USE OF A DISCRIMINANT FUNCTION IN THE MORPHOLOGICAL SEPARATION OF ASIAN AND NORTH AMERICAN RACES OF PINK SALMON, *ONCORHYNCHUS GORBUSCHA* (WALBAUM)

by
Murray H. Amos, Raymond E. Anas and Roger E. Pearson
Biological Laboratory, Bureau of Commercial Fisheries
Seattle, Washington

ABSTRACT

Pink salmon (*Oncorhynchus gorbuscha*) collected from representative North American and Asian areas in 1957 were studied to see how effectively morphological characters would separate continental stocks. A discriminant function was computed using three morphological characters and the Karaginskii and Kodiak-Cook Inlet samples as continental morphotypes. Applying this function, North American pink salmon populations from Kodiak Island and eastward were well separated from the Asian morphotype. Indications were that very few if any pink salmon from these areas were present in the high-seas samples examined. A predominance of pink salmon of Karaginskii morphotype were found in samples taken as far east as 175° West longitude.

CONTENTS

INTRODUCTION

Among the investigations carried out by the United States Fish and Wildlife Service under the research program of the International North Pacific Fisheries Commission is the determination of the continental origin of pink salmon (*O. gorbuscha*) found in the North Pacific Ocean and Bering Sea.

One method of attacking this classification problem is to analyze a selected set of morphological characters. This implies selection of characters that separate races with a low risk of misclassification, and combination of these into a method with a known risk. Tagging and catch data are used as corroborating evidence of continental separation based on morphological characters.

The purposes of this study are: (1) to select morphological characters for Asian and North American pink salmon; (2) to define continental morphotypes based on these characters; and (3) to estimate the contribution of each morphotype to samples of possibly mixed origin. The results of this study should help the United States Section of the International North Pacific Fisheries Commission to carry out its duties in connection with fishery conservation problems in the North Pacific Ocean.

ACKNOWLEDGMENTS

The authors wish to acknowledge Dr. W. F. Royce, Fisheries Research Institute of the University of Washington, for critical review of the manuscript and the following Bureau of Commercial Fisheries personnel: R. A. Fredin for suggested use of the discriminant function; D. D. Worlund for statistical guidance and many helpful suggestions as well as programming the analysis for the IBM 650 computer; and D. D. Worlund and E. DeCorvet for the electronic computations.

METHODS AND MATERIALS

Methods of Sampling

Samples of pink salmon were collected from the principal fisheries of North America in 1957. An attempt was made to obtain the samples during the most active period of fishing. Mature fish were taken

---

Received for publication August 3, 1961. Original, English.
Source: Contribution from the Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, Washington 25, D.C. INPFC Document 412–Rev. 1.
Bull. 11, Int. North Pac. Fish. Comm., 1963.

from their spawning streams whenever possible, but most were obtained from estuarine fisheries.

No pink salmon were obtained from Siberia; however, salmon of probable Siberian origin were obtained from Japanese mothership fisheries operating off the east coast of the Kamchatka Peninsula and in the Okhotsk Sea. These samples were caught in Japanese commercial gillnets with mesh size of 4–8/10 inches stretched measure.[1] Samples from the Japanese fisheries of Hokkaido Island supplemented Asian collections.

High-seas samples were obtained from gillnet catches of the Japanese high-seas fishery and from Japanese, Canadian and United States research vessels. The research vessels used a standard string of gillnets with mesh sizes of 2½, 3¼, 4½ and 5¼ inches stretched measure.

All the specimens were two-year-old fish. Samples were preserved by freezing and subsequently transported to the Seattle Biological Laboratory of the Bureau of Commercial Fisheries in Seattle for examination.

Appendix A (p. 86) lists the location, date and number of pink salmon collected in 1957.

METHODS OF DATA COLLECTION

Ten morphological characters were examined for possible use in separating the various populations of pink salmon (Figure 1). They were as follows:

1. *Vertebrae* were counted, beginning with the atlas and terminating with the urostyle. Specimens with abnormal or fused vertebrae were not included in the analysis.

2. *Ventral gill rakers* were counted on the ventral arm of the first left gill arch commencing with the raker in the bend of the arch and including the rudimentary rakers at the anterior terminus. Branched rakers having a common base were counted as one. If the existence of a rudimentary raker was uncertain, the particular gill arch was re-radiographed or stained[2] for positive identification.

3. *Gill rakers* were counted on the first left gill arch using criteria and methods identical to those for character 2.

4. *Branchiostegal rays* on the left side of the head were also counted. Disagreement in the number of rays was resolved by staining and again counting the structures.

5. *The number of dorsal fin rays* included all rudimentary as well as principal fin rays. Occasionally a small bone was found anterior to the first rudimentary ray in the dorsal and anal fins. This was counted if it showed indications of developing into a fin ray by the presence of a small sharp projection. If this bone showed no sign of developing into a fin ray, it was excluded.

6. *Anal fin rays* were counted using methods and criteria identical to those for character 5.

7. *Pectoral fin rays* were counted on the left fin. No difficulties were experienced in counting this character.

8. *Circuli* from the focus of the scale to the annulus were counted.

9. *The scale length* from the focus to the annulus was measured (magnified 42 times).

10. *The intermediate zone* is the scale length of the first ten circuli from the focus (magnified 42 times).

Permanent photographic records of characters 1 through 7 were obtained by X-raying, and permanent scale impressions were made on acetate cards. The structures on every radiograph were counted by one trained worker and verified by another. Each scale was read by an experienced fishery scientist. Scale samples from selected areas were subjected to repeated readings to verify accuracy. The body length from the end of the hypural plate to the middle of the eye was also measured on each fish. This measurement was not used as a character to classify salmon; however, correlation between length and the other characters was tested for significance to detect possible bias due to selectivity of various mesh sizes. Characters significantly correlated with length were not used.

In the salmon examined, the sample size for scale characters was often smaller than the sample size of the seven characters counted on radiographs. This was particularly true in stream samples where the scales were more frequently absorbed due to approaching sexual maturity.

METHODS OF ANALYSIS

The discriminant function analysis as developed by Fisher (1936) is a multivariate normal technique by which individual observations within a sample may be classified to one of two groups (morphotypes) on the basis of a selected set of morphological variates. This type of analysis was used for pink salmon morphological characters. To apply this analysis it is

---

[1] Distance between opposite knots.

[2] Modified stain method of Hollister (1934).

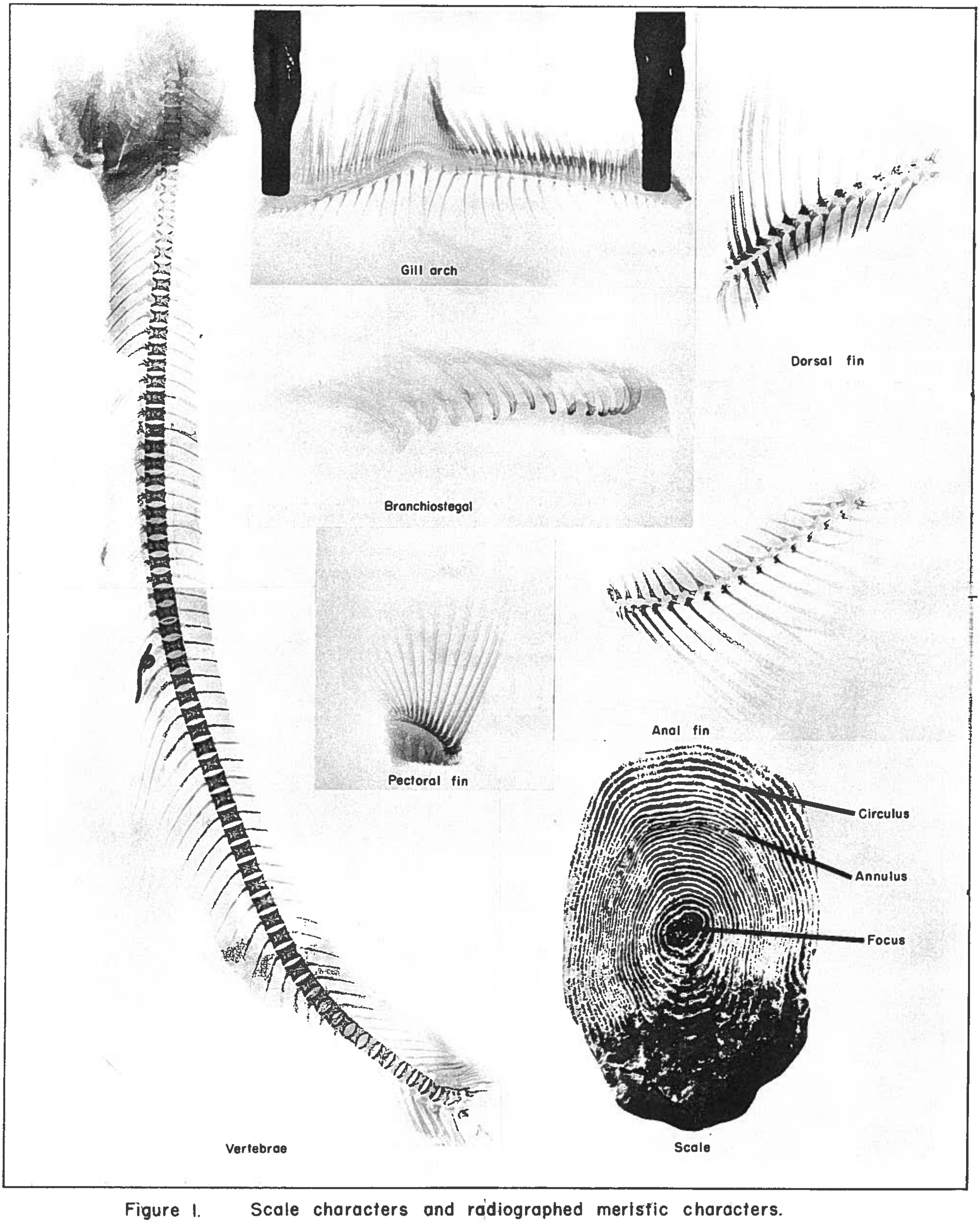

Figure 1. Scale characters and radiographed meristic characters.

necessary to assume that high-seas-caught fish of unknown origin were derived from the races represented by the samples composing the two morphotypes since all individuals will be classified into one or the other regardless of true origin. Additional statistical assumptions require the data to have jointly normal distributions with a common dispersion (variance-covariance) matrix in the populations selected for use as inshore morphotypes and into which specimens are to be classified. There is no single test for a multivariate normal distribution, although satisfaction of certain other conditions can indicate conformity in some of the important aspects. These conditions include common variance, normality of distributions, common correlation and linearity of regression. If common variance and common correlation exist as required for a multivariate normal distribution, the conditions for a common dispersion matrix are simultaneously satisfied.

RESULTS

Examination of Intra-Area Variability

The ten morphological characters were examined for two possible sources of intra-area sampling variability, sexual dimorphism and correlation with fish length. Since mixtures of races could also cause extraneous variability, examination was restricted to stream samples which were assumed to be of one race.

Appendices B-1 (p. 88) and B-2 (p. 90) show that the variances between sexes are significantly different only for ventral gill rakers. None of the means are significantly different between sexes, but the value for total vertebrae is close to the 95 percent critical value. Heterogeneity of variances generally biases analysis of variance tests toward more frequent significant *F*-values. Despite this presumed influence on the means of the ventral gill raker data, there is no evidence of sexual dimorphism. The sexes have been combined for further analyses.

