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Rihei Kawashima

Ken-ichiro Kyuûshin

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ON THE ANALYSIS OF CHUM SALMON SCALE PATTERN BY USE OF AUTO-CORRELATION COEFFICIENT

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Rihei Kawashima and Ken-ichirô Kyuûshin

Edited by

George C. Grant

Translated by

Goro Nagase

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ON THE ANALYSIS OF CHUM SALMON SCALE PATTERN BY USE OF AUTO-CORRELATION COEFFICIENT

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(Abstract in English)

I. Introduction

The scale of chum salmon is cycloid. The characteristic of the scale pattern is mainly shown by the width of the ridge interval. The compactness of the formation of ridges is considered to be dependent on the rate of scale growth and the rate of expansion of the scale. In a broad sense the ridges represent a biological time measure, and the change of expansion of scales (the ridge interval) in the course of time shows an irregular wave pattern. Therefore the auto correlation method is used to analyze the characteristics of the scale pattern.

In recent years the auto correlation method, together with the development of the technique of data analysis, has played a very important role in the fields of engineering, medicine, and biology. It is used, for instance, in the statistical treatment of auto-controlled systems, the detection of signals hidden in the noises, and the detection of certain properties in the physiological and ecological irregular phenomena of living organisms. The analytical method of auto correlation is treated in "Spectra analysis of constant probability process" by the Statistical Institute (see references).

This study was conducted by the scale detection research team at the Department of Fisheries Science, University of Hokkaido and the Marine Institute of Hokkaido. (Acknowledgements are omitted).

Preface
to Translation[1]

Translation of this paper was undertaken to aid a research project on the population dynamics of striped bass, *Roccus saxatilis* (Walbaum).[2]

Although an effort has been made to keep the translation as near the original as possible, some degree of freedom has been used in rendering the manuscript more readible. Distortion of the authors' meaning may have resulted from this treatment, and for this we can only apologize to the authors and readers.

This translation is intended as a service to researchers. Though effort has been made to make it comprehensible, accurate and useful, it is likely that improvements can be made. Should literary improvements or verification appear desirable it is suggested that the researcher make his own translation. We will appreciate constructive suggestions for improvements in this and future translations.

Appreciation is extended to Mrs. Alice Lee Tillage of the Virginia Institute of Marine Science for typing and assembling the manuscript.

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[2] Translation and editing supported by funds from the Anadromous Fish Act (P.L 89-304) through the Bureau of Sport Fisheries and Wildlife.

II. Materials and Methods of Scale Measurements.

The scale samples were collected from chum salmon caught in July and August in 1959 and 1960 in the Yukon and Skeena Rivers of Canadian-American waters and in the Bolshaya and Amur Rivers of Asian waters. As the scale pattern is considered to be different according to age, samples of 4 year-olds were studied. Samples of five females and five males were collected from each above-mentioned river, but in the Bolshaya river group in 1960, only 4 females were used due to an undefinable scale pattern on the plastic impression.

Scale impressions on plastic were used. The measurements of scales were performed at a magnification of 100 X, using an Olympus projector. The longest axis of the scale was chosen for measurement, and the distance between the edges of the successive ridges was chosen for the ridge interval (See Fig. 1). Scales were taken from above or below the lateral line between the adipose fin and the posterior end of the dorsal fin. One scale was studied for each fish.

Calculations of the auto correlation coefficient and power spectra were performed by the automatic digital calculation of the auto correlation coefficient at this department.

III. Expression of the Ridge Interval of the Scale as the Function, and the Calculation of the Correlogram and Power Spectra.

Let the ridge number counted from the center of the scale be expressed as the biological time measure t and let the ridge interval be x(t). X(t), which changes as t changes, is called the time pattern system. Since we can choose the time pattern system in numerous ways, it can be expressed in the probability process $S = x(t,\omega)$. On the condition that the time pattern system of ridges are random samples (events?) in the stationary probability process, and it is ergodic*, we may calculate the correlogram and estimate the power spectra.

*Translator's note: "This terminology is a little bit different in each book of probability (especially on the chapter of Markov chain). It could also mean "persistent" from the general ergodic theorems (for Markov processes) that under any circumstance the limits $\lim_{n \to \infty} Pn^{(t)} = Pn$ exist and are independent of the initial conditions."

