Morphometric Characteristics and Relative Growth of Yellowfin Tuna *(Neothunnus macropterus)* from Central America

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THE PROBLEM of whether the yellowfin tuna stocks inhabiting different parts of the Pacific Ocean are genetically independent is of interest both from taxonomic and economic viewpoints. Several species of yellowfin tuna have been described from the Pacific Ocean, supposedly differentiated from each other by the relative lengths of the fins. The determination of the validity of these species requires examination of series of fish of all sizes, and of both sexes, to determine whether some of the descriptions may not be based on sex-connected or size-connected variations of a single species. Since the yellowfin tuna is one of the most valuable commercial varieties, it is of considerable importance to determine whether the groups encountered in different parts of the Pacific are all members of one large stock which is, therefore, entirely open to exploitation at any point in its range, or whether there are a number of separate stocks, in which case the exploitation of one would have no effect on the exploitation of the others.

Approach to the problem by methods of morphometric analysis requires the examination of series from each of a number of different localities. Since these fish are of large size, the few specimens in the various museums are insufficient for the purpose. The only practical procedure is to make the counts and measurements in the field. The area to be covered is so very large that it is impractical, at present at least, for one person to visit all the various localities. Therefore, it seems desirable that the data for the fish from a given locality be put on recor as soon as obtained, for subsequent compariso with those of other places as they becom available.

MORPHOMETRIC DATA

From late January until late June, 1947, th factory ship "Pacific Explorer" was anchored i the Gulf of Nicoya, on the Pacific coast of Cost Rica, for the purpose of freezing a cargo o tunas from the adjacent oceanic fishing grounds The author was aboard this vessel and the fishin boats supplying the mother ship as an observe for the Fish and Wildlife Service until March 7, when he was relieved by J. C. Marr. Between January 22 and April 15 morphometric measurements and counts were made by the author and Mr. Marr on a series of 46 yellowfin tuna from the waters off Costa Rica. These were made on recently caught, unfrozen fish, either aboard the fishing vessels or aboard the mother ship. Data for each fish are tabulated in Table 1. All measurements are in millimeters. Specimens were selected according to size, so as to give a fairly even representation throughout the range of sizes encountered in this fishery. Our specimens ranged in length from 542 to 1,571 mm. Since we are interested in determining the morphometric characteristics of fish of different sizes, the arbitrary selection of fish by sizes is justified because "the regression function does not depend on the frequency distribution of the independent variate" (Fisher, 1934:127).

Sex was determined for most of the fish measured. For fish over about 650 mm. this was quite easy, because these larger fish were undergoing development of the gonads during

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TABLE 1. MORPHOMETRIC DATA FOR COSTA RICAN YELLOWFIN TUNA

(Specimens above horizontal line measured by author, those below by J. C. Marr.)