Some types of fishing gear are size selective. Correlation of morphological characters with fish length could introduce bias. Appendices B-3 (p. 91) and B-4 (p. 91) show that only the numbers of circuli and scale length had significant correlation coefficients, and that only 4.62 percent and 8.73 percent of the variation in these characters was attributable to length. None of the other morphological characters was significantly correlated to fish length. No serious bias due to correlation of fish length with morphological characters is indicated in these data.

Selection of Morphotypes

Karaginskii and Kodiak-Cook Inlet were selected as continental morphotypes.

Some direct and some circumstantial evidence is available on the origin of the populations composing

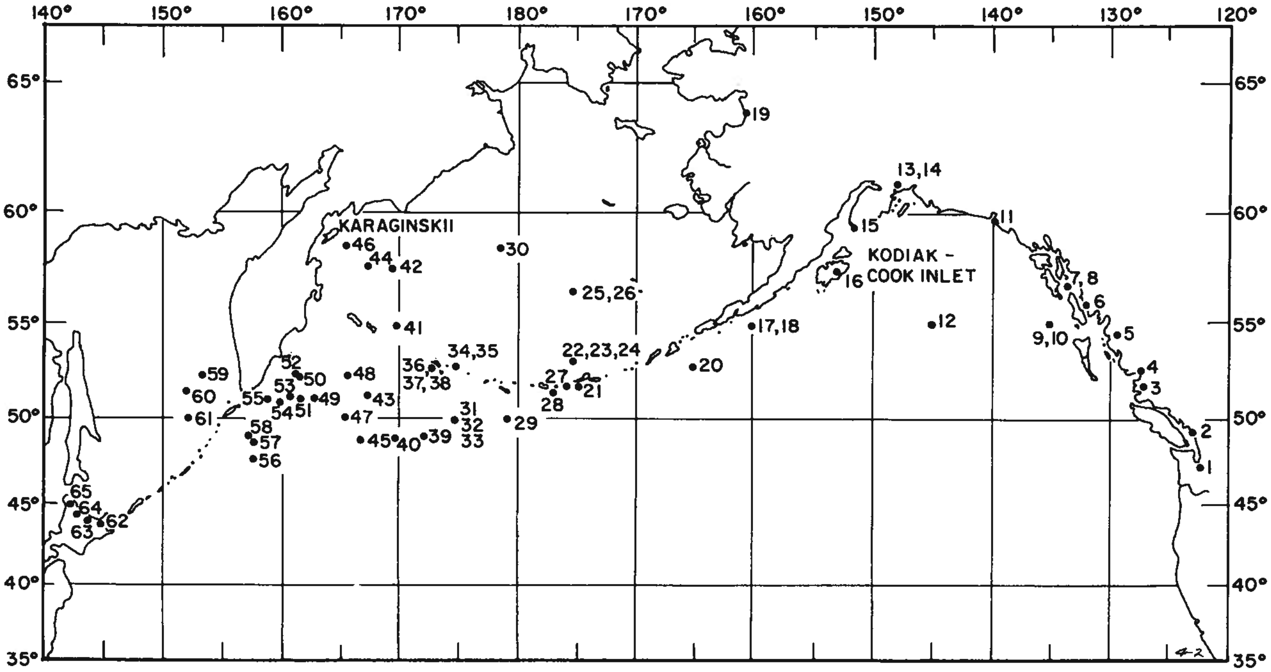

Figure 2. Sampling locations for 1957 pink salmon (see Tables 5 and 6).

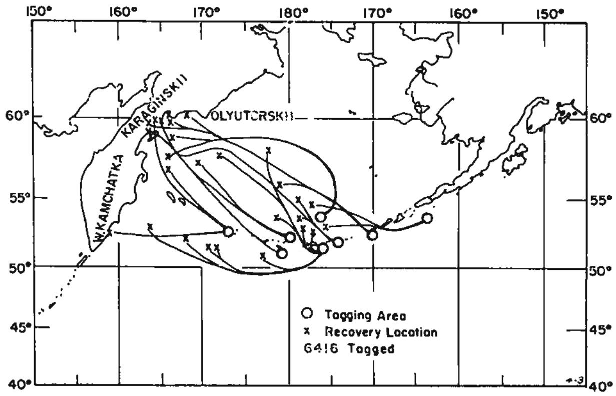

FIGURE 3. 1957 tag recoveries of pink salmon tagged during 1957.

most of the high-seas samples collected in 1957 (Figure 2). The United States tagging vessels tagged 6,416 high-seas-caught pink salmon during 1957 (Annual Report, International North Pacific Fisheries Commission, 1958). Fish were tagged along the Aleutian Islands and to a limited extent offshore both north and south of the Aleutians. All recoveries (68) of 1957 pink salmon tags were made by the U.S.S.R. on the east coast of the Kamchatka Peninsula or by the Japanese high-seas fishery, westward of the tagging site and between the areas of tagging and Kamchatka (Figure 3). None was recovered in west Kamchatka, the Japanese Okhotsk Sea fishery, the Hokkaido Island land-based fishery or in North American fisheries or stream surveys. Most Soviet recoveries were made in the Karaginskii region of the Kamchatka Peninsula.

The Karaginskii region is reported to be an area of fairly heavy pink salmon production, though it does not approach the level of production reported for the west Kamchatka region (Taguchi, 1957). Although samples representing elements of the latter were included in 1957 pink salmon collections from the Japanese Okhotsk Sea fishery, samples from the immediate proximity of the Karaginskii region were not obtained. Therefore, it was necessary to constitute a Karaginskii morphotype from the high-seas fisheries samples taken closest to the Karaginskii region. Three such samples, taken at 58°12′N., 166°48′E.; 57°02′N., 169°11′E. and 57°26′N., 167°27′E. were used. Of the 99 pink salmon so obtained, 25 were excluded for lack of complete sets of morphological data. These samples were statistically identical in the morphological characters used in the analysis and may be pooled (Appendix C–1, p. 92).

Although there is no direct evidence that populations other than those from Karaginskii occurred in the area of tagging, pink salmon from other Asian and also from North American areas could have been present on the high seas. For example, samples are included that were obtained beyond the areas of tagging. As previously stated, west Kamchatka appears to be the most productive Asian pink salmon area and might be considered as the morphotype into which high-seas pink salmon should be classified. However, as will be demonstrated later, with Karaginskii as one morphotype in the discriminant function, the west Kamchatka populations differ more from most North American pink salmon races than do the pink salmon of Karaginskii. It follows that Karaginskii samples provide the more efficient continental morphotype.

Without direct evidence, selection of samples from North American areas for use as a morphotype must be made wholly on intuitive grounds. Catches of pink salmon in 1957 in the Central Alaska district, to which the Kodiak Island and Cook Inlet areas are major contributors, totaled about 6.5 million fish (U.S. Fish and Wildlife Service, 1959). This figure plus the corresponding escapement indicates an abundance well above that of any other North American area reasonably close to the high-seas sampling area.

Knowledge concerning pink salmon of the Western Alaska district north of the Alaska Peninsula and of the Aleutian Islands is meager. However, these races are thought to be minor, particularly when compared to a Japanese high-seas catch of about 21 million pink salmon during the 1957 season (Fukuhara and Tanonaka, 1958). On these bases, Kodiak Island and Cook Inlet samples were chosen to typify the second morphotype. Samples from these areas have common variances and means and may be pooled to form a Kodiak-Cook Inlet morphological type (Appendix C–1, p. 92).

SELECTION OF CHARACTERS

Data were collected for ten meristic characters, seven from pink salmon morphology and three from scale characteristics. Past experience indicated that some of these characters would contribute little if anything to separation of the two morphotypes. To eliminate characters contributing little or nothing to the separation, we computed a discriminant function (Rao, 1952) using all ten characters. Three characters contributed approximately 98 percent of the separation; the remaining seven characters were dropped from consideration in the tests of assumptions and final analysis which follow. This procedure greatly simplified the calculations for the discriminant function.

The selected characters and their approximate percentage contribution to the total separation of the morphotypes as indicated by the preliminary discriminant function were: total vertebae, 62 percent; intermediate scale zone length, 32 percent; and dorsal fin rays, 4 percent. With the morphotype samples determined and the useful characters selected, we can test a greatly reduced volume of data for conformity to the requirements of the discriminant function.

TABLE 1. Results of tests for homogeneity of variance in selected morphological characters of the 1957 pink salmon morphotypes.

Morphological character	Kodiak-Cook Inlet variance	Karaginskii variance	Ratio	Critical 1-percent F value[1]
Total vertebrae	0.7168	0.9583	1.3370	1.55
Dorsal fin rays	0.5460	0.5413	1.0087	1.63
Intermediate scale length	3.5197 $N=167$	3.9948 $N=74$	1.1350	1.55

[1] Actual significance level of two percent for this two-tailed test.

TABLE 2. "r" values and the results of common correlation tests on the Karaginskii and Kodiak-Cook Inlet morphotypes between all pairs of characters.

Character pairs	"r" values		"t" values $d.f.=$inf. (∞) $t_{.01}=\pm2.58$
	Kodiak-Cook Inlet	Karaginskii	
Intermediate scale length Total vertebrae	−0.0761	−0.0115	0.4553
Intermediate scale length Dorsal fin rays	−0.0140	0.0144	0.1999
Total vertebrae Dorsal fin rays	0.0676	0.1671	0.7108

Common variance is required between each identical character of the two morphotypes. This feature can be tested by a variance ratio in which the larger variance is the numerator and the smaller variance the denominator. The values obtained are compared with the values in published F-distribution tables with the appropriate degrees of freedom.

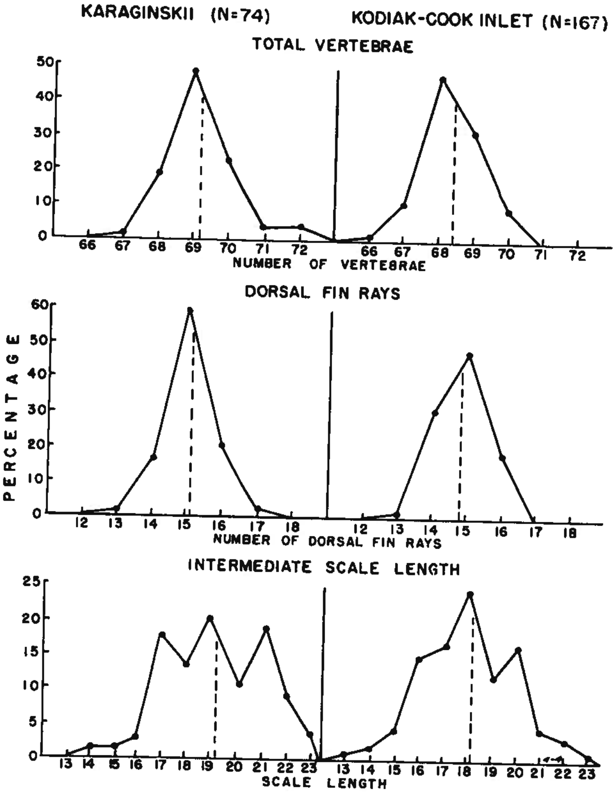

FIGURE 4. Frequency distributions of morphological characters used in separating Karaginskii and Kodiak-Cook Inlet 1957 pink salmon morphotypes. Broken lines indicate means.

TABLE 3. Results of tests for linearity of regression in three morphological characters used in racial separation of 1957 samples of pink salmon.

