UNITED STATES DEPARTMENT OF THE INTERIOR, OSCAR L. CHAPMAN, *Secretary*
FISH AND WILDLIFE SERVICE, ALBERT M. DAY, *Director*

BIOMETRIC COMPARISON BETWEEN YELLOWFIN TUNAS (*NEOTHUNNUS*) OF ANGOLA AND OF THE PACIFIC COAST OF CENTRAL AMERICA

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Aquatic Biologists

March 3, 1849

Fishery Bulletin 56

From Fishery Bulletin of the Fish and Wildlife Service

VOLUME 51

UNITED STATES GOVERNMENT PRINTING OFFICE • WASHINGTON : 1950

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Price 15 cents

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The several species of fishes commonly called tuna are characteristically widely distributed and probably generally composed of many populations. The determination of the identity of these populations is fundamental to understanding the biology of tunas. This can be accomplished only by extensive biometric comparison between samples of tunas taken throughout the range of their distribution.

During November 1948 one of us (Walford) had occasion to visit the Port of Mossamedes in Angola (Portuguese West Africa) which is the center of a growing tuna-canning industry. Through the kindness of Capt. Josina Da Costa, of Lisbon, Portugal, he was able to visit canneries where tuna were being packed, to go out on a fishing vessel, and to make a number of measurements and counts on freshly caught specimens of yellowfin tuna. The opportunity to gather these data was particularly gratifying because it meant that measurement data could be collected exactly comparable with those available for Pacific yellowfin tuna, thus making possible a detailed comparison of the morphometric characteristics of the two. Such a comparison will be, we hope, a valuable contribution to the solution of the problems of speciation of the tunas.

Measurements and counts were made of various characters on 60 yellowfin tuna selected to cover as evenly as possible the size range of available specimens. Measurements were made in millimeters in accordance with the methods employed by American researchers studying Pacific tunas (Schaefer 1948; Marr and Schaefer 1949). Although slide calipers of the type employed by those authors were not available, exactly comparable measurements were made by the use of large dividers and a millimeter scale. The basic original data are tabulated in table 1.

The many detailed computations in this paper were performed by Mr. Kalfred Yee, whose assistance is gratefully acknowledged.

RELATIVE GROWTH OF ATLANTIC YELLOWFIN TUNA

Morphometric data on tunas, like those on other fishes, following the methodology of classical taxonomy, have usually been recorded in terms of body proportions, that is, the number of times one dimension is contained in another. The committee of experts for the examination of scientific methods applied to the study of tunas, which met in Madrid and Cadiz in 1932, for example, (Anonymous 1933) recommended the employment of various "indices biométriques" which are ratios of one body dimension to another. In this they followed the usage of Frade (1929, 1931) and Heldt (1931) who were members of the committee and who had employed similar indices in studies of Mediterranean and Atlantic tunas. Both of these authors have employed such indices to compare tunas of the same species from different regions. Jordan and Evermann (1926) and Nichols and LaMonte (1941) have employed body proportions in characterizing species, as have Godsil and Byers (1944) in their painstaking study of Pacific tunas.

Body proportions are, in general, not satisfactory for comparing tunas of different sizes, because the differential growth of different body parts causes the value of a proportion to change as the fish grows. Only when no differential growth exists between the parts whose dimensions are used in computing the ratio, that is, only when there is a constant ratio between the dimensions of such parts, can the average value of such a ratio be used to compare fish of different sizes. Where the ratio does not remain constant as the fish grows, it is necessary to compare only fish of the same size or to compare the regressions of one dimension on another. Schaefer (1948) computed such regressions to characterize the yellowfin tuna (*N. macropterus*) from the Pacific Ocean off Central America, employing linear regressions, or

TABLE 1.—*Morphometric data from 60 specimens of Yellowfin tuna (Neothunnus albacora) from the commercial catch at Mossamedes, Angola, Nov. 12–15, 1948*

Total length	Head length	Snout to insertion first dorsal	Snout to insertion second dorsal	Snout to insertion anal	Snout to insertion ventral	Greatest depth	Length pectoral	Pectoral insertion to insertion first dorsal	Length base first dorsal	Length base second dorsal	Spread caudal	Length longest dorsal spine	Length first dorsal spine	Length second dorsal	Length anal	Length longest dorsal finlet	Diameter of iris	Length maxillary	Least depth caudal peduncle	Greatest width caudal peduncle at keels	Number of first dorsal spine	Number of dorsal finlets	Number of anal finlets	Number of gill rakers	Sex
Nov. 12																									
751	205	240	417	455	231	184	214	116	186	68	230	86	86	108	111	19	28	80	19	62	14	8+1	8+1	9+21	M
1536	400	442	766	846	430	409	373	241	343	125	590	180	180	450	491	51	45	152	40	(?) 157	13	9+1	8+1	9+21	M
1238	323	367	651	719	360	319	338	190	296	104	432	147	147	254	273	43	33	128	32	135	14	8+1	8+1	10+20	M
1626	416	464	835	903	463	436	417	249	391	130	605	189	189	445	454	57(4th)	37	153	46	154	14	8+1	6+1	9+22	M
1600	405	435	812	901	449	456	404	249	398	136	-----	189	189	426	505	58(4th)	44	156	43	153	14	9	8+1	9+22	M
1299	344	365	647	721	375	343	346	189	305	106	449	161	161	318	367	44(6th)	38	135	35	117	14	8+1	8+1	8+20	F
844	243	250	459	516	269	222	251	127	214	70	230	102	102	137	130	28(4th)	30	96	22	65	14	9	8+1	9+21	M
1318	350	376	677	741	388	335	348	197	311	108	487	162	162	344	355	45(4th)	39	128	33	138	14	9	9	10+21	F
1577	404	438	793	970	445	409	372	231	379	141	555	185	185	402	461	50(4th)	40	155	41	148	14	9	9	11+21	M
Nov. 13																									
1193	310	336	615	673	345	318	321	194	285	95	396	130	130	238	250	35(4th)	36	120	29	117	13	9+1	9	8+21	F
1406	361	391	705	769	397	360	327	215	323	121	453	143	143	297	327	46(4th)	37	141	33	137	14	9+1	9	10+22	M
1437	376	401	735	796	418	390	371	216	347	116	524	167	167	353	407	48(5th)	36	138	37	135	14	9	8+1	9+20	M
1276	344	369	659	716	373	307	318	176	310	102	447	156	156	289	292	43(4th)	38	128	31	126	14	9	9	9+20	F
1373	346	386	690	758	389	350	338	210	330	104	457	144	144	339	363	46(4th)	39	129	33	132	14	9	9	9+21	F
1338	347	370	675	744	385	362	347	190	318	106	490	152	152	296	332	42(4th)	37	125	34	129	14	9	9	10+21	M
1371	360	381	695	760	382	344	354	196	332	107	480	171	171	347	400	46(5th)	37	133	37	125	14	8+1	9	9+20	F
1381	353	391	701	750	384	362	344	200	342	93	471	149	149	398	335	45(4th)	38	133	33	141	14	9	9	9+21	M
1166	310	339	604	661	348	298	339	174	293	91	390	125	125	233	227	40(4th)	34	115	29	110	14	8+1	8+1	9+21	M
491	160	167	279	316	179	145	131	76	123	45	153	55	55	43	44	14(4th)	27	58	11	30	15	8+1	8+1	9+19	-----
Nov. 14																									
769	223	248	442	482	250	-----	236	-----	205	-----	-----	-----	-----	113	117	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
805	230	256	455	485	260	-----	224	-----	204	-----	-----	-----	-----	132	137	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
797	220	242	427	479	255	-----	230	-----	194	-----	-----	-----	-----	124	118	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
831	243	255	454	505	262	-----	242	-----	214	-----	-----	-----	-----	118	124	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1172	313	325	595	665	349	-----	348	-----	288	-----	-----	-----	-----	238	269	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
828	238	265	446	500	256	-----	233	-----	188	-----	-----	-----	-----	135	112	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
787	226	244	434	482	246	-----	220	-----	198	-----	-----	-----	-----	119	128	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
799	226	250	436	476	252	-----	230	-----	200	-----	-----	-----	-----	113	120	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
807	225	248	428	485	256	-----	220	-----	217	-----	-----	-----	-----	196	124	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
790	225	247	435	483	252	-----	220	-----	197	-----	-----	-----	-----	121	124	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
830	238	261	455	508	263	-----	225	-----	204	-----	-----	-----	-----	116	120	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
826	230	250	456	493	265	-----	225	-----	198	-----	-----	-----	-----	132	131	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1114	289	328	584	624	330	-----	289	-----	162	-----	-----	-----	-----	197	207	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
985	264	290	513	572	291	-----	268	-----	235	-----	-----	-----	-----	154	157	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
802	220	262	452	480	251	-----	219	-----	201	-----	-----	-----	-----	118	122	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
789	217	243	435	471	241	-----	220	-----	203	-----	-----	-----	-----	118	119	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1170	309	337	612	672	350	-----	315	-----	294	-----	-----	-----	-----	240	241	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1183	316	338	608	672	339	-----	327	-----	281	-----	-----	-----	-----	262	283	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1254	327	349	649	720	358	-----	326	-----	306	-----	-----	-----	-----	286	311	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1448	356	395	736	816	414	-----	345	-----	351	-----	-----	-----	-----	326	277	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1200	320	350	618	684	358	-----	329	-----	286	-----	-----	-----	-----	(1)	345	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1364	357	371	691	772	395	-----	360	-----	327	-----	-----	-----	-----	373	423	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1194	318	336	620	694	349	-----	332	-----	294	-----	-----	-----	-----	243	257	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1133	299	323	589	647	337	-----	321	-----	280	-----	-----	-----	-----	210	248	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1180	309	335	613	671	349	-----	313	-----	290	-----	-----	-----	-----	256	278	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1207	315	342	614	686	345	-----	320	-----	289	-----	-----	-----	-----	229	263	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1255	328	354	648	716	367	-----	356	-----	303	-----	-----	-----	-----	300	316	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1286	332	356	666	733	380	-----	353	-----	315	-----	-----	-----	-----	328	356	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1468	378	408	757	828	420	-----	372	-----	358	-----	-----	-----	-----	531	570	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Nov. 15																									
1372	350	376	704	777	393	-----	349	-----	335	-----	-----	-----	-----	303	290	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1365	361	375	695	764	401	-----	347	-----	327	-----	-----	-----	-----	290	345	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1324	339	373	674	754	386	-----	339	-----	316	-----	-----	-----	-----	285	301	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1421	350	386	715	773	389	-----	362	-----	350	-----	-----	-----	-----	367	388	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1430	371	416	720	794	412	-----	382	-----	333	-----	-----	-----	-----	385	439	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
791	226	249	425	475	256	-----	219	-----	194	-----	-----	-----	-----	123	132	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
793	227	235	420	480	248	-----	231	-----	193	-----	-----	-----	-----	111	115	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
809	230	242	449	483	254	-----	230	-----	214	-----	-----	-----	-----	129	130	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
810	240	248	438	488	250	-----	221	-----	193	-----	-----	-----	-----	122	122	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
789	226	240	434	475	247	-----	226	-----	193	-----	-----	-----	-----	136	120	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
798	223	245	450	472	244	-----	222	-----	207	-----	-----	-----	-----	120	120	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
823	231	244	445	473	252	-----	235	-----	203	-----	-----	-----	-----	141	131	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

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[1] Broken.

transformations which yield linear regressions. Godsil (1948) employed a generalized formula which would fit both linear and curvilinear regressions to describe the growth of head length and the distances from snout to each fin insertion in relation to body length of *N. macropterus*, and also for a number of body proportions of albacore (*Thunnus germo*).