SEX	WEIGHT	TOTAL LENGTH	HEAD LENGTH	SNOUT TO INSERTION FIRST DORSAL	SNOUT TO INSERTION SECOND DORSAL	SNOUT TO INSERTION ANAL	GREATEST DEPTH	LENGTH PECTORAL FIN	PECTORAL INSERTION TO INSERTION FIRST DORSAL	LENGTH OF BASE OF FIRST DORSAL	LENGTH OF LONGEST (FIRST) DORSAL RAY	LENGTH OF SECOND DORSAL FIN	LENGTH OF ANAL FIN	LENGTH OF LONGEST DORSAL FINLET	DIAMETER OF IRIS	MAXILLARY LENGTH	FIRST DORSAL FIN RAYS	DORSAL FINLETS	ANAL FINLETS	GILL RAKERS
	kilos	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*no.*	*no.*	*no.*	*no.*
F	10.8	835	228	253	456	505	215	219	121	194	99	101	99	27	31	89	14	9+1	9+1	......
F	19.1	1,041	275	297	524	605	256	......	146	246	118	......	......	34	32	107	14	9+1	9+1	11+21
F	21.3	1,080	284	313	564	629	270	283	154	260	130	188	204	34	34	109	14	9+1	9+1	8+23
....	18.1	1,030	282	300	530	612	258	270	......	242	116	169	189	31	35	106	14	9+1	9	9+20
....	8.3	719	203	223	334	441	188	195	......	168	89	83	88	23	29	81	13	9+1	9+1	9+22
....	10.8	854	235	249	447	513	207	248	131	205	98	132	141	28	30	92	14	9+1	10	9+21
M	70.3	1,571	405	440	805	917	410	346	232	389	189	305	309	53	44	153	13	10	10	8+19
....	31.3	1,173	306	340	607	686	321	300	185	281	144	242	203	48	34	119	14	9+1	9+1	9+22
....	6.4	703	209	207	393	434	170	201	103	169	97	85	95	22	30	80	14	9+1	9+1	10+21
F	......	1,475	389	425	746	845	372	345	217	337	166	255	313	44	40	147	13	10	9+1	10+21
F	22.2	1,084	293	314	566	632	271	280	151	261	......	170	216	33	33	114	13	10	9+1	10+21
F	30.8	1,166	312	347	611	673	305	297	185	275	142	189	232	41	38	122	13	9+1	9	10+20
M	......	1,411	372	405	705	782	357	335	214	318	158	308	397	46	41	143	13	10	9+1	10+21
M	......	1,242	329	352	641	702	321	291	190	302	147	265	284	41	37	125	14	9+1	9+1	9+20
M	......	1,189	310	344	614	693	306	304	177	288	146	211	245	39	36	119	14	9+1	9	9+21
F	......	1,057	290	319	557	625	268	275	160	251	126	172	192	33	36	111	14	9+1	9	9+20
M	......	823	229	251	442	492	221	237	125	206	100	115	116	29	30	89	14	9+1	9	10+21
M	9.1	770	226	250	429	466	209	217	127	191	85	101	103	26	31	86	14	8+1	8+1	9+22
M	26.3	1,144	311	336	602	669	293	301	174	275	132	230	243	38	35	120	14	9+1	8+1	11+22
F	22.7	1,090	295	323	570	635	272	294	163	261	140	209	216	37	35	114	13	9+1	9+1	10+20
M	3.2	542	165	177	304	339	147	152	85	132	61	55	59	17	27	63	14	9+1	8+1	11+21
M	12.2	887	247	265	480	529	225	259	125	206	108*	130	128	27	......	96	13	9+1	9+1‡	9+21
M	29.9	1,132	312	338	601	664	299	313	181	256	147	221	231	37	......	119	13	9+1	9+1	10+21
F	6.4	698	205	213	381	423	181	196	108	164	83	88	92	23	......	77	14	8+2	7+1	10+20
M	13.1	897	251	264	484	530	223	245	133	214	104	131	137	27	......	94	14	9+1	8+1	9+20
F	4.5	637	185	201	348	393	161	184	98	142	72	77	77	20	......	73	13	9+1	9+1‡	10+21
M	13.1	883	247	263	475	522	225	243	135	205	98	127	130	29	......	95	14	9+1	8+1	11+20
M	5.4	662	190	204	366	409	170	191	99	......	74	75	80	22	......	73	13	9+1	8+1‡	9+20
M	15.9	973	266	279	515	575	230	268	143	223	115	155	167	31	......	102	14	9+1	8+1‡	8+20
F	15.4	922	264	275	499	556	238	262	145	201	111	132	160	30	......	101	13	8+2	8+1‡	11+22
F	15.0	931	257	270	487	553	234	245	128	198	108	119	132	29	......	96	13	8+2	8+1‡	10+21
M	15.9	918	261	284	494	558	240	257	145	206	111	143	166	30	......	94	14	9+1	9+1‡	9+21
M	15.9	963	270	288	516	579	241	268	149	210	112	131	137	29	34	102	13	9(+1?)	8+1	9+21
M	15.4	957	262	279	510	567	245	262	146	216	112	139	164	28	32	102	14	8+2	8+1	11+21
F	15.4	943	257	276	498	552	236	264	141	199	108	143	146	30	34	98	13	8+2	8+1	10+21
M	16.8	976	265	287	510	572	247	274	147	202	115	153	176	32	35	105	13	8+1	9(+1?)	11+21
M	29.0	1,233	323	358	644	706	329	313	194	271	152*	231	274	40	38	120	14	9+1	8+1	9+21
M	3.6	574	169	182	325	352	152	159	93	136	65	63	62	18	30	62	14	8+2	8+1	10+21
M	19.1	996	267	296	524	583	257	268	157	224	122	157	173	32	34	110	14	8+2	9+1	11+21
M	25.9	1,114	296	322	575	642	281	285	169	246	130	166	173	37	38	116	14	9+1	8+2	9+21
M	15.4	931	257	274	496	561	242	260	141	219	108	133	137	30	33	97	14	8+2	8+2	9+22
F	16.8	976	270	293	522	584	235	274	141	224	119	139	155	32	35	102	14	8+2	8+2	10+22
F	6.4	693	204	220	391	428	178	198	109	161	82	94	......	22	32	80	14	7+2†	8+1	11+21
M	3.6	618	180	193	343	381	155	173	92	136	72	67	70	20	29	68	13	8+2	8+2	10+20
M	5.0	638	186	199	360	399	167	188	102	153	83	77	75	21	29	73	14	8+2	8+1	9+20
F	4.5	624	184	195	349	387	164	168	97	143	81	71	68	20	29	71	14	8+2	8+2	11+21

