USE OF A DISCRIMINANT FUNCTION TO CLASSIFY NORTH AMERICAN AND ASIAN PINK SALMON, *ONCORHYNCHUS GORBUSCHA* (WALBAUM), COLLECTED IN 1959

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ABSTRACT

A discriminant function analysis with six morphological characters was used to determine the continental origin of pink salmon (*Oncorhynchus gorbuscha*) taken from the Bering Sea and North Pacific Ocean in 1959. The spawning regions of eastern Kamchatka and western Alaska were assumed to be the destination of the pink salmon taken on the high seas. Consequently, morphological characters taken from eastern Kamchatkan and western Alaskan fish were used to compute continental morphotypes. Applying the function, pink salmon populations from all North American inshore areas were well separated from the eastern Kamchatkan morphotype. Alaskan morphotype fish were dominant in the two high seas samples taken at longitude 160°W. in the North Pacific Ocean, in one sample taken at longitude 177°W. in the North Pacific Ocean, and in one sample taken at longitude 170°W. in the Bering Sea. Eastern Kamchatkan morphotype fish were dominant in all other high seas samples taken at longitude 170°W. and to the westward. No high seas samples were taken between longitudes 170°W. and 160°W.

CONTENTS

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INTRODUCTION

The Bureau of Commercial Fisheries, United States Fish and Wildlife Service, is engaged in several investigations for the International North Pacific Fisheries Commission (INPFC). This commission was established to promote and coordinate scientific studies pertaining to conservation measures required to secure the maximum sustained productivity of fisheries in the North Pacific Ocean and Bering Sea. One species of joint interest to the member nations is the pink salmon, *Oncorhynchus gorbuscha* (Walbaum).

Pink salmon spawn in the coastal streams of Asia and North America, but spend most of their two-year life span in the high seas areas of the North Pacific Ocean and Bering Sea. The Commission is attempting to determine whether there are high seas areas in which pink salmon originating in the rivers of Canada and the United States intermingle with pink salmon originating in the rivers of Asia. When such areas are found, the Commission is instructed to determine a line or lines which best divide salmon of Asiatic origin from salmon of North American origin. To accomplish this objective, it is necessary to distinguish Asian from North American pink salmon in high seas samples.

This paper describes a method of determining the origin of pink salmon caught on the high seas in 1959. Here, six morphological characters were selected to separate samples of known origin into a continental group (morphotype) with a low probability of misclassification. The same characters were then used to classify salmon taken on the high seas into a continental morphotype with a known probability of misclassification.

The objectives of this study were: (1) to select morphological characters capable of distinguishing Asian from North American pink salmon; (2) to define continental morphotypes based on these characters; and (3) to estimate the contribution of each morphotype to high seas samples.

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EXPERIMENTAL PROCEDURE

Methods of Sampling

Samples of whole pink salmon were collected from inshore fisheries in North America and from high seas areas of the North Pacific Ocean and Bering Sea. Appendix A lists the location, date and number of fish collected in 1959.

The North American inshore samples were obtained by means of gillnets, beach seines and purse seines. These fish were collected from streams or rivers where pink salmon were known to spawn. An attempt was made to obtain all samples at the peak of the run from streams which were major contributors to the local fisheries. The principal commercial fisheries of North America were represented, but the remote areas of the Aleutian Islands and northwestern Alaska where a personal use fishery exists (INPFC, 1962) were not adequately sampled.

High seas samples were obtained from the Japanese commercial fishery and from Japanese, Canadian and United States research vessels. The Japanese commercial fishery samples were obtained from both the mothership fleet off the east coast of the Kamchatka Peninsula and from Hokkaido Island landbased vessels. These samples were caught in gillnets with 4.8″ stretched measure between opposite knots. The Japanese research vessels fished with longline gear. The United States and Canadian research vessels used a standard string of gillnets with mesh sizes of $2\frac{1}{2}''$, $3\frac{1}{4}''$, $4\frac{1}{2}''$ and $5\frac{1}{4}''$ stretched measure between opposite knots.

All specimens were preserved by freezing and later transported to the Seattle Biological Laboratory of the Bureau of Commercial Fisheries at Seattle, Washington, for examination.

Methods of Data Collection

Six morphological characters were used to classify the 1959 collections to continent of origin. Four were taken from scales and two from radiographs of ossified structures.

The scale characters were: (1) the number of circuli in the first half of the distance from the outermost edge of the center ring to the annulus; (2) the number of circuli in the second half of the distance from the outermost edge of the center ring to the annulus; (3) the number of circuli in the second sixth of the distance from the outermost edge of the center ring to the annulus; (4) the width in millimeters of the narrowest band of three successive circuli interspaces included between circuli 1 to 10 (either circuli 1 to 4, 4 to 7, or 7 to 10). The scales were taken from the fish, cleaned in a detergent solution, and mounted with the sculptured side up on gummed paper. Scales were taken from the body position two rows above the lateral line on the diagonal scale column which extends downward from the posterior insertion of the dorsal fin. Plastic impressions (Clutter and Whitesel, 1956) of the mounted scales were made on clear cellulose acetate cards. A projection microscope (Mosher, 1950) was used to examine the plastic scale impressions at 100× magnification. All scales collected in 1959 were examined by one worker. This worker could accurately repeat circuli counts and measurements (Appendix B).

The characters obtained from radiographs were: (1) the number of branchiostegal rays on the left side of the head and (2) the number of vertebrae beginning with the atlas and terminating with the urostyle. Permanent photographic records of these characters were obtained by use of X-ray technique. The structures on every radiograph were counted by a trained worker and verified by another. Doubts as to the number of branchiostegal rays were resolved by staining (Hollister, 1934) and counting the rays on the stained branchiostegal.

It was not always possible to collect every character from each specimen (Appendix C). This was particularly true in regard to scales. Fifty percent of the specimens came into the laboratory with missing or absorbed scales from the preferred body position.

The body length from the end of the hypural plate to the middle of the eye was measured on each fish. This measurement was considered to be the least affected by sexual maturity or by possible body damage incurred while handling and transporting the frozen specimens. The measurement was not used as a character to classify the 1959 collections. It was used to determine if the characters were related to fish length.

Each character was examined for sexual differences and the effect of fish length (Appendix D). The results of the examinations indicated that these two possible sources of variation would not bias the classification of samples taken from the high seas.

Method of Analysis

A discriminant function analysis was selected to classify the 1959 high seas collections to continent of origin. The discriminant function analysis (Fisher, 1936) is a multivariate normal technique by which individual fish may be classified to one of two groups by means of a set of morphological characters. The six previously mentioned characters were used (1) to define a representative continental morphotype composed of samples of known origin and (2) to separate the high seas collections into North American and Asian morphotypes. It is necessary to assume that the high seas collections originated from areas represented by the samples composing the morphotypes. The presence of fish from other areas would affect the calculated probability of correctly classifying individual fish into either morphotype.

The statistical assumptions for obtaining the best discriminant function analysis require the characters to have multivariate normal distributions with a common dispersion matrix in the populations selected for use as continental morphotypes. Common variance and common correlation are conditions that indicate a common dispersion matrix. Linear relationship between all possible pairs of characters and normality of each character are important conditions in multivariate normal distributions.

In a previous study, a discriminant function analysis was used to classify pink salmon collected on the high seas in 1957 to continent of origin (Amos, Anas and Pearson, 1963). It was found that additional characters were needed to separate pink salmon of the Alaska Peninsula, Aleutian Islands and northwestern Alaska from those of Kamchatka. For this reason, the characters used here are substantially different from those used by Amos, Anas and Pearson (1963).

RESULTS

Selection of Samples for Morphotypes

The continental morphotypes were composed of samples from spawning regions that were the destination of the fish caught on the high seas. Two offshore samples from the east coast of the Kamchatka Peninsula were selected to represent the Asian spawning region and five inshore samples from central and western Alaska were selected to represent the North American spawning region.

The selection of eastern Kamchatka as the destination of the Asian fish and western Alaska as the destination of the North American fish was based on (1) the results of tagging experiments, (2) sizes of coastal catches and (3) proximity of the spawning regions to the offshore sampling areas (Fig. 1).

High seas tagging by United States research vessels in 1959 resulted in 129 recoveries from the high seas and 39 from the east coast of the Kamchatka Peninsula (INPFC, 1960). A dominant northwest movement of tagged fish toward the Karaginski region in eastern Kamchatka is observed from the tag returns (Fig. 2). Although tagged fish were not recovered from North American inshore areas in 1959, pink salmon tagged in the Aleutian areas were recovered in North America in 1958, 1960, 1961 and 1962 (Hartt, 1961; INPFC, 1961; Rausch and Hartt, 1962). Except for one recovery from the south side of the Alaska Peninsula, all North American tag recoveries were from western Alaska.

The pattern of recovery from Japanese high seas tagging in 1959 was similar to the United States recovery pattern (INPFC, 1961). The coastal recoveries from fish tagged in Aleutian and Bering Sea waters were all from eastern Kamchatka. However, coastal recoveries in the Okhotsk Sea area were reported from tagging in the western areas of the North Pacific Ocean. The easternmost tagging location yielding a return to an Okhotsk Sea spawning region was at 163° E. Tagging experiments by the Japanese have generally shown the high seas distribution of Asian pink salmon from the Okhotsk Sea coast, Sakhalin, Kuril, Primorski and Hokkaido Island areas to be southwest of Aleutian and Bering Sea waters (INPFC, 1961).

