A MORPHOMETRIC STUDY OF YELLOWFIN TUNA *THUNNUS ALBACARES* (BONNATERRE)

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ABSTRACT

Morphometric measurements were compared for 4,180 yellowfin tuna from 28 locations in the Pacific Ocean; from off Angola, Africa, in the Atlantic Ocean; and from off Somaliland, Africa, in the Indian Ocean. The measurements used were head length; pectoral fin length; heights of second dorsal and anal fins; distances from snout to insertion of first dorsal fin, to second dorsal fin, anal fin, and ventral fin; distance from insertion of ventral to anterior edge of vent; and greatest body depth. Each measurement was related to fork length by regression analysis, and each relationship was considered a character. Curvilinear regression due to allometric growth was controlled by transforming some data to logarithms and by separating all samples into small, medium, and large size groups (less than 80, 80–120, and greater than 120 cm. fork lengths). Mean character sizes were determined for each sample at lengths of 65, 100, and 140 cm.

A comparison of mean character sizes revealed a cline in most characters from samples taken along the Pacific Equator between the vicinity of Costa Rica and the Caroline Islands. Yellowfin from the eastern Pacific have larger heads and greater distances from snout to insertion of first dorsal, second dorsal, ventral, and anal fins; a greater distance from insertion of ventral fins to insertion of anal fin; and a greater body depth. On the other hand, they have shorter pectoral fins and much shorter anal and second dorsal fins. The samples from the more temperate parts of the Pacific and from off the coasts of Africa differed little from some part of this cline.

A multiple character comparison of overlap among samples from near the Pacific Equator showed less than 50-percent overlap between samples separated by 1,500 miles, less than 25-percent overlap between samples separated by 3,000 miles, and less than 6-percent overlap between samples separated by 6,000 miles. The possibility of long intermigrations among the equatorial stocks seems remote.

The full variation in length of the pectoral fin and heights of second dorsal and anal fins, which most authors have used to separate the species of yellowfin, occurs within the cline along the Pacific Equator. This occurrence, plus the continuous circumtropical high seas distribution of the yellowfin, indicates a single worldwide species. The appropriate name is *Thunnus albacares* (Bonnaterre) 1788.

A problem of immediate concern to us in investigation of the tuna fisheries of the Pacific is to determine the degree of intermingling of the tuna populations. Intermingling matters because tunas are being sought in different parts of the ocean by fishermen who are asking whether the catch by one nation in one area is affecting the population of tunas and catch by another nation in another area. In other words, do these tunas migrate thousands of miles, as do some of our migratory birds, or are they relatively localized, hatching, maturing, and dying within an area of a few hundred miles? A closely related matter of secondary concern is to distinguish the species and subspecies of each kind of tuna in the oceans of the world.

Among the tuna fisheries of the Pacific, those for the yellowfin (*Thunnus albacares*) [1] are the most

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[1] The Pacific yellowfin tuna has been named *Neothunnus macropterus* (Temminck and Schlegel) by recent authors. I consider the yellowfin to be a single worldwide species, which I choose to call *Thunnus albacares* (see page 428).

important. The yellowfin is a major fishery resource from California to Chile and from Japan to Indonesia, especially near the Caroline Islands. Smaller fisheries also exist off Hawaii, Australia, and many of the islands of the central Pacific. In addition, exploration by the Bureau of Commercial Fisheries Pacific Oceanic Fishery Investigations (POFI) [2] in the central Pacific revealed major concentrations of yellowfin along the Equator from longitude 110° W. to 180°. These stocks were fished repeatedly by research vessels and subsidized commercial vessels between 1950 and 1955. The methods and results have been summarized by Sette (1954) and detailed by Murphy and Shomura (1953a, 1953b, and 1955) and Shomura and Murphy (1955). Since 1955 these populations have been fished with increasing intensity by Japanese commercial concerns.

One approach to the general problem of relations among Pacific tuna stocks has been through morphometric studies. Workers have included Schaefer (1948), who described the morphometric characteristics and relative growth of yellowfin off central America; Godsil (1948), who made a preliminary population study of yellowfin and albacore, *Germo alalunga* (Bonnaterre); Schaefer and Walford (1950), who compared yellowfin from off Angola, Africa, and the Pacific coast of Central America; Schaefer (1952), who compared yellowfin from the Hawaiian Islands with those from the Pacific coast of Central America; Royce (1953), who compared numerous groups of Pacific yellowfin; Tsuruta (1954), who compared yellowfin from the Gilbert Islands with those from Hawaii; and Schaefer (1955), who further compared yellowfin tuna from Central America and Hawaii with those of southeastern Polynesia.

A different technique, which may provide direct evidence of intermingling, has been applied by the California Department of Fish and Game, Marine Fisheries Branch, and used subsequently by other groups. Yellowfin, albacore, and skipjack, *Katsuwonus pelamis* (Linnaeus), have been tagged with plastic tags, as reported by Wilson (1953), and have already shown some remarkable migrations. One albacore released 18 miles south of Los Angeles, California, was recovered nearly 1 year later about 5,000 miles distant at latitude 31°30′ N., longitude 149°40′ E., off the coast of Japan (Ganssle and Clemens, 1953) and two other albacore, tagged near Guadalupe Island, were recovered about 6 months later in the vicinity of Midway Island (Blunt, 1954). Yellowfin also were tagged off the Line Islands from March 1955 to February 1956 (Iversen and Yoshida, 1957). Of the 1,056 that were released, 2 were recaptured locally and 1 was recovered 800 miles east of the point of release after being at liberty 13 months. But these tag returns are as yet too few to provide good evidence of the extent of intermingling or of any different migratory behavior of the several species.

Much interest in these problems of intermingling of tuna populations has been expressed at various meetings of the Indo-Pacific Fisheries Council, and the collection of data has been a matter of major concern to its Tuna Subcommittee. Through this organization the aid of numerous people in the Indo-Pacific area has been enlisted in the collection of data, which have been used in this report. This interest has also been expressed by some independent studies along the same lines in other countries, particularly in Japan by Tsuruta (1954) and in Australia where morphometric studies are underway.

STATISTICAL COMPARISON OF MORPHOLOGICAL DATA

The following section is a summary of a general review of the problem involved in statistical comparisons of morphological data previously made by Royce (1957).

In all morphometric studies of yellowfin tuna the authors have used essentially the same methods. All have used measurements of body parts, especially lengths and heights of the fins and distances from the snout to insertion of the fins, as principal characters. All have used regression analysis to relate part size to fork length and then have compared samples by covariance analysis. All have found much larger differences between samples than would be expected from chance variations, and from such differences there has been a tendency to conclude that the populations were distinct.

But this method of analysis is not wholly satisfactory. It provides a test of whether a difference is significant, but this conclusion may be trivial, because significant differences can be found commonly between even the most closely related

[2] Now the Biological Laboratory of the Bureau of Commercial Fisheries, Honolulu, Hawaii.

natural populations (Mayr, Linsley, and Usinger, 1953: 151). It does not show how great the differences are in terms that can readily be compared. It does not provide evidence of clines or character gradients, which are to be expected in tuna populations because of their continuous distribution and which are useful indicators of relations of the populations. Neither do the methods in current use provide information on the key problem of the amount of intermingling.

Use of regression analysis to relate size of body parts to fork length does provide basic data needed for finding clines according to the method described by Hubbs and Hubbs (1953). The regression statistics provide the mean character size estimated for a fixed length of fish; the measure of dispersion about the mean, which is the standard deviation from regression; and the measure of reliability, which is the standard error of the estimated mean. I showed that clines exist among yellowfin tuna populations (Royce, 1953), but I did not use the method of Hubbs and Hubbs nor employ sufficiently precise methods of regression analysis. In this paper I will use more refined methods of regression analysis and try to show fully the nature of the clines.

The problem of intermingling will be approached through an extension of the concept of overlap, which has been applied to comparison of natural populations by many taxonomists. The methods in current use have been summarized by Mayr, Linsley, and Usinger (1953: 142). They have indicated overlap between populations by a coefficient of difference (CD), which is computed according to the formula—

$$CD=\frac{\bar{x}_1-\bar{x}_2}{s_1+s_2}$$

The overlap is the difference between means $\bar{x}_i$ divided by the sum of standard deviations s_i of the two populations. I prefer to change this formula slightly to—

$$D=\frac{\bar{x}_1-\bar{x}_2}{s}$$

in which s is the within-sample standard deviation computed from the pooled variance, and D is the distance between the means in the standard measure of statistics, i.e., in units of the standard deviation. It is obvious that $CD\simeq\frac{D}{2}$.

The concept of overlap of two frequency distributions is shown graphically (1A and 2A) in figure 1. The mutual area (1B and 2B) of

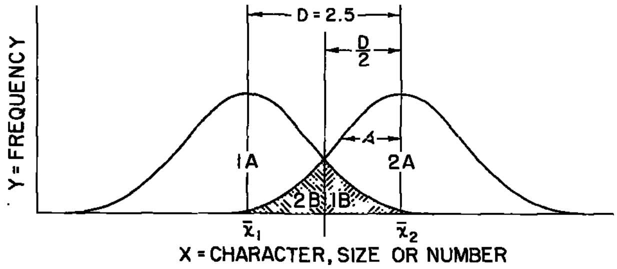

FIGURE 1.—Overlap of normal distributions. 1A and 2A indicate normal populations which overlap in the shaded areas 1B and 2B; s indicates one standard deviation, $\bar{x}_1$ and $\bar{x}_2$ indicate means; D is the distance between means in units of the standard deviation.

the two curves is shaded; one-half of the shaded area, or tail of one distribution, which I designate as p, may be determined readily from a table of the probability integral, such as table 2 in Pearson (1948). The table is entered with the value of $\frac{D}{2}$. The value of p represents the probability of misclassifying the individuals on the basis of the character used. When the two means are identical and the chances of making a proper choice are equal, p will range from 0.5 to essentially zero when the two curves are widely separated, and for all practical purposes there is no overlap. However, the value p, while indicative of overlap, is not fully satisfactory because it approaches a maximum of 0.5 and because it must be considered properly as a probability of misclassification rather than a measure of the mutual area of the frequency curves.

A more satisfactory measure of overlap may be obtained if one considers the area of one frequency curve and within it the proportion (2_p) that might belong to another specified frequency curve. I have designated this by $\Omega=200\ p$, expressed as a percentage. It is a measure of overlap which will be 100 percent when the curves have the same mean and will approach zero as the means become widely separated.

The particular usefulness of Ω is in the concept that it is an estimate of the proportion of one sample with the characteristics of another. If the samples are representative of populations in

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a specific time and place, it follows that Ω is that proportion which might have come from another population, and thus the value of the overlap indicates a maximum for the amount of intermingling. The overlap Ω does not show that intermingling has occurred, and when large it merely shows that a large amount of intermingling may have occurred. Whether intermingling did occur must be determined by other means. When Ω is small, however, and we can establish that the characters used do not change during migration, we may then be able to establish that no significant intermingling occurs.

The most satisfactory measure of overlap is obtained from several characters simultaneously, which requires a substantial extension of the computations. The measure in current use by most taxonomists has been applied merely to comparisons of single counted characters. I have shown (Royce, 1957) that it may be applied readily to single measured characters through substitution of the regression statistics. The much greater extension to multiple characters is based on D as already defined. The use of D as a distance between populations has been generalized for multiple characters by Mahalanobis (1936). In his generalization, each additional character adds to D only to the extent that it is not correlated with previously considered characters. Thus, all arbitrary combinations of characters as ratios or indices are avoided. Rao (1947, 1952) pointed out that D satisfies two fundamental postulates of distance: (1) the distance between two groups is not less than zero; (2) the sum of distances from one group to two other groups is not less than the distance between the two other groups (triangle law of distance). The further empirical requirement that the distance must not decrease when additional characters are considered is also satisfied.

AVAILABLE DATA

There were available for this study 28 samples of yellowfin from the Pacific Ocean, 1 from the Atlantic Ocean off Angola, Africa, 1 from the Indian Ocean off Somaliland in northeast Africa, and 1 of only 3 specimens from off Ceylon.[3] The data include the measurements of yellowfin from off the American coast published by Godsil (1948), whose 13 samples have been combined into 6; those from off Costa Rica by Schaefer (1948); from Angola by Schaefer and Walford (1950); from Fiji, Palmyra, and Hawaii by Godsil and Greenhood (1951); from Hawaii by Schaefer (1952); and those from the Gilbert Islands by Tsuruta (1954). The original measurements of most of the remaining samples were published by Dung and Royce (1953). The remainder, a sample from the Pacific Equator near longitude 110° W. and another from northeast Africa, are listed in appendix tables 1 and 2.

The geographic distribution of Pacific samples is shown in figure 2. There is an excellent series from about 8,000 miles along the Pacific Equator between the American coast and the central Caroline Islands. In addition, there are samples from the South Pacific off the Fiji and Society Islands, and from the North Pacific off the Philippines, Japan, Bikini Island, Hawaii, Mexico, and Guatemala. All major areas of the Pacific where yellowfin are known to occur are included except the South American coast and the southwest Pacific from Australia to the coast of Asia.

It was necessary to omit four samples from the Pacific. Those from the western Marshall, western Caroline, and Fiji Islands have not been further considered, because they contain less than 20 fish, the number I arbitrarily established as the minimum. In another sample from near the Gilbert Islands, reported by Tsuruta (1954), measurements of one specimen are questionable (No. 2 in his table 1), and I have been unable to verify the computations shown in his table 2. Fairly large discrepancies occur in the regression statistics, apparently because enough digits were not carried during the computations. This sample was obtained on only 3 days from a limited area. For these reasons I have not further considered it.

Certain basic statistics about the samples will be needed repeatedly in the ensuing discussion and are presented here. The length distribution of all samples is shown in table 1. Pertinent data on how the samples finally used were collected are shown in table 2. The sums, sums of squares, and sums of products for all characters of all samples which have not been published are given in appendix table 3. Included, also, are the means, regression constants, and estimated character sizes at certain lengths for all samples.

[3] This sample was compared with the Pacific samples by Royce (1953) and found to be most like the Phoenix Islands sample. It will not be further considered here.

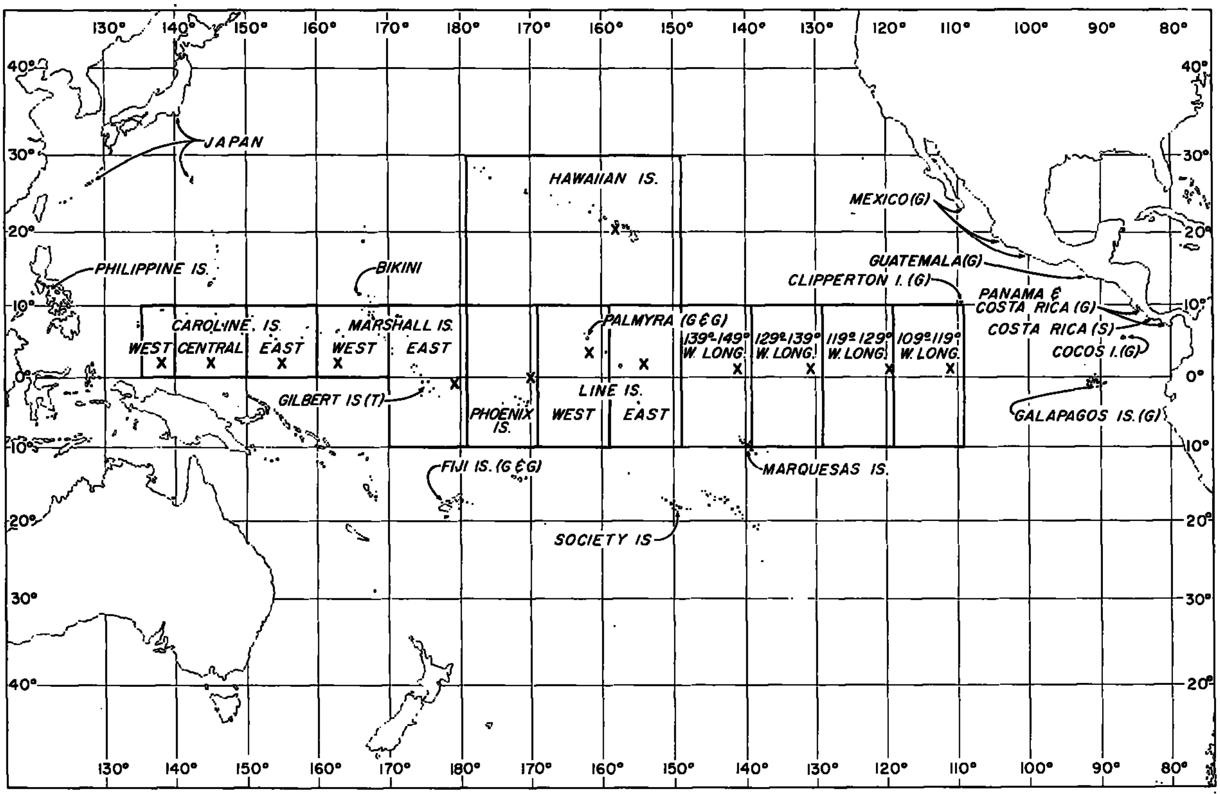

FIGURE 2.—Geographic distribution of Pacific samples of yellowfin tuna. (X indicates approximate center of distribution of fish comprising each sample from Hawaii and the equatorial area. (G) indicates Godsil, 1948; (G & G) Godsil and Greenhood, 1951; (S) Schaefer, 1952; (T) Tsuruta, 1954.)

MORPHOLOGICAL CHARACTERS USED

The morphological characters I have used in this study were selected through precedent and experience. The precedent was established by several workers who attempted thorough morphometric studies. None of the recent workers (Schaefer, 1948; Godsil, 1948; or Schaefer and Walford, 1950) explained how they selected their characters, but undoubtedly they were guided by previous research reported in the literature in which yellowfin tuna had been differentiated largely on the basis of fin length. Godsil (1948) defined 16 measurements but presented data on only 6: fork length; head length; and distances from the snout to insertion of first dorsal, second dorsal, anal, and ventral fins. He states that he investigated counts but discarded them because they were unsatisfactory. Schaefer (1948) used five of these measurements (he did not measure snout to insertion of ventral fin). He added the greatest body depth; length or height of the pectoral, second dorsal, and anal fins; longest dorsal finlet and dorsal ray; distance from pectoral fin insertion to insertion of first dorsal fin; length of the base of first dorsal fin; diameter of iris; and length of maxillary. In addition, he obtained four counts: number of dorsal fin rays (including spines if any), dorsal finlets, anal finlets, and gill rakers.

Schaefer and Walford (1950), for part of the specimens measured off Angola, Africa, used the same measurements as Schaefer (1948), but added spread of caudal fin, length of first dorsal spine, least depth of caudal peduncle, greatest width of caudal peduncle at keels, and snout to insertion of ventral fins. They also obtained the same four counts and recorded the sex of some of the fish. Subsequently, this list of measurements was markedly reduced by Schaefer (while he was directing the morphometric program at POFI) to fork length; head length; snout to insertion of first dorsal, second dorsal, anal, and ventral fins; length or height of pectoral, second dorsal, and anal fins; greatest body depth; and diameter of the

TABLE 1.—*Number of tuna measured, by size interval and place of collection*

Area	Number of fish in fork length (cm.) interval of—															Total
	30–39.9	40–49.9	50–59.9	60–69.9	70–79.9	80–89.9	90–99.9	100–109.9	110–119.9	120–129.9	130–139.9	140–149.9	150–159.9	160–169.9	170–179.9	
Mexico [1]			52	143	155	8	3									361
Guatemala [1]			49	54	16	1										120
Panama and Costa Rica [1]		1	129	283	282	36	42	43	48	20	3					887
Costa Rica [2]			2	7	3	6	11	6	6	2		2	1			46
Cocos Island [1]		6	8	36	128	80	28	2		4	10	5	4			311
Galapagos Island [1]			97	14	9	65	9									194
Clipperton Island [1]			1	21	7	4	2	1	2							38
109°–119° W					1	2		1	2	3		7	5	6		27
119°–129° W										3	10	16	14	4		47
129°–139° W				1	1		1			5	5	12	10	11		46
139°–149° W										4	25	29	33	20	2	113
East Line Islands				1	4	4	8	16	5	12	35	48	52	10		195
West Line Islands		1	5	16	22	28	22	19	17	11	21	18	7	1		188
Palmyra Island [3]			1	10	24	18	27	10	2	1		1				94
Phoenix Islands			4	19	14	16	19	9	15	15	21	7	2	1		142
East Marshall Islands									2	6	16	16				40
Gilbert Islands [5]									2	3	13	14	1			33
West Marshall Islands	2	2	7	1									4	2		18
Bikini Island			21	6	4	5	4	3	1							44
East Caroline Islands		1	18	23	18	19	16	6	14	12	21	9	13	1		171
Central Caroline Islands		1	6	11	19	21	21	33	27	33	24	13	2			211
West Caroline Islands				2	1	1	3		2	7	1					17
Philippines (SW. Panay)		1	58	121	62	47	19	9	6	15	11	5	2			356
Japan	1	11	6	6	7	8	6	1								46
Hawaii [2]		16	15	3	2	4	9	15	6	17	29	22	15	32	18	203
Hawaii [3]			42	5		11			1		7	11	1	1		79
Society Islands		2	15	3	2	7	1					2				32
Fiji Islands [3]			1	2		3	1	6								13
Northeast Africa				5	12	30		1								48
Angola, Africa [4]		1			11	11	1		9	8	9	6	2	2		60
Total	3	43	537	793	804	435	253	181	167	181	261	243	168	91	20	4,180

[1] Godsil (1948). [2] Schaefer (1952). [3] Godsil and Greenhood (1951). [4] Schaefer and Walford (1950). [5] Tsuruta (1954).

iris. But another measurement was added—the distance from insertion of the ventral fins to the anterior edge of the vent.

This reduction was undertaken without conclusive evidence that the omitted characters were less satisfactory than those retained; but some reduction was clearly necessary in order to have a manageable number of characters, and we think that the selection was good. The characters retained are, in general, external measurements that differentiate several species of tuna closely related to the yellowfin. Of special importance are length of the pectoral fin, length of the anal and second dorsal fins, and the general body proportions, which are reflected by length of the head and distance to the insertions of several fins. It is reasonable to assume that if these characters have differentiated during evolution of these other tuna species, they may well be differentiating in the evolution of the yellowfin group.

Some characters were excluded because they were troublesome to measure or count. For example, the counting of dorsal and anal finlets is complicated occasionally by the apparent absence of a finlet in the midst of the series. Sometimes it is obvious that a finlet has been torn off, at other times it is uncertain whether there had been a finlet in the space. The diameter of the iris has been omitted because of confusion among our workers between measuring the diameter of the iris and that of the eye. When plotted, these measurements seemed to fall into two groups and we found that measurements had been taken in different ways. We also have not used the gill raker counts, even though we obtained considerable numbers of them, because of uncertainty that our numerous field people were counting gill rakers in the same way. The difficulty is that gill rakers become progressively smaller on one side of the gill arch until covered by skin and, in any gross examination such as must be made in the field, it is always necessary to decide whether certain gill rakers are big enough to be counted. In addition, the number of gill rakers is not entirely independent of length of the fish. In one long series of counts made with great care in the laboratory on yellowfin from a single area, we found a statistically significant association between number of gill rakers and length of the fish.

Thus, the selection of characters has obviously been haphazard and I cannot claim to have selected the best ones. I can say only that they are the principal external characters which have served to differentiate the species of tunas and they

TABLE 2.—*Characteristics of yellowfin tuna morphometric samples*

[Size groups: S, < 80 cm., M, 80–120 cm., and L, > 120 cm.]

Area and size group	Number	Mean fork length (cm.)	Sampling effort				Numbers of fish by gear [1]			Remarks
			Years	Months	Days	Examiners	Long-line	Pole and line	Troll	
Mexico: [2] S	361	68.46	2	2	5	1	--------	361	--------	(2)
Guatemala: [2] S	120	62.26	1	1	2	1	--------	120	--------	
Panama and Costa Rica: [2]										
S } M	887	75.19	3	5	?	1	--------	887	--------	
Costa Rica: [3] M	29	99.88	1	6	?	[4] 2	--------	29	--------	
Cocos Island: [2]										
S } M } L	311	82.16	2	2	<6	1	--------	311	--------	
Galapagos Island: [2] S	194	68.32	1	1	?	1	--------	194	--------	
Clipperton Island: [2] S	38	73.89	1	1	3	1	--------	38	--------	
109°–119° W.: L	21	149.82	1	1	5	[4] 2	21	--------	--------	
119°–129° W.: L	47	146.72	1	4	12	4	46	--------	--------	
129°–139° W.: L	47	144.67	1	3	15	5	45	--------	2	
139°–149° W.: L	113	148.73	1	3	23	6	109	--------	1	
East Line Islands:										
M	33	102.51	3	8	13	9	17	--------	16	
L	157	145.35	4	9	36	9	149	--------	3	From catches of POFI vessels.
West Line Islands:										
S	44	68.68	4	9	28	9	1	7	32	
M	87	97.76	4	8	31	9	7	8	63	
L	58	138.13	4	8	23	8	46	1	9	
Palmyra Island: [6]										
S	35	72.49	1	1	Ca.	1	--------	--------	--------	All fishing done close to Palmyra, Fanning and Christmas Islands.
M	57	94.38	1	1	12	1	--------	--------	--------	
Phoenix Islands:										
S	37	67.67	3	5	16	5	1	9	27	
M	59	98.23	2	6	24	7	--------	16	42	From catches of POFI vessels.
L	46	133.53	3	6	26	7	19	13	9	
East Marshall Islands: L	40	136.34	1	1	8	3	32	--------	--------	
Bikini Island: S	31	59.03	1	2	?	1	--------	--------	31	Measured by J. C. Marr.
East Caroline Islands:										
S	60	65.27	2	6	24	[4] 3	59	1	--------	
M	55	98.26	2	4	20	[4] 2	55	--------	--------	
L	56	139.95	2	5	21	[4] 3	56	--------	--------	
Central Caroline Islands:										Obtained by POFI observers on Japanese mothership expeditions.
S	37	67.94	1	3	17	[4] 2	36	1	--------	
M	102	100.88	1	3	22	[4] 2	102	--------	--------	
L	72	132.29	2	4	17	[4] 3	72	--------	--------	
Philippines:										
S	242	65.19	--------	--------	--------	--------	--------	--------	--------	Contributed by D. V. Villadolid, Philippine Bureau of Fisheries.
M	81	90.74	--------	--------	--------	--------	--------	--------	--------	
L	33	132.99	--------	--------	--------	--------	--------	--------	--------	
Japan: S	31	57.73	1	2	7	1	1	28	--------	Measured by POFI observers in Japan.
Hawaii:										
S	36	52.35	2	7	17	4	--------	19	5	From POFI catches and Honolulu fish market.
M	34	101.95	1	7	21	[4] 4	15	15	2	
L	133	150.04	1	7	77	[4] 4	129	1	--------	
Hawaii: [5]										
S	47	57.01	1	--------	--------	1	--------	--------	--------	From near Johnston Island and near islands northwest of Kauai.
L	20	142.96	1	--------	--------	1	--------	--------	--------	From Honolulu market.
Society Islands: S	22	57.30	1	--------	--------	4	--------	22	--------	From frozen fish landed in Honolulu.
Northeast Africa: S	48	79.15	1	2	9	1	--------	--------	--------	Courtesy of FAO, measured by A. Fraser-Brunner.
Angola, Africa: [6]										
M	21	97.64	1	1	4	1	--------	--------	--------	
L	27	137.67	1	1	4	1	--------	--------	--------	

[1] A few specimens lacked record of gear used. [2] Statistics based on curvilinear regressions, Godsil (1948). Additional information from correspondence. [3] Schaefer (1952). [4] More than half of samples measured by one person. [5] Godsil and Greenhood (1951). [6] Schaefer and Walford (1950).

appear to be the most variable ones within the yellowfin group that can be measured with precision and consistency by different people.

METHODS OF MEASUREMENT

Our methods of measuring tuna follow the specifications given by Marr and Schaefer (1949). I think we have measured the fish exactly as they intended, but we slightly modified their definitions to overcome some confusion existing among our measurers. The most recent instructions given POFI workers have been as follows:

The measurements described are all made in millimeters with calipers or dividers, depending on the size of the fish and the distance to be measured. All distances are straight lines. The tip of the fixed arm of the calipers (or one point of the dividers) is applied to the first point mentioned and the tip of the sliding arm of the calipers (or the other point of the dividers) is applied to the second point mentioned. Where a choice of sides is involved, all measurements and counts are made on the left side of the fish. Fin insertions are to be determined while holding the fin approximately perpendicular to the contour of the fish.

Fork length.—(Total length of Marr, Schaefer, and Godsil.) The distance from the tip of the snout (most anterior point on upper jaw), with jaws closed, to the cartilaginous median part of the caudal fork (seating the sliding arm of the caliper firmly and thus depressing the small fleshy flap extending posteriorly).

Head length.—Distance from the tip of the snout to the most posterior point on the margin of the subopercle (depressing the fleshy flap extending posteriorly).

Snout to insertion of first dorsal fin.—The distance from the tip of the snout to the insertion of the first dorsal. The insertion of the first dorsal is the intersection of the anterior margin of the first dorsal spine, when the fin is held erect, with the contour of the back. This point is identical with the most anterior point of the first dorsal fin slot.

Snout to insertion of second dorsal fin.—The distance from the tip of the snout to insertion of the second dorsal. The insertion of the second dorsal is not so clearly defined as the insertion of the first dorsal, particularly on larger fish; but it is the intersection of the anterior margin of the second dorsal with the contour of the back when the fin is held erect. When the second dorsal is raised, the determined point should be marked with thumbnail or scalpel.

Snout to insertion of anal fin.—The distance from the tip of the snout to the insertion of the anal fin. The insertion of the anal fin is determined in the same manner as the insertion of the second dorsal.

Snout to insertion of ventral fin.—The distance from the tip of the snout to the insertion of the ventral. The insertion of the ventral is the intersection of the anterior margin of the ventral, when the fin is extended, with the contour of the body.

Insertion of ventral fins to anterior edge of vent.—The midline distance from the insertion of the ventrals to the anterior edge of the vent.

Greatest body depth.—The greatest distance between the dorsal and ventral contours perpendicular to the axis of the fish. The measurement is taken from the dorsal body contour to the ventral body contour, with the first dorsal fin depressed in its slot. It is oriented by reference to the dorsal spine, the insertion of which is at or nearest to the upper end of the vertical. Dorsal spines are counted posteriorly, the most anterior spine being the first.

Length of pectoral fin.—The distance from the anterior end of the fin slot to the most posterior point, taken with the pectoral fin extended posteriorly and opposed to the side.

Height (length) of second dorsal fin.—The distance from the insertion of the second dorsal fin to its distal end, with the fin in a normal position. Note that this fin is often extended in a long filament, especially in large Neothunnus, and care should be taken to notice if this extension is frayed.

Height (length) of anal fin.—The distance from the insertion of the anal fin to its distal end, with the fin in a normal position. Remarks under height of second dorsal fin apply here.

