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A Racial Study of the Pacific Mackerel, Pneumatophorus diego

By

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1. INTRODUCTION1

1.1. THE FISHERY

The Pacific mackerel (Pneumatophorus diego) is one of the more important commercial fishes found in California waters. It is fished intensively off Southern California, the great bulk of the catch being delivered to canneries located at Los Angeles and Long Beach Harbors and at Newport Beach. Landings at San Diego are erratic, though appreciable quantities have been delivered there in past years. Small amounts of mackerel are caught off Central California, but over 95 percent of the state-wide catch is made between Point Conception and the Mexican border.

The Southern California mackerel canning industry started in 1928, but demand was limited until 1933. Since that time, a virtually unlimited market has existed but the total catch has fluctuated widely and the trend has been downward since 1936. About 130,000,000 pounds were landed in the Los Angeles-Newport Beach area during the best season, 1935–1936, and some 32,000,000 pounds during the worst season, 1950–1951. Croker (1933, 1938) gives detailed accounts of the early years of the fishery, and more recent developments are presented by Roedel (1952).

1.2. BIOLOGICAL KNOWLEDGE

Mackerel have been taken from the Gulf of Alaska (Rounsefell and Dahlgren, 1934) south and into the Gulf of California. They are uncommon north of Monterey Bay but are very abundant off Southern California and off much of the Pacific Coast of Baja California. Their presence in the Gulf of California was not demonstrated until 1939 (Roedel, 1948), and nothing is known of the magnitude of the population found there.

The early life history is fairly well known (Fry, 1938a, b; Roedel, 1949). Eggs and larvae up to 11 mm. have been described. Spawning appears largely confined to inshore waters less than 100 fathoms in depth; both eggs and larvae have been collected along the Pacific Coast from Southern California to Cape San Lucas and into the eastern portion of the Gulf of California a distance of about 250 miles. Surface water temperatures ranged from 59 degrees to 75 degrees F. at stations where eggs were collected. The spawning season is known to extend from January through August, and apparently starts earlier in the Gulf than it does along the Pacific coast. Limited surveys from Point Conception to Monterey Bay failed to produce any evidence of spawning, but juveniles have been captured near Monterey.

Mackerel seldom exceed a length of 40 cm. and a weight of two pounds. The largest specimen known was 630 mm. total length and weighed 6.36 pounds (Roedel, 1938).

An extensive tagging program revealed that mackerel from as far north as Oregon and as far south as central Baja California eventually reached the Southern California fishing grounds (Fry and Roedel, 1949).

Recent studies (Fitch, 1951) have shown that age may be determined accurately through the fifth year from otolith readings. The commercial catch in recent seasons has been dependent largely on fish one to three years old and the fish do not mature until their second or third year. The future of the fishery is, consequently, not bright, and the magnitude of the catch is and probably will remain a function of spawning success from year to year.

1.3. ACKNOWLEDGMENTS

Especial thanks are due Mr. D. H. Fry, Jr., who directed the Pacific mackerel program of the California Department of Fish and Game from 1928 through 1946. While this analysis and concusions were made by the writer in 1950 and 1951, the original study was planned by Mr. Fry and directed by him during its initial stages. Many staff members of the department assisted in various ways both at sea and ashore. I am particularly grateful to Mr. C. R. Clothier for his help in preparing skeletons and in making meristic counts.

The material from British Columbia was sent by Dr. J. L. Hart of the Fisheries Research Board of Canada. His cooperation is gratefully acknowledged.

Finally, I wish to express my appreciation to Drs. W. H. Rich and D. E. Wohlschlag of Stanford University for their assistance and advice, particularly in reference to statistical methods.

2. PURPOSE

of fundamental importance in building a practical management program for this species is a knowledge of the movements of the fish within their broad range. Is the Southern California fishery drawing on one of several relatively isolated populations or is it drawing from the entire population found along the North Pacific Coast? First the tagging program and later the present population study were undertaken in an attempt to answer this question.

The purpose of the population study was to determine whether or not mackerel taken from different regions along the coast formed physically distinguishable groups. If such groups were found to exist, it could be presumed that those differing from the group found off Southern California either did not enter the fishery of that region or entered in relatively negligible quantities. If fish from all regions considered formed a reasonably homogeneous unit, as far as physical characters are concerned, it would, of course, demonstrate nothing as to whether interregional movements did in fact take place but would show only that the evidence of physical characteristics did not rule out such an occurrence.

The population study thus formed a complement to the tagging experiments, offering an extension in that it included samples from British Columbia, the southern portion of Baja California and from the Gulf of California—regions in which it did not prove practicable to mark fish.

3. MATERIAL

3.1. SOURCE AND CONDITION

The pertinent data regarding each sample used in the study are given in Table 1, while the several collecting stations are indicated in Figure 1.

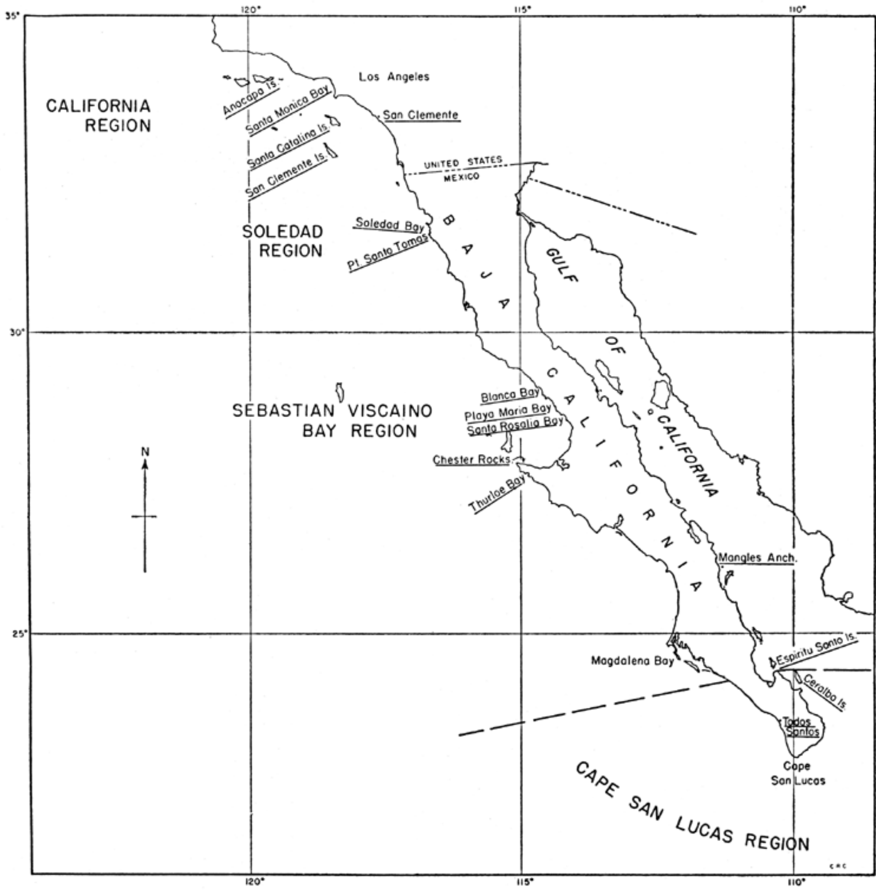

FIGURE 1. Southern California and Baja California showing collecting stations (underlined) and geographic regions

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The Mexican material was collected in the course of three research trips made by the Department of Fish and Game research vessel N. B. SCOFIELD. All collections from the Gulf of California and from the southern portion of the peninsula were obtained on the first two trips, one made in February, 1940, under the direction of Mr. D. H. Fry, Jr., and the other made in February, 1941, under the direction of the writer. Collections in the northern and central sections were made by the writer during the third trip in October and November, 1941.

The Southern California samples were obtained from commercial vessels making deliveries at Los Angeles Harbor canneries. Collections were made in October, 1939, August, 1940, in March, August, September and November, 1941, and in February, March and April, 1942. Most of

TABLE 1

List of Samples

Date	Sample number	Place collected	Total in sample	Number used in each study				
				Studies based on all fish			Studies based on size categories Haemal arch and braces	
				Haemal arch	Haemal braces	Head length	Small only	Large only
California Region								
9 Oct. 39	1	"Southern California"	11	11	11			11
10 Oct. 39	2	San Clemente (town)	26	26	26			26
11 Oct. 39	3	Anacapa Island	27	27	27			27
18 Oct. 39	4	Anacapa Island	26	26	26			26
12 Aug. 40	5	Santa Catalina Island	50		50			50[1]
14 Aug. 40	6	San Clemente Island	50		50			50[1]
16 Aug. 40	7	Santa Catalina Island	50		50			50[1]
12 Mar. 41	8	Santa Catalina Island	98	98	98		58	40
27 Aug. 41	9	Santa Catalina Island	99	99	99		99	
5 Sep. 41	10	Santa Monica Bay	50	50	50			50
10 Nov. 41	11	Santa Catalina Island	77	77	76	64	76[2]	
9 Feb. 42	12	Santa Catalina Island	56	56	56		56	
10 Feb. 42	13	Santa Catalina Island	20	20	20			20
13 Feb. 42	14	Santa Catalina Island	25	25	25			25
19 Feb. 42	15	Santa Catalina Island	40	40	40			40
19 Feb. 42	16	Santa Catalina Island	35	30	30	35	30	
9 Mar. 42	17	Anacapa Island	50	50	50	49		50
10 Mar. 42	18	"Southern California"	49	49	49			49
11 Mar. 42	19	Santa Catalina Island	31	23	23	31	23	
10 Apr. 42	20	Santa Catalina Island	27	27	27	27		27
		Totals	897	734	883	206	342	541

TABLE 1
List of Samples

British Columbia Region								
Rec'd Sep. 40	1	Unknown	60		60			60[1]
Rec'd Jun. 44	2	Unknown	81	81	81			81
		Totals	141	81	141			141
Soledad Region								
13 Oct. 41	1	Soledad Bay	153	153	153	133	98	55
14 Oct. 41	2	14 mi. S. Santo Tomas Pt.	43	43	43	43	43	
		Totals	196	196	196	176	141	55
Viscaino Region								
17 Oct. 41	1	8 mi. NW. Blanca Bay	91	91	90	82	90[2]	
18 Oct. 41	2	Blanca Bay	82	82	82	80	8	74
19 Oct. 41	3	Playa Maria Bay	118	118	118	110	14	104
20 Oct. 41	4	Santa Rosalia Bay	34	34	34	33		34
22-24 Oct. 41	5	Thurloe Bay	124	124	124	113		124
1 Nov. 41	6	Chester Rocks	11	11	11	11		11
		Totals	460	460	459	429	112	347
Cape San Lucas Region								
20 Feb. 41	1	Ceralbo Island	379	379	379	328		230
22 Feb. 41	2	Todos Santos	262	262	262	196		262
		Totals	641	641	641	524		492
Gulf of California Region								
2 Feb. 40	1	Espiritu Santo Island	17	17	17			17
5 Feb. 40	2	Mangles Anchorage	61	61	61			49
18 Feb. 41	3	Espiritu Santo Island	126	126	126	114		126
19 Feb. 41	4	Espiritu Santo Island	38	38	38	34		38
		Totals	242	242	242	148		230
		Grand totals	2,577	2,354	2,562	1,483	595	1,806

[1] No haemal arch counts.
[2] One additional haemal arch count.

these fish were caught at Santa Catalina Island, though other fishing grounds are represented as well.