Independent variable	Dependent variable	F value	Degrees of freedom	$F_{.01}$
Karaginskii morphotype				
Intermediate scale zone length	Dorsal fin ray counts	0.2572	8,64	2.79
Dorsal fin ray counts	Intermediate scale zone length	1.0332	3,69	4.08
Dorsal fin ray counts	Total vertebrae counts	1.6648	3,69	4.08
Total vertebrae counts	Dorsal fin ray counts	1.0276	4,68	3.61
Total vertebrae counts	Intermediate scale zone length	0.8579	4,68	3.61
Intermediate scale zone length	Total vertebrae counts	0.1466	8,64	2.79
Kodiak-Cook Inlet morphotype				
Intermediate scale zone length	Dorsal fin ray counts	0.8673	9,156	2.53
Dorsal fin ray counts	Intermediate scale zone length	0.7791	2,163	4.75
Dorsal fin ray counts	Total vertebrae counts	0.7746	2,163	4.75
Total vertebrae counts	Dorsal fin ray counts	1.0815	3,162	3.91
Total vertebrae counts	Intermediate scale zone length	1.1956	3,162	3.91
Intermediate scale zone length	Total vertebrae counts	1.0648	9,156	2.53

Table 4. The variance-covariance matrix and calculation of the discriminant function for the 1957 pink salmon[1].

		Variance-covariance matrix			
		X_1	X_2	X_3	Mean Diffs.
Total vertebrae	1.	0.790550	0.066141	−0.090931	0.831446
Dorsal fin rays	2.		0.544553	−0.007034	0.242758
Intermediate scale length	3.			3.664841	1.177375
	4.				0.000000
		Discriminant function matrices			
	11.	1.000000	0.083665	−0.115022	1.051731
	12.	0.083665	0.539019	0.000574	0.173195
	13.	−0.115022	—	3.654382	1.273010
	14.	1.051731	—	—	−0.874458
	22.	0.155217	1.000000	0.001065	0.321315
	23.	−0.115111	0.001065	3.654381	1.272826
	24.	1.024848	0.321315	—	−0.930108
	33.	−0.031499	0.000291	1.000000	0.348301
	34.	1.064941	0.320944	0.348301	−1.373435

$\Upsilon = 1.064941\, X_1 + 0.320944\, X_2 + 0.348301\, X_3$

Morphotype Means:	Total vertebrae (X_1)	Dorsal fin rays (X_2)	Intermediate scale zone length (X_3)
Karaginskii	69.202703	15.081081	19.243243
Kodiak-Cook Inlet	68.371257	14.838323	18.065868

Υ (Karaginskii) $= 85.239419$

Υ (Kodiak-Cook Inlet) $= 83.865985$

$\Upsilon_0 = 84.552702$

---

[1] Using Pivotal Condensation Method (Rao, 1952).

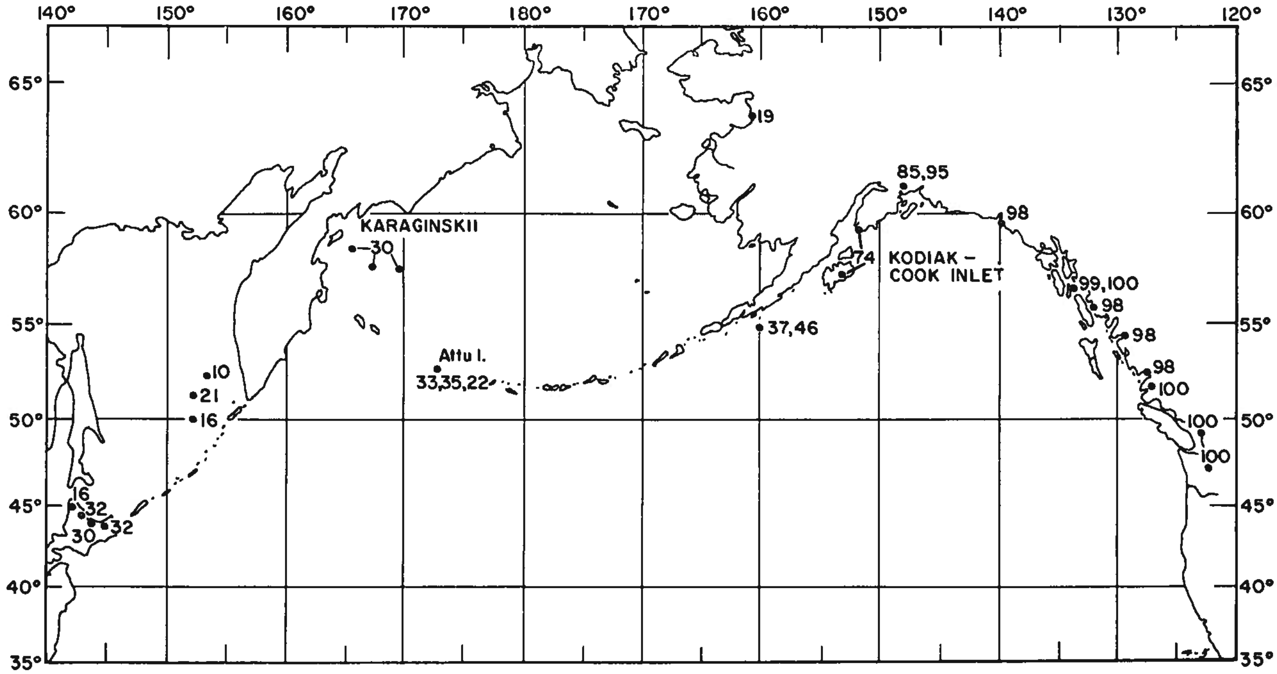

Figure 5. Percentage of each stream or inshore 1957 pink salmon sample classified as of Kodiak Island-Cook Inlet morphotype.

The results of this procedure for the selected morphotypes and characters are shown in Table 1. None of the ratios show significant differences between the variances of the two morphotypes for any character at the 2-percent level, with evidence that the larger variances are less than one and one-half times the smaller variances.

For small samples there exists no adequate test for normality (Fisher, 1944; Cochran, 1947). Frequency distribution curves are given in Figure 4 for the three characters of each of the two morphotypes. No radical departures from normality are evident. Fisher has indicated that very drastic departures are required before statistical procedures based on normality are disturbed. On this basis the normality of the data is accepted as adequate for the discriminant function.

To test the assumption of common correlation, we calculated sample correlation coefficients (*r*'s) between all possible pairs of characters in each morphotype. The coefficients are given in Table 2. The test for common correlation used is that given by Snedecor (1956), in which the "*r*" values are converted by tables to Fisher's "*z*" values. The differences between the "*z*" values of the two areas for the same characters are divided by the standard error of the difference to obtain "*t*" values with infinite degrees of freedom. Significance is then determined in the usual fashion from the published tables of "*t*". The "*t*" values obtained are listed in the right column of Table 2. The "*t*" values show no significant differences between the correlation coefficients of each pair of characters of the morphotypes when compared with the tabled "*t*" values. The assumption of common correlation between the morphotypes for these data is accepted.

The final assumption requiring verification is that

TABLE 5. Classification of fish in 1957 pink salmon stream and inshore samples as to percentage resembling each morphotype.

Map. No.[1]	Source	Location	Date	Sample size	Percentages	
					Kodiak-Cook Inlet	Karaginskii
1	Puget Sound	La Conner, Washington	9/6	76	100.00	0.00
2	Fraser River	Gulf of Georgia fishery	9/4	65	100.00	0.00
3	Rivers Inlet	—	8/13	81	100.00	0.00
4	Skeena River	Tyee	7/30	82	97.56	2.44
5	Nass River	Sommerville Island	8/4	59	98.31	1.69
6	Ketchikan	Point Eaton	8/14	97	97.94	2.06
7	Petersburg	Windham Bay	8/8	90	98.89	1.11
8	Petersburg	Tenakee	7/30	14	100.00	0.00
11	Yakutat	Situk-Ahrnklin River	8/1	85	97.65	2.35
13	Pr. Wm. Sound	Anderson Bay	7/16	34	85.29	14.71
14	Pr. Wm. Sound	Anderson Bay	8/1	42	95.24	4.76
15	Cook Inlet	Tutka Bay	7/4	82 } 169	73.96	26.04
16	Kodiak Island	Uyak Bay	7/30	87		
17	King Cove	Shumagin Island	7/11	68	36.76	63.24
18	King Cove	Shumagin Island	7/26	24	45.83	54.17
19	Unalakleet	Unalakleet River	7/9	67	19.40	80.60
36	Attu Island	Gravel Pit	8/4	55	32.73	67.27
37	Attu Island	Gravel Pit	8/5	46	34.78	65.22
38	Attu Island	Lake Cornica	8/-	27	22.22	77.78
42	Nippon Suisan[2]	57°02′ N., 169°11′ E.	7/12	27 } 74	29.73	70.27
44	Nippon Suisan[2]	57°26′ N., 167°27′ E.	7/13	26		
46	Nippon Suisan[2]	58°12′ N., 166°48′ E.	7/15	21		
59	Okhotsk Sea	52°08′ N., 154°15′ E.	6/24	51	9.80	90.20
60	Okhotsk Sea	51°16′ N., 153°39′ E.	7/14	81	20.99	79.01
61	Okhotsk Sea	50°52′ N., 153°28′ E.	7/4	68	16.18	83.82
62	Hokkaido Island	Shari fishery	9/-	53	32.08	67.92
63	Hokkaido Island	Abashiri fishery	9/-	56	30.36	69.64
64	Hokkaido Island	Tokoro fishery	9/-	62	32.26	67.74
65	Hokkaido Island	Yubetsu River	9/-	62	16.13	83.87

[1] Numbers refer to sampling locations as shown in Figure 2.

[2] Nippon Suisan Fisheries Company (Karaginskii).

of linearity of regression. An analysis of variance technique (Dixon and Massey, 1957) was employed in which variance about the regression line was tested against the variance within groups. All three possible pairs of characters were tested, with first one of each pair as the independent variable, and then the other. Results given in Table 3 show no indication of departure from linearity by any of the combinations. Details of the testing and the numerical values will be found in Appendix C–2 (p. 94).

Construction of Karaginskii and Kodiak-Cook Inlet Discriminant Function

The assumptions having been provisionally verified, a discriminant function of the form $Y=l_1X_1+l_2X_2+l_3X_3$ was calculated using the data of the variance-covariance matrix from the top of Table 4. A detailed description of the technique is available from Rao (1952), who also demonstrates that it produces the best linear discriminant function obtainable. The first three values in row 34, Table 4, are the coefficients (l's) needed for the equation. The equation then appears as $Y = 1.064941\,X_1 + 0.320944\,X_2 + 0.348301\,X_3$, where X_1 is the total vertebae count, X_2 the dorsal fin ray count and X_3 the intermediate scale length. The last value in row 34 is the variance of Y, commonly called D^2.

The probability of correctly classifying an individual into either of the two populations considered as morphotypes, provided the individual is actually from one of the populations, is equal to the probability that a normal deviate with mean zero and standard deviation of one will be less than, or equal to, $D/2$. In the present analysis, D^2 has a value of 1.373435; thus $D/2$ equals 0.585968. The probability of correctly classifying a single fish into its morphotype is 72.08 percent, again provided the fish originated from one of the two populations.

Classification of Samples into Morphotypes

Let us consider first the effect of classifying, with the calculated discriminant function, fish which we are reasonably sure did not originate from one of the two morphotype populations. Table 5 and Figure 5 give the results of classifying the pink salmon of the 1957 samples collected in streams or inshore near known spawning grounds. Classification is presented as percentage of specimens in each sample resembling the Kodiak-Cook Inlet morphotype (Y values less than 84.553) and percentage of specimens in each sample resembling the Karaginskii morphotype (Y values greater than 84.553). With 3,455 fish to classify, it is not practicable to present individual Y values in this paper; therefore the mean of the Y values from each sample is given. In general, the samples are arranged in the table by longitude from east to west with sample size also given.