In this study we have followed Schaefer (1948). We have computed the linear mean square regressions for the original data where the variables have a linear relationship, and where they were found to have a nonlinear relationship we have employed a transformation that yields a linear relationship between the new variables. The statistics describing the various regressions, together with the sums of squares and products of deviations about the means, are tabulated in table 2. The sums of squares and products of deviations about the means are included for the convenience of other workers desiring to compare similar data with ours by means of covariance analysis. In figures 1 to 15 are plotted various regressions, together with similar regressions from Schaefer's Costa Rican data.

A linear relationship between the original variables was evident for each regression except length of anal fin on total length, length of second dorsal fin on total length, and length of pectoral fin on total length. Except in these three cases, the rate of increase of the dimension in question remains proportional to the rate of increase in total length, over the size range considered. The second dorsal and anal fins grow much faster than the body, and the rate of growth relative to rate of growth of total length also increases with size of fish. The rate of growth of the pectoral fin relative to rate of growth of total length decreases as the size of the fish increases.

Although with the three exceptions noted there appears to be a linear relationship between the variables, the ratio of one dimension to another does not in most cases remain constant since the *y* intercepts of the linear-regression lines are different from zero, in which cases the ratios in question will change with size of fish. However, the regression of greatest body depth on total length has a *y* intercept that does not differ significantly from zero; the same result was found for Costa Rican yellowfin. Similarly, for both the African and the Costa Rican yellowfin, the *y* intercept of the regression of longest (first) dorsal ray on total length does not differ significantly from zero. The regression of distance from pectoral insertion to insertion of first dorsal on total length for African yellowfin has a *y* intercept not differing significantly from zero; in the case of Costa Rican fish this regression was found to differ significantly from zero, but so slightly that expression of the dependent variable as a percentage of total length would result in a negligibly small error. The length of base of first dorsal, the regression of which on total length for Costa Rican fish was found to have a *y* intercept only slightly different from zero, differs from zero in the case of African fish to the extent that the ratio of the dimensions in question would change appreciably with size of fish.

TABLE 2.—*Statistics describing regressions of body proportions of yellowfin tuna from Angola*

Independent variable x	Dependent variable y	N	$\bar{x}$	$\bar{y}$	Sx^2	Sy^1	Sxy	b	$s_{y.x}$	a
Total length	Head length	60	1113.6	297.03	4777250	241246	1069271	.2238	5.73	47.8
Do	Snout to insertion first dorsal	60	1113.6	322.4	4777250	282829	1155796	.2419	7.42	67.0
Do	Snout to insertion second dorsal	60	1113.6	580.9	4777250	1008031	2189948	.4584	8.49	70.4
Do	Snout to insertion anal	59	1105.8	634.8	4558918	1154267	2289060	.5021	9.35	79.6
Do	Snout to insertion ventral	60	1113.6	329.7	4777250	294313	1181866	.2474	5.78	54.2
Do	Greatest body depth	19	1274.8	334.2	1562973	115626	418487	.2678	14.5	−7.2
Do	Pectoral insertion to insertion first dorsal	19	1274.8	191.4	1562973	36004	233649	.1495	7.96	0.80
Do	Length base first dorsal	59	1113.6	271.2	4777250	251797	1089396	.2280	7.62	17.3
Do	Spread caudal	18	1256.7	435.5	1451335	252568	594723	.4098	23.5	−79.5
Do	Length longest (first) dorsal spine	19	1274.8	147.0	1562973	22576	182003	.1164	9.01	−1.45
Do	Length longest dorsal finlet	19	1274.8	42.1	1562973	2296	58791	.0376	2.24	−5.83
Log total length	Length pectoral fin	60	3.0317	297.2	0.822463	245933	441.9995	537.4	12.0	-------
Do	Log length second dorsal fin	58	3.0330	2.3240	0.804606	2.977096	1.524508	1.895	.0398	-------
Do	Log length anal fin	60	3.0317	2.3415	0.822463	3.443019	1.651653	2.008	.0467	-------
Length second dorsal fin	Length anal fin	58	239.0	253.2	739047	931501	817109	1.106	22.4	−11.0
Length of head	Diameter of iris	19	334.6	36.5	81785	384.7	4971.8	.0608	2.20	16.1
Do	Length of maxillary	19	334.6	126.5	81785	11509	30356	.3712	3.77	2.28

Logarithms are to the base 10
N=number of specimens
$\bar{x}$=mean of values of x
$\bar{y}$=mean of values of y
Sx^2, Sy^2, Sxy=sums of squares and products about the mean values $\bar{x}$, $\bar{y}$
b=regression coefficient of y on x
$s_{y.x}$=standard deviation from regression (standard error of estimate)
a=y intercept of regression line

In the course of fitting regression lines to the data of table 1, it was discovered that a few measurements were quite obviously in error. These were discarded in fitting the final regressions and in subsequent covariance studies. The snout to insertion of anal of the 1577-mm. specimen measured on November 12 was recorded as 970 mm. This point fell about 6 standard deviations away from the regression line computed from data including it. Since such an extreme deviation is unlikely, and since if the value of the ordinate were 870 mm. it would fall very near the regression line, it was regarded as most probably a recording error and was discarded from the computations. Similarly, the length of base of first dorsal of the 1114-mm. specimen measured on November 14 was recorded as 162 mm., a value almost 7 standard deviations away from the regression line computed from data including it. If the value were 262 mm. it would fall very near the regression line. This value was similarly presumed to have been a recording error and was therefore discarded in the final computations. The 807-mm. tuna measured on November 14 was recorded as having a second dorsal fin 196 mm. in length. This value is probably also a recording error, being over 4 standard deviations away from the regression line computed from the data with this point included, and was therefore discarded in the final computations.

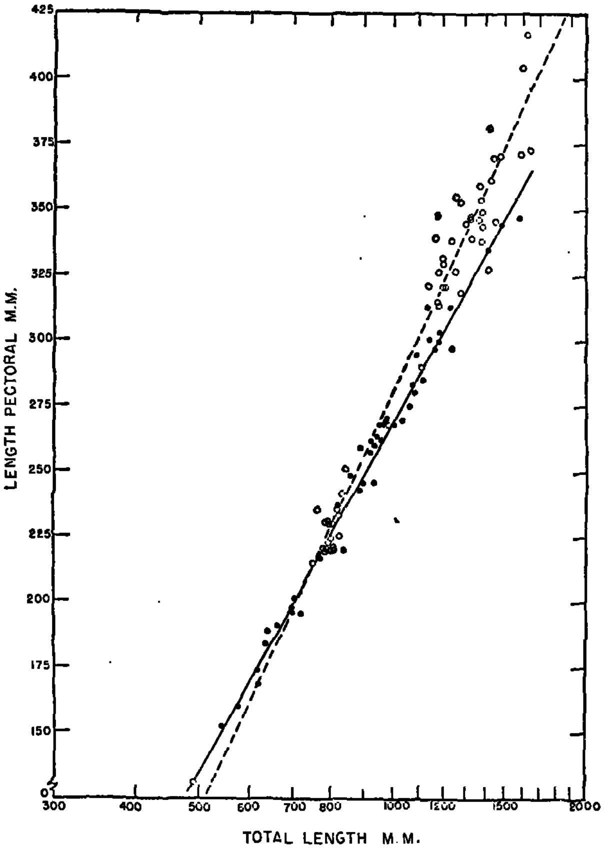

Figure 1.—Regressions of length of pectoral fin on logarithm of total length for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

The length of the second dorsal fin, 531 mm., of the 1468-mm. specimen measured on November 14 lies 3.5 standard deviations away from the regression line (fig. 2) of log of fin length on log of total length. This is a much greater deviation than one can reasonably expect to encounter among a series of 60 random samples from a homogeneous population. However, this same specimen had an anal fin 570 mm. long, which lies 2.8 standard deviations away from the line of regression of log of anal fin length on log of total length (fig. 3). This value is again a little larger than can reasonably be expected to be encountered in random sampling from a homogeneous population. These values of second dorsal fin length and anal fin length are such, also, that they fall very nearly on the line of regression of anal fin length on second dorsal fin length (fig. 4). It was concluded, therefore, that these fin lengths were correctly measured and recorded but that this particular fish had second dorsal and anal fins longer than might be expected from the values encountered among the remainder of the sample. Again, a specimen 1448 mm. long had an anal fin only 277 mm. in length, which is a good deal shorter than would be expected to occur by chance alone, being about 3 standard deviations away from the regression line. In this connection, however, it should be noted that the standard error of estimate employed here is the mean-square deviation about the regression line. As may be seen from a close inspection of figures 2 and 3, and as was pointed out by Schaefer (1948), the variability tends to increase with size of fish so that for large fish the actual range of variation which we may expect to encounter in random sampling will be somewhat greater than the value computed from the mean-square deviation from regression of all values in the sample. Considering this fact, these extreme deviations of fin

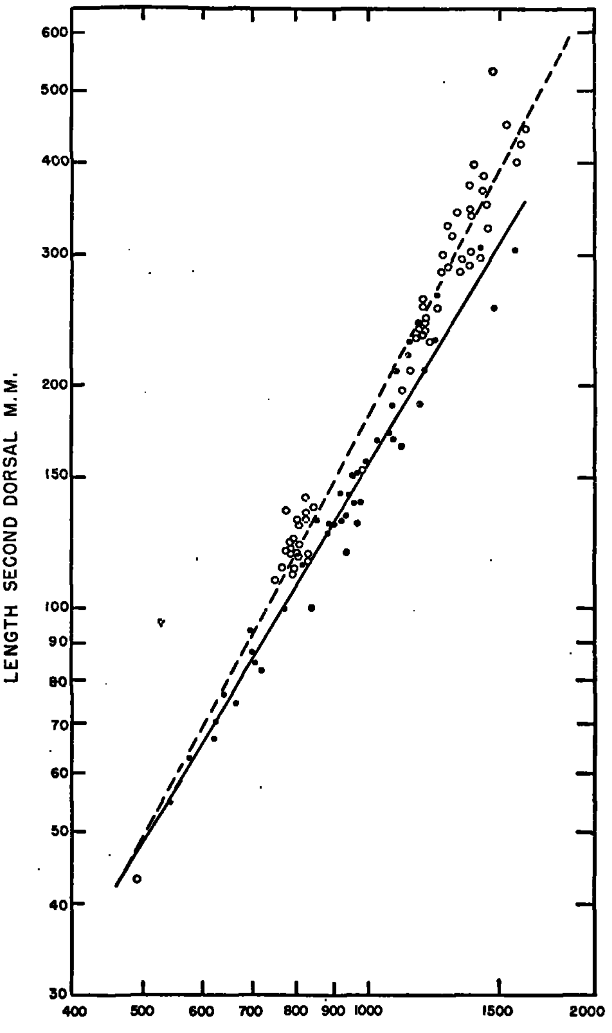

FIGURE 2.—Regressions of logarithm of length of second dorsal fin on logarithm of total length for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

lengths may not be entirely improbable as having been drawn from the same population as the rest of our sample; they were therefore retained.

