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COMPARISON OF YELLOWFIN TUNA OF HAWAIIAN WATERS AND OF THE AMERICAN WEST COAST

BY MILNER B. SCHAEFER

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By MILNER B. SCHAEFER, *Fishery Research Biologist*

The yellowfin tuna of the vicinity of the Hawaiian Islands, like the form from the adjacent waters of the American west coast (Schaefer 1948), is here referred to *Neothunnus macropterus* (Temminck and Schlegel) 1842. As has been pointed out previously (Schaefer and Walford 1950), it is possible that the various Pacific forms, the form from the Indian Ocean, and perhaps also those from the Atlantic, should be considered a single species of world-wide distribution. The data presented herein support such a conclusion. This cannot be finally settled until populations from more places have been carefully studied, particularly a series from the Indian Ocean from which was described the specimen of *N. argentivittatus* (Cuvier and Valenciennes) 1831, which should be considered the type of this species.

It is also my opinion that the species now referred to the genera *Thunnus*, *Neothunnus*, *Parathunnus*, and *Kishinoella* should all be referred, as has been done by Fraser-Brunner (1950), to a single genus, *Thunnus*. However, since this paper is written to compare the yellowfin tuna from the vicinity of the Hawaiian Islands with the form from the waters adjacent to the American west coast in order to settle the question whether they are racially distinct, questions of taxonomy, synonymy, and nomenclature will be passed over at this time, and for convenience both forms will be referred to the commonly accepted name *N. macropterus*.

The yellowfin tuna is the object of an extensive and intensive fishery along the American west coast from California to the Galapagos Islands. In the Hawaiian Islands there exists a minor fishery that promises to be expanded in the near future to encompass other islands of the mid-Pacific and to increase in intensity in the presently exploited region. Whether the population of the Hawaiian region is part of the same stock of fish as that fished along the American west coast, or is an independent stock, is a question of considerable practical importance: if they are the same stock, the new fisheries would merely add to the strain on the stock already being exploited; if they are independent, there is being tapped an essentially virgin resource.

Schaefer (1948) has published measurement data and counts of denumerable characters on yellowfin tuna from the waters of the Pacific near Costa Rica. Godsil (1948) has published the measurements of a few selected dimensions taken from a very large number of specimens from several sampling localities, extending from the tip of lower California to Panama. Godsil and Byers (1944) have also published gill-raker counts of value to the present study. Those data and those presented herein from the Hawaiian Islands are directly comparable, having been taken in the same manner. Details of measurement methods are given in the papers cited and by Marr and Schaefer (1949). Measurements were made by several field assistants, but all followed identical procedures.

For this study, Hawaiian yellowfin tuna were measured during 1949, between February 21 and September 28. They were selected to give as even a representation as practicable of all sizes of fish available. All specimens were fresh and recently landed from commercial fishing vessels. Most specimens were measured at the Honolulu fresh-fish wholesale auction market, not only a very convenient place to work but almost ideal from a sampling standpoint.

The fish handled there are caught by flag-lines which, by the nature of their operation, sample the fish population very widely. Description of the fishery and the method of handling and marketing the fish will be found in June (1950). Smaller sizes of yellowfin tuna, under about 80 cm. in total length, are seldom taken by the flag-line fishery. These small fish are frequently taken by pole-and-line fishing, in the same manner as on the American west coast, incidental to fishing for skipjack (*Katsuwonus pelamis*). Specimens of the small sizes were mostly obtained, therefore, from landings at the local tuna cannery, where most of the skipjack catch is landed, particularly during the summer season of good catches. These fish are landed fresh soon after being caught, and are thus comparable to the specimens from the flag-line fishery. The original data on the 203 Hawaiian yellowfin tuna employed in this study are tabulated in table 1. All length measurements are in millimeters, taken as described by Marr and Schaefer (1949). Weights were taken in pounds, because at the auction market the fish were weighed by commercial scales graduated in pounds. Blanks in the table indicate that the measurement or count was not taken on the particular specimen. In addition, a few of the tabulated values were omitted from the analyses, because they were found to deviate more than three standard deviations from the appropriate regression line and seemed probably to be recording errors. These values were as follows:

	Rejected value
1670-mm. specimen, snout to insertion first dorsal	423
1780-mm. specimen, snout to insertion first dorsal	446
1780-mm. specimen, snout to insertion second dorsal	835
1464-mm. specimen, snout to insertion anal	767
1629-mm. specimen, body depth	454
1333-mm. specimen, longest dorsal finlet	34
1259-mm. specimen, length first dorsal spine	97
1397-mm. specimen, length first dorsal spine	129
969-mm. specimen, diameter of iris	26
1605-mm. specimen, diameter of iris	52

Many of the routine computations involved in the analysis of the Hawaiian data, reanalysis of American-west-coast data, and comparison of the two, were performed by Dorothy Dung, whose assistance is gratefully acknowledged.

ON THE SELECTION OF REGRESSION EQUATIONS

It is characteristic of many animals—perhaps of all—that the various parts of the body grow at different rates, so that as the organism increases in size the ratio of one dimension to another changes. For yellowfin tuna this has been demonstrated by Godsil (1948), Schaefer (1948), and Schaefer and Walford (1950). Since this is the case, one cannot use the measurement ratios normally employed in systematic ichthyology for comparing samples of tunas from different places, except in the trivial case where the fish from the two places are of exactly the same size, because differences connected with size could be confused with differences in form of fish of the same size.

In order to avoid this difficulty, the authors of the papers cited above have based their comparisons of samples on the comparison of the regression of one dimension on that of another (usually total length), taken as a measurement of over-all size. This procedure is also employed in the present paper. It may be noted that the efficiency of sampling may be much improved over simple random sampling in such circumstances by selecting the specimens according to total length (the independent variate) to give an even representation of all sizes available so far as is practical; such a sampling scheme was employed in obtaining the data for table 1.

The comparison of body form among fish populations by comparison of regressions would be a simple and straightforward process if the relations between the body dimensions corresponded exactly to the straight lines or simple curves that must be employed in such analyses. Unfortunately, they do not and this may lead to some confusion in the analysis, particularly in situations where one is dealing with small differences and large numbers of specimens. Over restricted ranges of sizes at least, the dimensions of some body parts relative to others seem to be sufficiently well approximated by straight lines (Schaefer 1948, Schaefer and Walford 1950). Large samples of the same size range of the same populations may reveal, however, that regression curves of slight curvilinearity give a better fit to the data, as Godsil (1948) has found for certain dimensions of the American-west-coast yellowfin.

In other cases, such as the fin lengths of yellowfin tuna, the regressions are very strongly curvilinear but may, in some cases at least, be transformed by the allometry equation or other transformation to a linear or nearly linear relation, as has been done in my papers above cited. Whatever the equation employed, however, it is necessary to bear in mind two things. First, the relation employed in the analysis (the mathematical model of the true relation between variables), be it linear or otherwise, is only an approximation to the true relation and as such does not completely eliminate the effect of size of organism on the character being compared. Second, there sometimes occur rather marked changes in growth rate of one part relative to another at certain sizes, so that a regression which over a considerable range may be represented by a particular equation may not be so represented at all when the range is slightly extended. Indeed, as has been shown by Martin (1949), there seem to be sharp inflection points in the relative-growth curves of several fish species. The avoidance of misleading conclusions demands that these matters be kept in mind in analyses of morphometric data.

TABLE 1.—*Morphometric measurements and counts for Yellowfin tuna* (Neothunnus macropterus) *from the Hawaiian Islands Feb. 21–Sept. 28, 1949*

Total length	Weight	Head length	Snout to insertion first dorsal	Snout to insertion second dorsal	Snout to insertion anal	Snout to insertion ventral	Greatest depth	Taken at dorsal spine No. —	Length pectoral fin	Length first dorsal (first spine)	Length second dorsal	Length anal	Length longest dorsal finlet	Longest dorsal, No. —	Diameter of iris	Length of maxillary	Number of spines first dorsal	Number of dorsal finlets	Number of anal finlets	Number of gill rakers	Sex
	Lb.	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*		*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*		*Mm.*	*Mm.*					
451 mm	4.0	128	143	249	272	145	114	7	125	53	50	44	14	5	23	50	14	8+0	8+0	10+20	M
457 mm	4.25	130	148	255	281	146	127	7	134	—	48	38	17	6	25	52	13	8+1	8+0	10+20	F
466 mm	4.5	135	152	263	292	153	125	6	132	54	50	49	15	5	24	55	14	8+2	8+1	10+21	F
466 mm	4.5	137	152	266	294	153	128	7	138	54	54	47	16	6	25	53	14	7+2	7+2	9+20	M
466 mm	5.0	132	153	267	284	148	132	7	130	—	55	49	17	6	25	53	—	8+2	8+2	9+22	M
472 mm	5.0	132	148	265	287	153	130	7	143	56	56	—	16	6	23	55	14	8+2	8+1	9+22	F
476 mm	4.5	136	153	265	295	154	128	6	140	—	53	53	19	6	26	55	13	7+2	7+1	9+20	M
477 mm	4.5	137	156	266	285	153	124	7	135	58	52	52	16	6	25	56	13	7+1	8+0	—	—
477 mm	4.75	138	156	264	290	154	123	7	131	—	55	49	16	5	25	55	—	8+1	8+0	10+20	M(?)
488 mm	5.25	135	158	274	302	157	129	9	149	57	59	54	17	6	24	55	14	8+1	8+0	10+20	M
488 mm	5.5	137	155	269	296	156	132	6	147	—	59	53	16	6	24	54	14	8+0	8+0	10+20	F
493 mm	5.0	142	151	259	302	177	123	8	142	56	56	56	16	5	26	57	13	8+1	8+0	10+21	—
493 mm	5.25	140	154	269	301	157	126	9	146	58	61	60	17	5	26	56	14	8+1	8+1	10+22	M
496 mm	6.0	145	160	274	305	166	133	8	148	57	63	58	16	6	25	57	14	8+1	7+1	10+20	M
497 mm	5.5	138	159	276	303	158	139	7	149	—	58	46	17	5	25	56	13	8+1	8+1	9+22	M
498 mm	5.25	140	161	276	302	161	125	6	151	59	59	52	16	6	26	57	14	8+0	8+1	10+20	F(?)
500 mm	5.0	141	155	274	298	158	125	7	149	56	62	59	18	6	25	57	13	8+1	8+0	9+20	—
501 mm	6.0	142	163	275	307	163	143	6	144	62	52	54	17	6	27	57	12	8+1	8+1	9+20	M
502 mm	5.5	142	163	278	306	158	136	6	152	58	—	51	18	6	25	58	13	8+1	7+2	9+22	M
509 mm	5.0	142	164	277	306	162	132	7	151	59	66	65	19	5	26	58	13	7+2	7+2	9+20	M
509 mm	6.0	146	165	281	309	166	130	10	154	60	66	60	19	5	26	60	13	7+1	7+2	10+21	M(?)
509 mm	6.0	146	165	280	303	159	133	7	145	59	62	62	19	6	27	58	13	8+1	8+0	10+22	M
510 mm	6.0	146	157	283	310	171	128	6	136	62	55	53	20	6	26	60	13	8+1	8+1	—	—
510 mm	6.5	148	168	292	322	170	133	7	154	62	69	65	20	6	27	59	14	7+2	7+1	9+20	M(?)
511 mm	5.5	145	167	282	317	164	135	10	149	58	68	60	17	5	26	58	14	7+2	7+1	9+21	M
525 mm	6.0	145	166	287	311	168	125	8	152	57	—	—	19	5	27	58	14	7+1	7+2	8+21	M
528 mm	6.0	145	168	293	315	168	131	9	145	58	68	65	18	6	25	59	13	8+0	7+1	10+21	—
530 mm	6.0	153	171	294	325	167	133	8	141	60	63	61	18	6	25	58	13	8+0	8+0	9+21	M
530 mm	6.5	154	166	290	319	173	136	9	141	60	68	62	19	6	26	62	14	8+2	8+2	9+20	—
533 mm	6.5	150	166	289	319	171	135	8	156	63	68	61	18	6	26	58	14	8+1	7+1	10+19	M(?)
534 mm	7.5	153	173	302	328	172	144	9	152	—	—	60	18	5	27	60	14	8+1	7+2	8+22	M
625 mm	10	174	189	342	375	196	155	6	191	74	68	72	20	7	30	59	14	8+1	8+1	10+20	F
656 mm	12	180	204	357	393	206	166	8	188	73	83	84	21	6	27	72	13	8+0	8+0	10+20	—
681 mm	—	196	215	377	415	226	172	7	216	84	98	105	—	—	30	81	14	8+1	8+1	—	F
727 mm	16	205	237	396	423	230	184	8	221	78	104	101	28	4	29	78	13	7+1	7+1	10+22	—
755 mm	18.5	207	237	408	452	229	192	8	220	88	113	117	25	6	31	84	13	8+1	8+1	—	—
867 mm	22.0	237	256	456	500	266	205	7	279	101	169	184	28	6	33	92	14	8+1	7+2	9+22	—
882 mm	31.5	228	254	456	500	251	237	9	254	96	149	159	28	6	33	90	14	8+1	8+1	8+21	—
885 mm	31.0	238	272	478	521	271	234	6	258	97	143	142	27	5	33	92	13	7+2	7+2	9+22	—
888 mm	30.0	246	269	475	525	273	232	7	254	107	166	179	34	6	33	98	13	8+1	8+1	9+21	—
912 mm	34	244	275	477	526	274	244	7	265	108	161	171	32	6	34	95	14	8+1	8+1	9+22	—
934 mm	34	260	288	494	551	289	237	7	264	93	139	145	30	5	32	99	14	7+1	7+1	8+21	—
934 mm	35	251	283	497	548	287	241	8	264	102	157	166	29	5	36	101	14	8+1	8+0	8+20	—
940 mm	34.5	247	282	504	550	278	246	7	283	—	160	196	—	—	—	99	14	8+1	8+1	—	—
940 mm	39	259	280	492	559	292	238	—	270	—	157	150	—	—	—	101	—	8+1	8+1	—	—
958 mm	33.5	258	280	497	537	289	231	7	293	113	195	217	38	5	34	101	14	8+1	8+1	10+21	F
969 mm	40.0	255	287	509	557	281	251	7	272	100	143	151	26	6	26	100	13	8+1	8+1	10+21	—
973 mm	39.5	257	291	509	556	280	243	8	278	97	166	184	35	6	34	100	14	8+1	8+1	8+21	—
991 mm	41	260	299	525	575	286	258	8	274	110	156	168	34	6	33	98	14	8+1	7+2	10+20	—
1,004 mm	44	266	302	521	567	279	234	4	303	112	192	201	38	6	35	101	14	8+1	8+1	8+20	M
1,007 mm	46.5	261	289	521	588	298	265	8	285	—	187	217	—	—	—	104	14	8+1	8+1	—	—
1,008 mm	39.5	270	301	523	574	302	240	7	313	110	186	207	36	6	35	105	13	8+1	7+1	10+22	F
1,012 mm	46	272	296	524	597	306	268	7	274	109	190	177	36	6	33	103	13	7+2	7+2	9+20	—
1,016 mm	38	269	278	517	576	304	245	8	258	109	183	192	36	6	33	104	14	8+1	8+1	10+20	—
1,016 mm	43	262	281	530	583	300	258	7	298	117	197	211	36	5	34	104	13	7+2	7+2	9+20	F
1,023 mm	43	262	290	512	592	302	249	9	300	118	190	212	37	7	33	98	14	8+1	7+2	9+22	—
1,043 mm	49	268	309	538	593	305	257	7	315	111	202	209	38	6	33	102	13	8+1	8+1	9+21	—
1,045 mm	46	268	307	545	593	303	269	7	322	112	199	215	39	5	32	105	14	8+1	7+2	10+21	M
1,064 mm	52	277	307	546	605	315	271	9	306	107	205	218	37	6	32	105	14	7+2	8+1	8+22	—
1,077 mm	49	282	314	570	622	322	267	7	309	127	229	232	40	7	35	108	13	8+1	8+1	10+20	—
1,081 mm	48	290	320	556	626	323	263	7	283	119	183	185	39	6	36	109	14	8+1	8+0	10+21	—
1,086 mm	53	285	314	561	617	321	273	8	294	124	196	198	36	6	34	108	13	8+0	8+1	8+22	—
1,090 mm	50	293	329	566	621	333	269	5	286	115	170	180	37	6	35	109	13	8+1	8+1	9+22	—
1,090 mm	51	286	316	557	606	325	269	8	319	126	205	246	39	6	36	111	13	8+1	8+1	9+21	—
1,132 mm	58	288	322	580	636	319	293	7	323	—	210	236	43	6	36	110	14	8+1	8+1	9+21	—
1,134 mm	60	285	330	591	639	315	295	8	311	114	206	340	34	6	35	110	14	8+1	8+1	9+20	—
1,142 mm	63	304	342	596	651	340	289	9	310	121	231	248	41	6	35	115	14	8+1	8+1	8+20	—
1,170 mm	66	311	336	596	677	349	292	9	305	119	204	210	40	7	34	117	14	8+1	8+0	9+21	—
1,172 mm	66	292	330	591	661	325	291	9	332	128	322	336	44	6	37	111	14	8+1	8+1	9+21	—
1,179 mm	70	301	323	503	657	340	295	9	350	118	249	262	40	5	34	117	14	8+2	8+1	9+21	—