Diameter of iris.—The greatest diameter measured to the margin of the yellow iris and the adjoining black tissue. This is generally not a line parallel to the median line of the body.

Number of gill rakers.—The number of anterior rakers on the most anterior gill arch on the left side of the fish (some species also have posterior rakers on this same arch). The counts of the rakers on the two arms of the arch are kept separate. For example, $10+20=30$ gill rakers with 10 on the upper arm and 20 on the lower. The counts include all rakers that project above the surrounding epithelium. We have encountered no difficulty in assigning rakers near the angle of the arch to one arm or the other.

Sex.—Determined by inspection. Very immature males and females may be difficult to distinguish. Ovaries, which are tubular, may often roll between the fingers, while testes, which are solid, will turn over. The testes of ripening or ripe males are enlarged, solid, white bodies, not round in cross section. The ovaries of ripening or ripe females are enlarged, turgid, pink or yellow-orange bodies, round in cross section. Ova may often be distinguishable with the naked eye. The testes of spawned-out males are less turgid, tougher, and pinker than those not spawned, and are difficult or impossible to distinguish from maturing testes in early stages. The ovaries of spawned-out females are hollow, more or less flabby, saclike tubes.

Weight.—Should be determined in pounds on steelyards of proper range. Do not weigh on steelyard having capacity greater than about three times the weight. Be sure to subtract the weight of any hooks used to hold the fish. Record weight to smallest unit on steelyard. Note if fish is weighed in pieces.

IMPORTANT

Check steelyards before each cruise. Errors must not exceed 1 percent.

Check calipers each time they are used. Errors must not exceed 1 mm.

In addition to these instructions, diagrams were provided on the back of each field sheet (fig. 3).

All measurements of distances exceeding about 55 mm. have been obtained with sliding calipers. This lower limit occurs because some of our calipers will not measure closer than that and hence the shorter distances have been measured with dividers and millimeter rule. All measurements are the actual distance between two points and not the distance parallel to the midline of the body and between perpendiculars as specified by LeGall (1951) for body measurements of European tunas.

Our calipers have usually been of two sizes, 1 m. and 2 m. They evolved through brass and aluminum to standard wooden meter sticks.

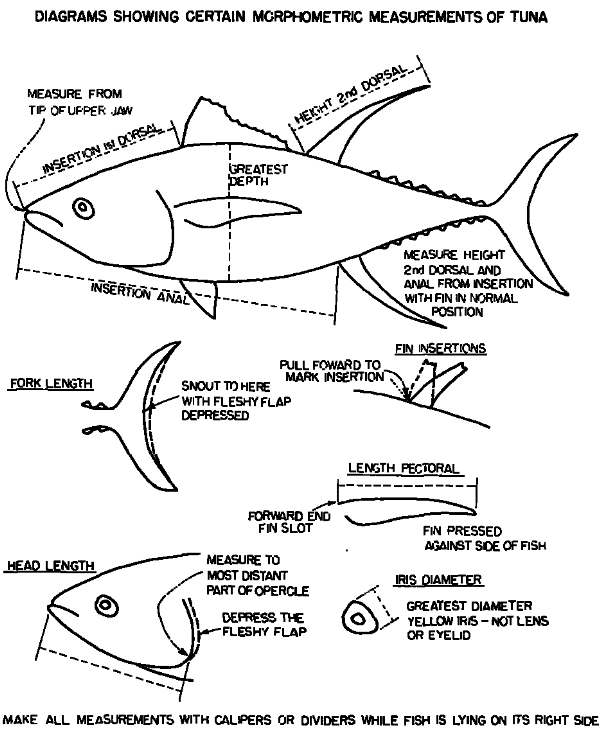

FIGURE 3.—Diagrams on the back of the field data sheet showing certain morphometric measurements of tuna.

The 1-m. caliper consisted simply of a fixed jaw and a slider on a standard meter stick. If the meter sticks are selected with care to get straight ones, we find it easy to maintain the accuracy within 1 mm. by checking the caliper prior to each use. (We found this checking equally essential with the metal calipers because of the ease with which they can be bent.) For the 2-m. calipers we put two meter sticks end to end in a sheet aluminum channel. The channel was made slightly longer than the two meter sticks to permit a third meter stick with a movable jaw to be inserted when we were measuring large sharks or marlins more than 2 m. long.

Almost all of our measurements were obtained in the field and usually on shipboard. In equatorial areas on POFI vessels it was customary to measure up to about 10 tuna of all species during the course of a day's fishing. During longline fishing operations, which were usually carried out along a line of stations, this ensured that the sample included tunas from a wide-spread area. On the Japanese mothership expeditions in the Caroline Islands area, POFI observers measured fish on the deck of the mothership a few days after capture by catcher vessels.

The original measurements not obtained on POFI vessels came from a variety of sources. In the Honolulu area most measurements were from specimens received at the fresh fish market. The Japanese specimens were measured by members of the POFI reconnaissance team that visited Japanese markets in 1949. Specimens from the Society Islands were measured from the catch of the vessel *Hawaiian Tuna* when they were landed at the Honolulu market and after they had thawed.

METHODS OF COMPUTATION

As indicated in the general discussion on the comparison of morphometric data, I have not considered ratios or indexes but have used regression analysis entirely in order to control the effect of size of fish in our comparisons. I have used the regressions for yellowfin tuna proposed by Schaefer (1948), who stated that the original measurements provided a satisfactory straight-line relation with fork length in the case of head length, snout to insertion of first dorsal fin, snout to insertion of second dorsal fin, snout to insertion of anal fin, and greatest body depth.[4] For the length of the pectoral fin he used the actual length of the fin with the logarithm of fork length, and for heights of the second dorsal and anal fins he used the logarithm of length of fin with the logarithm of fork length. For the other character, the distance from the insertion of the ventral fins to the anterior edge of the vent, which Schaefer (1948) did not use, no transformation is needed to obtain a reasonably straight line.

After accumulating several thousand sets of measurements for several species of tunas, we found that the labor of analysis was beyond our facilities and we turned to the International Business Machines Corporation for assistance. On most of our material, in which the original field data sheets had one fish per sheet, codes were added for species, locality, 10-cm.-length group, month, year, sex, and the examiner. Certain measurements were transformed to logarithms and the code and measurements were punched on cards. It was then possible to square, cross multiply, and tabulate automatically. A complete tabulation of sums, sums of squares, and sums of the products for regression analysis was obtained, arranged according to species, locality, and 10-cm.-length group. Subsequently, special tabulations of the material were made as needed.

After the data had been completely tabulated and totaled, scatter diagrams were made for each character on all specimens from each area to permit an immediate judgment of aberrant observations. If any data were obviously aberrant,[5] they were checked with the original field data, and, if plotted as recorded, they were assumed to be in error and were discarded. The regression line was then computed and plotted along with parallel lines plus and minus three standard deviations from regression. At this time, any remaining points more than three standard deviations from regression were assumed to be in error and were dropped. Then, final regression and the standard deviation from regression were computed. I have not tabulated the number of discarded observations, but I estimate it to be less than 2 percent of the total.

Discarding any data is questionable because correct but unusual observations may be discarded. By my method, however, most of those dropped were far removed from the line. The rejected values frequently were so located that one suspected that digits had been transposed or errors made in the decimeter digit. I believe that few if any correct observations were discarded. Furthermore, some culling is desirable for all data of this kind which have been collected under difficult field conditions where it is not practical to check original measurements.

Checks were made at all stages of computations. All IBM card punching was verified. All desk calculator operations that could not be independently checked were repeated. Finally, the plots of the regression line and standard deviations from regression provided a visual check which detected any but trivial errors.

SELECTION OF REGRESSION EQUATIONS

In the analysis of yellowfin tuna morphometrics, two fundamental statistics, mean and variance, are required. Both must be unbiased estimates of corresponding population parameters. These statistics are estimated from the best regression formulae. If I apply straight line regressions to data that are curvilinear, then my estimates of the means may diverge an unknown amount from the population parameter and the estimates of variance will tend to be excessive. On the other hand, curvilinear regression techniques tremendously increase already laborious calculations and for practical reasons should be avoided unless fully justified.

The two authors who have dealt with relative growth of the yellowfin tuna are in fundamental disagreement on whether curvilinear regression is needed for several characters. Schaefer (1948: 117) stated, "Over the range of sizes considered, all the characters measured, with the exception of the lengths of the pectoral, second dorsal and anal fins, bear a linear relationship to the length of the fish." For the length of the pectoral fin he used the logarithm of fork length and for the other two fin dimensions he used the logarithm of both fin length and fork length and simply states, without offering proof, that these transformations are appropriate. Schaefer later (1952) cautioned that the relationships were only approximations that did not completely describe the relation between

[4] An evaluation of the regression formulae will be found in the following section.

[5] This was usually more than about 15 percent (about four standard deviations) of the size of the character away from the general trend.

fork length and size of the body part. On the other hand, Godsil (1948: 7) stated—

> Plotting to a large scale the actual measurements of a given character against body length in each case, revealed that the sample regressions were nearly but not quite linear. Of the various functions tried, the expression $Y=a+bx+c\frac{1}{x}$ (where x=body length in each case and Y=the dependent variable) resulted in the best fit.

The other functions tried included $y=a+bx$, $y=a+bx+cx^2$, $y=a+bx+cx^2+dx^3$, $y=ax^b$, and $y=ae.^{bx}$ He also stated that the reduction in the sum of the squared deviations from the above expression when compared with the sum from the linear regression was in most cases highly significant. He offered no statistical data supporting this assertion; but his graphs, with the plotted points and curved lines, show clearly that the data for head length and snout to the insertions of first dorsal, ventral, second dorsal, and anal fins are slightly curvilinear and the computed lines fit well. The curvilinearity in Godsil's data is further puzzling because Schaefer and Walford (1950) presented data for characters used by Godsil that show no curvilinearity.

Therefore, it is desirable to examine in greater detail the source of curvilinearity in Godsil's data. This may be done by comparing the mean-square deviations from linear regression with those from curvilinear regression (table 3). When such comparisons are summed for the 13 samples for each character, I find that curved lines significantly reduced the mean square of pooled data as well as the mean square of within-sample data for each character. I notice, however, that for all characters reduction in the mean square from linear to curvilinear regression is much greater for pooled data than it is for within-sample data. Such differences between pooled and within-sample data suggest than a major part of the curvilinearity is between samples rather than within samples.

More conclusive evidence of the source of curvilinearity is to be found by examining the significance of the reduction in the mean square, character by character and sample by sample (table 3). Here significant or highly significant curvilinearity for most characters occurs in samples 1, 3, 4, 5, 6, and 7. In the remaining seven samples, 2 and 8 through 13, only four instances of a significant but not highly significant reduction in mean square occur in 35 comparisons. Since two significant reductions would be expected to occur by chance in this number of comparisons, little importance can be attached to the four. Clearly, curvilinearity is associated with certain samples and not with certain characters for all samples, as would be expected from a truly curvilinear regression of body part on fork length.

One characteristic of the samples that might be associated with curvilinearity is size, since it is obvious that very large samples (DF=385, 348) show curvilinearity whereas small samples (DF=25, 36, 67) do not. Among the eight samples of intermediate size, however, four, with degrees of freedom equaling 192, 121, 98, and 96, show no more than one character with significant curvilin-

TABLE 3.—*Mean-square deviations from linear and curvilinear regressions of yellowfin morphometric measurements*

[Measurements from Godsil, 1948]

Sample number	Degrees of freedom [1]	Length of head		Snout to insertion of—								Date of collection [2]
				First dorsal fin		Second dorsal fin		Anal fin		Ventral fin		
		Linear	Curvilinear	Linear	Curvilinear	Linear	Curvilinear	Linear	Curvilinear	Linear	Curvilinear	
1	92	7.84	**6.69	14.53	**13.49	20.15	*19.22	20.26	**17.66	13.07	**11.41	Mar. 13, 1939.
2	96	5.71	5.68	10.06	10.21	12.83	12.45	19.59	*18.47	11.89	11.79	Mar. 8, 1939.
3	166	10.80	*10.58	12.40	12.10	21.17	**19.29	26.93	*26.44	16.87	17.10	Apr. 25, 27, 1940.
4	385	11.06	**10.34	20.98	**19.70	32.46	**29.91	29.40	30.63	25.07	**24.70	Nov. 5 to Dec. 7, 1936.
5	348	11.08	**8.91	18.97	**15.72	22.95	**15.59	22.63	**19.70	20.06	**19.07	Jan. 14 to Feb. 13, 1937.
6	118	5.82	**5.32	10.66	**9.24	13.27	13.21	13.40	13.44	12.86	*12.32	Mar. 26, 27, 1939.
7	141	18.40	**14.19	25.57	**22.22	38.00	**32.30	34.09	**30.69	31.75	**28.29	Jan. 16 to 19, 1937.
8	192	7.73	8.37	12.01	12.49	11.62	12.55	16.56	16.85	14.07	15.71	Apr. 1 to 19, 1940.
9	67	6.37	6.29	4.84	14.55	12.81	13.06	16.07	16.15	8.42	8.58	May 12, 1940.
10	121	5.45	*5.26	9.91	10.30	11.19	11.03	15.74	16.43	13.79	14.16	Jan. 21 to Feb. 10, 1937.
11	36	7.81	7.83	9.94	*8.83	21.92	21.03	13.97	14.17	18.63	19.32	Mar. 22 to 24, 1940.
12	25	6.92	7.21	7.84	8.17	15.16	15.75	23.60	24.54	21.12	21.96	Apr. 29, 1940.
13	98	8.28	8.32	14.99	15.11	13.04	*12.66	16.72	16.84	14.27	14.28	Mar. 30, 31, 1940.
Pooled-sample variance	1909	12.07	**9.53	19.07	**15.78	24.93	**20.40	27.25	**25.85	19.91	**19.31	
Within-sample variance	1885	9.71	**8.80	16.14	**14.94	21.69	**19.24	22.65	**21.99	18.73	**18.34	

[1] Varies slightly with different characters. [2] Supplied by Godsil in personal communication. * Statistically significant reduction in mean square ($0.05> p>0.01$). **Highly significant reduction in mean square ($p<0.01$).

earity. The other four samples of intermediate size show highly significant curvilinearity in at least one character and significant curvilinearity in more than half of the characters. It is likely that something other than sample size alone has caused curvilinearity.

Another source of curvilinearity may be accidents of sampling. Such accidents appear to be rather likely because most of Godsil's samples (table 2) were obtained on a single day or over a period of a few days. It is well-known that yellowfin school by size, and when one of the larger samples includes a considerable range in sizes it is probable that it was obtained from only a few schools of different average size. If the sample included schools of slightly different morphological characteristics and also of different mean size, there would be two sources of regression—one within schools fished and the other between schools fished. The combined regressions might appear to be curvilinear.

Therefore, when I examined our data for curvilinear regression I turned first to the sample that I considered had the best coverage of the area sampled and that contained a good size distribution of fish. It was the sample from the western Line Islands area, obtained during 13 different months with the majority of the fish caught by longlining and trolling and measured by 12 different measurers. During both longlining and trolling operations, it was customary to measure only a few fish a day (rarely more than 10), and thus these fish came from several dozen different schools and as many different locations within the area. There are 188 sets of measurements available in this sample, with good numbers in most 10-cm. length groups from 50 to 160 cm.

Evidence of curvilinearity was sought in the plots of complete data that were made to check each sample. Some evidence of curvilinearity appeared in the plots for certain characters, but the scatter of points around the line made interpretation difficult. Hence, I sought a way to magnify any curvilinearity and plotted the deviations of the 10-cm. group means from the rectilinear regression equations for each character in the sample (fig. 4). These equations were based on the transformations, proposed by Schaefer (1952), which are log fork length and log height of second dorsal fin, log fork length and log height of anal fin, and log fork length and length of pectoral fin.

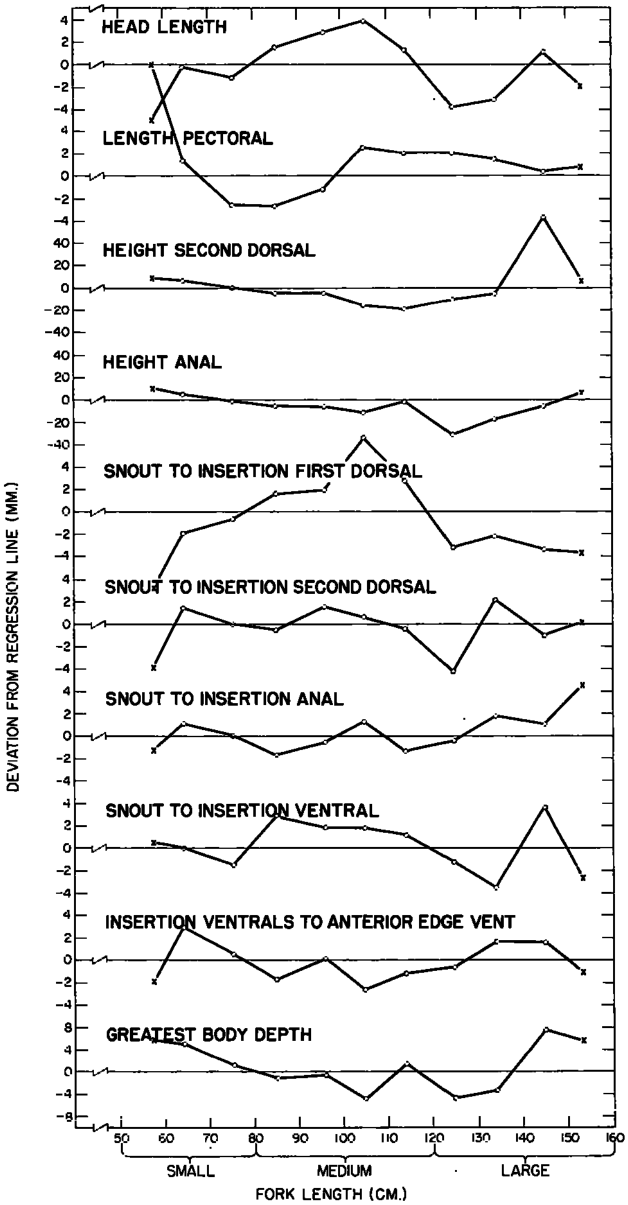

FIGURE 4.—Sample of yellowfin tuna from western Line Islands area. Deviations of 10-cm. group means from regressions were used. (X, average of less than 10 fish; 0, average of 10 or more fish.)

The data for all other characters were not transformed.

The graph suggests that some curvilinearity occurs in several characters. If a random distribution of 10-cm.-group means about the regression line is assumed, a line connecting the group means would be expected to cross the regression line an average of five times (with 11 points). To the contrary, for four characters—

length of pectoral, height of second dorsal fin, height of anal fin, and snout to insertion of first dorsal fin—the lines crossed only twice. In the case of only one character—the snout to insertion of second dorsal fin—did the lines cross more than the most probable number of times.

The question then arose whether the curvilinearity prevailed in other samples, and I made a similar analysis of our other two large samples

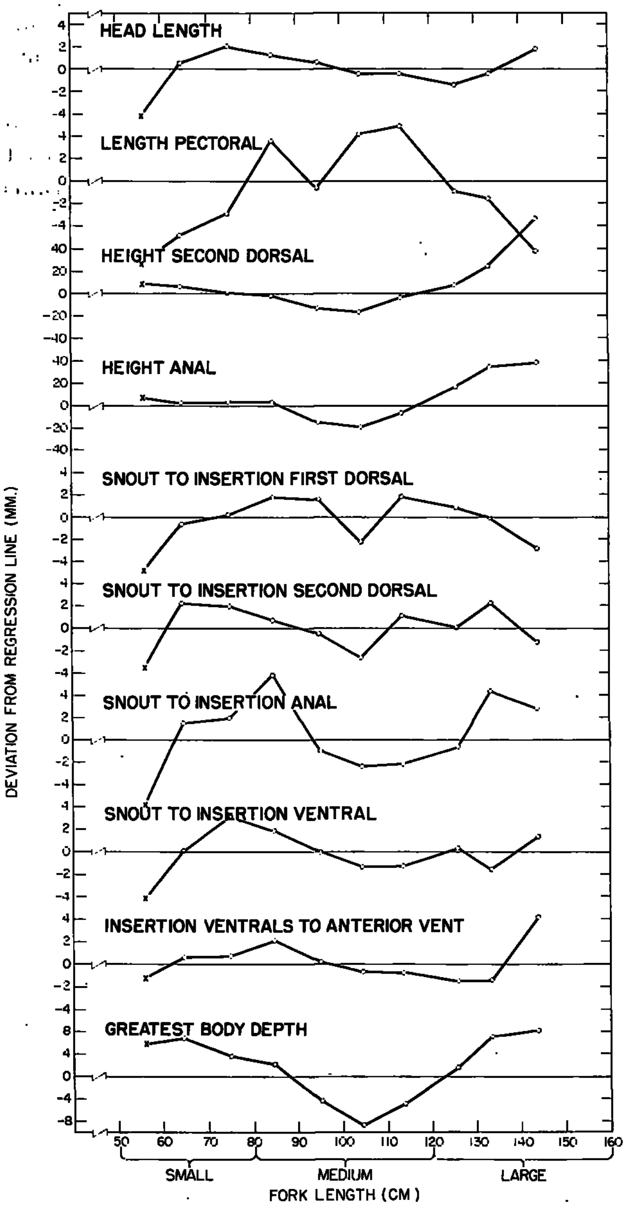

FIGURE 5.—Sample of yellowfin tuna from central Caroline Islands area. Deviations of 10-cm.-group means from regression. (X, average of less than 10 fish; 0, average of 10 or more fish.)

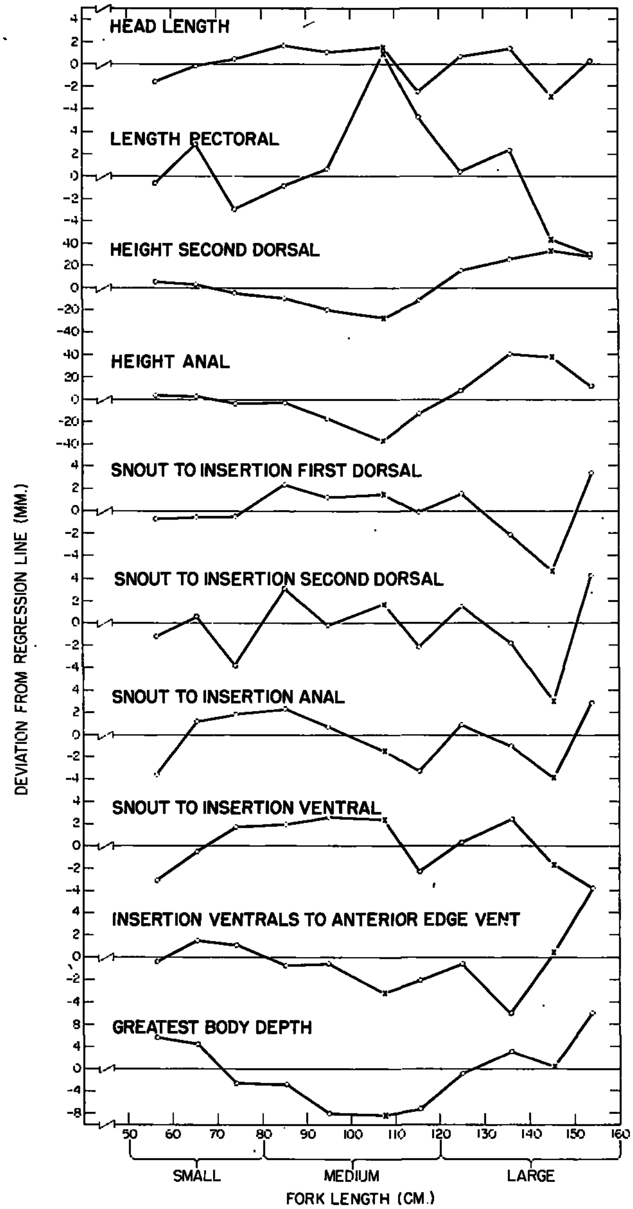

FIGURE 6.—Sample of yellowfin tuna from eastern Caroline Islands area. Deviations of 10-cm.-group means from regression. (X, average of less than 10 fish; 0, average of 10 or more fish.)

that also are well distributed over a wide range of lengths. They were the samples from the eastern Caroline Islands and the central Caroline Islands, which contained 171 and 211 sets of measurements, respectively. Similar plots of deviations of 10-cm.-group means from the rectilinear regression lines (figs. 5 and 6) indicated again that the lines cross less than the expected number of times for most characters.

When compared, the deviations from regressions of all three areas indicate that they tend to form a curve concave upwards for height of second dorsal fin, height of anal fin, and greatest body depth. Other characters, especially head length, snout to insertion of first dorsal fin, and snout to insertion of ventral fin, appear sinuous with some tendency for the line connecting means to start below the regression, then go above, then below, and then upward again. The line appears to be curved for length of the pectoral fin, but in a different way in each sample.

I conclude that for most characters in these large samples some curvilinearity remains that is not associated with sampling, but is rather an expression of the allometric growth of the fish. Furthermore, it is an irregular allometry which is not readily expressed by any linear or simple curvilinear formulation.

Such curvilinearity would not be troublesome if all samples had similarly distributed lengths, in which case it would probably be satisfactory to use the regression techniques proposed by Schaefer (1948). The rather small amount of curvilinearity would result in some bias in mean, variance, and regression constants, but if such bias were similar among samples it would not matter. However, it has not been possible to obtain samples covering a uniform range of lengths. In numerous areas, particularly along the Pacific Equator, where we have fished only with longline gear, we have obtained only very large fish, and in other areas, where fishing has been done only by trolling, we took mostly small fish.

The compromise solution has been to split the samples into three size groups and compare them at three different standard lengths, each very close to the grand mean of its size group. The following groups have been used:

Small (S)—fish less than 80 cm., most of which are more than 50 cm. and which have been compared at a length of 65 cm. (about 12 lb.); medium (M)—fish from 80 to 120 cm., compared at a length of 100 cm. (about 43 lb.); large (L)—fish more than 120 cm., most of which are less than 170 cm. and which have been compared at a length of 140 cm. (about 118 lb.).

Further restrictions were adopted: first, to avoid uncertainties due to the small samples it was required that there be more than 20 specimens in each size group, and second, to minimize the effect of any curvilinearity remaining within a size group, it was required that more than 10 percent of the sample be above and more than 10 percent below the comparison size. For example, in Godsil's sample from Panama and Costa Rica there were 23 fish between 120 and 140 cm. and none above 140 cm. This part of his sample was not considered in the large group, whereas his sample from Cocos Island including 23 fish ranging from 120 to 160 cm., with 9 above 140 cm., was considered. One sample remains that is not well distributed in fork length—the one from northeast Africa. It has been used, but the comparisons are made with reservations.

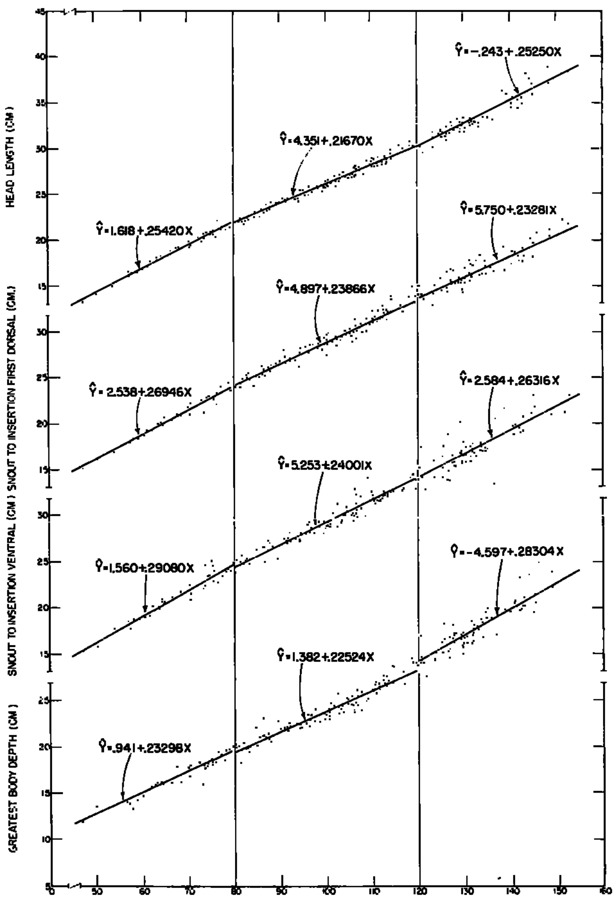

FIGURE 7A.—Regressions of head length, distances from snout to insertions of first dorsal and ventral fins, and greatest body depth in yellowfin tuna from central Caroline Islands area.

The fit of the lines to the three size groups may be judged from the plots of the data from the central Carolines area (figs. 7A, 7B, and 7C). Each of the three separate lines appears to be a good fit in its limited range, but when projected beyond the range it may rapidly diverge from the plotted points. The tendency that has been noted toward a sinuous line in certain characters is again evidenced in the plots and in the changing regression constants. I judge, however, that any remaining curvilinearity within each size group is much less than the dispersion of points about the line and that samples within each size group may be compared with little fear of erratic results due to curvilinear regression.

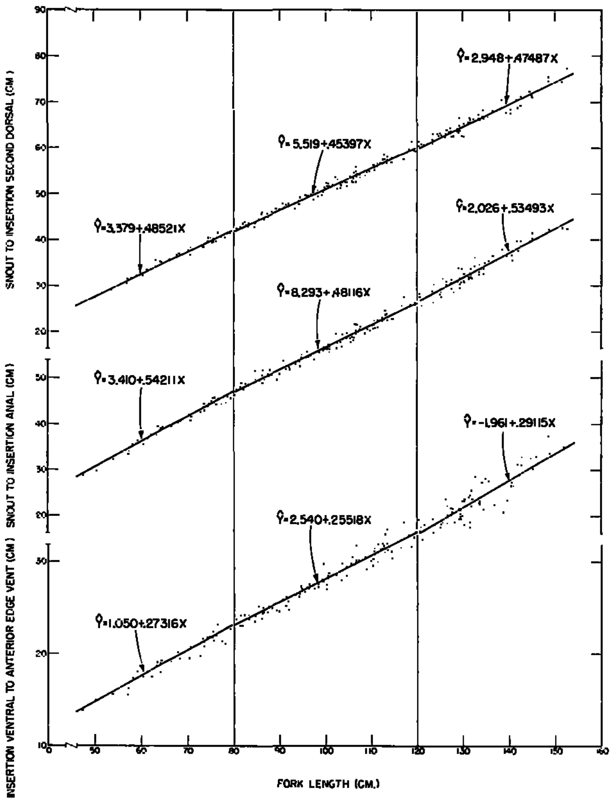

FIGURE 7B.—Regressions of distances from snout to insertion of second dorsal and anal fins and distance from insertion of ventral fin to anterior edge of vent, in yellowfin tuna from central Caroline Islands area.