Since the discriminant function produces a linear equation, the mean Y values obtained from whole samples from presumed known races may also be placed on a straight line, as shown in Figure 6. With this type of presentation it becomes apparent that samples from the presumed Asian races have discriminant scores about equal to or higher than that of the Karaginskii morphotype using the morphological

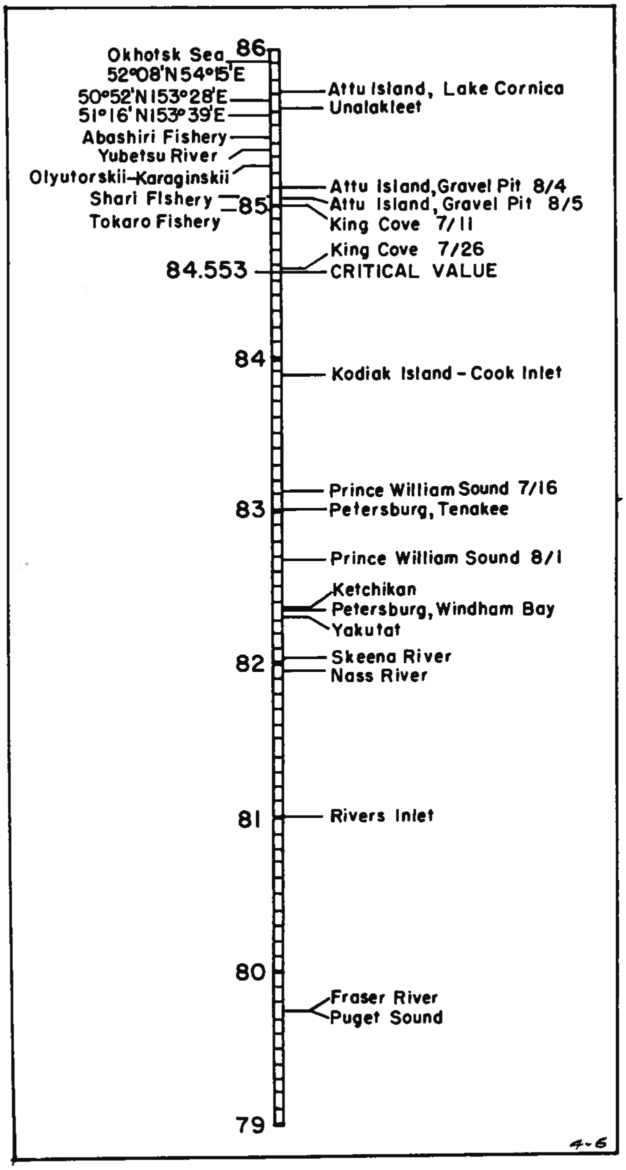

Figure 6. Linear comparison of mean discriminant scores of 1957 pink salmon samples from presumed known races.

TABLE 6. Classification of fish in high-seas 1957 pink salmon samples as to percentage resembling each morphotype.

Map. No.[1]	Source	Location	Date	Sample size	Percentages	
					Kodiak-Cook Inlet	Karaginskii
9	MV *Key West*	55°00′ N., 135°00′ W.	7/31	9	100.00	0.00
10	MV *Key West*	55°00′ N., 135°00′ W.	8/1	28	100.00	0.00
12	MV *Key West*	55°00′ N., 145°00′ W.	7/12	54	87.04	12.96
20	MV *Attu*	53°40′ N., 165°00′ W.	7/25	13	76.92	23.08
21	MV *Commander*	12 mi. so. Atka Is.	6/6	33	12.12	87.88
22	MV *Attu*	53°00′ N., 175°00′ W.	6/8	59	15.25	84.75
23	MV *Attu*	53°00′ N., 175°00′ W.	6/9	49	12.24	87.76
24	MV *Attu*	53°00′ N., 175°00′ W.	6/10	42	30.95	69.05
25	MV *Pioneer*	56°00′ N., 175°00′ W.	6/29	99	21.21	78.79
26	MV *Pioneer*	56°00′ N., 175°00′ W.	6/30	57	31.58	68.42
27	MV *Commander*	6 mi. so. Little Tanaga Is.	6/8	28	21.43	78.57
28	MV *Commander*	8 mi. so. Adak Is.	6/20	27	11.11	88.89
29	*Kano Maru*	50°05′ N., 179°56′ E.	6/8	42	21.43	78.57
30	Nippon Suisan[2]	58°10′ N., 177°17′ E.	7/1	23	4.35	95.65
31	MV *Pioneer*	50°00′ N., 175°00′ E.	6/10	124	16.94	83.06
32	MV *Pioneer*	50°00′ N., 175°00′ E.	6/11	83	25.30	74.70
33	MV *Pioneer*	50°00′ N., 175°00′ E.	6/12	96	21.88	78.12
34	MV *Pioneer*	53°00′ N., 175°00′ E.	6/14	95	22.11	77.89
35	MV *Pioneer*	53°00′ N., 175°00′ E.	6/20	189	25.93	74.07
39	*Kano Maru*	49°37′ N., 171°00′ E.	6/1	29	20.69	79.31
40	*Kano Maru*	49°45′ N., 170°24′ E.	5/25	17	5.88	94.12
41	Nippon Suisan[2]	54°51′ N., 170°24′ E.	7/6	18	27.78	72.22
43	Nippon Suisan[2]	51°41′ N., 167°27′ E.	6/28	24	8.33	91.67
45	*Etsuzan Maru*	49°02′ N., 167°25′ E.	5/31	86	13.95	86.05
47	*Etsuzan Maru*	50°03′ N., 166°47′ E.	6/1	83	7.23	92.77
48	Nichiro[3]	52°33′ N., 166°04′ E.	6/20	28	21.43	78.57
49	Nippon Suisan[2]	51°39′ N., 162°16′ E.	7/1	29	13.79	86.21
50	Nichiro[3]	52°28′ N., 161°42′ E.	6/30	51	19.61	80.39
51	Nichiro[3]	51°39′ N., 161°40′ E.	7/20	47	21.28	78.72
52	Nichiro[3]	52°36′ N., 161°21′ E.	7/10	49	10.20	89.80
53	Nippon Suisan[2]	51°28′ N., 161°15′ E.	7/5	31	19.35	80.65
54	Nichiro[3]	51°22′ N., 160°15′ E.	7/22	50	30.00	70.00
55	Nichiro[3]	51°13′ N., 159°45′ E.	7/24	42	26.19	73.81
56	Nippon Suisan[2]	48°57′ N., 158°30′ E.	7/15	68	35.29	64.71
57	Nippon Suisan[2]	49°02′ N., 158°21′ E.	7/14	32	6.25	93.75
58	Nippon Suisan[2]	49°14′ N., 158°11′ E.	7/10	27	18.52	81.48

[1] Numbers refer to sampling locations as shown in Figure 2.
[2] Nippon Suisan Fisheries Company.
[3] Nichiro Fisheries Company.

characters and the equation outlined previously.

A similar situation prevails with the Kodiak-Cook Inlet morphotype. The mean Y value of the morphotype is 83.866 and all other North American areas so far sampled have lower mean Y values with the present discriminant function, with the exception of pinks taken from the Shumagin Islands, from the Unalakleet River and from Attu Island. Pinks from these areas collected in 1957 are indistinguishable from those of Karaginskii with the characters now utilized. Whether this resemblance to Karaginskii morphotype prevails in all pink salmon originating in North American and Aleutian Island areas north and west of the Alaska Peninsula is not known at present.

Evidently, then, pink salmon of Asian origin captured on the high seas are as likely (72 percent of the time) to be classified as Karaginskii-type fish as are fish from Karaginskii proper. From recently released catch statistics of the U.S.S.R. (International North Pacific Fisheries Commission, 1959), it seems

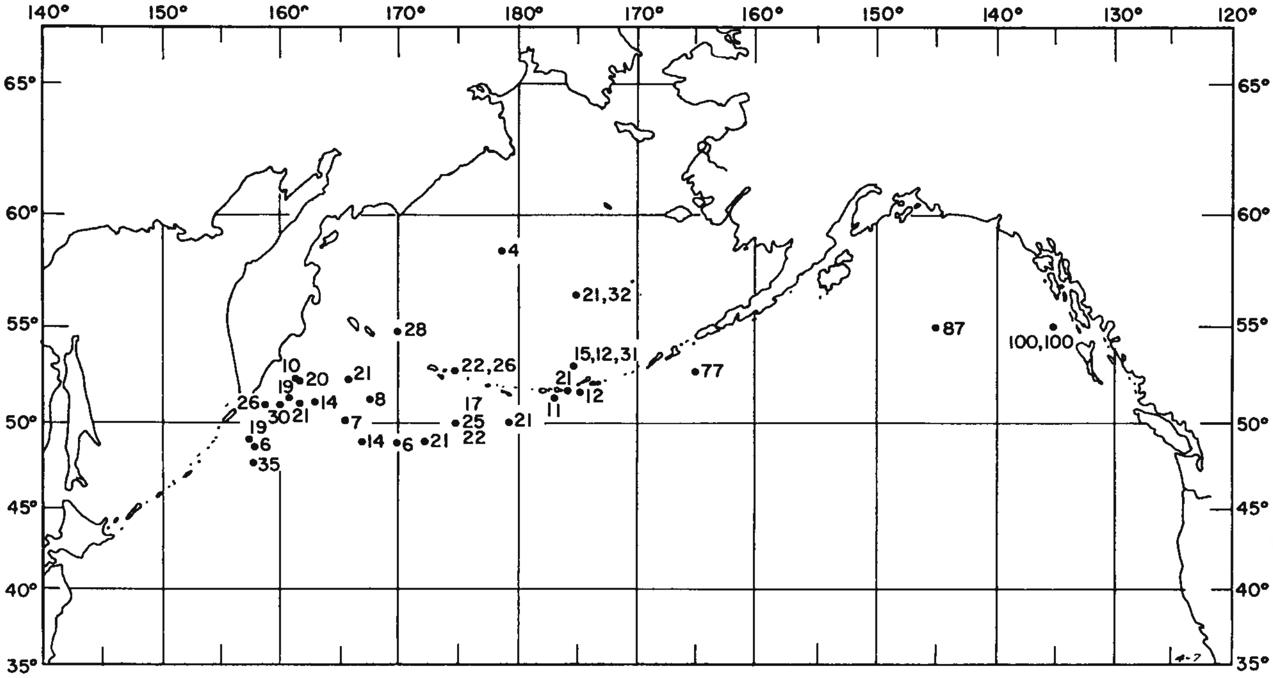

FIGURE 7. Percentage of each high seas 1957 pink salmon sample classified as of Kodiak Island-Cook Inlet morphotype.

likely that many of the fish in high-seas samples taken outside the tagging area were from the highly productive west Kamchatka spawning areas. These records indicate a catch of 53,100 metric tons of pink salmon near the west Kamchatka area and only 22,300 metric tons for the entire east Kamchatka coast, including Karaginskii. West Kamchatka fish taken on the high seas will be classified as Karaginskii-type more often than Karaginskii fish themselves.

Similarly, high-seas-caught pink salmon originating from Kodiak Island streams and North American continental streams east of Kodiak will be classified proportionately (72 percent or more) as Kodiak-Cook Inlet type fish.

All pink salmon are, of course, not exclusively from one or the other of the two morphotype populations. The discriminant function obtained does classify such fish into the morphotype of their originating continent with a minimum probability of correct classification of 72 percent. Certain North American stocks west and north of the Kodiak-Cook Inlet area which were morphologically similar to Karaginskii fish in 1957 must be expected.