Eastern Kamchatka was the closest major Asian spawning area to the location of the high seas samples. It was found to have the largest Asian coastal catch in 1959 (Table 1). Since it was not possible to collect inshore samples from this region, it was

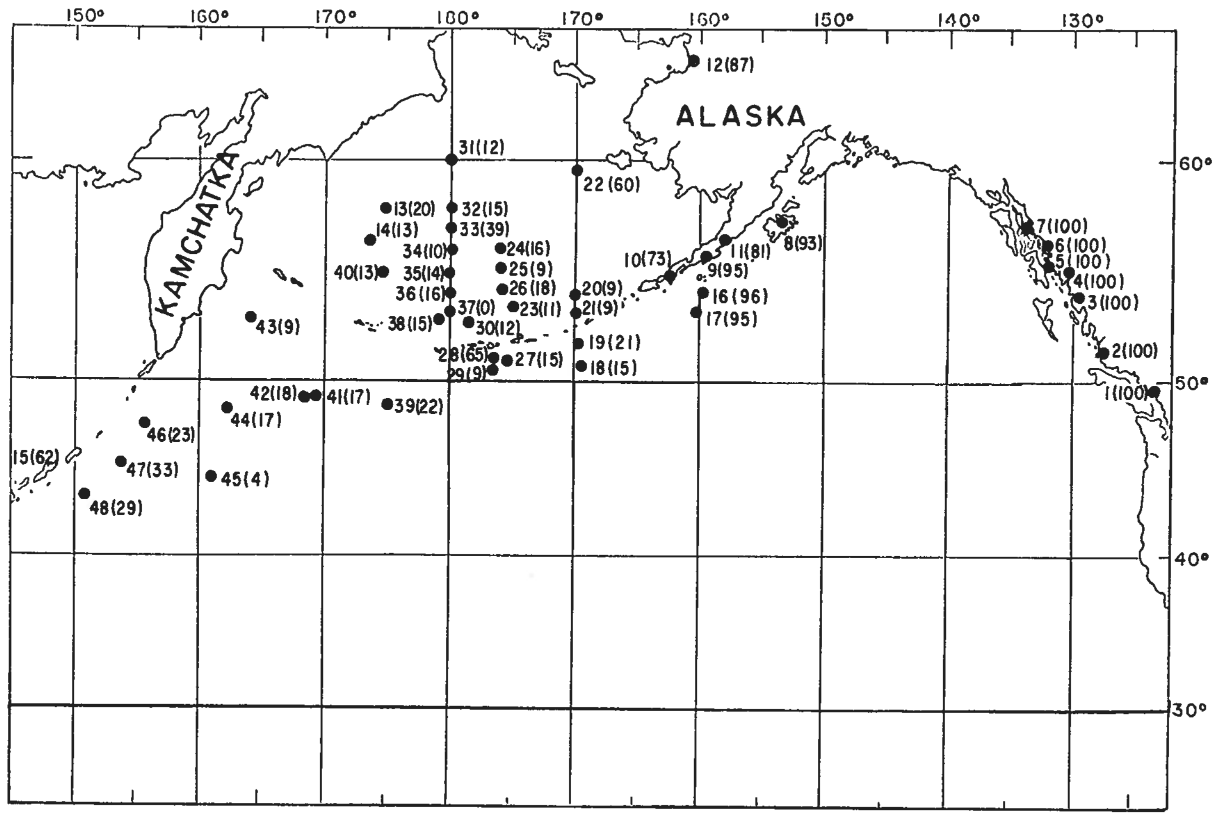

FIGURE 1. Sampling locations for 1959 pink salmon. The first number indicates sample map number (see Tables 6 and 7). The second number indicates percent western Alaska-type fish in sample (see Tables 6 and 7).

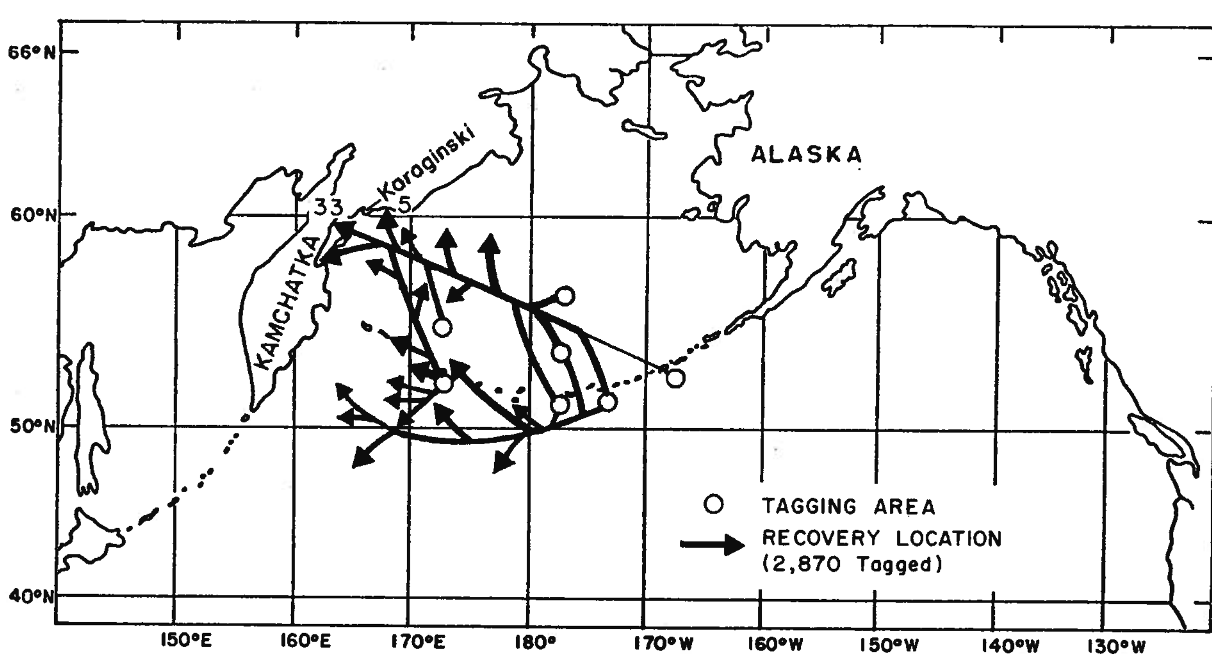

FIGURE 2. Recovery distribution of pink salmon tagged and recovered in 1959.

TABLE 1. Coastal catch of North American and Asian pink salmon in 1959.

Area	*Thousands of fish*
NORTH AMERICA[1]	
Western Alaska	22
Central Alaska	3,057
Southeastern Alaska	7,851
British Columbia	6,776
Washington	2,616
ASIA	
West Kamchatka[2]	6,806
East Kamchatka[2]	13,875
Sakhalin & Kuril Islands[2]	11,364
Okhotsk coast[2]	1,868
Amur[2]	612
Primorski[2]	1,722
Hokkaido Island[1,3]	58

[1] INPFC Statistical Yearbook 1959.
[2] Data submitted to the INPFC by VNIRO—INPFC Doc. 363 (converted from weight to number of fish with a rate of 1.3 kilograms per fish).
[3] Freshwater landings converted from weight to number of fish with a rate of 3.7 pounds per fish.

necessary to use two high seas samples for the morphotype. These samples were taken at 58°00'N., 175° 00'E. on July 4 and 56°49'N., 173°22'E. on July 5. They were the largest samples taken close to the Karaginski region of eastern Kamchatka.

The most likely spawning destination of the North American pink salmon in the high seas samples was central and western Alaska. Although fish tagged in Aleutian waters were not recovered from North American inshore areas in 1959, the results of tagging experiments in other years showed that western Alaskan pink salmon were present westward to at least 177°E. and central Alaskan pink salmon were present westward to at least 168° W. (INPFC, 1961). Pink salmon tagged in Aleutian waters have not been recovered from North American spawning regions other than western and central Alaska.

Western and central Alaska were the closest North American spawning regions to the location of the high seas samples. Their combined 1959 catch was 3,079,000 fish. Although the combined central and western Alaskan catch is generally high in all years (INPFC, 1961), 1959 was a year of unusually low abundance.

Five inshore samples from central and western Alaska were selected for a morphotype. They were collected from Uyak Bay on Kodiak Island, Hook Bay on the Alaska Peninsula, Coal Bay Stream on the Alaska Peninsula, Ivanof Bay on the Alaska Peninsula and Unalakleet River on Norton Sound in northwestern Alaska.

The continental areas selected as the spawning destinations for the 1959 high seas samples may not be suitable for samples taken in other years. This is especially true for eastern Kamchatka where the coastal catch of pink salmon is generally high in odd-numbered years but low in even-numbered years (INPFC, 1961). In years of low abundance, such as 1956 when the coastal catch was 380,000 fish, we would not expect to find large numbers of eastern Kamchatkan pink salmon in Aleutian waters.

SELECTION OF CHARACTERS

The discriminant function analysis uses a set of multiple measurements to discriminate between any two groups (Fisher, 1936). It provides the best linear function for discriminating two morphotypes (Rao, 1952). Since this analysis was selected to classify the high seas samples to continent of origin, it necessitated the selection of characters that (1)

TABLE 2. Mean differences in morphological characters between the western Alaskan and eastern Kamchatkan morphotypes.

Morphological character	Morphotype	Character mean	Mean difference	Pooled variance
First half circuli	Western Alaska	11.5501		
	Eastern Kamchatka	10.3567	1.1934	0.6353
Second half circuli	Western Alaska	11.6314		
	Eastern Kamchatka	10.6722	0.9592	0.8548
Second sixth circuli	Western Alaska	3.8487		
	Eastern Kamchatka	3.3971	0.4516	0.2244
Narrowest three circuli	Western Alaska	10.7994		
	Eastern Kamchatka	12.0151	−1.2157	2.2167
Branchiostegal rays	Western Alaska	12.8381		
	Eastern Kamchatka	12.2155	0.6226	0.4388
Vertebrae	Western Alaska	68.6422		
	Eastern Kamchatka	69.3813	−0.7391	0.8019

TABLE 3. Results of tests for homogeneity of variance in morphological characters between morphotypes.

