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# A Comparison of the Populations of Yellowfin Tuna, Neothunnus macropterus, From the Eastern and Central Pacific

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## ACKNOWLEDGMENTS

The present study, like most conducted at this laboratory, is essentially a cooperative work. The entire staff has helped at one time or another with some phase of the work, and this assistance is gratefully acknowledged. Especial thanks are extended to Mrs. C. J. Laing, Mrs. M. MacIntire and Mr. E. K. Holmberg, who did much of the detailed computations.

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# 1. INTRODUCTION

The present study is a continuation of the work published in 1948 by the senior author. At that time the attempt was made to determine whether or not the yellowfin tuna from Japan and from the Hawaiian Islands comprised populations distinct from and nonintermingling with that of the eastern Pacific region exploited by the California fleet. Using body measurements, empirical regression lines for those characters investigated were established for the eastern Pacific population, based upon 13 separate samples comprising a total of approximately 1,900 fish. It was found that, although these samples differed significantly in a statistical sense from one another when tested by methods of analysis of variance, nevertheless all sample regression lines from these grounds conformed to the empirical population regression lines within narrow limits. When the data from the Japanese and Hawaiian samples were compared with the local population regression lines, it was found that in some characters these samples diverged from the local stock by amounts many times greater than the most divergent local sample. (Local, as used herein, refers to the eastern Pacific population.) The Japanese fish diverged more than the Hawaiian, but in all cases the direction of divergence was the same, suggesting a closer relationship between the Japanese and Hawaiian populations than existed between either of these with the local stock. The tentative conclusion was therefore drawn that the local, or eastern Pacific, stock of yellowfin tuna was separate and distinct from that of the central and western Pacific.

While this conclusion represented the most probable hypothesis upon which to formulate a management program, it was nevertheless based upon a single small sample from each of the two distant regions. Every effort was therefore made to obtain additional and larger samples in order to check this important conclusion.

In the summer of 1948 we succeeded in getting a sample of 58 yellowfin tuna caught in the vicinity of the Hawaiian Islands during the course of a cruise of the State's research vessel N. B. SCOFIELD. This sample was derived in part from Johnston Island (16° 31' N., 169° 25' W.) and in part from those banks and islands situated between French Frigate Shoals and the island of Kauai. It is therefore a composite sample from the region rather than from any one specific area. The fish in this sample were relatively small and the range in body length extended from 224 to 851 millimeters. Three of the smallest fish were eliminated from the final sample because lack of small calipers prevented us from making comparable measurements. The residual range in body length was from 514 to 851 millimeters. Because of this restricted size range, we attempted to supplement the sample by obtaining measurements from larger yellowfin delivered to the Honolulu markets at the time we were in port. Here we added 24 measurements to each series, made upon large, locally caught yellowfin, and thus extended the range to 1,638 millimeters.

A few months later we were fortunate in obtaining comparable measurements upon 94 fish in a load of yellowfin tuna caught in the central Pacific in February, 1949, by the vessel CALISTAR. Again, this is a composite sample as the fish in the load were caught in part at Palmyra Island (5° 52' N., 162° 02' W.) and in part at Fanning Island (3° 50' N., 159° 20' W.).

In April, 1950, before this analysis was completed, a small shipment of yellowfin tuna from the Fiji Islands was received by a local canner. of this shipment we obtained measurements upon 13 yellowfin, all caught in the vicinity of Suva. These three additional samples afforded the desired opportunity to check the tentative conclusions drawn from the analysis of the original samples; and in addition, the four available samples from the central pacific furnished material for a preliminary test of the homogeneity of the stock within that region.

# 2. METHODS

In the present study the methods used are identical with those discussed and explained in the earlier publication (Godsil, 1948). First, standard methods of analysis of variance were applied to the data. The results thus obtained yielded, in the aggregate, a statistical probability overwhelmingly supporting the original tentative conclusion that the central Pacific stock differed from that of the eastern Pacific. However, significant statistical differences of a smaller magnitude were found, in the earlier study, to exist between the several samples from the eastern Pacific. For this reason a distinction was made between biological and statistical significance. To evaluate the former, a method was evolved, used and described in the earlier study, by which the average squared distance separating a sample line from a second or empirical line could be calculated. Differences between sample and empirical lines were then evaluated in the light of sampling experience rather than in statistical probabilities. Briefly, if the sum of squared deviations of the sample is first calculated about the sample regression line (the line of best fit) and then calculated from any empirical population regression line, one obtains two values,

a. The variance of the sample about the sample line; and

b. The variance of the same sample about the population line. Inasmuch as the variates are the same, the difference between these two variances is proportional to the average squared distance separating the sample and population regression lines. Where these two lines are identical, the difference in the variances is obviously zero, and the difference in variances increases as the two lines become progressively more divergent, either in slope or intercept, or both. Thus the method enables one to arrive at a numerical difference between any two lines.

From the earlier work the magnitude of such differences was determined for successive samples of tuna from the eastern Pacific, compared with an empirical eastern Pacific population line. The limit of such differences was then used to evaluate the corresponding differences found to exist between the empirical eastern Pacific line and samples derived from the central Pacific. We thus obtained a numerical measure of such differences to compare with the maximum difference actually observed in samples derived from the assumedly homogeneous eastern Pacific stock. In the present study this approximate biological evaluation is in complete accord with the results of the conventional statistical tests.

Throughout this work the function used to express the regression is

$$Y = a + bX + c\frac{1}{X}$$

*EQUATION*

where X in each case is the body length, and Y the second measurement entering into the respective regression.

For the line of best fit

$$\Sigma(Y_o - Y_c)^2 = \Sigma Y^2 - a\Sigma Y - b\Sigma XY - c\Sigma\frac{1}{X}Y$$

*EQUATION*

and the corresponding sum of squared deviations of a sample of variates measured from the empirical population line is given by the expansion of

$$\Sigma(Y_o - Y_c)^2 = \Sigma\left[Y_o - (a + bX + c\frac{1}{X})\right]^2$$

which is

$$= \Sigma Y^2 - 2a\Sigma Y - 2b\Sigma XY - 2c\Sigma\frac{1}{X}Y + Na^2 + 2ab\Sigma X + 2ac\Sigma\frac{1}{X} + b^2\Sigma X^2 + 2Nbc + c^2\Sigma\left[\frac{1}{X}\right]^2$$

*EQUATION*

in which the constant and regression coefficients are those of the empirical line, and the sums and products of variates are those of the actual sample under comparison. For a more complete discussion of the method the reader is referred to Godsil (1948, pages 9 and 10).

## 3. EFFECTS OF FREEZING

Unfortunately, the four samples from the central Pacific were not in comparable physical condition. The original Hawaiian sample consisted of 12 fish in excellent condition. They had been individually wrapped and frozen shortly after capture and were in perfect physical condition when thawed and measured after some months of storage.

The second Hawaiian sample, that of 1948, was taken by the crew of the N. B. SCOFIELD. Each fish was measured fresh. Apart from any effects of freezing, storage and thawing the two Hawaiian samples were essentially comparable in physical condition.

The Palmyra sample, however, was caught commercially and stored for a period of five to six weeks in the hold of a tuna boat. Although storage conditions and temperatures on such a boat are quite satisfactory for the preservation of a food resource, the volume handled and stored results in a certain amount of distortion and minor physical damage to individual specimens. For purposes of the present study measurements from such fish are not entirely satisfactory. The characteristic regression line remains basically the same, but the scatter of individual measurements about this line is excessive, resulting in a mean square deviation that is higher than that obtained from fresh or carefully

TABLE 1

The Summation of All Comparable Measurements in Millimeters Made Upon the Fresh and the Frozen Fish of the 1948 Hawaiian Sample, With the Actual and Percentage Loss Caused by Freezing and Cold Storage

| Sample N=54 | Body length | | Head length | | First dorsal insert | | 2d dorsal insert | | Anal insertion | | Ventral insertion | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Average | Total | Average | Total | Average | Total | Average | Total | Average | Total | Average |
| Fresh | 33,186 | 614.56 | 9,355 | 173.24 | 10,229 | 189.43 | 17,971 | 332.80 | 19,788 | 366.44 | 10,623 | 196.72 |
| Frozen | 32,739 | 606.28 | 9,339 | 172.94 | 10,200 | 188.89 | 17,862 | 330.78 | 19,606 | 363.07 | 10,499 | 194.43 |
| Loss | 447 | 8.28 | 16 | 0.30 | 29 | 0.54 | 109 | 2.02 | 182 | 3.37 | 124 | 2.29 |
| Percent loss | ---------- | 1.35 | ---------- | 0.17 | ---------- | 0.29 | ---------- | 0.61 | ---------- | 0.92 | ---------- | 1.16 |

*TABLE 1*

***The Summation of All Comparable Measurements in Millimeters Made Upon the Fresh and the Frozen Fish of the 1948 Hawaiian Sample, With the Actual and Percentage Loss Caused by Freezing and Cold Storage***

preserved fish. As this has been repeatedly observed in numerous commercial samples, allowance must be made for it in interpreting the results. The Fijian sample was comparable with the Palmyra sample, but was, if anything, in poorer condition.