Results of classifying pink salmon of unknown origin obtained on the high seas are presented in Table 6 as percentage of fish in each sample classified into the two morphotypes. From the accompanying map (Figure 7) showing percentage of each sample resembling the Kodiak-Cook Inlet type, there is little statistical evidence of Kodiak-Cook Inlet fish westward of 175° West longitude. Approximately 28 percent of Karaginskii pink salmon are expected to have a discriminant score mis-identifying them as Kodiak-Cook Inlet fish. The high-seas samples west of 175° West longitude range only as high as 35 percent resembling the Kodiak-Cook Inlet morphotype, which is probably no greater than expected in random sampling of pure Asian stocks or of stocks from the previously excepted areas.

Some of the fish in these samples may have originated from Attu Island, the Unalakleet River or the Alaska Peninsula. The discriminant classification of Alaska Peninsula fish is not clearly defined at this time since no mainland samples from the area were available. Two samples obtained from traps just offshore in the Shumagin Islands area indicated relatively high percentages of Karaginskii-type fish. The time of capture (July 11 and 26) and degree of maturity suggest a not-too-distant spawning site. Whether this was on the Bering Sea coast, on an Aleutian island or on the Alaska Peninsula is not known.

High-seas fishing operations took few pink salmon eastward of 175°W. to 160°W. longitude. The U.S. research vessel MV *Attu* fished repeatedly in June and August of 1957 between longitudes 160°W. to 170°W. and latitudes 50°N. to 56°N., obtaining very few pinks. Early in June, this same vessel had caught fair numbers of pinks per set along 175°W. The MV *Pioneer* fished north and south along 175°W. in late June and early July, obtaining very few pinks after having caught them in fair abundance along 175°E. in mid-June. When the MV *Pioneer* returned to 175°E. in mid-July very few pinks were obtained. Still another vessel, the MV *Paragon*, fished steadily along 175°W. from mid-August without netting a single pink salmon.

The low catches of pink salmon east of 170°W. longitude, and their relative abundance to the west, suggest a scarcity of North American pink salmon in the high-seas sampling areas of the western Bering Sea. On one station (sample 20), at 165°W. and south of the Aleutian Chain at which a few pinks (13) were caught, a relatively higher percent of Kodiak-Cook Inlet type was indicated. Very high percentages of Kodiak-Cook Inlet morphotype fish were found in three additional high-seas samples well to the east in the Gulf of Alaska.

SUMMARY AND CONCLUSIONS

The evidence, while based on limited data, suggests little intra-area variability in pink salmon morphological characters. Factors considered included sexual dimorphism and correlation of morphological characters with fish length. Two characters taken from the scales proved to be slightly correlated with length. These characters, however, were not used in the racial analysis.

Ten morphological characters, three from scale structures and seven from other physical characteristics, were considered for use in a discriminant function racial analysis of 1957 pink salmon collections from the North Pacific Ocean and Bering Sea. Three characters—total vertebrae, intermediate zone and dorsal fin rays—provided approximately 98 percent of the separation in a discriminant function.

These three characters were tested for assumptions necessary to satisfy multivariate analysis; the other seven characters were discarded. The required assumptions were fulfilled.

Tests for conformity of the distributions of the morphological characters employed in the Fisher discriminant function indicated the presence of multivariate normal distributions as required.

The assumption that the individuals of unknown origin (high-seas catches) were derived only from the two sources employed as morphotypes could not be completely satisfied. However, the linear discriminant function classified 72 percent or more of all sampled Asian pink salmon as Karaginskii morphotype and 72 percent or more of all sampled North American fish as Kodiak-Cook Inlet morphotype except for fish in samples from Attu Island, the Unalakleet River and the Shumagin Islands which more frequently resembled the Karaginskii morphotype.

The high-seas fish of unknown origin can thus be classified to most probable continent of origin on the basis of their resemblance to one or the other of the two morphotypes even though they may have come from another region of the same continent. Again, high-seas-caught pink salmon which came from Attu Island, the Unalakleet River, the Shumagin Islands and perhaps other areas north and west of the Alaska Peninsula must, for the present, be excepted.

Results of the classificatory analysis of 1957 high-seas-caught pink salmon indicated the obvious dominance of Karaginskii morphotype in all samples from 175°W. longitude westward. Some of these fish may have come from the excepted areas; however, the runs of Attu Island and the Unalakleet River are known to be small in comparison to the size of the Japanese high-seas catch and presumably could not greatly influence the distribution pattern obtained even if they could be separated from Asian stocks. The samples from the Shumagin Islands traps could be representative of a morphotype to be found in the nearby Alaska Peninsula areas, the eastern Aleutian Islands or in Bristol Bay. If this is the case, and these are from larger runs, it is difficult to understand the scarcity of pink salmon from 175°W. eastward on the high seas.

One small sample of 13 pinks taken south of the Aleutian Chain and west of the Shumagins at 165°W. was classified mainly as being Kodiak-Cook Inlet morphotype. It seems most likely that the Shumagin fish classified to the Karaginskii morphotype were from a local North American stock of restricted distribution and that the pink salmon of Karaginskii morphotype obtained from 175°W. westward were probably actually Asian fish.

Three additional samples obtained well to the east at 135°W. and 145°W. longitude were almost entirely composed of Kodiak-Cook Inlet morphotype specimens.

Conclusions drawn from the 1957 data will almost certainly apply only to odd-year spawning fish, since the two-year life history of this species ensures complete genetic isolation between adjacent year classes. Furthermore, extension of the results to other odd-year broods would have to be made with caution, for with only the single year's data from pink salmon treated here, the magnitude of parent-offspring variability cannot as yet be accurately assessed.

LITERATURE CITED

COCHRAN, W.G. 1947. Some consequences when the assumptions for the analysis of variance are not satisfied. *Biometrics*, 3(1): 22–38.

DIXON, WILFRID J., AND FRANK J. MASSEY, JR. 1957. Introduction to statistical analysis. Second Edition, McGraw-Hill Book Co., Inc. (New York), 488 pp.

FISHER, R.A. 1936. The use of multiple measurements in taxonomic problems. *Annals of Eugenics*, 7(2): 179–188.

FISHER, R.A. 1944. Statistical methods for research workers. Ninth Edition, Oliver and Boyd, Ltd. (Edinburgh), 350 pp.

FUKUHARA, FRANCIS M., AND GEORGE K. TANONAKA. 1958. A Japanese high-seas salmon fishery in the North Pacific since 1952. *U.S. Fish and Wildlife Service, Commercial Fisheries Review*, 20(4): 1–16.

HOLLISTER, GLORIA. 1934. Clearing and dyeing fish for bone study. *Zoologica*, 12(10): 89–101.

INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION (INPFC). 1958. Annual Report for the year 1957. International North Pacific Fisheries Commission (Vancouver, Canada), 86 pp.

INPFC. 1959. Pacific salmon catch statistics of the Union of Soviet Socialist Republics 1940–1958 (as given to the International North Pacific Fisheries Commission by the All-Union Research Institute of Marine Fisheries and Oceanography, Moscow). International North Pacific Fisheries Commission (Vancouver, Canada), 4 tables (mimeographed).

POWERS, E.A. 1959. Fishery statistics of the United States, 1957. *U.S. Fish and Wildlife Service, Statistical Digest*, No. 44, 429 pp.

RAO, C. RADHAKRISHNA. 1952. Advanced statistical methods in biometric research. John Wiley and Sons, Inc. (New York), 390 pp.

SNEDECOR, GEORGE W. 1956. Statistical methods applied to experiments in agriculture and biology. Fifth Edition, The Iowa State College Press (Ames), 534 pp.

TAGUCHI, KISABURO. 1957. Salmon fisheries and the resources of the North Pacific Ocean. (Revised Edition) Nichiro Gyogyo Kabushiki Kaisha (Tokyo) (Nichiro Fishing Company, Ltd.), 266 pp.

APPENDIX A. LIST OF PINK SALMON SAMPLES OBTAINED DURING 1957 AND PROCESSED FOR MORPHOLOGICAL CHARACTERISTICS.

1957 Inshore Fishery and Stream Samples.

Area	Location	Date	Sample size
Puget Sound	La Conner, Washington	9/6	102
Fraser River fishery	Gulf of Georgia	9/4	100
Rivers Inlet	—	8/13	100
Skeena River fishery	Tyee	7/30	96
Nass River fishery	Sommerville Island	8/4	92
Ketchikan	Vicinity Point Eaton	8/14	114
Petersburg	Tenakee	7/30	50
Petersburg	Windham Bay	8/8	111
Yakutat	Situk-Ahrnklin River	8/1	99
Prince William Sound	Anderson Bay	7/16	45
Prince William Sound	Anderson Bay	8/1	56
Cook Inlet	Tutka Bay	7/4	100
Kodiak Island	Uyak Bay	7/30	101
King Cove	Shumagin traps	7/11	70
King Cove	Shumagin traps	7/26	30
Northwest Alaska	Unalakleet River	7/9	99
Attu Island	Lake Nicholas	7 & 8/-	29
Attu Island	Gravel Pit	8/4	67
Attu Island	Gravel Pit	8/5	54
Attu Island	Lake Cornica	8/-	26
Attu Island	Lake Cornica	8/10	30
Hokkaido Island	Yubetsu River	9/-	100
Hokkaido Island	Shari fishery	9/-	63
Hokkaido Island	Tokoro fishery	9/-	70
Hokkaido Island	Abashiri fishery	9/-	65

1957 High-Seas Samples by Longitude.

Source	Location	Date	Sample size
MV *Key West*	55°00′ N., 135°00′ W.	7/31	16
MV *Key West*	55°00′ N., 135°00′ W.	8/1	49
MV *Key West*	55°00′ N., 145°00′ W.	7/12	88
MV *Attu*	54°00′ N., 160°00′ W.	7/15	6
MV *Attu*	53°40′ N., 165°00′ W.	7/25	24
MV *Commander*	52°00′ N., 174°20′ W. (approx)	6/6	48
MV *Attu*	50°00′ N., 175°00′ W.	5/28	17
MV *Attu*	53°00′ N., 175°00′ W.	6/8	67
MV *Attu*	53°00′ N., 175°00′ W.	6/9	88
MV *Attu*	53°00′ N., 175°00′ W.	6/10	47
MV *Pioneer*	56°00′ N., 175°00′ W.	6/29	122
MV *Pioneer*	56°00′ N., 175°00′ W.	6/30	70
MV *Pioneer*	51°00′ N., 176°00′ W.	7/8	11
MV *Commander*	51°55′ N., 176°05′ W. (approx)	6/8	60
MV *Commander*	51°50′ N., 176°20′ W. (approx)	6/20	51
MV *Pioneer*	53°00′ N., 180°00′	6/22	16
Kano Maru	50°05′ N., 179°56′ E.	6/8	53
Nippon Suisan Fisheries Co.	58°15′ N., 179°10′ E.	6/27	23
Nippon Suisan Fisheries Co.	58°10′ N., 177°17′ E.	7/1	29
MV *Pioneer*	50°00′ N., 175°00′ E.	6/10	151
MV *Pioneer*	50°00′ N., 175°00′ E.	6/11	95
MV *Pioneer*	50°00′ N., 175°00′ E.	6/12	110
MV *Pioneer*	53°00′ N., 175°00′ E.	6/14	110

Continued

Appendix A. (Continued)

