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A STUDY ON THE RACIAL CLASSIFICATION OF ASIAN CHUM, *ONCORHYNCHUS KETA* (WALBAUM) BASED ON SCALE CHARACTERISTICS

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인상(鱗相)에 의한 아시아계 백연어, *Oncorhynchus keta* (Walbaum)의 계통판정에 관한 연구

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북태평양의 백연어에는 카나다, 아라스카, 소련 및 일본의 네 계통이 있고, 소련과 일본의 아시아계는 경도 180° 이서(以西) 해역에 분포하는 것으로 알려져 있다. 북태평양의 서방 해역의 백연어의 계통을 추적한다는 것은 공해상에서 어획된 백연어의 형질 측정치에 대해서 그것이 소련과 일본의 두 모집단의 어느 쪽으로부터 얻어진 것인가를 판별하는 문제에 귀착된다. 이 때 각 개체에 대해 관찰된 각 형질을 두 모집단간에 개별 비교한 결과를 종합하여 계통을 판별하는 것 보다는, 이들 다수의 형질의 일차변환(一次變換)에 의해 각 형질에 나타나는 공통의 변동양상을 적절히 나타내고, 한편 두 모집단간의 차를 가장 확실히 표현하는 새로운 변량을 구하여, 이 새 변량에 의해 백연어의 계통을 판정하는 방법이 보다 높은 신뢰도를 기대할 수 있을 것이다.

본 연구에서 일본의 홋가이도와 소련의 캄차카반도의 일곱 하천으로부터 총 476개체의 백연어의 산란군(Fig. 1, Table 1)으로부터 채집한 비늘의 첫 해의 연륜에 있어서 폭과 성장선 수의 두 형질을 측정하여, 선형판별함수(線型判別函数)를 구해, 이것이 북태평양 서방 해역에 분포하는 백연어의 계통을 분리하는 데에 있어서 얼마나 유효한가를 조사했다. 정확한 판별 분석을 위해서 두 형질이 두 모집단간에 있어서 동일한 분산 및 공분산을 가진 다변량정규분포를 하고 있는가를 검토하여 두 형질이 판별 분석에 적합함을 확인했다(Table 2, 3 및 4). 구해진 선형판별함수 $Y=0.4803\ X_1+0.01156\ X_2$($X_1$은 성장선의 수, X_2는 폭)는 북태평양 서방 해역에 분포하는 백연어의 약 80%를 일본계와 소련계로 정확히 분리했다(Fig. 2). 두 형질중 성장선의 수만으로써도 두 형질로부터 구한 선형판별함수에 의했을 때와 거의 동일한 확률로 계통을 분리할 수 있음을 알았다.

INTRODUCTION

Chum salmon demonstrate the widest distribution of all the Pacific salmons. In past the fisheries were concentrated almost in the coastal waters usually within a few kilometers from shore and in the estuaries of rivers accessible to the spawning adults. Beginning in 1950's, however, a new high seas mothership fishery was developed, and it has since operated in various parts of the North Pacific. The exploitation of stocks on the high seas led to the requirement of informations on the intermingling of salmon from different areas on the high seas.

The vast cooperative program of the International North Pacific Fishery Commission started in 1955, and intensive investigations have since been conducted to develop adequate means of determining the

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continental origin of fish taken on the high seas. Comparisons of meristic counts, blood constituents, scale patterns, body measurements, and even parasite content have been carried out, but as yet have not been successful perhaps except the attempts based on scale characteristics.

The scales of adult salmon returning to rivers are characterized by geographical differences in the numbers and spacing of circuli and in the widths of the annual growth bands. Such differences have been used to identify the continental origins of chum from the high seas by Sato(1959, 1962), Kobayashi(1961), Shepard et al(1968), and Tanaka et al(1969). These studies reveal that chums in the North Pacific have four areas of origin: the British Columbia and southeastern Alaska region, the northern Alaska region, the U. S. S. R. region and the Japan region.

The author attempted to classify chums of Asian origin to two morphotypes, the Hokkaido and Kamchatkan types. This paper describes the construction of a discriminant function to separate samples of known origin into either of the two morphotypes with a low probability of misclassification.