Apart from this consideration there is undoubtedly a degree of shrinkage in cold-stored fish. In a preliminary measure of this it appeared that the change in measurements caused by prolonged cold storage was not sufficient to change appreciably the resulting regression lines, although there was a slight upward displacement of "frozen" measurements in the case of second dorsal and anal insertion plotted against body length (Godsil, 1948, page 21). This preliminary test indicated that the regression lines of head length, first dorsal and ventral insertion, upon body length, were not appreciably affected.

The present material offered an opportunity to investigate further the effects of freezing upon proportional measurements. Fifty-five individuals of the tuna included in the 1948 Hawaiian sample were measured fresh upon capture. They were then promptly frozen and carefully stored at low temperatures. The fish were not individually marked. Four to five weeks later the fish were again measured. For the 54 fish on which duplicate measurements were made Table 1 shows separately for the fresh and frozen fish the summation of all comparable measurements, and the aggregate and the percentage loss for each.

In general the actual shrinkage is small and, with one exception, is proportional to the magnitude of the initial dimension. Thus, the length of the head is the least measurement and shows the least change. The body length is the greatest and shows the greatest change. The measurement of the ventral insertion, although roughly comparable with the measurement of the first dorsal insertion, shows a shrinkage far in excess of the latter. The reason is not apparent.

The effect of shrinkage upon the regression lines is shown in Figure 1. Here the individual regression lines for both the fresh and the frozen samples are shown superimposed. In four of these regressions, namely, head length, first dorsal insertion, second dorsal insertion and anal insertion, all on body length, the line for the frozen sample is displaced slightly above that of the fresh sample. In the case of the ventral insertion the two lines are practically coincident.

It is apparent that in the four specified regressions freezing and cold storage cause a slight upward displacement of the resulting regression lines. Figure 1 suggests that this effect is greatest in the case of head length and second dorsal insertion, less in the case of first dorsal and anal insertion and negligible in the case of ventral insertion. In general, the comparable lines are in all cases approximately parallel.

The magnitude of this displacement can be measured in several ways. One of the simplest is to compute, over the same range of body length, the sum of the calculated ordinates of both the fresh and the frozen regression line, thus:

$$\Sigma Y_z = Na_z + b_z \Sigma X + c_z \Sigma \frac{1}{X}$$

*EQUATION*

where subscript z designates the respective quantity pertaining to the frozen regression line, and:

$$\Sigma Y_f = Na_f + b_f \Sigma X + c_f \Sigma \frac{1}{X}$$

*EQUATION*

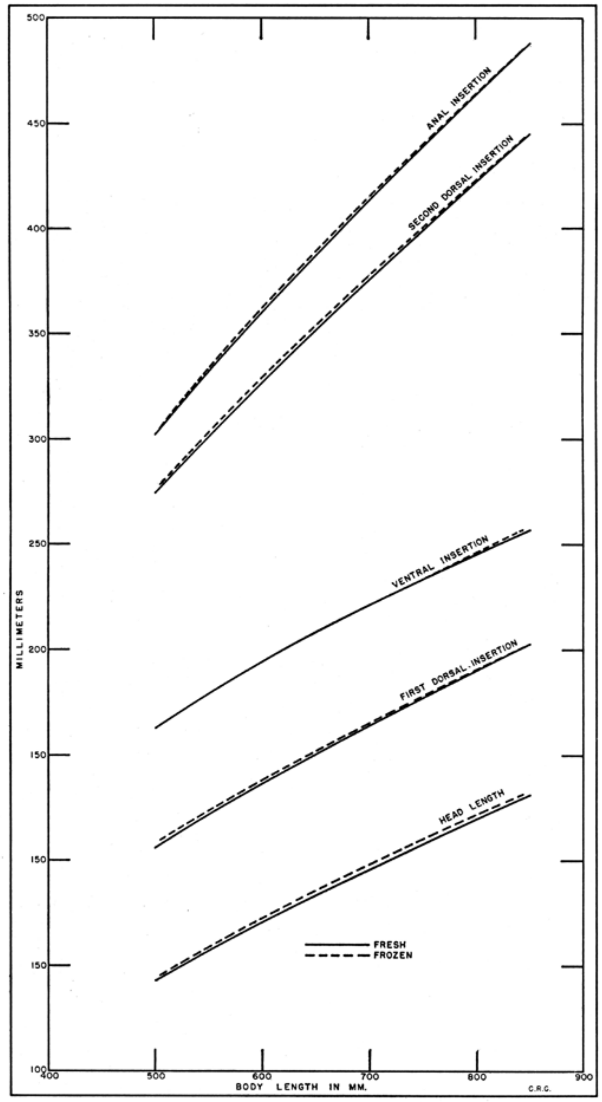


**FIGURE 1.** A comparison of the regression lines derived from measurements made upon the 1948 Hawaiian sample before and after freezing and cold storage

*FIGURE 1. A comparison of the regression lines derived from measurements made upon the 1948 Hawaiian sample before and after freezing and cold storage*

where subscript f designates the respective quantity pertaining to the fresh regression line. As [EY] is required only over the range of the frozen sample, N, [EX] and [E 1/X] would theoretically be the same in both lines and actually equal, respectively, to the total number of ordinates and the sum of all the [X's and 1/X's] within this range. As these values are not available, and in the case of the [1/X's], not readily obtainable, it will suffice for the present purpose to use the values of N, [EX]and [E 1/X] derived from the frozen sample, which will yield a close approximation to the required values. Combining the two equations will then give the total difference in the sum of the ordinates of the two curves, thus:

$$\Sigma Y_z - \Sigma Y_f = N(a_z - a_f) + \Sigma X(b_z - b_f) + \Sigma \frac{1}{X}(c_z - c_f).$$

*EQUATION*

If this difference is divided by N, the quotient tells the actual average linear distance separating the two regression lines, and the sign of the difference confirms the direction of displacement of the frozen variates.

The magnitudes of the present average differences, thus determined, are as follows:

| Head length | 1st dorsal | 2d dorsal | Anal | Ventral |
|---|---|---|---|---|
| + 1.839 mm. | + 1.772 mm. | + 2.166 mm. | + 1.149 mm. | + 0.085 mm. |

Therefore for the five characters discussed the effects of freezing and cold storage are such as to raise the frozen regression line, without appreciable change in slope, above the fresh line by linear distances corresponding approximately with those tabulated above. Hence in evaluating differences observed between frozen samples and fresh material a preliminary approximate correction of this magnitude will probably enhance the validity of such comparisons.

The mechanics of applying the correction are simple. As the slope of the respective fresh and frozen line of a sample is to all intents the same, the correction may be applied directly to "a," which determines the relative height of the line. The correction may either be added to the "a" of the comparative fresh line, or subtracted from the "a" of the frozen sample line. If, for example, the appropriate correction of 1.839 mm. in the case of head length is subtracted from the value of "a" derived from the frozen line of the Hawaiian sample, the two regression lines, i.e., the fresh and the frozen line, should then be the same. That this is so is shown by Table 2 in which the figures shown are, for each

**TABLE 2**

**The Average Squared Distance in Millimeters Between the "Fresh" and the Adjusted "Frozen" Line of the Hawaiian Sample. The Magnitude of "the Difference Between Lines" Reflects the Accuracy of the Applied Correction**

| | Head length | First dorsal | Second dorsal | Anal | Ventral |
|---|---|---|---|---|---|
| Variance from fresh line | 7.2780 | 10.9585 | 14.2923 | 12.2166 | 10.2763 |
| Variance from corrected frozen line | 7.2761 | 10.9575 | 14.2921 | 12.2169 | 10.2763 |
| Difference between lines | .0019 | .0010 | .0002 | —.0003 | .0000 |

*TABLE 2*

***The Average Squared Distance in Millimeters Between the "Fresh" and the Adjusted "Frozen" Line of the Hawaiian Sample. The Magnitude of "the Difference Between Lines" Reflects the Accuracy of the Applied Correction***

regression, the difference in variance of the frozen variates deviated, first from the fresh regression line, and secondly from the frozen line to which the correction factor has been applied.

While the directional effect of freezing upon the resulting variates is consistent throughout, the magnitude of this displacement should be further investigated. Until better factors are available, the present approximations will be used in this discussion.