In the case of Costa Rican yellowfin tuna, Schaefer (1948) found that the relationship between length of pectoral and total length was nonlinear, but that plotting length of pectoral on logarithm of total length yielded a linear regression. For yellowfin tuna from Angola, the length of pectoral plotted against total length yields a regression much more nearly linear than is the case for the Costa Rican

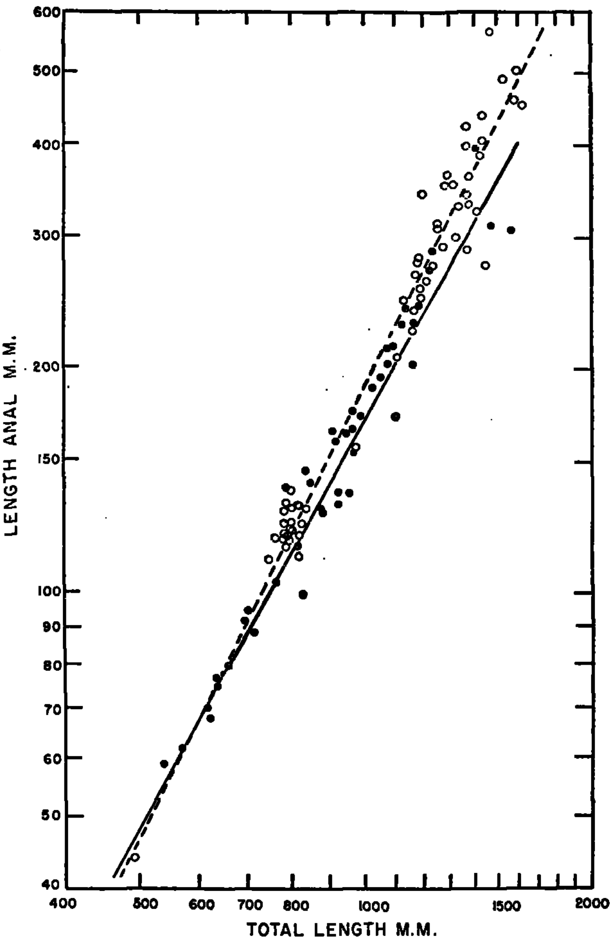

FIGURE 3.—Regressions of logarithm of length of anal fin on logarithm of total length for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

material. Indeed, a linear relationship between the original variables appeared to be a fairly good "fit" to the points. However, the employment of a linear regression of pectoral fin length on logarithm of total length, which for these data from Angola leads to the mean square regression

$$y = 537 \log_{10} x - 1{,}332$$

results in a very significant reduction of sum of squares of deviations from the regression line over the sum of squares of deviations obtained employing a linear regression between the original variables. It was concluded, therefore, that the growth law adduced for relative growth of pectoral fin length and total length of Pacific yellowfin gave the best fit to the Atlantic data also. The data and the fitted regression line are shown in figure 1.

Growth of the second dorsal and anal fins relative to body length was found to be well fitted by the equation

$$y = cx^b$$

where y is fin length, x is total length, and c and b are constants, yielding a linear relationship when the logarithm of fin length is plotted against logarithm of total length (figs. 2 and 3). Where the measurements are in millimeters, the equations fitting our African yellowfin data are for second dorsal length on total length

$$y = .000378x^{1.895}$$

and for anal length on total length

$$y = .000179x^{2.008}$$

From these equations it may be seen that the length of second dorsal and anal fins are in proportion to the 1.90 power and the 2.01 power, respectively, of the total length. These values are sufficiently nearly equal that the regression of length of anal on length of second dorsal is well represented by a straight line (fig. 4).

COMPARISONS WITH PACIFIC TUNA

The comparison of body form of these specimens of *N. albacora* from waters off Angola with similar specimens of *N. macropterus* from waters off Central America, the measurements of which were recorded by Schaefer (1948), is of interest from two standpoints. First, there is the question whether the yellowfin tuna from the Atlantic and those from the Pacific are actually members of a single species or whether they belong in separate species. Second, regardless of whether they are to be placed in one or in two species, it is of interest to determine how much difference is found in body form among *Neothunnus* from widely separated regions of the world, mixing of fish between which is not likely, as a possible basis of judging the significance with respect to racial distinctness of fish from various parts of the same ocean. It seems unlikely that the yellowfin tuna from the Pacific Ocean off Central America intermix with yellowfin tuna from the Atlantic off Angola. Migration around the southern tip of Africa and across the Pacific is not entirely impossible, since during at least a part of the year the waters off the Cape of Good Hope are of high enough temperature to be inhabitated by these fish. Such a migration, however, seems sufficiently unlikely that we may assume that there is a high degree of likelihood that the yellowfin tuna from waters off Angola and the yellowfin tuna from the Pacific Ocean off Central America are separate and distinct populations. If the degree of morphological difference is a function of degree of separation of populations, the differences between these two populations may then indicate the kind and degree of differences to be expected between distinct and well-separated populations of yellowfin tuna.

Since, as we have pointed out earlier, body-proportion ratios or "biometric indices" vary with size of fish, their suitability for comparing measurements of fish from different populations is very limited. We have, therefore, employed the regressions of table 2 and similar regressions from Schaefer (1948) as a basis of comparison by means of the analysis of covariance. In our analyses we have followed the procedures set forth by Kendall (1946) page 237 *et seq.*

Perhaps the most striking difference exhibited by our samples between the Atlantic and Pacific yellowfin is in the length of the pectoral fin relative to the length of the body. As illustrated in figure 1, the same type of relationship fits the data from both samples, but the regression coefficients are markedly different. For both Atlantic and Pacific yellowfin tuna the length of pectoral fin relative to length of body decreases as the size of the fish increases, but the rate of decrease is more rapid for Pacific than for Atlantic fish. In consequence, among small sizes the length of pectoral is about the same for Atlantic and Pacific specimens, but among large fish the Atlantic yellowfin tuna have pectorals which are, on the average, very much longer than those of Pacific yellowfin tuna.

An equally marked difference between fish from the two places is observed in the relative growth of the second dorsal and anal fins (figs. 2 and 3). In both cases, the regression coefficients for the Atlantic yellowfin are very significantly [1] larger than for the

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[1] In this paper a probability of one chance in a hundred is taken as the maximum value for a conclusion of significance, except where otherwise stated.

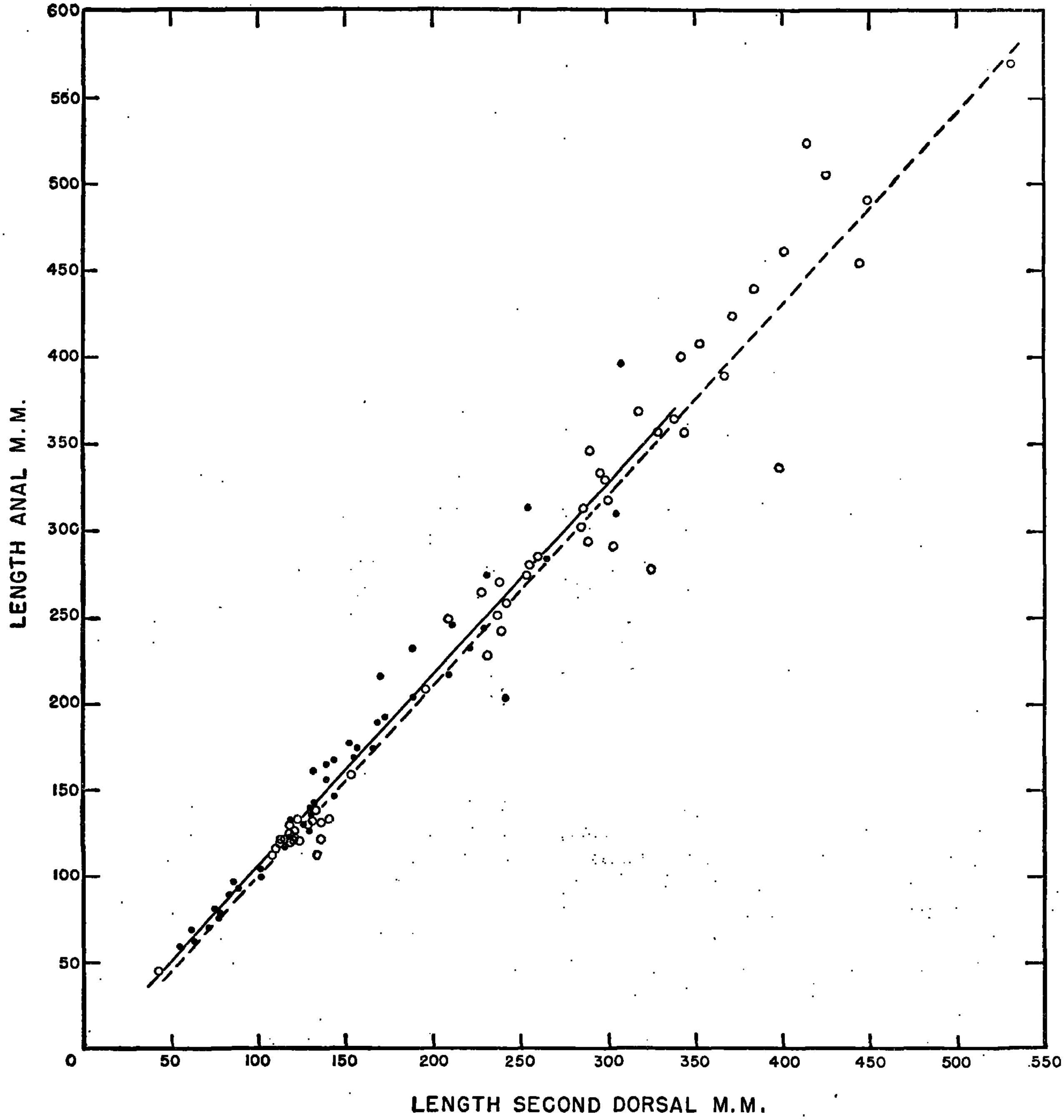

FIGURE 4.—Regressions of length of anal fin on length of second dorsal fin for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

Pacific yellowfin. The second dorsal and anal fins of Pacific tunas grow much faster than the body, so that large fish have fins very much longer in proportion to body length than do small fish; in Atlantic yellowfin this phenomenon is even more marked. Among small fish there is little difference between specimens from the two localities, but larger fish from the Atlantic have fins very significantly longer on the average than those from the Pacific.