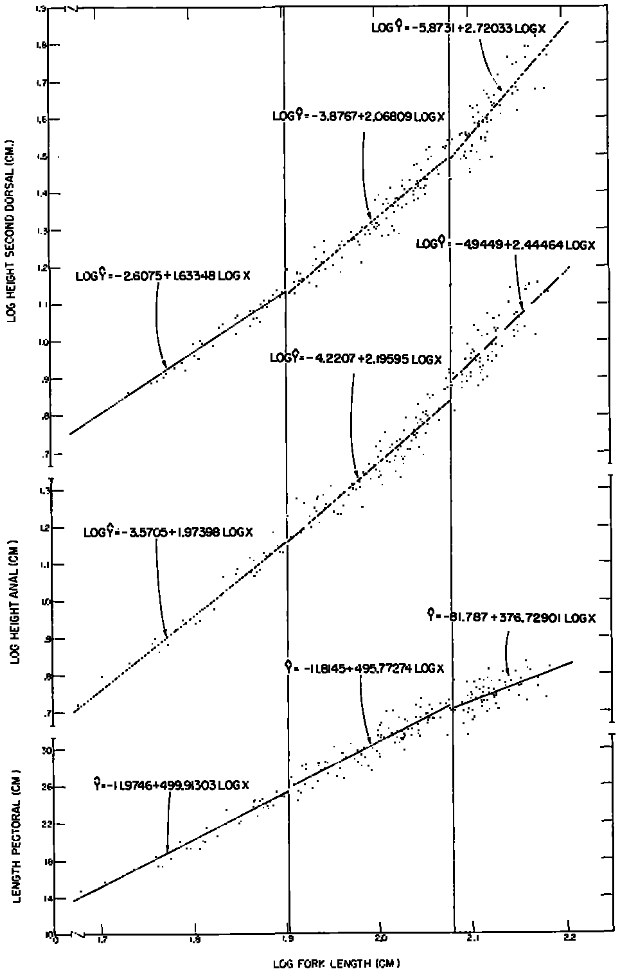

FIGURE 7C.—Regressions of log heights of second dorsal and anal fins and length of pectoral fin, in yellowfin tuna from central Caroline Islands area.

RELIABILITY OF SAMPLE STATISTICS

In addition to determining methods of regression analysis that will give reliable estimates of mean and variance the reliability of the raw data must be assessed. Two matters may be examined: first, the adequacy of the sampling, and second, the accuracy of the measurements.

An ideal sample of yellowfin tuna for a morphometric study would be representative of all sizes of tuna in the specified area during the period of study. Such a sample would contain a distribution of sizes proportionate to the numbers of each size in the ocean and would be randomized over the time and area covered. This ideal is far out of reach because it is not possible to catch all of the sizes, as each fishing gear selects certain size groups, and it has not been possible to fish any area at randomly selected locations or times.

Consideration of the habits of the yellowfin suggests, however, that satisfactory samples may be obtained from a relatively limited coverage.

The yellowfin is a schooling species (Murphy and Elliott, 1954), and I have suggested that schools in a limited area may vary slightly in their morphometric characteristics (p. 406). The yellowfin are fast swimmers, however, and it seems probable that they could cover hundreds of miles in a few days. Furthermore, the larger yellowfin at least are entirely independent of coastal regions. The ocean in which they are found is relatively uniform, with no absolute barriers to migration, although the yellowfin do prefer certain areas, presumably where they find the most food. So it is possible that a sample made up of subsamples from numerous, different schools may be adequately representative of an area even though the area is not randomly covered. The schools may be assumed to have been randomly swimming in the area. A similar assumption with regard to time is less safe because many species migrate annually, and even if yellowfin are present in an area throughout the year, they might be different spawning groups.

Even though the ideal sample cannot be obtained, samples with widely varying coverage in area and time (table 2) may be compared. As the samples were extended in space and time, however, they were taken by an increasing number of people, who may have varied in their techniques of measurement. Therefore, the problems of sampling and precision in measuring the fish must be considered simultaneously, and here I digress briefly to consider the problem of obtaining consistent measurements of yellowfin.

Fortunately, all tunas are easy to measure consistently. The body is stiff, and even when not in rigor mortis has almost no tendency to bend when the fish is laid on a flat deck on its side. The parts to be measured were accurately defined by Marr and Schaefer (1949). The numerous measurers from POFI have compared their methods—almost no one measured tuna without first working with someone who had measured them before—and most differing interpretations of the definitions have been quickly settled. Nevertheless, I consider that minor differences of technique must have occurred both among POFI and other measurers, and the problem is to assess how great the differences have been.

One approach to this problem might be to have different people repeat measurements on the same fish and then analyze the differences. We have made repeat measurements to standardize our methods but have not analyzed the differences, because our concern is with what people have done independently and routinely and not what they could do under experimental conditions.

It will not be possible to separate the differences in technique from differences of time and area, but the combined problem can be approached by examining the variance in relation to coverage of the sample and number of measurers. Also mean values and overlap of closely related samples obtained by different measurers can be compared. The latter comparison must be left until I have introduced the method of comparing means and overlap.

The variance itself is not suitable for our comparison. Better is the standard deviation from regression $S_{y.x}$, which is directly indicative of the spread of points about the line, but it obviously is related to the size of the character, even when the characters have been transformed to logarithms. So I have used a kind of coefficient of variation,

$$C=\frac{100\ S_{y.x}}{\bar{x}},$$

to eliminate the effect of size of character $\bar{x}$ and so obtain a better mean value for all characters in a sample.

These coefficients of variation have been computed for each character in each sample and are shown in table 4 (except the samples of Godsil (1948) from Panama and Costa Rica and from Cocos Island, in which his curvilinear regressions were used and in which the range spreads extensively over two or more of our size groups).

Several samples contained measurements for only five characters, and hence the sample means and the grand means were computed from these five characters only.

This table shows close agreement among grand means of the coefficients of size groups for the five characters, which indicates that the standard deviation from regression is almost exactly related to size of the fish. Further, there is some difference among characters: length of pectoral fin and greatest body depth have a high coefficient; log heights of second dorsal and anal fins show coefficients that increase with size of fish; distances from snout to insertion of second dorsal and anal fins have the lowest values.

TABLE 4.—*Coefficients of variation of yellowfin morphometrics*

Area and size [1]	Length of head (1)	Length of pectoral fin (2)	Weight of second dorsal fin (3)	Weight of anal fin (4)	Snout to insertion of— First dorsal fin (5)	Snout to insertion of— Second dorsal fin (6)	Snout to insertion of— Anal fin (7)	Snout to insertion of— Ventral fin (8)	Greatest body depth (9)	Insertion ventral to anterior edge vent (10)	Means [2]
Mexico: [3] S	1.38	------	------	------	1.70	1.05	1.04	1.60	------	------	1.35
Guatemala: [3] S	1.32	------	------	------	1.64	1.06	.96	1.76	------	------	1.35
Costa Rica: [4] M	1.75	3.13	1.67	1.85	1.76	1.38	.95	------	3.14	------	1.46
Galapagos Island: [3] S	1.42	------	------	------	1.61	.92	.99	1.71	------	------	1.33
Clipperton Island: [3] S	1.33	------	------	------	1.36	1.18	.85	1.83	------	------	1.31
109°–119° W.: L	1.94	3.58	1.32	2.55	3.03	1.44	1.10	2.35	2.19	2.88	1.97
119°–129° W.: L	2.20	4.68	2.58	2.53	2.01	1.18	1.38	2.90	4.29	2.80	1.93
129°–139° W.: L	1.16	4.17	2.66	2.58	2.07	1.33	1.24	2.04	4.09	2.61	1.73
139°–149° W.: L	1.81	3.50	2.47	2.60	2.23	1.28	1.33	2.14	2.96	2.72	1.76
East Line Islands:											
M	1.57	3.03	2.50	2.34	2.02	1.34	1.63	1.84	3.24	2.27	1.68
L	1.82	4.05	2.57	2.71	2.44	1.62	1.33	2.55	2.51	2.54	1.95
West Line Islands:											
S	2.28	3.77	1.56	1.55	2.63	1.34	1.63	2.53	3.43	2.65	2.08
M	2.16	4.40	2.15	2.84	2.27	1.48	1.55	2.70	4.19	2.23	2.03
L	1.96	2.88	2.44	2.26	1.76	1.29	1.11	1.94	3.19	2.64	1.61
Palmyra Island: [5]											
S	2.02	------	------	------	2.64	1.38	1.24	1.58	------	------	1.77
M	1.57	------	------	------	1.86	1.36	1.59	1.72	------	------	1.62
Phoenix Islands:											
S	2.33	4.09	1.63	1.80	1.85	2.20	1.50	2.53	2.59	2.15	2.08
M	2.30	4.45	2.02	2.59	2.00	2.49	1.70	2.57	4.10	1.99	2.21
L	1.93	3.22	2.22	1.97	2.09	1.37	1.32	2.80	3.73	2.53	1.90
East Marshall Islands: L	1.45	3.78	2.08	1.97	1.41	1.03	1.04	1.58	2.54	2.57	1.30
Bikini Island: S	1.51	3.30	1.28	1.58	1.78	.84	1.10	2.41	2.18	------	1.53
East Caroline Islands:											
S	1.34	4.04	1.25	1.49	2.04	1.21	1.19	1.75	2.83	2.50	1.51
M	1.25	3.79	1.34	1.49	1.66	.93	.87	1.78	2.68	2.28	1.30
L	1.60	3.27	1.98	1.66	2.22	1.10	1.11	1.90	3.23	2.04	1.59
Central Caroline Islands:											
S	1.64	3.01	.90	1.50	1.61	1.37	1.74	3.14	3.32	2.93	1.90
M	1.31	3.91	1.52	1.56	2.05	1.41	1.52	2.48	2.93	2.51	1.75
L	1.97	3.63	2.46	2.07	2.23	1.48	1.52	3.13	3.72	3.13	2.07
Philippines:											
S	2.14	------	------	------	2.82	2.49	2.02	2.50	------	------	2.39
M	2.37	------	------	------	2.31	1.62	1.55	2.30	------	------	2.03
L	2.74	------	------	------	3.11	1.87	2.25	3.62	------	------	2.72
Japan: S	1.78	3.65	1.32	1.49	2.01	1.34	1.11	2.16	2.91	------	1.68
Hawaii:											
S	1.77	4.87	1.75	1.79	2.17	1.51	1.56	2.77	3.70	------	1.96
M	2.19	5.04	1.95	2.55	2.65	1.37	1.49	2.72	3.42	------	2.08
L	1.74	3.84	2.20	2.13	2.01	1.41	1.26	2.04	3.36	------	1.69
Hawaii: [5]											
S	1.52	------	------	------	1.70	1.01	1.05	1.98	------	------	1.45
L	1.32	------	------	------	2.03	1.20	1.05	1.51	------	------	1.42
Society Islands: S	1.49	4.12	1.60	1.97	2.42	1.43	------	------	------	------	1.78
Northeast Africa: S	2.19	3.90	1.53	2.08	2.92	1.93	1.87	2.98	2.52	------	2.38
Angola, Africa: [6]											
M	1.88	3.98	1.33	1.47	2.29	1.39	1.46	1.62	------	------	1.73
L	1.90	3.58	1.86	2.36	2.24	1.19	1.46	1.72	------	------	1.70
Means:											
S	1.72	3.86	1.42	1.69	2.06	1.39	1.32	2.22	2.94	2.56	1.74
M	1.84	3.97	1.82	2.09	2.09	1.48	1.43	2.19	3.39	2.26	1.81
L	1.88	3.68	2.24	2.28	2.21	1.34	1.32	2.30	3.26	2.65	1.81

[1] S, fish less than 80 cm., and compared at a length of 65 cm.; M, fish from 80 to 120 cm., and compared at a length of 100 cm.; L, fish more than 120 cm., and compared at a length of 140 cm.
[2] Mean of columns (1), (5), (6), (7), and (8). [3] Godsil (1948) and in correspondence. [4] Schaefer (1952). [5] Godsil and Greenhood (1951). [6] Schaefer and Walford (1950).

Of most interest, however, is the rather small amount of variation in the mean *C* values for the different samples. These values range from a low of 1.30, equal in the eastern Marshalls group L and the eastern Carolines group M, to a high of 2.72 in the Philippines group L. The Philippines group S and the northeast Africa group S are next highest. (I have no information on how these samples were collected and the factors that may have caused the higher values.) Among the POFI samples the highest (2.21) value is found in the Phoenix Islands group M.

When I tried to relate the mean *C* to the number of measurers and to the coverage of the sample in figure 8, I found little relation. The grand mean for one to three examiners is 1.62; for four to six examiners, 1.88; and seven or more, 1.92. The relation to length of sampling period is similar: for 1 to 9 days the mean is 1.64; for 10 to 19 days, 1.91; and for 20 or more days, 1.80.

None of this evidence is conclusive, but there appears to be a slight increase in the value of *C*, which is associated with increased time, greater number of measurers, or greater area sampled. I cannot segregate these factors, but because curvilinearity appears in some of Godsil's (1948) samples which were collected during only a few days, the samples taken on fewer than 10 different

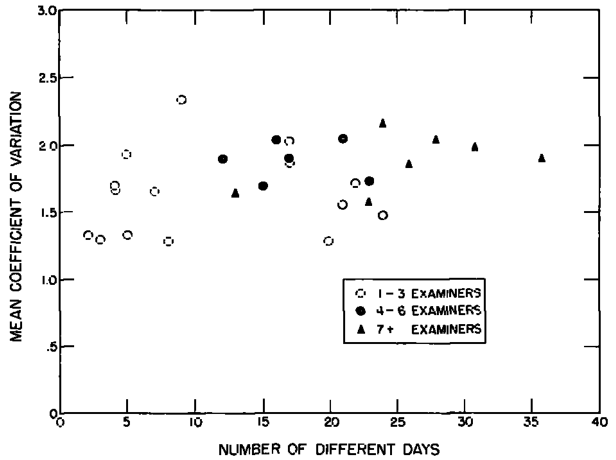

FIGURE 8.—Relation of the mean coefficient of variation of five selected characters to number of examiners and number of days on which parts of the sample were taken.

days may be less representative. Therefore, I conclude that important bias was not introduced by different techniques among measurers, at least not in the central and eastern Pacific area, where all of the measurers worked closely with one another.

CHARACTER-BY-CHARACTER COMPARISON OF SAMPLES

One of the most direct and useful ways of comparing morphological data is simply to compare the mean values estimated for certain fixed lengths. These values are particularly useful because they may be associated readily with geographic features and show directly the presence of character gradients or clines. Unlike tests of significance or amounts of overlap, an examination of the means shows directly the differences in number of parts or in body form. Of course, with all characters associated with body size it is necessary to control body size by the use of appropriate regressions.

A first comparison of samples is logically among the considerable series available from the equatorial Pacific. Areas from which these samples came extend from the American coast westward about 8,400 miles to the central Carolines area, which is bounded on the west by longitude 140° E. (fig. 2). This area of comparison is limited to the region between latitude 10° N. and latitude 10° S., although some of the samples are more restricted than this in latitudinal coverage. In the southern and extreme northern parts of this zone are the westerly flowing South Equatorial and North Equatorial Currents. Between these two currents (5° N. to 10° N.) is the easterly flowing Countercurrent. Throughout this area [6] yellowfin tuna have been taken near the Equator and have been found to be especially abundant between the Equator and the Countercurrent. They also have been found to be rather consistently scarce north of the Countercurrent and south of the Equator. They do, however, occur well to the north and south of this equatorial region, and no known barriers to their horizontal migration exist in any direction until water too cold for their liking is reached in the vicinity of latitude 40° N. or S.

So we know that the distribution of yellowfin is continuous from east to west in this equatorial band and that the tuna prefer a band about 300 miles wide in a north-south direction. Here is a situation where character gradients may be expected if the tuna are not freely intermingling across the whole equatorial Pacific.

In order to seek gradients I have adopted a slightly modified form of the method proposed by Hubbs and Hubbs (1953). Theirs is a graphical method in which the mean is plotted, a measure of dispersion is indicated by one standard deviation plotted on either side of the mean as a hollow bar, and a measure of reliability is indicated by two standard errors of the mean plotted as a solid bar on either side of the mean. The range is indicated by a base line. I have used comparable regression statistics, except for the range. First, the mean part size $\hat{Y}$ was calculated directly from the regression equation

$$\hat{Y}=a+bX.$$

Second, the dispersion around the regression line is indicated by one standard deviation from regression

$$S_{y\cdot x}=\sqrt{\frac{\Sigma y^2-(\Sigma xy)^2/\Sigma x^2}{n-2}}$$

plotted as a hollow bar on either side of the mean. The reliability of the mean is indicated by two

[6] In the gap between longitude 109° W. and the American coast (fig. 2), yellowfin have been taken by commercial vessels and research ships sponsored by the Inter-American Tropical Tuna Commission.

standard errors of the mean estimated from regression

$$2S_{\hat{y}\cdot x}=2S_{y.x}\sqrt{1/n+x^2/\Sigma x^2}$$

plotted as a solid bar on either side of the mean.

These statistics were computed separately for each size group in each sample. For the small (S) group they were computed at a fork length of 65 cm., for the medium (M) group at 100 cm., and for the large (L) group at 140 cm. The three size groups are shown separately for all samples in figures 9 to 18. In each graph the equatorial Pacific samples are arranged in order from east to west and the other samples are added at the bottom.

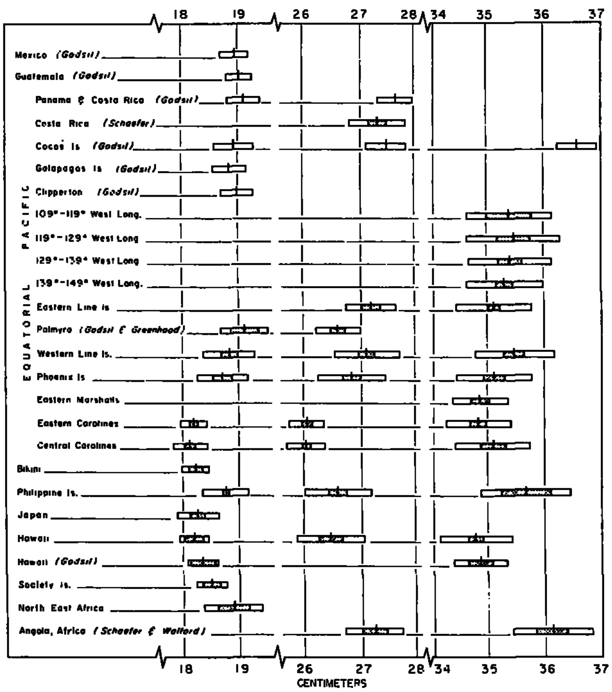

FIGURE 9.—Head length of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, solid bar ± two standard errors of the mean, hollow bar ± one standard deviation from regression.)

Almost all of the characters show gradients—sometimes stepped, sometimes continuous, and sometimes confused, perhaps because differences are small and sampling variation has its effect. The gradients, however, in most cases are unmistakable.

There is a distinct tendency toward shorter heads (fig. 9) in all three size groups from the western Pacific. The gradient is not smooth, because fish of the large group from longitude 109° W. to the western Line Islands area have much the same size head, and head size in the samples from the medium and small groups is much the same near the ends of the range.

The length of the pectoral fin (fig. 10) is distinctly greater in fish from the Caroline Islands area than in those from the eastern Pacific. Again similar tendencies occur in all size groups except

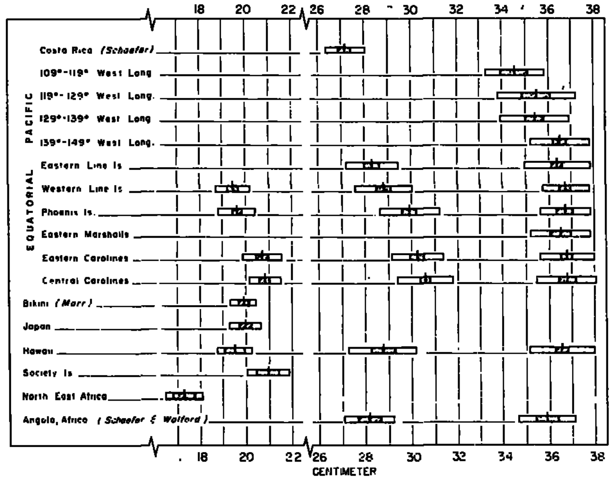

FIGURE 10.—Length of pectoral fin of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, solid bar ± two standard errors of the mean, hollow bar ± one standard deviation from regression.)

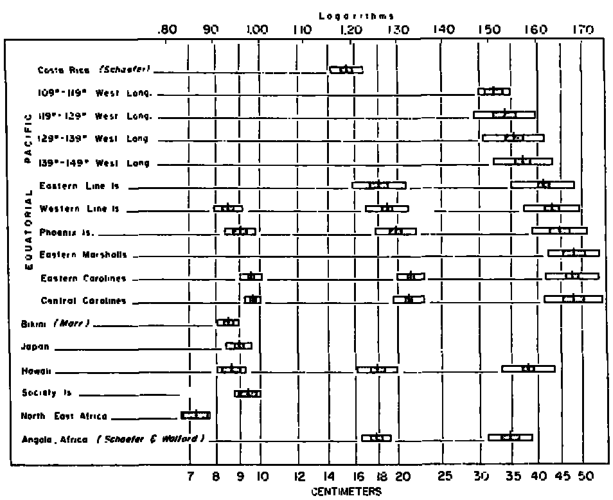

FIGURE 11.—Height of second dorsal fin of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± one standard deviation from regression.)

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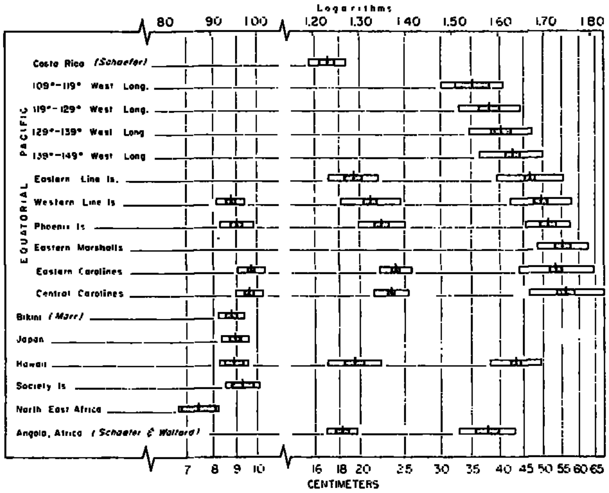

FIGURE 12.—Height of anal fin of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± two standard errors of the mean, the hollow bar ± one standard deviation from regression.)

that both the small and medium groups suggest a rather smooth cline, whereas the large group shows a rather similar fin length from longitude 139° W. to the Caroline Islands.

The differences in the height of the anal fin (fig. 12) and the height of the second dorsal fin (fig. 11) are even more marked, with clear and almost uniform gradients from the vicinity of Costa Rica to the eastern Marshalls and then about the same length fins on through the Caroline Islands area. Here the difference among samples of the large size group is about 16 cm. for height of second dorsal fin and 20 cm. for height of anal fin from longitude 109° W. to the Caroline Islands.

The distance between the snout and the insertion of the first dorsal fin (fig. 13) shows a distinct but somewhat irregular trend in the opposite direction, with the fish in the eastern Pacific having the greater measurement between these two points. In all size groups, insofar as samples are available, clearer trends in the same direction are to be noted in the measurements between the snout and the insertion of the second

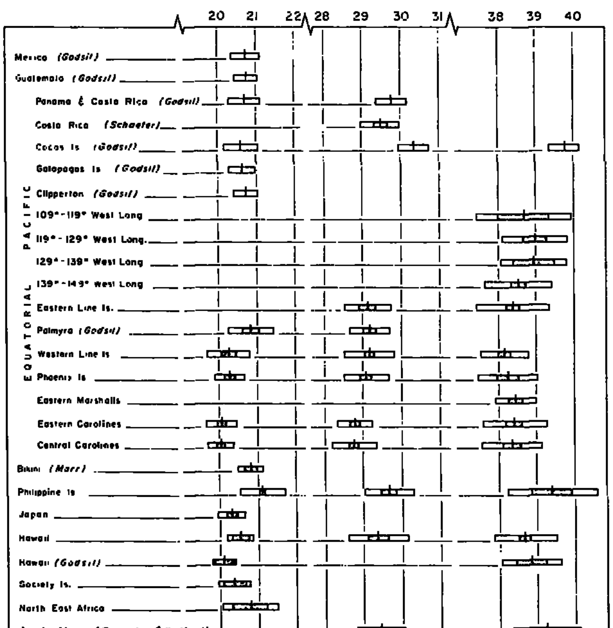

FIGURE 13.—Distance from snout to insertion of first dorsal fin of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± two standard errors of the mean, the hollow bar ± one standard deviation from regression.)

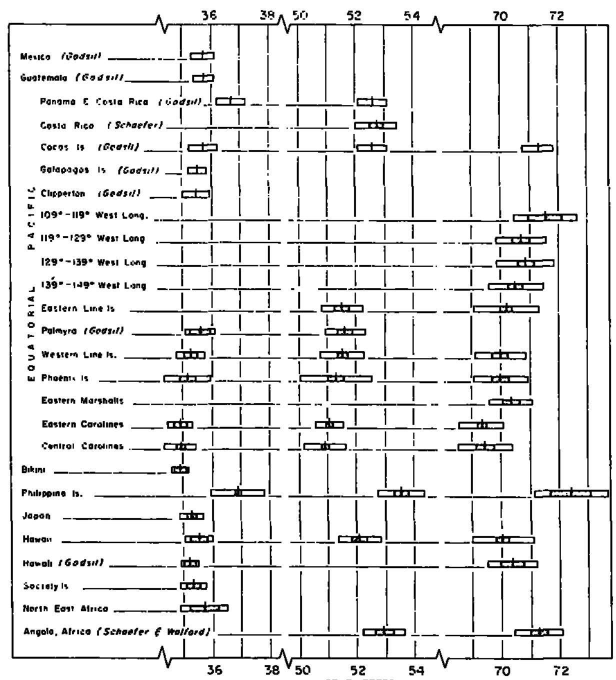

FIGURE 14.—Distance from snout to insertion of second dorsal fin of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± two standard errors of the mean, the hollow bar ± one standard deviation from regression.)

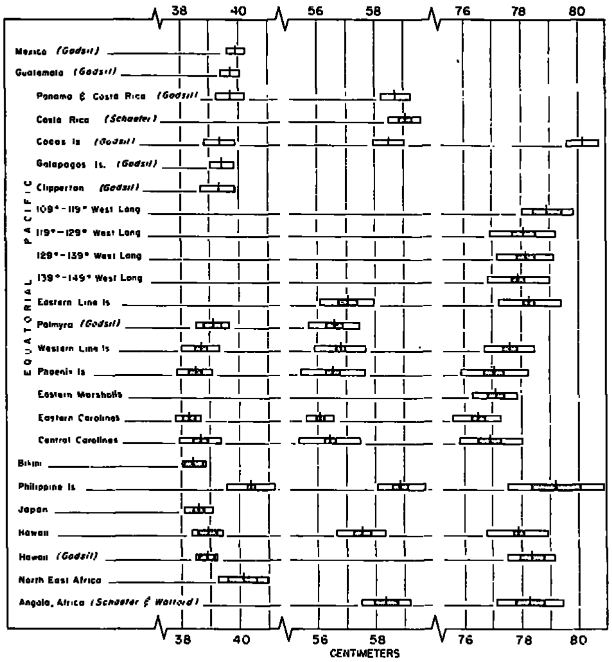

FIGURE 15.—Distance from snout to insertion of anal fin of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± two standard errors of the mean, the hollow bar ± one standard deviation from regression.)

dorsal fin (fig. 14) and between the snout and the insertion of the anal fin. In the large fish the trend is especially clearcut for the snout to insertion of anal fin (fig. 15). The snout to insertion of ventral fins (fig. 16) shows a somewhat similar tendency, but again the differences are smaller and sampling variation causes some confusion. The remaining characters, distance from the insertion of the ventral fins to the anterior edge of the vent (fig. 17) and greatest body depth (fig. 18), present a more confused picture. In the medium-sized fish there is a tendency for the fish from the eastern Pacific to have a greater body depth, but this tendency is not so noticeable among the larger specimens. The distance from the ventral insertion to the anterior edge of the vent divides the samples into two groups. The distance is about 40 cm. in the large size group among all samples from between longitudes 109° W. and 149° W. and about 39 cm. in the samples from the eastern Line Islands to the central Caroline Islands area.

Clearly, then, a more or less steady cline from the eastern to the west-central Pacific exists, with the average yellowfin in the eastern Pacific having the larger head, shorter pectoral, second dorsal, and anal fins, and greater distances from the snout to the insertions of first dorsal and ventral fins. It also has considerably the greater distances from the snout to the insertion of the second dorsal and anal fins, a greater body depth, and greater length from the ventral fins to the vent. Evidently, these greater distances to the insertions of the second dorsal and anal fins mean a correspondingly shorter caudal peduncle.

When this series of samples from the equatorial Pacific is compared with other samples from the more temperate waters some surprising differences are found. In the Bikini Island sample, which came from just outside the equatorial area at latitude 12° N., the fish would be expected to resemble those from the nearby Caroline Islands to the southwest, but they had especially short second dorsal and anal fins and a greater distance from the snout to the insertion of the first dorsal fin. The Bikini fish were small and were taken by trolling close to the island. In many regions of the Pacific these small yellowfin appear to be

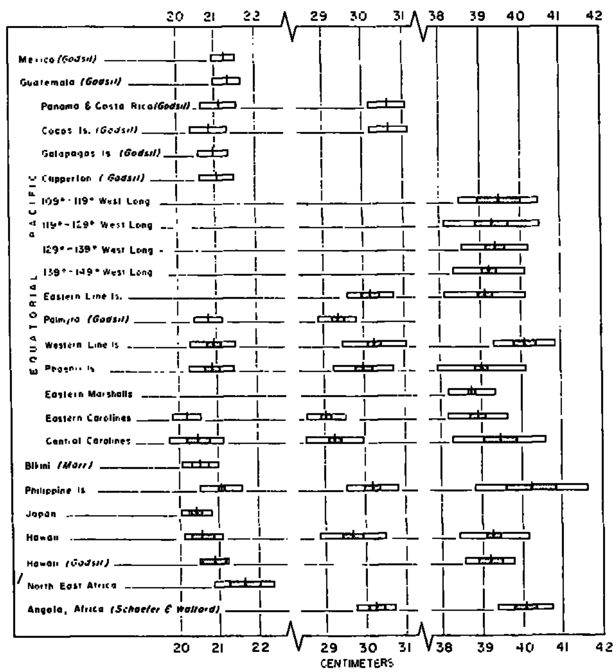

FIGURE 16.—Distance from snout to insertion of ventral fins of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± two standard errors of the mean, the hollow bar ± one standard deviation from regression.)

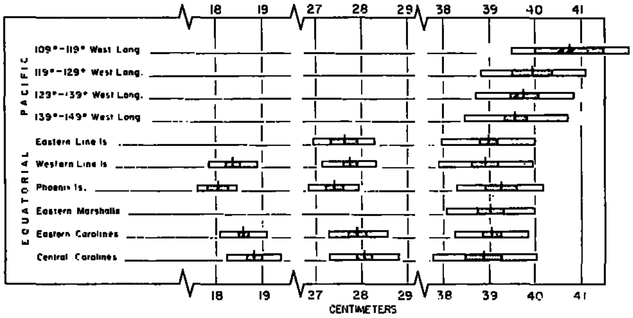

FIGURE 17.—Distance from insertion of ventral fin to anterior edge of vent of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± two standard errors of the mean, the hollow bar ± one standard deviation from regression.)