# 4. COMPARISON OF CENTRAL PACIFIC STOCK WITH THAT OF THE EASTERN PACIFIC

For the five characters discussed, the population regressions for the local or eastern Pacific stock of yellowfin tuna are given by the function

$$Y = a + bX + c\frac{1}{X}$$

*EQUATION*

in which the constant and coefficients have the values (ascertained in the earlier study) tabulated below.

| *Regression (on body length)* | *a* | *b* | *c* | *Mean square* |
|---|---|---|---|---|
| Head length | 83.27424 | .212240 | -20,467.8084 | 9.6352 |
| First dorsal | 95.19221 | .226156 | -23,086.8236 | 15.9386 |
| Second dorsal | 111.91554 | .441629 | -27,416.5652 | 20.5399 |
| Anal | 88.79915 | .515977 | -18,202.4687 | 25.2867 |
| Ventral | 58.22874 | .257736 | -9,616.8242 | 19.3271 |

If these lines are used empirically to define the eastern Pacific stock, the individual central Pacific samples may then be compared directly with them, using the standard method of analysis of variance. The results summarized in Table 3 are derived uniformly from the analysis illustrated below, using the raw data without adjustment for the effects of freezing. The F values for the Palmyra and Fijian samples are much larger when this correction is applied.

1948 Hawaiian Sample

| *Source of variation* | *Sum of squares* | *D. F.* | *Mean square* |
|---|---|---|---|
| Deviations from empirical eastern Pacific line | 8,431.9038 | 79 | |
| Deviations from Hawaiian sample line | 1,149.0067 | 76 | 15.1185 |
| Difference between lines | 7,282.8971 | 3 | 2,427.6324 |

$$F = \frac{2{,}427.6324}{15.1185} = 160.5736: \ P = \text{less than } .001$$

*EQUATION*

From such an analysis one must conclude that the central Pacific stock of yellowfin tuna is distinct from, and in all probability noninter-mingling with, that of the eastern Pacific.

While the probabilities thus derived are convincingly high, it must be recalled that in the earlier study similar methods showed that the several samples derived from the eastern Pacific differed significantly in a statistical sense, although the actual differences between the respective lines was small. On page 8 of the earlier study this problem is discussed, and the concept of biological homogeneity is contrasted with that of statistical homogeneity. This led to the use of the average squared distance separating lines as a criterion for evaluating results.

TABLE 3

**Summary Comparison, by Means of Analysis of Variance, of Individual Central Pacific Samples With Empirical Eastern Pacific Population Regression Lines**
**No Correction Has Been Applied for the Effects of Freezing**

| Regression | 1948 Hawaiian | | | Palmyra | | | Fijian | | |
|---|---|---|---|---|---|---|---|---|---|
| | D. F. | F Value | Probability | D. F. | F Value | Probability | D. F. | F Value | Probability |
| Head length | 3/76 | 160.57 | Less than .001 | 3/91 | 76.49 | Less than .001 | 3/10 | 24.00 | Less than .001 |
| First dorsal | 3/76 | 40.69 | Less than .001 | 3/91 | 22.14 | Less than .001 | 3/10 | 8.98 | Between .01 and .001 |
| Second dorsal | 3/76 | 23.97 | Less than .001 | 3/90 | 49.81 | Less than .001 | 3/10 | 6.25 | About .01 |
| Anal insertion | 3/76 | 100.77 | Less than .001 | 3/91 | 144.72 | Less than .001 | 3/10 | 14.18 | Less than .001 |
| Ventral insertion | 3/76 | 127.85 | Less than .001 | 3/91 | 121.65 | Less than .001 | 3/ 9 | 27.71 | Less than .001 |

*TABLE 3*
***Summary Comparison, by Means of Analysis of Variance, of Individual Central Pacific Samples With Empirical Eastern Pacific Population Regression Lines No Correction Has Been Applied for the Effects of Freezing***

Table 4 is a reproduction of Tables 4 and 5 of Fish Bulletin No. 70. Samples 1 to 13 are derived from the eastern Pacific, and all "differences" discussed are measured from the corresponding empirical eastern Pacific population line. The Japanese, Hawaiian and Peruvian samples are the original ones discussed in the earlier study shown here for comparison with present results. The tabulated values of this table give an estimate of the extent of divergence that can be anticipated from any sample derived from the eastern Pacific population of yellowfin tuna. Also, they afford, with the empirical regression line, a means of deciding the identity or distinctness of populations elsewhere in the Pacific. Accordingly, in the following discussion the sample regression lines for the three recent samples from the central Pacific are compared, graphically and numerically, with the corresponding regression line characterizing the local population.

**TABLE 4**

**The Difference Between the Individual Sample Regression Lines and the Eastern Pacific Population Regression Line, Expressed in Terms of the Difference in Mean Squares. This Table Is a Reproduction of Tables 4 and 5 of Fish Bulletin No. 70**

| Sample | Head length | First dorsal | Second dorsal | Anal | Ventral |
|---|---|---|---|---|---|
| No. 1 | 0.853 | 0.349 | 2.318 | 10.755 | 5.027 |
| No. 2 | 0.411 | 0.938 | 6.943 | 4.428 | 1.081 |
| No. 3 | 0.351 | 1.773 | 1.267 | 14.946 | 0.702 |
| No. 4 | 1.761 | 0.979 | 0.797 | 1.964 | 0.700 |
| No. 5 | 0.754 | 0.292 | 0.334 | 0.190 | 0.541 |
| No. 6 | 0.124 | 0.853 | 1.373 | 1.388 | 2.513 |
| No. 7 | 1.427 | 3.471 | 2.067 | 3.784 | 6.079 |
| No. 8 | 1.754 | 2.876 | 2.353 | 4.798 | 1.272 |
| No. 9 | 0.673 | 0.809 | 0.876 | 3.367 | 0.336 |
| No. 10 | 0.287 | 0.077 | 0.024 | 2.166 | 0.958 |
| No. 11 | 0.881 | 1.283 | 2.814 | 10.864 | 0.166 |
| No. 12 | 2.333 | 1.778 | 2.793 | 7.795 | 1.204 |
| No. 13 | 1.568 | 0.616 | 0.237 | 3.115 | 0.841 |
| Japan | 284.809 | 92.283 | 21.588 | 17.381 | 214.860 |
| Hawaii | 20.255 | 1.330 | 0.249 | 27.638 | 37.622 |
| Peru | 6.143 | 22.652 | 38.333 | 160.112 | 5.026 |

*TABLE 4*

***The Difference Between the Individual Sample Regression Lines and the Eastern Pacific Population Regression Line, Expressed in Terms of the Difference in Mean Squares. This Table Is a Reproduction of Tables 4 and 5 of Fish Bulletin No. 70***

In the case of the Hawaiian sample two separate comparisons with the local population were made. One was based upon the sample obtained by the N. B. SCOFIELD, and the other upon this sample plus the market measurements. The results of the two comparisons were in essential agreement. However, differences were in some cases accentuated in the analysis based upon the combined sample because in these proportions the slope of the lines characterizing the local and Hawaiian populations differed, and the divergence between the lines increased with increase in size of fish. Because the extended regression lines based upon the greater size range give a better picture of differences and similarities, the present comparison of the Hawaiian with the local population is based upon the total Hawaiian sample, including the market fish.

In Figures 2 to 6 the regression line characterizing the local population is represented by the long-dashed line. The short-dashed line is that of the Hawaiian sample: the solid line is the comparable regression line of the Palmyra sample, while the dash-dot line is that of the Fijian sample. In the computations an adjustment has been made for the effects of freezing.

## 4.1. HEAD LENGTH ON BODY LENGTH

Figure 2 shows that in the regression of head length upon body length the four lines differ appreciably. Selecting the local population line as a base for comparison, the regression lines of the Hawaiian and Fijian samples are in parts roughly parallel to this but removed from it a minimum distance of six to nine millimeters which is considerably in excess of anticipated variation for the samples from the eastern Pacific. Moreover, both these lines diverge progressively with increasing size of fish, indicating a slightly lesser slope. The regression line of the Palmyra sample has a decidedly different slope. Starting higher than the local line the Palmyra sample line intersects the local line at approximately 700 mm. body length, and from this point diverges increasingly at higher values. In the upper range the three central Pacific samples are in general similar. All possess a lesser slope and all fall, predominantly, appreciably below the eastern Pacific population line. The corresponding numerical values of this divergence are shown in Table 5. The differences

**TABLE 5**

**Difference in Mean Squares Calculated From Sample and Eastern Pacific Population Regression Lines. Palmyra and Fijian Sample Regressions Have Been Adjusted for the Effects of Freezing**

| Sample | Head length | First Dorsal | Second Dorsal | Anal | Ventral |
|---|---|---|---|---|---|
| Hawaiian | 92.1886 | 39.4118 | 28.4660 | 115.9449 | 109.5313 |
| Palmyra | 64.2164 | 36.8743 | 95.3632 | 260.4178 | 83.1996 |
| Fiji | 127.5253 | 67.5339 | 57.5855 | 184.1002 | 77.1631 |
| Maximum local difference | 2.333 | 3.471 | 6.943 | 14.980 | 6.079 |

*TABLE 5*

***Difference in Mean Squares Calculated From Sample and Eastern Pacific Population Regression Lines. Palmyra and Fijian Sample Regressions Have Been Adjusted for the Effects of Freezing***

in mean squares are excessively higher than in any sample obtained from the local population. In this character, therefore, the data indicate that the central Pacific stock differs from that of the eastern Pacific.