Neither catch localities nor dates of capture are known for the two British Columbia samples collected by Dr. Hart. The first was received in September, 1941, and the second in the spring of 1944.

All of the specimens collected in Mexican and Southern California waters were frozen. Both British Columbia samples were salted.

3.2. GEOGRAPHIC REGIONS

As shown in Table 1, the samples are separated on a geographic basis into six groups taken in the British Columbia, California, Soledad, Viscaino, Cape San Lucas and Gulf of California regions. The first four form logical entities, representing collections made in British Columbia, Southern California, northern Baja California, and central Baja California (Sebastian Viscaino Bay), respectively. The two remaining, the Cape and Gulf regions, are not clear cut geographically. In preliminary work, they were considered as a single region, not without some misgivings because Todos Santos on the Pacific side of the peninsula is about 125 miles by sea from Ceralbo Island, the southernmost collection station in the gulf itself. It was found that the samples taken in this southern region as originally defined were composed of two apparently quite different groups of fish. Those taken at Mangles Anchorage and at Espiritu Santo Island proved similar but differed from those collected at Ceralbo Island and at Todos Santos which were also similar. The separation into two regional groups followed. That such differences should be found is particularly surprising when one considers that Ceralbo and Espiritu Santo Islands are within about 20 miles of each other. The significance to be attached to these differences is discussed in a following section.

3.3. SIZE OF FISH

The distribution in length of the fish collected in each of the regions is shown in Figure 2. All measurements were made from snout to fork of tail and recorded to the nearest millimeter. Data are lacking for the British Columbia material and for the 150 fish in California samples 5, 6, and 7 because these fish were not measured. Both the British Columbia and the unmeasured California samples were composed of relatively large fish, all of which were more than 25 cm. in length.

Excepting the California region, all samples were taken at random. In California, the samples were selected for size. For this reason, the frequency must not be regarded as having significance in respect to size distribution but rather as showing the sizes available for study. The frequencies for other regions might be regarded as having some significance in respect to size distribution despite the fact that they combine collections made over a considerable time interval. However, it is the sizes available, not the nature of the distribution, which is of importance in this study.

It was not possible to determine the ages of individual fish. From preliminary age studies based on otolith readings it is reasonably certain, however, that the groups of small fish from the Viscaino and Soledad

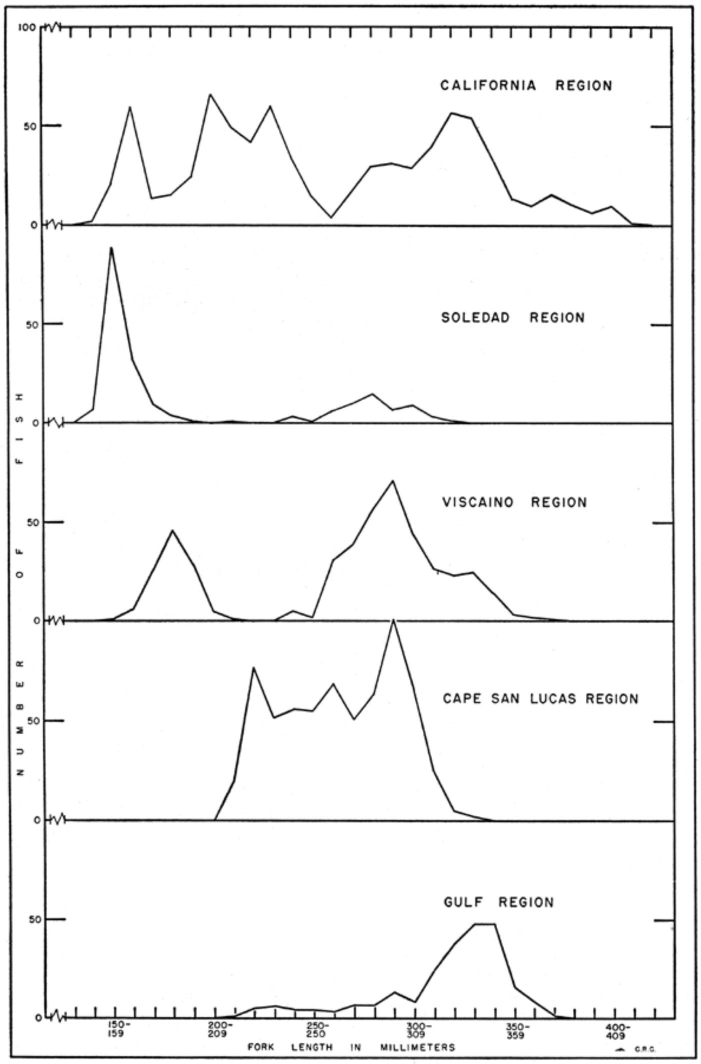

FIGURE 2. Length frequencies by region. The British Columbia material and 150 California fish were not measured

FIGURE 2. Length frequencies by region. The British Columbia material and 150 California fish were not measured

regions consist of representatives of the 1941 year class. Model values for these groups are 150–159 mm. and 180–189 mm. respectively. In the California region, samples 9, 11, 12, 16 and 19 can also be presumed to be drawn largely from the 1941 year class. The mode at 160–169 mm. is comprised of these fish as is a large part of the mode at 200–209 mm. Different collecting dates account for the bimodal distribution. Most of the smaller fish were collected in August and most of the larger fish the following February and March.

Subsequent studies (Fitch, 1951) have demonstrated the validity of otolith readings as means of age determination and, further, verify the technique used in the preliminary studies. The assumption that the small fish represented the 1941 year class is strongly reinforced by Fitch's work.

In certain vertebral counts, it was found that these small fish, particularly those from the Viscaino region, differed considerably from large fish collected in the same region. Consequently, analyses were based on small and large size categories as well as on the basis of all fish. The implications to be drawn from these differences which appear to be related to age are considered in a following section.

By drawing the line between small and large fish at 240 mm., considering all fish 239 mm. and less as small, the 1941 year class is fairly well segregated in the "small" category. One sample of California fish (No. 8) collected in March, 1941, and probably representing the 1940 year class is also included in the small category. The 58 specimens in this sample differed in no respect from the other samples of small California fish.

The division into large and small size groups has little meaning when applied to the Cape and Gulf samples. Because of the earlier collecting dates, no fish from the 1941 year class were taken there. Most of the fish from the Gulf were over 240 mm., and the small fish (probably from the 1940 year class) from the Cape did not dominate the samples. These regions were not included in comparisons based on "small fish only."

4. METHODS

4.1. MERISTIC COUNTS

Meristic counts were centered on variations in position of structures of the vertebral column with respect to the number of the vertebra on which they first occurred. The most variable characteristic proved to be the position of a structure extending from the centrum to the haemal arch (Figure 3). As far as can be determined, this structure has not previously been named; it is not discussed by Starks (1910) nor by Kishinouye (1923), Ford (1937) or Clothier (1950), although it is visible in drawings in the latter three papers. The term haemal brace is proposed and applied to the structure in this paper. The haemal brace may be either paired or single on the vertebra of first occurrence, though it is most frequently paired. The first one may be as far forward as the fourteenth or as far back as the eighteenth vertebra. The degree of variation encountered is illustrated by the three samples, totaling 150 fish, collected during August, 1940, in Southern California. The first brace was paired in 98 specimens, appearing on the fourteenth vertebra in two.

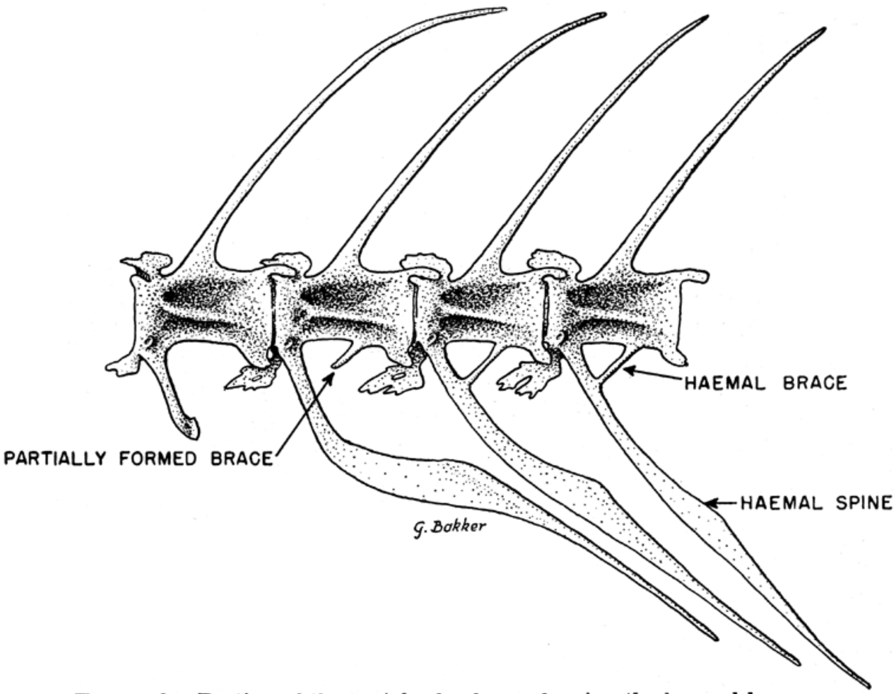

FIGURE 3. Portion of the vertebral column showing the haemal brace

FIGURE 3. Portion of the vertebral column showing the haemal brace

On the remaining 52 fish the brace first appeared as a single structure and the following combinations were noted:

1st single brace on vertebra	*1st pair of braces on vertebra*	*Number of individuals*
14	15	7
14	16	2
15	16	39
15	17	2
16	17	2

An incomplete haemal brace extending from the centrum but not reaching the haemal arch was found in a number of specimens (Figure 3). These incomplete braces were not included in making the counts.

Routine counts included:

1. Position of the first haemal arch;
2. Position of the first haemal spine;
3. Position of the first haemal brace (paired or single);
4. Position of the first paired haemal brace;
5. Total number of vertebrae including the urostyle.

The number of vertebrae and the position of the first haemal spine did not show sufficient variation within and between geographic regions to warrant detailed analysis.

4.2. PROPORTIONAL MEASUREMENTS

Proportional measurements were made on many of the fish collected after 1939. All measurements showed some variation between regions.

Variation was most pronounced in the relation of head length to fork length and this character alone was studied in detail. Fork length is defined as the length from the tip of the snout to the tip of the central rays of the caudal fin. Head length is defined as the distance from the tip of the snout to the posterior edge of the operculum along the center line of the body; it is a slant measurement, not the distance in the plane of the body.

A standardized procedure was followed in handling the specimens and all measurements were made by the writer so as to avoid the effect of different personal biases. Fork length was taken to the nearest millimeter with the fish lying on a measuring board, its snout touching a perpendicular. Head length was measured with calipers read to the nearest millimeter.

4.3. STATISTICAL METHODS

For this problem, a method of analysis was required which would indicate, first, whether or not the fish caught in the several regions formed a homogeneous population. If a heterogeneous population was indicated, it would become important to know whether the samples from each region were in themselves homogeneous and whether homogeneous subpopulations composed of fish from one, two or more regions could be detected.