* Second dorsal ray is the longest. † Sixth finlet missing. ‡ Doubtful whether +1 or +2.

this season, and many of them were in advanced stages of maturing of the sexual products. The smallest fish, under about 650 mm., which are believed to be fish only a year old, had undeveloped gonads and the determination of sex was difficult.

Measurements were made in millimeters with the same slide-calipers used by Godsil and Byers (1944), or with dividers for short distances such as diameter of iris or length of maxillary. The various measurements and counts were made in the exact manner described by these authors in their Appendix II except as noted below.

Pectoral insertion to insertion first dorsal was measured with the tip of the fixed arm of the caliper at the insertion of the first dorsal fin, the sliding arm being brought to the anterior termination of the dorsal margin of the pectoral fin.

Length of longest (first) dorsal ray was measured with dividers from the juncture of the ray (with the fin extended) and the contour of the body to the tip of the ray. The longest ray was the first ray in all cases except two, which are indicated in the table.

I refer to the "length" of the second dorsal and anal where Godsil and Byers use the term "height."

Length of longest dorsal finlet (the 5th or 6th) was measured with dividers from the anterior margin of the finlet to the tip of the posterior filament. The number of dorsal finlets and number of anal finlets were counted from posteriorly forward and if the last, most anterior, finlet (the last two in some cases) was attached to the second dorsal (or anal fin) by a membrane, it is recorded separately from the count of the free finlets. Thus if there were 9 finlets, all free, the record is 9; if there were 9 free finlets and one attached by a membrane to the fin, the record is 9+1. This seems not to be a very good character because of the difficulty of distinguishing between attached finlets and the posterior end of the fin itself. It may be noted that our counts tend to average higher than those of Godsil and Byers, even when the difference in method of counting is taken into account. There also seems to be some difference between the author and Mr. Marr as to when a finlet is considered attached.

The character "length of base of first dorsal" would be more accurately called "first dorsal insertion to second dorsal insertion" since, following Godsil and Byers, that is the measurement taken for this character.

Weights were usually taken with a spring balance reading in pounds. Fish over 100 pounds were weighed in pounds on a platform scale. Some small fish were weighed on a small spring balance, read to 0.1 kilo. Because the readings recorded in pounds to the nearest pound were later translated to kilos, the accuracy is slightly less than indicated; individual weights may be in error by as much as 0.25 kilo.

RELATIVE GROWTH

The measurement data in Godsil and Byers' paper (1944) are recorded in terms of body proportions, that is, in terms of the times a given measurement is contained in the body length, or in the head length, depending on the character. Body proportions have also been used to characterize supposed species, for example, by Jordan and Evermann (1926) and by Nichols and La Monte (1941). Where data from fish of different sizes are compared, this is unsatisfactory unless the ratio of the dimension under consideration bears a constant ratio to the dimension, such as total length, which is employed as a standard. Where such a constant ratio does not exist, it is necessary to compare only fish of the same size or, which is more efficient, to compare the regression of the given character on fish length (or head length). Nichols and La Monte have recognized this in the case of the length of the second dorsal and anal fins and have combined a fish size with a ratio of fin length to body or head length in drawing up species descriptions, and have made some attempt to take this into account in their key.