MATERIALS AND METHODS

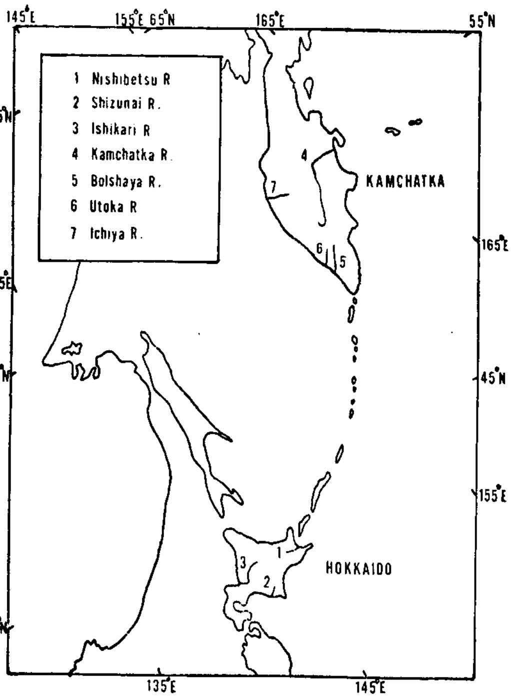

Figure 1. Map showing locations of rivers where samples were taken.

Materials utilized in this paper were all from original records of Sato(1959, 1962). Localities of the rivers and the numbers of fish sampled in this study are shown in Figure 1 and Table 1.

A discriminant function analysis was applied to two scale characters: the width of the first-year band (distance along the lougest axis of the scale from the focus to the outermost edge of the first winter ring), and the number of circuli in the first-year band.

Methods of calculating the discriminant function was elaboratorily described by Rao(1952). For the best discriminant function the characters are required to have multivariate normal distributions with a common dispersion matrix in the populations selected for use as continental morphotypes (Amos et al, 1963). Thus the two characters were examined for conformity to the statistical requirements before entering the construction of a discriminant function.

Table 1. Rivers and numbers of chum collected

Hokkaido	Nishibetzu river	92	1956
	Shizunai river	102	1956
	Ishikari river	102	1956
Kamchatka	Kamchatka river	56	1957
	Bolshaya river	51	1957
	Utoka river	50	1957
	Ichia river	23	1957

CONFORMITY OF THE TWO CHARACTERS TO THE STATISTICAL REQUIREMENTS

A common dispersion matrix is indicated by common variance and correlation, and multivariate normal distributions are by normality of each character.

A variance ratio was examined to test common variance in which the larger variance is the numerator and the smaller the denominator. The results of this test are shown in Table 2. None of the ratios was significant at the five percent level.

Table 2. Results of tests for homogeneity of variance in scale characteristics of the first-year band between two morphotypes

Character	Hokkaido variance	Kamchatka variance	Ratio	Critical 2.5-percent F
Circuli number	10.10	8.04	1.256	1.31
Band width	213.23	189.42	1.126	1.31
	N=296	N=180		

Table 3. Results of tests for common correlation between the two scale characters of the first-year band

	N	Average correlation coefficient "r" value	"z" value	1/(N-3)
Hokkaido	296	0.640	0.758	0.0034130
Kamchatka	180	0.601	0.693	0.0056497
			Difference=0.065	Sum=0.0090627
$S_{z_1-z_2}=\sqrt{0.0090627}\doteq 0.095$,			$t=0.065/0.095=0.68$,	$P\doteq 0.50$

Table 4. Results of tests for normality of characters used in separating Hokkaido and Kamchatka chum salmon.

Origin	Character	Class interval	Observed freq.	Expected freq.	(Obs. −Exp.)²/Exp.	Chi-square
Hokkaido	Circuli counts	-24	7	11	1.45	
		25-27	33	46	3.67	$\chi^2=7.20$
		28-30	105	99	0.36	d.f. =6−3=3
		31-33	98	94	0.17	$\chi^2_{0.5}=7.81$
		34-36	42	38	0.42	
		37-	11	8	0.13	
	Band width	-100	12	8	2.00	
		101-110	17	24	2.04	
		111-120	52	55	0.16	$\chi^2=6.67$
		121-130	84	77	0.64	d.f. =8−3=5
		131-140	66	71	0.35	$\chi^2_{0.5}=11.67$
		141-150	46	41	0.16	
		151-160	16	15	0.07	
		161-	3	5	0.80	
Kamchatka	Circuli counts	-21	7	14	3.50	$\chi^2=7.55$
		22-24	47	52	0.48	d.f. =5−3=2
		25-27	83	71	2.03	
		28-30	33	36	0.25	$\chi^2_{0.5}=5.99$
		31-	10	7	1.29	
	Band width	-90	8	11	0.82	
		91-100	35	27	2.37	$\chi^2=7.57$
		101-110	40	42	0.10	d.f. =6−3=3
		111-120	42	53	2.28	$\chi^2_{0.5}=7.81$
		121-130	40	32	2.00	
		131-	15	15	0	

Common correlation between the two characters in each group was examined employing a technique given by Snedecor (1956). Sample correlation coefficients estimated for each morphotype, were converted to Fisher's z values. The value of Student's t was calculated as the ratio of the difference between the two z values to the standard error of the difference. As found in Table 3, with $P=0.50$ there is clearly no reason to reject the assumption that the data from the two regions have a common population correlation.