The conventional chi square test of homogeneity was employed in evaluating the significance of differences in the initial position of vertebral structures. The data were arranged in R x C tables and the expected number for each cell computed from the border totals. Then, with o = the observed frequently and c = the expected, $[x]^{2} = (o-c)^{2} 2/c$ with degrees of freedom, df, = (R—1) (C—1). The probabilities associated with the various values of chi square were determined from published tables. It is generally felt that the expected number of occurrences in any given cell should exceed five if the chi square test is to be properly applied. In a few of the tests, one or two cells are, by this standard, under-represented and the probabilities obtained are to be interpreted with this in mind. It is not believed that this under-representation causes any gross errors in the general magnitude of the probabilities. In most cases, it was possible to avoid poorly represented cells by combining counts, and the expected numbers as a rule are greater than ten.

In evaluating the significance of differences in head length the methods of regression analysis were employed. The technique for the analysis of covariance as presented by Snedecor (1946, Chapter 12) was followed and is described in greater detail under "Head Length and Fork Length."

5. RESULTS

5.1. NUMBER OF VERTEBRAE

The most constant character checked in the course of this study proved to be the total number of vertebrae. Counts were made on 2,352 fish and of these 2,342 had 31 vertebrae including the urostyle, three had but 30, and seven had 32 (Table 2).

TABLE 2

Total Number of Vertebrae

Region	Number of vertebrae			Number of fish
	30	31	32	
British Columbia	0	81	0	81
California	2	728	2	732
Soledad	0	195	1	196
Viscaino	0	459	1	460
Cape	0	638	3	641
Gulf	1	241	0	242
Totals	3	2,342	7	2,352

TABLE 2

Total Number of Vertebrae

TABLE 3

Position of the First Haemal Spine

Region	Vertebra number			Number of fish
	14	15	16	
British Columbia	0	78	3	81
California	6	720	6	732
Soledad	2	192	2	196
Viscaino	9	447	3	459
Cape	4	633	3	640
Gulf	2	240	0	242
Totals	23	2,310	17	2,350

TABLE 3

Position of the First Haemal Spine

5.2. FIRST HAEMAL SPINE

The first haemal spine appeared quite constantly on the fifteenth vertebra. Its position was noted on 2,350 individuals (Table 3); it was found on the fourteenth vertebra in only 23 cases and on the sixteenth in but 17.

5.3. FIRST HAEMAL ARCH

Haemal arch counts were made on 2,354 fish. The structure was first formed on the eleventh vertebra in over 90 percent of the cases and on either the tenth or the twelfth vertebra in the remainder.

The distribution of the counts for the various regions together with the expected distributions and the resultant chi square values are presented in Appendix A, and the probabilities are given in Table 4 as well. Tests among regions indicated that:

1. There were tremendous differences among the six regions, the value of P falling far below the .000001 level of significance.
2. Differences among the four northern regions were not significant ($P>.05$).
3. Differences between the two southern regions, Cape and Gulf, were not significant ($P>.05$).
4. Differences between Viscaino, the southernmost of the northern regions, and Cape, the adjoining region to the south, were highly significant, the value of P falling about at the .000001 level.

Expected numbers fall below five in two cells in the first two tests and in one cell in the third. It seems safe to consider that this does not alter the general order of the results and that fish in the two southern regions can be regarded as distinguishable from those found to the north.

No tests were made of the significance of differences among samples within regions because of the small numbers at vertebrae 10 and 12 for individual samples.

5.4. FIRST OCCURRENCE OF A HAEMAL BRACE

A haemal brace first occurred as either a paired or a single structure on the fifteenth or the sixteenth vertebra in over 90 percent of the 2,562 specimens examined. It was found on the fourteenth vertebra in most of those remaining, but was not developed until the seventeenth vertebra in 14 fish and the eighteenth in two.

TABLE 4

Summary of Results of Chi Square Tests of the Significance of Differences in the Initial Appearance of Vertebral Structures, Giving Probabilities of Homogeneity. See Text

Comparison	Value of P		
	Haemal arch	First brace	Paired brace
All regions	<.000001	<.000001	<.000001
Four northern regions, all fish	>.05	>.05	>.05
Four northern regions, large fish		.05	>.05
Four northern regions, small fish [1]		.0001	.001
Two southern regions	>.05	<.0001	.000001
Viscaino-Cape, all fish	.000001	<.000001	<.000001
Viscaino-Cape, large fish		.00001	<.000001
Soledad-Viscaino, small fish		<.0001	<.001
California-Soledad, small fish		>.05	>.05
British Columbia—samples		>.05	>.05
California—samples		.01	>.05
California—large vs. small		>.05	>.05
Soledad—samples		>.05	>.05
Viscaino—samples, all fish		<.0001	<.01
Viscaino—samples, large fish		>.05	.05
Viscaino—large vs. small		<.000001	.001
Cape—samples		>.05	>.05
Gulf—samples		>.05	>.05

[1] No small fish from British Columbia.

TABLE 4

Summary of Results of Chi Square Tests of the Significance of Differences in the Initial Appearance of Vertebral Structures, Giving Probabilities of Homogeneity. See Text

The actual and expected distributions of the counts together with the associated chi square values and probabilities of homogeneity appear in Appendix B and the probabilities also appear in Table 4.

As for the haemal arch, differences among the six regions and between the Viscaino and Cape regions were extreme (P<.000001), and differences among the four northern regions were not significant (P>.05). Unlike the haemal arch, differences between the two southern regions were pronounced (P<.0001). Among the Cape fish, the brace was first found on the sixteenth vertebra more often than was the case elsewhere.

Differences among samples within regions were not significant (P>.05) for British Columbia, Soledad, Cape and Gulf, were more pronounced in California (P = .01) and were significant in Viscaino (P<.0001). It was suspected that the variation in Viscaino was associated with differences between age classes, for a sample (number 1) of 90 small fish believed to represent the 1941 year class contributed 17.5 to the total chi square of 26.5. The remaining samples consisted almost entirely of large fish, containing but 22 small fish, eight in sample 2 and 14 in sample 3. Differences among samples of large fish proved nonsignificant (P>.05) and differences between large and small size groups highly significant (P<.000001). This suggested that the differences among California samples might also be associated with size, but a comparison of the two size groups gave nonsignificant results (P>.05).

The pronounced differences between small and large Viscaino fish led to further tests on a size basis. It was found that differences were not significant (P = .05) among large fish in the four northern regions, but there were highly significant differences between large Viscaino and Cape fish (P = .00001). The small Viscaino fish proved sharply set off from the small Soledad and California specimens (for the three regions P = .0001; for Viscaino and Soledad P<.0001). It is obvious from an inspection of the data that the small Viscaino fish were unlike other material collected in that the first brace was first found on either the fourteenth or the fifteenth vertebra in a high proportion of the cases.

In summary, fish from the four northern regions were strikingly differentiated from those in the Cape region, and, unlike the haemal arch study, the Cape fish were separable from those in the Gulf region. The small Viscaino fish formed a group apart, and the results suggest that differences in environmental factors between spawning grounds in any given year may produce variations in meristic characters as pronounced as those between size or age classes. While the differences could be considered as giving evidence of a distinct stock, this would presume two stocks—one of large fish, one of small—within the Viscaino region itself, hardly a likely happening. The fact that the four northern regions were not separable on an "all fish" basis adds weight to the belief that the observed differences can be attributed to age and spawning ground—that, given time, the fish mingle and these factors are obscured in composite samples. By any hypothesis, the fish from the Cape can only be thought of as a distinct (e.g. presumably nonintermingling) group so far as the northern regions are concerned.

5.5. FIRST PAIR OF HAEMAL BRACES

The first pair of haemal braces was found most often on the sixteenth vertebra, frequently on the fifteenth, rather rarely on the seventeenth and in scattered cases on the fourteenth and eighteenth. One would anticipate a close correlation between this count and the one preceding, and the results of the chi square tests (Appendix C and Table 4) proved to be essentially the same as for the first occurrence of a brace. The differences in results in no case were sufficient to alter the conclusions previously drawn. The Viscaino samples gave less evidence of heterogeneity, but the value of P still fell below the .01 level (vs<.0001); differences between size groups in this region remained significant but less strikingly so ($P = .001$ vs $P<.000001$). The small Viscaino fish again differed from those in California and Soledad ($P = .001$ vs $P = .0001$). There was no evidence of heterogeneity among the California samples ($P>.05$). Fish from the Cape region once more proved unlike those found elsewhere.

5.6. HEAD LENGTH AND FORK LENGTH

Head and fork lengths were measured on 1,483 fish. No departure from linearity over the size ranges involved was observable within regions (Figure 4), and the data were handled on the basis of a straight line relationship.

To test whether differences within and between regions should be considered the result of chance variation or as representing probable true differences in the relative length of the head necessitated employing the methods of regression analysis and the analysis of covariance as presented by Snedecor (1946, Chapter 12). Two questions are posed for any group of samples under consideration. First, can the regression coefficients be considered as drawn from a common population—e.g., are the differences in the slopes of the repression lines likely a result of sampling error? Second, if homogeneity is indicated so far as slope is concerned are there differences in adjusted means around a common regression line—e.g., after making allowance for differences in fork lengths, do the mean head lengths of the several samples differ significantly? This second test, then, measures differences in the relative position of the regression lines with respect to mean head length, as opposed to differences in slopes. If the first test indicates heterogeneity, the second becomes inappropriate, for it is based on the assumption that use of a common regression line for the samples is legitimate, and that such a line best represents the true population regression.

In handling the mackerel data, samples within regions were first tested and then various pairs of regions. The original measurements and the sums of variates, squares and products are presented in Appendices D and E. The regressions for each sample and for each region (there are no data for British Columbia) were computed; statistics describing the regressions for each region are presented in Table 5 and the regression lines are plotted in Figure 5.

In performing the first test, that for differences among regression coefficients, the least sum of squared deviations for each sample under consideration was first computed ($Sd_{y.x}{}^2 = Sy^2 - (Sxy)^2 / Sx^2$; X = fork length and Y = head length). The values for each sample appear, together with similar data for each region, in the next to the last column of Appendix E. Two degrees of freedom are lost for each sample. The total of the individual sample sums is, by the principal of least squares, the smallest possible for that group of samples. Using the California region as an example (Table 6), this sum equals 237.5 (from Appendix E). What is in effect an average sum for the samples was then obtained by adding

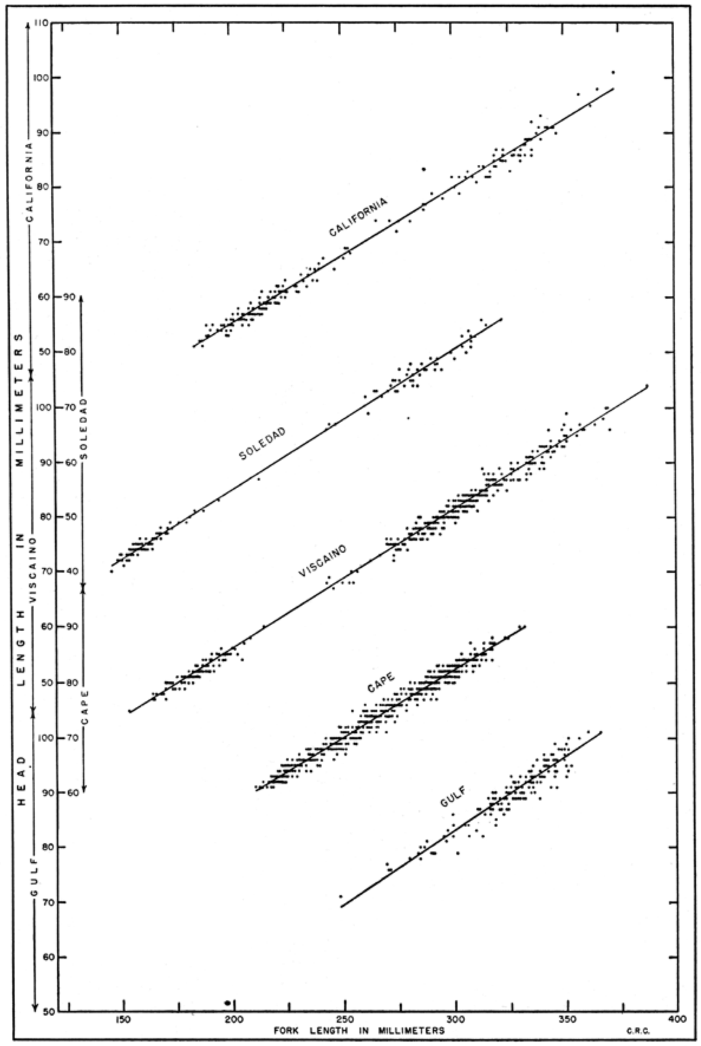

FIGURE 4. The regression of head length upon fork length for each region, showing the distribution of the individual variates. Data from Table 5 and Appendix D.