## 4.2. FIRST DORSAL INSERTION ON BODY LENGTH

In this regression (Figure 3) the Hawaiian and Fijian sample lines are again similar. Both are approximately parallel to the eastern Pacific line but lie at a distance of five to eight millimeters below it. Again the Palmyra line has a different slope. It intercepts the local line at about 740 mm. body length, and its divergence increases from this point on. The graph, in conjunction with the numerical values in Table 5, suggests that in this character also the central Pacific stock differs from that of the eastern Pacific, although the differences are not as pronounced as in the head length.

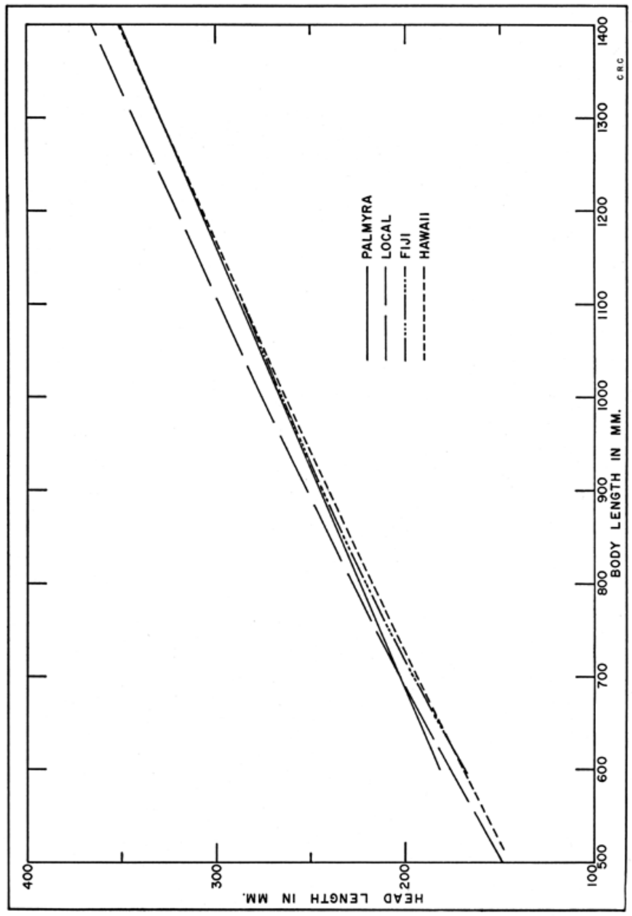


FIGURE 2. Comparison of the regression of head length on body length in the three central Pacific samples with the eastern Pacific population line

*FIGURE 2. Comparison of the regression of head length on body length in the three central Pacific samples with the eastern Pacific population line*

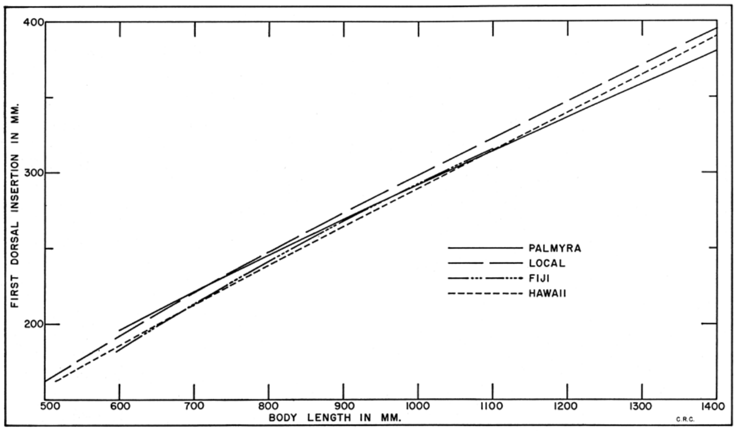


FIGURE 3. Comparison of the regression of first dorsal insertion on body length in the three central Pacific samples with the eastern Pacific population line

*FIGURE 3. Comparison of the regression of first dorsal insertion on body length in the three central Pacific samples with the eastern Pacific population line*

## 4.3. SECOND DORSAL INSERTION ON BODY LENGTH

In this character (Figure 4) the differences between the various samples are less than in any other. The Hawaiian and Palmyra samples are similar. Both have a slightly lesser slope, that of Palmyra being the least, and both lie slightly below the eastern Pacific line. In terms of mean square difference this divergence is many times greater than would be anticipated in samples from the local population. The two samples can therefore be considered different from the eastern Pacific stock.

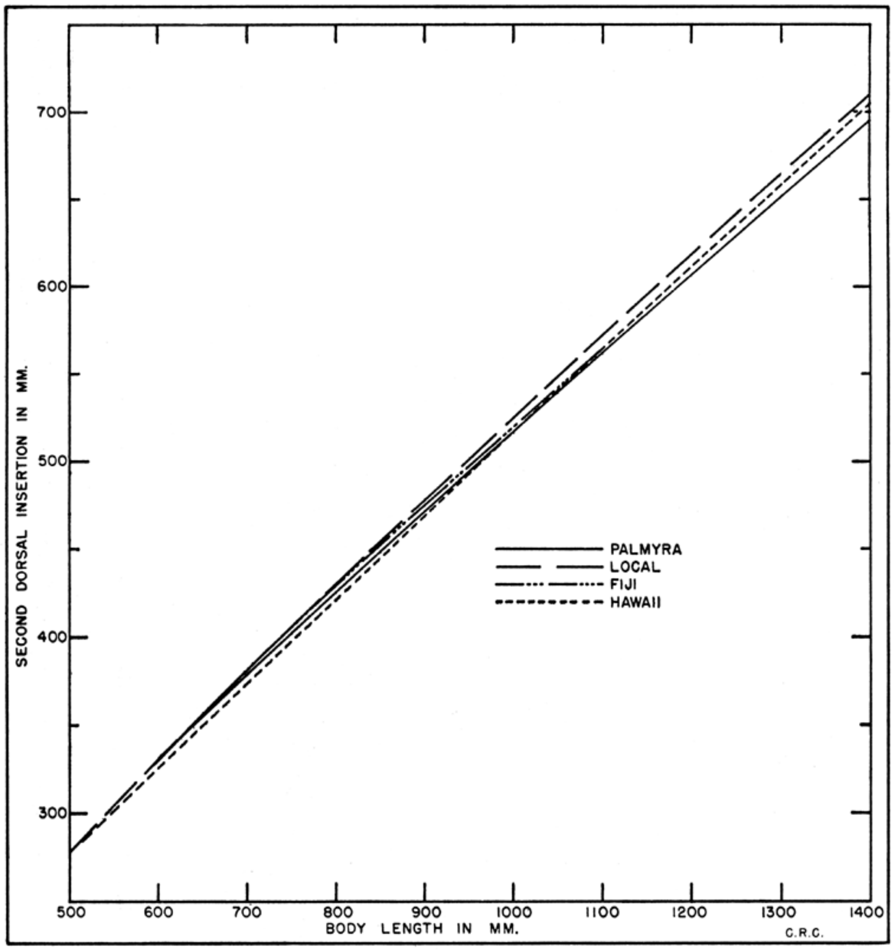


**FIGURE 4. Comparison of the regression of second dorsal insertion on body length in the three central Pacific samples with the eastern Pacific population line**

*FIGURE 4. Comparison of the regression of second dorsal insertion on body length in the three central Pacific samples with the eastern Pacific population line*

The Fijian sample is intermediate. The lower portion of this line is coincident with or extremely close to the eastern Pacific line, but from approximately 800 mm. body length the former diverges more and more, to approximate eventually the Hawaiian and Palmyra lines. In terms of mean square difference this divergence is several times greater than anticipated variation in local samples. To this extent the Fijian sample may also be considered distinct from the eastern Pacific stock.