TABLE 1.—*Morphometric measurements and counts for Yellowfin tuna* (Neothunnus macropterus) *from the Hawaiian Islands Feb. 21–Sept. 28, 1949*—Continued

Total length	Weight	Head length	Snout to insertion first dorsal	Snout to insertion second dorsal	Snout to insertion anal	Snout to insertion ventral	Greatest depth	Taken at dorsal spine No. —	Length pectoral fin	Length first dorsal (first spine)	Length second dorsal	Length anal	Length longest dorsal finlet	Longest dorsal, No. —	Diameter of iris	Length of maxillary	Number of spines first dorsal	Number of dorsal finlets	Number of anal finlets	Number of gill rakers	Sex
	Lb.	Mm.	Mm.	Mm.	Mm.	Mm.	Mm.		Mm.	Mm.	Mm.	Mm.	Mm.		Mm.	Mm.					
1,206 mm	75	309	342	605	685	346	299	9	336	133	278	315	43	6	38	122	13	8+1	8+1	7+19	—
1,217 mm	76	313	346	621	693	358	305	7	370	146	305	327	45	5	37	117	14	8+1	8+1	9+20	—
1,238 mm	75	310	348	621	694	351	300	9	342	136	359	267	43	6	37	120	14	8+1	8+1	8+20	—
1,238 mm	80	311	342	624	703	352	303	10	341	134	280	303	44	6	37	118	13	8+1	8+1	9+21	—
1,239 mm	84	307	343	615	681	339	316	9	344	131	274	294	44	7	37	118	14	8+1	8+1	8+21	—
1,240 mm	78	317	351	629	702	355	297	7	341	131	276	293	45	6	33	121	13	8+1	8+1	8+19	—
1,255 mm	86	314	357	645	700	357	319	9	336	142	276	310	42	6	38	124	13	8+1	8+1	9+20	—
1,256 mm	86	324	356	650	720	370	320	8	375	136	278	306	42	5	37	129	14	8+1	8+1	9+21	M
1,258 mm	88	314	356	629	689	351	310	7	343	149	284	355	45	5	39	126	13	8+1	8+1	9+20	—
1,259 mm	82	317	358	632	702	358	303	9	349	97	348	363	51	7	38	124	13	8+2	8+1	10+22	—
1,278 mm	85	311	343	629	702	346	313	10	349	143	298	311	46	5	39	115	13	8+1	8+1	9+20	—
1,287 mm	86	313	353	648	720	357	309	7	348	141	331	377	45	5	40	124	14	8+1	8+1	9+22	F
1,288 mm	88	318	359	645	716	365	309	10	359	142	351	398	46	6	38	121	14	8+1	8+1	9+21	—
1,289 mm	88	328	376	645	729	365	325	10	337	134	320	332	49	5	38	129	14	8+1	8+1	9+21	—
1,297 mm	85	330	363	659	723	372	325	7	354	145	270	337	45	6	37	131	14	8+1	8+1	9+21	F
1,297 mm	90	324	358	643	706	366	313	9	353	141	337	387	50	5	38	125	13	8+1	8+1	9+21	—
1,299 mm	85	323	353	648	716	363	304	9	365	132	358	382	44	6	39	125	14	7+2	8+1	10+21	—
1,313 mm	98	330	361	657	741	366	318	8	369	149	367	370	47	4	39	129	13	8+1	7+1	9+21	—
1,323 mm	96	329	369	668	752	377	321	8	340	139	354	387	46	6	37	127	13	8+2	7+2	9+20	F
1,323 mm	97	329	357	655	730	371	327	6	367	148	397	458	53	5	40	127	13	7+2	7+2	9+21	—
1,323 mm	101	340	360	662	746	396	335	11	336	151	359	372	44	5	38	128	14	8+1	8+1	9+22	—
1,325 mm	99	333	364	676	740	374	325	7	338	137	307	335	50	6	37	131	13	8+1	8+1	......	......
1,327 mm	104	342	377	679	737	381	337	7	367	162	306	323	46	6	38	135	13	8+2	8+1	......	......
1,330 mm	100	335	363	670	757	381	330	8	354	162	385	437	51	6	40	126	14	7+2	7+1	9+20	......
1,331 mm	99	331	372	668	732	373	342	9	378	152	305	342	47	6	38	128	14	8+1	8+1	9+21	......
1,332 mm	93	327	362	661	733	365	306	9	366	146	318	385	47	5	40	128	13	8+2	8+1	10+21	......
1,333 mm	98	336	369	665	746	376	316	6	345	135	275	289	34	5	35	126	14	7+2	7+2	......	......
1,337 mm	95	338	379	670	734	375	326	9	349	148	344	365	46	6	39	131	14	8+2	8+1	8+21	......
1,339 mm	92	324	366	669	741	364	307	7	355	142	317	354	40	6	36	128	13	8+1	8+0	9+20	F
1,339 mm	100	330	367	652	742	366	312	11	355	153	386	388	54	7	40	131	13	8+2	8+1	8+21	M
1,344 mm	99	334	367	667	752	375	312	9	367	131	327	342	49	4	38	130	14	8+1	7+2	8+21	......
1,352 mm	112	333	368	668	751	372	348	10	363	145	406	425	54	5	39	132	13	7+2	7+2	9+21	......
1,353 mm	93	337	375	671	752	378	329	9	335	146	349	450	46	5	40	127	13	7+2	7+2	9+20	......
1,358 mm	108	333	381	689	775	384	350	7	368	157	363	364	45	5	40	132	14	8+0	8+1	9+20	......
1,359 mm	120	335	367	673	747	378	361	7	372	145	350	374	53	6	40	135	14	8+1	8+1	9+21	M
1,371 mm	99	337	376	692	762	380	319	9	353	......	337	348	42	5	38	129	13	8+2	8+1	......	F
1,371 mm	114	344	378	695	779	405	353	10	356	164	244	334	49	5	37	133	13	8+1	8+1	9+21	F
1,378 mm	110	345	387	694	759	379	347	9	361	155	323	351	52	5	39	134	13	8+1	8+1	9+19	M
1,380 mm	107	342	382	686	755	392	337	6	341	147	377	409	50	6	39	129	13	8+2	8+1	9+21	F
1,385 mm	121	348	377	711	792	393	354	8	370	175	336	401	50	6	41	136	14	8+1	8+0	10+21	......
1,391 mm	110	346	389	698	772	396	346	7	380	139	371	395	50	4	38	134	13	8+1	8+1	10+21	F
1,391 mm	112	346	403	706	781	395	339	8	342	147	304	319	51	6	38	132	13	7+2	8+1	10+21	......
1,396 mm	113	336	372	685	776	379	345	10	360	138	404	447	56	7	39	127	14	8+1	8+1	9+20	F
1,397 mm	123	349	401	706	792	400	365	9	361	129	345	352	48	5	37	134	13	8+2	8+1	9+22	M
1,397 mm	124	354	391	707	777	395	364	8	350	107	308	367	57	6	41	139	13	8+1	8+1	9+20	M
1,390 mm	116	340	371	700	780	382	341	8	341	151	383	420	54	5	39	132	14	8+1	8+1	9+21	F
1,405 mm	116	346	394	709	783	397	344	8	350	156	406	459	51	6	39	137	14	8+1	7+1	8+21	......
1,409 mm	136	346	397	713	788	391	371	10	362	157	470	495	54	6	41	135	13	8+2	8+1	9+20	M
1,413 mm	116	346	396	712	786	394	346	9	368	158	428	506	50	5	40	136	13	8+2	8+1	9+20	F
1,423 mm	128	356	405	715	798	401	357	8	358	161	467	532	51	6	40	142	13	8+2	8+1	8+19	—
1,429 mm	128	352	396	719	785	394	353	11	359	155	309	363	44	5	39	135	13	8+1	8+1	10+20	F
1,429 mm	133	355	388	705	796	401	363	9	355	162	417	500	45	5	41	141	......	7+2	8+1	8+21	—
1,431 mm	122	362	403	724	799	414	362	7	367	151	341	360	50	5	38	131	14	8+2	8+1	10+21	M
1,435 mm	133	360	403	720	816	407	371	7	391	173	466	487	52	6	41	145	13	9+1	8+1	......	......
1,437 mm	122	351	389	703	794	393	346	9	377	168	462	505	54	5	42	131	13	8+1	8+1	10+21	......
1,438 mm	117	362	397	732	804	412	338	11	381	174	418	427	49	6	39	138	14	8+2	7+1	......	......
1,441 mm	123	355	399	726	811	404	350	10	350	155	380	490	51	4	39	143	13	7+2	8+1	11+21	F
1,441 mm	131	352	392	702	776	392	369	8	382	157	512	541	58	6	41	137	13	8+1	8+1	10+20	......
1,444 mm	126	351	402	729	794	391	350	6	368	171	406	460	44	6	40	136	13	8+2	8+1	9+22	......
1,455 mm	131	359	407	741	805	409	358	......	376	169	405	443	51	6	38	141	......	8+2	8+2	9+20	......
1,457 mm	133	353	394	750	807	398	367	6	351	148	303	363	58	6	39	137	14	8+1	8+1	9+21	......
1,464 mm	123	347	385	696	767	400	371	9	376	145	465	561	50	6	41	139	14	9+1	9+1	......	M
1,465 mm	125	374	402	726	822	423	350	7	368	173	335	365	51	6	43	141	13	8+1	8+1	9+20	F
1,466 mm	136	361	403	750	816	408	369	7	342	183	432	521	51	5	40	140	14	8+2	8+1	9+21	M
1,474 mm	135	366	404	733	799	408	379	8	362	167	372	512	59	6	42	142	13	8+2	8+1	9+22	M
1,480 mm	148	376	412	750	837	421	388	9	386	177	452	503	55	6	42	149	13	7+1	8+1	9+20	M
1,486 mm	134	364	409	739	835	413	365	7	377	169	442	520	52	5	40	149	14	8+2	8+2	10+22	F
1,488 mm	143	367	395	726	825	428	375	8	372	165	569	645	65	7	43	143	14	8+2	8+1	8+20	F
1,506 mm	135	368	422	760	851	413	383	10	389	175	430	466	49	4	40	147	13	8+1	8+1	8+22	F
1,514 mm	163	369	423	764	826	415	412	8	394	158	466	493	63	5	41	144	13	8+2	8+1	9+20	......
1,517 mm	139	386	416	748	836	437	373	6	375	176	587	687	56	5	44	144	14	8+1	7+2	9+20	M
1,518 mm	155	372	404	742	859	417	386	10	370	169	417	464	55	5	39	145	13	8+1	8+1	8+21	M
1,520 mm	158	366	414	756	830	412	386	10	390	169	521	557	57	6	42	144	13	8+1	8+1	10+20	......
1,521 mm	146	372	400	742	832	421	377	9	377	178	517	580	54	5	42	143	14	8+1	8+1	9+21	......
1,534 mm	162	378	421	761	833	422	403	11	396	......	605	665	60	4	45	144	13	8+2	8+1	9+20	......
1,548 mm	157	397	432	777	858	441	409	7	380	177	465	465	53	5	43	152	14	8+2	8+1	9+23	M
1,550 mm	177	383	420	769	852	430	416	9	379	188	540	527	57	6	44	148	13	8+2	8+1	8+19	M
1,556 mm	180	385	428	804	879	440	412	9	392	175	566	617	58	4	45	152	13	8+2	8+1	8+19	—
1,564 mm	153	404	439	798	885	452	388	8	376	193	548	650	58	7	44	157	13	8+2	8+2	9+20	M
1,579 mm	169	398	435	779	880	459	399	8	368	164	382	424	53	6	44	149	13	8+1	8+1	11+21	M
1,581 mm	179	387	434	783	888	441	400	8	381	162	437	481	56	5	40	148	13	8+2	8+2	9+20	M
1,582 mm	166	389	443	789	881	437	392	6	397	187	647	803	61	6	45	156	13	7+1	7+2	......	—
1,584 mm	182	392	430	789	864	440	421	7	382	169	502	570	55	7	42	150	14	8+2	8+1	10+21	M
1,604 mm	201	394	431	806	884	447	430	11	394	190	560	668	63	6	43	152	13	8+2	8+1	9+21	......
1,605 mm	202	396	446	782	892	444	425	10	387	152	372	556	60	6	52	151	13	8+2	8+1	10+20	M