Source	Location	Date	Sample size
MV *Pioneer*	53°00′ N., 175°00′ E.	6/20	226
MV *Pioneer*	56°00′ N., 175°00′ E.	7/16	17
Kano Maru	49°37′ N., 171°00′ E.	6/1	37
Kano Maru	49°45′ N., 170°24′ E.	5/25	30
Nippon Suisan Fisheries Co.	54°51′ N., 170°24′ E.	7/6	27
Nippon Suisan Fisheries Co.	57°02′ N., 169°11′ E.	7/12	39
Kano Maru	49°13′ N., 169°00′ E.	5/24	23
Nippon Suisan Fisheries Co.	51°41′ N., 167°27′ E.	6/28	35
Nippon Suisan Fisheries Co	57°26′ N., 167°27′ E.	7/13	32
Etsuzan Maru	49°02′ N., 167°25′ E.	5/31	105
Nippon Suisan Fisheries Co.	58°12′ N., 166°48′ E.	7/15	29
Etsuzan Maru	50°03′ N., 166°47′ E.	6/1	100
Nichiro Fisheries Co.	52°33′ N., 166°04′ E.	6/20	50
Nippon Suisan Fisheries Co.	51°39′ N., 162°16′ E.	7/1	35
Nichiro Fisheries Co.	52°28′ N., 161°42′ E.	6/30	67
Nichiro Fisheries Co.	51°39′ N., 161°40′ E.	7/20	54
Nichiro Fisheries Co.	52°36′ N., 161°21′ E.	7/10	67
Nippon Suisan Fisheries Co.	51°28′ N., 161°15′ E.	7/5	34
Nichiro Fisheries Co.	51°22′ N., 160°15′ E.	7/22	68
Nichiro Fisheries Co.	51°13′ N., 159°45′ E.	7/24	49
Nippon Suisan Fisheries Co.	48°57′ N., 158°30′ E.	7/15	99
Nippon Suisan Fisheries Co.	49°02′ N., 158°20′ E.	7/14	35
Nippon Suisan Fisheries Co.	49°14′ N., 158°11′ E.	7/10	35
Hokkaido Fisheries Co.	52°08′ N., 154°15′ E.	6/24	92
Hokkaido Fisheries Co.	51°16′ N., 153°39′ E.	7/14	90
Hokkaido Fisheries Co.	50°52′ N., 153°28′ E.	7/4	90

APPENDIX B. INTRA-AREA VARIABILITY TESTS.

APPENDIX B-1. Results of variance ratio tests for homogeneity of variance and analysis of variance tests of the means between sexes with chi-square tests of the combined probabilities from other than scale characters.

Total vertebrae

Locality	Date	Age	Sex	Sample size	Variance				Means				
					S^2	F	$d.f.$	P	Mean	$S_{\bar{x}}$	F	$d.f.$	P
Kodiak Island	8/22/56	2	M	45	0.6432	1.0874	44,47	.78	69.644	0.1195	1.6136	1,91	.21
(Karluk Weir)			F	48	0.5915				69.438	0.1110			
Northwest Alaska	7/9/56	2	M	51	0.8120	1.0043	50,47	.99	70.294	0.1262	5.9147*	1,97	.018
(Unalakleet R.)			F	48	0.8085				69.854	0.1298			
Hokkaido Island	9/-/57	2	M	61	0.8483	1.0802	60,34	.85	69.574	0.1179	0.2082	1,94	.33
(Yubetsu R.)			F	35	0.7853				69.486	0.1498			
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = .842$ $\chi^2_{.95}(6\ d.f.) = 12.592$				$C = -2\sum_{i=1}^{k} \log_e P_i = 12.018$ $\chi^2_{.95}(6\ d.f.) = 12.592$				

* Significant at 5-percent level.

Ventral gill rakers

Locality	Date	Age	Sex	Sample size	Variance				Means				
					S^2	F	$d.f.$	P	Mean	$S_{\bar{x}}$	F	$d.f.$	P
Kodiak Island	8/22/56	2	M	47	1.0217	1.9831*	46,46	.022	19.021	0.1474	0.1251	1,92	.72
(Karluk Weir)			F	47	0.5152				19.085	0.1047			
Northwest Alaska	7/9/56	2	M	52	0.7980	1.1089	51,46	.76	18.788	0.1239	0.9539	1,97	.33
(Unalakleet R.)			F	47	0.7196				18.617	0.1237			
Hokkaido Island	9/-/57	2	M	60	0.4542	2.0000**	36,59	.009	18.450	0.0870	1.0766	1,95	.30
(Yubetsu R.)			F	37	0.9083				18.622	0.1567			
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 17.604^{**}$ $\chi^2_{.95}(6\ d.f.) = 12.592$ $\chi^2_{.99}(6\ d.f.) = 16.812$				$C = -2\sum_{i=1}^{k} \log_e P_i = 5.283$ $\chi^2_{.95}(6\ d.f.) = 12.592$				

* Significant at 5-percent level.
** Significant at 1-percent level.

Total gill rakers

Locality	Date	Age	Sex	Sample size	Variance				Means				
					S^2	F	$d.f.$	P	Mean	$S_{\bar{x}}$	F	$d.f.$	P
Kodiak Island	8/22/56	2	M	47	1.9065	1.3031	46,46	.37	30.915	0.2014	1.0676	1,92	.30
(Karluk Weir)			F	47	1.4630				31.191	0.1764			
Northwest Alaska	7/9/56	2	M	51	2.1980	1.1369	50,45	.68	30.627	0.2076	0.0038	1,95	.95
(Unalakleet R.)			F	46	1.9333				30.609	0.2050			
Hokkaido Island	9/-/57	2	M	60	1.1644	1.6986	36,59	.071	30.233	0.1393	1.4667	1,95	.23
(Yubetsu R.)			F	37	1.9778				30.514	0.2312			
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 8.050$ $\chi^2_{.95}(6\ d.f.) = 12.592$				$C = -2\sum_{i=1}^{k} \log_e P_i = 5.450$ $\chi^2_{.95}(6\ d.f.) = 12.592$				

Appendix B-1. (Continued).

Branchiostegals

Locality	Date	Age	Sex	Sample size	Variance				Means				
					S^2	F	$d.f.$	P	Mean	$S_{\bar{x}}$	F	$d.f.$	P
Kodiak Island	8/22/56	2	M	47	0.4391	1.0515	47,46	.89	13.319	0.0967	0.5022	1,93	.48
(Karluk Weir)			F	48	0.4617				13.417	0.0981			
Northwest Alaska	7/9/56	2	M	52	0.3157	1.5908	46,51	.11	12.365	0.0779	0.0173	1,97	.90
(Unalakleet R.)			F	47	0.5022				12.383	0.1034			
Hokkaido Island	9/–/57	2	M	61	0.3950	1.4276	36,60	.22	12.934	0.0805	1.1397	1,96	.29
(Yubetsu R.)			F	37	0.5639				12.784	0.1234			
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 7.676$ $\chi^2_{.95}(6\ d.f.) = 12.592$				$C = -2\sum_{i=1}^{k} \log_e P_i = 4.155$ $\chi^2_{.95}(6\ d.f.) = 12.592$				

Pectoral fin rays

Locality	Date	Age	Sex	Sample size	Variance				Means				
					S^2	F	$d.f.$	P	Mean	$S_{\bar{x}}$	F	$d.f.$	P
Kodiak Island	8/22/56	2	M	47	0.5609	1.0337	46,47	.91	16.298	0.1092	0.0308	1,93	.86
(Karluk Weir)			F	48	0.5426				16.271	0.1063			
Northwest Alaska	7/9/56	2	M	52	0.2902	1.1144	47,51	.70	15.846	0.0747	0.0653	1,98	.80
(Unalakleet R.)			F	48	0.3234				15.875	0.0821			
Hokkaido Island	9/–/57	2	M	62	0.3426	1.1912	37,61	.54	16.048	0.0743	2.7377	1,98	.10
(Yubetsu R.)			F	38	0.4081				15.842	0.1036			
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 2.135$ $\chi^2_{.95}(6\ d.f.) = 12.592$				$C = -2\sum_{i=1}^{k} \log_e P_i = 5.353$ $\chi^2_{.95}(6\ d.f.) = 12.592$				

Dorsal fin rays

Locality	Date	Age	Sex	Sample size	Variance				Means				
					S^2	F	$d.f.$	P	Mean	$S_{\bar{x}}$	F	$d.f.$	P
Kodiak Island	8/22/56	2	M	47	0.5304	1.2160	46,47	.51	15.234	0.1062	0.0000	1,93	.99
(Karluk Weir)			F	48	0.4362				15.229	0.0953			
Northwest Alaska	7/9/56	2	M	52	0.4373	1.0816	51,47	.79	15.615	0.0917	4.0427*	1,98	.048
(Unalakleet R.)			F	48	0.4043				15.354	0.0918			
Hokkaido Island	9/–/57	2	M	62	0.3443	1.1226	37,61	.68	15.016	0.0745	3.3611	1,98	.073
(Yubetsu R.)			F	38	0.3865				14.789	0.1085			
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 2.590$ $\chi^2_{.95}(6\ d.f.) = 12.592$				$C = -2\sum_{i=1}^{k} \log_e P_i = 11.328$ $\chi^2_{.95}(6\ d.f.) = 12.592$				

* Significant at 5-percent level.

Appendix B-1. (Continued).

Anal fin rays

Locality	Date	Age	Sex	Sample size	Variance				Means				
					S^2	F	$d.f.$	P	Mean	$S_{\bar{x}}$	F	$d.f.$	P
Kodiak Island	8/22/56	2	M	47	0.2848	1.5913	47,46	.13	17.617	0.0778	2.4513	1,93	.12
(Karluk Weir)			F	48	0.4532				17.813	0.0972			
Northwest Alaska	7/9/56	2	M	52	0.5294	1.5552	51,47	.14	18.481	0.1090	0.0000	1,98	.99
(Unalakleet R.)			F	48	0.3404				18.479	0.0842			
Hokkaido Island	9/-/57	2	M	62	0.5902	1.2499	61,36	.47	18.000	0.0976	1.1153	1,97	.29
(Yubetsu R.)			F	37	0.4722				17.838	0.1130			
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 9.523$				$C = -2\sum_{i=1}^{k} \log_e P_i = 6.736$				
					$\chi^2_{.95}(6\ d.f.) = 12.592$				$\chi^2_{.95}(6\ d.f.) = 12.592$				

Appendix B-2. Results of variance ratio tests for homogeneity of variance and analysis of variance tests of the means between sexes with chi-square tests of the combined probabilities in scale characters.

Number of circuli

Locality	Date	Age	Sex	Sample size	Variance				Means				
					S^2	F	$d.f.$	P	Mean	$S_{\bar{x}}$	F	$d.f.$	P
Northwest Alaska	7/9/56	2	M	43	2.1190	1.2231	36,42	.55	21.977	.2220	0.5192	1,78	.48
(Unalakleet R.)		2	F	37	2.5917				21.730	.2646			
Hokkaido Island	9/-/57	2	M	39	5.5105	1.0327	38,25	.47	27.744	.3759	0.4826	1,63	.49
(Yubetsu R.)		2	F	26	5.3360				28.154	.4530			
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 1.256$				$C = -2\sum_{i=1}^{k} \log_e P_i = 2.894$				
					$\chi^2_{.95}(4\ d.f.) = 9.488$				$\chi^2_{.95}(4\ d.f.) = 9.488$				

Scale length

Locality	Date	Age	Sex	Sample size	Variance				Means				
					S^2	F	$d.f.$	P	Mean	$S_{\bar{x}}$	F	$d.f.$	P
Northwest Alaska	7/9/56	2	M	43	16.5810	1.0005	36,42	.99	38.884	.6210	0.1891	1,78	.67
(Unalakleet R.)		2	F	37	16.5889				38.486	.6695			
Hokkaido Island	9/-/57	2	M	39	33.8158	1.2387	38,25	.58	53.974	.9312	0.1123	1,63	.74
(Yubetsu R.)		2	F	26	27.3000				53.500	1.0247			
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 1.110$				$C = -2\sum_{i=1}^{k} \log_e P_i = 1.402$				
					$\chi^2_{.95}(4\ d.f.) = 9.488$				$\chi^2_{.95}(4\ d.f.) = 9.488$				

APPENDIX B-2. (Continued).