## 4.4. ANAL INSERTION ON BODY LENGTH

Figure 5, illustrating this regression, is in general similar to the foregoing. The differences, however, are more pronounced. The Hawaiian

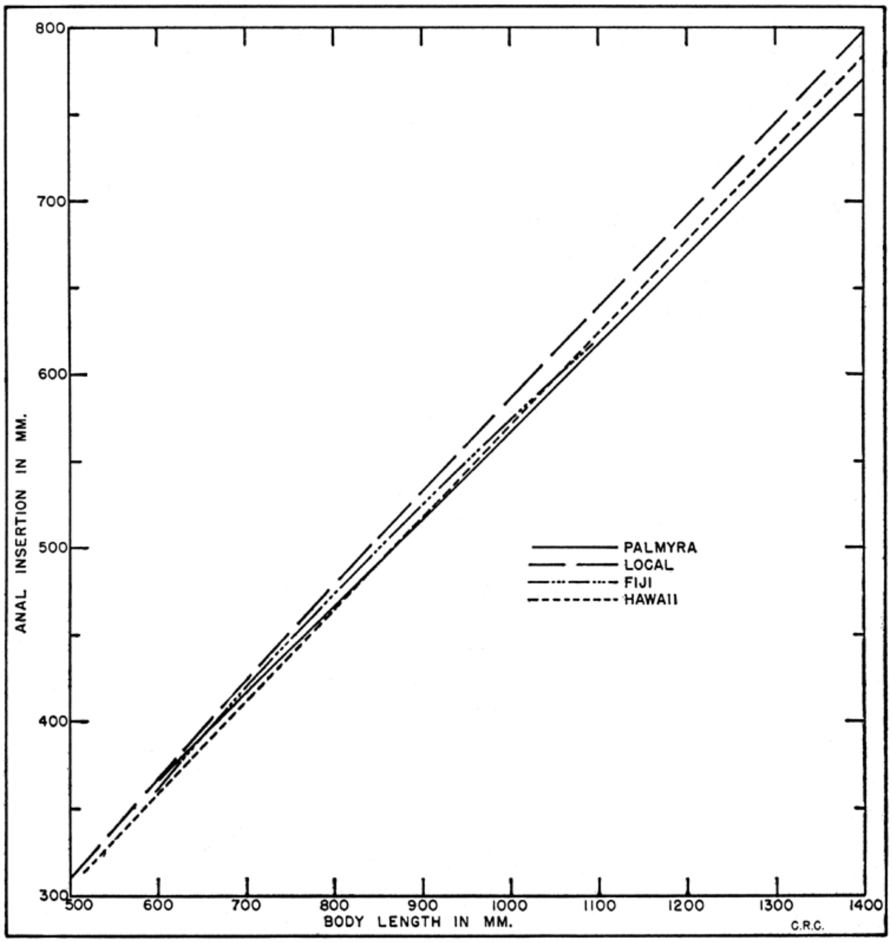


**Figure 5.** Comparison of the regression of anal insertion on body length in the three central Pacific samples with the eastern Pacific population line

*FIGURE 5. Comparison of the regression of anal insertion on body length in the three central Pacific samples with the eastern Pacific population line*

and Palmyra samples, with mean square differences of 116 and 260 respectively, are clearly distinct from the eastern Pacific population. The Fijian sample is again intermediate in position. Over the lower portion of its range it lies closer to the eastern Pacific line than to the other central Pacific sample lines. As in the case of the second dorsal, it subsequently diverges from the local line to approximate at its upper extremity the Hawaiian and Palmyra samples. The mean square difference is excessively greater than any derived from a local sample, and on this basis the Fijian stock must be considered distinct from that of the eastern Pacific.

## 4.5. VENTRAL INSERTION ON BODY LENGTH

Figure 6, depicting this character, shows that the central Pacific samples are clearly distinct from the eastern Pacific stock. All central Pacific samples have a comparable slope and position, which differs appreciably from that of the eastern Pacific population. The mean square differences confirm the conclusion that in this character the central Pacific stock is clearly differentiated from that of the eastern Pacific.

## 4.6. DISCUSSION

In the five characters discussed all central Pacific samples diverge in every case from the eastern Pacific regression lines by amounts far in excess of anticipated variation of local samples. These numerical differences are reflected in the majority of the graphs. Visual inspection of the latter would alone suggest that the central Pacific stock differed in at least three characters. In general the slope of the central Pacific regression lines is less than that of the eastern Pacific lines. Excluding intersection at the lower size range, every central Pacific regression line falls below that of the eastern Pacific population line. In view of the fact that the foregoing observations are supported by extremely high F values resulting from application of analysis of variance, one must conclude that the central Pacific stock is distinct from that of the eastern Pacific.

## 4.7. COMPARISON WITH EARLIER RESULTS

It is of interest at this point to compare the above findings with those published in 1948. In that study the results showed that the Hawaiian fish differed significantly in three characters, the head length, anal and ventral insertions. In these three characters the Hawaiian specimens fell distinctly below the eastern Pacific population line. These results led to a tentative conclusion that the Hawaiian stock was different from that of the eastern Pacific, and hence to the assumption that if such were correct, then subsequent samples of Hawaiian yellowfin should differ from those of the eastern Pacific in like manner. In the original study, the head length, anal insertion and ventral insertion of the Hawaiian sample differed significantly from the corresponding eastern Pacific line, with the Hawaiian values falling distinctly below the latter. In the present study it is these three characters that differ most, and again the sample values fall appreciably below the local line. In the remaining two regressions, the first and second dorsal insertions, there were no significant differences in the earlier comparison, whereas in the present study the Hawaiian sample yields significant F values and large mean square differences. However, these values are not as great as in the remaining three regressions. In all cases the present Hawaiian regression lines fall below the eastern Pacific lines. A comparison of the two Hawaiian samples by means of analysis of variance indicates that no significant differences exist between the two samples in four of the five regressions tested. In one, the regression of ventral insertion upon body length, the resulting F value indicates a probability approximating the 1 percent level of significance. In Figure 6 the short regression line of the original Hawaiian sample is shown for comparison. It has been omitted in the remaining figures because the line of this sample approximates the others so closely as to preclude reproduction. In general, the

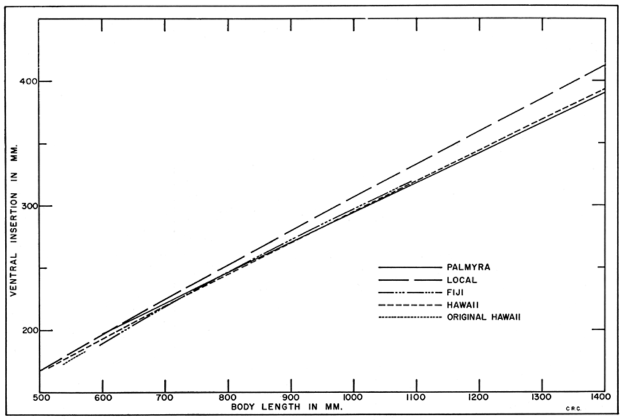


FIGURE 6. Comparison of the regression of ventral insertion on body length in the three central Pacific samples with the eastern Pacific population line

*FIGURE 6. Comparison of the regression of ventral insertion on body length in the three central Pacific samples with the eastern Pacific population line*

present data are in close agreement with the original findings, and support the preliminary conclusions. The probability of their correctness is therefore considerably augmented.

# 5. HOMOGENEITY OF THE CENTRAL PACIFIC STOCK

Though beyond the original intent of this investigation it is nonetheless interesting to investigate the homogeneity of the central Pacific stock of yellowfin tuna. For this purpose four samples are available, namely, the three discussed in this paper, and the original Hawaiian sample of 12 fish.

If these four samples are combined into a single, central Pacific sample, the homogeneity of this stock may be tested by means of analysis of variance, in which the sums of squares of the several samples, measured from the individual sample lines, are added together and compared (with the corresponding degrees of freedom) with the sums of squares measured from the combined sample line, thus:

| *Source of variation* | *Sum of Squares* | *D.F.* | *Mean square* |
|---|---|---|---|
| Deviations from combined central Pacific line | 4,162.1089 | 195 | |
| Deviations from (4) individual sample lines | 2,936.4299 | 186 | 15.7873 |
| Difference between lines | 1,225.6790 | 9 | 136.1866 |

$$F = \frac{136.1866}{15.7873} = 8.626 \qquad P = \text{less than } .001$$

*EQUATION*

A summary of such analyses is shown with the resulting probabilities in Table 6. In these comparisons no correction has been made for the effects of freezing. From this it appears that the central Pacific stock may not be considered statistically homogeneous.

**TABLE 6**

**Summary of Results of a Test of Homogeneity, Using Analysis of Variance, of the Four Central Pacific Samples**

| Regression | D. F. | F Value | Probability |
|---|---|---|---|
| Head Length | 9/186 | 8.63 | Less than .001 |
| 1st Dorsal | 9/186 | 6.60 | Less than .001 |
| 2nd Dorsal | 9/185 | 3.01 | About .001 |
| Anal | 9/186 | 4.62 | Less than .001 |
| Ventral | 9/185 | 1.96 | About .05 |

*TABLE 6*

***Summary of Results of a Test of Homogeneity, Using Analysis of Variance, of the Four Central Pacific Samples***

A study of the graphs (Figures 2 3 4 5 6) will show that in one character, the ventral insertion, all the central Pacific samples are extremely similar. In the remaining four there is at some point in the range a considerable spread in position. Moreover, the differences are not consistent. In two regressions, the second dorsal and anal insertions, the Palmyra and Hawaiian samples are more akin, with the Fijian sample divergent; while in the remaining two, the head length and the first dorsal insertion, the Fijian and Hawaiian samples are more alike, with the Palmyra sample differing. In general, the Palmyra sample, by reason of a consistently lesser slope, appears to be the nonconforming one, suggesting a possible difference in origin or stock.