Although the second dorsal and anal fins of the Atlantic yellowfin tuna grow much more rapidly than those of the Pacific yellowfin tuna, the relation of length of anal to length of second dorsal is the same, on the average, for both groups (fig. 4); there is no significant difference between the regression equations.

The regressions of length of head, snout to insertion of first dorsal, snout to insertion of second dorsal, and snout to insertion of anal are in each case slightly but quite significantly different between the Atlantic and Pacific samples. In each case, as may be seen from figures 5 to 8, the regression coefficient for the Atlantic fish is smaller than the regression coefficient for Pacific fish. Furthermore, in each of these cases the regression lines cross one another in the neighborhood of a meter of total length. This consistency of results in each of these four cases argues even more strongly than the results of individual covariance analyses that there is a real difference in relative growth rates involved, if our samples are indeed representative of the populations from which they were drawn. There is indicated a small but definite difference in the growth of the head, and perhaps of the anterior part of the body, relative to total length, the rate of growth decreasing more rapidly for Atlantic than Pacific fish. Among small fish below about a meter in total length, the length of the head and the distance from the snout to the insertions of first dorsal, second dorsal, and anal fins is, on the average, slightly greater for Atlantic fish than for Pacific fish, while for larger fish above about a meter in total length these dimensions are, on the average, greater for Pacific fish than for Atlantic fish.

Covariance analysis of the data on what we term length of base of first dorsal, which is actually the distance from first dorsal insertion to second dorsal insertion, (fig. 9) indicates that the regression coefficients are sufficiently similar that the slight difference between them could very well have been the result of random sampling. However, there is a very significant difference between the levels of the two regression lines. It appears that over the range of sizes included in this study there is at each size of fish a small constant difference between the lengths of bases of first dorsals of Atlantic and of Pacific fish, the distance being shorter for Pacific tuna. This conclusion must, however, be approached with a good deal of caution because the data for this character for the Pacific fish have been shown to be peculiar in some inexplicable respect. It was noted by Schaefer (1948) that there was a significant difference between his measurements and those made by his coworker, J. C. Marr, with respect to the levels of the regression lines resulting from their sets of data treated separately. A comparison of our Atlantic measurements with the measurements by Schaefer alone, the regression line of which is closest to the regression line of the Atlantic tuna data, shows, however, that while there is no difference in regression coefficients there is a small but significant difference attributable to class means. It appears likely, therefore, that there is actually a small difference in this dimension between the two yellowfin-tuna populations in question.

The regressions of length of longest dorsal finlet on total length (fig. 10) are not to be regarded as different for the two groups of tunas since analysis of covariance shows that the probability of two such samples arising from a single homogeneous population is greater than one chance in twenty.

Although there is no significant difference between the two groups with respect to the length of longest dorsal finlet, it appears that there is a difference in the location of the longest finlet. Among the fish examined by Schaefer and Marr from the Pacific, the longest finlet was always No. 5 or No. 6 (enumerated from the most posterior forward). Among the yellowfin tuna examined from the Atlantic, however, No. 4 was the longest in 13 cases out of 16, as may be seen from table 1.

It is doubtful whether there exists a difference between the two populations in diameter of iris relative to head length. The regression coefficients are nearly identical for the two groups (fig. 11), but there might be a difference in the levels of the two lines. In testing the hypothesis that the two sets of data might have been drawn from the same population we arrived at a probability lying between 0.05 and 0.01, and a similar level of probability is arrived

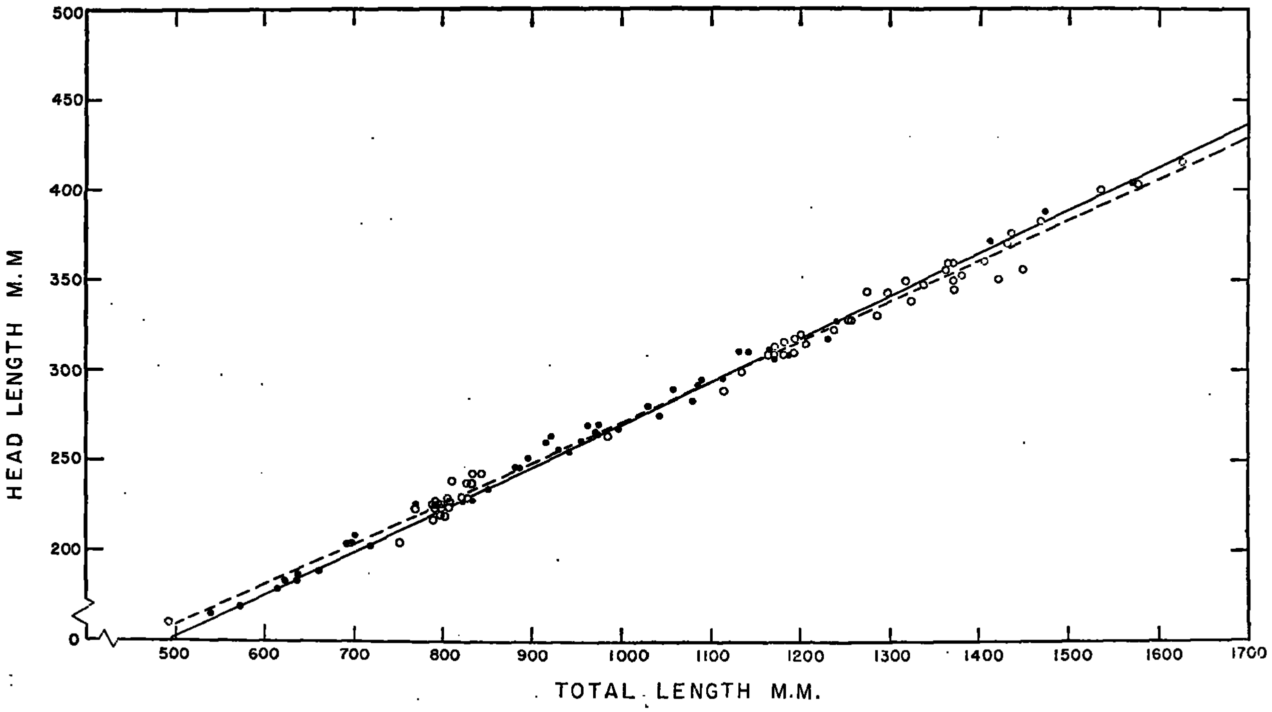

Figure 5.—Regressions of head length on total length for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

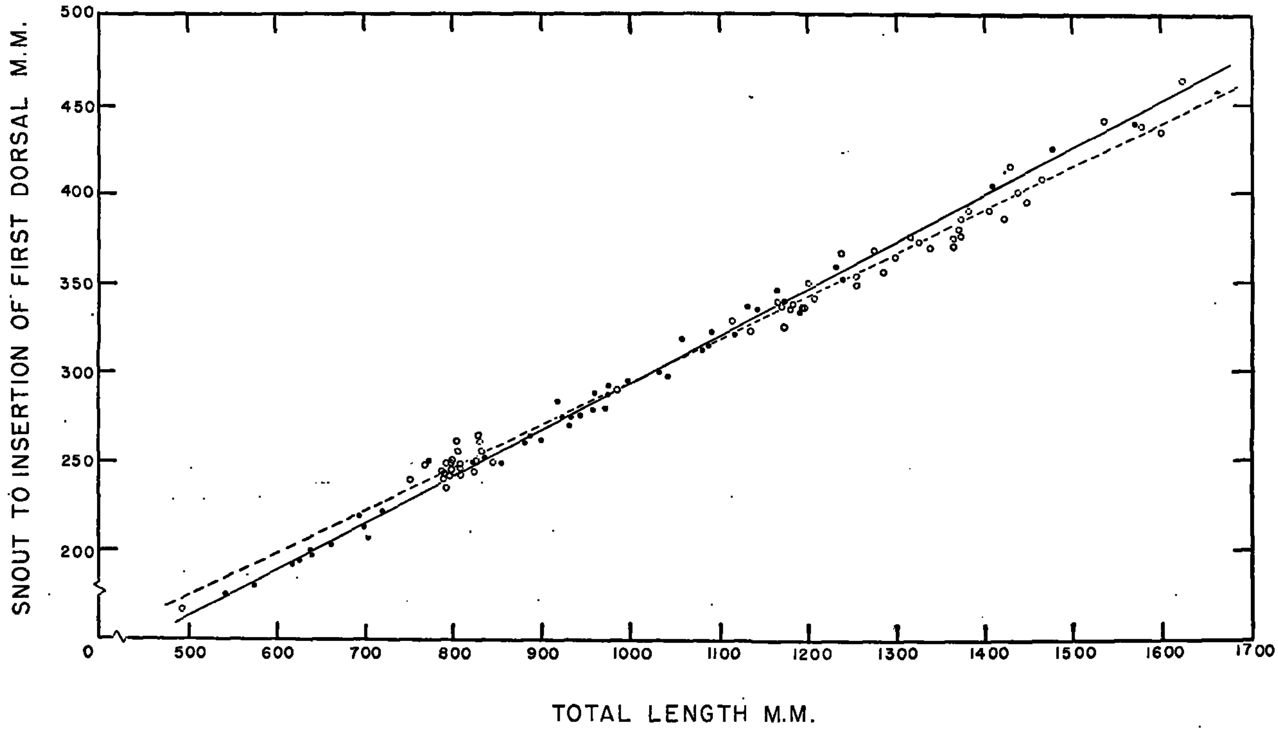

Figure 6.—Regressions of distance from tip of snout to insertion of first dorsal fin on total length for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