Character	Western Alaskan variance[1]	Eastern Kamchatkan variance[2]	Ratio	F value[3]
Number of circuli in first half	0.6219	0.6674	1.0732	1.34
Number of circuli in second half	0.8342	0.9042	1.0839	1.34
Number of circuli in second sixth	0.2192	0.2368	1.0803	1.34
Width of narrowest three circuli	2.0777	2.5510	1.2278	1.34
Number of branchiostegal rays	0.4411	0.4331	1.0185	1.37
Number of vertebrae	0.8107	0.7808	1.0383	1.37

[1] Sample size of 296 fish.
[2] Sample size of 123 fish.
[3] Significance level of five percent for a two-tailed test.

differed between morphotype means and (2) conformed to the statistical requirements of the function. Therefore, the six morphological characters were examined for differences between morphotype means and for conformity to the statistical requirements of a discriminant function.

The mean differences of the morphological characters were computed between the two morphotypes. The results of this study are found in Table 2. The first character, number of circuli in the first half, has a mean difference between morphotypes of 1.1934 circuli with a pooled variance of 0.6353. This character will correctly classify 77 percent of the fish. In a similar manner, the number of circuli in the second half will classify 70 percent of the fish; the number of circuli in the second sixth, 68 percent; the narrowest three circuli measurement, 66 percent; the number of branchiostegal rays, 68 percent; and the number of vertebrae, 66 percent. Each morphological character shows some degree of difference between morphotypes.

The statistical assumptions for obtaining the best discriminant function require the characters to have: (1) a common dispersion matrix in the populations selected for use as continental morphotypes and (2) multivariate normal distributions. The characters were examined for conformity to these requirements.

Common variance and common correlation are conditions that indicate a common dispersion matrix. Common variance was tested by a variance ratio test in which the larger variance was the numerator and the smaller variance the denominator. The values obtained were compared with the values in F-distribution tables with the appropriate degrees of freedom. The results of this test are shown in Table 3. None of the F values was significant at the five percent level.

Common correlation between all possible pairs of characters in each morphotype was examined with a test given by Snedecor (1956). Average sample correlation coefficients were calculated for each morphotype. The r values were converted by tables to Fisher's z values. The differences between the z values were divided by the standard error of the difference to obtain t values with infinite degrees of freedom. The results of these tests are found in Table 4. Of the 15 pairs examined, two significant differences were found between morphotypes. The character pairs were (1) first half circuli—second half circuli and (2) second half circuli—second sixth circuli. In the first pair, the morphotype with the largest average correlation coefficient was eastern Kamchatka. Since the average correlation coefficient was 0.4859, the percent variation in one character attributable to the variation in the other was (100) $(0.4859)^2$ or 23.6. In the second pair, the morphotype with the largest average correlation was once again eastern Kamchatka. The calculated percent variation in one character attributable to the variation in the other was 17.4. Because of the lack of common correlation in the two character pairs, the best discriminant function may not be obtained. However, due to the low level of correlation and the relatively large differences between morphotype character means, the affected characters were included in the analysis.

Linearity of regression between the 15 possible pairs of characters and the frequency distribution curves of the six characters were examined for each of the two morphotypes. Linearity of regression is one of the conditions required for multivariate normal distributions of morphological characters. A polynomial regression was calculated to examine linearity of regression. The results of this test indicated no great departure from linearity by any of the character pairs.

TABLE 4. Results of tests for common correlation with the western Alaskan and eastern Kamchatkan morphotype samples between all pairs of characters.

Character pairs	Average correlation coefficients: Western Alaska	Eastern Kamchatka	t values
First half circuli Second half circuli	0.2906	0.4859	2.1386*
First half circuli Second sixth circuli	0.5421	0.6410	1.4113
First half circuli Narrowest three circuli	−0.3654	−0.5000	1.5360
First half circuli Branchiostegal rays	−0.0063	−0.0279	0.1996
First half circuli Vertebrae	0.1028	0.1969	0.8900
Second half circuli Second sixth circuli	0.1256	0.4168	2.9344*
Second half circuli Narrowest three circuli	0.2055	0.0947	1.0490
Second half circuli Branchiostegal rays	0.0833	0.0616	0.2015
Second half circuli Vertebrae	−0.0403	0.0721	1.0397
Second sixth circuli Narrowest three circuli	−0.3363	−0.3121	0.2495
Second sixth circuli Branchiostegal rays	−0.0561	0.0410	0.8983
Second sixth circuli Vertebrae	0.0440	0.1243	0.7486
Narrowest three circuli Branchiostegal rays	−0.0014	0.0851	0.8013
Narrowest three circuli Vertebrae	−0.0532	−0.0892	0.3336
Branchiostegal rays Vertebrae	−0.0934	0.0143	0.9982

* Significant at the five percent level.

There are no adequate tests for normality of small samples (Fisher, 1944; Cochran, 1947). Fisher states that drastic departures are required before statistical procedures based on normality are disturbed. Frequency distribution curves are given in Figure 3 for the six characters of each morphotype. No radical departures from normality are evident. On this basis, the normality of the data is assumed to be adequate for the discriminant function.

Construction of a Western Alaskan and Eastern Kamchatkan Discriminant Function

A discriminant function for western Alaskan and eastern Kamchatkan pink salmon of the form $Y = l_1X_1 + l_2X_2 + l_3X_3 + l_4X_4 + l_5X_5 + l_6X_6$ was calculated using data from the variance-covariance matrix of

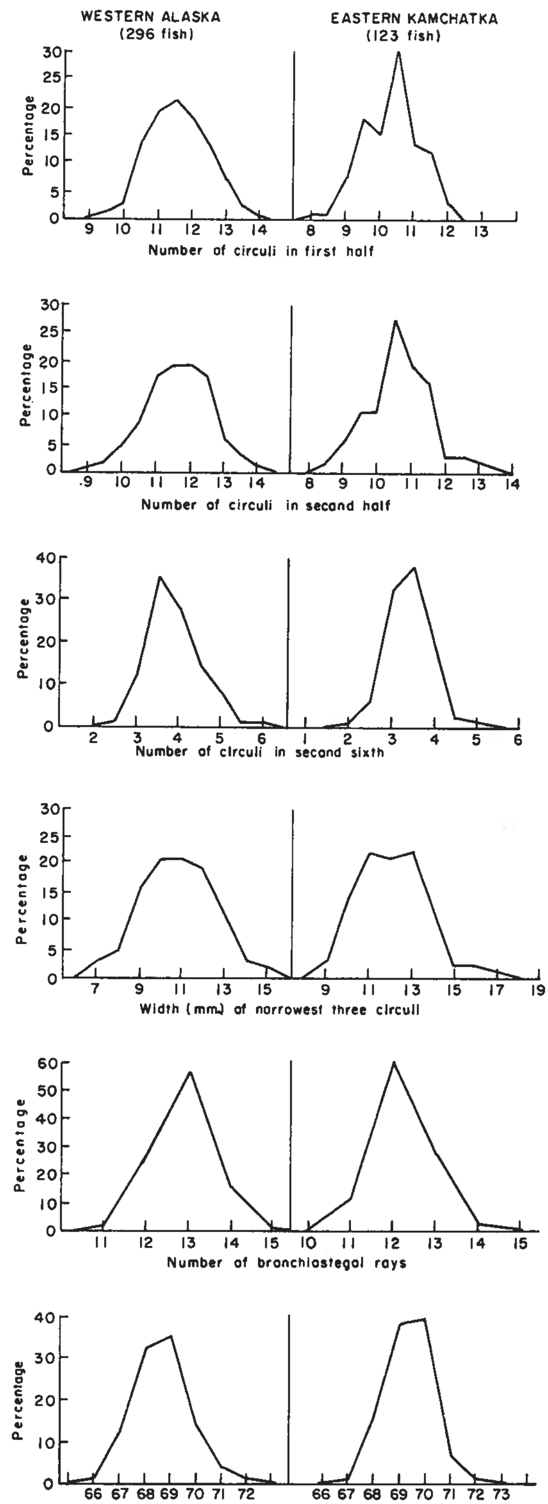

FIGURE 3. Frequency distributions of morphological characters used in separating western Alaskan and eastern Kamchatkan pink salmon morphotypes.

TABLE 5. The variance-covariance matrix and calculation of the discriminant function for the 1959 pink salmon collections[1].