TABLE 1.—*Morphometric measurements and counts for Yellowfin tuna* (Neothunnus macropterus) *from the Hawaiian Islands Feb. 21–Sept. 28, 1949*—Continued

Total length	Weight	Head length	Snout to insertion first dorsal	Snout to insertion second dorsal	Snout to insertion anal	Snout to insertion ventral	Greatest depth	Taken at dorsal spine No. —	Length pectoral fin	Length first dorsal (first spine)	Length second dorsal	Length anal	Length longest dorsal finlet	Longest dorsal, No. —	Diameter of iris	Length of maxillary	Number of spines first dorsal	Number of dorsal finlets	Number of anal finlets	Number of gill rakers	Sex
	Lb.	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*		*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*		*Mm.*	*Mm.*					
1,611 mm	163	393	432	796	883	445	393	7	368	184	390	664	62	6	45	156	14	8+1	8+1	9+21	------
1,614 mm	201	399	445	811	877	440	440	8	400	184	567	627	65	5	44	153	14	8+1	8+1	9+21	M
1,621 mm	176	405	430	785	902	452	408	9	380	192	438	495	63	6	44	157	14	8+2	8+1	9+21	M
1,620 mm	212	415	447	822	907	457	427	10	400	185	453	700	63	5	45	158	13	8+1	8+1	9+18	M
1,629 mm	220	411	455	829	905	457	454	7	422	165	614	672	62	5	42	151	13	8+2	8+1	9+20	M
1,631 mm	201	412	459	810	901	468	437	10	396	203	554	592	70	5	45	156	13	8+1	8+1	8+21	M
1,635 mm	211	403	470	811	895	457	452	9	390	195	651	745	63	7	45	154	13	8+1	8+1	10+20	M
1,636 mm	209	399	447	813	890	442	443	7	401	195	603	582	64	6	43	153	13	8+1	8+1	9+19	M
1,638 mm	172	401	442	810	901	451	389	11	417	194	586	702	60	5	45	152	14	7+2	7+2	10+21	------
1,639 mm	200	404	454	812	889	448	432	8	440	179	540	603	66	6	45	150	13	8+2	8+1	8+20	M
1,640 mm	192	403	444	813	890	442	427	9	370	206	760	850	67	6	48	153	14	8+1	8+1	8+20	M
1,641 mm	206	402	442	809	896	450	438	10	408	189	564	644	61	4	44	157	14	7+2	7+2	9+17	M
1,642 mm	195	403	445	797	910	451	426	10	406	192	604	615	62	6	44	154	13	8+1	8+1	9+20	------
1,643 mm	200	404	441	822	915	453	432	11	390	184	490	510	63	7	42	156	14	8+2	8+0	8+21	------
1,648 mm	209	408	448	808	919	449	445	8	440	180	624	720	69	6	44	161	13	8+2	8+1	8+21	M
1,654 mm	201	408	458	820	913	454	427	9	394	196	703	725	64	5	45	153	13	8+1	8+1	9+21	M
1,659 mm	201	401	444	818	903	449	428	8	383	181	639	716	63	6	46	------	13	8+2	8+1	8+21	M
1,660 mm	204	404	447	827	907	453	429	7	415	200	654	620	63	6	45	159	13	8+2	8+1	9+19	M
1,662 mm	208	409	446	814	916	460	435	8	406	187	555	579	68	6	45	163	13	8+2	8+1	9+20	M
1,665 mm	203	399	456	825	910	453	437	8	395	196	602	685	65	6	46	158	13	8+1	8+1	9+20	------
1,665 mm	205	400	451	835	923	443	428	10	430	200	527	688	64	5	45	150	13	8+2	8+1	9+21	M
1,670 mm	200	414	464	822	924	464	417	10	399	190	644	790	66	5	47	158	13	8+2	8+1	9+21	—
1,670 mm	205	414	423	803	902	483	422	6	407	200	668	759	65	6	47	158	13	8+2	8+1	10+21	—
1,673 mm	201	408	457	829	914	456	419	9	377	185	592	676	64	6	45	158	13	8+1	8+1	8+20	------
1,674 mm	193	412	461	850	917	464	420	8	402	199	683	715	64	6	45	161	13	8+2	8+1	9+20	------
1,674 mm	209	410	450	827	908	459	450	7	414	185	560	607	62	6	44	154	13	9+1	8+1	9+20	M
1,676 mm	196	411	449	817	919	462	423	11	412	207	661	732	60	5	46	157	13	7+2	8+1	9+21	------
1,677 mm	192	419	447	829	923	469	438	7	382	186	634	753	62	6	47	167	14	8+1	8+0	9+20	M
1,682 mm	209	421	455	845	907	475	408	6	380	196	590	684	65	5	45	169	13	8+2	8+1	9+19	------
1,696 mm	215	411	462	844	920	462	427	7	394	170	604	596	68	5	42	160	13	7+2	8+1	9+21	M
1,700 mm	214	410	461	841	918	452	443	7	389	188	615	657	68	5	46	162	13	8+1	8+1	9+20	M
1,700 mm	215	410	453	839	927	455	435	6	398	186	594	714	62	6	45	160	13	8+2	8+1	10+21	M
1,700 mm	216	430	483	849	927	486	440	8	431	204	670	722	65	5	46	174	13	8+1	8+1	9+20	M
1,703 mm	205	411	460	847	923	462	420	10	442	203	607	536	71	6	46	160	13	8+1	8+2	9+21	------
1,703 mm	225	419	463	848	941	474	451	11	432	196	553	584	69	7	43	160	13	8+1	8+1	9+21	M
1,705 mm	222	414	459	835	919	464	430	10	392	186	567	565	67	6	43	156	14	8+1	8+1	9+20	------
1,714 mm	227	420	460	838	930	463	462	9	420	191	598	648	69	6	45	158	13	8+2	8+1	9+21	M
1,716 mm	219	417	458	845	930	472	451	8	398	185	668	733	69	6	46	163	13	8+1	8+1	8+20	M
1,717 mm	229	415	471	846	938	473	445	8	402	197	634	742	64	5	45	156	13	8+2	8+1	10+20	M
1,718 mm	227	408	450	830	935	460	438	11	414	175	614	651	65	6	43	154	14	8+1	8+1	10+21	M
1,721 mm	221	439	476	861	953	480	425	10	422	184	444	522	62	5	46	171	13	7+2	7+1	9+20	------
1,723 mm	223	411	468	832	923	466	452	9	431	190	604	565	60	5	44	158	13	8+1	8+1	7+18	------
1,724 mm	224	419	469	850	939	476	447	10	401	196	583	611	67	6	42	162	13	8+2	8+2	9+21	M
1,734 mm	212	416	449	847	935	463	432	9	420	174	712	742	70	5	45	157	13	8+1	8+1	8+21	M
1,748 mm	238	419	451	847	955	470	447	10	402	187	630	693	61	6	46	159	14	8+2	8+1	9+21	------
1,778 mm	236	423	466	866	953	491	456	8	417	208	647	634	72	6	45	166	13	8+2	8+1	9+21	M
1,780 mm	230	418	446	835	948	470	452	10	398	192	688	781	72	5	52	165	13	8+1	8+2	10+20	M
1,785 mm	230	430	487	889	960	485	455	10	416	211	777	836	72	5	48	168	14	8+1	8+1	9+19	M

Godsil (1948), whose work will be discussed subsequently, has found that a curvilinear equation fits the regressions on body length of the distances from the tip of the snout to various fin insertions and head length rather better than a linear one. He also discovered that when he fitted regression equations of the selected type to each of several samples from the same region, and also fitted an equation of this same type to the pooled data of all such samples, the individual regressions differed from the regression for the pooled data to a greater extent than might be expected from purely random variation. This he attributed to a lack of "biological homogeneity" (which he contrasts to "statistical homogeneity") within the stock of fish sampled, arising from incomplete mixing of fish from different spawning grounds. This may indeed be true. A rather simpler explanation is that the small differences he found between regressions among the samples from the same region are due to rather great differences in size composition of the several samples and the necessarily approximate nature of the regression equations employed. Whatever the cause, it is necessary to recognize that such differences can and do arise and to take suitable account of them where required, both in the sampling and in the subsequent analysis. By drawing samples widely from many different schools within the region to be studied, one minimizes for purpose of comparison the effects, if any, of lack of "biological homogeneity" by including in the variance of the sample any differences between subdivisions of the population with different genetic histories. By comparing only samples of the same size range from different regions, one will tend to reduce the apparent difference due to the failure of the regression equation employed to completely correct for differences in size composition of the samples.

There is probably no purely routine method of analysis which may be safely employed in comparing body dimensions of tunas from different regions. The selection of regression equations, and the application of other statistical techniques, should be undertaken with proper consideration of the particular data at hand, the hypotheses regarding it that are to be tested, and the precision required in each particular case.

RELATIVE GROWTH OF HAWAIIAN YELLOWFIN TUNA

Schaefer (1948) and Schaefer and Walford (1950) fitted linear regression lines to head length and distances from tip of snout to insertions of the first dorsal, second dorsal, anal, and ventral fins plotted against total length for yellowfin tuna from the west coast of Central America and from the Atlantic coast of Africa. Godsil (1948) found more extensive data on the same dimensions of yellowfin from the American west coast to be better fitted by a regression line of slight curvilinearity. To the Hawaiian data have been fitted linear regressions, the constants for which are given in table 2, as well as curvilinear regressions of the type selected by Godsil. Equations for the latter and corresponding standard errors of estimate (s) about them are as follows:

Head length	$y=69.54+0.20805x-15419/x$	$s=6.02$
Snout to insertion first dorsal	$y=80.34+0.22868x-16997/x$	$s=7.77$
Snout to insertion second dorsal	$y=17.28+0.48226x+11445/x$	$s=10.94$
Snout to insertion ventral	$y=78.87+0.23340x-16778/x$	$s=7.96$
Snout to insertion anal	$y=109.92+0.49037x-25129/x$	$s=9.32$

Over the range of sizes in our sample, the curvilinear regressions result in slightly smaller variances about them than the linear regressions; but, as may be seen from the above equations or from the graphs in the next section (figs. 6–10), the differences between these curves and straight lines are slight. Indeed, for snout to second dorsal insertion the slight curvature of the regression is opposite in direction to those fitting the data of other dimensions and to that of Godsil for his American-west-coast fish (fig. 8). Furthermore, the difference between the linear and curvilinear regressions for this dimension is, for the Hawaiian data, such as might arise by chance alone in between 1 in 20 and 1 in 100 cases.