The normality of the data was examined by testing the significance of deviations of the samples from the theoretical distribution. Chi-square was computed as shown in Table 4. The results indicate that the data do not depart significantly from the normal distribution at the five percent level, but the numbers of circuli obtained from the Kamchatkan morphotype show a little departure from normality which may be caused probably by the small samples from the region.

CONSTRUCTION OF A HOKKAIDO-KAMCHATKA DISCRIMINANT FUNCTION

On the basis of the common dispersion matrix and normality of data as verified above, a discriminant function for Hokkaido and Kamchatka chum salmon of the form $Y=l_1X_1+l_2X_2$ was calculated using data from the variance-covariance matrix and the vector indicating mean difference of each character between two morpotypes:

$$W=\begin{pmatrix} 9.73 & 29.73 \\ 29.73 & 204.24 \end{pmatrix} \qquad d=\begin{pmatrix} 4.82 \\ 16.64 \end{pmatrix}$$

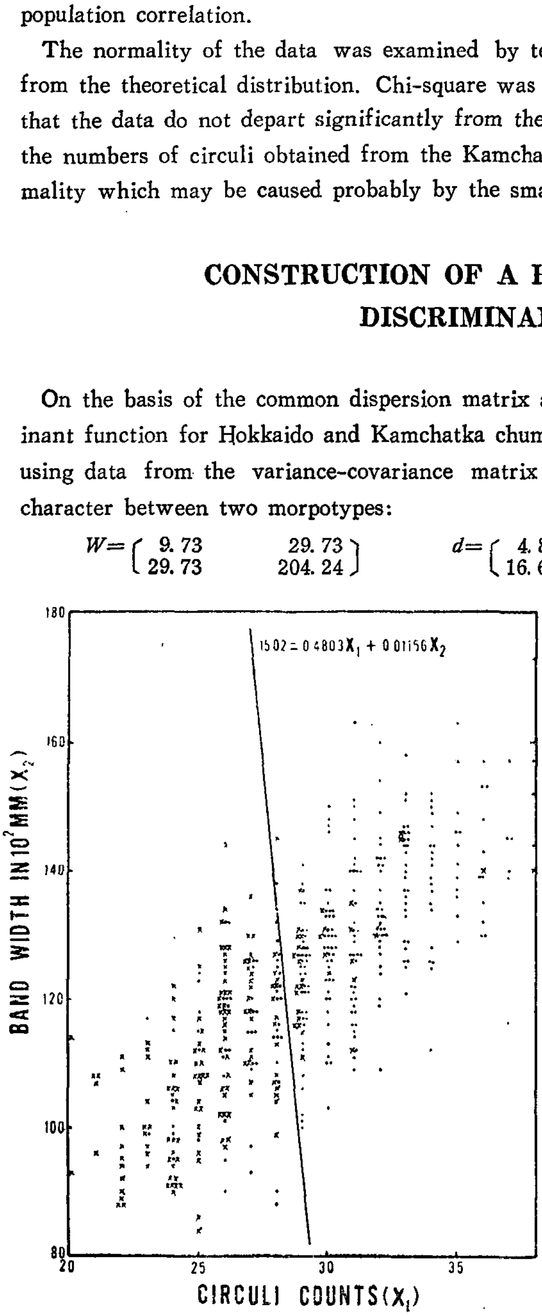

Fig. 2. Classification of Asian chums to two morphotypes, Hokkaido and Kamchatkan. Circles stand for Hokkaido morphotype, and crosses for Kamchatkan.

The mean differences of the two characters, 4.82 in the circuli counts and 16.64 in the band width, were all significant at one percent level between the two groups (Student's $t=16.348$ in the circuli counts and 11.874 in the band width, where $t_{.01}=2.576$ in both).

From these statistics the compounding coefficients of the best linear function, l_1 and l_2, were 0.4803 and 0.01156, respectively. The equation giving the function then appears as

$$Y=0.4803X_1+0.01156\,X_2,$$

where X_1 is the number of circuli, and X_2 the width of the first-year band.