Character		Variance-covariance matrix						Mean difference
		X_1	X_2	X_3	X_4	X_5	X_6	
First half circuli[2]	1.	63.5274	25.5602	21.7720	−4.7359	−0.0502	0.9108	11.9343
Second half circuli[2]	2.		85.4753	8.9694	2.3364	0.4838	−0.0887	9.5925
Second sixth circuli[2]	3.			22.4361	−2.3215	−0.1029	0.2878	4.5165
Narrowest three circuli	4.				2.2167	0.0257	−0.0731	−1.2157
Branchiostegal rays	5.					0.4388	−0.0398	0.6226
Vertebrae	6.						0.8019	−0.7391
	7.							0.0000
		Discriminant function matrices						
	11.	1.0000	0.4023	0.3427	−0.0745	−0.0008	0.0143	0.1879
	12.	0.4023	75.1924	0.2105	4.2417	0.5040	−0.4551	4.7913
	13.	0.3427		14.9748	−0.6985	−0.0857	−0.0243	0.4266
	14.	−0.0745			1.8639	0.0220	−0.0052	−0.3266
	15.	−0.0008				0.4388	−0.0391	0.6321
	16.	0.0143					0.7904	−0.9098
	17.	0.1879						−2.2425
	22.	0.0054	1.0000	0.0028	0.0564	0.0067	−0.0061	0.0637
	23.	0.3416	0.0028	14.9742	−0.7104	−0.0871	−0.0230	0.4132
	24.	−0.0972	0.0564		1.6247	−0.0064	0.0205	−0.5968
	25.	−0.0035	0.0067			0.4354	0.0361	0.6000
	26.	0.0168	−0.0061				0.7876	−0.8806
	27.	0.1623	0.0637					−2.5477
	33.	0.0228	0.0002	1.0000	−0.0474	−0.0058	−0.0015	0.0276
	34.	−0.0810	0.0565	−0.0474	1.5910	0.0105	0.0194	−0.5772
	35.	−0.0015	0.0067	−0.0058		0.4349	−0.0362	0.6024
	36.	0.0173	−0.0061	−0.0015			0.7876	−0.8800
	37.	0.1529	0.0636	0.0276				−2.5591
	44.	−0.0509	0.0355	−0.0298	1.0000	−0.0066	0.0122	−0.3628
	45.	−0.0020	0.0071	−0.0061	−0.0066	0.4348	−0.0361	0.5986
	46.	0.0183	−0.0068	−0.0009	0.0122		0.7874	−0.8730
	47.	0.1235	0.0841	0.0104	−0.3628			−2.7685
	55.	−0.0046	0.0163	−0.0140	−0.0152	1.0000	−0.0830	1.3767
	56.	0.0181	−0.0062	−0.0014	0.0117	−0.0830	0.7844	−0.8233
	57.	0.1263	0.0743	0.0188	−0.3537	1.3767		−3.5926
	66.	0.0231	−0.0079	−0.0018	0.0149	−0.1058	1.0000	−1.0496
	67.	0.1453	0.0678	0.0173	−0.3414	1.2896	−1.0496	−4.4567

$$Y = 0.1453X_1 + 0.0678X_2 + 0.0173X_3 - 0.3414X_4 + 1.2896X_5 - 1.0496X_6$$

Character	*Western Alaskan morphotype mean*	*Eastern Kamchatkan morphotype mean*
First half circuli (X_1)[2]	115.5011	103.5668
Second half circuli (X_2)[2]	116.3142	106.7217
Second sixth circuli (X_3)[2]	38.4875	33.9710
Narrowest three circuli (X_4)	10.7994	12.0151
Branchiostegal rays (X_5)	12.8381	12.2155
Vertebrae (X_6)	68.6422	69.3813

Y Western Alaska $= -33.8435$

$Y_0 = -36.0716$

Y Eastern Kamchatka $= -38.2998$

[1] Using pivotal condensation method (Rao, 1952).

[2] Each character value was multiplied by 10 to facilitate use of automatic data processing equipment. The listed mean values are 10 times larger than they really are. The variances and covariances are 100 times larger.

Table 6. Classification of 1959 pink salmon morphotype and inshore samples to western Alaskan or eastern Kamchatkan morphotypes.

Map number[1]	Location	Date	Sample size	Percent classified	
				Western Alaskan	Eastern Kamchatkan
1	Fraser River (British Columbia)	9/1	45	100.0	0.0
2	Rivers Inlet (British Columbia)	8/14	52	100.0	0.0
3	Skeena River (British Columbia)	8/14	56	100.0	0.0
4	Ketchikan (southeastern Alaska)	8/16	26	100.0	0.0
5	Ketchikan (southeastern Alaska)	8/18	24	100.0	0.0
6	Petersburg (southeastern Alaska)	8/3	47	100.0	0.0
7	Petersburg (southeastern Alaska)	8/9	20	100.0	0.0
8	Uyak Bay (Kodiak Island)	8/6	60	93.3	6.7
9	Ivanof Bay (Alaska Peninsula)	7/30	63	95.2	4.8
10	Coal Bay (Alaska Peninsula)	8/1	66	72.7	27.3
11	Hook Bay (Alaska Peninsula)	8/13	47	80.9	19.1
12	Unalakleet (northwestern Alaska)	7/10	60	86.7	13.3
13	Eastern Kamchatka[2]	7/4	70	20.0	80.0
14	Eastern Kamchatka[3]	7/5	53	13.3	86.7
15	Yubetsu River (Hokkaido Island)	8/17	52	61.5	38.5

[1] Numbers refer to sampling locations in Figure 1.
[2] Sample was obtained offshore at 58°00′N., 175°00′E.
[3] Sample was obtained offshore at 56°49′N., 173°22′E.

Table 5. A description of this method of calculation is available from Rao (1952), who demonstrates that it produces the best linear discriminant function obtainable. The first six values in row 67, Table 5, are the coefficients (l's) needed for the equation. The equation then appears as $Y=0.1453X_1+0.0678X_2+0.0173X_3-0.3414X_4+1.2896X_5-1.0496X_6$, where X_1 is the number of circuli in the first half, X_2 is the number of circuli in the second half, X_3 is the number of circuli in the second sixth, X_4 is the width of the narrowest three circuli, X_5 is the number of branchiostegal rays and X_6 is the number of vertebrae. The last value in row 67 is the variance of Y or D^2 value.

The probability of correctly classifying an individual fish from one of the two morphotypes is equal to the probability that a normal deviate with mean zero and standard deviation of one will be less than, or equal to, $D/2$. Since D^2 has a value of 4.4567 (Table 5), $D/2$ equals 1.0555. The probability of correctly classifying a single fish into its morphotype is 85.7 percent.

Classification of Samples into Morphotypes

Pink salmon samples with at least 20 usable fish were classified into either morphotype group with the calculated western Alaskan-eastern Kamchatkan discriminant function.

Table 6 gives the results of classifying the 1959 morphotype and inshore samples. Classification is presented as percentage of specimens in each sample resembling the western Alaskan morphotype (Y values greater than -36.0716) and eastern Kamchatkan morphotype (Y values less than -36.0716). The mean Y values were also placed on a straight line in order of magnitude (Fig. 4).

Twelve North American inshore samples were classified. Their mean Y values can be found in Figure 4. Since all values are greater than -36.0716, we would expect that individual fish will be classified predominantly into the western Alaskan morphotype. This is verified in Table 6 where the percentages range from 72.7 to 100. It is apparent that the morphological relationships of all North American inshore samples were such that the majority of their individual fish were classified into the western Alaskan morphotype. Therefore, we would expect high-seas-caught pink salmon originating from these areas to be predominantly classified as western Alaska-type fish.

The two samples used to represent eastern Kamchatka had mean Y values less than -36.0716. Individual fish from these samples were classified 80.0 and 86.7 percent into the Asian morphotype. Therefore, we would expect high-seas-caught pink salmon originating from this morphotype's spawning area to be predominantly classified as eastern Kamchatka-type fish.

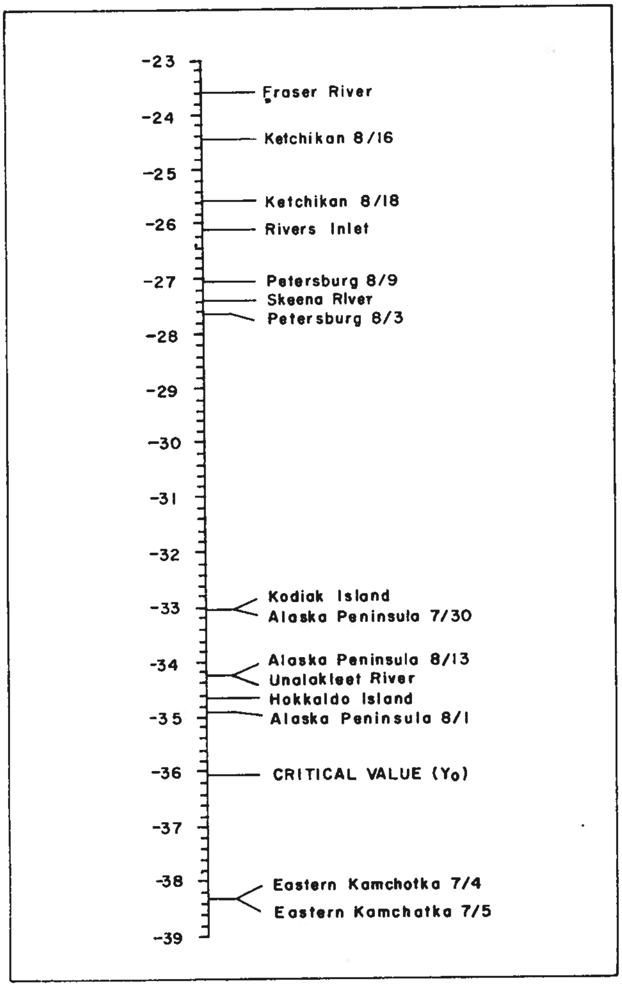

Figure 4. Linear comparison of mean discriminant scores of 1959 pink salmon morphotype and inshore samples.

An inshore sample collected from Hokkaido Island in Japan had a mean Y value greater than -36.0716. Over 61 percent of the fish in the sample were erroneously classified into the western Alaskan morphotype. However, the coastal catch of 58,000 fish (Table 1) from Hokkaido Island was small in comparison to 13,875,000 from eastern Kamchatka and 3,079,000 from central and western Alaska. Even if the fish from Hokkaido Island could be separated from the North American stocks, their presence would not greatly influence the high seas distribution pattern. Other Asian stocks from unsampled spawning regions may also have a high percentage of erroneously classified western Alaska-type fish. Some of these regions had large coastal catches in 1959 (Table 1). Intermingling of these fish with eastern Kamchatkan pink salmon might result in erroneously high estimates of the percentage of North American pink salmon in the high seas samples.