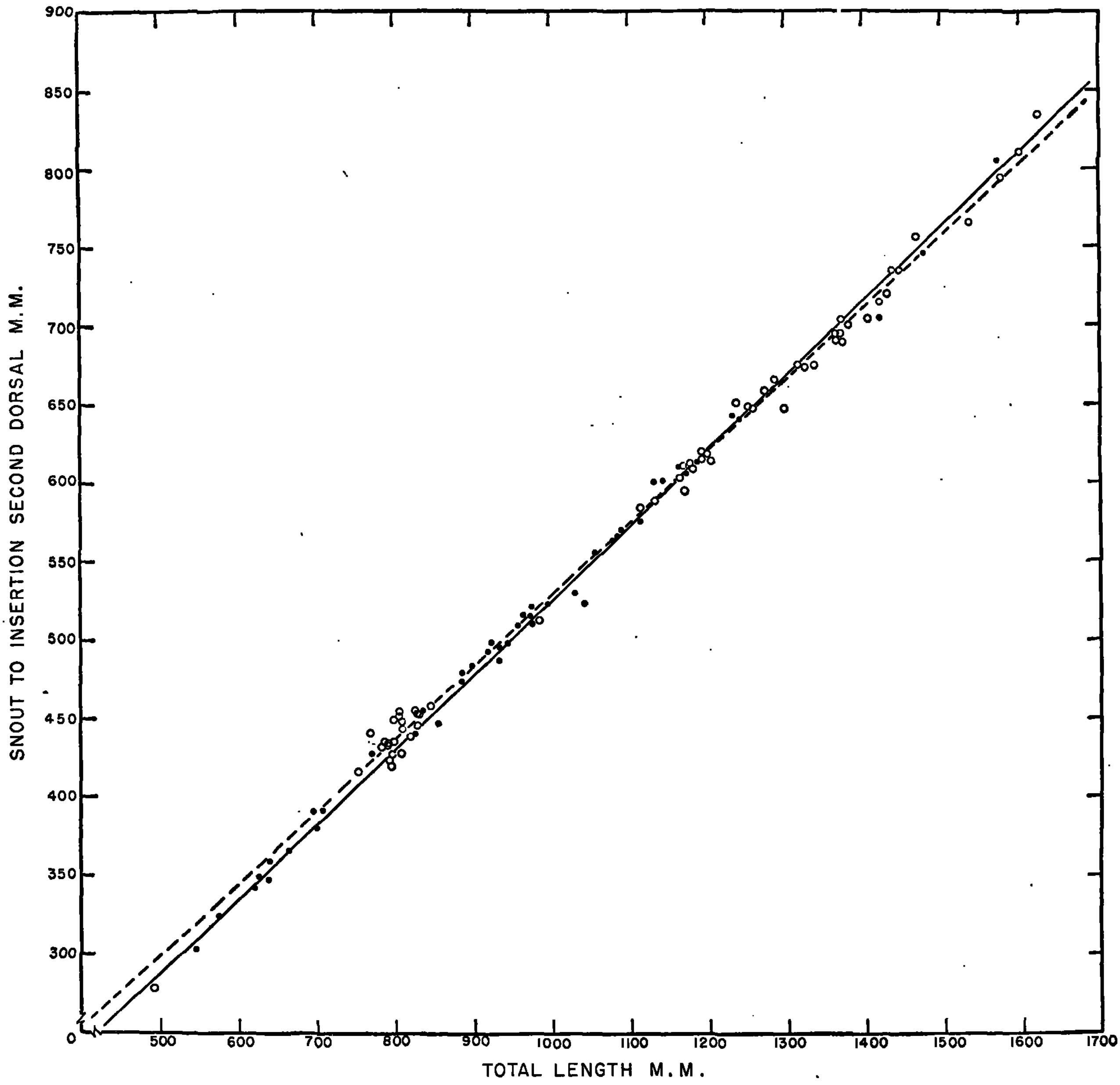

FIGURE 7.—Regressions of distance from tip of snout to insertion of second dorsal fin on total length for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

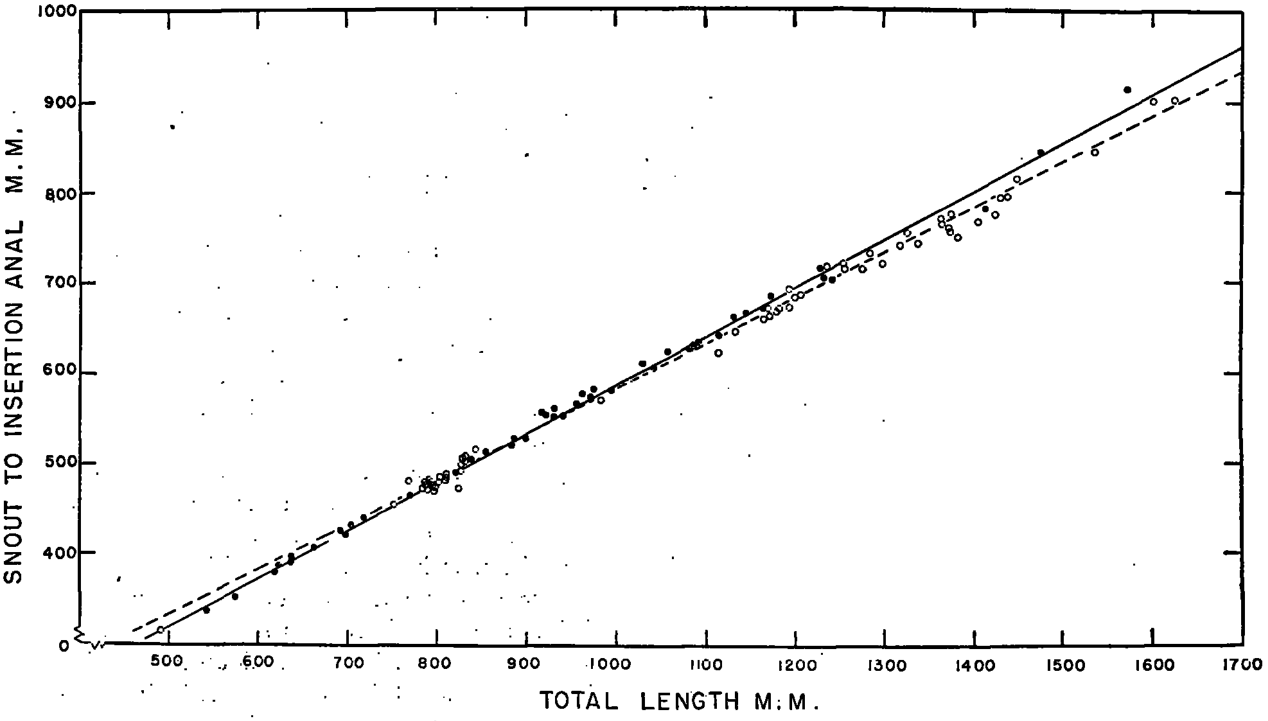

FIGURE 8.—Regressions of distance from tip of snout to insertion of anal fin on total length for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

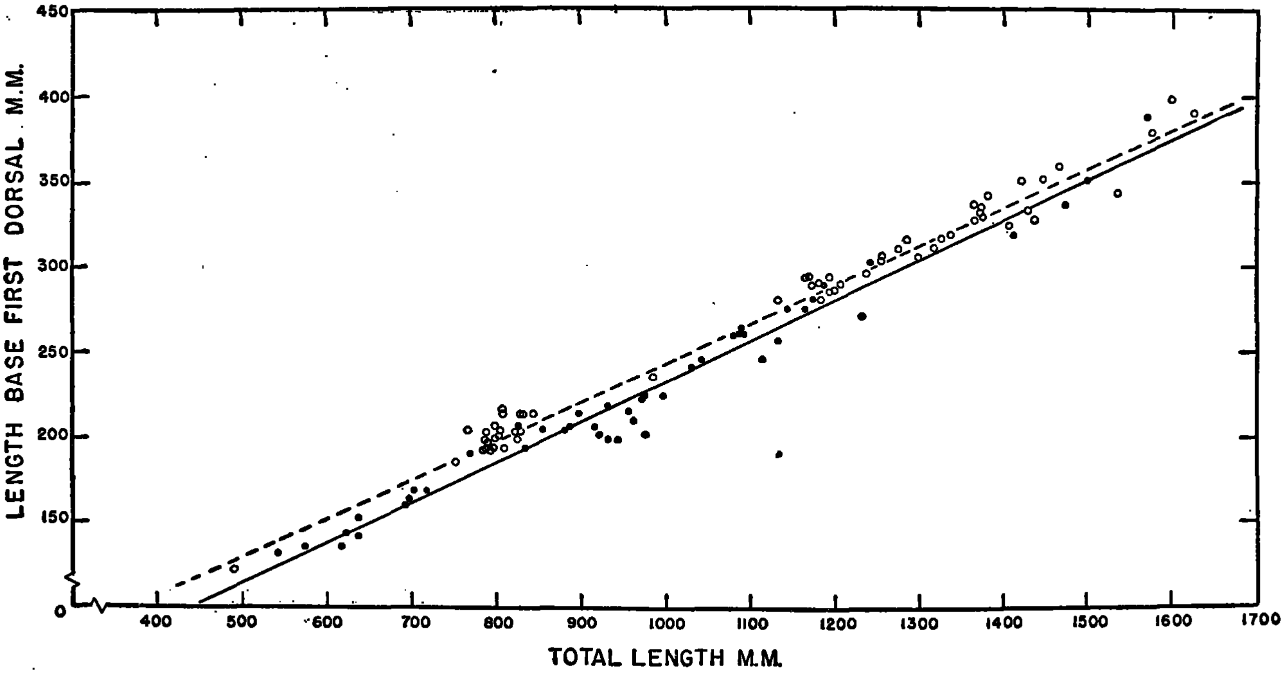

FIGURE 9.—Regressions of length of base of first dorsal on total length for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

at when the variance due to difference between class means is compared with the average variance within classes. The difference in the levels of the two lines in figure 11 cannot, therefore, be concluded to be significant, although the probability values are such that the possibility of the existence of such a difference between the populations cannot be ruled out either.

Covariance analyses indicate that our data show no significant differences between the Atlantic and Pacific samples with respect to the regressions of length of maxillary on head length (fig. 12), greatest body depth on total length (fig. 13), pectoral insertion to insertion first dorsal on total length (fig. 14), or length of longest dorsal spine on total length (fig. 15).