D^2: the generalized distance between the two populations as estimated from the sample on the basis of the two characters was 2.5070. The mean Y value of the Hokkaido morphotype was 16.27, and that of the Kamchatkan 13.76. Thus the mean value, 15.02, of the two can be used as a critical value to classify chum salmon to their original population(Fig. 2). If the Y value of a fish exceeds the critical, the fish is judged to be the Hokkaido group, where the probability of a correct classification is equal to the probability that a normal deviate with mean zero and standard deviation of unity will be less than, or equal to, D/2. Here D/2 appears as 0.7917, and thus the probability of correctly classifying an individual chum into its morphotype is 78.5 percent.

DISCUSSIONS

In distinguishing the probable origin of the high-seas salmon, various procedures have been employed, of which important may be use of Harzen's probability paper, establishment of a key, and construction of a discriminant function.

The technique based on the Harzen's probability paper (Harding, 1949) was employed by Sato(1959) to compare the mixture of chums on the high seas. Sato(1962) also used the paper, on which was plotted the ratio of the first-year band width to the second-year band width of scales in an attempt to study the distribution of chums in the western North Pacific. A single population with normal distribution is plotted on the paper in a straight line, while polymodal distributions give a curve which reflects the combinations of two or more straight lines corresponding to their component populations. Inflection points of the curve indicate the approximate proportions in which the populations are mixed. As simple this graphical method is some mistakes are likely to be involved in locating the positions of the inflection points and straight lines, which should be adjusted on the basis of trial and error.

The method based on establishment of a key was used by Tanaka et al(1969). They selected five single characters and three compound characters from the first two year bands for chums sampled on coastal areas. For each of the eight characters the upper and lower limits as a key were defined from data for individual sampling areas. The origins of chums taken on the high seas were determined by matching their scale characteristics with the key established based on the characteristics of chums from coastal areas. To estimate the contribution of the key to the samples from the high seas, a total of 11,362 chums of known origin were processed in the same way as if they had occurred among samples taken on the high seas. Of them 33.5 percent was classified to the regions of origin. This result is rather disappointing in spite of the fact that the key was established with thoroughful considerations given to variations in scale characteristics associated with age at maturity and brood year.

Fukuhara et al(1962) first applied a discriminant function analysis to continental separation of the high-seas salmon stocks. Their discriminant function, constructed with seven meristic characters, was estimated to classify pink salmon taken on the high seas with a probability of 77.3 percent or more to two continents of origin, southwestern Kamchatka and western Alaska. Employing the same technique later Amos et al (1963) and Pearson (1964) also attempted to classify the pink salmon stocks of the North Pacific.

The key of Tanaka et al (1968) identified no more than 26 percent out of 2,609 chums originating in Asia, whereas the discriminant function given in this study had a confidence of 78.5 percent to classify Asian chums to their original regions, Hokkaido and Kamchatka. These results suggest that a discriminant function analysis is very usuful to attack the classification problem.

It should be pointed out that a contribution to the discriminant function established in this study is made almost exclusively by the circuli counts of the two characters as shown in Figure 2, were the boundary between the two morphotypes is represented by a straight line nearly perpendicular to the axis of X_1. The mean difference of the circuli counts between the two groups was significant, and the critical value to give the continental separation of chums was estimated to be 28.36. An individual with scales marked by the circuli counting to 29 or more falls into Hokkaido, otherwise into Kamchatka. The probability of correct classification is around 78 percent. Here D/2 was calculated to be 0.7894. In the case of the band width only, on the other hand, D/2 was 0.5822. This presents a convincing evidence that the number of circuli can alone serve as a good measure to identify the geographical origins of chums although unfortunately it is much more laborous to read off than the band width.

SUMMARY

Two scale characters, the width and circuli counts of the first-year band, were used in a discriminant function analysis to see how effectively the two scale characters would separate geographical chum stocks from the western North Pacific. A total of 476 scale samples were taken from spawning adults which ascended to rivers of Hokkaido, Japan, in 1956, and Kamchatka, the U.S.S.R., in 1957.

The scale characters were examined for conformity to the statistical requirements of a discriminant function. As a result of the examinations the two characters were verified to be able to be used in a discriminant function analysis that would classify chum taken on the high seas to most probable origin.

A discriminant function computed using the two characters correctly classified 78.5 percent of the Hokkaido and Kamchatka chum fish. Of the two characters the number of the circuli could alone classify fish to its origin with nearly the same probability of correct classification as the discriminant function based on the two characters can.

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