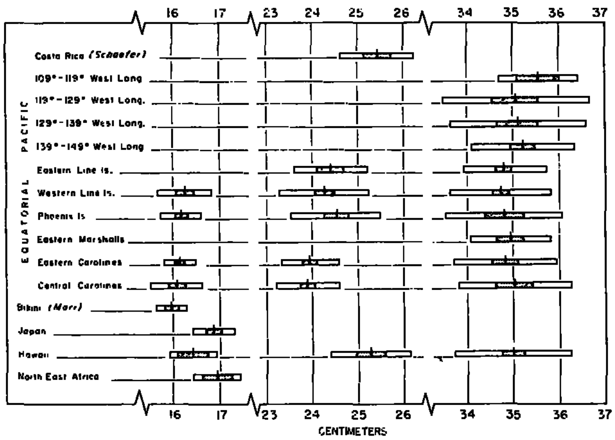

FIGURE 18.—Greatest body depth of small (65 cm.), medium (100 cm.), and large (140 cm.) yellowfin tuna, as estimated from regression statistics. (The center line indicates the mean, the solid bar ± two standard errors of the mean, the hollow bar ± one standard deviation from regression.)

common in the vicinity of islands and are very rarely taken on longlines. So this group of small fish near Bikini may be a relatively isolated one.

Characteristics of the sample from the Philippines are particularly surprising, because in all of the characters examined the fish are much more like those of the eastern Pacific than those of the nearby Caroline Islands area. This is consistently true for all size groups in all characters. Further, in the distance from the snout to the insertion of the first dorsal fin and also to the second dorsal, the means for the Philippine sample are distinctly larger than for any other samples.

The sample from Japan consisted only of small fish and in all respects is remarkably like the groups sampled from Hawaii. In not a single character is the difference of the means great enough to separate the dark bars that represent twice the standard error of the mean and, hence, indicate a statistically significant difference between the means.

The samples from Hawaii show somewhat mixed relationships with those from the equatorial area. In head length they are similar to those from the Caroline Islands, whereas in length of fins and in the distances from snout to insertion of the second dorsal and anal fins they are much more like the yellowfin of the equatorial area southeast of Hawaii between longitudes 129° and 159° W.

The sample of small yellowfin from the Society Islands was measured after being landed and thawed in Honolulu. Such handling may have changed the dimensions and this sample may not be directly comparable to the others. For this reason this is not a satisfactory sample. It is, however, near the Phoenix Islands sample in head length, height of the anal fin and distances from snout to first and second dorsal fins, but it has a very short second dorsal fin and much longer pectoral and anal fins than any other sample.

The sample from off Somaliland in northeast Africa is the most diverse of the group. It is similar to one or more central Pacific equatorial samples in head length and distances from snout to insertion of first and second dorsal fins, but it has very short pectoral, second dorsal, and anal fins. Somaliland fish also have a very long distance from the snout to the insertion of the anal fin, an especially deep body, and a long distance from the snout to the insertion of the ventral fins. This sample is very different from the sample from the west coast of Africa taken near Angola, where the fish are remarkably similar to those of the eastern Pacific in most dimensions. The yellowfin from Angola differ from those from Costa Rica principally in having slightly longer fins (as was pointed out by Schaefer and Walford, 1950).

In summary, yellowfin from the Pacific show a continuous cline morphologically along the Equator, whereas the samples taken in areas distant from the Equator differ erratically from the equatorial cline. The dimensions, however, are within the range of characters in the equatorial cline or are so close to one of the ends of the cline that there appears to be no evidence of genetically isolated stocks in the Pacific. This evidence will be considered further after data on overlap have been discussed.

COMPARISON OF SAMPLES FROM THE SAME AREA

Samples by Godsil (1948) and Godsil and Greenhood (1951) were obtained from areas also sampled by Schaefer and Walford (1950) or by POFI, and it is useful to look for evidence that different methods of measurement may have been used. Godsil's sample from Panama and Costa Rica came from an area close to that of Schaefer and Walford's from Costa Rica, and agreement among the four characters available for comparison is generally good even though Godsil's fish have slightly longer heads and a slightly longer distance from the snout to first dorsal fin. In addition, Godsil's sample from Hawaii may be compared with that of POFI, for it was obtained from rather limited areas: the small fish came from near Johnston Island and off islands between Kauai and French Frigate Shoals and the large fish from the Honolulu fish market. The POFI sample was obtained from a much wider area, although again most of the large fish were measured in the Honolulu market. Five measurements in two size groups are available to compare, and in not a single instance is the difference between means great enough to separate the black bars (and indicate a statistically significant difference).

Not as close statistically are Godsil and Greenhood's samples from Palmyra Island and the POFI samples from the eastern and western Line Islands, but the differences are complicated. Samples are available for comparison of small and medium size yellowfin taken by Godsil and Greenhood with similar sizes taken by POFI from the western Line Islands and a sample of medium size yellowfin from the eastern Line Islands. Godsil and Greenhood's data from Palmyra Island were obtained from frozen fish in a catch made during about 12 days of fishing in the vicinity of Fanning and Palmyra Islands. These days were nearly consecutive during February 1949. The POFI samples of small and medium fish were obtained from these islands as well as in the vicinity of the neighboring Washington and Christmas Islands, Kingman Reef, and a few from farther offshore. (All of these islands are near the borderline between our eastern and western Line Islands areas.) They were, however, taken over a much longer period (table 2) so they should be much more representative of the areas than Godsil and Greenhood's samples.

When a comparison of the mean character sizes of group M fish is made between our eastern and western Line Islands samples, not a single character differs by more than the length of the black bars, except height of the anal fin, and here the difference is in line with the general trend along the Equator. But when these two samples and the sample of small yellowfin from the western Line Islands are compared with Godsil and Greenhood's sample, I find that in head length their group M runs smaller and their group S somewhat larger; in distance from snout to insertion of first dorsal fin, their group M is about the same, and their group S considerably larger. Their distances from snout to insertions of second dorsal and anal fins show fairly good agreement with POFI samples. In the last character—distance from snout to insertion of the ventral fins—there is fairly good agreement between Godsil and Greenhood's sample and the POFI sample from the western Line Islands for group S; but then for group M the distance is markedly shorter than in either of the other two samples. Such erratic results suggest either that Godsil and Greenhood may have been sampling too few schools of fish to obtain a thoroughly representative sample or that freezing and thawing may have changed the proportions of the fish.

Despite these differences, I conclude that the techniques of measurement used by POFI were sufficiently close to those used by Godsil and Greenhood to arrive at about the same conclusions with regard to morphological differences among yellowfin from different areas of the Pacific.

MULTIPLE CHARACTER COMPARISON

After having examined the data for the mean differences in body shape, I shall consider next the overlap of the frequency distributions not merely of one character but of all characters considered simultaneously.

The measure of overlap that I shall use is similar to the measures of overlap used by taxonomists in many fields (Mayr et al., 1953: 146). The measures have all arisen from the concept of two overlapping frequency distributions and are expressed either as the percent of the actual frequency classes in the area of overlap or as a proportion of the observations estimated to be in the area of overlap of two normal distributions. The amount of overlap can be indicated as the distance between the means in units of the standard deviation or as an area under the curves. I prefer a measure of the overlapping area under two normal curves, which I have described fully (Royce, 1957) and which I have called Ω. The overlap (Ω) is expressed as a percent and varies from 0 to 100 as the means of the distributions approach one another.

This concept of overlap is especially useful because it answers the question, "What parts of population *A* possess characters that are within the range of population *B*?" I shall construe the answer to this question as a maximum for the proportion of population *A* which might have migrated from the area of population *B*.

In the computational procedure I shall follow closely the method outlined by Rao (1952, chapters 8 and 9). His method starts with pooled estimates of the correlations and standard deviations which are applied to the normalized mean values in order to transform them to values that are uncorrelated and that have unit standard deviations. In this method of analysis the amount of work increases approximately as the square of the number of characters used. To reduce the number, we have dropped from further consideration the greatest body depth, the distance from insertion of ventral fin to anterior edge of vent, and the distance from snout to insertion of ventral fins. This procedure seemed justifiable because (1) in some of our samples one or more of these characters were not measured, (2) none of them revealed as large differences between areas as other characters, (3) the distance from snout to insertion of ventral fins is highly correlated with head length and distance from snout to insertion of anal fin, and (4) it will be shown subsequently that seven characters are probably more than are necessary.

Because the statistics have arisen from regression analysis, it will be necessary to substitute for Rao's statistics comparable statistics determined from regression. Instead of the intragroup standard deviations from the mean, I use the intragroup standard deviations from regression. Instead of the intragroup correlations of the several characters, I use the intragroup partial correlations independent of total length. Instead of the actual mean values of the characters, I use the mean values estimated for certain given fork lengths. Therefore, in all of the statistics the effect of any changes with fork length is removed.

It has been impossible to assume that the regression lines were satisfactory beyond limited length groups, so we have broken down all of our statistics (except for partial correlations) into the length groups which were used in the previous section for character-by-character comparisons. They are group S, composed of fish less than 80-cm. fork length, which are compared at a length of 65 cm. (about 12 lb.); group M, from 80 to 120 cm., compared at a length of 100 cm. (43 lb.); and group L, more than 120 cm., compared at a length of 140 cm. (118 lb.). The basic regression constants, means, et cetera are in the appendix.

Because adequacy of the sampling varied widely, I have sought to obtain estimates of standard deviations from samples that I consider to be more representative. I have chosen the three areas most widely represented in time and among all three length groups; namely, Hawaii, western Line Islands, and eastern Caroline Islands. From these samples for each character in each size group I have obtained the standard deviation from regressions squared, $S_{y.x}^2$, averaged it for the three areas, and ended with an estimate of a pooled standard deviation from regression (within groups) which gives equal weight to the three areas (table 5).

TABLE 5.—*Pooled mean standard deviations from regression for each body character for the three size groups*

Size group (cm.)	Head length	Length of pectoral fin	Height of— Second dorsal fin	Height of— Anal fin	Snout to insertion of— First dorsal fin	Snout to insertion of— Second dorsal fin	Snout to insertion of— Anal fin
Small, <80	0.3981	0.7822	0.03163	0.03283	0.4470	0.5990	0.5897
Medium, 80–120	.5903	1.2891	.04626	.06141	.6776	.9426	.8943
Large, >120	.6596	1.2280	.06011	.05680	.7576	.9581	.9614

These standard deviations are the basic units of morphological distance, and it is desirable to examine them to determine how representative they are of all samples. Two matters are pertinent: first, I have used the actual standard deviation from regression without adjusting for the difference of the mean $\bar{x}$ from the X used for comparisons, so I need to know how close the means are to the comparison values; and second I need to consider whether the average dispersion about the lines is close to the grand average of all samples. The mean lengths of the three areas (giving equal weight to each) are 62.10, 99.32, and 142.04 cm. The means chosen for comparison are 65, 100, and 140 cm. If we consider that the standard deviation is directly proportional to the length of fish, then I have tended to underestimate slightly the standard deviation for the small and the medium groups and have slightly overestimated it for the large group.

In addition, the standard deviation of $\hat{Y}$ increases with distance from $\bar{y}$. For this reason I have tended to slightly underestimate the $S_{y.x}$ for the small and large groups.

Finally, the average coefficients of variation (table 4) of the three selected areas (for five characters) for the three size groups are 1.85, 1.80, and 1.63. These coefficients are close to the grand means of all samples, which are 1.74, 1.81, and 1.81 for small, medium, and large groups, respectively. With these partly compensating and in all cases small differences, I have chosen to make no adjustments but used the standard deviations from regression directly with confidence that they are very close to the grand average.

For the partial correlations of the several characters independent of fork length I have used a selected sample of 30 fish each from Hawaii, Costa Rica, eastern Line Islands, western Line Islands, and central Carolines. The 30 fish were selected from each area in the size range from 80 to 130 cm. and were chosen at random within the size group. From these, the intragroup correlations (table 6) and partial correlations were calculated (table 7).[7]

From the means and the pooled standard deviations the normalized mean values of each character have been obtained. The means were simply averaged to obtain a grand average, and then the deviations of each mean from the grand average in units of the average standard deviation were found (table 8).

Using the notation of Rao (1952), the normalized mean values $x_1 \ldots x_p$ were then transformed to values $Y_1 \ldots Y_p$, which are uncorrelated, and subsequently to other values $y_1 \ldots y_p$, which have unit standard deviation. The general formulas as given by Rao are—

$$Y_p = x_p - a_{pp-1} - \ldots - a_{p1}Y_1$$

$$a_{ij} = \frac{b_{ij}}{V(Y_j)} \text{ when } j < i-1$$

$$b_{ij} = \lambda_{ij} - \sum_{t=j-1}^{1} a_{jt}b_{it}$$

$$V(Y_i) = \lambda_{ii} - \sum_{j=1}^{i-1} a_{ij}b_{ij}$$

$$y_i = \frac{Y_i}{\sqrt{V(Y_i)}}.$$

The a and b values (tables 9 and 10) are convenient intermediate values in the computations. $V(Y_i)$ (table 11) is the variance of Y_i and y_i and is the final transformed value of the normalized mean (table 12). From these transformed means which have unit standard deviation and which are uncorrelated with one another, I obtained the distance in units of the standard deviation squared (D^2) for each possible area comparison in each size group (table 13). The total D^2, obtained by adding the D^2 values for each of the seven characters, is subject to a small bias due to the number of characters and the size of the samples. This bias (which is largest in the smallest samples and most troublesome in the samples most closely related) is removed by subtracting the value

$$p\frac{n_1+n_2}{n_1 n_2},$$

in which p is the number of characters and n_1 and n_2 the number of observations in each sample (Rao, 1952: 364).[8]

From the adjusted sum of D^2 the value of the overlap (Ω) is determined by finding D, then $\frac{D}{2}$, which is used as an argument to enter the tables of the area under a normal curve to find the area of one tail and then multiplying by 200 to express the area of two tails as a percentage Ω.

[7] This table of partial correlations is one of the more laborious parts of the entire computation. The particular data were chosen during preliminary computations as a test of the method on rather widely dispersed groups, all with good sample coverage. The size group corresponds nearly but not exactly to size group M. I have assumed that the partial correlations of these body parts for what is essentially the medium-size group for five samples with wide coverage are the same for all areas and also for the small and large size groups.

[8] I have ignored the slight variation in value of n among different characters within the samples.

TABLE 6.—*Intragroup correlations of body characters*

[See text for explanations]

Character	Head length	Length of pectoral fin	Height of— Second dorsal fin	Height of— Anal fin	Snout to insertion of— First dorsal fin	Snout to insertion of— Second dorsal fin	Snout to insertion of— Anal fin
Fork length	0.98422	0.92124	0.93830	0.92534	0.97846	0.99448	0.99210
Head length		.90009	.92767	.91515	.98329	.98667	.98618
Length of pectoral fin			.92373	.89801	.89439	.90894	.90865
Height of—							
Second dorsal fin				.96177	.91393	.92877	.92584
Anal fin					.90770	.91479	.90931
Snout to insertion of—							
First dorsal fin						.98647	.97739
Second dorsal fin							.99074

TABLE 7.—*Partial correlations of body characters, independent of fork length*

Character	Head length	Length of pectoral fin	Height of— Second dorsal fin	Height of— Anal fin	Snout to insertion of— First dorsal fin	Snout to insertion of— Second dorsal fin	Snout to insertion of— Anal fin
Head length	1.0000	−0.0960	0.0683	0.0657	0.5549	0.4243	0.4387
Length of pectoral fin		1.0000	.4409	.3088	−.0873	−.1766	−.1088
Height of—							
Second dorsal fin			1.0000	.7133	−.0583	−.1199	−.1164
Anal fin				1.0000	.0292	−.1367	−.1833
Snout to insertion of—							
First dorsal fin					1.0000	.6191	.2571
Second dorsal fin						1.0000	.3131
Anal fin							1.0000

TABLE 8.—*Normalized mean values* x_i *of body characters*

Size group and area	Head length	Length of pectoral fin	Height of— Second dorsal fin	Height of— Anal fin	Snout to insertion of— First dorsal fin	Snout to insertion of— Second dorsal fin	Snout to insertion of— Anal fin
SMALL-SIZE GROUP							
West Line Islands	0.9797	−0.3068	−0.2308	−0.1889	−0.2461	0.0334	−0.1187
Phoenix Islands	.6782	−.0511	.5185	.2315	−.2237	−.0334	−.5257
Bikini Island	−.5024	.2813	−.2940	−.1614	.9843	−.4841	−.5935
East Caroline Islands	−.5777	1.3424	1.2235	1.2489	−.7383	−.5175	−.8818
Central Caroline Islands	−.7284	1.5597	1.3468	1.0448	−.7383	−.4674	−.2035
Japan	−.3266	.3963	.3351	.1340	−.2013	.1669	−.2713
Hawaii	−.5526	−.1790	−.1676	−.0061	.3803	.5342	.2544
Northeast Africa	1.1304	−3.0043	−2.7347	−2.3089	.8725	.7846	2.3402
MEDIUM-SIZE GROUP							
Costa Rica	.8809	−1.4274	−1.7034	−1.3109	.4870	1.0397	2.0463
East Line Islands	.6776	−.5740	−.2810	−.3843	−.0443	−.2228	−.1565
West Line Islands	.5590	−.1164	.0843	.2215	0	−.2228	−.4137
Phoenix Islands	.1016	.7214	.5275	.6009	−.1033	−.5092	−.7045
East Caroline Islands	−1.2197	.9619	1.1911	1.0780	−.5313	−.7532	−1.3083
Central Caroline Islands	−1.2367	1.2411	1.1176	.9168	−.5756	−.8805	−.8722
Hawaii	−.5252	−.1551	−.4172	−.3713	.3542	.3395	.3466
Angola, Africa	.7623	−.6283	−.5275	.7572	.4280	1.2306	1.0846
LARGE-SIZE GROUP							
109°–119° W	.2122	−1.3029	−1.5339	−1.9894	.1320	1.2420	1.2690
119°–129° W	.3335	−.5130	−1.1429	−1.2993	.5280	.4175	.364
129°–139° W	.2426	−.5782	−.8285	−.8838	.4884	.5219	.4473
139°–149° W	.0910	.2524	−.5107	−.4806	−.0528	.1774	.2288
East Line Islands	−.2122	.1629	.2196	.2289	−.2640	−.1566	.5409
West Line Islands	.3487	.3502	.5523	.6954	−.5412	−.3862	−.1144
Phoenix Islands	−.2122	.3339	.7969	1.0000	−.4488	−.3549	−.6969
East Marshall Islands	−.5761	.2769	1.2610	1.4754	−.1584	−.0417	−.6553
East Caroline Islands	−.6216	.5375	1.3026	1.5933	−.2376	−1.0437	−1.3106
Central Caroline Islands	−.2274	.4805	1.3159	1.5827	−.3300	−.9498	−.8217
Hawaii	−.6822	.3013	−.3876	−.4947	.1188	−.2818	.1768
Angola, Africa	1.3190	−.2606	−1.0497	−1.4261	.8316	.9185	.5721

The results of these computations expressed as the percentage of overlap between areas appear in table 14. Here the equatorial series has been arranged in order from Costa Rica on the east to the central Carolines on the west. The other samples from Bikini Island, Japan, Hawaii, Angola, and northeast Africa are added in no special order.

TABLE 9.—*Table of* a

[See text for explanation]

Character	Head length	Length of pectoral fin	Height of—		Snout to insertion of—		
			Second dorsal fin	Anal fin	First dorsal fin	Second dorsal fin	Anal fin
Head length	1.0000	−0.0960	0.0633	0.6507	0.5549	0.4243	0.4387
Length of pectoral fin		1.0000	.45162	.31804	−.03435	−.13713	−.06731
Height of—							
Second dorsal fin			1.0000	.71415	−.10190	−.11033	−.14654
Anal fin				1.0000	.12486	−.11991	−.21979
Snout to insertion of—							
First dorsal fin					1.0000	.55912	.01926
Second dorsal fin						1.0000	.14781
Anal fin							1.0000

TABLE 10.—*Table of* b

[See text for explanation]

Character	Head length	Length of pectoral fin	Height of—		Snout to insertion of—		
			Second dorsal fin	Anal fin	First dorsal fin	Second dorsal fin	Anal fin
Head length	1.0000	−0.0960	0.0683	0.0657	0.5549	0.4243	0.4387
Length of pectoral fin		1.0000	.44746	.31511	−.03403	−.13587	−.06668
Height of—							
second dorsal fin			1.0000	.56650	−.08083	−.08752	−.11625
Anal fin				1.0000	−.06129	−.05886	−.10790
Snout to insertion of—							
First dorsal fin					1.0000	.37742	.01300
Second dorsal fin						1.0000	.08478
Anal fin							1.0000

NOTE.—These values are recorded in 5 significant figures; however, 8 significant figures were carried in the computations leading to *a*-values. The first row was obtained by preceding computations to 4 significant figures.

TABLE 11.—*Variances and square roots of variances for various body measurements*

[See text for explanation]

Variate	Variance [1] $V(Y_i)$	D $\sqrt{V(Y_i)}$	Variate	Variance [1] $V(Y_i)$	D $\sqrt{V(Y_i)}$
$V(Y_1)$	1.00000	1.00000	$V(Y_6)$	.57360	.75730
$V(Y_2)$	.99078	.99538	$V(Y_7)$	.74952	.86575
$V(Y_3)$	.79325	.89065	$V(Y_8)$	.76599	.87521
$V(Y_4)$	.49090	.70064	$V(Y_9)$	.40215	.63415
$V(Y_5)$	.67503	.82160	$V(Y_{10})$	.33024	.57466

[1] Values are recorded in 5 significant figures; however, 8 significant figures were carried in the computations leading to *a*-values (in table 9).

In the equatorial series there is a clear tendency for more closely located samples to have greater overlap. The overlap varies from a maximum of 82 percent and 81 percent in medium and large size groups for the comparison between eastern Carolines and central Carolines to a low of 3 percent for the comparison of Costa Rica with eastern Carolines and central Carolines. The relation of the average overlap to the separation of the samples in miles (fig. 19) is clear cut and much the same in all size groups. This graph has been made with the assumption that each population was located in the center of each 10° block of longitude and that the centers of these blocks were separated by units of 600 miles.

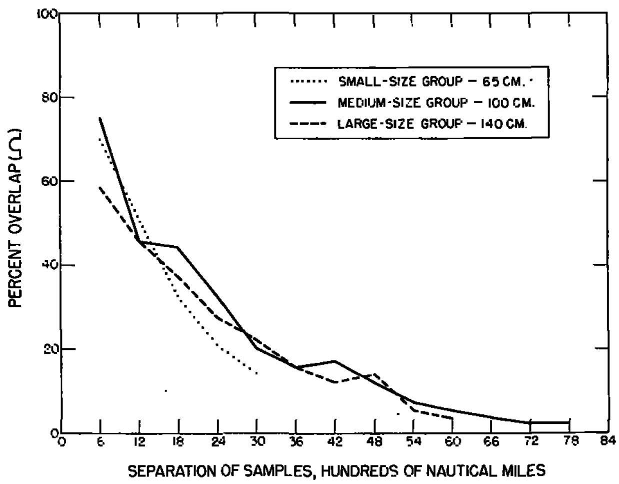

FIGURE 19.—Average percent of overlap of samples of yellowfin from the equatorial Pacific.

(This assumption disregards the small variations in location within the sample areas and the fact that one sample area was 11° of longitude in width instead of 10°.)

From this graph it appears that, on the average, samples of yellowfin tuna from along the Equator separated by 1,500 miles overlap less than 50

TABLE 12.—*Transformed normalized mean values* y_i *of characters*

[See text for explanation]

Size group and area	Head length	Length of pectoral fin	Height of—		Snout to insertion of—		
			Second dorsal fin	Anal fin	First dorsal fin	Second dorsal fin	Anal fin
SMALL-SIZE GROUP							
West Line Islands	0.9797	−0.2137	−0.2209	−0.0644	−0.9877	0.0200	−0.6794
Phoenix Islands	.6782	.0141	.5269	−.2178	−.6483	.0159	−.8993
Bikini Island	−.5024	.2342	−.4126	.0855	1.4924	−1.2648	−.3236
East Caroline Islands	−.5777	1.2929	.7622	.5606	−.4301	.2953	−.4415
Central Caroline Islands	−.7284	1.4967	.8085	.1493	−.2710	.3465	.3585
Japan	−.3266	.3666	.2144	−.1384	.0293	.5073	−.1779
Hawaii	−.5526	−.2331	−1.0979	.2481	.7879	.5083	.5033
Northeast Africa	1.1304	−2.9092	−1.6824	−.5596	.5116	−.4330	1.6070
MEDIUM-SIZE GROUP							
Costa Rica	.8809	−1.3491	−1.2942	−.1691	−.1833	.5606	1.5185
East Line Islands	.6776	−.5113	−.1056	−.2852	−.5141	−.4994	−.5564
West Line Islands	.5590	−.0630	.0867	.2135	−.3933	−.3452	−.6631
Phoenix Islands	.1016	.7346	.2143	.3217	−.1744	−.4276	−.6604
East Caroline Islands	−1.2197	.8487	.9957	.3656	.2835	−.1604	−.5967
Central Caroline Islands	−1.2367	1.1276	.7736	.2127	.2444	−.2908	−.1059
Hawaii	−.5252	−.2065	−.3269	−.0907	.7508	.1975	.5458
Angola, Africa	.7623	−.5577	−.3650	−.5689	.0031	.9849	.5397
LARGE-SIZE GROUP							
109°–119° W	.2122	−1.2885	−1.0870	−1.2903	−.0190	1.0161	.7226
119°–129° W	.3335	−.4832	−1.0630	−.7023	.3547	−.1536	−.5763
129°–139° W	.2426	−.5575	−.6661	−.4276	.3794	.0888	.1557
139°–149° W	.0910	.2448	−.7034	−.1665	−.1755	.2241	.0757
East Line Islands	−.2122	.1432	.1894	.1100	−.1628	.0735	.7850
West Line Islands	.3487	.3855	.4008	.4218	−.8788	−.0040	−.1270
Phoenix Islands	−.2122	.3150	.7508	.6232	−.3732	.1000	−.4551
East Marshall Islands	−.5761	.2226	1.3444	.8387	.2648	.4147	−.1544
East Caroline Islands	−.6216	.4800	1.2644	.9676	.1873	−.7855	−.7008
Central Caroline Islands	−.2274	.4608	1.2610	.9273	−.1883	−.6629	−.3540
Hawaii	−.6822	.2369	−.5063	−.2895	.5901	−.4029	.4817
Angola, Africa	1.3190	−.1346	−1.2044	−1.0049	.0897	.1274	−.3964

percent in the seven characters considered; those separated by 3,000 miles overlap less than 25 percent; and those separated by 6,000 miles overlap less than 6 percent.

The graph also shows that the average overlap varies little with the size group of fish, although the data in table 14 indicate a slight tendency for the small and medium size groups to have less overlap than the large. This tendency appears to be most marked in the comparisons of samples from the western Line and Phoenix Islands areas with those from the eastern and central Caroline Islands areas. In all of these comparisons the large size group shows the most overlap and the small size group the least. In the comparisons of the Hawaiian samples with those from the equatorial area, the small size group shows the least overlap, but the medium size group generally shows slightly greater overlap than the large. The data are too scant to establish the significance of this tendency, but it may be associated with more wandering by the larger fish.