Results of classifying pink salmon of unknown origin obtained on the high seas are presented in Table 7 as percentage of fish in each sample classified into the two morphotypes. Samples are listed by longitude from east to west.

Only four of the 33 samples have more than 50 percent western Alaska-type fish. These western Alaska-type samples were taken from the following locations: south of the Alaska Peninsula at 53°55′N. and 159°40′ W. on July 26, south of the Alaska Peninsula at 53°00′N. and 160°00′W. on July 25, the eastern Bering Sea at 59°00′N. and 175°00′W. on June 27 and south of Adak Island at 51°31′N. and 176°42′W. on July 27. The last two samples were classified as 40.5 and 34.6 percent eastern Kamchatka-type fish. Since these values are higher than we would expect in random sampling of pure North American stocks, it is possible that they contain some Asian fish or misclassified North American fish. In a similar manner, North American fish may be present in the sample taken at 57°00′N. and 180°, which was classified as 38.6 percent western Alaska-type.

The three samples from the North Pacific Ocean containing more than 50 percent western Alaska-type fish were taken south of Adak Island on July 27 and south of the Alaska Peninsula on July 25 and July 26. Table 8 shows that approximately 97.0 percent of the eastern Kamchatkan pink salmon coastal catch occurred by August 1. Since the majority of eastern Kamchatkan pink salmon migrated to the coastal areas by late July, we would not expect large numbers of eastern Kamchatkan pink salmon in the samples taken south of Adak Island on July 27 and south of the Alaska Peninsula on July 25 and July 26.

With the possible exception of two samples taken south of Kamchatka at 152°58′E. and 150°27′E., the remaining samples appear to be eastern Kamchatka-type fish (Fig. 1). Their percentages of western Alaska-type range only as high as 22.6, which is no greater than the misclassification expected in pure Asian samples.

One assumption for use of the discriminant function is that the high seas collections originate from areas represented by the samples composing the morphotypes. This assumption cannot be completely satisfied for samples taken from outside the high seas tagging area and pink salmon from these samples may have originated from other areas. For example, it seems possible that large numbers of fish from Asian spawning areas other than eastern Kamchatka were present in the collections obtained south of Kam-

Table 7. Classification of 1959 pink salmon high seas samples to western Alaskan or eastern Kamchatkan morphotypes.

Map number[1]	Location	Date	Sample size	Percent classified	
				Western Alaskan	Eastern Kamchatkan
16	53°55′N, 159°40′W	7/26	50	96.0	4.0
17	53°00′N, 160°00′W	7/25	38	94.7	5.3
18	51°00′N, 169°56′W	7/5	52	15.4	84.6
19	52°00′N, 169°53′W	7/4	43	20.9	79.1
20	53°58′N, 170°01′W	7/2	23	8.7	91.3
21	53°18′N, 170°00′W	7/3	54	9.3	90.7
22	59°00′N, 170°00′W	6/27	42	59.5	40.5
23	52°59′N, 175°00′W	6/21	64	10.9	89.1
24	56°00′N, 176°00′W	6/24	69	15.9	84.1
25	55°00′N, 176°00′W	6/23	53	9.4	90.6
26	54°00′N, 176°00′W	6/22	49	18.4	81.6
27	51°31′N, 176°25′W	6/15	41	14.6	85.4
28	51°31′N, 176°42′W	7/27	26	65.4	34.6
29	51°23′N, 176°45′W	6/14	32	9.4	90.6
30	52°38′N, 178°47′W	6/22	40	12.5	87.5
31	60°00′N, 180°	6/30	64	12.5	87.5
32	58°00′N, 180°	6/28	60	15.0	85.0
33	57°00′N, 180°	6/27	44	38.6	61.4
34	56°00′N, 180°	6/26	20	10.0	90.0
35	55°00′N, 180°	6/25	63	14.3	85.7
36	54°00′N, 180°	6/24	86	16.3	83.7
37	53°30′N, 180°	6/13	23	0.0	100.0
38	52°59′N, 179°55′E	6/23	48	14.6	85.4
39	48°00′N, 175°00′E	5/25	45	22.2	77.8
40	55°00′N, 175°00′E	7/15	84	13.1	86.9
41	48°57′N, 169°29′E	5/26	23	17.4	82.6
42	48°48′N, 168°36′E	7/15	22	18.2	81.8
43	52°32′N, 163°48′E	7/5	34	8.8	91.2
44	48°31′N, 162°31′E	6/15	23	17.4	82.6
45	44°54′N, 161°03′E	5/30	22	4.5	95.5
46	47°20′N, 155°53′E	7/10	53	22.6	77.4
47	45°24′N, 152°58′E	6/30	33	33.3	66.7
48	43°48′N, 150°27′E	6/14	42	28.6	71.4

[1] Numbers refer to sampling locations in Figure 1.

Table 8. Percentage of the yearly catch of pink salmon taken from June to September in 1959 from the coastal areas of eastern Kamchatka in Asia and central and western Alaska in North America.

Area	Month			
	June	July	August	September
	Percent	*Percent*	*Percent*	*Percent*
Eastern Kamchatka[1]	0.3	96.7	2.0	1.0
Central and western Alaska[2]	4.0	45.6	49.8	0.6

[1] Data submitted to the INPFC by VNIRO—INPFC Doc. 363.

[2] INPFC Statistical Yearbook 1959.

chatka. Two samples taken from 152°58′E. and 150°27′E. were classified 66.7 and 71.4 percent into the Asian morphotype. These figures are slightly lower than we would expect from pure eastern Kamchatkan fish. Since fish tagged in this area were recovered from Okhotsk Sea and western Kamchatkan spawning regions (INPFC, 1961), it is possible that these fish were from the Okhotsk Sea or western Kamchatka.

SUMMARY AND CONCLUSIONS

Six morphological characters, four from scales and two from radiographs of ossified structures, were used in a discriminant function analysis to determine continent of origin of pink salmon from the North Pacific Ocean and Bering Sea in 1959. Samples were collected from the high seas and the principal spawning areas of Alaska and British Columbia.

The destination of the pink salmon taken from Aleutian and Bering Sea waters was assumed to be eastern Kamchatka in Asia and western or central Alaska in North America. Consequently, morphological characters from eastern Kamchatkan and Alaskan fish were used to compute continental morphotypes.

The morphological characters were examined for differences between morphotype means and for conformity to the statistical requirements of a discriminant function. The results of these examinations indicated that the characters could be used in a discriminant function analysis that would classify fish taken on the high seas to most probable continent of origin on the basis of their resemblance to one or the other morphotype.

A discriminant function was calculated that correctly classified 85.7 percent of the eastern Kamchatkan and western Alaskan fish. When the high seas collections were classified with this analysis, only four of the 33 samples had more than 50 percent western Alaska-type fish. In the Bering Sea, eastern Kamchatkan fish were dominant in all samples taken west of 170° W. longitude. However, one sample taken at 59° N. and 170° W. had 60 percent western Alaska-type fish. In the North Pacific Ocean, eastern Kamchatkan fish were dominant in all samples taken west of 170°W. with one exception. That sample was taken at 51°31′N. and 176°42′W. on July 27. It was classified as 65.4 percent western Alaska-type fish.

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APPENDICES

Appendix A. Pink Salmon Samples Collected in 1959 and Processed for Morphological Characters.

Inshore Samples

Area	Location	Date	Sample size
Northwestern Alaska	Unalakleet River	7/10	44
"	"	7/12	31
Alaska Peninsula	Ivanof Bay	7/29	3
"	"	7/30	72
"	Coal Bay Stream	8/1	75
"	Hook Bay	8/13	59
Kodiak Island	Uyak Bay	8/6	75
"	Olga Bay	8/9	76
Prince William Sound	Sheep Bay	7/5	74
Petersburg	Sanborn Canal	8/3	73
"	Mole Harbor	8/9	75
Ketchikan	Robinson Creek	8/18	75
"	Halibut Bay	8/16	75
Skeena River	Point Edward	8/14	75
Rivers Inlet	Fitzhugh Sound	8/14	75
Fraser River	Steveston	9/1	74
Hokkaido Island	Yubetsu River	8/17	75

High Seas Samples

Vessel	Location	Date	Sample size
	United States Research Vessels		
Commander	52°12′N, 173°43′E	7/10	13
Pioneer	48°00′N, 175°00′E	5/25	100
"	52°47′N, 171°00′E	6/4	4
"	55°00′N, 171°00′E	6/8	1
"	53°30′N, 180°	6/13	44
"	52°38′N, 178°47′W	6/22	69
"	52°59′N, 179°55′W	6/23	103
"	54°00′N, 180°	6/24	119
"	55°00′N, 180°	6/25	100
"	56°00′N, 180°	6/26	36
"	57°00′N, 180°	6/27	74
"	58°00′N, 180°	6/28	99
"	60°00′N, 180°	6/30	119
"	58°00′N, 175°00′E	7/4	105
"	55°00′N, 175°00′E	7/15	124
"	54°00′N, 175°00′E	7/16	24
"	51°54′N, 174°00′E	7/19	10
"	51°30′N, 175°00′E	7/22	3
"	50°30′N, 175°00′E	7/23	3
"	51°31′N, 176°42′W	7/27	36
"	51°31′N, 176°40′W	7/28	5
"	51°29′N, 176°38′W	7/29	36
"	50°00′N, 175°00′W	8/6	2
"	49°05′N, 170°10′W	8/12	1

Continued . . .