FIGURE 4. The regression of head length upon fork length for each region, showing the distribution of the individual variates. Data from Table 5 and Appendix D

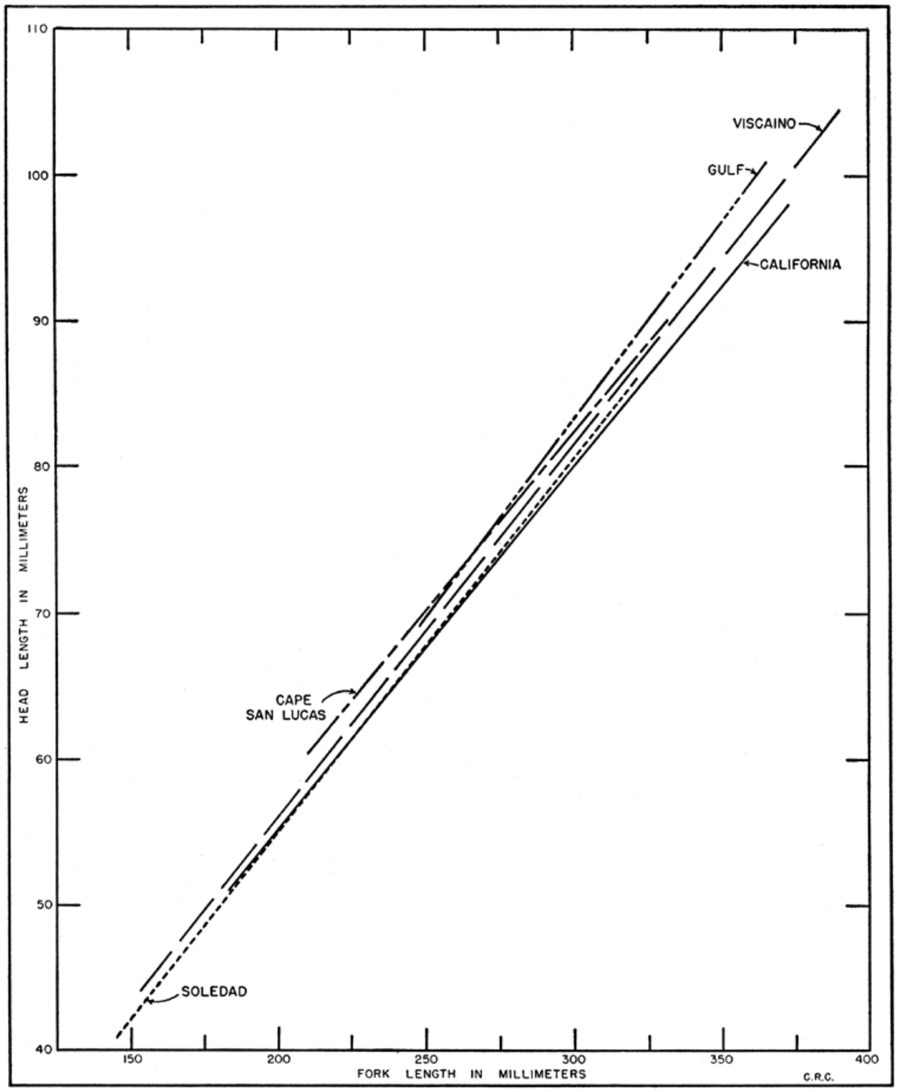

FIGURE 5. The regression of head length upon fork length for each region. Data from Table 5.

FIGURE 5. The regression of head length upon fork length for each region. Data from Table 5

the individual sums of squares and products (Sx^2, Sxy, Sy^2) and computing a second value of $Sd_{y.x}{}^2$ from the totals. Unless the regression coefficients for each sample are identical, this average sum of squared deviations will be larger than the sum of the individual sample sums. One degree of freedom is lost for each sample and one for the computation of the sum of squared deviations. For California (Appendix E), $Sd_{y.x}{}^2 = 3520 - (13201)^2 / 53366 = 254.5$. A measure of the significance to be attached to variations in the sample regression coefficients was obtained by determining the mean square of the difference between the two sums (for California, 4.25 with 4 degrees of freedom, Table 6) and

TABLE 5

Statistics Describing the Regression of Head Length on Fork Length for Each Region

Region	Number of samples	Number of fish	Size range, mm. fork length	Mean fork length, $\bar{x}$	Mean head length, $\bar{y}$	Y intercept of regression line	Regression coefficient of y on x	Standard error of estimate
California	5	206	183-373	256.14	68.99	5.62	.2474	1.17
Soledad	2	176	145-322	197.39	54.37	4.09	.2547	0.92
Viscaino	6	429	153-391	277.99	75.80	5.13	.2542	1.68
Cape	2	524	210-332	266.42	74.10	9.12	.2439	1.20
Gulf	2	148	248-366	326.13	90.13	1.98	.2703	1.79

TABLE 5
Statistics Describing the Regression of Head Length on Fork Length for Each Region

TABLE 6

Analyses of Differences in Head Length, California Region

Data From Appendix E

Differences in Regression Slopes

	Sum of squares	Degrees of freedom	Mean square
Deviations from average "within samples" regression	254.5	200	------------
Deviations from individual sample regressions	237.5	196	1.21
Differences among sample regressions	17.0	4	4.25

F=4.25/1.21=3.51 P=.01—

Differences in Adjusted Means

	Sum of squares	Degrees of freedom	Mean square
Deviations from region regression line	276.9	204	------------
Deviations from average "within samples" regression	254.5	200	1.27
Differences	22.4	4	5.60

F=5.60/1.27=4.41 P=.001—.01

TABLE 6

Analyses of Differences in Head Length, California Region Data From Appendix E

then dividing this value by the mean square deviation from the individual sample regressions (1.21 with 196 degrees of freedom). The resultant value, F, is interpreted in terms of probability by use of tables. For California, F = 3.51 with 196 and 4 degrees of freedom. In this case, P lies just below .01 (the .01 level with 200 and 4 degrees of freedom is 3.41).

To measure the significance of differences in adjusted means, a least sum of squared deviations from all the variates without regard for individual samples was computed. The associated regression is a line of best fit for the pooled samples. Returning to the California region this sum was found to equal 276.9 with 204 degrees of freedom (Appendix E). The average "within samples" sum of squared deviations, considered, on the basis of the previous test to be a suitable estimate of population regression, was subtracted from this total sum of squares. The mean square of the difference was divided by the mean square of the average "within samples" sum of squares to obtain the appropriate value of F. The second portion of Table 6 shows the calculations. The F value of 4.41 with 200 and 4 degrees of freedom is well below the .01 level of significance but is greater than .001.

The differences among California samples, particularly those associated with the second test, are significant by any conventional interpretation of the P values. These probabilities can be interpreted as giving evidence that two or more genetically separable populations may be present or they can be considered to reflect differences between age groups and/or recruits from different spawning grounds. The latter hypothesis appears more probable in view of the results of tagging experiments which showed a general dispersion of marked fish throughout Southern

TABLE 7

Length of Head Relative to Fork Length—Results of Analyses of Differences Within and Between Regions

Comparison	Difference in slope of regression				Difference in adjusted means around common regression lines			
	Degrees of freedom		F	P	Degrees of freedom		F	P
	Samples	Fish			Samples	Fish		
California—samples	4	196	3.5	.01—	4	200	4.4	.001—.01
Soledad—samples	1	172	<1	>.05	1	173	1.6	>.05
Viscaino—samples	5	417	1.5	>.05	5	422	<1	>.05
Cape—samples	1	520	<1	>.05	1	521	<1	>.05
Gulf—samples	1	144	<1	>.05	1	145	2.1	>.05
California-Soledad	1	378	14.8	<.001				
Soledad-Viscaino	1	601	<1	>.05	1	602	119.8	<.001
Viscaino-Cape	1	949	16.9	<.001				
Cape-Gulf	1	668	20.5	<.001				

TABLE 7
Length of Head Relative to Fork Length—Results of Analyses of Differences Within and Between Regions

California waters (Fry and Roedel, 1949). In any event, the pooled data provide the only measure of the amount of variation to be found among mackerel on the Southern California fishing grounds. Pooling can of course be protested on the grounds that the use of a common regression line is not justified.

The same method was followed in the remaining "within region" comparisons and it was found that the samples from these four remaining regions could be considered as drawn from common regional populations, all values of P exceeding .05 (Table 7).

Similar tests were then made involving pairs of adjoining regions, disregarding individual samples and basing the computations on region regressions. Here it was found that differences between regression coefficients were significant ($P<.001$) in each case save Soledad-Viscaino ($P>.05$), and in this instance the differences in adjusted means were significant (Table 7).

These regional differences are far greater than those found associated with meristic characters, and from this study of proportional measurements one can only conclude that each region was characterized by distinct groups of fish: those in California and Soledad with relatively short heads; those to the south with progressively longer heads (Figure 5).

6. CONCLUSIONS

6.1. SUMMARY OF THE MORPHOMETRIC STUDIES

From the results of the several analyses it is possible to make a number of generalizations:

1. The mackerel population along the Pacific coast proved to be extremely heterogeneous.

2. Samples taken in the British Columbia, Soledad, Cape and Gulf regions gave no evidence of intraregional variation.

3. Samples taken in the California region showed some variation in the position of the first pair of haemal braces and marked variation in head length. These differences, evidenced by P values of .01 and less than .01 respectively, are regarded as representing the amount of variation normally to be expected among mackerel taken commercially off the Southern California coast.

4. Samples taken in the Viscaino region formed two distinct groups, one including small fish presumed to represent the 1941 year class, and the other, larger, older individuals. Differences were associated with the position of the haemal braces, these structures being found in a more anterior position in the small fish.

5. Fish from the four northern regions, British Columbia, California, Soledad and Viscaino, are not considered separable on the basis of vertebral characters. The observed differences were associated with the small Viscaino fish and are considered to reflect differences between year classes and spawning grounds.

6. Viscaino and Cape fish were sharply set apart in all respects, all P values falling far below the .001 level. The Cape fish were characterized by the more posterior appearance of the vertebral structures and by relatively longer heads.