The relations between body depth and total length, diameter of iris and head length, and length of maxillary and head length seem to be well described by linear regressions over the entire size range. The statistics of these regressions are tabulated in table 2.

In each of these cases where linear regressions fit the data, the y intercept of the regression line differs significantly from zero. Furthermore, except for depth of body on total length and length of maxillary on head length, the difference is sufficiently great that the expression as ratios of the relation between variables would result in a considerable error from this source. This

TABLE 2.—*Statistics of linear regressions of measurements of Hawaiian* N. macropterus

All logarithms are to base 10.
N=number in sample.
$\bar{x}$, $\bar{y}$=means of x and y.
Sx^2, Sy^2, Sxy are sums of squares and products of deviations from the means $\bar{x}$, $\bar{y}$.
$b=\frac{Sxy}{Sx^2}$=regression coefficient of y on x.
$s^2=\frac{Sy^2-b^2Sx^2}{N-2}$=estimate of variance about regression line.

Independent variable x	Dependent variable y	N	$\bar{x}$	$\bar{y}$	Sx^2	Sy^2	Sxy	b	s
Total length	Head length	203	1247	314	32,985,274	1,688,363	7,443,781	0.22567	6.51
Do	Snout to insertion first dorsal	201	1242	348	32,516,976	2,016,613	8,071,090	.24821	8.17
Do	Snout to insertion second dorsal	202	1244	628	32,699,372	7,221,223	15,340,597	.46914	11.03
Do	Snout to insertion ventral	203	1247	354	32,985,274	2,118,502	8,331,748	.25259	8.34
Do	Snout to insertion anal	202	1246	697	32,937,786	8,906,792	17,108,301	.51941	10.14
Do	Greatest body depth	202	1245	310	32,838,330	2,162,089	8,363,540	.25469	12.64
Head length	Diameter of iris	198	315	37.6	1,667,677	9,005	119,469	.07164	1.51
Do	Length of maxillary	203	314	121.8	1,688,191	244,663	640,453	.37937	2.90
Log total length	Length pectoral	203	3.06448	324	6.52772	1,617,580	3211.2003	491.93	13.73
Do	Log length second dorsal [1]	172	3.13093	2.55442	1.54087	8.11623	3.41003	2.21305	.0579
Do	Log length anal [1]	172	3.13093	2.59682	1.54087	8.66325	3.52758	2.28934	.0588
Do	Log length first dorsal spine	188	3.07798	2.12768	5.42218	5.30176	5.30154	.97775	.02530
Do	Log length longest dorsal finlet	198	3.06657	1.62583	6.44930	7.67031	6.94360	1.07664	.03146
Do	Weight in pounds	202	3.06566	1.82955	6.47257	58.24926	19.39100	2.99587	.02793

[1] Only specimens 600 mm. and over in total length.

result is similar to that obtained from Central American and African yellowfin tuna (Schaefer 1948, Schaefer and Walford 1950) and illustrates again the generalization that, owing to differential growth rates, comparison of dimensions expressed as ratios is invalid for yellowfin tuna.

Also similar to previous Central American and African results, is the finding that the growth of the pectoral fin of Hawaiian yellowfin tuna is such that over the entire range of sizes available in our sample, the relation between length of fin and total length is well described by the equation

$$y=491.9 \log x-1184,$$

a linear regression giving a good fit to the length of fin plotted against logarithm of total length. The regression statistics are given in table 2.

For Central American and African fish, the lengths of second dorsal and anal fins plotted against total length were found to be fitted by an equation of the type $y=ax^b$, so that a linear regression was obtained by plotting logarithms of fin length against logarithms of total length. The sizes of fish involved were from about 50 cm. to 160 cm. in total length for the fish from both regions. For Hawaiian yellowfin tuna, a linear relation between logarithm of fin length and logarithm of fish length provides a fairly good fit over the range of sizes 60 cm. to 178 cm., but when smaller sizes are included, the regression is obviously curvilinear (fig. 2 and 3). Linear-regression equations were fitted, for comparative purposes, only to the data for fish 60 cm. and over in total length, the results being tabulated in table 2. To provide a reasonable fit to the data for all sizes, however, the second-degree polynomials illustrated in the figures were fitted, the equations being, for logarithms of length of second dorsal (y_1) on logarithm of total length (x_1),

$$y_1=7.64965-5.59555x_1+1.26613x_1^2 \qquad s=.05238$$

and for logarithm of length of anal (y_1) on logarithm of total length (x_1)

$$y_1=4.79192-3.82511x_1+0.99707x_1^2 \qquad s=.03607$$

It is obvious that the relative rates of growth of the second dorsal and the anal fins accelerate very rapidly with increase in size of fish, the large fish having, relatively, enormously longer fins.

The equation $y=ax^b$ was found to provide a good fit to our Hawaiian data over the entire range of sizes for length of longest dorsal spine (the first spine in each specimen) and length of longest dorsal finlet relative to total length, the logarithms of the dimensions plotted against logarithm of total length being well fitted by linear regressions, the constants for which are given in table 2. In previous studies of Costa Rican and African fish, linear regressions were found adequate for these relations over the size range 50 cm. to 160 cm., and for only that range of sizes it would be difficult to perceive that the allometry equation provides a better fit to the Hawaiian data. The availability of a longer range of sizes from Hawaiian waters made it possible to observe the slightly curvilinear nature of the relation. How little it differs from a straight line may be seen from the closeness to unity of the values of b tabulated in table 2 for these regressions.

The weight of Hawaiian yellowfin varies almost exactly as the cube of the length, the relation between length in millimeters (x) and weight in pounds (y) being expressed by the equation

$$\log y=2.996x-7.35477$$

COMPARISON OF TUNA FROM HAWAII AND FROM THE AMERICAN WEST COAST

Fin lengths

The most outstanding differences revealed by this study between yellowfin tuna from Hawaii and those from waters off Costa Rica are the relative lengths of the pectoral, second dorsal, and anal fins. There seem also to be small but dependable differences in length of longest dorsal spine and length of longest dorsal finlet.

Figure 1 illustrates the relation between length of pectoral fin and total length for Hawaiian and Costa Rican fish. The points plotted in this figure, and in the other figures in this paper, do not represent individual fish but are the mean values of the two variables for each 10-cm. size category. This method of plotting recommends itself because the data for individual fish are too numerous to be clearly depicted. It has also the advantage of making possible a visual comparison of mean values of the dimension under consideration for fish of each single 10-cm. size category from the two populations. The inherent disadvantage is, of course, that each point does not represent the same number of fish, so that their positions are of varying degrees of reliability. The regression

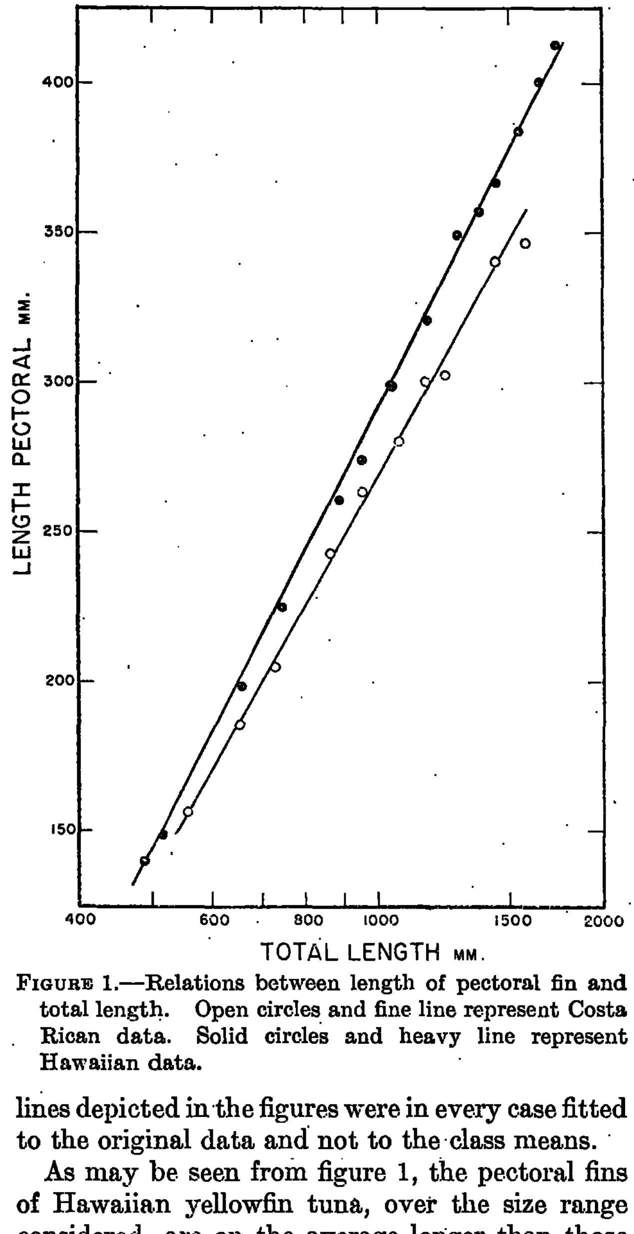

FIGURE 1.—Relations between length of pectoral fin and total length. Open circles and fine line represent Costa Rican data. Solid circles and heavy line represent Hawaiian data.

lines depicted in the figures were in every case fitted to the original data and not to the class means.

As may be seen from figure 1, the pectoral fins of Hawaiian yellowfin tuna, over the size range considered, are on the average longer than those of Costa Rican fish, and the difference increases as the size of fish increases. No elaborate statistical analysis is required to show that these samples cannot be considered as arising from the same population. If inspection of the figure itself is not sufficiently convincing, a very simple test suffices to show that the probability of the two samples arising by random sampling from a single population is very small, regardless of whether or not the growth law on the basis of which the regressions were calculated is exactly correct. Under the hypothesis that the Costa Rican sample was drawn from the same population as the Hawaiian sample, we should expect the points for Costa Rican fish to be half the time above and half the time below the corresponding values predicted from the Hawaiian sample. For each size class, the Costa Rican value falls below the value which would be expected on the basis of the Hawaiian sample. The probability of this occurring by chance alone for all 10 Costa Rican points is $(\frac{1}{2})^{10}$ or 1 chance in 1024; it is, then, most unlikely.

In figure 2 are plotted values of logarithm of length of second dorsal fin against logarithm of total length. This transformation yields a linear regression for the Costa Rican sample, the fish in which are from 54 cm. to 157 cm. in total length. Similarly, the Hawaiian data for fish 62 cm. and over in total length are rather well fitted by a linear regression, as shown in the figure (we have no Hawaiian specimens between 54 cm. and 62 cm.). We have also plotted in the figure the second-degree polynomial that fits the Hawaiian data for all sizes of fish in our sample. It is obvious, whichever regression we employ for the Hawaiian fish, that the second dorsal fins of yellowfin tuna from waters of the Hawaiian Islands grow, relative to total length, faster than those of yellowfin tuna from waters off Costa Rica. The difference in fin lengths is small at smaller sizes of fish, but increases with size of fish until among large fish the difference is very striking.

As may be seen from figure 3, the same situation obtains for the length of anal fin relative to total length. As has been reported for Costa Rican fish and African fish, the variability of fin lengths of second dorsal and anal fins, even on a logarithmic scale, is not entirely independent of size of fish, but tends to be greater at larger sizes. For this reason the values of s for the corresponding equations in table 2 and on page 359 are average values, and will be a little too small at large fish sizes and too large at small sizes.

Comparison of the linear regressions of figures 2 and 3 may be made by means of analysis of covariance (Kendall 1946, p. 237 *et seq.*); or, without reference to regression equations, we may simply compare the mean values of the several size classes and, following the same sort of reasoning as above in the case of the pectoral fin, arrive at the conclusion that the probability of the samples being drawn from a single population is very small.