If one uses the regressions of the Hawaiian sample collected in 1948 as reference lines, and computes the differences between the divergence of the other central Pacific samples from these reference lines and from their own sample regression lines, the results are those shown in Table 7. In this, the original Hawaiian sample, the Palmyra and the Fijian sample have been adjusted for the effects of freezing.

**TABLE 7**

**The Differences Between the Mean Squares Computed From the Sample Lines, and From the 1948 Hawaiian Line**

| Sample | Head length | First dorsal | Second dorsal | Anal | Ventral |
|---|---|---|---|---|---|
| Original Hawaiian | 0.7342 | 8.7845 | 3.8639 | 10.1443 | 11.5125 |
| Palmyra | 18.5727 | 23.1484 | 7.7171 | 16.2261 | 2.3953 |
| Fijian | 2.1464 | 4.1861 | 10.1561 | 22.5980 | 4.6425 |

*TABLE 7*

***The Differences Between the Mean Squares Computed From the Sample Lines, and From the 1948 Hawaiian Line***

In a comparison of the Palmyra sample with the 1948 Hawaiian lines, the mean square differences are high in the case of head length, first dorsal insertion and anal insertion. In the case of the anal insertion the difference is only slightly in excess of observed variation within the eastern Pacific stock, whereas in the regression of head length and first dorsal the divergence is much greater than one would anticipate in a homogeneous stock. This suggests the need for further study, and indicates a probable difference between the Palmyra and Hawaiian stocks of yellowfin.

In the comparison of the Fijian with the Hawaiian stock, the mean square differences are relatively high in the case of the second dorsal and the anal insertion. In view of this one must conclude from the present data that there are indications of differences between the Fijian and Hawaiian stocks, but further studies based on larger samples of fresh material are needed to confirm this.

The two Hawaiian samples are very similar in head length and second dorsal insertion, and relatively so in the case of anal insertion. In the two remaining characters the differences are in excess of the maximum divergence recorded for the eastern Pacific stock. However, one important consideration must be kept in mind in evaluating all these comparisons. In measuring the divergence in samples from the eastern Pacific, this was done from relatively accurate parameters obtained by combining all (13) samples. The resulting regressions are therefore averages, and the divergence from these averages of any one sample would be less than the corresponding differences between extreme samples. The present comparisons of individual samples from the central Pacific, however, are between samples, and therefore greater resulting differences must be anticipated. Until such time as more reliable population parameters become available, the present results must be considered only indicative.

In general, this preliminary survey shows that the several central Pacific samples differ appreciably from one another in some regressions, leading to a suspicion that the stock may be composed of two or more distinct units. In particular, the consistently lesser slope of the Palmyra sample merits investigation.

# 6. SUMMARY AND CONCLUSIONS

This study was designed to test the preliminary conclusion that the stock of yellowfin tuna in the central pacific differs from that of the eastern Pacific.

Three additional samples were obtained from the central Pacific, originating respectively in the Hawaiian, Palmyra and Fijian area.

Standard methods of analysis of variance are employed, and these are supplemented by an objective comparison of regression lines in terms of the mean square distance separating them.

The effects of freezing and cold storage of samples are investigated. The proportional change in measurements and the displacement of the resulting regression lines is small but consistent. Approximate corrections for this effect are developed.

Results of this study confirm the earlier findings and enhance considerably the probability that the central Pacific stock is distinct from and nonintermingling with that of the eastern Pacific.

A comparison of the four samples available from the central Pacific does not warrant positive conclusions. There are, however, indications that the stock within this large region may itself consist of separate discrete units. In particular, the Palmyra sample regression lines have a consistently lesser slope.

# 7. REFERENCES


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# APPENDICES

# APPENDIX A

## APPENDIX A

### HAWAIIAN SAMPLE

"N. B. Scofield" catch plus market specimens

| Body length | Head length | 1st dorsal insertion | 2d dorsal insertion | Anal insertion | Ventral insertion |
|---|---|---|---|---|---|
| | | "N. B. Scofield" catch | | | |
| mm. | mm. | mm. | mm. | mm. | mm. |
| 514 | 146 | 160 | 283 | 312 | 163 |
| 526 | 150 | 168 | 286 | 314 | 171 |
| 529 | 151 | 161 | 290 | 315 | 172 |
| 532 | 157 | 171 | 297 | 327 | 176 |
| 534 | 153 | 167 | 287 | 316 | 173 |
| 535 | 147 | 166 | 289 | 318 | 168 |
| 538 | 157 | 172 | 295 | 327 | 180 |
| 545 | 156 | 172 | 303 | 335 | 176 |
| 548 | 157 | 169 | 302 | 334 | 179 |
| 549 | 157 | 173 | 302 | 333 | 183 |
| 553 | 159 | 174 | 304 | 335 | 182 |
| 554 | 158 | 170 | 303 | 332 | 181 |
| 558 | 158 | 168 | 301 | 332 | 182 |
| 561 | 161 | 175 | 303 | 341 | 181 |
| 562 | 161 | 179 | 312 | 344 | 184 |
| 564 | 159 | 171 | 305 | 336 | 179 |
| 565 | 162 | 178 | 312 | 342 | 184 |
| 567 | 162 | 178 | 313 | 343 | 187 |
| 567 | 160 | 179 | 312 | 344 | 184 |
| 567 | 163 | 179 | 308 | 338 | 185 |
| 568 | 162 | 177 | 313 | 345 | 192 |
| 569 | 160 | 174 | 316 | 342 | 180 |
| 569 | 162 | 176 | 310 | 339 | 187 |
| 570 | 160 | 178 | 312 | 341 | 183 |
| 571 | 162 | 172 | 304 | 338 | 188 |
| 572 | 162 | 175 | 311 | 348 | 189 |
| 573 | 168 | 180 | 313 | 347 | 194 |
| 573 | 164 | 181 | 318 | 351 | 190 |
| 576 | 163 | 177 | 314 | 349 | 187 |
| 578 | 163 | 184 | 317 | 346 | 188 |
| 579 | 169 | 182 | 320 | 354 | 190 |
| 582 | 168 | 186 | 317 | 355 | 192 |
| 583 | 163 | 177 | 315 | 351 | 184 |
| 583 | 167 | 181 | 321 | 353 | 193 |
| 584 | 161 | 177 | 316 | 346 | 183 |
| 584 | 163 | 179 | 320 | 356 | 182 |
| 588 | 163 | 183 | 317 | 351 | 186 |
| 590 | 168 | 183 | 321 | 354 | 195 |
| 594 | 170 | 187 | 326 | 357 | 197 |
| 597 | 167 | 182 | 323 | 358 | 191 |
| 598 | 172 | 186 | 330 | 363 | 196 |
| 600 | 169 | 186 | 324 | 360 | 194 |
| 613 | 179 | 191 | 334 | 366 | 197 |
| 628 | 174 | 195 | 342 | 375 | 197 |
| 632 | 181 | 202 | 343 | 375 | 205 |
| 652 | 185 | 200 | 349 | 386 | 206 |
| 816 | 227 | 249 | 431 | 479 | 255 |
| 816 | 225 | 246 | 430 | 466 | 255 |
| 821 | 224 | 248 | 427 | 470 | 249 |
| 825 | 222 | 242 | 439 | 469 | 247 |
| 836 | 227 | 247 | 436 | 483 | 252 |
| 837 | 227 | 247 | 434 | 483 | 250 |
| 846 | 230 | 255 | 451 | 491 | 255 |
| 846 | 232 | 250 | 444 | 490 | 259 |
| 851 | 230 | 250 | 443 | 488 | 257 |