The overlap of the other samples with those from the equatorial Pacific area follows, in general, the relations that were deduced from consideration of single characters. The Bikini Island sample shows rather little overlap with any of the equatorial samples—even the sample from the nearby Caroline Islands area—but a considerable overlap with samples from Japan and Hawaii. The Japanese sample, on the other hand, is apparently intermediate in structure between the Bikini Island and equatorial samples, for it shows a considerable overlap with all other samples where a comparison is possible. The samples from Hawaii, likewise, show a fairly large amount of overlap with most of the equatorial samples, but the largest size group is most similar to the equatorial yellowfin from between longitudes 129° and 159° W. This area is generally southeast of Hawaii rather than directly south. The Angola, Africa, fish show a large amount of overlap with the large fish from longitudes 119° to 149° W. They are as similar to these fish as are many of the samples from adjoining areas along the Pacific Equator. Moreover, in all comparisons of Angola samples with samples from 119° to 149° W. there is a marked tendency for the overlap to be less among the larger size group than the medium size group. This finding conforms with the observation made by Schaefer and Walford (1950) that the principal characters differentiating

Table 13.—*Value of D^2 computed from transformed means and adjusted for sample size to determine percentage of overlap* (Ω)

Size group and area	Head length	Length of pectoral fin	Height of— Second dorsal fin	Height of— Anal fin	Snout to insertion of— First dorsal fin	Snout to insertion of— Second dorsal fin	Snout to insertion of— Anal fin	D^2	Bias	Adjusted D^2	Ω
SMALL-SIZE GROUP											
West Line-Phoenix Islands	0.0909	0.0519	0.5592	0.0235	0.1152	0.0000+	0.0484	0.8891	0.3482	0.5409	71
-Bikini Island	2.1966	.2006	.0367	.0225	6.1509	1.6507	.1266	10.3846	.3849	9.9997	11
-East Caroline Islands	2.4255	2.2698	.9665	.3906	.3109	.0758	.0566	6.4957	.2758	6.2199	21
-Central Caroline Islands	2.9176	2.9255	1.0597	.0457	.5137	.1066	1.0772	8.6460	.3482	8.2978	15
-Japan	1.7064	.3367	.1895	.0055	1.0343	.2375	.2515	3.7614	.3849	3.3765	36
-Hawaii	2.3479	.0004	.7691	.0977	3.1528	.2384	1.3988	8.0051	.3535	7.6516	17
-Northeast Africa	.0227	7.2657	2.1360	.2452	2.2479	.2052	5.2276	17.3503	.3049	17.0454	4
Phoenix-Bikini Islands	1.3938	.0484	.8827	.0920	4.5826	1.6402	.3314	8.9711	.4150	8.5561	14
-East Caroline Islands	1.5773	1.6353	.0554	.6059	.0476	.0781	.2096	4.2092	.3059	3.9033	32
-Central Caroline Islands	1.9785	2.1981	.0793	.1348	.1424	.1093	1.5821	6.2245	.3784	5.8461	23
-Japan	1.0096	.1243	.0977	.0063	.4591	.2415	.5204	2.4589	.4150	2.0439	47
-Hawaii	1.5149	.0611	2.6400	.2171	2.0627	.2748	1.9673	8.7379	.3836	8.3543	15
-Northeast Africa	.2045	8.5457	4.8810	.1168	1.3454	.2015	6.2815	21.5764	.3350	21.2414	2
Bikini-East Caroline Islands	.0057	1.1208	1.3802	.2257	3.6960	2.4339	.0139	8.8762	.3425	8.5337	14
-Central Caroline Islands	.0511	1.5939	1.4911	.0041	3.1096	2.5963	.4653	9.3114	.4150	8.8964	14
-Japan	.0309	.0175	.3931	.0501	2.1407	3.1403	.0212	5.7938	.4516	5.3422	25
-Hawaii	.0025	.2184	.4696	.0264	.4963	3.1439	.6838	5.0409	.4203	4.6206	28
-Northeast Africa	2.6660	9.8810	1.6124	.4162	.9620	.6919	3.7272	19.9567	.3716	19.5851	3
East Caroline-Central Caroline Islands	.0227	.0415	.0021	.1692	.0253	.0026	.6400	.9034	.3059	.5975	70
-Japan	.0631	.8580	.3001	.4886	.2110	.0449	.0695	2.0352	.3425	1.6927	51
-Hawaii	.0006	2.3287	3.4600	.0977	1.4835	.0454	.8926	8.3085	.3111	7.9974	16
-Northeast Africa	2.9176	17.6576	5.9761	1.2548	.8868	.5304	4.1964	33.4197	.2625	33.1572	.4
Central Caroline Islands-Japan	.1614	1.2771	.3530	.0828	.0902	.0259	.2877	2.2781	.4150	1.8631	49
-Hawaii	.0309	2.9922	3.6344	.0098	1.1213	.0262	.0210	7.8358	.3836	7.4522	17
-Northeast Africa	3.4551	19.4120	6.2046	.5025	.6125	.6076	1.5588	32.3531	.3350	32.0181	.4
Japan-Hawaii	.0511	.3596	1.7221	.1494	.5755	.0000+	.4640	3.3217	.4203	2.9014	39
-Northeast Africa	2.1228	10.7309	3.5979	.1774	.2326	.8842	3.1859	20.9317	.3716	20.5601	2
Hawaii-Northeast Africa	2.8325	7.1615	.3416	.6524	.0763	.8860	1.2182	13.1685	.3403	12.8282	7
ΣD^2	33.8002	101.3132	45.2911	6.3107	37.8848	20.1191	36.5245				
Mean	1.2072	3.6183	1.6175	.2254	1.3530	.7185	1.3044				
Σmeans	1.2072	4.8255	6.4430	6.6684	8.0214	8.7399	10.0443				
Ω	58	27	20	20	16	14	11				
MEDIUM-SIZE GROUP											
Costa Rica-East Line Islands	0.0413	0.7019	1.4128	0.0135	0.1094	1.1236	4.3052	7.7077	0.4535	7.2542	18
-West Line Islands	.1036	1.6541	1.9069	.1464	.0441	.8205	4.7594	9.4350	.3218	9.1132	13
-Phoenix Islands	.6073	4.3418	2.2756	.2409	.0001	.9765	4.7476	13.1898	.3600	12.8298	7
-East Caroline Islands	4.4125	4.8303	5.2436	.2859	.2179	.5198	4.4741	19.9841	.3686	19.6155	3
-Central Caroline Islands	4.4842	6.1340	4.2758	.1458	.1829	.7249	2.6387	18.5863	.3100	18.2763	3
-Hawaii	1.9771	1.3055	.9357	.0061	.8725	.1318	.9461	6.1748	.4473	5.7275	23
-Angola, Africa	.0141	.6263	.8634	.1598	.0347	.1800	.9580	2.8363	.5747	2.2616	45
East Line-West Line Islands	.0141	.2010	.0370	.2487	.0146	.0238	.0114	.5506	.2926	.2580	80
-Phoenix Islands	.3318	1.5523	.1023	.3683	.1154	.0052	.0108	2.4861	.3308	2.1553	46
-East Caroline Islands	3.5997	1.8496	1.2129	.4235	.6362	.1149	.0016	7.8384	.3394	7.4990	17
-Central Caroline Islands	3.6645	2.6860	.7730	.2479	.5753	.0435	.2030	8.1932	.2807	7.9125	16
-Hawaii	1.4467	.0929	.0490	.0378	1.6000	.4857	1.2148	4.9269	.4180	4.5089	19
-Angola, Africa	.0072	.0022	.0673	.0805	.2675	2.2031	1.2014	3.8292	.5454	3.2838	36
West Line-Phoenix Islands	.2092	.6362	.0163	.0117	.0479	.0068	.0000+	.9281	.1991	.7290	67
-East Caroline Islands	3.1638	.8312	.8263	.0231	.4581	.0342	.0044	5.3411	.2077	5.1334	26
-Central Caroline Islands	3.2245	1.4175	.4718	.0000+	.4067	.0030	.3105	5.8340	.1491	5.6849	23
-Hawaii	1.1755	.0206	.1711	.0925	1.3090	.2945	1.4614	4.5246	.2863	4.2383	30
-Angola, Africa	.0413	.2447	.2040	.6121	.1571	1.7692	1.4467	4.4751	.4138	4.0613	31
Phoenix-East Caroline Islands	1.7458	.0130	.6106	.0019	.2097	.0714	.0041	2.6565	.2459	2.4106	44
-Central Caroline Islands	1.7910	.1544	.3128	.0119	.1754	.0187	.3075	2.7717	.1873	2.5844	42
-Hawaii	.3929	.8857	.2929	.1701	.8560	.3908	1.4549	4.4433	.3245	4.1188	31
-Angola, Africa	.4365	1.6700	.3356	.7932	.0315	1.9952	1.4402	6.7022	.4520	6.2502	21
East Caroline-Central Caroline Islands	.0003	.0778	.0493	.0234	.0015	.0170	.2409	.4102	.1959	.2143	82
-Hawaii	.4823	1.1134	1.7493	.2082	.2184	.1281	1.3053	5.2050	.3332	4.8718	27
-Angola, Africa	3.9283	1.9780	1.8515	.8733	.0786	1.3117	1.2914	11.3128	.4606	10.8522	10
Central Caroline Islands-Hawaii	.5062	1.7798	1.2111	.0921	.2564	.2384	.4247	4.5087	.2745	4.2342	30
-Angola, Africa	3.9960	2.8402	1.2964	.6109	.0582	1.6274	.4168	10.8459	.4019	10.4440	11
Hawaii-Angola, Africa	1.6577	.1233	.0015	.2287	.5591	.6200	.0000+	3.1903	.5392	2.6511	41
ΣD^2	43.4554	39.7637	28.5558	6.1582	9.4942	15.8797	35.5809				
Mean	1.5520	1.4201	1.0199	.2199	.3391	.5671	1.2707				
Σmeans	1.5520	2.9721	3.9920	4.2119	4.5510	5.1181	6.3888				
Ω	53	39	32	30	29	26	21				
LARGE-SIZE GROUP											
109°–119° West-119°–129° W	.0147	.6485	.0006	.3457	.1397	1.3682	1.6871	4.2045	.4823	3.7222	33
-129°–139° W	.0009	.5344	.1772	.7443	.1587	.8599	.3214	2.7968	.4823	2.3145	45
-139°–149° W	.1469	2.3510	.1471	1.2629	.0245	.6273	.4185	4.9782	.3953	4.5829	28
-East Line Islands	.1801	2.0498	1.6292	1.9608	.0207	.8885	.0039	6.7330	.3779	6.3551	21
-West Line Islands	.0186	2.8023	2.2135	2.9313	.7393	1.0406	.7218	10.4674	.4540	10.0134	11
-Phoenix Islands	.1801	2.5712	3.3775	3.6615	.1255	.8392	1,3870	12.1420	.4855	11.6565	9
-East Marshall Islands	.6214	2.2834	5.9117	4.5326	.0805	.3617	.7691	14.5604	.5083	14.0521	6
-East Caroline Islands	.6952	3.1276	5.5291	5.0981	.0426	3.2458	2.0261	19.7645	.4583	19.3062	3
-Central Caroline Islands	.1932	3.0601	5.5131	4.9177	.0287	2.8190	1.1591	17.6909	.4306	17.2603	4
-Hawaii	.8000	2.3268	.3372	1.0016	.3710	2.0136	.0580	6.9082	.3860	6.5222	20
-Angola, Africa	1.2250	1.3315	.0138	.0815	.0118	.7898	1.2522	4.7056	.5926	4.1130	31

TABLE 13.—*Value of D^2 computed from transformed means and adjusted for sample size to determine percentage of overlap (Ω)*—Continued

Size group and area	Head length	Length of pectoral fin	Height of—Second dorsal fin	Height of—Anal fin	Snout to insertion of—First dorsal fin	Snout to insertion of—Second dorsal fin	Snout to insertion of—Anal fin	D^2	Bias	Adjusted D^2	Ω
LARGE-SIZE GROUP—continued											
119°-129° West-129°-139° W	0.0083	0.0055	0.1575	0.0755	0.0006	0.0588	0.5358	0.8420	0.2979	0.5441	71
-139°-149° W	.0588	.5300	.1293	.2871	.2811	.1427	.4251	1.8541	.2109	1.6432	52
-East Line Islands	.2978	.3924	1.5685	.0598	.2678	.0516	1.8531	5.0910	.1935	4.8975	27
-West Line Islands	.0002	.7546	2.1427	1.2636	1.5215	.0224	.2019	5.9069	.2696	5.6373	24
-Phoenix Islands	.2978	.6371	3.2899	1.7570	.5298	.0643	.0147	6.5906	.3011	6.2895	21
-East Marshall Islands	.8274	.4982	5.7956	2.3747	.0081	.3230	.1780	10.0050	.3239	9.6811	12
-East Caroline Islands	.9122	.9278	5.4168	2.7886	.0280	.3993	.0155	10.4882	.2739	10.2143	11
-Central Caroline Islands	.3146	.8911	5.4010	2.6556	.2948	.2594	.0494	9.8659	.2462	9.6197	12
-Hawaii	1.0316	.5185	.3099	.1704	.0554	.0622	1.1194	3.2674	.2016	3.0658	38
-Angola, Africa	.9712	.1215	.0200	.0916	.0702	.0790	.0324	1.3859	.4082	.9777	62
129°-139° West-139°-149° W	.0230	.6437	.0014	.0682	.3079	.0183	.0064	1.0689	.2109	.8580	64
-East Line Islands	.2068	.4910	.7319	.2890	.2940	.0002	.3960	2.4089	.1935	2.2154	46
-West Line Islands	.0113	.8892	1.1383	.7215	1.5831	.0086	.0799	4.4319	.2696	4.1623	31
-Phoenix Islands	.2068	.7613	2.0076	1.1042	.5664	.0001	.3731	5.0195	.3011	4.7184	28
-East Marshall Islands	.6703	.6086	4.0421	1.6035	.0131	.1062	.0962	7.1400	.3239	6.8161	19
-East Caroline Islands	.7468	1.0764	3.7268	1.9466	.0369	.7644	.7336	9.0315	.2739	8.7576	14
-Central Caroline Islands	.2209	1.0369	3.7137	1.8358	.3223	.5651	.2598	7.9545	.2462	7.7083	16
-Hawaii	.8553	.6311	.0255	.0191	.0444	.2418	.1063	1.9235	.2016	1.7219	51
-Angola, Africa	1.1586	.1788	.2898	.3333	.0839	.0015	.3048	2.3507	.4082	1.9425	49
139°-149° West-East Line Islands	.0919	.0103	.7971	.0765	.0002	.0227	.5031	1.5018	.1065	1.3953	55
-West Line Islands	.0664	.0198	1.2193	.3461	.4946	.0520	.0411	2.2393	.1826	2.0567	47
-Phoenix Islands	.0919	.0049	2.1147	.0236	.0391	.0154	.2817	3.1713	.2141	2.9572	39
-East Marshall Islands	.4450	.0005	4.1935	1.0104	.1939	.0363	.0529	5.9325	.2369	5.6956	23
-East Caroline Islands	.5078	.0553	3.8722	1.2861	.1316	1.0193	.6030	7.4753	.1869	7.2884	18
-Central Caroline Islands	.1014	.0467	3.8589	1.1964	.0002	.7868	.1846	6.1750	.1592	6.0158	23
-Hawaii	.5978	.0001	.0388	.0151	.5861	.3931	.1648	1.7958	.1146	1.6812	52
-Angola, Africa	1.5080	.1439	.2510	.7029	.0703	.0094	.2229	2.9084	.3212	2.5872	42
East Line-West Line Islands	.3146	.0587	.0447	.0972	.5127	.0060	.8317	1.8656	.1653	1.7003	51
-Phoenix Islands	.0000+	.0295	.3152	.2634	.0443	.0007	1.5378	2.1909	.1967	1.9942	48
-East Marshall Islands	.1324	.0063	1.3340	.5310	.1828	.1164	.8825	3.1854	.2196	2.9658	39
-East Caroline Islands	.1676	.1135	1.1556	.7355	.1226	.7379	2.2076	5.2403	.1696	5.0707	26
-Central Caroline Islands	.0002	.1009	1.1483	.6670	.0007	.5423	1.2973	3.7567	.1418	3.6149	34
-Hawaii	.2209	.0088	.4840	.1596	.5669	.2270	.0920	1.7592	.0972	1.6620	52
-Angola, Africa	2.3446	.0772	1.9427	1.2430	.0638	.0029	1.3957	7.0699	.3038	6.7661	19
West Line-Phoenix Islands	.3146	.0050	.1225	.0406	.2556	.0108	.1076	.8567	.2729	.5838	70
-East Marshall Islands	.8553	.0265	.8904	.1738	1.3078	.1753	.0751	3.5042	.2957	3.2085	37
-East Caroline Islands	.9415	.0889	.7458	.2979	1.1366	.6107	.3292	4.0706	.2457	3.8249	33
-Central Caroline Islands	.3319	.0057	.7399	.2555	.4768	.4341	.0515	2.2954	.2179	2.0775	47
-Hawaii	1.0628	.0221	.8228	.5059	2.1577	.1591	.3705	5.1009	.2476	4.8533	27
-Angola, Africa	.9415	.2705	2.5767	2.0355	.9380	.0173	.0726	6.8521	.3799	6.4722	20
Phoenix-East Marshall Islands	.1324	.0085	.3524	.0464	.4070	.0996	.0904	1.1361	.3272	.8089	65
-East Caroline Islands	.1676	.0272	.2638	.1186	.3142	.7841	.0604	1.7359	.2772	1.4587	55
-Central Caroline Islands	.0002	.0213	.2603	.0925	.0342	.5826	.6546	1.6451	.2494	1.3957	55
-Hawaii	.2209	.0061	1.5803	.8330	.9279	.2529	.8776	4.6987	.2048	4.4939	29
-Angola, Africa	2.3446	.2021	3.8228	2.6507	.2143	.0008	.0034	9.2387	.4114	8.8278	11
East Marshall-East Caroline Islands	.0021	.0663	.0064	.0166	.0060	1.4405	.2986	1.8365	.3000	1.5365	53
-Central Caroline Islands	.1216	.0567	.0070	.0078	.2053	1.1612	.0398	1.5994	.2722	1.3272	56
-Hawaii	.0113	.0002	3.4251	1.2728	.1058	.0685	.4046	5.8883	.2276	5.6607	23
-Angola, Africa	3.5914	.1276	6.4964	3.3989	.0307	.0825	.0586	13.7861	.4343	13.3518	7
East Caroline-Central Caroline Islands	.1554	.0004	.0000+	.0016	.1411	.0150	.1203	.4338	.2222	.2116	81
-Hawaii	.0037	.0591	3.1354	1.5803	.1622	.1464	1.3983	6.4854	.1776	6.3078	21
-Angola, Africa	3.7659	.3777	6.0950	3.8908	.0095	.8334	.0927	15.0650	.3843	14.6807	6
Central Caroline Islands-Hawaii	.2068	.0501	3.1233	1.4806	.6059	.0676	.6984	6.2327	.1498	6.0829	22
-Angola, Africa	2.3914	.3545	6.0782	3.7334	.0773	.6246	.0018	13.2612	.3565	12.9047	7
Hawaii-Angola, Africa	4.0048	.1380	.4873	.5118	.2504	.2812	.7711	6.4446	.3119	6.1327	22
ΣD^2	41.0543	37.1912	128.5601	78.4819	20.8264	29.4377	33.4614				
Mean	.6220	.5635	1.9479	1.1891	.3156	.4460	.5070				
Σ means	.6220	1.1855	3.1334	4.3225	4.6381	5.0841	5.5911				
Ω	69	59	38	30	28	26	24				

the Angola and Costa Rica samples—length of the pectoral fin and heights of the second dorsal fin and the anal fins—all have significantly higher regression coefficients in the Angola samples and diverge more from the Costa Rica sample in the larger size groups.

Lastly, the sample from northeast Africa shows little overlap with any other sample. Such is to be expected because of the marked differences in fin lengths and distance from the snout to the insertion of the anal fin, which have already been pointed out. However, it has also been mentioned that this sample from northeast Africa was not composed of yellowfin of a size strictly comparable to any of our size groups. Thus, much of these differences may have arisen because of the effects

TABLE 14.—*Percent of overlap (Ω) between areas, using seven characters*

Area and size group	109°–119° W.	119°–129° W.	129°–139° W.	139°–149° W.	East Line Islands	West Line Islands	Phoenix Islands	East Marshall Islands	East Caroline Islands	Central Caroline Islands	Bikini Island	Japan	Hawaii	Angola, Africa	Northeast Africa
Costa Rica: M					18	13	7		3	3			23	45	
109°–119° W.: L		33	45	28	21	11	9	6	3	4			20	31	
119°–129° W.: L			71	52	27	24	21	12	11	12			38	62	
129°–139° W.: L				64	46	31	28	19	14	16			51	49	
139°–149° W.: L					55	47	39	23	18	23			52	42	
East Line Islands:															
M						80	46		17	16			19	36	
L						51	48	39	26	34			52	19	
West Line Islands:															
S							71		21	15	11	36	17		4
M							67		26	23			30	31	
L							70	37	33	47			27	20	
Phoenix Islands:															
S									32	23	14	47	15		2
M									44	42			31	21	
L								65	55	55			29	14	
East Marshall Islands: L									53	56			23	7	
East Caroline Islands:															
S										70	14	51	16		.4
M										82			27	10	
L										81			21	6	
Central Caroline Islands:															
S											14	49	17		.4
M													30	11	
L													22	7	
Bikini Island: S												25	28		3
Japan: S													39		2
Hawaii:															
S															7
M														41	
L														22	

of curvilinear regressions, and I cannot say with confidence that this size group is as different as the data indicate.

EVALUATION OF MULTIVARIATE ANALYSIS

A full evaluation of the merits of the multivariate analysis which I have used here is beyond the scope of this article.[9] But the procedure is so laborious that some discussion of the value of considering extra characters is warranted. The labor increases approximately in relation to the square of the number of characters, but Mahalanobis, Majumdar, and Rao (1949) refer to Mahalanobis, Bose, and Roy (1937),[10] in which it is shown that D^2 approaches a limit as additional characters are considered. On an intuitive basis this would be expected to happen rather quickly, because as additional characters are considered they would have an increased chance of being correlated with previously considered characters. The extra amount of work involved in making the D^2 analysis is approximately related to the square of the number of characters considered, so the problem is how many characters must be considered to arrive at a reasonably stable estimate of overlap.

It can be shown readily that more than one character must be considered. To demonstrate this, I have taken 10 comparisons at random out of the total of 122 and calculated the overlap of the single characters showing the greatest difference between samples. These, I compared with the overlap computed from seven characters (table 15). In all but one [11] there is a substantial reduction in the overlap due to the extra characters. In fact, the single character comparison with the least overlap, that between eastern Marshalls and Angola with respect to height of the anal fin, still shows an overlap of 40 percent. This is reduced to 7 percent when six more characters are added.

The average effect of adding characters one by one may be obtained from the grand average, D^2, for each size group. These averages have been obtained from table 13 for each character and the overlap computed, first for one character, then two characters, and so on until the seven are considered. It may be seen (fig. 20) that most

[9] A detailed evaluation of the application of D^2 to an anthropometric survey may be found in Mahalanobis, Bose, and Roy (1937).

[10] Not available to me.

[11] In this instance the seven characters show an overlap of 82 percent and the single character with the greatest difference shows an overlap of only 75 percent. This anomaly occurs because the other six characters when combined show less difference than the correction for small samples.

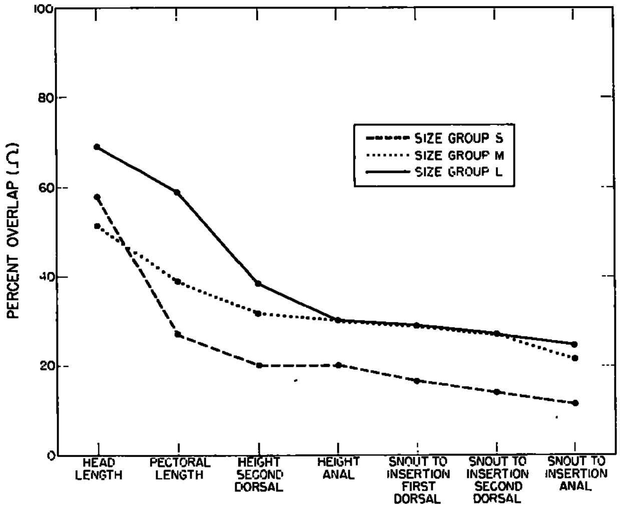

FIGURE 20.—Effect of adding characters on average overlap of all sample comparisons.

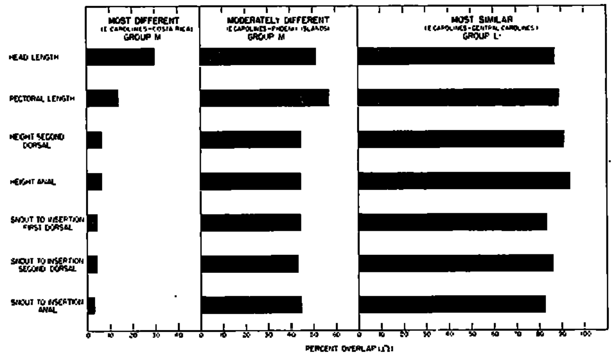

FIGURE 21.—Effect of adding characters on overlap of selected comparisons.

of the reduction (if any) in D^2 occurs in the first three or four characters, but that there is a continuing gradual reduction to the seventh character.

TABLE 15.—*Comparison of overlap of one character with overlap of seven characters considered simultaneously*

Sources of samples compared	Size group	Character showing greatest difference	Overlap (Ω)	
			1 character	7 characters
West Line Islands-Northeast Africa.	Small	Length of pectoral fin.	41	4
Bikini Island-Central Caroline Islands.	do	Height of second dorsal fin.	56	14
East Line Islands-Hawaii	Medium	Head length	59	19
East Caroline-Central Caroline Islands.	do	Snout to insertion of anal fin.	75	82
119°–129° West-East Line Islands.	Large	Height of anal fin.	54	27
129°–139° West-Phoenix Islands.	do	do	50	28
139°–149° West-Phoenix Islands.	do	do	55	39
Phoenix Islands-Hawaii	do	do	54	29
East Marshall Islands-Angola, Africa.	do	do	40	7
Hawaii-Angola, Africa	do	Head length	48	22

Another approach has been made in an examination of the character-by-character overlap of our most different, most similar, and moderately different equatorial samples (fig. 21). Here again it may be seen that in each case most of the reduction in overlap (if any) occurs in the first three or four characters.

It would also have been possible to improve the order in which I have considered the characters. The most useful characters are those that show the greatest difference among samples and the least correlation with other characters. Thus, a consideration of our character-by-character comparisons and the partial correlations of table 7 indicates that it would be desirable to consider height of the anal fin, which is one of the characters showing the greatest difference among samples, but not height of second dorsal fin, which is closely correlated with the height of the anal fin. For a similar reason I could have omitted the distance from the snout to insertion of the second dorsal fin after considering that of the snout to insertion of the first dorsal fin, with which it is highly correlated. Another rather high correlation exists between head length and distance from snout to insertion of first dorsal fin.

Thus, it would appear that had I considered only the best four characters, I would have found substantially the same overlap that I did in considering seven. This would have reduced the work of computation to about one-third of that for the seven characters. Rao (1952: 256) notes also that it is profitable to use samples of equal size.

EXTENT OF INTERMINGLING

As I have previously argued, the percentage of overlap of two samples may be considered to represent the maximum proportion of one sample that might belong to the other. When this concept is extended to two populations separated geographically, the overlap may be assumed to be the proportion of one which might have come from the other. There is, of course, no evidence that any part of the population did come from another, but the overlap may be used, together with other data, to estimate how much intermingling might be occurring.

Such use requires an assumption that the characters selected to estimate the overlap are fixed. If the characters are genotypic and fixed at time of fertilization, then the overlap would indicate a maximum amount of genetic mixing (gene flow). Many characters, however, are fixed during early development and vary according to environment, especially temperature. Even so, the amount of overlap would still indicate a maximum possible amount of intermingling.

Clearly, between the two ends of the Pacific Equator the overlap is so small (3 percent) that there can be practically no intermingling. Along this long belt where the yellowfin distribution is continuous, I have previously noted that the average overlap is less than 50 percent in samples separated by 1,500 miles and less than 25 percent in samples separated by 3,000 miles. Consequently, it seems probable that east-west migration must be relatively limited and that most yellowfin tuna probably remain within a few hundred miles of where they occur as postlarvae. The eggs and larvae drift passively with the currents, but development is rapid and it seems unlikely that they could drift more than 300 or 400 miles before becoming active swimmers.

I have noted previously that the average overlap among samples was about the same for the different size groups. This clearly indicates that after they reach a weight of about 5 pounds (50 cm.) there is no tendency for samples of the larger fish to become more diverse. Such evidence indicates that the morphological differences arise very early in life and considering the similar environment in the surface layers along the Equator it seems probable that the differences are genotypic.

The samples from farther away from the Equator—Bikini Island, Japan, and Hawaii—are separated from the Equator by a zone where yellowfin are relatively scarce. The Bikini sample shows little overlap with samples from the adjoining equatorial areas, much less in fact than with the Japanese sample. The Hawaiian sample shows little overlap with the smaller sizes from the equatorial areas, but the larger sizes are quite like those from the Equator southeast of Hawaii. There is also considerable similarity between the Japanese sample and the Hawaiian sample.

The sample from Angola, Africa, has so much overlap with some of the equatorial Pacific samples that the maximum amount of intermingling might be large, but of course the geographic separation makes absurd the suggestion of any intermingling. In the case of the northeast Africa sample, both the markedly low overlap with all other samples and the geographic separation make the possibility of intermingling very small.

GEOGRAPHIC DISTRIBUTION OF YELLOWFIN

One kind or another of yellowfin tuna, genus *Neothunnus*, has been described from each of the warm seas of the world except the Mediterranean. Rosa (1950) has reviewed the extensive literature and noted that the distribution extends from Point Conception, California, to San Antonio, Chile, in the eastern Pacific; from Hokkaido, Japan, south through the Indonesian Archipelago to Cape Naturaliste, southwest Australia; around the shores of the Indian Ocean to the tip of South Africa; from French Equatorial Africa north to the coast of Portugal in the eastern Atlantic, and from Maryland in the United States south to the coast of Brazil in the western Atlantic. He also reported that yellowfin occur in the Red Sea, which is the warmest sea in the world, so the distribution extends from the warmest waters to those in the vicinity of latitudes 40° N. and 40° S.

To these coastwise records must be added the records of capture in the open Pacific far from land, as reported by Yōichi Yabuta in the Japanese atlas "Average Year's Fishing Condition of Tuna Longline Fisheries," from the exploratory fishing of POFI along the central and eastern Pacific Equator, in offshore records from the eastern Atlantic by Mather and Day (1954), and in the more recent unpublished records of the capture of yellowfin tuna in the open parts of the Gulf of Mexico and Caribbean Sea by exploratory fishing vessels. The Japanese atlas records the capture of yellowfin tuna along the Equator from longitude 170° W. to the Philippines, thence northward at various places to as far as latitude 43° N. along the coast of Japan, in all of the major seas of the southwest Pacific, and in the Indian Ocean in the vicinity of Sumatra and the Nicobar Islands.

This distribution corresponds quite closely to that of waters warmer than the 65° F. isothere (line of equal warming) shown by Hutchins and Scharff (1947). Along the coast of Chile the limit is between the 65° F. and the 60° F. isotheres, and in other areas the most poleward record is not quite to the 65° F. isothere. Further, no temperature barrier exists between any of the populations of yellowfin, for there is a broad band of summer temperatures between 65° F. and 70° F. around the Cape of Good Hope between the Atlantic and Indian Oceans.

Within the broad range of this species, however, there are widely varying concentrations. Already mentioned is the concentration along the Pacific Equator, where the yellowfin occur in an east-west band, and the scarcity in the open ocean north and south of this band. They do, however, occur in concentrations in the vicinity of many islands, in the Coral Sea off Australia, and possibly in other places separated from this equatorial belt by a region of yellowfin scarcity. The small yellowfin, in particular, seem to be concentrated fairly close to the islands, because they are rarely seen or caught on the high seas. The persistence of groups of these yellowfin along the reefs of certain islands has led to commercial fishing for them by trolling, and many fishermen feel that such yellowfin populations are relatively static. Thus, concentrations of yellowfin may vary enormously in extent from the clearly continuous distribution along many thousands of miles of the Pacific Equator to perhaps a relatively isolated group around a coral atoll.

Despite the variations in abundance, their widespread occurrence in all tropical oceans, near land and far from land, indicates that yellowfin tuna belong to the pelagic fauna of the warm seas and not merely to local faunal areas.

NOMENCLATURE

A great variety of scientific names has been assigned to yellowfin tuna in various parts of the world, and there has been no general agreement on the correct names to be assigned to the various species or subspecies. Rosa (1950) recognized three species: *Neothunnus albacora* (Lowe) 1839 of the eastern Atlantic Ocean, *N. argentivittatus* (Cuvier and Valenciennes) 1831 from the western Atlantic Ocean, and *N. macropterus* (Temminck and Schlegel) 1842 from the Pacific and Indian Oceans. Schaefer and Walford (1950) considered the Atlantic form to be *N. albacora* and the Pacific form to be *N. macropterus*. They designated a specimen from the Malabar coast of India as the lectotype of *N. argentivittatus*, and thus this name clearly applies to the Indian Ocean form unless it is decided that the Indian Ocean form should be the same species as one with a prior name from another ocean. Later Ginsburg (1953) considered that the name *Thunnus albacares* (Bonnaterre) 1788 was appropriate for the eastern Atlantic yellowfin, *T. subulatus* (Poey) 1875 for the western Atlantic yellowfin, *T. catalinae* (Jordan and Evermann) 1926 for the eastern Pacific yellowfin, and *T. macropterus* (Temminck and Schlegel) 1842 for the western Pacific yellowfin.

Rivas (1954: 316) referred in a footnote to Ginsburg's usage of *T. albacares* and accepted it as a valid name for all Atlantic yellowfin. Rivas (1961) reviewed the status of *T. albacares* again and opined that the various yellowfin populations from the Atlantic and the Pacific were not worthy of separate nomenclaturial recognition. He noted the widespread distribution in tropical waters and stated, ". . . it would seem therefore, that the yellowfin tuna represents a single pantropical species . . . ."