7. Gulf fish were characterized by a longer head in relation to fork length than was the case in any other region coupled with a more anterior appearance of the haemal braces than was the case among Cape fish. They were strongly differentiated from the Cape fish in these respects and formed a unit apart on the basis of this study.

8. Five reasonably distinct populations among which little mingling would be expected can be postulated.

(a) A rather heterogeneous population found in the California region which was not separable from British Columbia material on the basis of vertebral characters. Data on head length were not available for British Columbia fish.

(b) A population in the Soledad region separable from the California material by the regression of head length on fork length.

(c) A population in the Sebastian Viscaino Bay area with marked variations between 1941 juveniles and older fish, a population which differed from those to the north only with respect to head length.

(d) A population found in the Cape San Lucas area on both the Pacific and Gulf sides of the Peninsula which was widely separated on all bases of comparison from the northern groups.

(e) A population in the Gulf differentiated from that in the Cape region.

6.2. COMPARISONS WITH TAGGING EXPERIMENTS

The conclusions just set forth are not compatible with evidence from tagging experiments (Fry and Roedel, 1949), for known movements of marked fish contradict them in part. Tagged fish from the Soledad and Viscaino regions were later recovered in both Southern and Central California. Those from Soledad were recaptured in large numbers. Those from the Viscaino region were found less often in proportion to the number tagged but were nevertheless represented in the catch. Representatives of both small and large size categories were included. Returns in Southern California from Southern California-tagged fish were far more numerous than were returns from Viscaino fish for the first two years after release. However, in the third and fourth years, returns from both regions were of the same magnitude. These results indicate that mingling occurred slowly but that migrations to or from Southern California over a period of time plus heavy fishing on the California fish in the first two years resulted finally in equal availability of the two groups on the fishing grounds. The separation of California and Viscaino populations is obviously not as complete as the study of physical characters alone would lead one to believe. While the total contribution of the Viscaino group to the fishery is far less as measured by tag returns, it is great enough to be of importance from the point of view of practical management.

Only 11 fish were tagged in the Pacific Northwest, these near the mouth of the Columbia River, but one of them was recaptured off Southern California. The British Columbia samples presumably originated farther north. No fish were tagged south of the Viscaino region.

6.3. EVALUATION

We are, then, faced with valid statistical differences in morphometric characters between fish taken in different geographic localities, differences which would, at face value, lead one to erroneous conclusions about the biological composition of the species.

If groups as dissimilar physically as those from Viscaino and Southern California mingle to a degree, what meaning can be attached to the results of the statistical analyses? Are the inter- and intraregional differences a measure of the effect of environmental factors on young fish, factors which might produce greater variation between year classes and between recruits from various spawning grounds than between any separate populations which might exist? If this were the case and the differences were a function of year class and spawning ground, in samples containing a wide size range and a number of year classes the effect of mingling variant groups should be complete and any interregional differences remaining would reflect actual differences in the populations, provided the sampling was truly random with respect to time and space and provided the samples contained proportional numbers of fish from each age group and spawning ground. This appears to have been generally true for the vertebral characters. Differences among fish from the four northern regions were associated with size, the small Viscaino fish forming the only strikingly differentiated group. Among large fish, any differences which might have existed between year classes and spawning grounds were obscured and there was no reason to postulate nonmingling populations on the basis of these characters alone.

The statistical differences in head length cannot be as easily interpreted in biological terms. Certainly no biological significance can be attributed to the differences in regression of head length between California and Soledad when the tag returns are considered.

The magnitude of the morphometric differences seems such as to rule out complete intermingling of Viscaino fish with California, although a degree of intermingling—larger than the morphometric differences would lead one to expect—is demonstrated by the tag returns.

Since some of the fish found in the Viscaino region eventually reached Southern California waters, what inferences can be drawn as regards the more southern regions in which tagging was not accomplished?

It seems extremely unlikely that fish from the Cape region contribute even a minimal amount to the fishery. The differences between Cape and Viscaino were emphasized by extremely low probabilities of homogeneity in every instance—less than one chance in a million that fish from the two regions were drawn from a common population on the basis of the position of the haemal braces.

On the other hand, it does not seem reasonable purely from a geographical standpoint to regard the Cape and Gulf populations as distinct. That separate populations should exist within a few miles of each other is scarcely credible unless they in fact differed in a specific sense. However, the differences in position of the haemal braces and in head length are such that on the basis of available evidence the two must be considered reasonably separate at very least.

As a final summation, with regard for results of both the population study and the tagging experiments, we can say that:

1. The Southern California mackerel fishery exploits to some degree the population found from the Pacific Northwest south to the vicinity of Sebastain Viscaino Bay in Central Baja California. Fish collected in this latter region differed physically from those taken farther north, but tag returns demonstrated that a proportion of them did move into Southern California waters. No estimate can be made of the actual contribution to the fishery from this area. From both the number of tags recovered in California and the magnitude of the physical differences it seems probable that relatively few Viscaino fish reach California waters. However, the region must be considered in drawing up a management plan for the fishery.

2. The sharp physical differentiation between fish collected in the Cape San Lucas region and those found farther north indicates that movement on the part of Cape fish into the fishery is highly improbable and that the population in this portion of the range may be disregarded as a source of supply.

3. The population in the Gulf is distinguishable from that of the Cape region. Though geographic considerations make it seem unlikely that nonmingling populations exist, the magnitude of the differences is such that very little interchange is to be expected.

7. SUMMARY

The Pacific mackerel (Pneumatophorus diego) ranges from Alaska into the Gulf of California but is fished intensively only off the coast of Southern California. Practical management of the resource is dependent upon knowledge as to whether the fishery is drawing from one of several separate populations or from the total population. The purpose of the racial study was to determine whether mackerel taken in different regions along the coast formed physically distinguishable groups.

A total of 2,577 specimens was examined, representing six geographic regions: British Columbia, Southern California, Northern Baja California (Soledad Bay), Central Baja California (Sebastain Viscaino Bay), the Cape San Lucas region including sections of both the Pacific and Gulf coasts of the peninsula, and the Gulf of California.

Four physical characteristics were selected for detailed study. Three related to the initial position of vertebral structures: the haemal arch, the haemal brace either single or paired, and the paired haemal brace; the fourth to the head length relative to fork length.

Results of the statistical analyses gave evidence of five populations, each region, with the exception of British Columbia and California, being separable in some degree from adjoining regions. However, tag returns demonstrated that a portion of the Viscaino fish eventually reached California waters. The Cape material differed radically in all respects from

the northern regions and was separable from the Gulf fish except as regards the initial position of the haemal arch. The California fishery can be regarded as drawing in some degree on the mackerel population from Canada to Central Baja California. It is felt that the fish from the southernmost portion of the range differ so greatly from the northern population that mingling can be regarded as minimal if it occurs at all. This area can be disregarded from the point of view of practical management at the present time.

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APPENDIX A

Position of the First Haemal Arch, Results of Chi Square Tests With Expected Numbers in Parentheses

All Regions

Region	Number of samples	Vertebra number			Total number of fish
		10	11	12	
British Columbia	1	7 (4.0)	73 (73.4)	1 (3.7)	81
California	17	61 (35.9)	661 (664.8)	12 (33.4)	734
Soledad	2	13 (9.6)	180 (177.5)	3 (8.9)	196
Viscaino	6	24 (22.5)	419 (416.6)	17 (20.9)	460
Cape	2	7 (31.3)	577 (580.6)	57 (29.1)	641
Gulf	4	3 (11.8)	222 (219.2)	17 (11.1)	242
Totals	32	115	2,132	107	2,354
		$\chi^2=96.7$	d.f.=10	P <.000001	

Four Northern Regions

Region	Number of samples	Vertebra number			Total number of fish
		10	11	12	
British Columbia	1	7 (5.8)	73 (73.4)	1 (1.8)	81
California	17	61 (52.4)	661 (665.1)	12 (16.5)	734
Soledad	2	13 (14.0)	180 (177.6)	3 (4.4)	196
Viscaino	6	24 (32.8)	419 (416.8)	17 (10.3)	460
Totals	26	105	1,333	33	1,471
		$\chi^2=10.5$	d.f. =6	P >.05	

Two Southern Regions

Region	Number of samples	Vertebra number			Total number of fish
		10	11	12	
Cape	2	7 (7.3)	577 (580.0)	57 (53.7)	641
Gulf	4	3 (2.7)	222 (219.0)	17 (20.3)	242
Totals	6	10	799	74	883
		$\chi^2=0.8$	d.f.=2	P >.05	

APPENDIX A
Position of the First Haemal Arch, Results of Chi Square Tests With Expected Numbers in Parentheses

Viscaino—Cape

Region	Number of samples	Vertebra number			Total number of fish
		10	11	12	
Viscaino	6	24 (13.0)	419 (416.1)	17 (30.9)	460
Cape	2	7 (18.0)	577 (579.9)	57 (43.1)	641
Totals	8	31	996	74	1,101
		$\chi^2=27.0$	d.f.=2	P=.000001	

APPENDIX B

First Occurrence of a Haemal Brace
Results of Chi Square Tests With Expected Numbers in Parentheses

All Regions, All Fish

Region	Number of samples	Vertebra number			Total number of fish
		14	15	16-18[1]	
British Columbia	2	12 (8.9)	76 (64.0)	53 (68.1)	141
California	20	73 (55.5)	444 (400.8)	366 (426.7)	883
Soledad	2	11 (12.3)	98 (89.0)	87 (94.7)	196
Viscaino	6	33 (28.8)	229 (208.4)	197 (221.8)	459
Cape	4	23 (40.3)	199 (291.0)	419 (309.7)	641
Gulf	2	9 (15.2)	117 (109.9)	116 (116.9)	242
Totals	36	161	1,163	1,238	2,562
		$\chi^2=110.7$	d.f.=10	$P<.000001$	

[1] Vertebra 17: 14 fish (5 California, 6 Cape, 1 each Soledad, Viscaino, Gulf). Vertebra 18: 2 fish (1 each, California, Cape).