In order to establish the morphometric characteristics of the stock of yellowfin tuna off Costa Rica, for subsequent comparison with stocks from other parts of the Pacific, I have computed for each dimension measured the linear mean-square regression on the total length, or on the length of head in the cases of length of maxillary and diameter of iris. Where the rate of increase of the character measured is not proportional to the rate of increase of the total length, that is, where the original variables do not yield a linear regression, a transformation of variables has been made so that the new variables yield a linear relationship. This was necessary in three cases. The rate of increase of length of second dorsal and of anal fins is greater than that of total length, while the rate of growth of the pectoral fin is less than that of total length, over the range of sizes examined.

The statistics describing the regressions are tabulated in Table 2. The linear mean-square regression is completely specified in each case by the means of the two variables, the number of specimens, the regression coefficient, and the standard deviation from regression. The latter is also called the standard error of estimate by some authors. Where the regression of the original variables is linear we have also tabulated the value of the *y* intercept in order to facilitate determination of whether the dependent variable may be considered to be in constant proportion to the independent variable.

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. That is, the rate of increase of each of the dimensions, with these exceptions, is proportional to the rate of increase in total length. The proportion of the dimension considered to the total length will be constant in a given case, however, only if, in addition, the *y* intercept of the regression line is zero. If the intercept differs from zero, the value of the proportion will vary with the size of the fish. Only for the re-

TABLE 2. STATISTICS DESCRIBING REGRESSIONS OF BODY PROPORTIONS OF YELLOWFIN TUNA FROM COSTA RICA

INDEPENDENT VARIABLE x	DEPENDENT VARIABLE y	$\bar{x}$	$\bar{y}$	$s_{y.x}$	b	a	N
Total length	Head length	951.6	261.4	4.39	0.2350	37.8	46
Total length	Snout to insertion first dorsal fin	951.6	282.2	5.35	0.2635	31.5	46
Total length	Snout to insertion second dorsal fin	951.6	503.0	11.45	0.4768	49.4	46
Total length	Snout to insertion anal fin	951.6	563.0	7.58	0.5351	53.8	46
Total length	Greatest body depth	951.6	243.5	7.60	0.2555	0.4	46
Total length	Pectoral insertion to insertion first dorsal	955.1	144.5	5.83	0.1469	4.2	44
Total length	Length base first dorsal	958.1	222.4	10.15	0.2358	–3.5	45
Total length	Length longest (first) dorsal ray	948.7	112.8	5.22	0.1178	1.2	45
Total length	Length longest dorsal finlet	951.6	30.9	2.00	0.03361	–1.1	46
Log total length	Length pectoral fin	2.9640	253.5	7.52	445.9	....	45
Log total length	Log length second dorsal fin	2.9640	2.1361	0.0362	1.694	....	45
Log total length	Log length anal fin	2.9668	2.1711	0.0414	1.832	....	44
Length second dorsal fin	Length anal fin	151.2	164.9	17.62	1.150	–9.0	44
Length of head	Diameter of iris	266.8	33.7	1.303	0.06038	17.6	35
Length of head	Length of maxillary	261.4	100.3	2.17	0.3781	1.5	46
Log total length	Log weight (kilos)	2.9538	1.1222	0.0266	2.940	....	93

Logarithms are to the base 10.
$\bar{x}$ = mean of values of x.
$\bar{y}$ = mean of values of y.
$s_{y.x}$ = standard deviation from regression (standard error of estimate).
b = regression coefficient of y on x.
a = y intercept of regression line.
N = number of specimens.

gression of greatest body depth on total length, and the regression of length of longest first dorsal ray on total length do the intercepts fail to differ significantly from zero. For the pectoral insertion to insertion of first dorsal, and length of base of first dorsal, the regressions on total length have *y* intercepts differing significantly but yet so slightly from zero that the expression of these measurements as percentages of total length would result in a negligibly small error from this source. This is also true for the regression of length of maxillary on length of head. For the remaining characters, the size of the fish has a considerable effect on the dimension expressed as a percentage of total length, and the same is true for diameter of iris expressed as a percentage of head length.