The first dorsal spine was the longest on each of the 188 specimens for which this character was measured. As noted on page 359, a linear regression did not provide a good fit to the original data, compared with a linear regression fitted to the logarithms of the variables. The latter is plotted in figure 4. It was found that the same transformation applied to the Costa Rican data, yielded a linear regression with a slightly improved fit to those data also (Schaefer 1948 fitted a linear regression to the original data); this regression

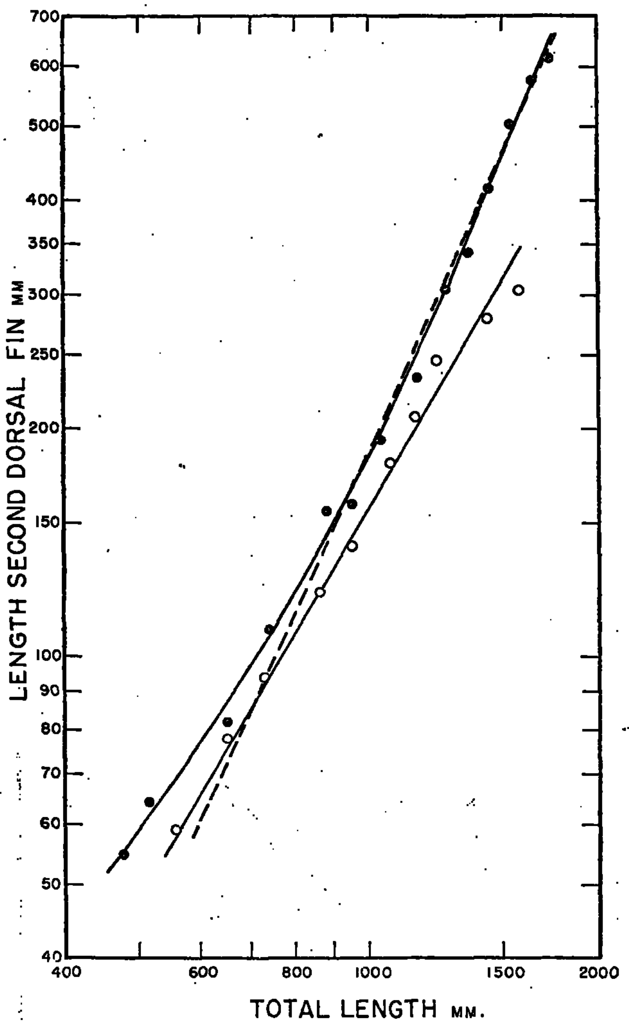

FIGURE 2.—Relations between length of second dorsal fin and total length. Open circles represent Costa Rican data; solid circles represent Hawaiian data. Solid straight line is linear regression line fitted to Costa Rican data. Broken straight line is linear regression line fitted to Hawaiian data from fish 600 mm. and over in total length. Solid curved line is second degree polynomial fitted to all Hawaiian data.

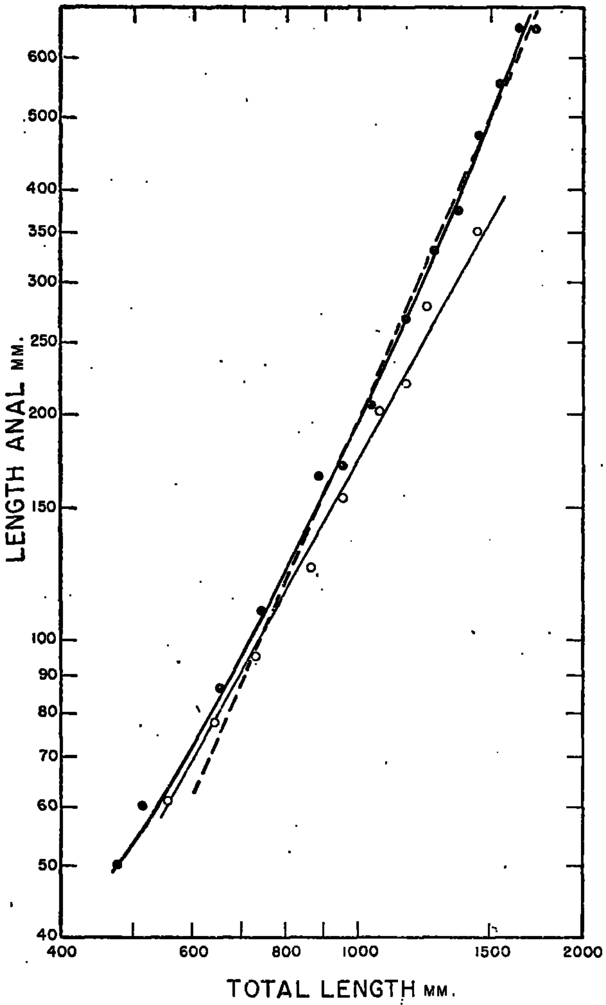

FIGURE 3.—Relations between length of anal fin and total length. Open circles represent Costa Rican data; solid circles represent Hawaiian data. Solid straight line is linear regression line fitted to Costa Rican data. Broken straight line is linear regression line fitted to Hawaiian data from fish 600 mm. and over in total length. Solid curved line is second degree polynomial fitted to all Hawaiian data.

also is plotted in figure 4. Analysis of covariance shows that the slopes of the two regressions do not differ more than might be expected by chance, but the levels do; the longest dorsal spines of Hawaiian fish appear on the average to be a small, constant percentage shorter than the longest dorsal spines of Costa Rican fish.

Similarly, the logarithms of length of longest dorsal finlet against logarithm of total length yielded a linear regression for the Hawaiian measurements on all sizes of fish, and proved also to provide a good fit to the Costa Rican data for

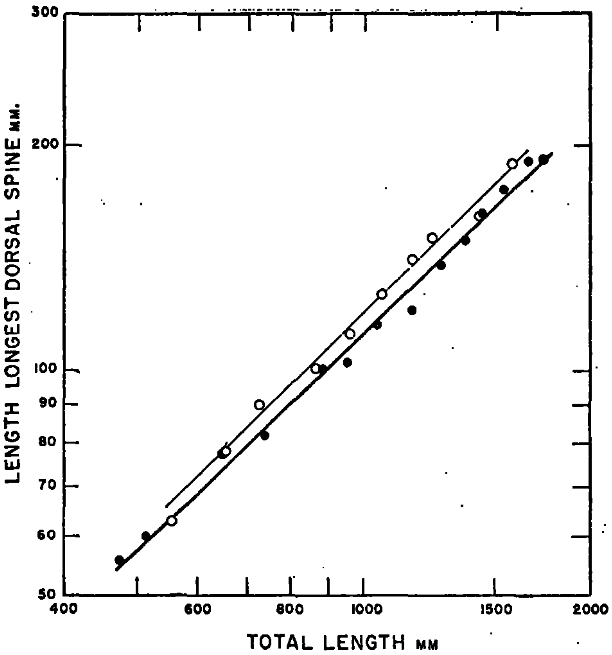

FIGURE 4.—Relations between length of longest dorsal spine and total length. Open circles and fine line represent Costa Rican data; solid circles and heavy line represent Hawaiian data.

which Schaefer (1948) had fitted a linear regression to the original data. Again, the resulting regressions, plotted in figure 5, when subjected to covariance analysis, indicate a small, constant average percentage difference between finlet lengths of the two populations, the Hawaiian fish having the longer finlets.

Head length and distances from snout to fin insertions

As mentioned earlier, Godsil (1948) has published the measurements of total length, head length, and distances from tip of snout to the insertions of first dorsal, second dorsal, anal, and ventral fins for nearly 2,000 specimens of yellowfin tuna from the American west coast between Cape San Lucas and Panama. The original measurements were published with his analyses of them, so we are able to compare these extensive data both with the Costa Rican data published by Schaefer (1948) and with the Hawaiian data presented herein. In figures 6 to 10 have been plotted head length and distances from snout to fin insertions against total length, which is taken in each case as the independent variable. For each of the three groups of data (Godsil's, Costa Rican, Hawaiian) have been plotted the mean values of the two variables in each graph for each 10 cm. of total length. To the pooled west-coast data (Godsil's plus my Costa Rican) have been fitted and plotted linear regressions. Also plotted are the curvilinear regressions computed by Godsil (1948, p. 13) for his data, of the type $y=a+bx+c/x$. On the same graphs have been plotted also the linear-regression line best fitting the Hawaiian data and the best-fitting curvilinear regression of the type selected by Godsil.

For the Hawaiian data, except in one case (snout to insertion of second dorsal of Hawaiian fish), the curvilinear regressions provide a slight improvement in fit over the linear regressions. Inspection of the figures, however, reveals that the differences between the linear and curvilinear regressions are small in comparison with the differences between west-coast and Hawaiian samples. The reduction of the variance about the regression line also is very small in comparison with the difference between the two regions when a curvilinear rather than a linear equation is employed. In consequence, the linear-regression equations will be employed below in considering the application of analysis of covariance to the comparison of samples.

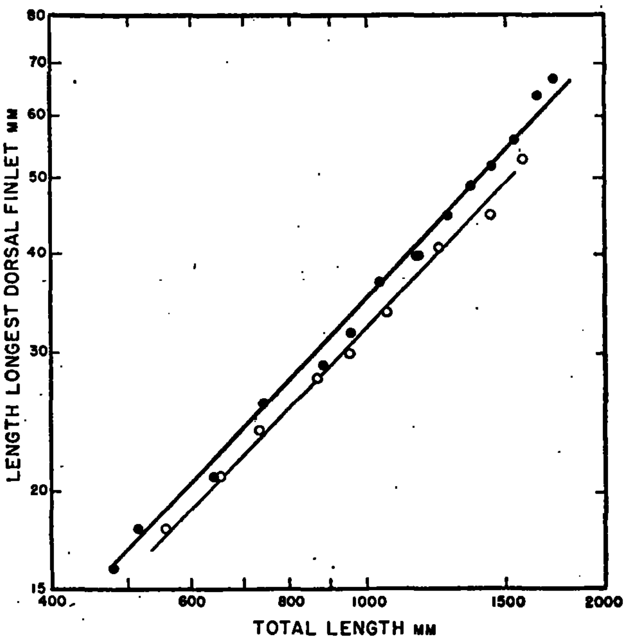

FIGURE 5.—Relations between length of longest dorsal finlet and total length. Open circles and fine line represent Costa Rican data; solid circles and heavy line represent Hawaiian data.

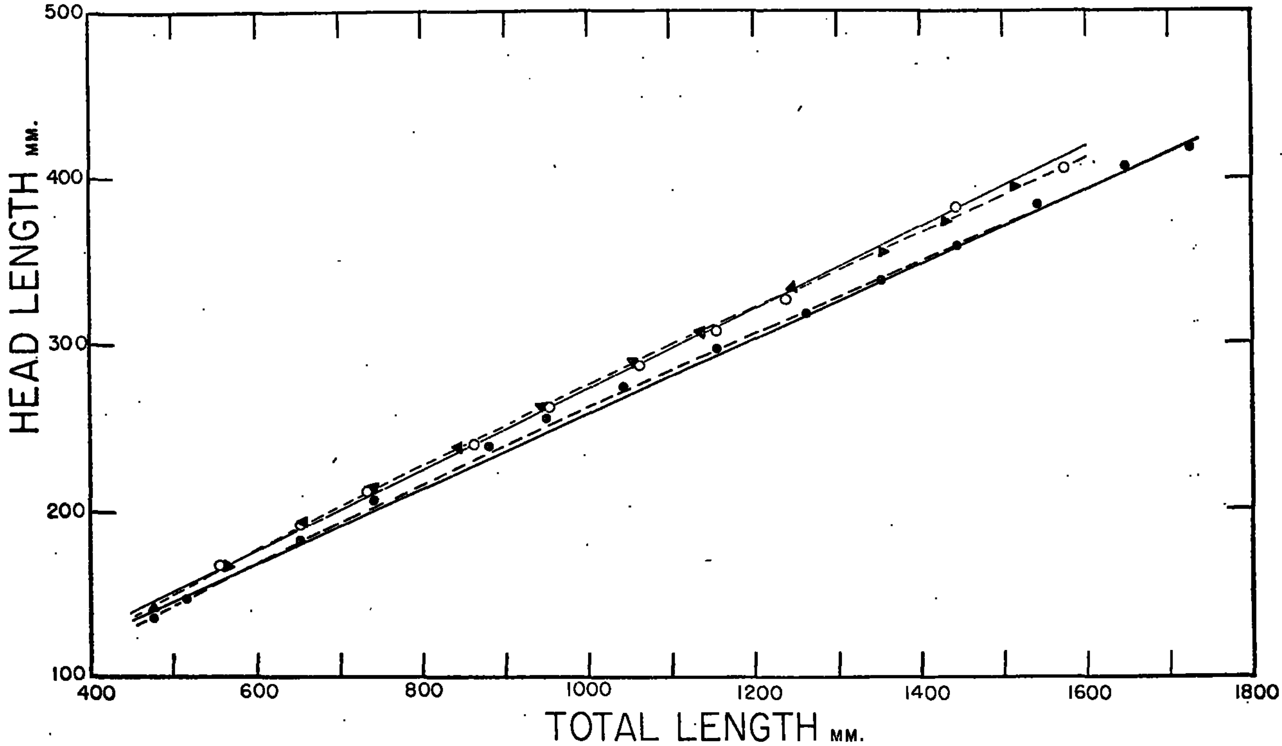

FIGURE 6.—Relations between head length and total length. Solid circles represent Hawaiian data; open circles represent Costa Rican data; solid triangles represent Godsil's west-coast data. Fine solid line is linear regression line fitting west-coast data, while heavy solid line is linear regression line fitting Hawaiian data. Fine broken line is Godsil's curvilinear regression for west-coast data, while heavy broken line is similar regression fitted to Hawaiian data.

A detailed analysis of covariance is not necessary to arrive at the conclusion that with respect to these dimensions the samples from the Hawaiian Islands are different from the samples from the west coast. It is quite obvious from the plots of the mean values for each 10-cm. size class (figs. 6 to 10) that the head length and the distances from snout to the fin insertions are significantly shorter for Hawaiian than for west-coast yellowfin tuna at the larger sizes. If a statement of probability is desired to test a null hypothesis respecting difference between regions, one may proceed in a manner similar to that suggested above in the case of pectoral-fin lengths, confining attention for sake of simplicity to the larger sizes of tuna, say over 800 mm. in total length.