The gill-raker counts of these 19 Atlantic yellowfin have a mean value of 30.00, while among 45 Pacific yellowfin studied by Schaefer (1948) the mean value was 30.60. The difference between these means, considered with the associated variances, yields a value of "t" of 1.79, which would occur by chance in between 5 percent and 10 percent of random samples from a single population with normally distributed counts. These data reveal, then, no significant difference in mean gill-raker counts.

There appears to be some difference in finlet counts between the Atlantic tunas and the Pacific specimens with which we are comparing them. As may be seen from table 1, a total dorsal finlet count of 9 characterized each of the 19 Atlantic yellowfin tuna on which counts were made. Schaefer's table 1 shows that of the 46 counts made by him and Marr, a count of 10 was recorded in 42 cases, with a count of 9 in only two cases, one case being questionable and one fish having 9 finlets but being an abnormal specimen with the sixth finlet obviously missing. It appears that the Atlantic yellowfin tunas have usually one less dorsal finlet than their Pacific counterparts.

Similarly for Atlantic yellowfin there were counted 9 anal finlets in 18 cases and 7 in 1 case, while for Pacific yellowfin the counts of anal finlets were as follows: 10 finlets in 20 counts; doubtful whether 10 or 9 in 4 counts; 9 in 17 counts; doubtful whether 9 or 8 in 4 counts; and 8 in 1 count. Assigning the doubtful counts to the lower value in each case, this yields

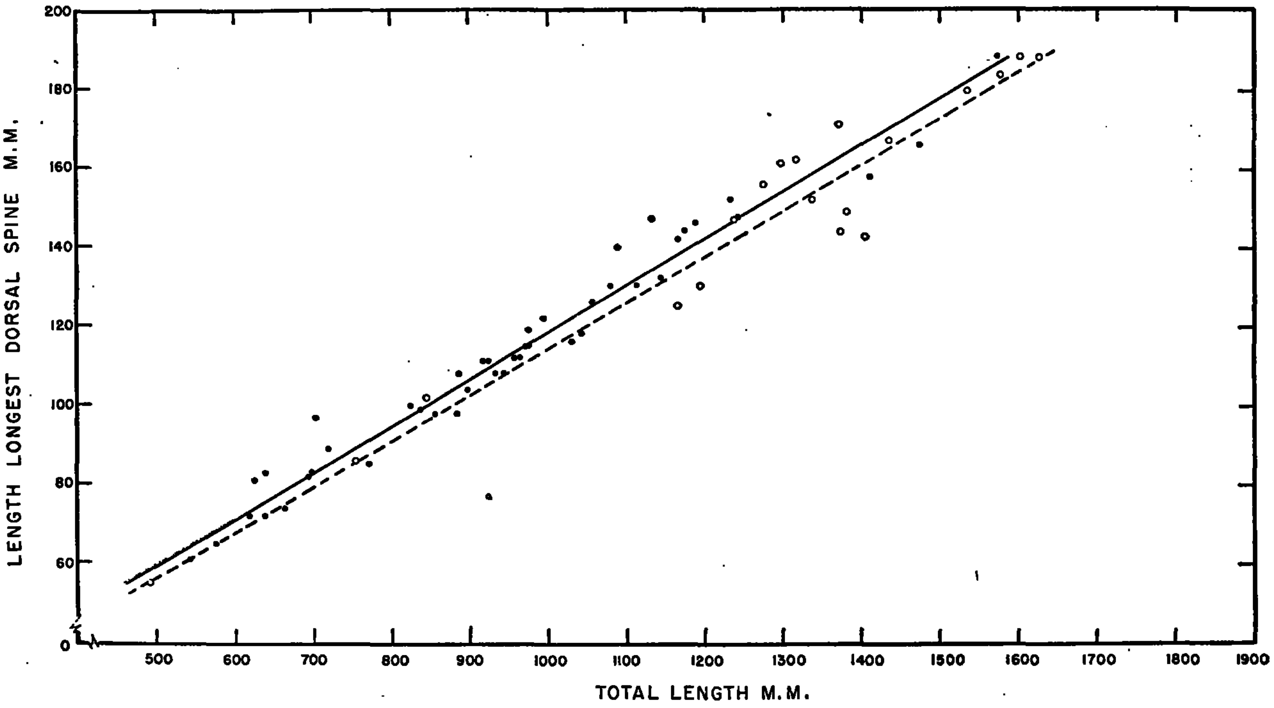

FIGURE 10.—Regressions of length of longest dorsal finlet on total length for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

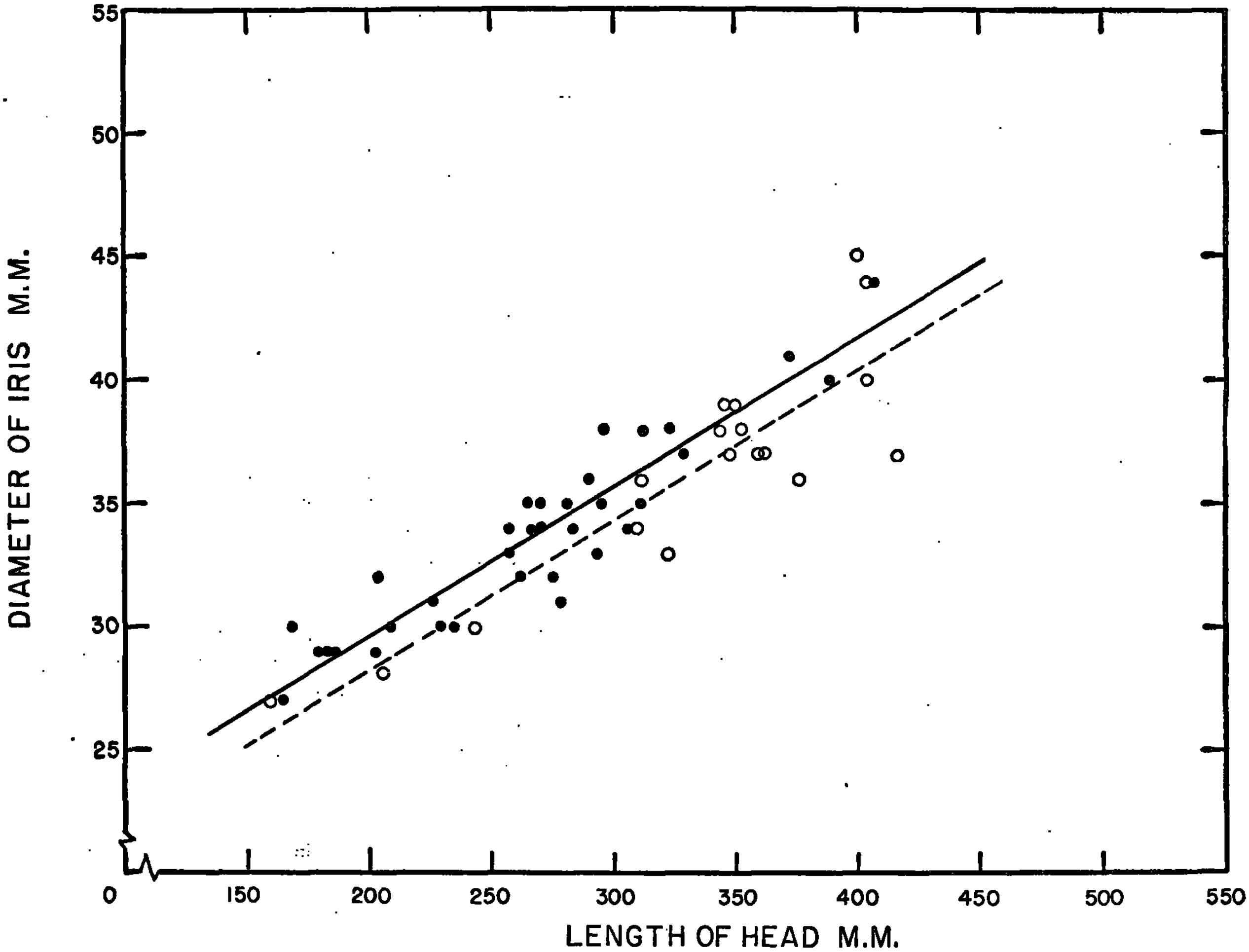

FIGURE 11.—Regressions of diameter of iris on length of head for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

a mean anal-finlet count of 9.33 for the Pacific specimens compared with 8.89 for the Atlantic. The difference between these means, 0.44, is associated with a probability, judged from the "t" distribution, just greater than one chance in a hundred and hence, probably significant. In view, however, of the difficulty of deciding between an attached finlet and the posterior ray of the anal fin, we hesitate to assert with certainty that the finlet counts are actually different for the two populations of tuna under consideration, the observed difference being possibly due to differences between observers rather than differences between the specimens observed.

COMPARISONS WITH DATA IN LITERATURE

Frade (1929) measured a series of 50 specimens from the Canary Islands and from the measurements computed various body-proportion ratios, which he calls "indices biométriques." For each such index he published the mean value and the extreme limits encountered among his data. The sizes of the fish measured are not given. In 1931 he published similar mean indices and observed limits for a sample of 100 fish from the Canaries, ranging in size from 99 cm. to 174 cm.

Four of Frade's indices are composed of dimensions that are nearly equivalent to dimensions measured by us. These are recapitulated in our table 3, together with the corresponding indices, computed from the regressions of our table 2, for the fish of mean length in our sample. We also give the "expected limits" of the index within the range of total lengths 990 mm. to 1740 mm. These "expected limits" are the ratios obtained by employing the y values of the regression equation corresponding to the x values 990 or 1740 mm. plus or minus 2.576 standard errors of estimate. For example, the regression of head length on total length (fig. 5) indicates that for the mean fish, which is 1114 mm. long, the head length is 297 mm., yielding a ratio of 3.75. At a total length of 990 mm. the average head length is 268 mm.; adding 2.576 standard errors of estimate (14.8), we obtain 282.8 giving a ratio of 3.50 as the minimum value expected. Similarly, at a total length of 1740 mm. the average head length is 439 mm.; subtracting 2.576 standard errors of estimate (14.8), we obtain 424.2 mm., yielding a ratio of 4.12 as the maximum expected value. The value 2.576 in these computations is the value of "t" corresponding to a probability level of one chance in a hundred. Thus, the expected limits in our table 3 are the values that would be expected to be exceeded less than one time in a hundred among any sample drawn from this size range, regardless of its size composition.