*HAWAIIAN SAMPLE*
*"N. B. Scofield" catch plus market specimens*

**HAWAIIAN SAMPLE—Continued**

| Body length | Head length | 1st dorsal insertion | 2d dorsal insertion | Anal insertion | Ventral insertion |
|---|---|---|---|---|---|
| | | Market specimens | | | |
| mm. | mm. | mm. | mm. | mm. | mm. |
| 519 | 150 | 165 | 285 | 314 | 169 |
| 889 | 237 | 261 | 468 | 513 | 265 |
| 896 | 242 | 264 | 472 | 526 | 275 |
| 1,186 | 302 | 332 | 614 | 675 | 345 |
| 1,332 | 330 | 383 | 673 | 743 | 366 |
| 1,349 | 335 | 378 | 678 | 766 | 384 |
| 1,355 | 335 | 378 | 688 | 759 | 378 |
| 1,361 | 336 | 369 | 689 | 771 | 378 |
| 1,370 | 343 | 384 | 690 | 771 | 382 |
| 1,375 | 339 | 387 | 697 | 764 | 382 |
| 1,379 | 341 | 375 | 676 | 757 | 376 |
| 1,405 | 352 | 379 | 694 | 768 | 402 |
| 1,405 | 348 | 384 | 703 | 783 | 396 |
| 1,410 | 361 | 393 | 716 | 790 | 401 |
| 1,416 | 363 | 399 | 721 | 789 | 405 |
| 1,445 | 356 | 384 | 724 | 812 | 400 |
| 1,450 | 365 | 411 | 731 | 813 | 412 |
| 1,457 | 369 | 406 | 721 | 830 | 415 |
| 1,465 | 358 | 402 | 742 | 829 | 403 |
| 1,469 | 369 | 402 | 726 | 825 | 412 |
| 1,477 | 369 | 414 | 749 | 821 | 412 |
| 1,479 | 366 | 407 | 739 | 822 | 409 |
| 1,555 | 388 | 442 | 779 | 873 | 430 |
| 1,638 | 419 | 463 | 840 | 911 | 466 |
| | | **Totals** | | | |
| $\Sigma Y$ | 17,596 | 19,377 | 34,503 | 38,168 | 19,878 |
| No. | 79 | 79 | 79 | 79 | 79 |
| $\Sigma X$ | 65,850 | 65,850 | 65,850 | 65,850 | 65,850 |
| $\Sigma X^2$ | 65,532,664 | 65,532,664 | 65,532,664 | 65,532,664 | 65,532,664 |
| $\Sigma \frac{1}{X}$ | .1105654308 | .1105654308 | .1105654308 | .1105654308 | .1105654308 |
| $\Sigma \left(\frac{1}{X}\right)^2$ | .0001717413321 | .0001717413321 | .0001717413321 | .0001717413321 | .0001717413321 |
| $\Sigma \frac{1}{X} Y$ | 21.62566004 | 23.74758018 | 42.03403043 | 46.42339229 | 24.50829696 |
| $\Sigma XY$ | 17,086,214 | 18,873,311 | 33,814,845 | 37,473,576 | 19,242,824 |
| $\Sigma Y^2$ | 4,470,350 | 5,450,727 | 17,472,291 | 21,451,350 | 5,675,070 |
| a | 65.843326 | 53.239415 | 55.65728626 | 32.73999612 | 63.11696195 |
| b | .2107177273 | .2449711919 | .4674080979 | .53534166 | .2405700836 |
| c | —13,398.26635 | —8,685.05428 | —6,084.6219 | +2,978.2546 | —8,590.20758 |
| Mean square | 14.5444 | 24.53655 | 30.08167 | 29.1489 | 21.7039 |

*HAWAIIAN SAMPLE*

**PALMYRA SAMPLE**

| Body length | Head length | 1st dorsal insertion | 2d dorsal insertion | Anal insertion | Ventral insertion |
|---|---|---|---|---|---|
| mm. | mm. | mm. | mm. | mm. | mm. |
| 594 | 169 | 185 | 328 | 357 | 189 |
| 651 | 188 | 199 | 349 | 390 | 205 |
| 652 | 197 | 215 | 364 | 391 | 212 |
| 654 | 192 | 209 | 354 | 392 | 210 |
| 656 | 192 | 210 | 358 | 396 | 207 |
| 669 | 195 | 215 | 363 | 403 | 216 |
| 670 | 200 | 219 | 369 | 396 | 215 |
| 681 | 202 | 223 | 381 | 414 | 220 |
| 683 | 204 | 213 | — | 408 | 218 |
| 691 | 203 | 221 | 375 | 417 | 220 |
| 697 | 197 | 217 | 370 | 406 | 217 |
| 705 | 208 | 231 | 382 | 425 | 226 |
| 713 | 212 | 238 | 394 | 424 | 222 |
| 718 | 201 | 218 | 383 | 424 | 228 |
| 719 | 207 | 226 | 387 | 424 | 227 |
| 727 | 213 | 232 | 393 | 428 | 236 |
| 727 | 213 | 231 | 395 | 435 | 227 |
| 733 | 207 | 236 | 394 | 432 | 228 |
| 741 | 211 | 233 | 394 | 441 | 232 |
| 744 | 214 | 224 | 397 | 444 | 236 |
| 750 | 213 | 234 | 407 | 445 | 232 |
| 750 | 216 | 240 | 408 | 453 | 233 |
| 751 | 213 | 235 | 404 | 436 | 233 |
| 752 | 211 | 230 | 400 | 450 | 233 |
| 758 | 211 | 226 | 398 | 448 | 231 |
| 760 | 217 | 243 | 414 | 447 | 236 |
| 764 | 223 | 242 | 411 | 451 | 245 |
| 770 | 216 | 233 | 399 | 449 | 237 |
| 772 | 218 | 239 | 411 | 448 | 241 |
| 781 | 229 | 248 | 419 | 454 | 251 |
| 782 | 223 | 238 | 414 | 464 | 247 |
| 785 | 228 | 245 | 420 | 466 | 249 |
| 787 | 221 | 242 | 413 | 448 | 242 |
| 790 | 216 | 235 | 414 | 455 | 240 |
| 795 | 227 | 250 | 429 | 470 | 250 |
| 807 | 230 | 246 | 422 | 468 | 243 |
| 815 | 220 | 239 | 422 | 471 | 247 |
| 818 | 228 | 248 | 425 | 460 | 253 |
| 834 | 232 | 258 | 450 | 481 | 256 |
| 840 | 243 | 259 | 456 | 507 | 269 |
| 843 | 231 | 260 | 439 | 481 | 252 |
| 861 | 233 | 256 | 454 | 482 | 253 |
| 862 | 231 | 256 | 450 | 497 | 261 |
| 862 | 240 | 266 | 463 | 507 | 264 |
| 864 | 236 | 253 | 448 | 496 | 261 |
| 875 | 240 | 258 | 456 | 499 | 269 |
| 877 | 240 | 275 | 466 | 504 | 262 |
| 880 | 239 | 259 | 458 | 500 | 262 |
| 883 | 232 | 257 | 451 | 514 | 260 |
| 883 | 245 | 268 | 465 | 516 | 269 |
| 886 | 236 | 258 | 457 | 511 | 264 |
| 893 | 242 | 264 | 468 | 520 | 275 |
| 897 | 241 | 267 | 470 | 520 | 272 |
| 903 | 245 | 266 | 483 | 516 | 271 |
| 906 | 248 | 268 | 470 | 520 | 281 |
| 910 | 248 | 269 | 479 | 522 | 273 |
| 917 | 249 | 271 | 481 | 529 | 273 |
| 918 | 249 | 274 | 480 | 527 | 275 |
| 919 | 254 | 279 | 487 | 517 | 278 |
| 920 | 246 | 273 | 484 | 541 | 273 |
| 925 | 250 | 265 | 483 | 536 | 277 |
| 928 | 249 | 269 | 481 | 532 | 275 |
| 934 | 249 | 272 | 477 | 537 | 279 |
| 939 | 248 | 274 | 482 | 537 | 279 |
| 940 | 254 | 278 | 480 | 545 | 284 |
| 944 | 259 | 289 | 500 | 540 | 280 |

*PALMYRA SAMPLE*

**PALMYRA SAMPLE—Continued**

| Body length | Head length | 1st dorsal insertion | 2d dorsal insertion | Anal insertion | Ventral insertion |
|---|---|---|---|---|---|
| 947 | 251 | 281 | 489 | 538 | 281 |
| 949 | 252 | 276 | 490 | 554 | 276 |
| 952 | 263 | 294 | 501 | 547 | 288 |
| 954 | 258 | 279 | 489 | 542 | 284 |
| 956 | 256 | 283 | 502 | 543 | 281 |
| 958 | 262 | 279 | 492 | 548 | 291 |
| 962 | 260 | 277 | 492 | 566 | 296 |
| 967 | 251 | 288 | 511 | 536 | 270 |
| 969 | 264 | 286 | 503 | 556 | 288 |
| 979 | 257 | 287 | 511 | 558 | 290 |
| 981 | 262 | 294 | 519 | 559 | 284 |
| 987 | 258 | 289 | 521 | 557 | 284 |
| 993 | 265 | 293 | 518 | 571 | 292 |
| 996 | 266 | 299 | 519 | 557 | 292 |
| 1,006 | 262 | 291 | 526 | 565 | 291 |
| 1,011 | 269 | 293 | 510 | 568 | 296 |
| 1,017 | 267 | 291 | 522 | 569 | 295 |
| 1,028 | 277 | 305 | 529 | 577 | 300 |
| 1,037 | 272 | 299 | 536 | 585 | 307 |
| 1,048 | 277 | 303 | 532 | 581 | 309 |
| 1,053 | 276 | 305 | 541 | 591 | 307 |
| 1,073 | 283 | 308 | 548 | 590 | 308 |
| 1,077 | 281 | 302 | 540 | 600 | 306 |
| 1,086 | 292 | 314 | 557 | 613 | 315 |
| 1,159 | 298 | 323 | 582 | 646 | 333 |
| 1,169 | 300 | 336 | 594 | 645 | 330 |
| 1,204 | 310 | 347 | 610 | 687 | 350 |
| 1,409 | 356 | 379 | 700 | 784 | 399 |