The lengths of the second dorsal and anal fins are in proportion to the 1.69 power and 1.83 power of the total length, respectively. This very rapid increase of fin length with fish length follows the equation

$$y=cx^{b} \text{.......................} (1)$$

where *y* is the fin length, *x* is the total length, *b* is the value indicated in Table 2, and *c* is an arbitrary constant depending on the units of measurement. (Here, where the measurements are in millimeters, $c=5.45\times10^{-4}$ for the anal fin and $c=1.30\times10^{-3}$ for the second dorsal.) The standard deviation from regression, converted from logarithms as expressed in Table 2 to percentages, amounts to 8.7 per cent for the second dorsal fin and 10.0 per cent for the anal fin. If the deviations were randomly assorted by fish size we would expect to find in about one case in 100 a fish with second dorsal fin varying as much as 25 per cent from the average for a given size of fish, and a fish with anal fin varying as much as 29 per cent from the average for a given size of fish. Examination of the data, however, has shown that the deviations are not entirely randomly assorted, but that they are to some degree related to size of fish, the variability, on a logarithmic plot, being somewhat greater for the larger fish. This means that at the larger sizes, say over about a meter in total length, the variation may be expected to be somewhat greater than the numerical values indicated, while for small fish it will be less.

The deviations from the average for a given size are not attributable to the sex of the fish in any case. No sexual dimorphism of fin lengths or other measurements has been found from our data.

The exponents *b* in (1) for anal fin length and second dorsal fin length are so nearly equal that the regression of the latter on the former is linear or nearly so. The least-squares fit to this regression indicates that, on the average, for any given size in the range investigated the anal is somewhat longer than the second dorsal.

The pectoral fin grows more slowly than the length of the fish over this range of sizes. It was found that, for this range, the relationship between fin length *y* and total length *x* may be expressed in the form

$$y=446 \log_{10} x-1068 \text{..........} (2).$$

There is no recognizable difference between the measurements of the two observers with the single exception of the character "length of base of first dorsal." Examination of the data indicates a tendency for the measurements of this distance by Mr. Marr to be a little smaller than those of the author. The statistics of the linear mean-square regressions, computed from the data of the two observers, are:

	Schaefer	Marr
Number of specimens..	21	24
Mean total length ($\bar{x}$ in Table 2)..............	1047.6	879.8
Mean length of base of first dorsal ($\bar{y}$ in Table 2)	250.0	198.1
Standard deviation from regression	7.35	7.29
Regression coefficient (b in Table 2)........	0.2330	0.2090

The slopes of these regressions do not differ significantly from those of the pooled data, the statistics for which may be found in Table 2. The levels of the lines however, that is, the values of x for a given value of y, are less in the case of Mr. Marr's measurements and greater in the case of the author's measurements than would ordinarily be expected from random sampling from a population having the values estimated from the pooled data. The probabilities, in each case, lie between 0.02 and 0.01. There seems, therefore, to be a real difference between the two sets of measurements. Since the measurements by the two persons were made on different groups of fish, there is a possibility that this difference represents an actual difference between the two groups of tunas. However, no difference between the two is shown by the data on other dimensions; in particular no difference between the distances of snout to insertion of first dorsal, snout to insertion of second dorsal or body depth, one of which should reflect any actual difference in the distance between the insertions of the first and second dorsal fins. Therefore, it seems most likely that the difference represents a difference in the measuring by the two observers, although it is not apparent just how this arose.

LENGTH–WEIGHT RELATIONSHIP

In addition to the data recorded in Table 1, the lengths and weights were determined for a number of specimens over the same size range, a total of 93 in all. The regression of logarithm of weight on logarithm of length is described in Table 2. This relationship corresponds to the equation

$$W = 2.74 \times 10^{-8} L^{2.940} \quad \text{............} (3)$$

where L is the total length in millimeters and W is the weight in kilos.