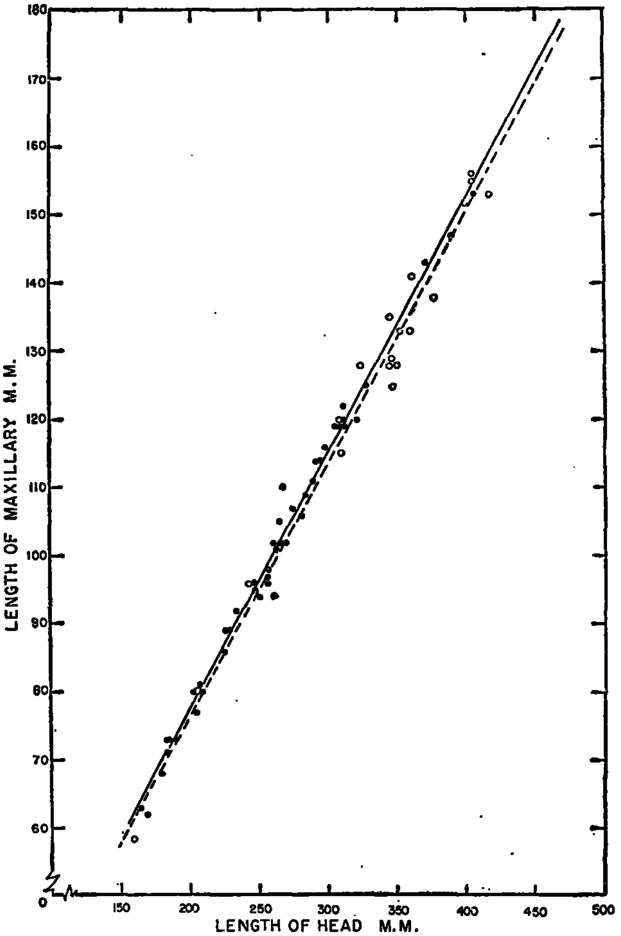

FIGURE 12.—Regressions of length of maxillary on length of head for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

Since our largest fish was 1626 mm. in total length, the computation of values corresponding to a total length of 1740 mm. represents a slight extrapolation of the regressions calculated from our data.

It may be seen from table 3 that the ranges of values of body-proportion indices encountered by Frade among yellowfin tunas from the Canary Islands are similar to those computed from our Angolan data. So far as these data go, the fish from the two localities may not be concluded to be morphometrically different. However, in view of the large ranges of values resulting from differential growth rates, as discussed previously, it would not be expected that any except very large differences would be detected by such indices. These data may illustrate the lack of precision of the statistics employed rather than the similarity of the morphology of the fish involved.

Frade also gives finlet counts for the specimens reported on in both 1929 and 1931. Nine finlets for both dorsal and anal series were most common. For his 1931 counts he reports a mean value of 9.06 with a probable error (.6745 standard errors) of 0.266 for the dorsal finlet counts and a mean value of 8.98 with a probable error of 0.285 for the ventral finlet counts. These values are not significantly different from the counts recorded for our Angolan specimens, but are very close to our mean values of 9.00 for dorsal finlets and 8.89 for anal finlets.

The lengths of second dorsal, anal, and pectoral fins of the one specimen, of 170 cm. from snout to fork of caudal, for which Frade (1929) gives the original measurements fall sufficiently close to the respective regression lines of our Angolan data to be well within the probable limits of random variation. At the

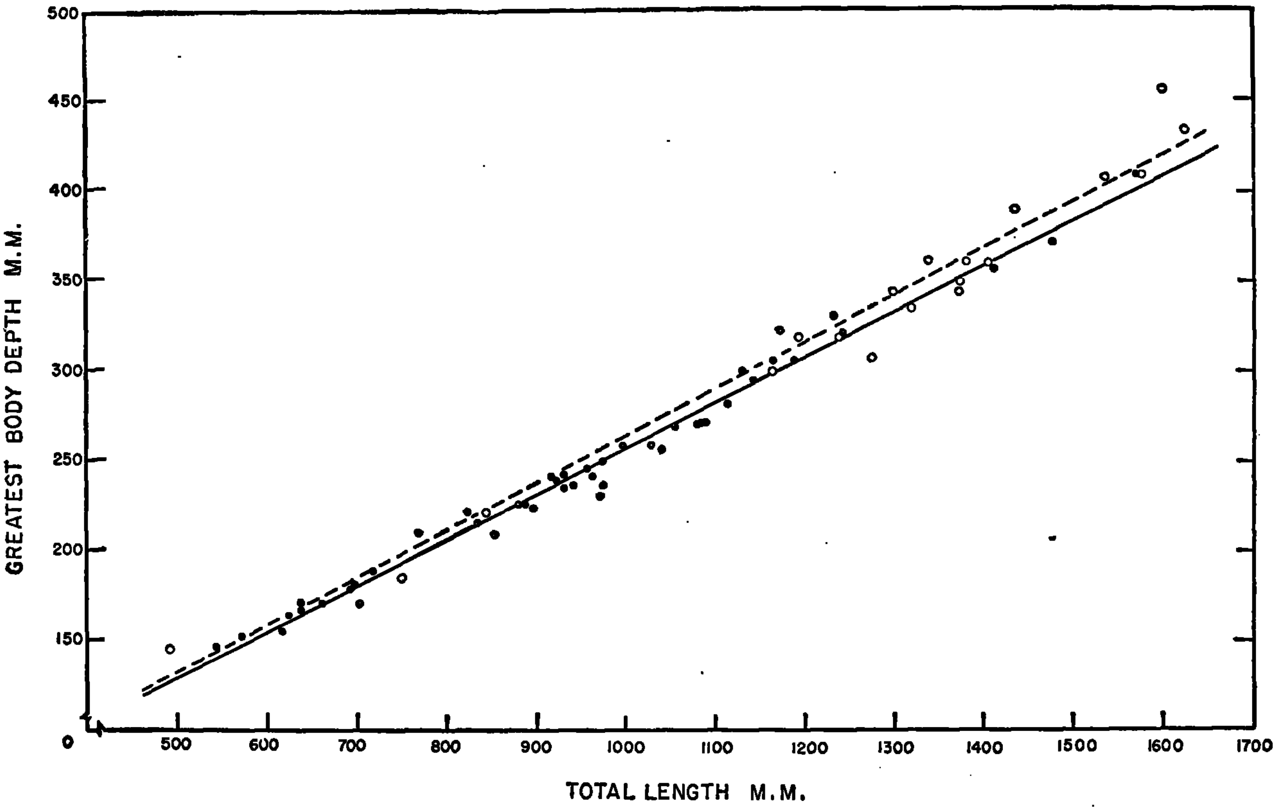

FIGURE 13.—Regressions of greatest body depth on total length for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

TABLE 3.—*Comparison of body proportion ratios of yellowfin tuna recorded by Frade from the Canary Islands with similar data from Angola*

Ratio	Frade's Index	Frade, 1929		Frade, 1931		Angolan regressions	
		Mean	Limits observed	Mean	Limits observed	Mean fish	Expected limits in range of total lengths 900 mm. to 1740 mm.
$\frac{\text{Total length}}{\text{Length of head}}$	Ti	3.83	3.57–4.07	3.86	3.50–4.20	3.75	3.50–4.12
$\frac{\text{Total length}}{\text{Length of pectoral}}$	Pl	4.03	3.57–4.72	4.08	3.45–4.65	3.62	3.19–4.60
$\frac{\text{Total length}}{\text{Snout to insertion first dorsal}}$	Di	3.54	3.15–3.95	3.52	3.10–4.00	3.45	3.18–3.82
$\frac{\text{Total length}}{\text{Snout to insertion second dorsal}}$	D'i	1.76	1.81–2.07	1.94	1.70–2.10	1.92	1.81–2.03

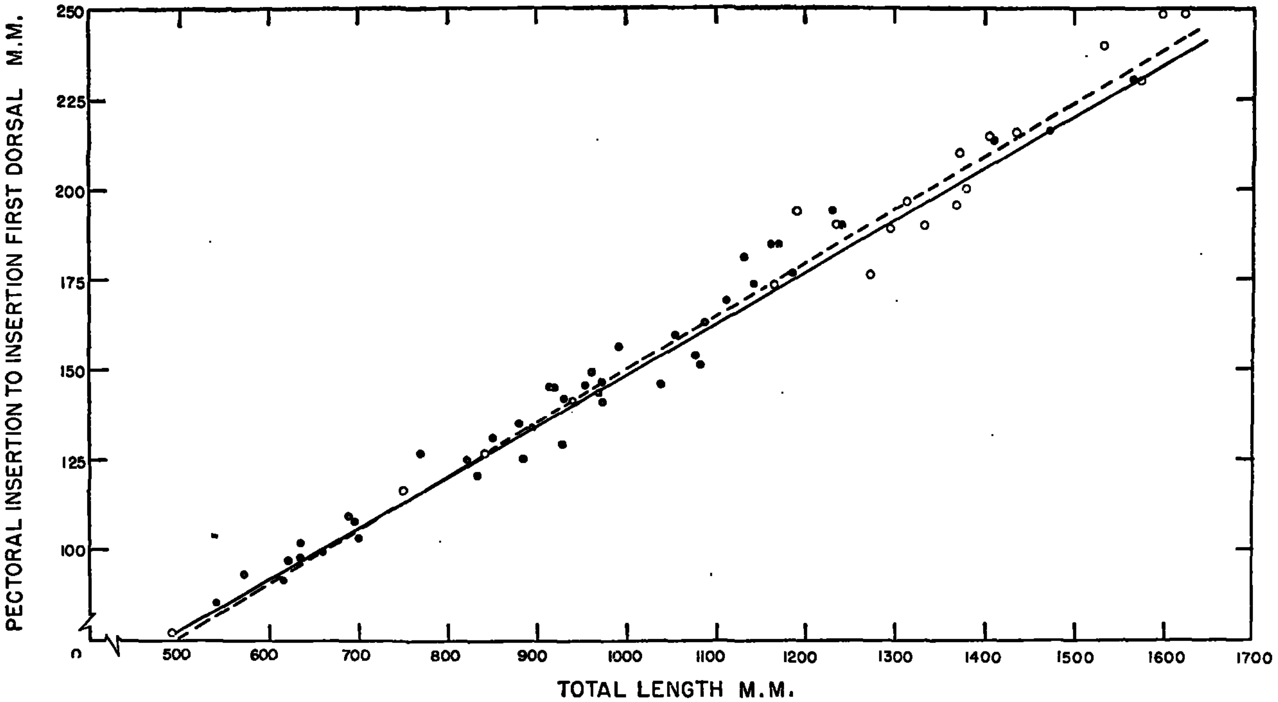

FIGURE 14.—Regressions of distance from insertion of pectoral fin to insertion of first dorsal fin on total length for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