The characters that almost all authors have used to distinguish the species have been length of the pectoral fin and height of the second dorsal and anal fins. Ginsburg (1953) admits that the differences between the tuna of the eastern Atlantic and Hawaii (which he calls western Pacific) are only of racial magnitude and do not warrant separate names. He retained the separate names because he considered that (1) specimens of the two populations had not been directly compared, (2) not all promising phases of the morphology had been studied, (3) the tuna inhabit totally different faunal areas, and (4) most authors have treated the populations as distinct species. He, therefore, considered it desirable to avoid the confusion of shifting names in and out of synonymy.

Schaefer and Walford (1950) considered the differences between the eastern Pacific and eastern Atlantic forms sufficient to warrant separate species pending more information on the variability within oceans as compared with the variability between oceans. This information is now at hand from our studies and it shows clearly that the entire range of variation which has heretofore been used to describe the species of yellowfin occurs within one continuous distribution of yellowfin along the Pacific Equator. In fact, the differences between yellowfin from Costa Rica and from Angola (which Schaefer and Walford consider to be sufficient for a separate species) are much less than the differences between yellowfin from Costa Rica and the eastern Carolines. This difference between the Costa Rican and Caroline Islands yellowfin is far beyond the conventional level of a subspecific difference, but because of the clear evidence of continuous distribution and morphological gradients between these two areas the yellowfin from the two areas must be considered conspecific.

There also may be a similar cline across the tropical Atlantic. Ginsburg (1953) reviewed the scanty evidence which indicates that the western Atlantic form has longer second dorsal and anal fins than the eastern Atlantic form. If the cline is present, then the Atlantic forms, also, are conspecific.

If we add to this evidence the fact that the yellowfin is clearly a fish of the high seas and not restricted to any coastal faunal areas and the strong probability that the distribution is continuous in the oceans from the Pacific through the Indian to the Atlantic, all of the forms should be considered conspecific. The confusion can best be settled by reducing them to one species.

There will remain, of course, the possibility that certain yellowfin populations may be distinct enough to warrant a separate specific or subspecific name. This must be considered for the sample from northeast Africa off Somaliland, in which the fins are shorter than any we have found in the Pacific. However, our sample is not good, and with the evidence of continuous distribution through the Indian Ocean it seems most probable that this group is not completely separated from other yellowfin populations. Futhermore, it occurs in one of the warmest parts of the ocean, where the yellowfin would be expected to be the most different in structure.

Settling the matter of the proper specific name is only part of the problem. The generic name is also in dispute. Fraser-Brunner (1950) and Ginsburg (1953) used *Thunnus* rather than the long established generic name of *Neothunnus*. Godsil (1954) did not follow Fraser-Brunner but separated *Thunnus*, *Neothunnus*, and *Parathunnus*, principally on the basis of markings on the liver; however, he gives this problem of generic separation

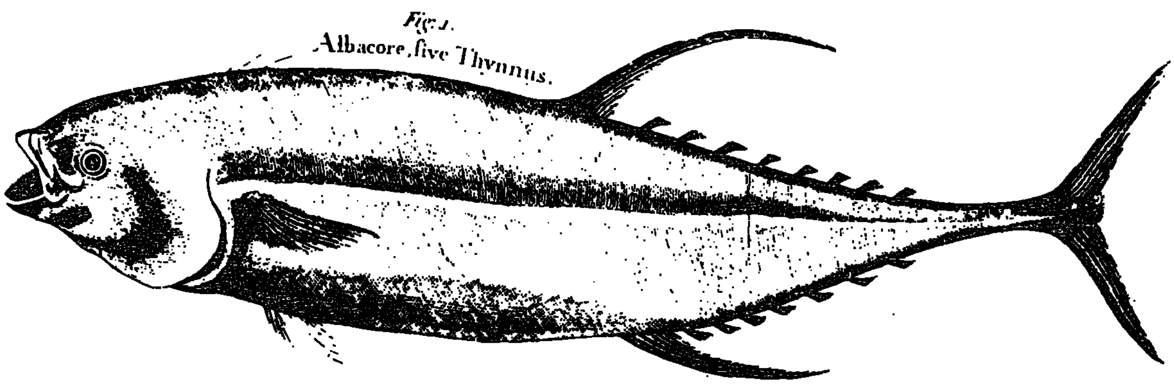

FIGURE 22.—Figure of tuna from Sloane (1707) on which Bonnaterre's description (1788) was based.

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little consideration. Fraser-Brunner reduced *Parathunnus* and *Neothunnus* to subgeneric status on the principle that a generic name is intended to express relationship. It is not desirable to have a group of monotypic genera. There is now no evidence to indicate that these genera should be separate, and so I follow Fraser-Brunner and Ginsburg, who use *Thunnus* for the bluefin, yellowfin, bigeye, and albacore group.

The final question is which specific name is correct. Schaefer and Walford (1950) considered that *T. argentivittatus* (Cuvier and Valenciennes) 1831 would have priority if only one species of yellowfin was recognized, but they did not discuss the merits of *T. albacares* (Bonnaterre) 1788. Ginsburg (1953) reviewed the question and concluded that the original figure of *albacares*, which shows the distinctive long second dorsal and anal fins of the yellowfin, must be considered a yellowfin even though the pectoral fin is too short. Bonnaterre's description of the yellowfin was based on a description and figure by Sloane (1707) which I reproduce here in full (fig. 22).

The Sea hereabout is very well provided with *Albacores*, or *Thynni*, whose Description follows:

ALBACORES DESCRIBED

This Fish was Five Foot long from the end of the Chaps to that of the Tail, the Body was of the make and shape of a Mackerel, being roundish or torose, covered all over with small Scales, White in some places, and Darker colour'd in others, there was a Line run along each side. The coverings of the Gills of each side were made of two large and broad Bones covered with a shining Skin, the Jaws were about Six Inches long, having a single row of short strong sharp Teeth in them, and were pointed. The Eyes were large, and the Gills very numerous, behind which were a small pair of Fins. *Post anum* was a Foot long Fin, about Three Inches broad at bottom, and Tapering to the end. It had another on its Back answering that on the Belly, and from these were small *Pinnula* at every Two Inches distance to the forked Tail, which was like a New Moon falcated, before which on the Line of the two sides was a membranous thick horny Substance, made up of the Fishes Skin, stood out about three quarters of an Inch where it was highest, something like a Fin. It was about Three Foot Circumference a little beyond the Head, where it was thickest. The Eye was about an Inch and a half Diameter. The Figure of this Fish is here added, *Tab.* I. *Fig.* I. taken from a dried Fish, where every thing was perfect save the first Fin on the Back, which I suppose was accidentally rub'd off.

It is frequently taken by Sailers with Fisgigs or White Cloath, made like Flying-Fish, and put to a Hook and Line for a Bait; The Flesh is coloured, and Tasts as the *Tunny* of the Mediterranean, from whence I am apt to believe it the same Fish. It is to be found not only about *Spain*, and in the way to the *West-Indies;* but in the South-Seas about *Guayaquil*, and between *Japan* and *New-Spain* every where.

This is called *Tunnyes* of *Oviedo fum. p.* 214. *Albicores* of *Terry, p.* 9. *Albocores* of *Mandelflo, p.* 196. *Dolphin* or *Tunin of Marten, Orcynus Rondelet, p.* 249. *Thunnus Gesner.* 1158. *Aldrovand. p.* 307. *Mus. srammerd. Raii. Hist. p.* 176. *Tab. M.* I. *Corett. Thynni Species ejusd. app. p.* 5. & 24. *Tab.* 9. *No.* I. where the Figure seems not good. *Thynnus Bellon. p.* 106. *Salvian. p.* 124. *An palamite of Oviedo Sum. p.* 211? *Guarapucu Brasiliensibus, an Cavala Lusitanis, nostratibus Coninghvisch. Marcgr. p.* 178? *Pif. Ed.* 1658. *p.* 59? *vel an Curvata pinima ejusd. p.* 150? *Ed.* 1650. *p.* 51? *Tons* of *Escarbot Nova Francia, p.* 35. *du Raveneau de Lussan, p.* 171. *An Albacoretta Pis. Ed.* 1658. *p.* 73? *Toni di Fernan Colon vita di Christof. f.* 29. An Ox-Eye of *Anonymus Portugal. ap. Purchas, p.* 1313? *vel Toninas Ejusd. ib. p.* 1314? *Tunnies of Francis Gualle. Purchas,* 806. *Albacoras Ejusd. p.* 446. *Hakl.* of *Smith New-England, p.* 227. of *Galvanos Purchas,* in 42°. North Lat. South-Seas, *p.* 1685. *Ton ou tasard de Cauche, p.* 138. *An tonine Ejusd. p.* 142? *Ulasso* a Tuny Fish of *Duddeley. p.* 576. *Albacore* of *Ligon. p.* 6. *Abbeville. p.* 30. *An* a *Spanish* Macquerel of *Ligon? Albachores Pyrard. de Laval. p.* 6. 137.

A tuna of the size of Sloane's specimen almost certainly must have been one of either the yellowfin or the bluefin group. A comparison of measurements of Atlantic bluefin, Angola yellowfin, and Sloane's figure (table 16) indicates that Sloane's figure is closer to the yellowfin than to the bluefin in all characters except length of the pectoral fin. Further, Sloane's figure was taken from a dried fish from which the first fin on the back was missing and his figure is a dorsolateral view instead of a lateral one. These facts explain most of the differences from an accurate sketch of a yellowfin, which include the shorter pectoral fin, shorter anal

TABLE 16.—*Comparison of body proportions calculated from Sloane's figure of Albacore, yellowfin from Angola, Africa, and bluefin tuna from Cape Cod, Mass.*

[Expressed as thousands of fork length]

Character	Sloane's figure [1]	Yellowfin [2]	Atlantic bluefin [3]
	cm.	*cm.*	*cm.*
Fork length	152	140	125.7–131.4
Head length	212	258	284–294
Length of pectoral fin	135	256	197–216
Height of second dorsal fin	27C	249	132–145
Height of anal fin	197	268	129–144
Snout to insertion of—			
First dorsal fin	190	280	306–318
Second dorsal fin	489	509	541–559
Anal fin	580	559	606–621
Ventral fins	276	286	315–339

[1] From Sloane (1707) fig. 1, table 1.
[2] From Schaefer and Walford (195C), using the regressions for our large size group and assuming a fork length of 140 cm.
[3] From Godsil and Holmberg (1950), page 7, converted from their ratios of part size to body length.

fin, more slender body, and first dorsal fin too far forward.

Therefore, I concur with Ginsburg and conclude that *T. albacares* (Bonnaterre) 1788 is a valid name for yellowfin tuna. It has priority and hence the appropriate name for a single worldwide species of yellowfin tuna is *Thunnus albacares* (Bonnaterre) 1788.

SUMMARY AND CONCLUSIONS

The study was undertaken in order to understand better the intermingling of the populations of yellowfin tuna and to distinguish the species.

Twenty-four samples of yellowfin tuna from the Pacific Ocean, one from the Atlantic off Angola, Africa, and one from the Indian off Somaliland are compared.

Regression statistics are used to control effect of size of fish in order to compare samples by each of ten characters. Seven of the characters are further used in a multiple character measure of overlap.

The regression equations used by Schaefer (1948) are used. These require log of fork length with log height of second dorsal fin and log height of anal fin, and log fork length with length of pectoral fin. All other characters approximate a linear relationship.

Neither linear, transformed linear, nor simple curvilinear regression equations are completely satisfactory for the full range of the data. Therefore, samples are divided into small fish, less than 80 cm.; medium, 80 to 120 cm.; and large, more than 120 cm. in fork length. Comparisons are made at 65 cm., 100 cm., and 140 cm., respectively.

A cline, or character gradient, exists along the Pacific Equator from the eastern Pacific to the Caroline Islands. The yellowfin in the eastern Pacific have larger heads, slightly shorter pectoral fins, much shorter second dorsal and anal fins, and greater distances from snout to the insertion of first dorsal, second dorsal, ventral, and anal fins. They also have a greater body depth and a greater distance from the insertion of the ventral fins to the vent.

Most other samples were like some part of the cline. The sample from Angola, Africa, closely resembled the samples taken between Costa Rica and the Line Islands. The samples from Hawaii were quite like those taken between longitude 129° W. and the Line Islands. The sample from Japan was like the one from the Caroline Islands. The Bikini Island sample, however, was rather unlike the others but most similar to those from Japan and Hawaii. The Philippine sample was most like samples from the eastern Pacific and very different from the nearby Caroline Islands samples. Most diverse was the sample from Somaliland, which had especially short fins, deep body, and a long distance from the snout to the insertion of the ventrals.

The overlap of samples from along the Pacific Equator is inversely related to distance between samples. The average between samples taken 1,500 miles apart is less than 50 percent; 3,000 miles apart, less than 25 percent; and 6,000 miles apart, less than 6 percent. It is concluded that east-west migration is limited and that most yellowfin remain within a few hundred miles of where they occur as juveniles.

The multivariate analysis is evaluated. It is shown that overlap is greatly reduced by considering more than one character but that it is not worthwhile to use more than four characters.

The distribution of the yellowfin indicates that it belongs to the pelagic faunal group and not to coastal faunal groups. It occurs in all oceans, except the Mediterranean, in waters warmer than 65° F. at the surface. No temperature barrier to movement of the yellowfin exists between the Atlantic and Indian or Indian and Pacific Oceans. The distribution is probably continuous although not uniform.

It is considered desirable to place all yellowfin tunas of the world in a single species because of the continuous distribution and because the full range of characters which have been used to distinguish species occurs in the series of samples from the Pacific Equator. The name should then be *Thunnus albacares* (Bonnaterre) 1788.

ACKNOWLEDGMENTS

My debt to the many people who have carefully measured thousands of tuna is detailed in a previous paper (Dung and Royce, 1953). The formidable task of analyzing the data has been accomplished almost entirely by Mrs. Dorothy D. Stewart, nee Dung. Joseph J. Graham, Garth I. Murphy, O. E. Sette, and A. L. Tester critically reviewed the manuscript.

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APPENDIX

TABLE A-1.—*Morphometric measurements of yellowfin tuna (mm.), from longline catches near the Equator and longitude 110° W., March 1954*

Fork length	Weight (lb.)	Head length	Snout to insertion of—				Insertion of ventral fin to anterior edge of vent	Greatest body depth	Length of pectoral fin	Height of—		Diameter of iris	Sex	Examiner
			First dorsal fin	Second dorsal fin	Anal fin	Ventral fin				Second dorsal fin	Anal fin			
764		217	243	416	454	238		188	207	98	99	33	F	William F. Royce.
800	23¼	223	242	430	479	243	242	214	225	113	113	30	M	Do.
823		228	247	435	487	252	235	202	242	119	119	31	F	Do.
1051		288	310	552	605	319		278	284	180	186	38	M	Do.
1175		310	342	616	678	350	343	306	309	222	205	36	F	Do.
1180		309	334	605	678	333		300	310	229	246	40	F	Do.
1206		308	341	627	689	344	353	293	322	218	213	34	F	Do.
1232		314	339	623	692	353	346	303	308	216	234	35	F	Do.
1283		325	359	661	733	365	.377	311	330	276	269	36	F	Do.
1412		350	387	722	791	391		348	336	363	434	40	F	H. S. H. Yuen.
1446		367	417	735	819	411		375	341	368	465	41	M	Do.
1449		360	400	732	816	399	428	380	356	378	416	41	M	William F. Royce.
1465		367	394	779	819	404	421	362	380	396	381	44	F	Do.
1466		366	383	737	817	400	448	388	343	366	319	38	M	Do.
1476		379	416	765	844	420	441	391	369	379	404	40	F	H. S. H. Yuen.
1480		369	391	756	840	419	427	379	358	363	393	38	F	Do.
1507		388	417	767	851	431	445	382	347	362	443	42	F	Do.
1525		385	425	764	853	430	433	398	378	391	465	40	M	Do.
1531		404	445	781	858	454		417	371	446	512	42	M	Do.
1537		379	420	777	846	417		400	379	417	434	45	M	William F. Royce.
1567	165	387	429	791	880	428	461	411	[1] 361		592	42	F	H. S. H. Yuen.
1603		408	437	813	893	459	452	420	367	506	[1] 0	41	M	Do.
1608		408	430	803	913	466	457	417	358	458	543	40	M	Do.
1649		415	450	828	906	454	470	429	391	420	502	41	M	Do.
1650		435	457	828	908	472	453	427	375	477	362	40	M	Do.
1680	200	429	438	841	937	471	478	445	404	493	543	42	M	W. F. Royce.
1690	220	427	483	871	957	471	508	454	406	640	716	46	M	Do.

[1] Frayed.

TABLE A-2.—*Morphometric measurements (cm.) of yellowfin tuna taken near Bender Cassim, Somaliland, Africa*

[Measured by A. Fraser-Brunner]

Fork length	Weight (kg.)	Head length	Snout to insertion of—				Insertion of ventral fin to anterior edge of vent	Greatest body depth	Length of pectoral fin	Height of—		Diameter of iris	Number of gill rakers	Sex	Months of 1953
			First dorsal fin	Second dorsal fin	Anal fin	Ventral fin				Second dorsal fin	Anal fin				
62.5	5.25	18.5	20.5	34	39	23	---------	16.5	16.5	7	6.5	2.5	9+18	M	March.
65	6.3	18.75	20	35.5	40	21.5	---------	17	18	7.25	7.5	3	8+20	M	February.
65	6.4	19	21	36	40	21.5	---------	17	18	8.5	8	3.5	9+18	F	January.
65	6.4	19	21.5	36.5	39.5	21	---------	17	17.5	9	9	3.5	9+18	F	February.
67.5	6	19.5	22.5	37.5	42	22	---------	17	18.5	8.5	9	3	10+19	F	Do.
68	6	19.5	23	38	42	22	---------	17.5	18.5	8.5	9	3	10+19	F	January.
69.5	6.4	20	21.5	38	42	22	---------	18.5	19	9.5	10	3.25	10+21	M	February.
70	5.6	20	24	41	44	23	---------	20	19.5	8.5	8	3	8+20	M	January.
70	5.8	20	22	29	43	22	---------	17.5	18	8.5	8	3.5	10+18	F	March.
70	7	20	22	29	43	22	---------	17.5	18	8	8.8	3.5	9+19	F	Do.
70.5	5	20	23	39	42.5	23	---------	18.5	19	8.5	8	3	9+20	F	January.
70.5	5.4	20.5	22	38	42.5	23.5	---------	18.5	18.5	8.5	8	3	9+20	M	February.
70.5	5.8	20	23.5	39	43	23	---------	19	20	9	8	3.5	9+20	F	January.
71.5	7.8	20.5	22.5	39	43	23.5	---------	19	18.5	8.25	9	3.5	9+20	F	March.
72	7	20.5	22.5	39.5	43	23	---------	19	20	8	8.5	3.5	10+20	M	Do.
73	8	20.5	22.5	38	45	24	---------	19	19.5	10	10	3.25	9+20	M	Do.
73	8	20.5	22	37.5	45	24	---------	19	19.5	9.5	10	3.5	9+20	M	Do.
73.5	7.3	20.5	23	39	44	23.5	---------	19	19.5	8.5	8.5	3	9+20	F	Do.
74	8	21	25	42	45	24	---------	20	20	9	11	3.5	9+20	F ?	February.
74	8	21	24	41	45.5	25	---------	20	20	9	10	3.5	9+20	M	March.
75	7.7	21.5	23	41.5	46	24	---------	19.5	20	9.5	10	3.5	9+19	F	Do.
76	5.5	18.5	21	36	40	21	---------	16.5	19	8	8.25	3.5	9+21	M	Do.
76	6	18.5	21	35	40	21.5	---------	16.5	13	8.5	8.25	3.5	9+21	M	Do.
76	9	22	24.5	42	46	25	---------	20.5	21.5	10	11.5	3.5	9+22	F	Do.
77	5.5	19	21.5	36.5	40.5	22	---------	17	19	8	8.5	3.5	9+20	M	Do.
80	10	23	24	42.5	49.5	26	---------	22	20	11.25	12	3.5	9+20	F	Do.
80	10	23	24	42.5	49	25	---------	22	20	11	11.5	3.75	10+20	F	Do.
80	11	23	26	44	48.5	26	---------	22	21.5	11	12	4	9+20	F	Do.
80	11	23	26	44	48	26	---------	22	21.5	11	12	4	9+21	F	Do.
80.5	10	22.5	25	44	48	26	---------	21	20.5	9.5	10	4	9+21	F	Do.
80.5	10	22.5	25	44	48	26	---------	21	20	9.5	10	4	9+22	F	Do.
81	10	23	25.5	44	47	25.5	---------	21	21	9	11	3.5	8+20	M	Do.
81	10	23	24	43	50	26	---------	22.25	20	11.5	12	3.75	9+20	F	Do.
81	10.7	23	25.5	44	47	25.5	---------	21	21	9	11	3.5	9+20	M	Do.
81.5	10	23	25	43.25	44	27	---------	20.5	22.5	9.5	10	4	10+22	F	Do.
81.5	10	24	26.5	44	49	25	---------	22	20.5	9.5	12	3.5	10+21	F	Do.
82	11.6	24	27	45.5	49	26	---------	21.5	23.5	10.5	12.5	4	10+22	M	Do.
82.5	10.5	22.5	24	43.5	46.5	24	---------	22	22.5	12	14	3.5	9+20	M	Do.
83	11.5	23	25.5	44.5	50	26.5	---------	22	21.5	11	12	3.5	9+20	F	Do.
83	11.7	23.5	25.5	44.5	50.5	26.5	---------	21.5	21.5	11	11.5	3.5	9+20	F	Do.
84	11	22.5	26	45	50	26.5	---------	22.5	22	11	13	3.5	9+20	F	Do.
84	11.8	23.5	25.5	44.5	50.5	26.5	---------	21.5	21.5	11	11	3.5	10+20	F	Do.
84	12	24	26.5	45	50	27	---------	23	21	11	12	4	10+20	M	Do.
84	12	24.5	26	46	50	27	---------	22.5	21	10.5	11.5	4	9+20	M	Do.
84	12.6	24	27	45	50.5	27	---------	22.5	21	11	12.5	4.25	9+21	M	Do.
84.5	12	24.5	26	47	52	28.5	---------	23	23	12.5	16.5	3.5	8+20	F	Do.
84.5	12	23	26	45.5	50.5	26.5	---------	22	21.5	11.5	11.5	4	9+21	M	Do.
84.5	12.7	23	26	45.5	50.5	26.5	---------	22	23	11.5	11.5	4	8+21	M	Do.
85.5	12	23.5	26.5	45	51	26	---------	22.5	22	11	14	4	10+20	F	Do.
86	12	23.5	27	45	49	26	---------	23	22	11.5	10.5	4	8+21	F	Do.
86	13	24	27.5	46.5	52.5	27.5	---------	23	24	12.5.	14	3.5	9+20	M	Do.
86	13	24	27	46.5	51	27.5	---------	23	22	12	13	4	10+20	F	Do.
87	13	24.5	26.5	45.5	50.5	26.5	---------	23.5	22	12	12	4	9+22	F	Do.
87	13.3	24.5	27	46	52	27.5	---------	23	24.5	13	14.5	3.75	9+20	M	Do.
89	14	26	28	48	52	29	---------	24	23	13.5	15	4	8+20	F	Do.
105.5	22	28	31.5	56	61	31.5	---------	27	26	16	18	4	9+20	M	Do.

NOTE.—Data furnished through the courtesy of G. L. Kesteven, Fisheries Division, U.N. Food and Agriculture Organization. Measurements were recorded in half or quarter centimeter units identified by the upper limit of each unit; thus are ⅛ to ¼ cm. too great.

TABLE A-3.—*Regression statistics of yellowfin tuna samples*

[N=number used in sample; S=summation; X=fork length (mm.) or log. (mm.); Y=other characters as listed; x=deviations from mean $\bar{x}$; y=deviation from mean $\bar{y}$; b=regression coefficient; a=constant in regression equation; s=standard deviation from regression (cm.); $\hat{Y}$=estimated character size (cm.) at standard comparison length of size group (cm. except for logarithms which have characteristics for mm.)]

Character and size group [1]	N	SX	SY	SX^2	SY^2	SXY	Sx^2
X=fork length; Y=head length:							
Costa Rica:[2] *M*	29	2, 896. 5	789. 9	292, 493. 79	21, 688. 87	79, 625. 98	3, 193. 3676
109°-119° W.: *L*	21	3, 146. 2	797. 0	475, 009. 34	30, 504. 64	120, 353. 68	3, 648. 6524
119°—129° W.: *L*	47	6, 895. 9	1, 739. 1	1, 016, 781. 01	64, 638. 71	256, 300. 39	5, 005. 7588
129°-139° W.: *L*	46	6, 667. 6	1, 680. 6	988, 059. 18	62, 520. 78	248, 469. 53	21, 605. 0548
139°-149° W.: *L*	111	16, 507. 1	4, 150. 5	2, 468, 765. 29	156, 032. 57	620, 546. 47	13, 951. 3223
East Line Islands:							
M	33	3, 382. 8	913. 8	349, 710. 50	25, 445. 64	94, 305. 02	2, 942. 7473
L	155	22, 524. 5	5, 631. 8	3, 288, 056. 75	205, 463. 66	821, 786. 66	14, 810. 9420
West Line Islands:							
S	43	2, 954. 4	849. 3	205, 448. 86	16, 939. 55	58, 973. 52	2, 460. 9680
M	86	8, 407. 2	2, 286. 3	832, 615. 32	61, 334. 71	225, 881. 39	10, 743. 0894
L	57	7, 876. 2	1, 998. 8	1, 094, 133. 62	70, 433. 44	277, 547. 24	5, 808. 5948
Palmyra Island:[3]							
S	35	2, 537. 2	730. 7	184, 770. 90	15, 308. 81	53, 170. 94	845. 6475
M	57	5, 379. 7	1, 446. 6	511, 367. 03	36, 886. 28	137, 303. 18	3, 627. 1688
Phoenix Islands:							
S	37	2, 503. 6	715. 2	171, 117. 96	13, 927. 34	48, 798. 54	1, 712. 2044
M	59	5, 795. 3	1, 559. 6	576, 982. 99	41, 586. 04	154, 811. 32	7, 737. 1918
L	46	6, 142. 5	1, 539. 6	836, 866. 39	52, 633. 16	209, 836. 18	16, 642. 3411
East Marshall Islands: *L*	40	5, 453. 4	1, 359. 8	746, 253. 02	46, 398. 12	186, 058. 56	2, 763. 7310
Bikini Island: *S*	31	1, 829. 9	520. 9	109, 843. 77	8, 859. 57	31, 185. 95	1, 826. 5439
East Caroline Islands:							
S	60	3, 916. 3	1, 096. 1	259, 183. 29	20, 224. 83	72, 382. 71	3, 559. 8619
M	55	5, 404. 4	1, 411. 5	539, 532. 20	36, 602. 69	140, 475. 74	8, 486. 0298
L	54	7, 516. 0	1, 872. 4	1, 052, 115. 44	65, 213. 40	261, 891. 54	5, 999. 5882
Central Caroline Islands:							
S	37	2, 513. 9	698. 9	173, 346. 55	13, 369. 39	48, 132. 23	2, 544. 0309
M	102	10, 289. 2	2, 673. 5	1, 049, 698. 10	70, 639. 51	272, 240. 75	11, 780. 0938
L	69	9, 125. 8	2, 287. 5	1, 211, 069. 54	76, 126. 13	303, 577. 84	4, 109. 7482
Philippines (SW. Panay):							
S	242	15, 776. 4	4, 550. 2	1, 040, 719. 56	86, 405. 94	299, 786. 77	12, 228. 6635
M	81	7, 349. 8	1, 993. 6	674, 621. 22	49, 439. 00	182, 526. 67	7, 713. 0714
L	32	4, 234. 2	1, 085. 1	562, 353. 60	36, 933. 97	144, 065. 00	2, 089. 5488
Japan: *S*	31	1, 789. 5	508. 7	108, 296. 33	8, 686. 13	30, 660. 85	4, 995. 9994
Hawaii:[2]							
S	36	1, 884. 6	534. 2	100, 518. 50	8, 061. 62	28, 461. 45	1, 859. 6900
M	34	3, 466. 4	913. 2	356, 040. 12	24, 662. 30	93, 673. 95	2, 630. 4448
L	133	19, 955. 4	4, 929. 5	3, 028, 042. 30	184, 479. 19	747, 259. 96	33, 922. 0808
Hawaii:[3]							
S	47	2, 679. 3	762. 9	153, 111. 13	12, 412. 53	43, 589. 67	373. 9281
L	20	2, 859. 2	714. 2	409, 803. 42	25, 588. 64	102, 393. 11	1, 052. 1880
Society Islands: *S*	17	988. 5	284. 4	58, 503. 31	4, 827. 06	16, 801. 56	1, 024. 9424
Northeast Africa: *S*	48	3, 805. 0	1, 077. 3	304, 447. 00	24, 356. 69	86, 085. 00	2, 821. 4792
Angola, Africa:[4]							
M	21	2, 050. 5	560. 5	206, 277. 69	15, 248. 01	56, 039. 06	6, 061. 0115
L	27	3, 717. 0	961. 3	515, 125. 62	34, 411. 43	133, 110. 49	3, 418. 6200
Y=pectoral fin length:							
Costa Rica:[2] *M*	28	83. 897	755. 5	251. 444377	20, 519. 41	2, 266. 4008	. 061998
109°-119° W.: *L*	21	66. 650	758. 0	211. 566268	27, 490. 42	2, 407. 5195	. 031863
119°-129° W.: *L*	46	154. 626	1, 680. 7	461. 064214	61, 652. 59	5, 322. 9928	. 043956
129°-139° W.: *L*	46	145. 115	1, 650. 4	458. 098769	60, 123. 18	5, 222. 2868	. 308265
139°-149° W.: *L*	113	358. 339	4, 216. 1	1, 136. 467083	157, 636. 55	13, 374. 0386	. 123376
East Line Islands:							
L	124	391. 907	4, 570. 7	1, 238. 755335	168, 894. 65	14, 450. 0028	. 117459
M	32	96. 266	917. 8	289. 652924	26, 501. 70	2, 763. 9444	. 054713
West Line Islands:							
S	43	121. 882	874. 9	345. 577724	18, 022. 45	2, 484. 4753	. 107447
M	86	256. 925	2, 418. 1	767. 775975	68, 804. 05	7, 236. 1381	. 212538
L	56	175. 831	2, 030. 0	552. 137153	73, 803. 70	6, 376. 8446	. 056072
Phoenix Islands:							
S	37	104. 643	751. 9	296. 022337	15, 457. 43	2, 129. 8423	. 072136
M	58	173. 291	1, 696. 1	517. 898774	50, 125. 13	5, 075. 4469	. 144108
L	46	143. 943	1, 643. 0	450. 460353	58, 862. 76	5, 142. 9820	. 034544
East Marshall Islands: *L*	40	125. 349	1, 441. 5	392. 839243	52, 058. 77	4, 518. 3636	. 029948
Bikini Island: *S*	31	85. 798	558. 8	237. 546178	10, 226. 10	1, 550. 0649	. 084991
East Caroline Islands:							
S	60	168. 697	1, 239. 1	474. 472711	25, 954. 71	3, 491. 1148	. 161415
M	53	158. 390	1, 568. 3	473. 500596	46, 927. 19	4, 695. 2196	. 153576
L	53	173. 007	2, 023. 5	544. 271157	74, 624. 13	6, 367. 6164	. 063484
Central Caroline Islands:							
S	36	101. 854	778. 3	288. 288240	17, 128. 15	2, 207. 7750	. 114982
M	102	306. 117	3, 125. 4	918. 930769	96, 471. 08	9, 391. 1201	. 228635
L	72	224. 688	2, 576. 1	701. 222332	92, 354. 33	8, 040. 8810	. 054980
Japan: *S*	30	82. 441	515. 3	226. 832298	9, 385. 21	1, 428. 2000	. 281682
Hawaii:[2]							
S	36	97. 754	550. 6	265. 544952	8, 636. 70	1, 499. 6342	. 104827
M	34	102. 230	990. 4	307. 429448	29, 046. 90	2, 980. 3779	. 047893
L	133	422. 105	5, 032. 9	1, 339. 929970	191, 379. 69	15, 986. 6720	. 286128
Society Islands: *S*	21	57. 897	374. 4	159. 676581	6, 854. 34	1, 035. 2576	. 054552
Northeast Africa: *S*	48	139. 053	999. 5	402. 913285	20, 984. 25	289. 8690	. 085435
Angola, Africa:[4]							
M	21	62. 646	569. 8	187. 000176	15, 924. 06	1, 707. 0178	. 118209
L	27	84. 710	953. 7	265. 799772	33, 830. 51	2, 993. 9101	. 029991

See footnotes at end of table.