Intermediate zone

Locality	Date	Age	Sex	Sample size	Variance S^2	Variance F	Variance *d.f.*	Variance P	Means Mean	Means $S_{\bar{x}}$	Means F	Means *d.f.*	Means P
Northwest Alaska	7/9/56	2	M	43	2.9468	1.0096	42,36	.98	16.6512	.2617	0.2417	1,78	.62
(Unalakleet R.)		2	F	37	2.9189				17.4324	.2809			
Hokkaido Island	9/-/57	2	M	39	3.1500	1.5010	25,38	.29	18.487	.2842	3.1398	1,63	.081
(Yubetsu R.)		2	F	26	4.7280				17.615	.4264			
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 2.516$ $\chi^2_{.95}(4\ d.f.) = 9.488$				$C = -2\sum_{i=1}^{k} \log_e P_i = 5.983$ $\chi^2_{.95}(4\ d.f.) = 9.488$				

APPENDIX B-3. Correlation of characters with length of fish, chi-square tests for common correlation, average r and average r^2.

Locality	Date	Sample size	Total vertebrae r	Ventral gill rakers r	Total gill rakers r	Branchiostegals r	Pectoral fin rays r	Dorsal fin rays r	Anal fin rays r
Attu Island (Gravel Pit)	8/-/55	74	−0.0242	0.0851	0.0822	0.0159	−0.1794	0.1608	0.1359
Fraser River (Sweltzer Creek)	11/2/55	47	0.0318	0.0118	0.1295	−0.0472	−0.2205	−0.1549	−0.1024
Unalaska Island (Unalaska Cr.)	8/17/55	33	−0.0096	−0.0263	0.0687	0.1908	−0.0462	0.0317	0.0432
Kodiak Island (Karluk Weir)	8/22/56	92	0.1501	0.1444	0.1452	0.1198	0.0525	0.1440	0.0991
Skeena River (Lakelse Lake)	10/26/56	50	−0.2923	−0.2290	−0.2425	−0.1248	−0.0918	−0.1240	−0.1764
Unalaska Island (Shaisnikoff R.)	8/11/56	43	−0.1366	0.1817	0.2049	0.0752	−0.1017	0.1814	−0.0455
Unalaska Island (Nanteeken R.)	8/23/56	45	0.0069	0.0202	0.1574	−0.3181	−0.0967	0.1402	0.0904
Northwest Alaska (Unalakleet R.)	7/9/56	95	0.2087	0.0571	0.0460	0.1152	−0.0293	−0.0189	0.1359
Attu Island (Gravel Pit)	8/4/57	64	−0.0126	0.0686	0.0730	0.0264	−0.0583	0.2080	0.1838
Attu Island (Gravel Pit)	8/5/57	52	−0.1174	0.1076	0.1251	−0.1041	0.1114	0.1872	0.0642
Attu Island (Lake Cornica)	8/10/57	30	−0.2776	−0.0032	0.0616	−0.0906	−0.0503	0.0538	−0.4105
Hokkaido Island (Yubetsu R.)	9/-/57	91	0.0070	0.0638	−0.0489	0.1445	−0.0393	−0.0047	0.2293
χ^2	=		14.159	5.925	7.921	11.567	5.085	9.046	15.668
$\chi^2_{.95}(11\ d.f.)$	=		19.675	19.675	19.675	19.675	19.675	19.675	19.675
Average r	=		−0.0010	0.0532	0.0620	0.0241	−0.0550	0.0696	0.0657
Average r^2	=		0.000001	0.0028	0.0038	0.0006	0.0030	0.0048	0.0043
Percent variation attributable to length	=		0.0001%	0.28%	0.38%	0.06%	0.30%	0.48%	0.43%

APPENDIX B-4. Correlation of scale characters with length of fish, chi-square tests for common correlation, average r and average r^2.[1]

Locality	Date	Sample size	No. of circuli r	Scale length r	Intermediate zone r
Unalaska Island (Shaisnikoff R.)	8/11/56	26	0.2584	0.0484	0.0173
Attu Island (Gravel Pit)	8/4/57	57	0.2213	0.2704	0.0811
Attu Island (Gravel Pit)	8/5/57	47	0.2130	0.2864	0.0525
Northwest Alaska (Unalakleet R.)	7/9/56	80	0.2424	0.3591	0.1688
Hokkaido Island (Yubetsu R.)	9/-/57	65	0.1734	0.3965	0.1548
Attu Island (Lake Cornica)	8/10/57	27	0.1812	0.1026	−0.2429
χ^2	=		0.261	3.739	3.685
$\chi^2_{.95}(5\ d.f.)$	=		11.070	11.070	11.070
Average r	=		0.2149**	0.2954**	0.0841**
Average r^2	=		0.0462	0.0873	0.0071
Percent variation attributable to length	=		4.62%	8.73%	0.71%

** Significant at 1-percent level.

[1] Reduced number of samples from those of Table 4 due to absorbed scales.

APPENDIX C.

APPENDIX C-1. Tests for differences between the samples pooled in composing the Karaginskii and Kodiak-Cook Inlet morphotypes.

KODIAK-COOK INLET MORPHOTYPE

Total vertebrae

Area	Sample size (n)	$\Sigma\chi$	$\Sigma\chi^2$	Corr. Sum Sq.	$n-1$	S^2	Variance ratio
Kodiak Island	87	5,936	405,066	53.4023	86	0.6210	$F=1.2628$
Cook Inlet	80	5,482	375,716	61.9500	79	0.7842	
	167	11,418	780,782	115.3523		$F_{.01}(79,86)=1.68$	

Total 780,782.0000−780,663.0180=118.9820 166 *d.f.*

Btw. 780,666.6477−780,663.0180= 3.6297 1 *d.f.* $\frac{3.6297}{0.6991}=5.1920=F$ $F_{.01}(1,165)=6.79$

115.3523 165 *d.f.*

Dorsal fin rays

Area	Sample size (n)	$\Sigma\chi$	$\Sigma\chi^2$	Corr. Sum Sq.	$n-1$	S^2	Variance ratio
Kodiak Island	87	1,281	18,907	45.3793	86	0.5277	$F=1.0288$
Cook Inlet	80	1,197	17,953	42.8875	79	0.5429	
	167	2,478	36,860	88.2668		$F_{.01}(79,86)=1.68$	

Total 36,860.0000−36,769.3653=90.6347 166 *d.f.*

Btw. 36,771.7332−36,769.3653= 2.3679 1 *d.f.* $\frac{2.3679}{0.5350}=4.4260=F$ $F_{.01}(1,165)=6.79$

88.2668 165 *d.f.*

Scale length of intermediate zone

Area	Sample size (n)	$\Sigma\chi$	$\Sigma\chi^2$	Corr. Sum Sq.	$n-1$	S^2	Variance ratio
Kodiak Island	87	1,566	28,494	306.0000	86	3.5581	$F=1.0130$
Cook Inlet	80	1,451	26,595	277.4875	79	3.5125	
	167	3,017	55,089	583.4875		$F_{.01}(86,79)=1.68$	

Total 55,089.0000−54,504.7246=584.2754 166 *d.f.*

Btw. 54,505.5125−54,504.7246= 0.7879 1 *d.f.* $\frac{0.7879}{3.5363}=.2228=F$ $F_{.01}(1,165)=6.79$

583.4875 165 *d.f.*

Appendix C-1. (Continued).

Karaginskii Morphotype

Total vertebrae

Area	Sample size (n)	$\Sigma\chi$	$\Sigma\chi^2$	Corr. Sum Sq.	$n-1$	S^2	$\log_e S^2$	Chi-square
57°02′ N., 169°11′ E.	27	1,864	128,706	20.9630	26	0.8063	−0.21530	
57°26′ N., 167°27′ E.	26	1,804	125,192	22.1538	25	0.8862	−0.12081	
58°12′ N., 166°48′ E.	21	1,453	100,559	25.2381	20	1.2619	0.23261	
	74	5,121	354,457	68.3549	71	0.9627	−0.03801	1.26714
						$\chi^2_{.01}$ (2 *d.f.*)=9.210		

Total	354,457.0000−354,387.0405=69.9595	73 *d.f.*		
Btw.	354,388.6451−354,387.0405= 1.6046	2 *d.f.*	$\frac{0.8023}{0.9627}=0.8334=F$	$F_{.01}(2,71)=4.92$
	68.3549	71 *d.f.*		

Dorsal fin rays

Area	Sample size (n)	$\Sigma\chi$	$\Sigma\chi^2$	Corr. Sum Sq.	$n-1$	S^2	$\log_e S^2$	Chi-square
57°02′ N., 169°11′ E.	27	405	6,091	16.0000	26	0.6154	−0.48548	
57°26′ N., 167°27′ E.	26	394	5,984	13.3846	25	0.5354	−0.62474	
58°12′ N., 166°48′ E.	21	317	4,795	9.8095	20	0.4905	−0.71234	
	74	1,116	16,870	39.1941	71	0.5520	−0.59421	0.29887
						$\chi^2_{.01}$ (2 *d.f.*)=9.210		

Total	16,870.0000−16,830.4865=39.5135	73 *d.f.*		
Btw.	16,830.8059−16,830.4865= 0.3194	2 *d.f.*	$\frac{0.1597}{0.5520}=0.2893=F$	$F_{.01}(2,71)=4.92$
	39.1941	71 *d.f.*		

Scale length of intermediate zone

Area	Sample size (n)	$\Sigma\chi$	$\Sigma\chi^2$	Corr. Sum Sq.	$n-1$	S^2	$\log_e S^2$	Chi-square
57°02′ N., 169°11′ E.	27	525	10,307	98.6667	26	3.7949	1.33366	
57°26′ N., 167°27′ E.	26	496	9,538	75.8462	25	3.0338	1.10981	
58°12′ N., 166°48′ E.	21	403	7,849	115.2381	20	5.7619	1.75127	
	74	1,424	27,694	289.7510	71	4.0810	1.40635	2.40504
						$\chi^2_{.01}$ (2 *d.f.*)=9.210		

Total	27,694.0000−27,402.3784=291.6216	73 *d.f.*		
Btw.	27,404.2491−27,402.3784= 1.8707	2 *d.f.*	$\frac{0.9354}{4.0814}=0.2292=F$	$F_{.01}(2,71)=4.92$
	289.7509	71 *d.f.*		

Appendix C-2. Bivariate frequency distributions and tests for linearity of regression between all pairs of morphological characters used for racial separation of 1957 pink salmon according to Dixon and Massey, 1957.

Pertinent Values for Computations

Karaginskii Morphotype	*Sample size*	*Sum*	*Sum of squares*
Dorsal fin rays	74	1116	16870
Intermediate scale zone length	74	1424	27694
Total vertebrae	74	5121	354457

Cross products

Sum of dorsal fin rays with intermediate scale zone lengths =21477

Sum of dorsal fin rays with total vertebrae =77239

Sum of intermediate scale zone lengths with total vertebrae =98543

Kodiak-Cook Inlet Morphotype	*Sample size*	*Sum*	*Sum of squares*
Dorsal fin rays	167	2478	36860
Intermediate scale zone length	167	3017	55089
Total vertebrae	167	11418	780782

Cross products

Sum of dorsal fin rays with intermediate scale zone lengths =44764

Sum of dorsal fin rays with total vertebrae =169431

Sum of intermediate scale zone lengths with total vertebrae =206256

Appendix C-2. (Continued).