TAXONOMIC NOTES

The yellowfin tuna off Costa Rica appear to be assignable to the species *Neothunnus macropterus* (Temminck and Schlegel). The specimens examined by me agree closely enough with the descriptions of that species in Kishinouye's monograph (1923) and in Godsil and Byers' paper (1944). The latter concluded that all the yellowfin tunas of the Pacific examined by them, including specimens from Costa Rica, were members of this single species. Nichols and La Monte's data (1941) on length of second dorsal and anal fins for *N. macropterus,* which they consider to be a synonym of *N. albacora,* given for various fish lengths, fall within the expected limits of variation of the values estimated for those same lengths from the regressions in our Table 2. The only exception to this is their Portuguese specimen 5 feet long, which had dorsal and anal lobes contained "2.6 to 2.8 times in the length." From our data, it is estimated that at this length only about 1 per cent of specimens would have second dorsals contained less than 3.9 times in the length, or anals contained less than 3.2 times in the length.

Frade (1929, 1931) has found that there are rather distinct anatomical differences between the Portuguese yellowfin, *N. albacora,* and the Pacific yellowfin, *N. macropterus.* He has found that the air bladder of *N. albacora* has a large dorsal diverticulum, which is not present on the air bladder of *N. macropterus* according to Kishinouye's description, which is confirmed by the study of Godsil and Byers (1944). Kishinouye's Figure Q (page 373) also shows the cutaneous artery of *N. macropterus* arising at the level of the 9th vertebra, whereas that of the Portuguese yellowfin was found by Frade to arise at the level of the 8th. This difference is not confirmed by Godsil and Byers, however, who also found the cutaneous artery arising at the level of the 8th vertebra in their specimens of *N. macropterus.*

Decision as to whether or not the variety of yellowfin tuna from the Hawaiian Islands, having very long anal and second dorsal fins at larger sizes, is distinct from the more common variety, and, if so, whether the difference is specific or only racial, must await examination of a series from the type locality. This fish was described from Hawaii by Jordan and Evermann (1926) as *Neothunnus itosibi.* Nichols and La Monte (1941) state that "at a weight of around 100 pounds the fin lobes . . . from the tropical Pacific compare in development with the maximum obtained by the Common Yellowfin. At about 4 feet 5 to 9 inches, weighing 140 pounds or less, the lobes are contained 2.1 to 2.8 times in standard length . . ." These anal and second dorsal fins seem to be significantly longer than we would expect to find in *N. macropterus,* from Costa Rica at least. However, it is also possible that the variability of fin length is greater among the members of the Hawaiian stock. Godsil and Byers' Hawaiian specimens do not help with the solution of this problem since they were of very small size, 537–573 mm.

It is of interest to note that Frade (1931) has found that in the vicinity of Portugal there exist for the same size two types of *N. albacora:* ". . . comme pour *N. macropterus* du Pacifique, il existe pour la même taille deux types de *N. albacora:* l'un à 2^e dorsale et anales longues, correspondant à *N. macropterus* forma *itosibi* et l'autre à 2^e dorsale et anales courtes, correspondant à *N. macropterus* forma *macropterus.*"

Beebe and Tee-Van (1936) consider that ". . . the various nominal forms of the yellow-finned tuna belong to the same species, and that the forms typified by the large Allison's tuna represent but large-finned specimens of the smaller short-finned individuals." Walford (1937) found that among yellowfin tunas examined in California canneries ". . . the dorsal and anal fins were of all lengths, intergrading to such an extent that it is impossible to separate them into two groups. In general, the largest, consequently the oldest fish had the longest fins."

It seems well established that wherever yellowfin tuna occur, both short-finned and long-finned individuals are encountered, and that this character is correlated with the size of the fish. Whether racial differences in the regressions of fin length on fish size will be found between localities we cannot say at this stage of our knowledge. Within the Costa Rican stock, however, as represented by the present sample, there seems to be but a single race of yellowfin tuna.

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