APPENDIX A. (Continued)

Vessel	Location	Date	Sample size
Tordenskjold	53°17′N, 165°35′W	5/25	3
”	51°56′N, 169°39′W	5/27	9
”	51°41′N, 171°57′W	5/28	13
”	51°00′N, 180°	6/2	10
”	49°59′N, 179°57′W	6/3	9
”	49°03′N, 179°56′W	6/4	104
”	49°01′N, 175°04′W	6/7	87
”	51°32′N, 176°31′W	6/12	57
”	51°32′N, 176°34′W	6/14	21
”	51°31′N, 176°25′W	6/15	105
”	52°59′N, 175°00′W	6/21	100
”	54°00′N, 176°00′W	6/22	97
”	55°00′N, 176°00′W	6/23	100
”	56°00′N, 176°00′W	6/24	100
”	57°00′N, 175°00′W	6/25	24
”	59°00′N, 170°00′W	6/27	87
”	58°00′N, 170°00′W	6/28	3
”	55°59′N, 170°00′W	6/30	60
”	55°01′N, 170°03′W	7/1	11
”	53°58′N, 170°01′W	7/2	57
”	53°18′N, 170°00′W	7/3	100
”	52°00′N, 169°53′W	7/4	104
”	51°00′N, 169°56′W	7/5	98
”	53°30′N, 165°00′W	7/11	39
”	52°58′N, 164°58′W	7/12	18
”	50°02′N, 165°00′W	7/15	2
”	47°01′N, 160°02′W	7/19	1
”	48°02′N, 160°00′W	7/20	1
”	49°55′N, 160°05′W	7/22	12
”	50°57′N, 159°55′W	7/23	19
”	51°57′N, 159°58′W	7/24	19
”	53°00′N, 160°00′W	7/25	93
”	53°55′N, 159°40′W	7/26	72
	Japanese Research Vessels		
Wakashio Maru	48°00′N, 170°00′E	5/26	5
”	48°07′N, 165°11′E	6/8	7
”	48°45′N, 162°37′E	6/11	9
”	49°31′N, 159°59′E	6/17	49
”	51°00′N, 159°28′E	8/8	3
”	51°25′N, 163°00′E	8/17	2
Tenyo Maru	57°58′N, 174°17′E	7/5	14
”	57°56′N, 170°00′E	7/17	23
”	51°31′N, 176°27′W	6/12	2
”	51°23′N, 176°45′W	6/14	52
”	51°23′N, 176°34′W	6/15	10
	Canadian Research Vessels		
Key West	50°00′N, 145°00′W	5/18	9
”	50°00′N, 145°00′W	5/19	19
”	53°00′N, 160°00′W	6/14	67
”	53°00′N, 160°00′W	6/24	36
”	50°00′N, 160°00′W	6/27	40
”	50°00′N, 160°00′W	6/28	43

Continued . . .

APPENDIX A. (Continued)

Vessel	Location	Date	Sample size
	Japanese Landbased Fishery		
Takuyo Maru	43°41′N, 157°10′E	5/20	72
”	44°54′N, 161°03′E	5/30	73
”	43°48′N, 150°27′E	6/14	75
”	45°24′N, 152°58′E	6/30	75
”	47°20′N, 155°53′E	7/10	80
	Japanese Mothership Fishery (Nichiro Fishing Company)		
Yae Maru	48°57′N, 169°29′E	5/26	75
Anshin Maru	51°21′N, 171°20′E	6/5	75
Chokai Maru	48°24′N, 163°55′E	6/15	75
Anshin Maru	49°06′N, 170°52′E	6/25	75
Kaiho Maru	52°32′N, 163°48′E	7/5	75
	Japanese Mothership Fishery (Nippon Suisan)		
Miyajima Maru	48°00′N, 169°12′E	5/27	75
”	46°21′N, 168°06′E	6/5	75
”	48°31′N, 162°31′E	6/15	70
”	56°49′N, 173°22′E	7/5	75
”	48°48′N, 168°36′E	7/15	75

Appendix B-1. Tests for Selecting a Scale Axis

The circuli on pink salmon scales form concentrically around a central platelet or focus. Although circulus counts and scale measurements can be taken along any axis from the focus, Clutter and Whitesel (1956) found that the counts and measurements vary with choice of angle for sockeye salmon. Therefore, if circuli counts or measurements are to be used as morphological characters, it is necessary to (1) select a specified scale axis and (2) choose this axis consistently.

The worker who made the measurements was tested to determine whether he was consistent in selecting a specified axis. The following methods of selecting an axis were examined: (1) the longest radius from the center of the focus to the annulus and (2) the longest radius from the focus to the seventeenth circulus. Ten scales from Unalakleet River fish and ten scales from eastern Kamchatkan fish were used in the tests. The identification of each scale was concealed from the worker. The angle of the axis that the worker selected was recorded from two separate observations for each method. The differences in angle between the first and second observations were examined with *t*-tests (Snedecor, 1956).

The results of these tests are shown in Appendix B-1 Table 1. Since the differences in angle were not significant at the five percent level, it was concluded that the worker could select the specified axis with each method. However, the mean square of the differences was 8.56 with the longest radius to the annulus and only 2.22 with the longest radius to the seventeenth circulus. Consequently, the scale axis used in this study was the longest radius from the center of the focus to the seventeenth circulus.

Appendix B-1 Table 1. Results of *t*-tests to determine if differences in angle occur when selecting a scale axis.

	Method of selecting the axis	
	Longest radius from focus to seventeenth circulus	Longest radius from focus to annulus
Number of scales	20	20
Mean of differences (degrees)	−0.25	−0.08
Mean square of differences	2.22	8.56
Standard deviation of differences	1.49	2.93
t-value from test	−0.76	−0.12
$t_{0.05}$ with 19 *d.f.*	±2.09	±2.09

Appendix B-2. Tests for Differences Between Readings of Scale Characters

The worker who made the measurements was tested to discover whether he could accurately repeat the necessary circuli count or measurement for each scale character.

Fifty scales were randomly sampled from each of the following 1959 samples: (1) Uyak Bay, (2) Ivanof Bay, (3) Unalakleet River, (4) United States research vessel *Pioneer* at 58°00′N., 175°00′E., and (5) Japanese mothership fishery vessel *Miyajima Maru* at 56°49′N., 173°22′E. The identification of each scale was concealed from the worker during the test. The character values were recorded from each scale from two separate observations. In each of the readings, the order of observation for the 250 scales was determined by random selection. The differences between the first and second readings were examined with a *t*-test (Snedecor, 1956).

The results of this examination are found in Appendix B-2 Table 1. Since the differences between the readings of the scales were not significant at the five percent level for any character, it was concluded that the worker could accurately repeat a previous circuli count or measurement.

Appendix B-2 Table 1. Results of *t*-tests to determine if differences occur between two readings of the scale characters.

	Scale character			
	Number of circuli in first half	Number of circuli in second half	Number of circuli in second sixth	Width (mm.) of narrowest three circuli
Number of scales	250	250	250	250
Mean of differences	−0.0280	−0.0520	+0.0220	−0.0520
Mean square of differences	0.2522	0.6117	0.1672	0.7242
Standard deviation of differences	0.5022	0.7821	0.4089	0.8510
Standard error of differences	0.0318	0.0495	0.0258	0.0538
t-value from test	−0.8805	−1.0505	+0.8527	−0.9665
$t_{0.05}$ with 249 *d.f.*	±1.971	±1.971	±1.971	±1.971

Appendix B-3. Mean Values of the Scale Characters Using Seven Different Radial Lines

The mean values of the scale characters were examined along radial lines different from the selected scale axis.

Data were collected on the following radial lines: (1) 60° to the left of the scale axis, (2) 40° to the left of the scale axis, (3) 20° to the left of the scale axis, (4) the scale axis, (5) 20° to the right of the scale axis, (6) 40° to the right of the scale axis and (7) 60° to the right of the scale axis. Ten scales from Kodiak Island fish and ten scales from eastern Kamchatkan fish were used. The scales were taken from the preferred body position on the left side of the fish.

The results of this examination are shown in Appendix B-3 Table 1. Although the sample sizes are small, it is apparent that the counts and measurements vary with change in position of the radial line. Generally, the circulus counts are greatest from 20° to 40° on the right side of the selected scale axis. The narrowest-three-circuli measurement is greatest on the scale axis. These results indicate that circulus counts and scale measurements should be taken along a particular radial line to obtain scale characters of the greatest consistency.

Because of the variation in mean value of circulus counts and scale measurements with different radial lines, the morphological characters used to classify the 1959 collections to continent of origin were taken only along the following three radial lines: (1) the scale axis, (2) 7.5° to the right of the scale axis when the first line could not be used and (3) 7.5° to the left of the scale axis when the first and second lines were not usable.

Appendix B-3 Table 1. Means and variances of the scale characters taken along seven different radial lines.