TABLE A-3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	N	SX	SY	SX^2	SY^2	SXY	Sr^2
Y=height second dorsal fin:							
Costa Rica: [2] *M*	28	83.896	61.318	251.435890	134.538996	183.841218	0.059504
109°–119° W.: *L*	20	63.455	51.701	201.358243	133.893361	164.117955	.031392
119°–129° W.: *L*	45	142.407	116.934	450.704783	304.507574	370.192937	.043591
129°–139° W.: *L*	45	141.932	115.801	447.967280	299.620879	365.902722	.307444
139°–149° W.: *L*	109	345.664	287.463	1,096.300848	759.324805	911.908839	.121023
East Line Islands:							
M	32	96.220	72.790	289.372416	165.827650	218.957612	.050903
L	155	489.958	412.957	1,548.906650	1,102.197991	1,305.785473	.139929
West Line Islands:							
S	42	119.137	83.006	338.044643	164.358096	235.620544	.101197
M	84	250.789	189.036	748.954439	426.449708	564.797120	.202981
L	57	178.935	149.275	561.771969	391.669033	468.777214	.057334
Phoenix Islands:							
S	36	101.821	71.606	288.058653	142.698836	202.657672	.072097
M	55	164.262	125.241	490.710168	285.685185	374.264864	.128266
L	44	137.612	114.589	430.427680	298.849489	358.489012	.039895
East Marshall Islands: *L*	38	119.107	100.708	373.357959	267.224844	315.739082	.029606
Bikini Island: *S*	30	82.938	55.723	229.368553	103.721167	154.177996	.078158
East Caroline Islands:							
S	60	168.697	118.869	474.472711	235.963849	334.477887	.161415
M	55	164.390	126.919	491.509308	293.653623	379.691955	.162543
L	54	169.785	144.748	533.898401	388.441770	455.251731	.066064
Central Caroline Islands:							
S	36	101.779	72.384	287.862165	145.852994	204.828458	.113142
M	102	306.117	237.642	918.930769	554.766056	713.671426	.228635
L	71	221.566	185.713	691.475448	486.391527	579.669959	.045979
Japan: *S*	31	85.269	57.732	234.830567	108.176324	159.229245	.288555
Hawaii: [2]							
S	33	89.605	59.351	243.40909	106.99218	161.30666	.10436
M	34	102.231	77.106	307.43281	175.05126	231.91726	.04524
L	133	422.105	352.442	1,339.93162	936.08809	1,119.25091	.28778
Society Islands: *S*	20	55.062	37.280	151.647056	69.692726	102.737708	.055864
Northeast Africa: *S*	43	124.960	86.819	363.189526	175.472595	252.384244	.049954
Angola, Africa: [4]							
M	20	59.739	44.580	178.549527	99.720328	133.352250	.112121
L	26	81.631	65.771	256.319531	166.546780	206.553552	.06448
Y=height anal fin:							
Costa Rica: [2] *M*	28	83.898	62.249	251.448856	138.676825	186.641229	.060484
109°–119° W.: *L*	20	63.445	52.351	201.294243	137.360109	166.158030	.030842
119°–129° W.: *L*	46	145.618	121.359	461.013894	320.731273	384.301592	.044287
129°–139° W.: *L*	44	138.731	115.337	437.720969	304.022121	364.330992	.305279
139°–149° W.: *L*	110	348.752	295.097	1,105.828784	792.763031	935.861205	.120079
East Line Islands:							
M	33	99.292	76.066	298.809600	175.647828	228.981829	.055016
L	153	483.531	414.601	1,528.254051	1,125.407081	1,310.662739	.134914
West Line Islands:							
S	42	119.118	83.219	337.939288	165.233633	236.198792	.103624
M	87	259.891	199.596	776.573131	459.480550	596.750578	.212995
L	54	169.496	144.323	532.067676	386.427807	453.165245	.051121
Phoenix Islands:							
S	37	104.641	73.489	296.010719	146.301409	207.982031	.071831
M	58	173.326	134.937	518.112303	314.633461	403.515203	.148471
L	43	134.444	114.370	420.379512	304.506932	357.661681	.026277
East Marshall Islands: *L*	39	122.276	105.833	383.395914	287.459047	331.880495	.026166
Bikini Island: *S*	31	85.907	57.758	238.182920	108.065174	160.283217	.117996
East Caroline Islands:							
S	60	168.697	119.181	474.472711	237.383145	335.404648	.161415
M	55	164.390	120.428	491.509308	305.394016	387.198621	.162543
L	52	163.420	142.437	513.642164	390.578717	447.776963	.063388
Central Caroline Islands:							
S	35	99.042	70.543	280.380896	142.657533	199.846930	.114674
M	101	303.205	239.524	910.451025	569.235948	719.542609	.220609
L	70	218.412	187.800	681.527732	504.318644	586.077836	.044850
Japan: *S*	30	82.632	55.604	227.876798	103.864654	153.619860	.275217
Hawaii: [2]							
S	34	92.360	60.270	250.99237	107.19607	163.90159	.09915
L	133	422.105	358.549	1,339.93164	968.75793	1,138.64039	.28780
M	34	102.239	78.230	307.48041	180.25731	235.32153	.04473
Society Islands: *S*	19	52.360	35.319	144.346252	65.858589	97.429882	.053115
Northeast Africa: *S*	43	124.960	88.273	363.189526	181.467413	256.620348	.049954
Angola, Africa: [4]							
M	21	62.646	46.863	187.000176	105.043883	140.028416	.118209
L	27	84.710	69.103	265.801668	177.057928	216.862426	.031887
Y=snout to insertion first dorsal fin:							
Costa Rica: [3] *M*	29	2,896.5	853.9	292,493.79	25,390.27	86,162.62	3,193.3676
109°–119° W.: *L*	21	3,146.2	865.8	475,009.34	35,969.34	130,656.84	3,648.6524
119°–129° W.: *L*	44	6,450.3	1,784.5	950,350.67	72,671.25	262,735.30	4,751.3498
129°–139° W.: *L*	46	6,667.6	1,848.3	988,059.18	75,600.75	273,216.64	21,605.0548
139°–149° W.: *L*	112	16,645.1	4,573.0	2,487,698.53	187,782.94	683,312.55	13,954.2978
East Line Islands:							
M	33	3,382.8	981.3	349,710.50	29,370.83	101,318.62	2,942.7473
L	155	22,538.9	6,152.4	3,292,495.07	245,222.02	898,248.44	15,062.7267
West Line Islands:							
S	44	3,022.1	935.9	210,032.15	20,100.84	64,948.35	2,461.9589
M	86	8,402.3	2,459.2	831,632.87	70,984.24	242,859.66	10,718.3899
L	55	7,576.8	2,068.7	1,049,124.22	78,177.79	286,342.03	5,344.2520
Palmyra Island: [3]							
S	35	2,537.2	797.5	184,770.90	18,240.39	58,031.19	845.6475
M	57	5,379.7	1,586.9	511,367.03	44,399.43	150,634.50	3,627.1688
Phoenix Islands:							
S	35	2,384.8	740.5	164,052.42	15,795.21	50,893.93	1,558.9618
M	59	5,795.3	1,690.9	576,982.99	48,913.93	167,924.19	7,737.1919
L	45	6,069.5	1,670.0	822,105.79	62,171.48	22,601.378	3,465.1178

See footnotes at end of table.

TABLE A-3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	N	SX	SY	SX^2	SY^2	SXY	Sr^2
East Marshall Islands: *L*	39	5,310.9	1,461.4	725,946.77	54,957.40	199,720.51	2,724.7493
Bikini Island: *S*	31	1,829.9	560.6	109,843.77	10,254.82	33,547.13	1,826.5439
East Caroline Islands:							
S	59	3,861.4	1,189.4	256,169.28	24,203.44	78,707.02	3,450.4672
M	55	5,404.4	1,560.8	539,532.20	44,782.08	155,380.26	8,486.0298
L	56	7,837.2	2,150.0	1,103,798.16	83,008.82	302,614.71	6,982.0200
Central Caroline Islands:							
S	35	2,378.7	729.8	163,986.53	15,390.80	50,225.33	2,323.2818
M	102	10,289.2	2,955.1	1,049,698.10	86,320.21	300,905.71	11,780.0938
L	71	9,404.3	2,597.7	1,249,939.11	95,321.55	345,077.67	4,293.2158
Philippines (SW. Panay):							
S	242	15,776.4	5,121.5	1,040,719.56	109,406.73	337,258.66	12,228.6635
M	81	7,349.8	2,232.5	674,621.22	61,959.87	204,321.76	7,713.0714
L	33	4,388.7	1,243.0	586,223.85	47,014.72	165,933.26	2,566.6473
Japan: *S*	31	1,789.5	564.0	108,296.33	10,681.40	33,999.64	4,995.9994
Hawaii: [2]							
S	36	1,884.6	601.8	100,518.50	10,234.96	32,067.13	1,859.6900
M	34	3,466.4	1,015.2	356,040.12	30,484.58	104,134.53	2,630.4448
L	131	19,610.4	5,379.7	2,968,469.30	222,997.89	813,401.91	32,837.3299
Hawaii: [3]							
S	47	2,679.3	834.6	153,111.13	14,856.44	47,686.86	373.9281
L	20	2,859.2	794.0	409,803.42	31,624.14	113,819.11	1,052.1880
Society Islands: *S*	22	1,260.6	400.2	73,377.44	7,375.30	23,254.99	1,145.0600
Northeast Africa: *S*	48	3,805.0	1,189.5	304,447.00	29,713.75	95,067.25	2,821.4792
Angola, Africa: [4]							
M	21	2,050.5	606.8	206,277.69	17,860.48	60,639.16	6,061.0115
L	27	3,717.0	1,042.7	515,125.62	40,514.29	144,427.97	3,418.6200
Y=snout to insertion second dorsal fin:							
Costa Rica: [2] *M*	29	2,896.5	1,527.6	292,493.79	81,184.30	154,073.13	3,193.3676
109°–119° W.: *L*	21	3,146.2	1,600.1	475,009.34	122,765.07	241,457.31	3,648.6524
119°–129° W.: *L*	44	6,470.7	3,255.0	956,166.11	241,933.41	480,926.32	4,576.1444
129°–139° W.: *L*	46	6,667.6	3,364.6	988,059.18	250,829.34	497,756.66	21,605.0548
139°–149° W.: *L*	112	16,666.4	8,371.8	2,494,141.78	629,133.06	1,252,559.93	14,062.4142
East Line Islands:							
M	33	3,382.8	1,739.9	349,710.50	92,411.27	179,750.04	2,942.7473
L	155	22,517.6	11,248.8	3,268,363.68	819,667.82	1,641,017.17	15,142.9719
West Line Islands:							
S	43	2,947.9	1,588.1	204,526.51	59,288.09	110,045.93	2,430.8261
M	86	8,394.8	4,337.7	830,036.12	221,074.05	428,290.45	10,586.5033
L	56	7,732.7	3,868.1	1,073,541.37	268,490.83	536,827.26	5,779.7756
Palmyra Island: [3]							
S	34	2,468.9	1,329.1	180,106.01	52,136.85	96,888.92	827.5627
M	57	5,379.7	2,796.1	511,367.03	137,936.41	265,548.40	3,627.1688
Phoenix Islands:							
S	37	2,503.6	1,347.5	171,117.96	49,464.81	91,972.04	1,712.2044
M	59	5,795.3	2,978.1	576,982.99	151,964.35	295,988.89	7,737.1919
L	46	6,207.1	3,110.9	841,039.55	211,181.35	421,398.64	3,472.3672
East Marshall Islands: *L*	39	5,321.7	2,675.8	728,908.13	184,225.62	366,426.68	2,741.6970
Bikini Island: *S*	31	1,829.9	993.7	109,843.77	32,271.29	59,529.17	1,826.5439
East Caroline Islands:							
S	59	3,844.2	2,063.0	253,984.88	72,921.12	136,067.49	3,512.4455
M	55	5,404.4	2,764.7	539,532.20	140,667.69	275,442.73	8,486.0298
L	56	7,837.2	3,881.4	1,103,798.16	270,556.54	546,441.18	6,982.0200
Central Caroline Islands:							
S	37	2,513.9	1,344.8	173,346.55	49,485.68	92,604.46	2,544.0309
M	101	10,183.7	5,180.5	1,038,567.85	268,193.53	527,681.15	11,758.4870
L	68	8,997.1	4,472.9	1,194,303.33	295,159.21	593,660.04	3,894.3828
Philippines (SW. Panay):							
S	241	15,711.8	8,908.0	1,036,546.40	332,391.36	586,730.54	12,228.3119
M	81	7,349.8	3,996.1	674,621.22	198,764.79	366,077.21	7,713.0714
L	28	3,713.5	1,925.6	494,392.59	132,923.10	256,315.20	1,889.6525
Japan: *S*	31	1,789.5	979.4	108,296.33	32,243.84	59,082.02	4,995.994
Hawaii: [2]							
S	36	1,884.6	1,041.4	100,518.50	30,637.02	55,486.52	1,859.6900
M	34	3,466.4	1,800.3	356,040.12	95,877.41	184,731.92	2,630.4448
L	132	19,777.4	9,852.0	2,996,358.30	742,617.26	1,491,512.29	33,134.4306
Hawaii: [3]							
S	47	2,679.3	1,463.8	153,111.13	45,690.52	83,635.85	373.9281
L	20	2,859.2	1,437.6	409,803.42	103,634.86	206,068.57	1,052.1880
Society Islands: *S*	21	1,209.3	665.7	70,745.75	21,367.69	38,872.54	1,107.3458
Northeast Africa: *S*	46	3,665.0	1,978.2	294,647.00	85,750.74	158,920.80	2,642.1087
Angola, Africa: [4]							
M	21	2,050.5	1,089.0	206,277.69	57,692.46	109,041.36	6,061.0115
L	27	3,717.0	1,892.8	515,125.62	133,489.44	262,208.21	3,418.6200
Y=snout to insertion anal fin:							
Costa Rica: [2] *M*	29	2,896.5	1,709.6	292,493.79	101,685.80	172,442.86	3,193.3676
109°–119° W.: *L*	21	3,146.2	1,766.2	475,009.34	149,575.84	266,533.77	3,648.6524
119°–129° W.: *L*	47	6,895.9	3,825.4	1,016,781.01	312,644.10	563,751.14	5,005.7588
129°–139° W.: *L*	46	6,667.6	3,711.3	988,059.18	305,168.05	549,037.23	21,605.0548
139°–149° W.: *L*	113	16,807.0	9,330.2	2,513,910.14	774,456.74	1,395,190.05	14,129.1754
East Line Islands:							
M	32	3,285.0	1,869.7	340,145.66	110,060.09	193,454.86	2,919.8788
L	153	22,239.8	12,270.3	3,247,595.60	988,185.19	1,791,256.16	14,858.9724
West Line Islands:							
S	43	2,956.6	1,750.1	205,741.90	71,942.63	121,639.51	2,451.5847
M	86	8,405.2	4,786.3	832,220.21	269,255.43	473,284.60	10,738.9654
L	56	7,724.0	4,286.3	1,070,968.78	320,570.95	594,058.99	5,608.4943
Palmyra Island: [3]							
S	35	2,537.0	1,503.1	184,770.90	64,785.69	109,397.75	845.6475
M	57	5,379.7	3,069.5	511,367.03	166,188.61	291,470.97	3,627.1688
Phoenix Islands:							
S	36	2,446.3	1,439.9	167,834.67	58,036.31	98,677.17	1,601.7898
M	58	5,697.8	3,229.9	567,476.74	181,796.19	321,112.35	7,736.6566
L	45	6,078.7	3,350.5	824,552.99	250,453.07	454,396.25	3,428.6858

See footnotes at end of table.

TABLE A-3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	N	SX	SY	SX^2	SY^2	SXY	Sr^2
East Marshall Islands: *L*	40	5,453.4	3,002.7	746,253.02	226,261.25	410,890.35	2,763.7310
Bikini Island: *S*	31	1,829.9	1,094.9	109,843.77	39,177.77	65,588.67	1,826.5439
East Caroline Islands:							
S	60	3,916.3	2,302.4	259,183.29	89,401.86	152,204.64	3,559.8619
M	54	5,312.8	2,982.3	531,141.64	166,751.45	297,557.13	8,440.8282
L	55	7,682.1	4,195.5	1,079,742.15	321,854.99	589,467.25	6,748.3244
Central Caroline Islands:							
S	37	2,513.9	1,489.0	173,346.55	60,687.04	102,546.64	2,544.0309
M	102	10,289.2	5,796.7	1,049,698.10	332,230.77	590,407.37	11,780.0938
L	68	8,977.3	4,940.0	1,189,017.29	360,056.26	654,229.69	3,842.0652
Philippines (SW. Panay):							
S	242	15,776.4	9,798.3	1,040,719.56	400,472.31	645,393.74	12,228.6635
M	81	7,349.8	4,391.4	674,621.22	240,101.84	402,363.09	7,713.0714
L	31	4,109.1	2,351.4	546,703.59	178,857.86	312,602.05	2,035.7575
Japan: *S*	31	1,789.5	1,071.4	108,296.33	38,581.78	64,628.88	4,995.9994
Hawaii: [2]							
S	36	1,884.6	1,144.4	100,518.50	36,977.80	60,956.99	1,859.6900
M	34	3,466.4	1,988.6	356,040.12	117,014.20	204,081.16	2,630.4448
L	132	19,809.0	10,946.0	3,006,609.34	916,354.34	1,659,647.04	33,908.7264
Hawaii: [3]							
S	47	2,679.3	1,613.8	153,111.13	55,536.18	92,207.49	373.9281
L	20	2,859.2	1,599.7	409,803.42	128,289.01	229,277.36	1,052.1880
Northeast Africa: *S*	47	3,723.5	2,236.5	297,804.75	107,216.25	178,643.00	2,816.4043
Angola, Africa: [4]							
M	21	2,050.5	1,196.7	206,277.69	69,706.95	119,863.37	6,061.0115
L	26	3,559.3	1,994.1	490,256.33	153,727.69	274,493.04	3,001.8497
Y=snout to insertion ventral fin:							
109°–119° W.: *L*	21	3,146.2	885.9	475,009.34	37,666.19	133,726.71	3,648.6524
119°–129° W.: *L*	47	6,895.9	1,929.5	1,016,781.01	79,629.77	284,429.37	5,005.7588
129°–139° W.: *L*	46	6,667.6	1,867.5	988,059.18	77,173.33	276,043.66	21,605.0548
139°–149° W.: *L*	113	16,807.0	4,688.3	2,513,910.14	195,546.89	700,965.38	14,129.1754
East Line Islands:							
M	31	3,183.1	955.3	329,762.05	29,610.51	98,779.60	2,919.2884
L	153	22,222.4	6,212.5	3,242,746.86	253,634.17	906,612.53	15,066.7178
West Line Islands:							
S	42	2,889.5	923.4	201,158.85	20,499.36	64,190.27	2,368.1298
M	84	8,216.6	2,495.6	814,259.78	74,868.24	246,773.28	10,539.3567
L	56	7,735.2	2,217.1	1,074,252.62	88,196.69	307,744.22	5,800.4943
Palmyra Island: [3]							
S	35	2,537.2	799.1	184,770.90	18,312.33	58,159.51	845.6475
M	57	5,379.7	1,598.4	511,367.03	45,029.14	151,696.73	3,627.1688
Phoenix Islands:							
S	35	2,383.6	757.8	163,903.38	16,512.26	51,994.83	1,573.4098
M	56	5,535.9	1,663.0	554,436.73	49,892.82	166,246.01	7,183.3584
L	46	6,207.1	1,738.5	841,039.55	65,959.63	235,434.15	3,472.3672
East Marshall Islands: *L*	38	5,180.2	1,434.9	708,885.88	54,390.23	196,334.36	2,715.5632
Bikini Island: *S*	31	1,829.9	587.3	109,843.77	11,263.09	35,156.10	1,826.5439
East Caroline Islands:							
S	60	3,916.3	1,216.9	259,183.29	24,959.13	80,411.50	3,559.8619
M	54	5,311.8	1,546.5	530,957.44	44,777.35	154,125.35	8,453.3800
L	55	7,685.0	2,136.2	1,080,633.32	83,369.90	300,077.18	6,829.2291
Central Caroline Islands:							
S	36	2,459.9	771.5	170,430.55	16,747.37	53,398.72	2,344.2164
M	101	10,204.4	2,979.7	1,042,507.06	88,623.57	303,814.74	11,519.1456
L	68	8,958.5	2,533.2	1,184,125.53	94,729.64	334,759.16	3,909.0264
Philippines (SW. Panay):							
S	241	15,702.8	5,088.9	1,035,302.60	108,524.29	335,066.42	12,157.6712
M	81	7,349.8	2,255.4	674,621.22	63,326.76	206,603.06	7,713.0714
L	32	4,257.3	1,233.6	568,957.89	47,760.94	164,733.11	2,564.0372
Japan: S	31	1,789.5	568.9	108,296.33	10,856.57	34,274.53	4,995.9994
Hawaii: [2]							
S	36	1,884.6	606.9	100,518.50	10,399.99	32,318.81	1,859.6900
M	34	3,466.4	1,025.2	356,040.12	31,093.84	105,169.90	2,630.4448
L	133	19,955.4	5,551.6	3,028,042.30	233,905.70	841,363.67	33,922.0808
Hawaii: [3]							
S	47	2,679.3	870.5	153,111.13	16,161.23	49,734.11	.373.9281
L	20	2,859.2	800.9	409,803.42	32,168.53	114,804.21	1052.1880
Northeast Africa: S	48	3,805.0	1,217.0	304,447.00	31,064.50	97,190.25	2,821.4792
Angola, Africa: [4]							
M	21	2,050.5	622.5	206,277.69	18,826.95	62,280.02	6,061.0115
L	27	3,717.0	1,065.6	215,125.62	42,276.26	147,542.99	3,418.6200
Y=greatest body depth:							
Costa Rica: [2] *M*	29	2,896.5	737.1	292,493.79	18,981.65	74,476.86	3,193.3676
109°–119° W.: *L*	21	3,146.2	813.0	475,009.34	31,865.56	122,976.02	3,648.6524
119°–129° W.: *L*	47	6,895.9	1,729.6	1,016,781.01	64,090.80	255,053.53	5,005.7588
129°–139° W.: *L*	46	6,667.6	1,673.6	988,059.18	62,388.60	248,086.74	21,605.0548
139°–149° W.: *L*	109	16,168.8	4,111.2	2,412,075.52	156,425.62	613,937.28	13,634.2958
East Line Islands:							
M	32	3,278.6	797.7	338,852.86	20,035.94	82,350.48	2,939.7988
L	154	22,339.4	5,580.4	3,255,028.66	203,481.16	813,560.86	14,452.0863
West Line Islands:							
S	43	2,947.9	736.8	204,526.51	12,786.92	51,111.30	2,430.8261
M	83	8,106.1	1,973.0	801,700.31	47,469.79	194,905.57	10,027.3316
L	57	7,876.2	1,949.6	1,094,133.62	67,274.94	271,142.41	5,808.5948
Phoenix Islands:							
S	36	2,428.3	602.8	165,447.87	10,182.66	41,030.24	1,652.2898
M	59	5,795.3	1,422.5	576,982.99	34,800.57	141,587.97	7,737.1918
L	44	5,943.0	1,478.5	806,235.34	49,956.87	200,558.37	3,525.1355
East Marshall Islands: *L*	39	5,314.9	1,318.7	727,070.77	44,873.79	180,554.56	2,758.9236
Bikini Island: *S*	31	1,829.9	453.4	109,843.77	6,729.06	27,179.80	1,826.5439
East Caroline Islands:							
S	60	3,916.3	974.8	259,183.29	15,994.84	64,346.21	3,559.8619
M	55	5,404.4	1,295.6	539,532.20	31,008.22	129,299.56	8,486.0298
L	56	7,837.2	1,949.7	1,103,798.16	68,456.67	274,743.15	6,982.0200

See footnotes at end of table.

TABLE A-3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	N	SX	SY	SX^2	SY^2	SXY	Sx^2
Central Caroline Islands:							
S	37	2,513.9	620.5	173,346.55	10,554.85	42,751.50	2,544.0309
M	102	10,289.2	2,458.5	1,049,698.10	59,904.61	250,653.30	11,780.0938
L	71	9,394.9	2,332.8	1,247,581.59	77,105.00	309,934.35	4,424.6040
Japan: *S*	30	1,728.2	450.4	104,538.64	7,083.56	27,201.25	4,982.7987
Hawaii: [2]							
S	36	1,884.6	490.7	100,518.50	6,787.50	26,098.06	1,859.6900
M	34	3,466.4	874.9	356,040.12	22,676.15	89,801.52	2,630.4448
L	132	19,792.5	5,011.4	3,001,505.89	193,468.40	761,486.24	33,755.4639
Northeast Africa: *S*	48	3,805.0	1,006.2	304,447.00	21,317.84	80,536.95	2,821.4792
Y=insertion ventral fin to anterior edge vent:							
109°–119° W.: *L*	17	2,553.6	739.8	387,099.44	32,482.38	112,090.41	3,518.6777
119°–129° W.: *L*	47	6,895.9	1,954.4	1,016,781.01	81,621.42	287,958.30	5,005.7588
129°–139° W.: *L*	46	6,667.6	1,891.8	988,059.18	79,521.56	280,216.10	21,605.0548
139°–149° W.: *L*	112	16,636.5	4,704.8	2,484,839.89	198,883.76	702,735.61	13,651.2091
East Line Islands:							
M	33	3,382.8	934.7	349,710.50	26,706.59	96,615.03	2,942.7473
L	153	22,251.1	6,194.2	3,251,069.35	252,070.96	904,976.23	15,046.7931
West Line Islands:							
S	38	2,600.9	734.4	179,843.35	14,337.12	50,761.20	1,825.4340
M	83	8,070.3	2,240.3	794,878.69	61,207.59	220,517.27	10,183.0022
L	56	7,746.7	2,154.5	1,077,363.37	83,350.01	299,562.14	5,731.9256
Phoenix Islands:							
S	19	1,309.2	363.7	90,720.80	7,006.19	25,206.01	510.0295
M	49	4,762.2	1,305.9	469,014.30	35,244.71	128,544.55	6,186.7727
L	36	4,834.4	1,353.4	651,354.14	51,091.58	182,369.37	2,147.9356
East Marshall Islands: *L*	39	5,321.7	1,479.3	728,908.13	56,402.21	202,694.27	2,741.6970
East Caroline Islands:							
S	60	3,916.3	1,120.2	259,183.29	21,192.68	74,090.23	3,559.8619
M	54	5,319.5	1,487.0	532,324.19	41,555.98	148,692.69	8,304.1854
L	55	7,699.4	2,146.7	1,084,809.32	84,431.95	302,578.93	6,977.3135
Central Caroline Islands:							
S	36	2,438.9	704.0	167,721.55	13,964.26	48,374.98	2,492.8498
M	102	10,289.2	2,884.7	1,049,698.10	82,400.69	293,998.80	11,780.0938
L	71	9,404.3	2,598.8	1,249,939.11	95,578.08	345,473.82	4,293.2158

TABLE A-3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	Sy^2	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}$
X=fork length; *Y*=head length:								
Costa Rica: [2] *M*	173.6283	731.3128	99.879	27.238	0.22901	4.365	0.477	27.266
109°–119° W.: *L*	256.5924	947.8990	149.819	37.952	.25979	.969	.738	35.402
119°–129° W.: *L*	288.3098	1,137.4179	146.721	37.002	.22722	3.664	.815	35.475
129°–139° W.: *L*	1,120.4244	4,870.2135	144.948	36.535	.22542	3.861	.716	35.420
139°–149° W.: *L*	837.5227	3,314.7714	148.713	37.392	.23760	2.059	.677	35.323
East Line Islands:								
M	141.6873	632.2127	102.509	27.691	.21484	5.668	.435	27.152
L	836.7488	3,377.1175	145.319	36.334	.22802	3.198	.660	35.121
West Line Islands:								
S	164.8874	620.6846	68.707	19.751	.25221	2.422	.451	18.816
M	553.6904	2,376.9556	97.758	26.585	.22125	4.956	.575	27.081
L	342.1867	1,355.1600	138.179	35.067	.23330	2.830	.688	35.492
Palmyra Island: [3]								
S	53.8817	201.4531	72.491	20.877	.23822	3.608	.422	19.092
M	173.0948	772.0569	94.381	25.379	.21285	5.290	.399	26.575
Phoenix Islands:								
S	102.7173	404.6286	67.665	19.330	.23632	3.339	.450	18.700
M	359.7323	1,618.9492	98.225	26.434	.20924	5.881	.607	26.805
L	1,103.4174	4,249.3757	133.533	33.470	.25534	−.626	.646	35.122
East Marshall Islands: *L*	171.7190	670.2270	136.335	33.995	.24251	.932	.492	34.883
Bikini Island: *S*	106.7697	437.7271	59.029	16.803	.23965	2.657	.254	18.646
East Caroline Islands:								
S	200.9099	838.4362	65.272	18.268	.23552	2.895	.244	18.204
M	378.4673	1,779.1837	98.262	25.664	.20966	5.062	.320	26.028
L	289.6638	1,281.1993	139.185	34.674	.21355	4.951	.556	34.848
Central Caroline Islands:								
S	167.7357	646.6973	67.943	18.889	.25420	1.618	.309	18.141
M	564.9781	2,552.7481	100.875	26.211	.21670	4.351	.344	26.021
L	290.5322	1,037.7314	132.258	33.152	.25250	−.243	.652	35.107
Philippines (SW. Panay):								
S	850.8985	3,151.3350	65.192	18.802	.25770	2.002	.402	18.753
M	371.8277	1,630.8518	90.738	24.612	.21144	5.426	.584	26.570
L	138.9072	485.9244	132.319	33.909	.23255	3.138	.929	35.695
Japan: *S*	338.5271	1,295.7323	57.726	16.410	.25935	1.439	.292	18.297
Hawaii: [2]								
S	134.6856	496.0800	52.350	14.839	.26675	.875	.263	18.214
M	134.8224	570.5241	101.953	26.859	.21089	4.746	.588	26.435
L	1,772.6468	7,634.8149	150.041	37.064	.22507	3.294	.644	34.804
Hawaii: [3]								
S	29.2021	99.5004	57.006	16.232	.26610	1.063	.246	18.360
L	84.5580	291.0780	142.960	35.710	.27664	−3.838	.473	34.892
Society Islands: *S*	69.2153	264.5365	58.147	16.729	.25810	1.721	.250	18.498
Northeast Africa: *S*	178.0382	686.5313	79.146	22.319	.24332	3.061	.489	18.877
Angola, Africa: [4]								
M	287.9981	1,310.2386	97.643	26.690	.21617	5.583	.501	27.200
L	185.5896	771.5233	137.667	35.604	.22568	4.535	.677	36.130

See footnotes at end of table.