Considering fish of size classes between 800 mm. and 1,600 mm. in total length, for which specimens were available both from the west coast and from Hawaii, the points for the mean values of each 10-cm. length class of Hawaiian fish fall below the values expected on the basis of west-coast data in all cases for head length (fig. 6), snout to insertion of anal (fig. 7), snout to insertion of second dorsal (fig. 8), and snout to insertion of ventral (fig. 9). Since there are 8 such points for each dimension, and under a null hypothesis they might equally well be above or below the value expected from west-coast data, the probability of the observations on the hypothesis is $(\frac{1}{2})^8=\frac{1}{256}$ for each dimension, which is unlikely. For snout to insertion of first dorsal, one point (900-mm. size class) falls barely above the expected value; the probability of having at most one point above the expected value under the null hypothesis is $(\frac{1}{2})^8+8(\frac{1}{2})^8=\frac{9}{256}$.

By the conventional methods of analysis of covariance (Kendall 1946, p. 237 *et seq.*), we may also test for each of the dimensions the null hypotheses (1) that the sample from the west coast and the sample from Hawaii may both be represented by a single linear-regression equation

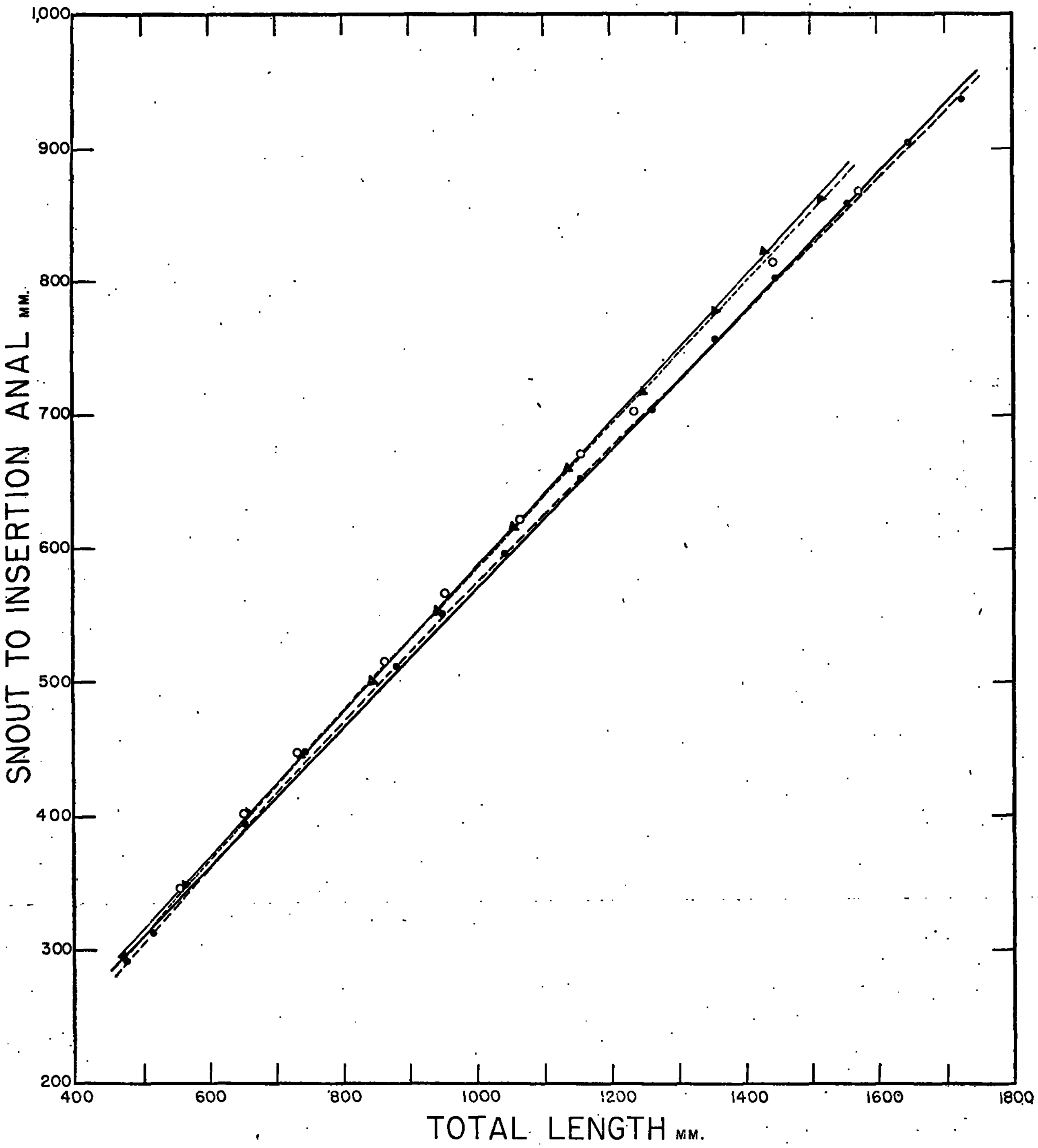

FIGURE 7.—Relations between distance from snout to insertion of anal fin and total length. Solid circles represent Hawaiian data; open circles represent Costa Rican data; solid triangles represent Godsil's west-coast data. Fine solid line is linear regression line fitting west-coast data, while heavy solid line is linear regression line fitting Hawaiian data. Fine broken line is Godsil's curvilinear regression for west-coast data, while heavy broken line is similar regression fitted to Hawaiian data.

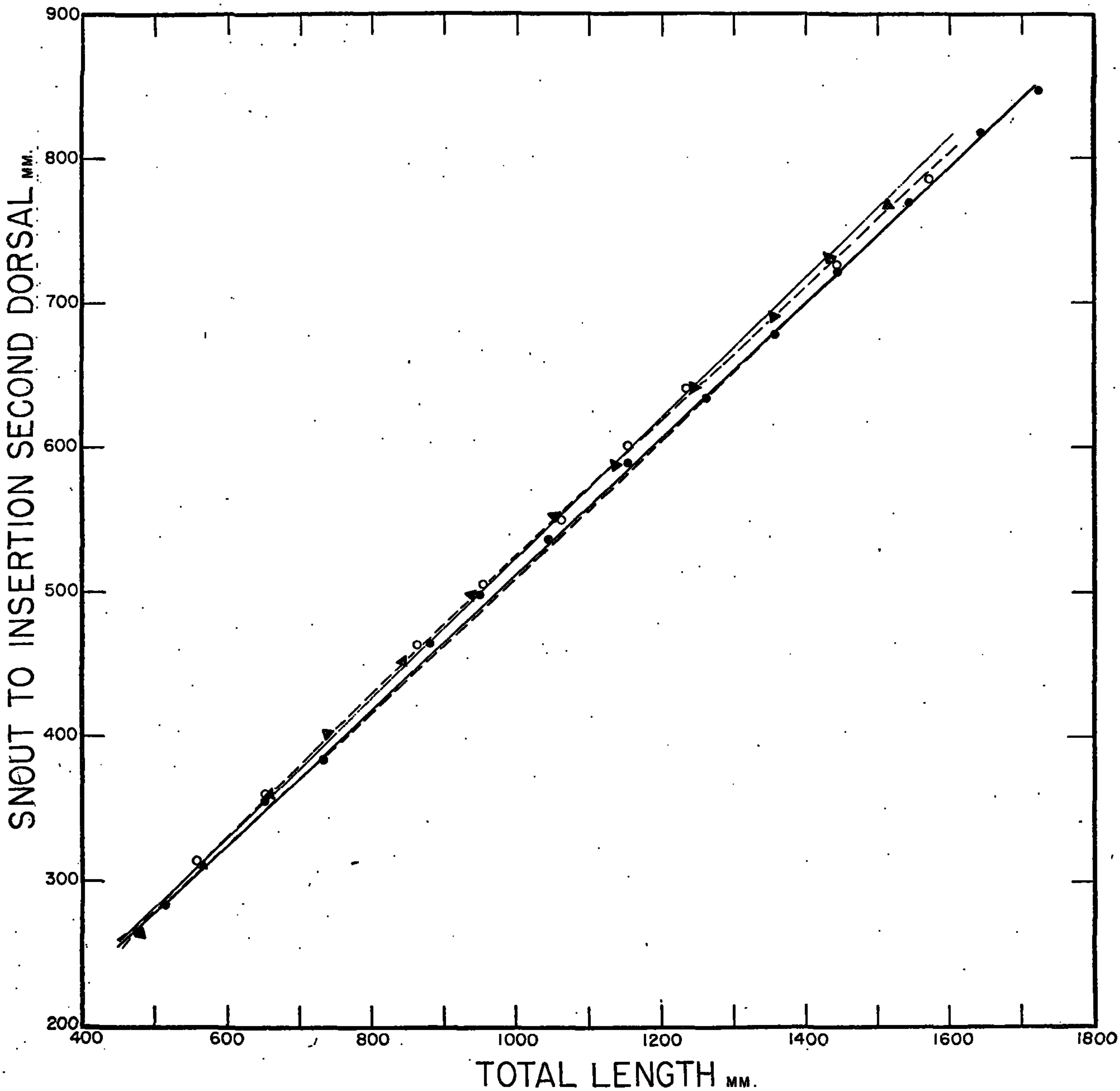

FIGURE 8.—Relations between distance from snout to insertion of second dorsal fin and total length. Solid circles represent Hawaiian data; open circles represent Costa Rican data; solid triangles represent Godsil's west-coast data. Fine solid line is linear regression line fitting west-coast data, while heavy solid line is linear regression line fitting Hawaiian data. Fine broken line is Godsil's curvilinear regression for west-coast data, while heavy broken line is similar regression fitted to Hawaiian data.

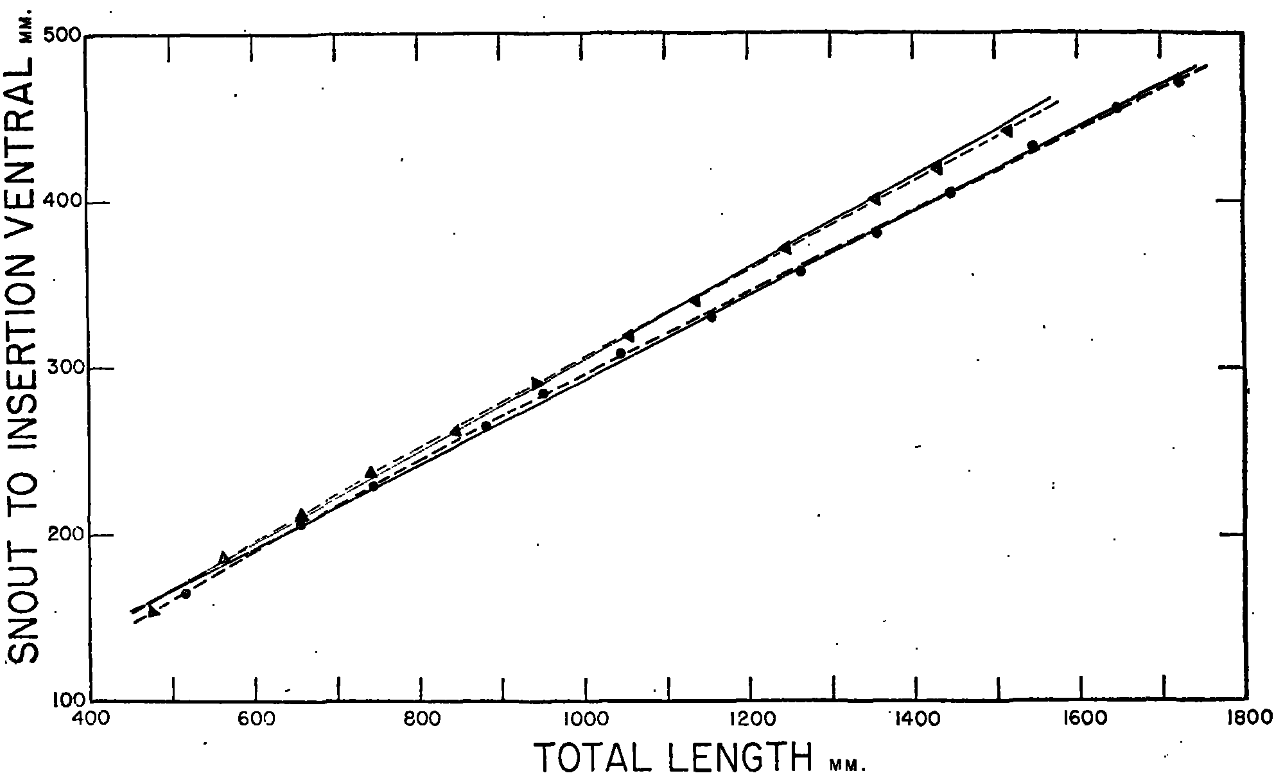

FIGURE 9.—Relations between distance from snout to insertion of ventral fin and total length. Solid circles represent Hawaiian data; open circles represent Costa Rican data; solid triangles represent Godsil's west-coast data. Fine solid line is linear regression line fitting west-coast data, while heavy solid line is linear regression line fitting Hawaiian data. Fine broken line is Godsil's curvilinear regression for west-coast data, while heavy broken line is similar regression fitted to Hawaiian data.

and, if this be false, (2) that the regression coefficients (slopes) of the regression lines fitting the samples from the two regions are equal. As may be seen from the variance ratios computed in table 3, both these hypotheses are to be rejected for each dimension considered, the west-coast data in this table including the measurements of both Schaefer and Godsil. If we compare the Hawaiian data with the data of Schaefer alone (table 4) we find here also that for no character considered may the data from the two regions be represented by a single linear-regression equation. In two cases, however, indicated by footnotes in the table, the appropriate variance ratio indicates that there is not sufficient reason from these particular data to reject the hypothesis of equality of regression coefficients. In general, it is quite apparent that for each character the regression lines are different for the two regions and that they differ in slope.