Character	Radial line	Kodiak Island		Eastern Kamchatka	
		Mean	Variance	Mean	Variance
Number of circuli in first half	60° left of scale axis	11.10	1.43	9.45	1.52
	40° left of scale axis	11.50	0.94	9.95	1.64
	20° left of scale axis	11.90	0.66	10.10	1.21
	Scale axis	11.90	0.66	10.35	1.78
	20° right of scale axis	12.00	0.44	10.35	1.72
	40° right of scale axis	11.45	1.30	9.80	2.18
	60° right of scale axis	11.15	0.45	9.35	2.22
Number of circuli in second half	60° left of scale axis	12.95	1.30	10.75	0.57
	40° left of scale axis	13.00	1.78	10.65	1.17
	20° left of scale axis	12.70	1.01	10.00	1.11
	Scale axis	12.50	1.28	10.15	1.45
	20° right of scale axis	13.30	0.90	11.35	0.84
	40° right of scale axis	13.25	0.68	11.40	1.16
	60° right of scale axis	12.65	1.34	10.85	1.45
Number of circuli in second sixth	60° left of scale axis	4.10	0.43	3.20	0.62
	40° left of scale axis	4.10	0.27	3.25	0.46
	20° left of scale axis	4.10	0.16	3.45	0.25
	Scale axis	3.90	0.27	3.45	0.19
	20° right of scale axis	4.15	0.28	3.55	0.30
	40° right of scale axis	4.10	0·27	3.40	0.60
	60° right of scale axis	4.20	0.23	3.40	0.93
Width of narrowest three circuli	60° left of scale axis	7.6	1.2	9.5	0.5
	40° left of scale axis	9.1	2.3	10.0	1.8
	20° left of scale axis	10.5	1.6	10.5	0.5
	Scale axis	10.8	2.3	11.7	1.6
	20° right of scale axis	9.7	1.8	11.1	2.3
	40° right of scale axis	9.0	1.8	10.3	2.0
	60° right of scale axis	7.9	1.4	9.3	2.0

Appendix B-4. Variation in Mean Value of Characters Observed in Scales from Different Body Positions on a Pink Salmon

Research workers have observed differences in the scales of *Oncorhynchus* sampled from various parts of the fish. Variation of scale characters with respect to body position has been observed by Hayashi (1957) on pink salmon and Clutter and Whitesel (1956) on sockeye salmon. Therefore, each scale character in this study was examined to determine if differences occur when scales are taken from several positions on an individual fish.

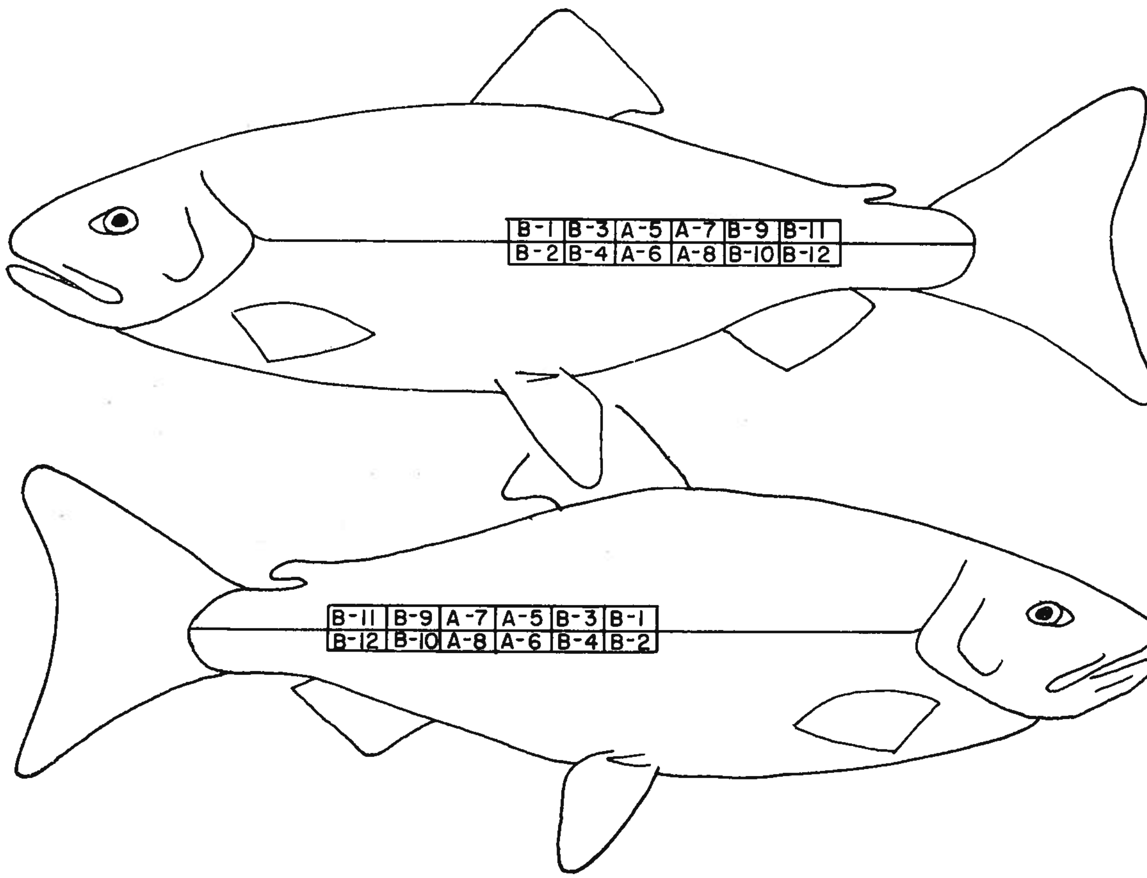
Scales were taken from the International North Pacific Fisheries Commission A and B sampling areas (Appendix B-4 Figure 1) on the left and right sides of a pink salmon caught in Karluk Lagoon on July 28, 1960. These areas were subdivided into four zones of four vertical scale rows and 15 horizontal scale rows. Fifteen scales were randomly sampled from each zone of 60 scales.

The results of this examination are found in Appendix B-4 Table 1. All characters except the narrowest three measurements follow a pattern similar to that of number of circuli in the first half of the first ocean zone where higher mean values occur in the posterior sampling zones. The mean values of the narrowest three measurements were less variable between the anterior and posterior sampling zones. In a similar manner, higher mean values were observed on the right side of the fish in all characters other than the narrowest three measurements. The mean values of the narrowest three measurements were less variable between sides.

Because of the variation in mean value of characters observed in scales from different body positions, scales from only the preferred body position were used to classify the 1959 collections to continent of origin. Further study was conducted to determine if the mean values of the characters were the same in preferred scales from both sides of the fish within samples. The results of that study are in Appendix B-5.

Appendix B-4 Table 1. Means and variances of scale characters from different body positions on a pink salmon.

Body position (See App. B-4 Fig. 1)			Scale character: Number of circuli in first half		Number of circuli in second half		Number of circuli in second sixth		Width of narrowest three circuli	
Side	Area	Zone	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
Right	B	1	10.7	0.25	10.1	0.45	3.6	0.15	9.2	0.74
		2	10.8	0.27	10.4	0.30	3.6	0.05	9.7	0.64
		3	10.9	0.48	10.5	0.41	3.7	0.10	9.1	1.50
		4	11.0	0.36	10.3	0.24	3.8	0.13	9.3	0.95
	A	5	11.0	0.16	10.4	0.39	3.7	0.10	9.0	1.14
		6	11.0	0.66	10.3	0.42	3.8	0.17	9.2	1.46
		7	11.7	0.27	10.5	0.23	3.9	0.17	9.0	0.29
		8	11.4	0.25	10.6	0.39	4.0	0.16	9.4	0.69
	B	9	11.5	0.36	10.9	0.26	3.8	0.10	9.4	0.83
		10	11.1	0.35	10.7	0.67	3.8	0.10	9.5	0.55
		11	11.4	0.20	11.0	0.41	3.8	0.06	9.5	0.55
		12	11.4	0.28	11.2	0.45	3.9	0.07	9.5	0.41
Left	B	1	10.6	0.23	10.2	0.63	3.5	0.14	9.9	0.55
		2	10.3	0.32	9.9	0.53	3.5	0.20	9.5	1.55
		3	10.8	0.28	10.4	0.44	3.6	0.22	9.5	0.55
		4	10.7	0.35	9.8	0.31	3.6	0.10	9.4	0.54
	A	5	11.1	0.57	10.4	0.61	3.8	0.07	9.3	0.68
		6	10.8	0.31	10.0	0.29	3.7	0.17	8.9	0.92
		7	11.3	0.38	10.7	0.14	3.7	0.14	9.1	0.92
		8	11.0	0.71	10.2	0.74	3.7	0.10	9.5	0.69
	B	9	11.3	0.27	10.8	0.35	3.7	0.13	9.5	0.55
		10	11.4	0.58	10.5	0.45	3.8	0.14	9.3	0.67
		11	11.2	0.20	10.6	0.53	3.7	0.06	9.3	0.50
		12	11.4	0.44	10.7	0.60	3.7	0.10	9.1	0.64



APPENDIX B-4 FIGURE 1. Scale sampling locations on the left and right sides of a pink salmon.

Appendix B-5. Tests for Difference in Mean Value of Characters from Preferred Body Position Scales Between Right and Left Side of Body

In Appendix B-4, the mean values of the scale characters were examined on the left and right sides of one pink salmon. Higher values were observed on the right side in all characters other than the narrowest three measurements. This condition was examined further to determine if the mean values differ between sides within samples.

Two spawning area samples were used. They were obtained from Ivanof Bay on August 6, 1960, and from Karluk Lagoon on July 28, 1960. Scales were taken from the preferred body position on the left and right sides of the fish. The character means and variances were computed for each side in each sample. The differences in mean value between the right and left sides were examined with a *t*-test (Snedecor, 1956).

The results of this test are found in Appendix B-5 Table 1. The differences in mean values between sides were not significant at the five percent level for any character. Since no difference was observed within samples, scales from the preferred body position on either the left or right side of the fish were used to classify the 1959 collections to continent of origin. Scales from the left side were preferred. If the left side scale was missing or damaged, the scale from the right side was used.

Appendix B-5 Table 1. Results of *t*-tests to determine if differences occur in mean value of characters from preferred body position scales between right and left sides of pink salmon within samples.