APPENDIX B
First Occurrence of a Haemal Brace Results of Chi Square Tests With Expected Numbers in Parentheses

Four Northern Regions

Region	Number of samples	Vertebra number 14	Vertebra number 15	Vertebra number 16-18	Total number of fish
			All Fish		
British Columbia	2	12 (10.8)	76 (71.1)	53 (59.0)	141
California	20	73 (67.8)	444 (445.4)	366 (369.7)	883
Soledad	2	11 (15.1)	98 (98.9)	87 (82.1)	196
Viscaino	6	33 (35.3)	229 (231.6)	197 (192.2)	459
Totals	30	129	847	703	1,679
		$\chi^2=3.2$	d.f.=6	$P>.05$	
			Large Fish		
British Columbia	2	12 (10.1)	76 (71.0)	53 (59.8)	141
California	15	44 (38.9)	284 (272.5)	213 (229.6)	541
Soledad	1	5 (4.0)	28 (27.7)	22 (23.3)	55
Viscaino	5	17 (25.0)	158 (174.8)	172 (147.3)	347
Totals	23	78	546	460	1,084
		$\chi^2=12.5$	d.f.=6	$P=.05$	
			Small Fish		
California	6	29 (29.3)	160 (173.0)	153 (139.7)	342
Soledad	2	6 (12.1)	70 (71.3)	65 (57.6)	141
Viscaino	3	16 (9.6)	71 (56.7)	25 (45.7)	112
Totals	11	51	301	243	595
		$\chi^2=23.6$	d.f.=4	$P=.0001$	
California	6	29 (24.8)	160 (162.9)	153 (154.4)	342
Soledad	2	6 (10.2)	70 (67.1)	65 (63.6)	141
Totals	8	35	230	218	483
		$\chi^2=2.7$	d.f.=2	$P>.05$	
Soledad	2	6 (12.3)	70 (78.6)	65 (50.2)	141
Viscaino	3	16 (9.7)	71 (62.4)	25 (39.8)	112
Totals	5	22	141	90	253
		$\chi^2=19.3$	d.f.=2	$P<.0001$	

Two Southern Regions—All Fish

Region	Number of samples	Vertebra number			Total number of fish
		14	15	16-18	
Cape	2	23 (23.2)	199 (229.4)	419 (388.4)	641
Gulf	4	9 (8.8)	117 (86.6)	116 (146.6)	242
Totals	6	32	316	535	883
		χ^2=23.5	d.f.=2	P<.0001	

Viscaino—Cape

Region	Number of samples	Vertebra number			Total number of fish
		14	15	16-18	
			All Fish		
Viscaino	6	33 (23.4)	229 (178.6)	197 (257.0)	459
Cape	2	23 (32.6)	199 (249.4)	419 (359.0)	641
Totals	8	56	428	616	1,100
		χ^2=55.3	d.f.=2	P<.000001	
			Large Fish		
Viscaino	5	17 (13.6)	158 (128.2)	172 (205.1)	347
Cape	2	16 (19.4)	152 (181.8)	324 (290.9)	492
Totals	7	33	310	496	839
		χ^2=22.3	d.f.=2	P=.00001	

British Columbia Region

Sample number	Vertebra number			Total number of fish
	14	15	16	
1	5 (5.1)	32 (32.3)	23 (22.6)	60
2	7 (6.9)	44 (43.7)	30 (30.4)	81
Totals	12	76	53	141
	χ^2=.03	d.f.=2	P>.05	

California Region

Sample number	Vertebra number		Total number of fish
	14-15	16-18	
1	7 (6.4)	4 (4.6)	11
2	15 (15.2)	11 (10.8)	26
3	23 (15.8)	4 (11.2)	27
4	18 (15.2)	8 (10.8)	26
5	37 (29.3)	13 (20.7)	50
6	30 (29.3)	20 (20.7)	50
7	30 (29.3)	20 (20.7)	50
8	58 (57.4)	40 (40.6)	98
9	54 (58.0)	45 (41.0)	99
10	23 (29.3)	27 (20.7)	50
11	39 (44.5)	37 (31.5)	76
12	30 (32.8)	26 (23.2)	56
13	6 (11.7)	14 (8.3)	20
14	13 (14.6)	12 (10.4)	25
15	28 (23.4)	12 (16.6)	40
16	19 (17.6)	11 (12.4)	30
17	29 (29.3)	21 (20.7)	50
18	34 (28.7)	15 (20.3)	49
19	13 (13.5)	10 (9.5)	23
20	11 (15.8)	16 (11.2)	27
Totals	517	366	883
	$\chi^2 = 35.9$ d.f. $= 19$ P $= .01$		

Size groups	Vertebra number			Total number of fish
	14	15	16-18	
Small	29 (28.3)	160 (172.0)	153 (141.8)	342
Large	44 (44.7)	284 (272.0)	213 (224.2)	541
Totals	73	444	366	883
	$\chi^2 = 2.8$ d.f. $= 2$ $P > .05$			

Soledad Region

Sample number	Vertebra number		Total number of fish
	14-15	16-17	
1	85 (85.1)	68 (67.9)	153
2	24 (23.9)	19 (19.1)	43
Totals	109	87	196
	$\chi^2 = 0$ d.f. $= 1$		

Viscaino Region

Sample number	Vertebra number		Total number of fish
	14-15	16-17	
	All Fish		
1	71 (51.4)	19 (38.6)	90
2	47 (46.8)	35 (35.2)	82
3	63 (67.4)	55 (50.6)	118
4	19 (19.4)	15 (14.6)	34
5	55 (70.8)	69 (53.2)	124
6	7 (6.3)	4 (4.7)	11
Totals	262	197	459
	$\chi^2=26.5$ d.f.=5 $P<.0001$		
	Large Fish		
2	41 (37.3)	33 (36.7)	74
3	53 (52.4)	51 (51.6)	104
4	19 (17.1)	15 (16.9)	34
5	55 (62.5)	69 (61.5)	124
6	7 (5.6)	4 (5.4)	11
Totals	175	172	347
	$\chi^2=3.7$ d.f.=4 $P>.05$		

Size groups	Vertebra number			Total number of fish
	14	15	16-17	
Small	16 (8.1)	71 (55.9)	25 (48.1)	112
Large	17 (24.9)	158 (173.1)	172 (148.9)	347
Totals	33	229	197	459
	$\chi^2=30.6$ d.f.=2 $P<.000001$			

Cape Region

Sample number	Vertebra number			Total number of fish
	14	15	16-18	
1	16 (13.6)	122 (117.7)	241 (247.7)	379
2	7 (9.4)	77 (81.3)	178 (171.3)	262
Totals	23	199	419	641
	$\chi^2=1.9$ d.f.=2 $P>.05$			

Gulf Region

Sample number	Vertebra number		Total number of fish
	14-15	16-17	
1	9 (8.9)	8 (8.1)	17
2	27 (31.8)	34 (29.2)	61
3	71 (65.6)	55 (60.4)	126
4	19 (19.8)	19 (18.2)	38
Totals	126	116	242
	$\chi^2=2.5$ d.f.=3 $P>.05$		

APPENDIX C

Position of the First Pair of Haemal Braces
Results of Chi Square Tests With Expected Numbers in Parentheses

All Regions, All Fish

Regions	Number of samples	Vertebra number			Total number of fish
		14-15[1]	16	17-18[2]	
British Columbia	2	57 (37.8)	83 (96.1)	1 (7.1)	141
California	20	292 (236.4)	553 (602.1)	38 (44.5)	883
Soledad	2	51 (52.5)	139 (133.6)	6 (9.9)	196
Viscaino	6	148 (122.9)	292 (313.0)	19 (23.1)	459
Cape	2	78 (171.6)	505 (437.1)	58 (32.3)	641
Gulf	4	60 (64.8)	175 (165.0)	7 (12.2)	242
Totals	36	686	1,747	129	2,562
		$\chi^2=129.2$ d.f.=10 $P<.000001$			

[1] 14th vertebra, 24 fish (British Columbia, 4; California, 7; Soledad, 1; Viscaino, 9; Cape, 2; Gulf, 1).
[2] 18th vertebra, 15 fish (California, 4; Viscaino, 1; Cape, 9; Gulf, 1).

APPENDIX C

Position of the First Pair of Haemal Braces Results of Chi Square Tests With Expected Numbers in Parentheses

Four Northern Regions

Regions	Number of samples	Vertebra number			Total number of fish
		14-15	16	17-18	
			All Fish		
British Columbia	2	57 (46.0)	83 (89.6)	1 (5.4)	141
California	20	292 (288.2)	553 (561.1)	38 (33.7)	883
Soledad	2	51 (64.0)	139 (124.6)	6 (7.5)	196
Viscaino	6	148 (149.8)	292 (291.7)	19 (17.5)	459
Totals	30	548	1,067	64	1,679
		$\chi^2=12.1$	d.f.=6	P > .05	

Regions	Number of samples	Vertebra number		Total number of fish
		14-15	16-18	
		Large Fish		
British Columbia	2	57 (46.6)	84 (94.4)	141
California	15	185 (178.7)	356 (362.3)	541
Soledad	1	18 (18.2)	37 (36.8)	55
Viscaino	5	98 (114.6)	249 (232.4)	347
Totals	23	358	726	1,084
		$\chi^2=7.5$ d.f.=3	P > .05	
		Small Fish		
California	6	107 (109.2)	235 (232.8)	342
Soledad	2	33 (45.0)	108 (96.0)	141
Viscaino	3	50 (35.8)	62 (76.2)	112
Totals	11	190	405	595
		$\chi^2=13.1$ d.f.=2	P=.001	
Soledad	2	33 (46.3)	108 (94.7)	141
Viscaino	3	50 (36.7)	62 (75.3)	112
Totals	5	83	170	253
		$\chi^2=12.8$ d.f.=1	P < .001	

Regions	Number of samples	Vertebra number			Total number of fish
		14-15	16	17-18	
			Small Fish		
California	6	107 (99.1)	223 (230.1)	12 (12.7)	342
Soldedad	2	33 (40.9)	102 (94.9)	6 (5.3)	141
Totals	8	140	325	18	483
		$\chi^2=3.0$	d.f.=2	P > .05	

Two Southern Regions

Region	Number of samples	Vertebra number			Total number of fish
		14-15	16	17-18	
Cape	2	78 (100.2)	505 (493.6)	58 (47.2)	641
Gulf	4	60 (37.8)	175 (186.4)	7 (17.8)	242
Totals	6	138	680	65	883
		$\chi^2=27.9$ d.f.=2 P=.000001			

Viscaino—Cape

Region	Number of samples	Vertebra number			Total number of fish
		14-15	16	17-18	
			All Fish		
Viscaino	6	148 (94.3)	292 (332.6)	19 (32.1)	459
Cape	2	78 (131.7)	505 (464.4)	58 (44.9)	641
Totals	8	226	797	77	1,100
		$\chi^2=70.2$ d.f.=2 $P<.000001$			
			Large Fish		
Viscaino	5	98 (64.1)	231 (256.0)	18 (26.9)	347
Cape	2	57 (90.9)	388 (363.0)	47 (38.1)	492
Totals	7	155	619	65	839
		$\chi^2=39.7$ d.f.=2 $P<.000001$			

British Columbia Region

Sample number	Vertebra number		Total number of fish
	14-15	16-17	
1	24 (24.3)	36 (35.7)	60
2	33 (32.7)	48 (48.3)	81
Totals	57	84	141
	$\chi^2=0$ d.f.=1		

California Region

Sample number	Vertebra number		Total number of fish
	14-15	16-18	
1	4 (3.6)	7 (7.4)	11
2	9 (8.6)	17 (17.4)	26
3	13 (8.9)	14 (18.1)	27
4	8 (8.6)	18 (17.4)	26
5	19 (16.5)	31 (33.5)	50
6	17 (16.5)	33 (33.5)	50
7	18 (16.5)	32 (33.5)	50
8	38 (32.4)	60 (65.6)	98
9	25 (32.7)	74 (66.3)	99
10	13 (16.5)	37 (33.5)	50
11	25 (25.1)	51 (50.9)	76
12	20 (18.5)	36 (37.5)	56
13	3 (6.6)	17 (13.4)	20
14	7 (8.3)	18 (16.7)	25
15	15 (13.2)	25 (26.8)	40
16	9 (9.9)	21 (20.1)	30
17	15 (16.5)	35 (33.5)	50
18	21 (16.2)	28 (32.8)	49
19	7 (7.6)	16 (15.4)	23
20	6 (8.9)	21 (18.1)	27
Totals	292	591	883
	$\chi^2=16.7$ d.f.=19	$P>.05$	
	Size Groups		
Large	185 (178.9)	356 (362.1)	541
Small	107 (113.1)	235 (228.9)	342
Totals	292	591	883
	$\chi^2=0.8$ d.f.=1	$P>.05$	