Karaginskii Morphotype: Bivariate frequency distribution of dorsal fin ray counts and intermediate scale zone lengths.

	Dorsal fin rays						
Int.	13	14	15	16	17	Freq.	*f*(D.F.R.)
14			1			1	15
15			1			1	15
16			2			2	30
17		2	9	2		13	195
18		4	3	2	1	10	150
19		2	9	3	1	15	228
20		1	3	4		8	123
21		3	8	3		14	210
22	1		4	2		7	105
23			3			3	45
Freq.	1	12	43	16	2	74	1116
f(Int.)	22	227	824	314	37	1424	

Test with intermediate scale zone lengths as the independent variable (X) and dorsal fin ray counts as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	16870.0000 − 16831.7250 = 38.2750	74 − 10 = 64	0.5980
Total	16831.7250 − 16830.4865 = 1.2385	9	
Regression	$b^2(27694.0000-27402.3784 = 291.6216)$		
	$\frac{(1.5406)^2}{(291.6216)^2}(291.6216) = 0.0081$	1	
About regression	= Total − regression = 1.2304	8	0.1538
	$F = \frac{0.1538}{0.5980} = 0.2572 \qquad F_{.01}(8,64) = 2.79$		
Decision:	Accept hypothesis regression line is straight line.		

Test with dorsal fin ray counts as the independent variable (X) and intermediate scale zone lengths as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	27694.0000 − 27414.9729 = 279.0271	74 − 5 = 69	4.0439
Total	27414.9729 − 27402.3784 = 12.5945	4	
Regression	$b^2(16870.0000-16830.4865 = 39.5135)$		
	$\frac{(1.5406)^2}{(39.5135)^2}(39.5135) = 0.0601$	1	
About regression	= Total − regression = 12.5344	3	4.1781
	$F = \frac{4.1781}{4.0439} = 1.0332 \qquad F_{.01}(3,69) = 4.08$		
Decision:	Accept hypothesis regression line is straight line.		

APPENDIX C-2. (Continued).

Karaginskii Morphotype: Bivariate frequency distribution of dorsal fin ray counts and total vertebrae counts.

	Dorsal fin rays						
Total vertebrae	13	14	15	16	17	Freq.	*f*(D.F.R.)
67			1			1	15
68		3	10	1		14	208
69		6	23	7	1	37	558
70	1	2	7	6		16	242
71			1	1	1	3	48
72		1	1	1		3	45
Freq.	1	12	43	16	2	74	1116
f(T.V.)	70	830	2967	1114	140	5121	

Test with dorsal fin ray counts as the independent variable (X) and total vertebrae counts as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	$354457.0000-354393.5833 = 63.4167$	$74-5=69$	0.9191
Total	$354393.5833-354387.0405 = 6.5428$	4	
Regression	$b^2(16870.0000-16830.4865 = 39.5135)$		
	$\frac{(8.7838)^2}{(39.5135)^2}(39.5135) = 1.9526$	1	
About regression	$=$ Total $-$ regression $= 4.5902$	3	1.5301
	$F = \frac{1.5301}{0.9191} = 1.6648 \quad F_{.01}(3,69) = 4.08$		
Decision:	Accept hypothesis regression line is straight line.		

Test with total vertebrae counts as the independent variable (X) and dorsal fin ray counts as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	$16870.0000-16833.7790 = 36.2210$	$74-6=68$	0.5327
Total	$16833.7790-16830.4865 = 3.2925$	5	
Regression	$b^2(354457.0000-354387.0405 = 69.9595)$		
	$\frac{(8.7838)^2}{(69.9595)^2}(69.9595) = 1.1028$	1	
About regression	$=$ Total $-$ regression $= 2.1897$	4	0.5474
	$F = \frac{0.5474}{0.5327} = 1.0276 \quad F_{.01}(4,68) = 3.61$		
Decision:	Accept hypothesis regression line is straight line.		

APPENDIX C-2. (Continued).

Karaginskii Morphotype: Bivariate frequency distribution of total vertebrae counts and intermediate scale zone lengths.

	Total vertebrae							
Int.	67	68	69	70	71	72	Freq.	*f*(T.V.)
14			1				1	69
15			1				1	69
16			1	1			2	139
17	1	1	5	5	1		13	901
18		3	4	2	1		10	691
19		3	10	1		1	15	1036
20		1	5	1		1	8	555
21		3	7	2	1	1	14	970
22		2	2	3			7	484
23		1	1	1			3	207
Freq.	1	14	37	16	3	3	74	5121
f(Int.)	17	278	706	307	56	60	1424	

Test with total vertebrae counts as the independent variable (X) and intermediate scale zone lengths as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	$27694.0000-27416.4248 = 277.5752$	$74-6=68$	4.0820
Total	$27416.4248-27402.3784 = 14.0464$	5	
Regression	$b^2(354457.0000-354387.0405 = 69.9595)$		
	$\frac{(-1.6486)^2}{(69.9595)^2}(69.9595) = 0.0388$	1	
About regression	$=$ Total$-$regression $= 14.0076$	4	3.5019
	$F = \frac{3.5019}{4.0820} = 0.8579 \quad F_{.01}(4,68) = 3.61$		

Decision: Accept hypothesis regression line is straight line.

Test with intermediate scale zone lengths as the independent variable (X) and total vertebrae counts as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	$354457.0000-354388.3081 = 68.6919$	$74-10=64$	1.0733
Total	$354388.3081-354387.0405 = 1.2676$	9	
Regression	$b^2(27694.0000-27402.3784 = 291.6216)$		
	$\frac{(-1.6486)^2}{(291.6216)^2}(291.6216) = 0.0093$	1	
About regression	$=$ Total$-$regression $= 1.2583$	8	0.1573
	$F = \frac{0.1573}{1.0733} = 0.1466 \quad F_{.01}(8,64) = 2.79$		

Decision: Accept hypothesis regression line is straight line.

APPENDIX C-2. (Continued).

Kodiak-Cook Inlet Morphotype: Bivariate frequency distribution of dorsal fin ray counts and intermediate scale zone lengths.

	Dorsal fin rays					
Int.	13	14	15	16	Freq.	f(D.F.R.)
13				1	1	16
14			2	1	3	46
15		4	2	1	7	102
16	1	7	12	5	25	371
17	1	12	9	6	28	412
18		12	23	6	41	609
19		5	13	2	20	297
20	1	7	11	8	27	404
21		2	5	1	8	119
22		2	4		6	88
23		1			1	14
Freq.	3	52	81	31	167	2478
f(Int.)	53	936	1477	551	3017	

Test with intermediate scale zone lengths as the independent variable (X) and dorsal fin ray counts as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	$36860.0000-36773.7015=86.2985$	$167-11=156$	0.5532
Total	$36773.7015-36769.3653=4.3362$	10	
Regression	$b^2(55089.0000-54504.7246=584.2754)$		
	$\frac{(-3.2216)^2}{(584.2754)^2}(584.2754)=0.0178$	1	
About regression	$=$ Total$-$regression $=4.3184$	9	0.4798
	$F=\frac{0.4798}{0.5532}=0.8673 \quad F_{.01}(9,156)=2.53$		

Decision: Accept hypothesis regression line is a straight line.

Test with dorsal fin ray counts as the independent variable (X) and intermediate scale zone lengths as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	$55089.0000-54510.3708=578.6292$	$167-4=163$	3.5499
Total	$54510.3708-54504.7246=5.6462$	3	
Regression	$b^2(36860.0000-36769.3653=90.6347)$		
	$\frac{(-3.2216)^2}{(90.6347)^2}(90.6347)=0.1145$	1	
About regression	$=$ Total$-$regression $=5.5317$	2	2.7658
	$F=\frac{2.7658}{3.5499}=0.7791 \quad F_{.01}(2,163)=4.75$		

Decision: Accept hypothesis regression line is a straight line.

Appendix C-2. (Continued).

Kodiak-Cook Inlet Morphotype: Bivariate frequency distribution of dorsal fin ray counts and total vertebrae counts.

	Dorsal fin rays					
Total vertebrae	13	14	15	16	Freq.	*f*(D.F.R.)
66		1		1	2	30
67		8	10		18	262
68	2	25	35	17	79	1173
69		14	27	11	52	777
70	1	4	9	2	16	236
Freq.	3	52	81	31	167	2478
f(T.V.)	206	3548	5543	2121	11418	

Test with dorsal fin ray counts as the independent variable (X) and total vertebrae counts as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	$780782.0000-780664.6776 = 117.3224$	$167-4 = 163$	0.7198
Total	$780664.6776-780663.0180 = 1.6596$	3	
Regression	$b^2(36860.0000-36769.3653 = 90.6347)$		
	$\frac{(7.0240)^2}{(90.6347)^2}(90.6347) = 0.5443$	1	
About regression	$=$ Total$-$regression $= 1.1153$	2	0.5576
	$F = \frac{0.5576}{0.7198} = 0.7746 \quad F_{.01}(2,163) = 4.75$		
Decision:	Accept hypothesis regression line is a straight line.		

Test with total vertebrae counts as the independent variable (X) and dorsal fin ray counts as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	$36860.0000-36771.5514 = 88.4486$	$167-5 = 162$	0.5460
Total	$36771.5514-36769.3653 = 2.1861$	4	
Regression	$b^2(780782.0000-780663.0180 = 118.9820)$		
	$\frac{(7.0240)^2}{(118.9820)^2}(118.9820) = 0.4146$	1	
About regression	$=$ Total$-$regression $= 1.7715$	3	0.5905
	$F = \frac{0.5905}{0.5460} = 1.0815 \quad F_{.01}(3,162) = 3.91$		
Decision:	Accept hypothesis regression line is a straight line.		

Appendix C-2. (Continued).

Kodiak-Cook Inlet Morphotype: Bivariate frequency distribution of total vertebrae counts and intermediate scale zone lengths.

	Total vertebrae						
Int.	66	67	68	69	70	Freq.	*f*(T.V.)
13				1		1	69
14				2	1	3	208
15		1	4	2		7	477
16		1	14	8	2	25	1711
17	1	3	9	11	4	28	1918
18	1	5	19	14	2	41	2799
19		4	9	5	2	20	1365
20		1	19	5	2	27	1844
21		1	3	3	1	8	548
22		1	2	1	2	6	412
23		1				1	67
Freq.	2	18	79	52	16	167	11418
f(Int.)	35	334	1437	918	293	3017	

Test with total vertebrae counts as the independent variable (X) and intermediate scale zone lengths as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	55089.0000 − 54520.6969 = 568.3031	167 − 5 = 162	3.5080
Total	54520.6969 − 54504.7246 = 15.9723	4	
Regression	$b^2(780782.0000-780663.0180=118.9820)$ $\frac{(-20.0838)^2}{(118.9820)^2}(118.9820)=3.3901$	1	
About regression	= Total − regression = 12.5822	3	4.1941

$$F=\frac{4.1941}{3.5080}=1.1956 \qquad F_{.01}(3,162)=3.91$$

Decision: Accept hypothesis regression line is a straight line.

Test with intermediate scale zone lengths as the independent variable (X) and total vertebrae counts as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	780782.0000 − 780670.5544 = 111.4456	167 − 11 = 156	0.7144
Total	780670.5544 − 780663.0180 = 7.5364	10	
Regression	$b^2(55089.0000-54505.7246=584.2754)$ $\frac{(-20.0838)^2}{(584.2754)^2}(584.2754)=0.6904$	1	
About regression	= Total − regression = 6.8460	9	0.7607

$$F=\frac{0.7607}{0.7144}=1.0648 \qquad F_{.01}(9,156)=2.53$$

Decision: Accept hypothesis regression line is a straight line.