Comparison of the regression lines of the dimensions of tuna from different regions is perfectly straightforward so long as we are able to assume that the sample regression lines are representative of the tuna populations of the regions in each case. As has been noted earlier, however, Godsil found that repeated samples from the west coast yielded regression lines (curvilinear) for which a null hypothesis could not be supported. The same thing is true if linear regressions are applied to his data (table 5). His various subgroups along the west coast differ significantly among themselves, and for each dimension they differ in respect of the regression coefficients. As may be seen from table 6, comparison of my Costa Rican data with Godsil's data from Costa Rica alone (his samples 4, 5, and 12) reveals that a single linear-regression equation does not, for any dimension, accurately describe both. It is quite evident that differences may be expected among different samples from the same region. The problem, then, is to determine whether the differences between regions are greater than might reasonably be expected among different samples from the same region. In comparing Hawaiian and west-coast data, where the differences are so large that the distributions of means of subclasses (size groups) are completely separate between the two regions for the most part, the answer is fairly obvious from the graphs of the type herein presented. In table 7 have been tabulated the linear-regression coefficients for each of Godsil's 13 samples, for my Costa Rican sample, and for the Hawaiian sample. From this tabulation it may readily be seen that the Hawaiian regression coefficients fall, for each dimension, well below the lowest value encountered among the several west-coast subsamples.

Although in the case at hand we are spared the need for an efficient means of comparing variation between samples within a region with differences between regions where a null hypothesis is not valid for samples within the region, this will not in general be true. The desirability of a test for application in other, less-clear situations is sufficiently great that some examination of the problem seems warranted, particularly in view of the fact that Godsil (1948) has already attempted to develop and employ such a test. We wish, therefore, to consider the problem of measuring the differences between groups where a null hypothesis is not satisfied.

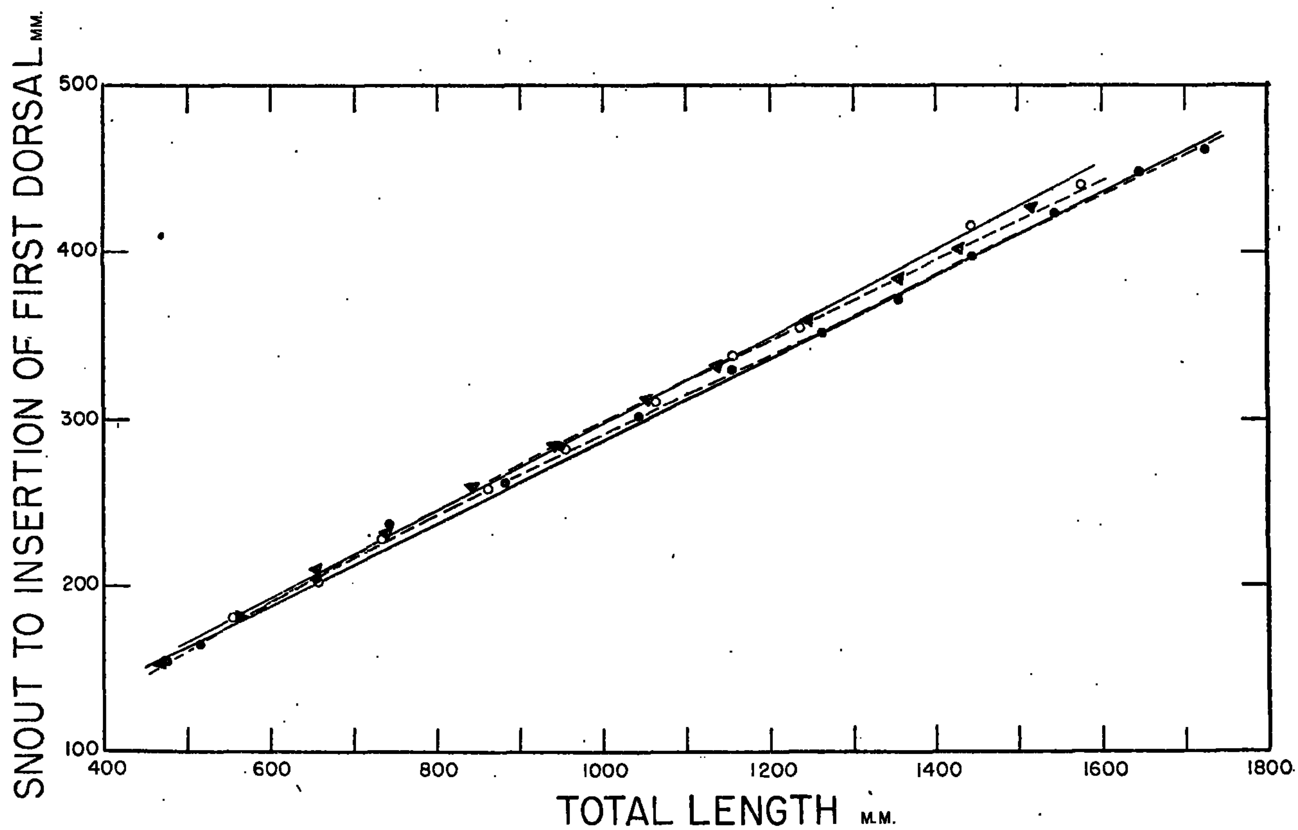

FIGURE 10.—Relations between distance from snout to insertion of first dorsal fin and total length. Solid circles represent Hawaiian data; open circles represent Costa Rican data; solid triangles represent Godsil's west-coast data. Fine solid line is linear regression line fitting west-coast data, while heavy solid line is linear regression line fitting Hawaiian data. Fine broken line is Godsil's curvilinear regression for west-coast data, while heavy broken line is similar regression fitted to Hawaiian data.

TABLE 3.—*Comparison of Hawaiian data and pooled American west-coast data by covariance analysis, linear regressions*

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance ratios
Head length:				
Deviations from total regression	2,158	73,920		$\frac{20,611}{15.17}=1359.0$
Deviations from regressions within regions	2,156	32,698	15.17	
Differences between regions	2	41,222	20,611	$\frac{6,257}{15.17}=412.5$
Differences between regression coefficients	1	6,257	6,257	
Differences between adjusted means	1	34,965		
Snout to insertion first dorsal:				
Deviations from total regression	2,156	67,803		$\frac{8,188}{23.88}=342.9$
Deviations from regressions within regions	2,154	51,427	23.88	
Differences between regions	2	16,376	8,188	$\frac{3,431}{23.88}=143.7$
Differences between regression coefficients	1	3,431	3,431	
Differences between adjusted means	1	12,945		
Snout to insertion ventral:				
Deviations from total regression	2,110	87,708		$\frac{17,881}{24.64}=725.7$
Deviations from regressions within regions	2,108	51,946	24.64	
Differences between regions	2	35,762	17,881	$\frac{7,709}{24.64}=312.9$
Differences between regression coefficients	1	7,709	7,709	
Differences between adjusted means	1	28,053		
Snout to insertion second dorsal:				
Deviations from total regression	2,156	102,228		$\frac{12,232}{36.10}=338.8$
Deviations from regressions within regions	2,154	77,765	36.10	
Differences between regions	2	24,463	12,232	$\frac{4,263}{36.10}=118.1$
Differences between regression coefficients	1	4,263	4,263	
Differences between adjusted means	1	20,200		
Snout to insertion anal:				
Deviations from total regression	2,153	128,518		$\frac{26,355}{35.24}=747.9$
Deviations from regressions within regions	2,151	75,808	35.24	
Differences between regions	2	52,710	26,355	$\frac{12,017}{35.24}=341.0$
Differences between regression coefficients	1	12,017	12,017	
Differences between adjusted means	1	40,693		

TABLE 4.—*Comparisons of Hawaiian data and Schaefer's Costa Rican data by covariance analysis, linear regressions*

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance ratios
Head length:				
Deviations from total regression	241	10,649		$\frac{625}{39.33}=15.89$
Deviations from regressions within regions	239	9,399	39.33	
Differences between regions	2	1,250	625	$\frac{143}{39.33}=$ [1] 3.64
Differences between regression coefficients	1	143	143	
Differences between adjusted means	1	1,107	1,107	$\frac{1,107}{39.76}=27.84$
Snout to insertion first dorsal:				
Deviations from total regression	245	16,558		$\frac{1,004}{59.88}=16.77$
Deviations from regressions within regions	243	14,550	59.88	
Differences between regions	2	2,008	1,004	$\frac{552}{59.88}=9.22$
Differences between regression coefficients	1	552	552	
Differences between adjusted means	1	1,456		
Snout to insertion second dorsal:				
Deviations from total regression	246	35,349		$\frac{2,626}{123.35}=21.29$
Deviations from regression within regions	244	30,097	123.35	
Differences between regions	2	5,252	2,626	$\frac{164}{123.35}=$ [1] 1.33
Differences between regression coefficients	1	164	164	
Differences between adjusted means	1	5,088	5,088	$\frac{5,088}{123.51}=41.20$
Snout to insertion anal:				
Deviations from total regression	246	36,130		$\frac{6,460}{95.12}=67.91$
Deviations from regression within regions	244	23,210	95.12	
Differences between regions	2	12,920	6,460	$\frac{536}{95.12}=5.63$
Differences between regression coefficients	1	536	536	
Differences between adjusted means	1	12,384		

[1] Not significant.

TABLE 5.—*Comparison of subgroups, Godsil's west-coast data, by covariance analysis, linear regressions*

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance ratios
Head length:				
Deviations from total regression	1,909	23,049		$\frac{198.1}{9.705}=20.41$
Deviations from regression within groups	1,885	18,294	9.705	
Differences among groups	24	4,755	198.1	$\frac{147.8}{9.705}=15.23$
Differences among regression coefficients	12	1,773	147.8	
Differences among adjusted group means	12	2,982		
Snout to insertion first dorsal:				
Deviations from total regression	1,909	36,411		$\frac{199.5}{16.78}=11.89$
Deviations from regression within groups	1,885	31,623	16.78	
Differences among groups	24	4,788	199.5	$\frac{187.3}{16.78}=11.17$
Differences among regression coefficients	12	2,248	187.3	
Differences among adjusted group means	12	2,540		
Snout to insertion ventral:				
Deviations from total regression	1,907	37,960		$\frac{112.1}{18.73}=5.99$
Deviations from regression within groups	1,883	35,269	18.73	
Differences among groups	24	2,691	112.1	$\frac{49.25}{18.73}=2.63$
Differences among regression coefficients	12	591	49.25	
Differences among adjusted group means	12	2,100		
Snout to insertion second dorsal:				
Deviations from total regression	1,908	47,560		$\frac{278.7}{21.69}=12.85$
Deviations from regression within groups	1,884	40,871	21.69	
Differences among groups	24	6,689	278.7	$\frac{364.9}{21.69}=16.82$
Differences among regression coefficients	12	4,379	364.9	
Differences among adjusted group means	12	2,310		
Snout to insertion anal:				
Deviations from total regression	1,905	51,914		$\frac{387.5}{22.65}=17.11$
Deviations from regression within groups	1,881	42,615	22.65	
Differences among groups	24	9,299	387.5	$\frac{228.8}{22.65}=10.10$
Differences among regression coefficients	12	2,745	228.8	
Differences among adjusted group means	12	6,554		

TABLE 6.—*Comparisons of Schaefer's and Godsil's Costa Rican data by covariance analysis, linear regressions*

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance ratios
Head length:				
Deviations from total regression	808	10,018		$\frac{144}{12.07}=11.93$
Deviations from regression within groups	806	9,730	12.07	
Differences between groups	2	288	144	$\frac{83}{12.07}=6.88$
Differences between regression coefficients	1	83	83	
Differences between adjusted group means	1	205	205	
Snout to insertion first dorsal:				
Deviations from total regression	808	16,550		$\frac{142}{20.18}=7.04$
Deviations from regression within groups	806	16,226	20.18	
Differences between groups	2	284	142	$\frac{120}{20.18}=5.95$
Differences between regression coefficients	1	120	120	
Differences between adjusted group means	1	164	164	
Snout to insertion second dorsal:				
Deviations from total regression	807	27,293		$\frac{65.5}{33.74}=$ [1] 2.00
Deviations from regression within groups	805	27,162	33.74	
Differences between groups	2	131	65.5	
Differences between regression coefficients	1	60	60	
Differences between adjusted group means	1	71	71	
Snout to insertion anal:				
Deviations from total regression	806	23,849		$\frac{218}{29.12}=7.49$
Deviations from regression within groups	804	23,412	29.12	
Differences between groups	2	437	218	$\frac{52}{29.12}=$ [1] 1.79
Differences between regression coefficients	1	52	52	
Differences between adjusted group means	1	385	385	$\frac{385}{29.15}=13.21$

[1] Not significant.