Soledad Region

Sample number	Vertebra number		Total number of fish
	14-15	16-17	
1	39 (39.8)	114 (113.2)	153
2	12 (11.2)	31 (31.8)	43
Totals	51	145	196
	$\chi^2=1.0$ d.f.=1	$P>.05$	

Viscaino Region

Sample number	Vertebra number 14-15	Vertebra number 16-18	Total number of fish
	All Fish		
1	40(29.0)	50(61.0)	90
2	34(26.4)	48(55.6)	82
3	31(38.0)	87(80.0)	118
4	8(11.0)	26(23.0)	34
5	30(40.0)	94(84.0)	124
6	5 (3.5)	6 (7.5)	11
Totals	148	311	459
	$\chi^2=17.0$ d.f.=5 $P<.01$		
	Large Fish		
2	30(20.9)	44(53.1)	74
3	25(29.4)	79(74.6)	104
4	8 (9.6)	26(24.4)	34
5	30(35.0)	94(89.0)	124
6	5 (3.1)	6 (7.9)	11
Totals	98	249	347
	$\chi^2=9.4$ d.f.=4 $P=.05$		
	Size Groups		
Large	98(111.9)	249(235.1)	347
Small	50 (36.1)	62 (75.9)	112
Totals	148	311	459
	$\chi^2=10.4$ d.f.=1 $P=.001$		

Cape Region

Sample number	Vertebra number 14-15	Vertebra number 16-18	Total number of fish
1	50(46.1)	329(332.9)	379
2	28(31.9)	234(230.1)	262
Totals	78	563	641
	$\chi^2=.09$ d.f.=1 $P>.05$		

Gulf Region

Sample number	Vertebra number		Total number of fish
	14-15	16-18	
1	4 (4.2)	13 (12.8)	17
2	15 (15.1)	46 (45.9)	61
3	31 (31.2)	95 (94.8)	126
4	10 (9.4)	28 (28.6)	38
Totals	60	182	242
	$\chi^2 < .1$ d.f.=3 P > .05		

APPENDIX D

Original Measurements of Fork and Head Length
California Region

SAMPLE 11
SANTA CATALINA ISLAND
10 November 1941

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
183	51	201	55	209	57	215	58
187	51	201	55	209	57	215	59
187	52	201	55	210	56	215	59
190	53	203	57	210	57	216	58
191	54	204	56	210	57	217	59
192	55	205	55	210	58	217	60
194	54	205	56	210	58	218	59
196	54	205	56	211	57	219	60
196	54	206	56	211	58	220	59
197	55	206	56	212	57	222	59
198	53	206	56	213	57	223	61
199	53	206	56	213	58	223	61
199	55	206	57	213	58	225	60
199	55	207	56	213	59	225	61
200	54	208	55	214	57	225	63
200	55	209	56	214	58	232	64

SAMPLE 16
SANTA CATALINA ISLAND
19 February 1942

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
186	52	201	57	209	59	224	62
189	53	203	56	213	60	226	61
189	55	203	57	213	60	237	63
196	55	203	58	214	61	252	69
198	54	205	57	215	59	266	74
198	56	206	56	216	59	272	74
200	56	206	57	220	60	275	72
201	55	208	57	220	61	276	74
201	56	208	58	224	61	------	------

APPENDIX D
Original Measurements of Fork and Head Length

California Region—Continued

SAMPLE 17
ANACAPA ISLAND
9 March 1942

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
281	74	319	84	328	86	336	86
287	77	320	84	328	86	336	87
301	80	320	87	328	87	336	92
303	79	322	85	330	86	338	90
306	82	323	86	331	85	339	91
311	81	323	86	331	86	340	89
312	84	323	87	331	87	340	89
314	84	323	87	332	88	342	91
314	84	324	85	333	88	343	91
316	82	324	85	333	89	346	91
317	82	326	83	334	89	357	97
317	83	328	86	335	89	366	98
						373	101

SAMPLE 19
3-4 MILES OFF CATALINA ISTHMUS
11 March 1942

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm	Head length mm.	Fork length mm.	Head length mm.
218	61	225	61	233	63	240	65
218	61	225	61	234	62	240	66
221	59	226	61	235	64	242	67
221	62	229	62	236	65	247	65
222	61	230	61	238	65	251	67
222	61	230	62	239	63	253	69
222	62	231	61	239	63	254	68
223	60	233	63	240	65		

SAMPLE 20
SANTA CATALINA ISLAND
10 April 1942

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
287	76	307	83	320	84	336	89
288	77	309	82	323	85	340	93
291	79	315	82	327	86	345	91
296	78	319	84	328	86	345	91
300	82	319	85	333	86	347	90
303	82	319	86	335	89	365	95
306	82	320	84	335	89		

Soledad Region

SAMPLE 1
SOLEDAD BAY
13-14 October 1941

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
145	40	155	44	163	45	281	78
148	42	155	44	163	45	282	74
148	42	155	45	164	45	282	75
149	42	156	44	164	46	282	76
149	43	156	44	165	46	284	74
149	43	156	44	165	46	284	77
150	42	156	44	168	48	285	76
150	42	156	45	170	47	286	78
150	43	157	43	173	48	287	77
151	41	157	43	179	49	287	77
152	43	157	44	194	53	288	77
152	43	157	45	212	57	290	79
152	43	157	45	243	66	292	77
152	43	158	45	244	67	292	78
152	43	158	45	247	67	293	78
153	42	158	46	261	72	293	79
153	42	158	46	261	72	295	77
153	43	159	44	262	69	299	80
153	43	159	44	265	73	301	79
153	43	159	44	266	73	301	79
153	44	159	44	268	72	304	81
153	44	159	44	271	73	304	83
153	44	159	45	272	74	306	80
154	43	159	45	273	75	307	84
154	43	159	45	274	73	308	81
154	43	159	45	274	75	308	82
154	44	159	45	275	73	308	83
154	44	161	44	276	75	310	83
154	44	161	45	276	77	313	86
154	44	161	45	278	74	315	85
155	43	161	45	279	76	322	86
155	43	161	46	280	77		
155	43	162	44	281	75		
155	44	162	45	281	78		

SAMPLE 2
19 MILES SOUTH OF POINT SANTO TOMAS
14 October 1941

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
148	42	157	44	163	45	168	48
150	43	157	45	164	44	170	47
152	42	158	43	164	45	170	47
153	43	158	44	165	46	171	47
153	43	158	45	165	46	171	48
155	44	158	45	166	46	172	49
155	44	159	44	166	46	176	49
156	44	160	44	166	47	181	50
157	43	161	44	167	47	183	51
157	43	161	46	168	46	187	51
157	44	162	45	168	47		

Viscaino Region

SAMPLE 1
8½ MILES OFF BLANCA BAY
17 October 1941

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
153	45	177	50	183	51	189	53
164	47	177	51	183	51	190	52
164	48	178	49	183	52	190	52
165	47	178	50	183	52	191	54
166	48	178	50	183	52	191	55
168	48	178	51	183	53	192	53
169	48	179	51	184	51	192	53
170	47	179	51	184	52	194	54
170	49	179	51	184	52	194	55
170	50	180	50	184	52	195	56
171	50	180	50	184	53	196	54
172	50	180	51	185	51	197	54
172	50	180	52	186	52	197	55
173	49	181	51	187	52	197	55
173	50	181	51	187	53	201	56
174	49	181	51	187	54	202	55
174	49	182	51	188	53	204	54
175	51	182	51	188	54	205	57
175	51	182	52	189	52	208	58
176	49	182	52	189	52	----	----
177	50	182	52	189	53	----	----

SAMPLE 2
BLANCA BAY
18 October 1941

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
184	51	281	77	300	83	313	85
185	52	283	78	301	80	314	85
187	52	284	77	301	81	315	84
188	52	286	77	301	82	315	86
188	54	287	77	302	81	316	88
193	55	288	76	302	82	318	86
196	55	288	78	302	82	318	87
214	60	288	79	305	82	318	88
244	69	290	78	305	84	320	86
246	67	291	79	306	82	326	88
250	68	292	78	306	84	329	90
255	68	292	79	307	83	333	88
270	75	293	80	307	83	334	90
273	72	294	80	307	84	334	91
275	75	294	81	308	83	335	91
276	74	295	81	308	84	336	91
277	75	296	79	309	84	345	92
279	78	297	80	310	85	346	92
280	76	298	82	312	84	353	96
280	77	300	81	313	84	371	96

Viscaino Region—Continued

SAMPLE 3
PLAYA MARIA BAY
19 October 1941

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
179	51	283	76	307	82	333	91
182	50	284	78	308	84	334	90
190	54	285	78	308	85	335	91
191	54	287	79	309	83	336	91
191	54	290	77	310	83	336	92
192	52	290	79	310	84	338	92
192	53	290	79	311	81	339	93
194	53	291	78	313	84	340	90
198	55	291	79	313	84	340	93
198	55	292	79	314	88	343	92
199	55	292	80	315	84	343	96
243	68	292	80	315	86	344	93
253	68	294	77	318	86	348	94
263	72	294	81	319	86	349	93
270	76	295	80	319	87	349	96
272	75	296	80	320	85	350	93
273	75	297	80	321	86	350	93
273	75	298	80	322	86	350	95
274	74	298	82	322	88	351	95
274	75	298	83	324	85	351	99
275	76	299	80	324	87	357	97
277	75	299	80	326	89	358	96
278	75	299	81	326	90	359	96
278	76	300	83	329	87	368	98
279	74	301	82	329	89	369	100
279	78	304	83	330	87	370	100
282	76	304	84	333	87	------	------
282	78	306	83	333	90	------	------

SAMPLE 4
SANTA ROSALIA BAY
20 October 1941

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm	Head length mm.	Fork length mm.	Head length mm.
271	75	300	80	329	90	347	93
279	74	300	83	336	90	348	94
279	75	301	81	340	91	350	97
282	76	302	80	341	89	350	97
288	78	305	82	341	93	351	94
288	79	305	83	342	92	364	97
291	77	309	83	344	93	------	------
293	79	318	84	344	94	------	------
296	78	319	87	345	92	------	------

Viscaino Region—Continued

SAMPLE 5
THURLOE BAY
22-24 October 1941

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
254	70	290	78	304	81	316	87
257	70	290	78	304	81	317	87
267	73	291	77	304	83	317	87
270	75	291	80	304	84	318	86
272	76	292	80	305	81	318	87
273	73	293	79	305	83	319	86
274	74	293	79	306	81	320	85
275	74	294	80	306	82	320	85
275	75	295	78	306	82	320	85
275	75	295	81	306	82	321	89
275	76	296	79	306	83	322	88
277	75	296	79	306	84	323	87
281	76	296	81	307	82	323	87
283	79	297	80	308	82	324	87
284	77	297	82	308	83	326	87
284	78	298	80	308	84	327	87
284	78	298	81	309	82	327	89
284	80	298	83	309	82	334	89
285	76	299	80	309	83	334	91
285	76	299	81	311	83	335	90
285	80	300	80	311	84	339	89
286	76	300	82	312	84	341	90
286	78	301	79	312	85	342	92
288	78	301	83	313	89	342	93
288	79	302	81	314	84	344	91
289	78	302	83	314	85	388	104
289	78	302	84	315	85		
289	79	303	82	315	87		
289	79	303	82	316	83		

SAMPLE 6
CHESTER ROCKS
1 November 1941

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
291	79	303	83	316	86	337	90
292	80	304	82	319	87	356	95
303	82	306	84	335	88		