Let x_i be the reading value of the ridge interval of the ridge i, and let M be the number of ridges. We first calculate the sample mean $\bar{x}$ and the deviation from the mean $\hat{x}_i$.

$$\bar{x} = \frac{1}{M} \sum_{i=1}^{M} x_i \qquad i = 1, 2, \ldots, M \qquad (1)$$

$$\hat{x}_i = x_i - \bar{x} \qquad i = 1, 2, \ldots, M \qquad (2)$$

Then we calculate the covariance $C_{xx}(k)$, using the M deviations, and we get

$$C_{xx}(k) = \frac{1}{M} \sum_{i=1}^{m-k} \hat{x}_i \cdot \hat{x}_{i+k} \qquad k = 0, 1, 2, \ldots, h \qquad (3)$$

Considering the number of ridges in each scale to be between 50 and 80, we assume spectra dispersion number h = 36.

The auto correlation coefficient $R_{xx}(k)$ can be obtained in the following equation:

$$R_{xx}(k) = C_{xx}(k) / C_{xx}(0) \qquad (4)$$

The graph of $R_{xx}(k)$ in (4) is called a correlogram.

The graph of $C_{xx}(k)$ in (3) is also called a correlogram.

Power spectra $\bar{P}_x(f)$ can be obtained from $C_{xx}(k)$

$$\bar{P}_x\left(\frac{r}{2\Delta th}\right) = \Delta t \left[C_{xx}(0) + 2 \sum_{k=1}^{h-1} C_{xx}(k) \cos \frac{\pi}{\Delta th} rk + (-1)^r C_{xx}(h)\right] \qquad (5)$$

where $f = \frac{r}{2\Delta th}$, the interval of ridges $\Delta t=1$, $r=0, 1, \ldots, h$.

Using average coefficient in $\bar{P}_x(f)$ in (5), we calculate final power spectra $\hat{P}_x(f)$

$$\hat{P}_x\left(\frac{r}{2\Delta th}\right) = \Delta t\left[0.23\bar{P}_x\left(\frac{r-1}{2\Delta th}\right) + 0.54\bar{P}_x\left(\frac{r}{2\Delta th}\right) + 0.23\bar{P}_x\left(\frac{r+1}{2\Delta th}\right)\right] \qquad (6)$$

Since $\Delta t=1$, $h=36$, it follows that power spectra of the time pattern system of the ridges in (5) and (6) were calculated on the frequencies of ridges, i.e. 0, 1/72, 2/72, 3/72,---- 36/72.

IV. Results and Discussion

Fig. 3 shows the correlogram $C_{xx}(k)$ of the biological time measure t for the data of the Yukon group in 1959. From the figure, we can see that there is no significant difference between male and female. This is also true with other data. Therefore, the mean of combined male and female samples was calculated for each river group for each year, and from the result, the correlogram $R_{xx}(k)$ was calculated (Fig. 4). In each case $R_{xx}(k)$ shows the wave motion pattern. As far as the result in 1959 is concerned, the Bolshaya and Amur river groups show the maximum value at $t = 18$, disregarding the value at $t = 0$, and shows minimum values respectively at $t=9$ and 26. On the other hand the maximum value for Yukon and Skeena groups is respectively at $t = 22$ and $t = 25$ and the minimum value is respectively at $t = 10$ and $t = 34$. Both these rivers have t values greater than those for the Asian waters. The absolute values of maximum and minimum values of $R_{xx}(k)$ in the Yukon are greater than in the other three rivers.

From the results of 1960, it is also characteristic of the Yukon group that the absolute maximum and minimum values are greater than those in the other three rivers. It appears that there are no significant differences in maximum and minimum values among the other three rivers. $R_{xx}(k) = 0$ at $t = 0$, and it decreases greatly as t gets larger but no significant difference in this decreasing tendency is shown among the river groups.

The correlogram $C_{xx}(k)$ in Fig. 5 shows the actual amount of fluctuation and the maximum and minimum values are the same as those of $R_{xx}(k)$. However the pattern of the correlogram is a little different from that of $R_{xx}(k)$ and a more pronounced difference in maximum and minimum values between the Yukon and the other the other three river groups is shown in $C_{xx}(k)$.

The power spectra (Fig. 6) was determined from $C_{xx}(k)$ by the Fourier cosine transformation by the equations (5) and (6). P_x has a remarkable peak at $f = 1/20$ for the Yukon, 1/24 for the Skeena, 1/18 for the Balshaya, and 1/20 for the Amur groups in 1959. In 1960, each river shows the peak respectively at $f = 1/20$, 1/20, 1/18 and 1/18.