Inshore area	Scale character	Side of fish	Sample size	Mean	Variance	Mean difference	Pooled variance	*t*-value from test
Ivanof Bay Aug. 6, 1960	Number of circuli in first half	Left	36	11.6250	0.7912	0.0000	0.6410	0.0000
		Right	84	11.6250	0.5776			$t_{0.05}$ with 118 *d.f.* $= \pm 1.982$
	Number of circuli in second half	Left	36	11.1528	1.7689	0.1528	1.4441	0.6383
		Right	84	11.0000	1.3072			$t_{0.05}$ with 118 *d.f.* $= \pm 1.982$
	Number of circuli in second sixth	Left	36	3.9722	0.2992	−0.0516	0.2832	−0.4868
		Right	84	4.0238	0.2765			$t_{0.05}$ with 118 *d.f.* $= \pm 1.982$
	Width of narrowest three circuli	Left	36	10.5000	2.0857	0.4762	1.8217	1.7709
		Right	84	10.0238	1.7104			$t_{0.05}$ with 118 *d.f.* $= \pm 1.982$
Karluk Lagoon July 28, 1960	Number of circuli in first half	Left	81	11.2901	0.9992	−0.0599	0.8738	−0.4189
		Right	90	11.3500	0.7610			$t_{0.05}$ with 169 *d.f.* $= \pm 1.976$
	Number of circuli in second half	Left	81	11.3827	0.9079	−0.0784	1.2559	−0.4571
		Right	90	11.4611	1.5687			$t_{0.05}$ with 169 *d.f.* $= \pm 1.976$
	Number of circuli in second sixth	Left	81	3.6296	0.3861	−0.0260	0.3237	−0.2989
		Right	90	3.6556	0.2677			$t_{0.05}$ with 169 *d.f.* $= \pm 1.976$
	Width of narrowest three circuli	Left	81	10.9630	2.2612	0.0074	1.9688	0.0345
		Right	90	10.9556	1.7059			$t_{0.05}$ with 169 *d.f.* $= \pm 1.976$

Appendix C. Percentages of Pink Salmon Collected in 1959 Having Usable Morphological Characters

	Sample size	Character (usable percentage in sample)		
		Scales	Branchiostegals	Vertebrae
Inshore samples	1106	60.8	98.8	96.0
High seas samples				
United States research vessels	2865	54.4	97.5	93.8
Japanese research vessels	176	40.1	96.0	94.3
Canadian research vessels	214	0.0	86.4	94.9
Japanese landbased vessels	375	45.1	98.9	97.3
Japanese mothership fishery	745	35.6	98.7	94.5

Appendix D. Within Race Variability Tests

The objective of Appendix D was to determine the effect of within race variation on counts and measurements obtained from the morphological characters collected from spawning streams in 1959. Two main sources of variation were examined: differences in counts between sexes and the relationship between length of fish and magnitude of counts.

Before the high seas collections can be classified by means of their morphological characters, it must be determined if the counts observed in the high seas samples are typical of those found in the races to which they belong. Since within race variation can bias the classification, the effect of possible sources of within race variation on each character was examined.

Appendix D-1. Tests for Sexual Differences in Morphological Characters

Each character was tested to determine if differences occurred in counts or measurements between sexes. An approximate two-way analysis of variance design with unequal numbers of observations in the cells (Snedecor, 1956), allows the effects of spawning area, sex and interaction to be determined in a single test. If a significant sexual difference was found, the unbiased estimate of the difference was calculated (Snedecor, 1956). Spawning area samples with 20 or more specimens of each sex were used in these tests (Appendix D-1 Table 1).

The results of the analysis of variance tests are found in Appendix D-1 Table 2. No significant interaction effects were found. One significant sexual difference was found in number of scale circuli in the first half. The unbiased estimate of the difference was 0.237 circuli higher in males. Since the discriminant function analysis was calculated with eastern Kamchatkan and western Alaskan fish, eastern Kamchatkan and western Alaskan samples were also tested for sexual differences in number of circuli in the first half. The results of this test are found in Appendix D-1 Table 3. Although the unbiased estimate of the difference was 0.132 circuli greater in males than in females, the sex effect was not significant at the five percent level. None of the other five morphological characters exhibited significant differences.

Appendix D-1 Table 1. Spawning area samples used in tests for sexual differences in morphological characters.

Area	Location
Alaska Peninsula	Ivanof Bay
" "	Coal Bay Stream
" "	Hook Bay
Kodiak Island	Uyak Bay
" "	Olga Bay[1]
Petersburg	Sanborn Canal
"	Mole Harbor[1]
Ketchikan	Robinson Creek[1]
"	Halibut Bay[1]

[1] Since 20 or more usable scales from specimens of each sex were not available for study, this sample was not used to determine if differences occurred in scale characters between sexes.

APPENDIX D-1 TABLE 2. Results of two-way analysis of variance tests for each character between sex of fish and spawning area.

Source of variation	Sum of squares	d. f.	Mean squares	Mean squares individual basis
	Number of circuli in first half			
Area	9.4399	4	2.3600**	
Sex	0.1793	1	0.1793*	
Interaction	0.1469	4	0.0367	1.0186
Error	212.9660	279	0.0275	0.7633
	Number of circuli in second half			
Area	7.6609	4	1.9152**	
Sex	0.0783	1	0.0783	
Interaction	0.0735	4	0.0184	0.5107
Error	255.3790	279	0.0330	0.9153
	Number of circuli in second sixth			
Area	0.8260	4	0.2065**	
Sex	0.0342	1	0.0342	
Interaction	0.0248	4	0.0062	0.1721
Error	77.9950	279	0.0101	0.2796
	Width of narrowest three circuli			
Area	1.5491	4	0.3873*	
Sex	0.2325	1	0.2325	
Interaction	0.0617	4	0.0154	0.4274
Error	611.0000	279	0.0789	2.1900
	Number of branchiostegal rays			
Area	0.9190	8	0.1149**	
Sex	0.0438	1	0.0438	
Interaction	0.0548	8	0.0069	0.2283
Error	278.5000	636	0.0132	0.4379
	Number of vertebrae			
Area	3.3584	8	0.4198**	
Sex	0.0487	1	0.0487	
Interaction	0.2096	8	0.0262	0.8371
Error	462.1000	610	0.0237	0.7575

** Significant at the one percent level.
* Significant at the five percent level.

APPENDIX D-1 TABLE 3. Results of two-way analysis of variance test for number of circuli in the first half between sex of fish and discriminant function samples.

Source of variation	Sum of squares	d. f.	Mean squares	Mean squares individual basis
Samples	6.5480	6	1.0913*	
Sex	0.0690	1	0.0690	
Interaction	0.0765	6	0.0128	0.3656
Error	268.0310	421	0.0223	0.6367

* Significant at the one percent level.

Appendix D-2. Examination of the Effect of Fish Length on Morphological Characters

It is not always possible to collect specimens with length typical of their race, for it is known that certain types and sizes of fishing gear will select fish by length. If the morphological characters being studied are correlated with length, biased samples will occur when specimens of non-representative length are collected. To examine this possibility, examinations of correlation between fish length and each of the characters were made. Correlation coefficients were computed for each sample. These *r*-values were tested to determine if they were obtained from a common population correlation. The resulting average correlation coefficients were tested for significance. Where a common population correlation was found, the average *r* and percent variation of the character attributable to the variation in length of fish were calculated. Stream samples from all spawning areas with at least 48 specimens were used in these tests with sexes combined. The two samples collected from Unalakleet River on different dates were combined after each morphological character count and measurement was tested to determine if differences occurred between times of sampling.

The results of these examinations are found in Appendix D-2 Table 1. Each character was found to have a common population correlation. The only character with a significant average *r* was the width of the narrowest three circuli. The average *r* value was 0.1524 and the percent variation in width of the narrowest three circuli attributable to the variation in length of fish was only 2.3226 percent.

The results of this examination indicated that length of fish was a negligible source of variation on the counts or measurements of all six morphological characters.

Appendix D-2 Table 1. Results of examinations for correlation of characters with length of fish, chi-square tests for common correlation, average *r*'s and percent variation of characters attributable to the variation in length of fish.

Location	*N*	Vertebrae *r*	Branchiostegal rays *r*	Number circuli first half *r*	Number circuli second half *r*	Number circuli second sixth *r*	Width of narrowest three circuli *r*
Unalakleet River	72	−0.0650	0.0036				
	63			−0.0795	0.0200	−0.2238	0.2535
Ivanof Bay	69	0.0090	−0.0525				
	65			−0.0597	0.0309	0.0097	0.2752
Coal Bay	72	0.1582	0.1012				
	67			0.2031	0.0236	0.1516	0.1844
Hook Bay	54	0.0900	0.0336				
	49			0.0959	0.1884	0.1264	−0.0750
Uyak Bay	74	0.0439	0.1459				
	60			0.1215	0.0637	0.0770	0.0334
Sanborn Canal	69	−0.0043	0.0370				
	48			0.1471	−0.1845	0.2325	0.1803
Olga Bay	76	−0.2436	−0.0022				
Sheep Bay	73	0.0709	0.2673				
Mole Harbor	65	0.1466	0.0306				
Robinson Creek	67	0.2366	0.0482				
Halibut Bay	70	−0.0215	−0.1193				
X^2		11.7496	7.8525	3.9633	3.3669	7.2866	4.9640
Average *r*		0.0338	0.0400	0.0582	0.0259	0.0527	0.1524*
Percent variation attributable to length		0.1142	0.1600	0.3387	0.0671	0.2777	2.3226

* Significant at the one percent level.