**Totals**

| | Head length | 1st dorsal insertion | 2d dorsal insertion | Anal insertion | Ventral insertion |
|---|---|---|---|---|---|
| $\Sigma Y$ | 22,439 | 24,570 | 42,562 | 47,197 | 24,724 |
| No. | 94 | 94 | 93 | 94 | 94 |
| $\Sigma X$ | 81,782 | 81,782 | 81,099 | 81,782 | 81,782 |
| $\Sigma X^2$ | 73,048,690 | 73,048,690 | 72,582,201 | 73,048,690 | 73,048,690 |
| $\Sigma \frac{1}{X}$ | .110865161 | .110865161 | .109401032 | .110865161 | .110865161 |
| $\Sigma \left(\frac{1}{X}\right)^2$ | .0001340887312 | .0001340887312 | .0001319450575 | .0001340887312 | .0001340887312 |
| $\Sigma \frac{1}{X} Y$ | 25.94737061 | 28.40337482 | 48.97087666 | 54.42859321 | 28.56546307 |
| $\Sigma XY$ | 19,922,256 | 21,818,368 | 37,964,472 | 42,018,676 | 21,969,215 |
| $\Sigma Y^2$ | 5,442,345 | 6,528,032 | 19,869,426 | 24,184,055 | 6,615,848 |
| a | 54.97026641 | 100.6969664 | 87.03146923 | 40.79405252 | 60.49083208 |
| b | .2110036685 | .2094130967 | .4409346815 | .5169120865 | .2374542630 |
| c | +139.74579 | —18,235.99675 | —11,803.25594 | +9,816.02154 | —3,442.22430 |
| Mean square | 16.72399 | 29.99339 | 36.08632 | 47.49337 | 20.40045 |

*PALMYRA SAMPLE*

## FIJIAN SAMPLE

| Body length | Head length | 1st dorsal insertion | 2d dorsal insertion | Anal insertion | Ventral insertion |
|---|---|---|---|---|---|
| mm. | mm. | mm. | mm. | mm. | mm. |
| 596 | 166 | 182 | 332 | 367 | 187 |
| 638 | 182 | 197 | 347 | 379 | 204 |
| 660 | 184 | 198 | 361 | 394 | 205 |
| 840 | 231 | 248 | 444 | 495 | 258 |
| 863 | 234 | 258 | 457 | 506 | 265 |
| 873 | 239 | 269 | 468 | 515 | 265 |
| 976 | 256 | 285 | 511 | 561 | 291 |
| 1,007 | 267 | 296 | 528 | 586 | 301 |
| 1,033 | 273 | 296 | 530 | 579 | 298 |
| 1,051 | 272 | 300 | 549 | 593 | 308 |
| 1,054 | 285 | 310 | 545 | 610 | — |
| 1,090 | 278 | 313 | 551 | 610 | 323 |
| 1,092 | 287 | 320 | 560 | 616 | 320 |
| **Totals** | | | | | |
| $\Sigma Y$ | 3,154 | 3,472 | 6,183 | 6,811 | 3,225 |
| No. | 13 | 13 | 13 | 13 | 12 |
| $\Sigma X$ | 11,773 | 11,773 | 11,773 | 11,773 | 10,719 |
| $\Sigma X^2$ | 11,040,153 | 11,040,153 | 11,040,153 | 11,040,153 | 9,929,237 |
| $\Sigma \frac{1}{X}$ | .01497421862 | .01497421862 | .01497421862 | .01497421862 | .01402545202 |
| $\Sigma \left(\frac{1}{X}\right)^2$ | .00001809845672 | .0000180984567 | .0000180984567 | .0000180984567 | .0000171982987 |
| $\Sigma \frac{1}{X} Y$ | 3.501277482 | 3.848725638 | 6.860832368 | 7.556250445 | 3.629844204 |
| $\Sigma XY$ | 2,944,541 | 3,245,299 | 5,774,894 | 6,362,147 | 2,973,839 |
| $\Sigma Y^2$ | 785,990 | 954,492 | 3,022,395 | 3,668,515 | 891,303 |
| a | 151.3411366 | 133.1939085 | 189.0146688 | 257.8553658 | 136.6157651 |
| b | .1619329046 | .2028449475 | .3845022769 | .3949112793 | .2015653571 |
| c | —48,074.0186 | —43,248.6260 | —53,487.6660 | —79,497.3202 | —40,994.63214 |
| Mean square | 12.4967 | 15.5646 | 17.4862 | 36.9349 | 8.1971 |

*FIJIAN SAMPLE*

# APPENDIX B
# OBSERVATIONS ON THE ANATOMY OF THE FIJIAN YELLOWFIN

In July, 1950, one of the local canners received a small shipment of yellowfin tuna from the Fiji Islands. Initial observations suggested that these fish differed slightly in appearance from locally caught yellowfin tuna. The caudal region appeared more elongate and the height of the second dorsal and anal fins seemed greater in proportion to body length. As the measurements made upon fish of this shipment were intended for a population study of yellowfin tuna, we took the precaution of acquiring two specimens of this lot for a more detailed study in order to determine whether or not they were actually Neothunnus macropterus.

Complete dissections were made of these two specimens according to the procedure described by Godsil and Byers (1944), and in every respect the condition in these Fijian specimens agreed with that described for N. macropteus. Variations encountered in the several systems examined were all within the limits observed in the earlier material, and diagnostic characters in every case identified these specimens positively with this species.

Regarding the observed apparent differences, the measurements show that the caudal region was in fact slightly more elongate than in the eastern Pacific stock. Figures 2 to 6 show that, for the central Pacific fish in general, the head length is shorter and the insertion of all the fins is more anterior than in the eastern Pacific stock. This slight difference was accentuated in appearance by the fact that the Fijian fish were relatively thin.

The apparent greater height of the second dorsal and anal fins was not substantiated by the measurements. The latter were well within the range established for the eastern Pacific population. Any difference in modal height that might exist would at most be of a population rather than a specific nature.

The several measurements and meristic counts made upon these two specimens are appended for the record.

**MEASUREMENTS AND COUNTS OBTAINED FROM TWO YELLOWFIN TUNA FROM THE FIJI ISLANDS**

**Measurements in millimeters**

| | Fish No. 1 | Fish No. 2 |
|---|---|---|
| External | | |
| Body length | 1,000 | 868 |
| Head length | 258 | 230 |
| Insertion 1st dorsal | 293 | 262 |
| Insertion 2d dorsal | 518 | 465 |
| Insertion anal fin | 564 | 512 |
| Insertion ventrals | 285 | 260 |
| Greatest body depth | 242 | 225 |
| (Location of above) | VI-VII dorsal spine | VII dorsal spine |
| Greatest body width | 180 | 167 |
| (Location of above) | VIII dorsal spine | V dorsal spine |
| Dorsal-ventral distance | 234 | 213 |
| Dorsal-anal distance | 361 | 327 |
| Length of 1st dorsal base | 236 | 213 |
| Length of pectoral | 292 | 251 |
| (Posterior extension of pectoral) | --- | 4th dorsal ray |
| Spread of caudal | --- | 287 |
| Height of 1st dorsal | --- | 95 (approx.) |
| Height of 2d dorsal | 165 | 121 (frayed) |
| Height of anal | 185 | 135 |
| Length of 2d dorsal base | 107* | 93* |
| Length of anal base | 88* | 68 |
| Diameter of iris | 36.5 | 33 |
| Maxillary length | 102 | 91 |
| Ventral fin insertion to vent | 281 | 261 |
| Internal | | |
| Length of body cavity | 338 | 314 |
| Coecal mass | 157 | 174 |
| Liver, center lobe | 45 | 22 |
| Stomach | 277 | 296 |
| Intestine, anterior loop | 141 | 150 |
| posterior loop | 279 | 256 |
| Air bladder | 181 | 133 |
| Counts | | |
| 1st dorsal spines | XIII | XIII |
| 2d dorsal rays | 15* | 15 |
| Dorsal finlets | 8 | 8 |
| Anal rays | 14* | 14 |
| Anal finlets | 8 | 8 |
| Gill rakers | 11–20 | --- |

* Including first finlet.

*MEASUREMENTS AND COUNTS OBTAINED FROM TWO YELLOWFIN TUNA FROM THE FIJI ISLANDS*
*Measurements in millimeters*

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