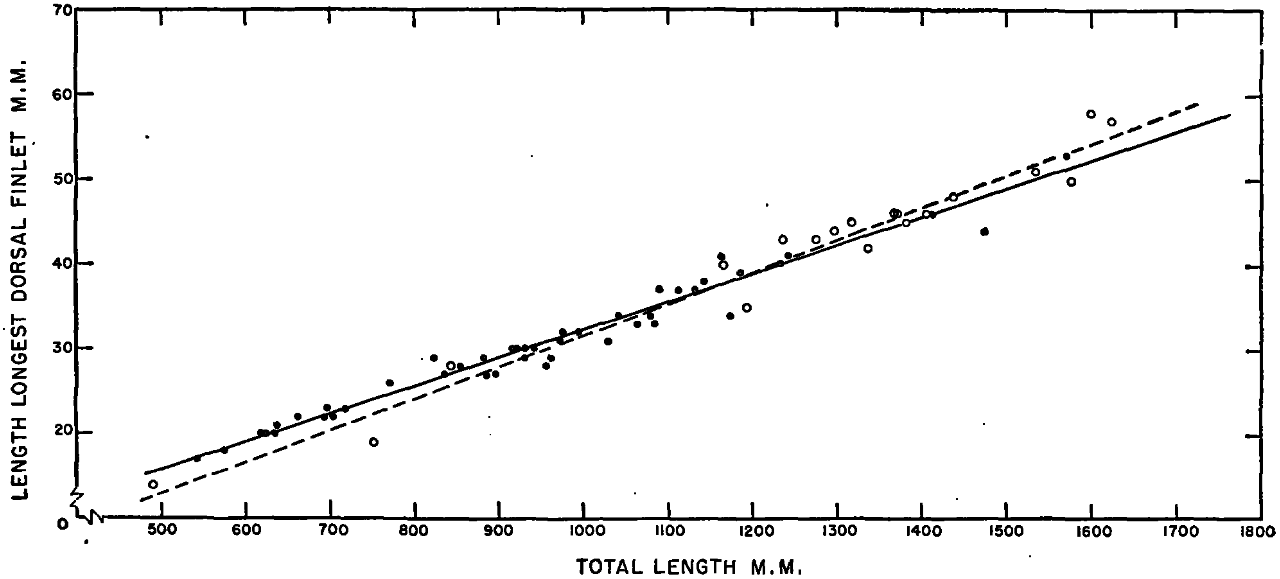

FIGURE 15.—Regressions of length of longest dorsal spine on total length for yellowfin tuna from the Atlantic Ocean off Angola (open circles and broken line) and for yellowfin tuna from the Pacific Ocean off Central America (solid circles and solid line).

same time the lengths both of the second dorsal and anal fins are sufficiently great to fall outside the values that would be expected to occur by chance deviation in one case in a hundred from the regression lines fitting the Pacific data studied by Schaefer (1948).

So far as these data go, the Canary Islands yellowfin appear to be similar to our Angolan yellowfin.

Nichols and LaMonte (1941) refer to a Portuguese specimen "about 5 feet" long having soft dorsal and anal fins contained "2.6 to 2.8 times in the length." For both fins this falls well within the expected limits of variation of our Atlantic material at this size.

From the western side of the Atlantic, Beebe and Tee-Van (1936) give on page 189 the lengths of second dorsal and anal fins of fish from the Carribean area in percent of standard length, together with the standard lengths of the specimens in question. Since their fish are recorded according to standard length, exact comparisons with our data are difficult. From their measurements of the 577 mm. specimen on page 191 it appears that at this size there is a difference of 22 mm. (4 percent) between the standard and total lengths. From Frade's data on a fish of 1700 mm. total length it appears that the correction factor at this size is about 9 percent. With or without the application of a correction factor for the difference between standard and total length, Beebe and Tee-Van's three smallest specimens (555, 645, and 690 mm. standard length) fall well within the limits of fin lengths expected from the regression lines and associated variances for our Angolan yellowfin. The 930-mm. specimen has a second dorsal fin a bit shorter than one would expect, but little weight can be given to this because the measurements were made from a photograph and are probably not very accurate. The 1220-mm. specimen also has second dorsal and anal fins falling within the expected range of our Angolan material, whether or not a 9-percent correction is added to the length as recorded by Beebe and Tee-Van. For the 1360- and 1450-mm. specimens, however, the converse is the case for length of anal fin. With or without a correction for standard length, both of these specimens have anal fins falling well outside the expected limits of variation of our Angolan material, even considering the fact that the variability increases with size of fish. The second dorsal fins of these two fish fall near the extreme upper limit of the expected variation about the regression line if a correction of 9 percent is added to the length recorded, and fall well outside the limit if such a correction is not applied. It appears that these specimens certainly had anal fins longer than would be expected on the basis of our Angolan sample and probably had second dorsals that were outside the expected range.

Nichols and LaMonte referring to "Allison's tuna" from St. Lucia state: "At about 4 feet 5 to 9 inches . . . the lobes are contained 2.1 to 2.8 times in standard length." These fin lengths are quite significantly longer than we would expect on the basis of our Angolan regressions and observed variances about them.

DISCUSSION

Beebe and Tee-Van (1936) synonymize *Thynnus albacora* (Lowe) 1839 with *Thynnus argentivittatus* (Cuvier and Valenciennes) 1831. Nichols and Murphy (1922) identified a photograph of a specimen from Peru as *argentivittatus*, and state that it agrees with Cuvier and Valenciennes' description and with a specimen in the Paris Museum labelled Malabar, Dussumier. On this basis Nichols and LaMonte (1941) disagree with Beebe and Tee-Van's use of *argentivittatus* for the Atlantic form, which they refer to *albacora*.

Examination of the description by Cuvier and Valenciennes reveals that they mention both a drawing by Quoy and Gaimard from the Atlantic and specimens collected from the Indian Ocean by Dussumier. We requested Dr. Leon Bertin of the Paris Museum to examine the material deposited there in order to determine which specimen should be designated the type of *argentivittatus*. He has kindly supplied the information that the specimens upon which Cuvier and Valenciennes' description of *Thynnus argentivittatus* is based are three in number:

> One specimen from the Atlantic, a drawing by Quoy and Gaimard. Collection of the Paris Museum No. A5572.
>
> One specimen from the Indian Ocean sent by Dussumier, preserved dry. Collection of the Paris Museum No. A5567.
>
> One specimen from the Indian Ocean, Coast of Malabar, sent by Dussumier. This specimen, Paris Museum No. A5816, is preserved in alcohol. According to Dr. Bertin, it corresponds to the description and numerical data given by Cuvier and Valenciennes and should be considered as the lectotype. It is hereby so designated.

It appears that the Indian Ocean yellowfin tuna should be called *Neothunnus argentivittatus* (Cuvier and Valenciennes) 1831, that from the Atlantic *Neothunnus albacora* (Lowe) 1839, and that from the Pacific *Neothunnus macropterus* (Temminck and Schlegel) 1842, until such time as it is determined whether or not the Indian Ocean form is identical with one of the other two, in which case *argentivittatus* would displace *albacora* or *macropterus*. There is the further question, of course, whether the Atlantic and Pacific forms should not be considered subspecies or varieties of a single species of cosmopolitan distribution. As noted below, we feel this question cannot be answered satisfactorily until more information is available regarding variability within oceans compared with variability between oceans.

The morphometric data presented in the foregoing study indicate that there are marked differences in relative growth rates of certain fins and body dimensions of yellowfin tuna from the Pacific off Central America and from the Atlantic off Angola. There seem also to be differences in average number of finlets and in the position of the longest dorsal finlet. There appears to be ample evidence that these two tuna populations are separate and distinct groups of fish which, at large sizes at least, can be distinguished readily by morphological characters. Whether the degree of difference is sufficient to warrant placing them in separate species, or whether they should be classed merely as subspecies or races of the same species will depend, however, upon further studies of the degree of variation encountered among populations within each ocean. Pending completion of such studies we place them in separate species, *Neothunnus albacora* (Lowe) 1839 for the Atlantic form and *N. macropterus* (Temminck and Schlegel) 1842 for the Pacific form.

Examination of published data on yellowfin tuna from other parts of the eastern Atlantic Ocean indicates that they are similar to our Angolan samples, and in some respects are dissimilar to the Pacific yellowfin tuna. The data, however, are not sufficiently complete or published in a satisfactory form for critical statistical comparisons. It is highly desirable that comparable measurements be made of representative series from other parts of the eastern Atlantic, and that either the original measurements or the regression statistics, or preferably both, be made available for comparison with our material.

Similarly, the few data available in the literature indicate that large yellowfin tuna from the western Atlantic may differ from those of the eastern Atlantic. The lengths of the second dorsal and anal fins of large specimens from the West Indies seem to be appreciably longer than would be expected on the basis of our Angolan material. Again, it is to be desired that representative series covering the entire range of sizes available be measured from various western-Atlantic localities, and that the data be made available in suitable form for critical statistical comparison with similar data from other parts of the world.

Schaefer (1948) found that the anal and second dorsal fins of the yellowfin tuna from the Pacific off Costa Rica grow much faster than the body of the fish, so that large individuals have fins relatively much longer than have small individuals. He found that the second dorsal and anal fin lengths are in proportion to the 1.69 and 1.83 powers, respectively, of the total length of the fish. Similarly, our data indicate that the Angolan yellowfin tuna possess second dorsal and anal fins with lengths in proportion to the 1.90 and 2.01 powers, respectively, of the total length, so that here also the large fish have enormously longer fins than do small fish (figs. 2 and 3). There is very great variability, however, in the lengths of these fins among fish of the same size. The standard deviations about the regression lines, converted from the logarithms in table 2, amount to 9.6 percent for the second dorsal fin and 11.4 percent for the anal fin, values similar to but slightly larger than those reported by Schaefer from Costa Rica. These values of standard deviation represent the average of the squared deviations from the regression lines. As may be seen from figures 2 and 3, however, the variability is not entirely evenly distributed, the variation at large sizes being greater than at small sizes even on a logarithmic scale. Because of the great range in fin length, particularly among large fish, it has been noted by various authors writing on *Neothunnus* that there exist at the same total length specimens with long fins and other specimens with short fins. Some authors have placed the long-finned and short-finned specimens in separate species or varieties (Jordan and Evermann 1926, Frade 1931, Nichols and LaMonte 1941), but where extensive series have been examined it has usually been concluded that the short-finned and long-finned varieties are merely extreme deviates of the same single population for a given locality (Herre 1936, Walford 1937, Schaefer 1948). Our data from Angola tend to confirm this view, although the occurrence, as described, of a single specimen with anal and second dorsal fins rather longer than might be expected to occur by chance from a single homogeneous population makes desirable further study of the matter, particularly in the western-Atlantic region where individuals with exceptionally long fins are reported to occur (Beebe and Tee-Van 1936) and from whence Allison's tuna (Mowbray 1920) was described.

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