17	7	7	34	10	12	76	8	60	16
17	8	6	34	16	9	72	24	76	23
19	7	5	38	11	23	80	17	80	23
17	2	4	34	3	10	80	21	80	15
19	3	4	38	9	10	80	20	80	9
19	0	2	38	3	5	80	27	80	27
15	2	3	30	5	7	80	24	84	14
18	8	5	36	14	8	80	33	80	61
19	8	6	38	13	9	80	43	80	38
20	4	3	40	12	5				
20	6	7	40	11	12				
20	8	5	40	13	8				
20	1	7	40	5	10				
20	1	6	40	7	13				
20	2	3	40	3	6				
20	6	9	40	13	14				
20	9	3	40	18	9				
20	5	8	40	8	16				
21	3	0	42	7	7				
20	11	15	40	27	34				
20	9	8	40	20	18				
15	3	9							
15	9	8							
15	8	9							
17	7	14							
17	1	2							
17	3	5							
17	8	3							
19	4	18							
17	1	6							
19	6	6							
19	3	3							
15	3	4							
18	6	3							
19	5	3							
20	8	2							
20	5	5							
20	5	3							
20	4	3							
20	6	7							
20	1	3							
20	7	5							
20	9	6							
20	3	8							
21	4	7							
20	16	9							
20	11	10							

1/ These catches have been adjusted to the equivalent of 80 baskets.

Table 9. Pacific Oceanic Fishery Investigations longline catch data, each set subdivided and arranged in pairs for the analyses of table 4. Each catch is based on exactly 20 baskets.

Manning cruises 12 and 13		Smith cruise 11		Manning cruise 11	
Set number 1		Set number 2		Set number 3	
0	2	3	0	15	9
4	1	3	3	6	7
2	2	0	2	8	4
2	4	1	3	5	11
10	8	13	10	7	9
4	5	4	10	6	5
0	2	21	17	2	1
7	1	15	11	4	0
0	2	10	10	6	2
2	2	19	18	5	6
5	2	6	13	6	2
3	2	29	15	0	2
1	3	17	13	1	3
2	0	7	4	3	4
1	2	12	11	0	5
7	2	16	15	1	3
5	3	6	9	6	2
2	1	38	33	11	4
1	0	11	20	6	4
2	1	3	2	3	4
3	0	3	1	1	2
5	9	1	0		
7	4	0	1		
7	7	4	1		
1	1				
7	1				
2	3				
11	12				
5	5				
5	3				
1	0				
1	2				
1	0				
1	1				
0	2				

Table 10. Paired Japanese commercial longline catches used in the analyses on table 5. Data are from records of mothership operations in the western Pacific in 1951.

Set number 1		Set number 2	
74	55	18	18
42	63	28	44
40	62	48	50
87	24	24	2
64	95	21	23
56	55	28	26
81	119	26	25
68	53	44	21
124	103	36	55
20	27	70	59
61	57	27	29
108	24	29	21
77	43	12	21
12	27	28	20
27	5	15	14
41	29	7	14
40	38	28	20
6	16	68	73
20	9	46	93
16	27	68	60
45	27	67	72
73	60	41	64
		12	35
		40	21
		44	38
		31	47
		49	30
		11	34
		37	11
		22	53
		19	37
		51	57
		37	42
		21	34
		27	14
		13	8
		23	26
		54	71
		92	29

BIBLIOGRAPHY

ANSCOMBE, F. J.

1949. The statistical analysis of insect counts based on the negative binomial distribution. Biometrics, vol. 5, No. 2, pp. 165-173.

BARNES, H.

1952. The use of transformations in marine biological statistics. Jour. Cons. Int. Expl. Mer, vol. 18, No. 1, pp. 61-71.

BARNES, H. and S. M. MARSHALL.

1951. On the variability of replicate plankton samples and some application of 'contagious' series to the statistical distribution of catches over restricted periods. Jour. Mar. Biol. Assoc., vol. 30, No. 2, pp. 233-263.

JUNE, F. C.

1950. Preliminary fisheries survey of the Hawaiian-Line Islands area. Part I - The Hawaiian long-line fishery. U. S. Fish and Wildlife Service, Comm. Fish. Rev., vol. 12, No. 1, pp. 1-23.

MOOD, A. N.

1950. Introduction to the theory of statistics. McGraw-Hill Book Co., 433 pp.

MURPHY, G. I., and R. S. SHOMURA.

1953. Longline fishing for deep swimming tuna in the central Pacific. July 1950-September 1951. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 98, pp. 1-47, May 1953.

NAKAMURA, H.

1949. The tunas and their fisheries. Takeuchi Shobō, Tokyo 1949. (Translated by W. Van Campen, U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries no. 82, pp. 1-115, August 1952).

NISKA, E. L.

1953. Construction details of tuna longline gear used by the Pacific Oceanic Fishery Investigations. Comm. Fish. Rev., vol. 15, No. 6, pp. 1-6, June 1953.

QUENOUILLE, M. H.

1949. A relation between the logarithmic, Poisson, and negative binomial series. Biometrics, vol. 5, No. 2, pp. 162-4.

SETTE, O. E., and E. H. AHLSTROM.

1948. Estimations of abundance of the eggs of the Pacific pilchard (Sardinopsis caerulea) off Southern California during 1940 and 1941. Jour. Mar. Res., vol. 7, No. 3, pp. 511-542.

SHAPIRO, S.

1950. The Japanese longline fishery for tunas. U. S. Fish and Wildlife Service, Comm. Fish. Rev., vol. 12, No. 4, pp. 1-27.

SNEDECOR, G. W.

1948. Statistical methods. The Iowa State College Press, Ames, Iowa, 4th ed., 485 pp.

SWED, F. S., and C. EISENHART.

1943. Tables for testing randomness of grouping in a sequence of alternates. Ann. Math. Stat., vol. XIV, No. 1, pp. 66-87.