The peak of $\hat{P}_x$ in the Yukon group is much higher than in the other three rivers. No difference is shown between that of the Yukon group. The value of the Amur group is somewhat smaller than that of the Skeena and Bolshaya groups. Comparing the values in the river groups for each year, the value for each river in 1960 is smaller than 1959 and there seems to be a similar yearly change in each river group.

In the Yukon group in both years and the Amur group in 1959, we find the components of long periodicity with more than 72 ridges.

We assume the correlogram determined from the measurement of the interval of the ridges of the scale consists of different components. Separating these components and estimating the original pattern, we can divide them into a random component and a periodic component.

The random component has the property to decrease the stimulus of the pattern itself against the external stimulus, so it is considered to show the characteristics of the internal response of the chum salmon against the stimulus of the environment. We can assume from the various studies of the scales of chum salmon (see the references) that the samples in this study come from different phylogenetic and local groups. The characteristics shown in the random compenent show no differences in river groups and ages and it may be considered an internal specific characteristic of chum salmon. On the other hand there is a difference in river groups and ages in the periodic components. The periodic components judged from the correlogram are not single, and they are composed of several different wave components.

These are considered to reflect the conditions of the external environment of chum salmon, such as water temperature, change of food, and the biological changes of growth and maturation.

Judging from the fact that chum salmon mature and lay eggs once in a life time, and that growth and other biological properties are quite dependent on the environmental conditions, the main cause of the periodic component is environmental in nature. This study cannot pin-point the conditions reflected on the scale pattern, but it can be seen from the results of correlogram and power spectra analysis that the changes of various conditions in the Yukon groups are generally greater than those in other river groups.

The frequency and power ((amplitude)^2) of the periodic components is already shown in the power spectra results. There are about 18 to 24 ridges among the compact ridge zones or widely spaced ridge zones, and more ridges are present in Canadian-American river groups. The fluctuation of the ridge interval is greater in this order: Yukon, Skeena or Balshaya and Amur groups.

According to the time pattern system (Fig. 2) the component of long periodicity found in Yukon samples in both years and Amur groups in 1959 shows that the ridge interval gets smaller as the scale diameter gets bigger, and it is a characteristic of the scale pattern. However it is unknown whether this characteristic reflects the external environmental condition or internal properties of the groups for each river and year.

There have been many studies concerning the analysis of scale patterns of salmon and trout. The length between the center of the scale and its resting zone, the number of ridges present between them, the number of ridges in a unit length in a certain area of the scale, or the length of the scale where certain numbers of ridges are formed are used as indicators to distinguish phylogenetic groups. This study made use of all measurements of ridge intervals on which various conditions might reflect, and tried to analyze the characteristics of the scale pattern. This is a different approach compared with previous studies. If we are able to measure the environmental condition of the fishes and also the biological internal condition of the fish in the future, we'll be able to clarify the factors producing the ffects on the changes of ridge intervals, using the mutual correlation coefficients and so on.

V. Summary

The scale pattern of chum salmon was analyzed with the auto correlation coefficient and its characteristics were pointed out. The scale samples were taken from the Yukon and Skeena populations of Canadian American waters and the Bolshaya and Amur populations of Asian waters for 1959 and 1960.

The Correlogram (Fig. 4) showed a wave motion pattern, and from this result, we estimated the original pattern and divided it into 2 components: the random component and the periodic component (Fig. 7). As far as the random component is concerned, no difference was found between the river and age groups. The periodic component showed a difference between the Canadian-American and Asian populations.

In Canadian-American populations, a difference was found between the Yukon and Skeena groups. The difference in ages was also seen in Canadian-American populations. The numbers of ridges among compact ridge zones or widely-spaced ridge zones ranged from 18 to 24, and there was a difference in the fluctuation of the ridge interval among each river and age group, as evidenced by the power spectra analysis (Fig. 6).

The characteristics of scale pattern seen in correlogram and power spectra are considered to be of use in distinguishing the chum salmon groups phylogenetically.