Cape Region

SAMPLE 1
CERALBO ISLAND
20 February 1941

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm	Head length mm.	Fork length mm.	Head length mm.
210	61	224	63	230	66	241	67
212	61	224	64	230	67	241	68
213	61	224	64	231	65	241	69
213	62	224	65	231	66	242	69
215	61	224	65	232	66	242	69
216	62	225	63	232	66	242	70
217	61	225	64	232	66	243	68
217	62	225	64	233	64	243	68
217	63	225	64	233	65	244	68
217	63	225	65	233	66	244	68
218	61	225	65	233	68	244	69
218	62	225	66	234	66	244	69
218	62	226	64	234	67	244	70
218	63	226	64	234	67	245	68
219	62	226	64	234	68	245	68
219	62	226	64	235	64	245	69
219	63	226	65	235	66	245	70
220	62	226	65	235	67	246	66
220	63	227	63	235	67	246	68
220	63	227	64	235	68	246	69
220	64	227	64	236	66	246	69
221	62	227	64	236	66	246	70
221	63	227	65	236	66	247	67
221	63	227	66	236	67	247	68
221	64	228	64	236	67	247	68
221	64	228	65	237	66	247	69
221	64	228	65	237	66	247	70
222	62	228	65	237	68	248	68
222	63	229	63	238	65	248	69
222	63	229	63	238	66	248	69
222	65	229	65	238	68	248	70
223	62	229	65	239	65	248	70
223	63	229	65	239	68	248	70
223	63	229	65	239	68	248	72
223	64	229	66	239	68	249	68
223	64	230	64	240	66	249	69
223	64	230	64	240	66	249	69
223	65	230	64	240	67	249	70
224	62	230	65	240	67	249	71
224	63	230	65	240	68	249	71
224	63	230	66	241	67	249	72

Cape Region—Continued

SAMPLE 1—Continued

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
249	72	259	71	266	74	280	78
250	68	259	72	267	74	280	79
250	70	259	75	267	74	281	78
250	71	260	73	267	74	282	78
251	67	260	74	267	75	282	78
251	68	260	74	268	75	283	77
251	69	260	75	268	76	283	78
251	71	260	75	268	76	285	78
251	72	260	76	269	73	285	78
252	69	261	72	269	74	285	78
252	69	261	73	269	75	285	79
252	71	261	73	269	76	285	79
252	72	261	74	270	74	285	80
252	72	261	74	270	75	286	77
253	70	261	74	270	75	286	77
254	70	261	75	270	76	287	80
254	70	262	71	271	76	288	80
254	71	262	71	272	75	288	82
254	72	262	72	272	75	289	79
254	72	262	73	272	76	289	80
254	72	262	74	272	76	289	82
254	75	262	74	272	77	290	78
255	69	262	74	273	75	290	79
255	70	263	72	273	76	290	80
255	71	263	73	273	76	291	80
256	69	263	74	273	78	291	81
256	70	263	75	274	76	292	83
256	70	264	74	274	77	293	80
256	71	264	74	274	78	293	82
256	71	264	75	275	77	299	80
256	72	265	71	276	76	301	81
257	70	265	72	276	78	303	85
257	70	265	72	276	78	304	84
257	70	265	73	277	79	308	83
257	72	265	74	278	75	310	85
257	73	265	74	278	78	312	84
257	73	265	75	279	77	312	85
258	70	266	72	279	77	314	85
258	71	266	73	280	77	317	84
258	73	266	73	280	77	317	86
258	74	266	74	280	78	332	90

Cape Region—Continued

SAMPLE 2
TODOS SANTOS
22 February 1941

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
247	68	283	79	295	81	301	84
248	69	284	78	295	81	302	81
251	70	284	79	295	81	302	82
254	70	284	80	295	81	302	83
255	70	285	78	295	82	302	83
256	70	285	79	295	82	302	83
257	73	285	79	295	83	302	84
258	70	286	79	296	80	303	82
259	73	286	79	296	80	303	83
263	72	286	80	296	81	303	84
263	75	287	78	296	82	304	84
265	73	287	79	296	82	305	82
265	74	287	79	297	80	305	83
265	76	287	79	297	80	305	84
265	76	287	81	297	80	305	84
267	73	288	79	297	80	305	84
267	76	288	79	297	81	306	84
268	77	288	80	297	81	306	84
269	71	288	81	297	82	307	84
269	75	289	77	297	83	307	84
269	76	289	79	298	80	307	85
270	74	289	79	298	80	307	87
270	75	289	81	298	81	308	82
270	76	290	79	298	81	308	83
270	77	290	80	298	82	308	84
271	74	290	81	298	82	308	84
271	76	291	79	298	83	309	83
272	74	291	79	298	83	309	84
272	75	291	80	299	80	309	85
273	73	291	80	299	81	309	86
273	76	291	81	299	82	310	84
273	78	291	81	299	82	310	85
274	74	291	82	299	82	310	85
274	76	292	77	299	83	311	83
275	76	292	79	299	83	312	85
276	78	292	80	299	83	313	85
276	79	292	81	300	80	313	86
278	76	292	81	300	81	313	87
278	78	292	81	300	82	314	84
279	79	293	79	300	82	316	86
280	77	293	80	300	82	316	86
280	80	293	81	300	83	316	87
281	78	293	82	301	81	317	86
281	79	293	83	301	81	317	87
282	77	294	81	301	82	317	88
282	80	294	81	301	82	318	87
283	76	294	81	301	82	323	88
283	77	294	82	301	82	324	88
283	77	294	82	301	83	329	90

Gulf Region

SAMPLE 1
ESPIRITU SANTO ISLAND
18 February 1941

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
248	71	317	88	330	91	341	96
269	77	317	89	330	91	342	95
270	76	318	84	330	91	342	96
271	76	318	89	331	90	343	97
279	78	318	90	332	89	343	97
283	79	319	88	332	92	344	96
284	78	320	87	332	93	344	97
284	80	321	88	333	91	345	93
286	80	322	86	333	92	345	93
287	81	322	89	333	94	345	94
289	79	323	87	334	90	345	95
290	79	323	89	334	93	345	96
291	79	323	90	334	94	345	99
295	82	323	91	335	91	346	91
296	81	324	88	335	92	346	97
299	84	325	90	335	93	348	98
299	86	325	93	336	90	349	96
301	79	326	92	336	93	349	97
304	84	327	89	336	93	350	93
306	82	327	90	337	92	350	99
306	84	327	90	337	96	351	97
309	83	327	91	338	89	351	98
310	87	327	92	338	93	351	98
310	87	328	92	338	94	351	100
311	87	329	89	339	93	356	100
312	82	329	90	340	95	360	101
316	87	329	93	340	96	366	101
316	88	330	90	340	97	-----	-----
317	87	330	90	341	95	-----	-----

SAMPLE 2
ESPIRITU SANTO ISLAND
19 February 1941

Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.	Fork length mm.	Head length mm.
297	83	321	87	331	89	346	94
299	82	324	87	334	92	347	98
313	86	324	90	335	91	348	98
315	89	325	90	335	95	349	98
316	86	325	91	338	92	350	95
317	89	326	89	340	93	351	94
317	90	328	89	341	95	352	95
318	85	328	91	342	94	-----	-----
320	89	328	92	343	91	-----	-----

APPENDIX E

Fork Length, X, and Head Length, Y

Sums of Variates, Squares and Products, and Errors of the Estimate

Sample	Totals						Sums of squares and products[1]				Errors of estimate	
	N	SX	SY	SX²	SXY	SY²	Sx²	Sxy	Sy²	d.f.	Sums of squares[2]	d.f.
						California	Region					
11	64	13,296	3,630	2,768,984	755,751	206,320	6,740	1,619	431	63	42.1	62
16	35	7,573	2,094	1,658,655	457,895	126,470	20,074	4,813	1,189	34	35.0	33
17	49	16,020	4,236	5,250,874	1,388,608	367,314	13,315	3,695	1,116	48	90.6	47
19	31	7,217	1,956	1,683,279	456,065	123,606	3,115	696	189	30	33.5	29
20	27	8,658	2,296	2,786,454	738,629	195,840	10,122	2,378	595	26	36.3	25
Totals	206	52,764	14,212	14,148,246	3,796,948	1,019,550	53,366	13,201	3,520	201	237.5	196
Average[3]											254.5	200
Region[4]							633,490	156,744	39,060	205	276.9	204
						Soledad	Region					
1	133	27,728	7,613	6,318,058	1,723,764	470,625	537,291	136,597	34,852	132	124.6	131
2	43	7,013	1,956	1,146,881	319,796	89,194	3,110	786	219	42	20.4	41
Totals	176	34,741	9,569	7,464,939	2,043,560	559,819	540,401	137,383	35,071	174	145.0	172
Average[3]											144.9	173
Region[4]							607,342	154,716	39,559	175	146.2	174

APPENDIX E
Fork Length, X, and Head Length, Y

						Viscaino	Region					
1	82	14,965	4,225	2,739,515	772,909	218,149	8,403	1,847	459	81	53.0	80
2	80	23,258	6,319	6,889,142	1,869,502	507,457	127,460	32,411	8,335	79	93.4	78
3	110	32,848	8,945	10,025,702	2,726,633	742,391	216,692	55,493	15,000	109	788.7	108
4	33	10,498	2,830	3,363,072	906,633	244,470	23,436	6,350	1,776	32	55.5	31
5	113	34,225	9,262	10,410,701	2,816,408	762,116	44,766	11,170	2,960	112	172.9	111
6	11	3,462	936	1,093,762	295,535	79,868	4,176	950	223	10	6.9	9
Totals	429	119,256	32,517	34,521,894	9,387,620	2,554,451	424,933	108,221	28,753	423	1,170.4	417
Average[3]											1,191.5	422
Region[4]							1,370,394	348,349	89,753	428	1,204.0	427
						Cape	Region					
1	328	82,449	23,103	20,908,039	5,852,115	1,638,697	182,924	44,739	11,415	327	472.9	326
2	196	57,157	15,726	16,716,309	4,597,709	1,264,904	48,336	11,735	3,133	195	284.0	194
Totals	524	139,606	38,829	37,624,348	10,449,824	2,903,601	231,260	56,474	14,548	522	756.9	520
Average[3]											757.0	521
Region[4]							430,006	104,860	26,328	523	757.1	522
						Gulf	Region					
1	114	37,044	10,250	12,091,150	3,345,419	925,984	53,800	14,709	4,383	113	361.5	112
2	34	11,223	3,089	3,711,373	1,021,370	281,179	6,793	1,728	534	33	94.4	32
Totals	148	48,267	13,339	15,802,523	4,366,789	1,207,163	60,593	16,437	4,917	146	455.9	144
Average[3]											458.2	145
Region[4]							61,285	16,563	4,941	147	464.6	146

[1] $Sx^2 = SX^2 - (SX)^2/N$
$Sxy = SXY - (SX)\ (SY)/N$
$Sy^2 = SY^2 - (SY)^2/N$
[2] $Sdy.x^2 = Sy^2 - (Sxy)^2/Sx^2$

[3] The sum of squared deviations from the average "within samples" regression is calculated from the totals of the sums of squares and products for each region; e.g. for California,
$3520 - (13201)^2/53366 = 254.5$
[4] Computed from the region totals, SSX, SSY, SSX^2, SSXY, SSY^2

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