TABLE A-3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	Sy^2	Sry	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}$
Y=pectoral fin length:								
Costa Rica: [2] *M*	134.4011	2.6800	2.9963	26.982	432.27201	−102.540	0.845	27.142
109°–119° W.: *L*	130.2295	1.7719	3.1378	36.095	556.09955	−140.400	1.292	34.554
119°–129° W.: *L*	244.9272	2.2620	3.1658	36.537	514.59869	−126.375	1.709	35.523
129°–139° W.: *L*	909.6983	15.8129	3.1547	35.878	512.96547	−125.947	1.497	35.437
139°–149° W.: *L*	331.2473	4.1885	3.1711	37.311	339.49066	−70.345	1.305	36.462
East Line Islands:								
M	416.4364	4.1211	3.1605	36.860	350.85434	−74.028	1.493	36.354
L	178.0487	2.9152	3.0083	28.681	532.81670	−131.606	.870	28.239
West Line Islands:								
S	221.2870	4.6018	2.8345	20.347	428.28557	−101.051	.768	19.421
M	813.2639	12.0643	2.9875	28.117	567.63026	−141.463	1.237	28.826
L	216.2000	2.9708	3.1398	36.250	529.81880	−130.103	1.044	36.583
Phoenix Islands:								
S	177.6027	3.3268	2.8282	20.322	461.18443	−110.110	.831	19.617
M	525.9023	7.8803	2.9878	29.243	546.83293	−134.140	1.3023	29.910
L	143.0861	1.7135	3.1292	35.717	496.03404	−119.502	1.149	36.555
East Marshall Islands: *L*	110.7138	1.0990	3.1337	36.038	366.96941	−78.959	1.361	36.493
Bikini Island: *S*	153.2794	3.4868	2.7677	18.026	410.25520	−95.520	.594	19.881
East Caroline Islands:								
S	365.2299	7.2406	2.8116	20.652	448.57046	−105.468	.835	20.710
M	520.3053	8.3698	2.9884	29.591	544.99401	−133.275	1.122	30.223
L	177.7255	2.5316	3.1456	36.791	398.77764	−88.648	1.204	36.811
Central Caroline Islands:								
S	301.7364	5.7481	2.8293	21.619	499.91303	−119.746	.650	20.875
M	705.1471	11.3351	3.0011	30.641	495.77274	−118.145	1.197	30.587
L	183.6188	1.7322	3.1207	35.779	376.72901	−81.787	1.300	36.736
Japan: S	534.0737	12.1384	2.7480	17.177	430.92565	−101.241	.627	19.974
Hawaii: [2]								
S	215.5789	4.5411	2.7154	15.295	433.19946	−102.336	.745	19.519
M	197.1306	2.4781	3.0068	29.129	517.42426	−126.450	1.467	28.777
L	927.9426	13.6475	3.1737	37.841	476.97184	−113.536	1.454	36.524
Society Islands: *S*	179.3229	3.0368	2.7570	17.829	556.67987	−135.648	.735	20.940
Northeast Africa: *S*	171.7448	3.4800	2.8962	20.698	407.32721	−97.272	.808	17.305
Angola, Africa: [4]								
M	463.4867	7.2230	2.9831	27.133	611.03638	−155.145	1.079	28.166
L	143.7067	1.7647	3.1374	35.322	588.40986	−149.286	1.263	35.834
Y=height second dorsal fin:								
Costa Rica: [2] *M*	.256956	.114971	2.9963	2.1899	1.93216	−3.5994	.0366	2.1971
109°–119° W.: *L*	.243691	.083607	3.1728	2.5851	2.66332	−5.8651	.0342	2.5140
119°–129° W.: *L*	.650678	.143601	3.1646	2.5085	3.29428	−7.8266	.0670	2.5375
129°–139° W.: *L*	1.623733	.661222	3.1540	2.5734	2.15071	−4.2099	.0685	2.5564
139°–149° W.: *L*	1.205756	.297734	3.1712	2.6373	2.46014	−5.1643	.0651	2.5755
East Line Islands:								
M	.253147	.087181	3.0069	2.2747	1.71269	−2.8752	.0588	2.2629
L	1.981966	.420403	3.1610	2.6642	3.00440	−6.8327	.0686	2.6194
West Line Islands:								
S	.310571	.166120	2.8366	1.9763	1.64155	−2.6801	.0308	1.9374
M	1.037693	.414389	2.9856	2.2504	2.04152	−3.8448	.0484	2.2798
L	.738760	.171563	3.1392	2.6188	2.99234	−6.7748	.0640	2.6394
Phoenix Islands:								
S	.270524	.130046	2.8284	1.9891	1.80376	−3.1127	.0325	1.9611
M	.497765	.222371	2.9866	2.2771	1.73367	−2.9007	.0460	2.3003
L	.425878	.106706	3.1275	2.6043	2.67467	−5.7607	.0578	2.6541
East Marshall Islands: *L*	.327443	.080457	3.1344	2.6502	2.71759	−5.8678	.0550	2.6820
Bikini Island: *S*	.219409	.126190	2.7646	1.8574	1.61455	−2.6062	.0237	1.9354
East Caroline Islands:								
S	.466530	.263826	2.8116	1.9812	1.63446	−2.6142	.0247	1.9834
M	.773031	.342603	2.9889	2.3076	2.10777	−3.9923	.0310	2.3310
L	.442076	.139895	3.1442	2.6805	2.11757	−3.9770	.0530	2.6845
Central Caroline Islands:								
S	.312898	.184815	2.8272	2.0107	1.63348	−2.6075	.0180	1.9873
M	1.102133	.472837	3.0011	2.3298	2.06809	−3.8767	.0353	2.3276
L	.626480	.125078	3.1205	2.6157	2.72033	−5.8731	.0644	2.6853
Japan: S	.660717	.430861	2.7506	1.8623	1.49317	−2.2448	.0245	1.9553
Hawaii: [2]								
S	.24851	.15071	2.7153	1.7985	1.44414	−2.1228	.0315	1.9394
M	.18846	.07539	3.0068	2.2678	1.66645	−2.7427	.0443	2.2566
L	2.13799	.69805	3.1737	2.6409	2.42564	−5.0484	.0583	2.5829
Society Islands: *S*	.202806	.102140	2.7531	1.8640	1.82837	−3.1697	.0299	1.9733
Northeast Africa: *S*	.180996	.084192	2.9054	2.0141	1.68539	−2.8826	.0309	1.8582
Angola, Africa: [4]								
M	.351508	.194019	2.9870	2.2290	1.73044	−2.9398	.0296	2.2515
L	.168917	.055379	3.1397	2.5297	2.09388	−4.0445	.0470	2.5431
Y=height anal fin:								
Costa Rica: [2] *M*	.286182	.120993	2.9964	2.2232	2.00041	−3.7708	.0412	2.2304
109°–119° W.: *L*	.328749	.087570	3.1723	2.6176	2.83931	−6.3895	.0667	2.5433
119°–129° W.: *L*	.557211	.126487	3.1656	2.6382	2.85608	−6.4030	.0667	2.5825
129°–139° W.: *L*	1.689768	.676053	3.1530	2.6213	2.21454	−4.3611	.0677	2.6061
139°–149° W.: *L*	1.106309	.264215	3.1705	2.6827	2.200343	−4.2935	.0697	2.6290
East Line Islands:								
M	.313393	.110760	3.0088	2.3050	2.01323	−3.7524	.0540	2.2873
L	1.916956	.385379	3.1603	2.7098	2.85648	−6.3175	.0735	2.6693
West Line Islands:								
S	.343110	.177820	2.8361	1.9814	1.71601	−2.8854	.0308	1.9416
M	1.566031	.506854	2.9873	2.2942	2.37965	−4.8145	.0651	2.3245
L	.703209	.162075	3.1388	2.6726	3.17042	−7.2787	.0603	2.6958
Phoenix Islands:								
S	.338352	.145208	2.8281	1.9862	2.02152	−3.7309	.0358	1.9554
M	.702531	.272264	2.9884	2.3265	1.83379	−3.1536	.0602	2.3478
L	.309330	.071908	3.1266	2.6598	2.73654	−5.8963	.0524	2.7131
East Marshall Islands: *L*	.263563	.064190	3.1353	2.7137	2.45318	4.9778	.0535	2.7401
Bikini Island: *S*	.452704	.224620	2.7712	1.8631	1.90363	−3.4122	.0294	1.9425

See footnotes at end of table.

TABLE A-3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	Sy^2	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}$
East Caroline Islands:								
S	0.647966	0.313363	2.8116	1.9863	1.94135	−3.4720	0.0261	1.9888
M	.819340	.350096	2.9889	2.3532	2.15387	−4.0845	.0351	2.3771
L	.419122	.141299	3.1427	2.7392	2.22911	−4.2662	.0456	2.7468
Central Caroline Islands:								
S	.477109	.226364	2.8298	2.0155	1.97398	−3.5705	.0303	1.9821
M	1.198853	.484446	3.0020	2.3715	2.19595	−4.2207	.0369	2.3672
L	.478073	.109642	3.1202	2.6829	2.44464	−4.9449	.0556	2.7462
Japan: *S*	.804493	.464202	2.7544	1.8535	1.68668	−2.7923	.0277	1.9522
Hawaii: [2]								
S	.35863	.17991	2.7165	1.7726	1.81452	−3.1565	.0317	1.9476
M	.25928	.08162	3.0070	2.3009	1.82473	−3.1861	.0587	2.2881
L	2.16105	.70561	3.1737	2.6959	2.45174	−5.0852	.0574	2.6282
Society Islands: *S*	.204286	.098154	2.7558	1.8589	1.84795	−3.2337	.0367	1.9644
Northeast Africa: *S*	.255261	.094904	2.9054	2.0478	1.89983	−3.4720	.0427	1.8720
Angola, Africa: [4]								
M	.465751	.229392	2.9831	2.2316	1.94056	−3.5573	.0329	2.2644
L	.197757	.058162	3.1374	2.5594	1.82400	−3.1632	.0605	2.5753
Y=snout to insertion first dorsal fin:								
Costa Rica: [2] *M*	247.3317	875.6769	99.879	29.445	.27422	2.056	.517	29.478
109°–119° W.: *L*	273.6429	943.5086	149.819	41.229	.25859	2.487	1.249	38.690
119°–129° W.: *L*	297.6080	1,131.6557	146.598	40.557	.23818	5.641	.817	38.986
129°–139° W.: *L*	1,335.2524	5,309.5731	144.948	40.180	.24576	4.558	.831	38.964
139°–149° W.: *L*	1,065.7168	3,687.1724	148.617	40.830	.26423	1.561	.912	38.553
East Line Islands:								
M	190.5364	726.4491	102.509	29.736	.24686	4.431	.601	29.117
L	1,015.4022	3,624.0635	145.412	39.693	.24060	4.707	.968	38.391
West Line Islands:								
S	193.8216	666.9093	68.684	21.270	.27089	2.664	.560	20.272
M	662.5582	2,592.9605	97.701	28.595	2.41917	4.959	.648	29.151
L	368.3411	1,357.9180	137.760	37.613	.25409	2.610	.663	38.183
Palmyra Island: [3]								
S	68.7829	219.2757	72.491	22.786	.25930	3.989	.601	20.844
M	219.5772	861.7644	94.381	27.840	.23758	5.417	.519	29.175
Phoenix Islands:								
S	128.3457	438.3757	68.137	21.157	.28120	1.997	.392	20.275
M	453.8824	1,834.8211	98.225	28.659	.23714	5.366	.574	29.080
L	195.9245	767.8912	134.878	37.111	.22161	7.221	.774	38.246
East Marshall Islands: *L*	196.1190	711.5547	136.177	37.472	.26114	1.911	.528	38.471
Bikini Island: *S*	117.0019	455.4545	59.029	19.331	.24935	4.612	.344	20.820
East Caroline Islands:								
S	225.9424	863.8139	65.445	20.159	.25035	3.775	.412	20.048
M	489.4139	2,013.2142	98.262	28.378	.23724	5.066	.472	28.790
L	464.1772	1,722.2100	139.950	38.393	.24666	3.873	.854	38.405
Central Caroline Islands:								
S	173.4274	626.0369	67.963	20.851	.26946	2.538	.336	20.053
M	706.3275	2,811.4461	100.875	28.972	.23866	4.897	.595	28.763
L	278.6586	999.4995	132.455	36.587	.23281	5.750	.816	38.343
Philippines (SW. Panay):								
S	1,019.2827	3,379.1865	65.192	21.163	.27633	3.148	.597	21.109
M	428.3114	1,748.5687	90.738	27.562	.22670	6.992	.636	29.662
L	195.0534	625.5600	132.991	37.667	.24373	5.253	1.172	39.375
Japan: *S*	420.2387	1,442.2852	57.726	18.194	.28869	1.529	.365	20.294
Hawaii: [2]								
S	174.8700	562.9000	52.350	16.717	.30268	.872	.363	20.546
M	171.9026	631.9042	101.953	29.859	.24023	5.367	.792	29.390
L	2,072.9122	8,073.1400	149.698	41.066	.24585	4.263	.827	38.682
Hawaii: [3]								
S	36.0749	109.3328	57.006	17.757	.29239	1.089	.302	20.094
L	102.3400	308.8700	142.960	39.700	.29355	−2.266	.805	38.831
Society Islands: *S*	95.2982	323.5300	57.300	18.191	.28254	2.001	.441	20.366
Northeast Africa: *S*	236.4532	774.5938	79.146	24.656	.27453	2.928	.719	20.772
Angola, Africa: [4]								
M	326.8495	1,389.4743	97.643	28.895	.22925	6.510	.661	29.435
L	246.7608	882.9367	137.667	38.619	.25827	3.064	.865	39.222
Y=snout to insertion second dorsal fin:								
Costa Rica: [2] *M*	716.6532	1,497.4956	99.879	52.676	.46894	5.839	.731	52.733
109°–119° W.: *L*	845.0696	1,731.8520	149.819	76.195	.47466	5.082	1.101	71.534
119°–129° W.: *L*	1,004.2098	2,109.2262	147.061	73.998	.46092	6.215	.873	70.744
129°–139° W.: *L*	4,730.7931	10,065.2044	144.948	73.143	.46587	5.616	.973	70.838
139°–149° W.: *L*	3,362.0565	6,772.2915	148.807	74.748	.48159	3.084	.956	70.507
East Line Islands:								
M	676.3607	1,394.4728	102.509	52.724	.47387	4.148	.709	51.535
L	3,309.7462	6,849.5643	145.275	72.572	.45233	6.860	1.176	70.186
West Line Islands:								
S	575.4945	1,172.4419	68.556	36.933	.48232	3.867	.494	35.218
M	2,287.5234	4,870.4040	97.614	50.438	.46006	5.530	.747	51.536
L	1,308.7299	2,704.8159	138.084	69.073	.46798	4.452	.892	69.969
Palmyra Island: [3]								
S	180.7674	376.7145	72.615	39.091	.45521	6.036	.539	35.625
M	775.4415	1,650.5199	94.381	49.054	.45504	6.107	.666	51.611
Phoenix Islands:								
S	390.3168	793.6346	67.665	36.419	.46352	5.054	.801	35.183
M	1,640.9668	3,463.7556	98.225	50.476	.44768	6.503	1.259	51.271
L	796.5933	1,623.2620	134.937	67.628	.46748	4.548	.926	69.995
East Marshall Islands: *L*	638.2959	1,303.4785	136.454	68.610	.47543	3.736	.709	70.296
Bikini Island: *S*	418.3968	872.0206	59.029	32.058	.47742	3.876	.268	34.908
East Caroline Islands:								
S	786.0523	1,650.8019	65.156	34.966	.46999	4.343	.423	34.892
M	1,693.7611	3,778.2813	98.262	50.267	.44524	6.517	.466	51.041
L	1,533.9336	3,239.2500	139.950	69.311	.46394	4.383	.759	69.335

See footnotes at end of table.

Table A-3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	Sy^2	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}$
Central Caroline Islands:								
S	607.6519	1,234.3865	67.943	36.346	0.48521	3.379	0.499	34.918
M	2,474.9137	5,338.0030	100.829	51.292	.45397	5.519	.722	50.916
L	941.0570	1,849.3255	132.310	65.778	.47487	2.948	.976	69.430
Philippines (SW. Panay):								
S	3,128.0239	5,980.6878	65.194	36.963	.48909	5.077	.921	36.868
M	1,618.9233	3,478.0029	90.738	49.335	.45092	8.419	.801	53.511
L	496.8372	932.5000	132.625	68.771	.49348	3.323	1.283	72.410
Japan: *S*	1,301.1187	2,545.3652	57.726	31.594	.50914	2.203	.422	35.297
Hawaii: [2]								
S	511.6323	969.2300	52.350	28.928	.52118	1.644	.437	35.521
M	551.5250	1,186.0400	101.953	52.950	.45089	6.980	.724	52.060
L	7,299.8055	15,399.0719	149.829	74.636	.46475	5.003	1.049	70.068
Hawaii: [3]								
S	100.9362	189.9066	57.006	31.145	.50787	2.193	.316	35.205
L	300.1720	549.2740	142.960	71.880	.52203	−2.749	.864	70.335
Society Islands: *S*	265.0000	537.7300	57.586	31.700	.48560	3.736	.452	35.300
Northeast Africa: *S*	679.5392	1,309.8653	79.549	42.879	.49576	3.442	.828	35.666
Angola, Africa: [4]								
M	1,220.0315	2,708.2886	97.643	51.857	.44684	8.226	.720	52.910
L	797.1497	1,632.7434	137.667	70.104	.47760	4.354	.833	71.218
Y=snout to insertion anal fin:								
Costa Rica: [2] *M*	901.9325	1,689.1911	99.879	58.952	.52897	6.119	.558	59.016
109°–119° W.: *L*	1,030.0096	1,923.3681	149.819	84.105	.52714	5.129	.921	78.929
119°–129° W.: *L*	1,289.0966	2,483.5686	146.721	81.391	.49614	8.597	1.124	78.057
129°–139° W.: *L*	5,738.7524	11,092.3631	144.948	80.680	.51342	6.261	.997	78.140
139°–149° W.: *L*	4,079.4653	7,467.2943	148.773	82.568	.52850	3.941	1.095	77.931
East Line Islands:								
M	817.0247	1,518.4694	102.656	58.428	.52005	5.042	.955	57.047
L	4,131.1894	7,667.8075	145.358	80.998	.51604	5.987	1.074	78.233
West Line Islands:								
S	713.5600	1,305.8900	68.758	40.700	.53267	4.075	.662	38.699
M	2,875.5732	5,496.1261	97.735	55.655	.51179	5.635	.864	56.814
L	1,492.9556	2,855.7543	137.929	76.541	.50918	6.311	.848	77.596
Palmyra Island: [3]								
S	233.9869	435.8838	72.491	42.946	.51544	5.581	.531	39.085
M	903.3425	1,769.4060	94.381	53.851	.48782	7.810	.855	56.592
Phoenix Islands:								
S	444.3098	831.9653	67.953	39.997	.51940	4.702	.599	38.463
M	1,929.7416	3,813.6566	98.238	55.688	.49293	7.264	.944	56.557
L	989.7312	1,803.2645	135.082	74.456	.52593	3.412	.981	77.042
East Marshall Islands: *L*	856.0678	1,517.2455	136.335	75.068	.54898	.223	.780	77.080
Bikini Island: *S*	506.6084	957.7826	59.029	35.290	.52437	4.337	.388	36.421
East Caroline Islands:								
S	1,051.0974	1,923.1547	65.272	38.373	.54023	3.111	.458	38.226
M	2,045.6484	4,142.9923	98.385	55.228	.49083	6.938	.483	56.021
L	1,814.6219	3,462.6946	139.675	76.282	.51312	4.612	.845	76.449
Central Caroline Islands:								
S	764.8509	1,379.1509	67.943	40.243	.54211	3.410	.701	38.647
M	2,802.0358	5,668.0991	100.875	56.830	.48116	8.293	.865	56.409
L	1,179.7895	2,055.2489	132.019	72.647	.53493	2.026	1.104	76.916
Philippines (SW. Panay):								
S	3,750.4799	6,625.5577	65.192	40.489	.54181	5.167	.818	40.385
M	2,022.9023	3,895.0441	90.738	54.215	.50499	8.393	.842	58.892
L	500.3775	920.1875	132.552	75.852	.45201	15.937	1.706	79.218
Japan: *S*	1,552.8136	2,781.4510	57.726	34.561	.55674	2.423	.384	38.611
Hawaii: [2]								
S	598.5956	1,047.6500	52.350	31.789	.56335	2.298	.497	38.916
M	704.4953	1,337.5412	101.953	58.488	.50848	6.647	.873	57.495
L	8,665.5824	17,000.7218	150.068	82.924	.50137	7.684	1.045	77.876
Hawaii: [3]								
S	124.4687	210.5892	57.006	34.337	.56318	2.232	.361	38.839
L	337.0055	584.2480	142.960	79.985	.55527	.604	.836	78.342
Northeast Africa: *S*	792.1596	1,459.8564	79.098	47.460	.51834	6.460	.888	40.152
Angola, Africa: [4]								
M	1,512.1458	3,014.1629	7.643	56.986	.49730	8.428	.834	58.158
L	787.8897	1,508.4197	136.893	76.696	.50250	7.907	1.116	78.257
Y=snout to insertion ventral fin:								
109°–119° W.: *L*	293.8657	1,002.0157	149.819	42.186	.27463	1.041	.992	39.489
119°–129° W.: *L*	417.6371	1,330.6669	146.721	41.053	.26583	2.051	1.192	39.267
129°–139° W.: *L*	1,356.8898	5,353.5948	144.948	40.598	.24779	4.681	.830	39.372
139°–149° W.: *L*	1,032.2273	3,653.3615	148.773	41.489	.25857	3.021	.888	39.221
East Line Islands:								
M	171.8619	688.7797	102.681	30.816	.23594	6.589	.568	30.183
L	1,378.2468	4,281.4189	145.244	40.605	.28416	—.668	1.035	39.114
West Line Islands:								
S	197.7514	662.5486	68.798	21.986	.27978	2.738	.556	20.924
M	725.1524	2,662.0067	97.817	29.710	.25258	5.003	.802	30.261
L	419.3256	1,499.3643	138.129	39.591	.25849	3.886	.767	40.075
Palmyra Island: [3]								
S	67.7354	231.6094	72.491	22.831	.27388	2.977	.361	20.779
M	206.6390	838.6164	94.381	28.042	.23120	6.221	.481	29.341
Phoenix Islands:								
S	104.8074	386.4849	68.103	21.651	.24564	4.922	.547	20.889
M	507.6593	1,849.5511	98.855	29.696	.25748	4.243	.763	29.991
L	255.6681	846.2511	134.937	37.793	.24371	4.908	1.060	39.027
East Marshall Islands: *L*	207.6508	727.2816	136.321	37.760	.26782	1.250	.598	38.745
Bikini Island: *S*	136.5968	488.3494	59.029	18.945	.26736	3.163	.456	20.541
East Caroline Islands:								
S	278.3699	982.4089	65.272	20.282	.27597	2.269	.354	20.207
M	487.3084	2,001.3000	98.367	28.639	.23674	5.352	.510	29.026
L	399.8920	1,591.7800	139.727	38.840	.23308	6.272	.738	38.903

See footnotes at end of table.

Table A-3.—*Regression statistics of yellowfin tuna samples*—Continued

Character and size group [1]	Sy^2	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}$
Central Caroline Islands:								
S	213.6964	681.6964	68.331	21.431	0.29080	1.560	0.674	20.462
M	716.5196	2,764.7333	101.034	29.502	.24001	5.253	.731	29.254
L	360.4895	1,028.6865	131.743	37.253	.26316	2.584	1.166	39.426
Philippines (SW. Panay):								
S	1,068.2601	3,489.7440	65.157	21.116	.28704	2.413	.528	21.071
M	526.4000	1,951.9623	90.738	27.844	.25307	4.881	.641	30.188
L	205.6600	614.1950	133.041	38.550	.23954	6.681	1.397	40.217
Japan: *S*	416.3374	1,434.3187	57.726	18.352	.28709	1.779	.396	20.440
Hawaii: [2]								
S	168.6675	547.5950	52.350	16.858	.29445	1.444	.467	20.583
M	181.0448	647.7448	101.953	30.153	.24625	5.047	.820	29.672
L	2,174.4026	8,398.2667	150.041	41.741	.24758	4.594	.852	39.255
Hawaii: [3]								
S	38.4587	110.0536	57.006	18.521	.29432	1.743	.367	20.874
L	96.4895	307.5460	142.960	40.045	.29229	−1.741	.605	39.180
Northeast Africa: *S*	208.4792	717.6459	79.146	25.229	.25435	5.098	.751	21.631
Angola, Africa: [4]								
M	374.2714	1,497.3414	97.643	29.643	.24704	5.521	.479	30.225
L	220.5800	845.3900	137.667	39.467	.24729	5.423	.679	40.044
Y=greatest body depth:								
Costa Rica: [2] *M*	246.6014	855.8203	99.879	25.417	.26800	−1.351	.799	25.449
109°–119° W.: *L*	390.8457	1,173.1343	149.819	38.714	.32153	−9.457	.848	35.557
119°–129° W.: *L*	441.5200	1,284.4100	146.721	36.800	.25659	−.847	1.577	35.076
129°–139° W.: *L*	1,498.6661	5,502.0583	144.948	36.383	.25467	−.530	1.488	35.124
139°–149° W.: *L*	1,361.7169	4,091.6786	148.338	37.717	.30010	−6.799	1.118	35.215
East Line Islands:								
M	150.7747	621.1294	102.456	24.928	.21128	3.281	.807	24.409
L	1,267.7564	4,062.2382	145.061	36.236	.28108	−4.538	.910	34.813
West Line Islands:								
S	161.9377	599.3763	68.556	17.135	.24657	.231	.587	16.258
M	569.4407	2,214.7833	97.664	23.771	.22087	2.200	.995	24.287
L	591.7793	1,748.7343	138.179	34.204	.30106	−7.396	1.090	34.752
Phoenix Islands:								
S	89.1089	369.7056	67.453	16.744	.22375	1.651	.433	16.195
M	503.8539	1,862.3048	98.225	24.110	.24070	.467	.988	24.537
L	275.9098	860.0632	135.068	33.602	.24398	.648	1.254	34.805
East Marshall Islands: *L*	284.8236	842.8003	136.279	33.813	.30548	−7.818	.860	34.949
Bikini Island: *S*	97.7194	416.0368	59.029	14.626	.22777	1.181	.319	15.986
East Caroline Islands:								
S	157.5893	719.3893	65.272	16.247	.20208	3.057	.459	16.192
M	488.5953	1,991.5484	98.262	23.556	.23469	.495	.632	23.964
L	575.7756	1,882.6350	139.950	34.816	.26964	−2.920	1.123	34.830
Central Caroline Islands:								
S	148.8973	592.7176	67.943	16.770	.23298	.941	.556	16.085
M	647.5291	2,653.3177	100.875	24.103	.22524	1.382	.706	23.906
L	457.7347	1,252.3399	132.323	32.856	.28304	−4.597	1.223	35.020
Japan: *S*	321.5547	1,255.2073	57.607	15.013	.25191	.501	.437	16.875
Hawaii: [2]								
S	98.9864	409.9150	52.350	13.631	.22042	2.092	.504	16.419
M	162.8941	602.8918	101.953	25.732	.22920	2.364	.879	25.284
L	3,209.8397	10,060.9787	149.943	37.965	.29805	−6.726	1.274	35.001
Northeast Africa: *S*	225.3725	774.6375	79.146	20.837	.27455	−.893	.525	16.953
Y=insertion ventral fin to anterior edge vent:								
109°–119° W.: *L*	288.0247	963.7465	150.212	43.518	.27389	2.376	1.267	40.721
119°–129° W.: *L*	351.6464	1,206.2371	146.721	41.583	.24097	6.228	1.164	39.964
129°–139° W.: *L*	1,719.2287	6,003.8027	144.948	41.126	.27776	.865	1.075	39.751
139°–149° W.: *L*	1,248.5543	3,883.7779	148.540	42.007	.28450	−.253	1.143	39.577
East Line Islands:								
M	231.9206	799.7837	102.509	28.324	.27178	.464	.685	27.642
L	1,298.9754	4,141.1737	145.432	40.485	.27522	.459	1.027	38.990
West Line Islands:								
S	143.8737	495.3853	68.445	19.326	.27138	.751	.512	18.391
M	738.3841	2,687.2328	97.233	26.992	.26389	1.333	.601	27.722
L	459.4699	1,521.6909	138.334	38.473	.26548	1.748	1.014	38.915
Phoenix Islands:								
S	44.2063	145.1658	68.905	19.142	.28462	−.470	.412	18.030
M	441.1425	1,627.0607	97.188	26.651	.26299	1.092	.531	27.391
L	211.2589	622.7878	134.289	37.594	.28995	−1.343	.950	39.250
East Marshall Islands: *L*	291.2231	838.0954	136.454	37.931	.30568	−3.780	.973	39.015
East Caroline Islands:								
S	278.5460	972.9090	65.272	18.670	.27330	.831	.467	18.596
M	608.4060	2,209.4215	98.509	27.537	.26606	1.328	.629	27.934
L	644.2975	2,064.3486	139.989	39.031	.29587	−2.388	.795	39.034
Central Caroline Islands:								
S	197.1489	680.9356	67.747	19.556	.27316	1.050	.573	18.805
M	817.7146	3,006.1016	100.875	28.281	.25518	2.540	.709	28.058
L	454.6795	1,249.9491	132.455	36.603	.29115	−1.961	1.147	38.800

[1] *S*, small, less than 80 cm., compared at length of 65 cm.; *M*, medium, 80 to 120 cm., compared at length of 100 cm.; *L*, large, over 120 cm., compared at length of 140 cm.

[2] Schaefer (1952). [3] Godsil and Greenhood (1951). [4] Schaefer and Walford (1950).