Denote by x_{ij}, y_{ij} the pair of variate values for the i^{th} member of the j^{th} group, by n_j the number of members of the j^{th} group, and by p the number of groups. Also let $x._j$ and $y._j$ be the mean values of the variates in the j^{th} group, $x..$ and $y..$ be the mean values of the variates for the total of all groups, and N be the total of all n_j. The variances about the linear-regression lines may be analyzed as follows:

Variation	Degrees of freedom	Sum of squares	Mean square
Total, from regression b_0	$N-2$	$S=\sum_{i,j}(y_{ij}-y..)^2-b_0\sum_{i,j}(x_{ij}-x..)(y_{ij}-y..)$	$S/N-2$
Within groups, from regression b_j	$N-2p$	$S_2=\sum_{i,j}(y_{ij}-y._j)^2-\sum_{i,j}b_j(x_{ij}-x._j)(y_{ij}-y._j)$	$S_2/N-2p=s_2$
Differences between groups	$2p-2$	$S_1=\sum_{j}n_j(y._j-y..)^2-b_0\sum_{j}n_j(x._j-x..)(y._j-y..)$ $-\sum_{i,j}(b_0-b_j)(x_{ij}-x._j)(y_{ij}-y._j)$	$S_1/2p-2=s_1$

TABLE 7.—*Regression coefficients for regressions of various dimensions on total length, for samples from the American west coast and Hawaii*

	Head length	Snout to insertion first dorsal	Snout to insertion ventral	Snout to insertion second dorsal	Snout to insertion anal
Godsil's west-coast samples:					
No. 1	0.24315	0.27134	0.26520	0.50285	0.54569
No. 2	.27902	.29256	.29840	.49022	.55697
No. 3	.24339	.26627	.27189	.48265	.53736
No. 4 [1]	.23771	.25647	.27185	.47464	.53656
No. 5 [1]	.24118	.25793	.27210	.48137	.54344
No. 6	.26280	.28873	.29487	.52624	.57669
No. 7	.23740	.25746	.27615	.47767	.54490
No. 8	.25580	.28390	.27536	.50448	.55711
No. 9	.26001	.28341	.28676	.50524	.54416
No. 10	.26014	.28015	.29405	.50883	.58550
No. 11	.23811	.26397	.27348	.49191	.54836
No. 12 [1]	.28004	.30858	.30067	.50391	.55914
No. 13	.25999	.28519	.28528	.50207	.58009
All samples	.24356	.26148	.27244	.48358	.54383
Schaefer's Costa Rican samples	.23504	.26346	----------	.47675	.53508
Hawaiian samples	.22567	.24821	.25259	.46914	.51941

[1] Samples from Costa Rican waters.

Where b_o is the regression coefficient for all data pooled and b_j is the regression coefficient for the j^{th} group.

When the null hypothesis is satisfied s_1 and s_2 are both unbiased estimates of the variance about the regression line, and their ratio will be distributed in the F distribution.

In the case where the null hypothesis is not satisfied, but a single regression coefficient adequately describes the effect of x on y for all groups, we may subtract

$$Y_{ij}=y..+b_o(x_{ij}-x..)$$

from each value of y_{ij} to allow for differences in the x variate. The new variable $y'_{ij}=y_{ij}-Y_{ij}$ is completely corrected for variations in x, so that differences between adjusted means of groups will be independent of the values of x. We may take, then, an estimate of the differences among the adjusted group means as a measure of the differences between groups which will not be affected by differences in size composition (values of x) of the samples from the different groups (Kendall 1946, p. 244). Geometrically, in this case, the lines are parallel, so that the distance between lines is constant for all values of x.

In the case where a single regression coefficient does *not* represent the effect of x on y for all groups, geometrically where the lines are not parallel, any measurement of the distance between lines will depend on the value or values of x employed for the measurement of the distance. Differences between corrected group means will, then, not be independent of the x values. Geometrically, the distances between regression lines will be dependent upon the selection of the place where the distances are measured. In this situation, obviously, differences between adjusted group means are of small value in measuring differences between groups, when the values of x are selected arbitrarily.

Godsil's statistic (Godsil 1948, p. 9, table 4), the mean-square deviation of the sample regression line of the group from the sample regression line of all data pooled, based on curvilinear regressions, is similarly dependent on the distribution of the x values of the variates composing the groups, since the regression coefficients are not equal (the lines are not parallel). Its employment as a standard for judging differences between regions as compared with differences among groups within the region is, therefore, subject to strong objection.

It seems, then, that where the groups within a region differ in their regression coefficients, as is true in the present instance, we have no method of measuring with any precision the differences among these groups as a basis of judging whether a further sample from another region could reasonably be expected to belong to the same population as that from which the groups in question were drawn. Of course, in the event the regression coefficient itself is not size-connected, it may be used to characterize the group, and one might compare the variation among group regression coefficients with the observed value of the regression coefficient from the further sample from another region (e. g. table 7).

Pending development of a method of precise analysis, comparison of differences among regression lines within regions with differences between regions does not appear to be very fruitful, except in those cases where the difference between regions is so very much greater than differences among samples within a region that it is quite apparent from a simple graph of the data and no precise method of analysis is required.

As a practical procedure it appears best, perhaps, to select fish from each region from many different schools, and of sizes that will cover the entire range available, and then, in comparing data between regions by covariance analyses, to compare samples of similar size range. In this manner any variation between groups within the region will tend to be assimilated into the variance of the total sample for the whole region, and the total sample will be nearly representative of the population of the region.

Other dimensions

Comparison of the regression of diameter of iris on head length of Hawaiian specimens with that of Costa Rican specimens indicates that the relation is different in the two regions. The relations and the means of the two variates for each 10 centimeters of total length are plotted in figure 11.

Comparison of Hawaiian and Costa Rican data respecting regressions of length of maxillary on head length, body depth on total length, and weight on total length indicated that in each case the two samples might have been drawn at random from a single population so far as these characters are concerned.

Counts of gill rakers

Counts of total gill rakers of 188 Hawaiian tuna (table 1) have a mean value of 29.66 with a standard error of .0870. Schaefer's (1948) Costa Rican data on 45 specimens have a mean value of 30.60 with a standard error of .186, while Godsil and Byer's (1944) counts of 60 American-west-coast specimens have a mean of 30.35 with a standard error of .146. Comparison of the Costa Rican and Godsil and Byer's data yields a t value of 1.06, so that the null hypothesis is reasonable and we may pool these data to estimate the mean gill-raker count of yellowfin from the American west coast as 30.46 with a standard error of .116. The difference of .80 between this value and the Hawaiian mean is associated with a t value of 5.52.

We have verified from our Hawaiian data that there is no correlation between size of fish and gill-raker count. This character seems to offer good possibilities for racial analysis of tunas for that reason, since it will avoid the difficulties in comparisons which plagued us in regression analyses.

DISCUSSION

Hawaiian yellowfin tuna differ from those of the American west coast in having, on the average, longer pectoral fins at the same fish size, and this difference is greater for the larger fish. The same is true of the second dorsal and anal fins, but in these cases the fins of the Hawaiian fish also grow at an accelerated rate compared to west-coast fish, so that the difference in fin lengths among the largest fish sizes is very striking. The first dorsal spine appears to be consistently shorter among Hawaiian fish, while the longest dorsal finlet is longer.

Among Hawaiian fish, the distance from tip of snout to the posterior edge of the opercle and to the various fin insertions increases, relative to total length, more slowly than among west-coast fish so that all these dimensions are shorter, on the average, for the large fish from Hawaii than for west-coast fish of comparable size. From this it is evident that the posterior part of the trunk grows faster among Hawaiian fish so that at large sizes, say above 700 or 800 mm., the posterior part of the body is more elongate than among west-coast fish of similar sizes.

On the basis of the magnitude and consistency of these differences between the biometric charac-

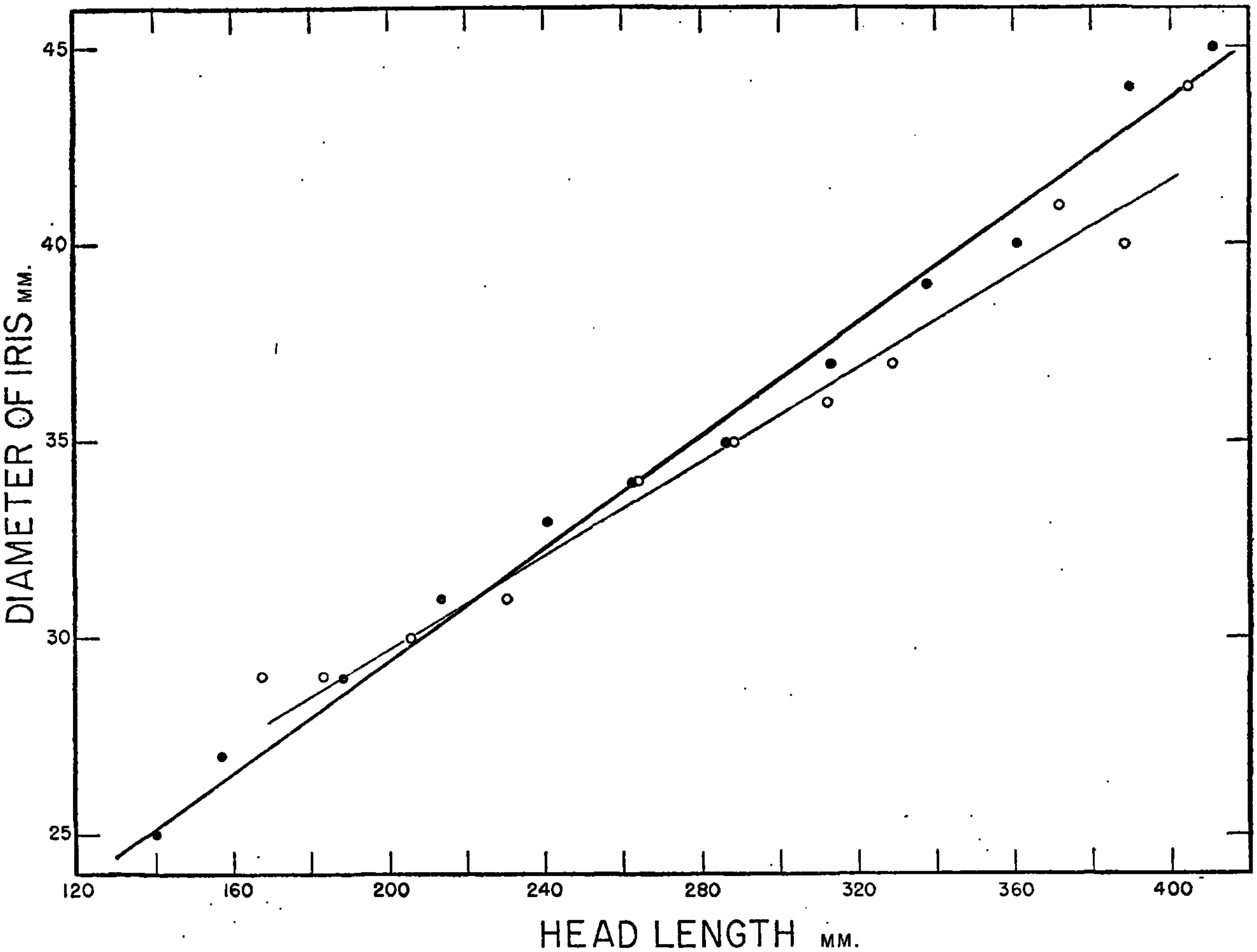

FIGURE 11.—Relations between diameter of iris and length of head. Open circles and fine line represent Costa Rican data; solid circles and heavy line represent Hawaiian data.

teristics of yellowfin tuna from the Hawaiian Islands and from the American west coast, there is no doubt that these two populations are to be regarded as distinct. The possibility of some mixing between them is not excluded, but if any exists it must be sufficiently small to permit the two populations to maintain their characteristic differences.

The statistical comparison of body-proportion data on tunas from different regions by regression analysis is beset with difficulties which are beyond the scope of this paper to deal with, and which seem not to be critical in this instance where the differences dealt with are of sufficient magnitude that sensitive methods are not required. The problem merits, however, further attention since it will become acute where differences to be measured are small.

This problem may be avoided by employing denumerable characters which are not size-connected. Gill-raker counts seem to be a useful character of this sort. The Hawaiian and west-coast yellowfin-tuna populations are quite distinct with respect to mean gill-raker count.

The fact, brought out by this study, that the yellowfin tuna of the central Pacific belong to a population distinct from that along the American west coast, has important implications in the development and management of the tuna fisheries. Since the yellowfin tuna of these regions belong to different populations which do not freely intermix, a fishery on one can have no effect on the abundance of the other. The fishery along the west coast is not tapping the entire yellowfin-tuna resource of the Pacific.

The various biometric differences demonstrated herein are of about the same magnitude as the differences between yellowfin tuna from the waters of the American west coast and from the Atlantic off Africa (Schaefer and Walford 1950). In some cases, such as the lengths of second dorsal and anal fins, the differences between the two samples from the Pacific are even more striking than the differences between African and American west-coast samples. If it is borne out by further study that the variation within oceans is about as great as the variation between them, it will be necessary to regard all the yellowfin tunas as belonging to a single species. It is particularly desirable that a series of specimens be examined from the Indian Ocean, whence comes the type of *N. argentivittatus*, which has priority among the several descriptions of species of *Neothunnus*, in order to settle the question of nomenclature.

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