VI. References

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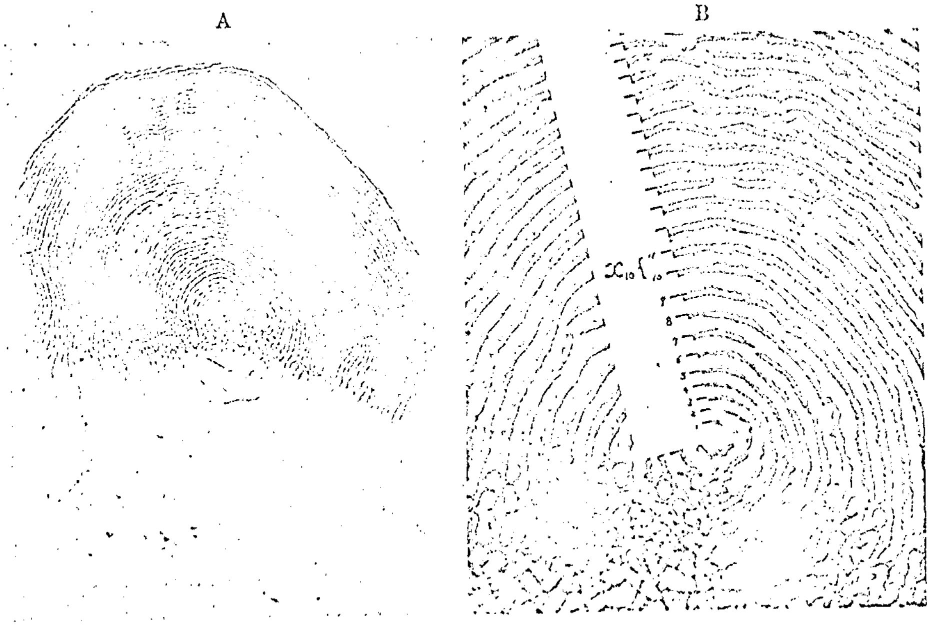

Fig. 1. A: Scale pattern of chum salmon
B: Central portion of scale showing the standard of distance between ridges

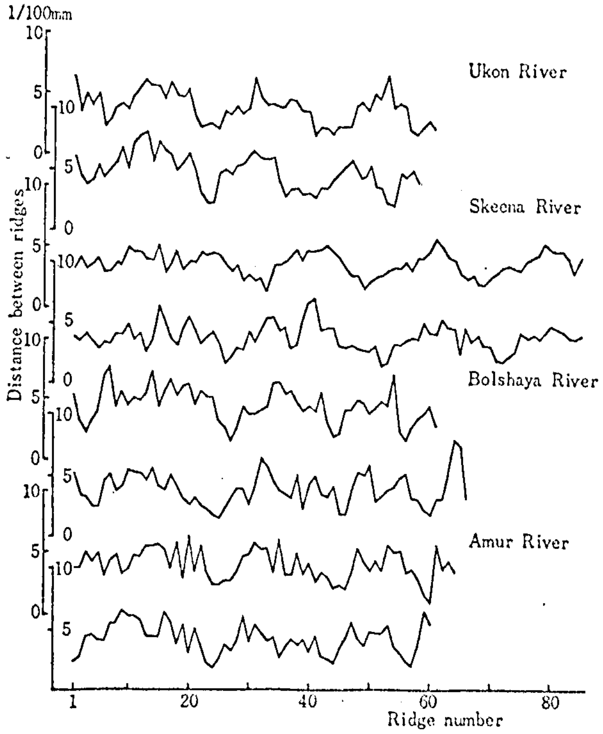

Fig. 2. Variations of the distance between ridges versus the ridge number

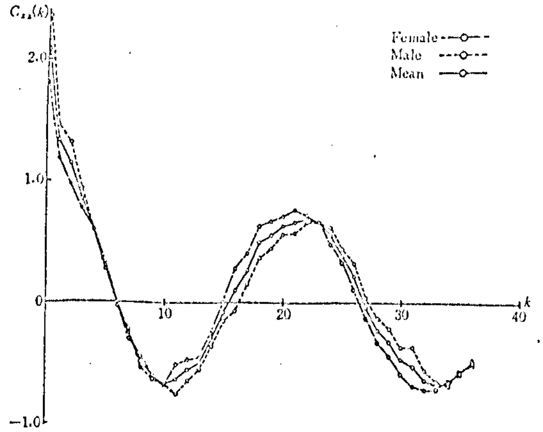

Fig. 3. Correlogram of the distance between ridges calculated from the data for the Ukon river in 1959

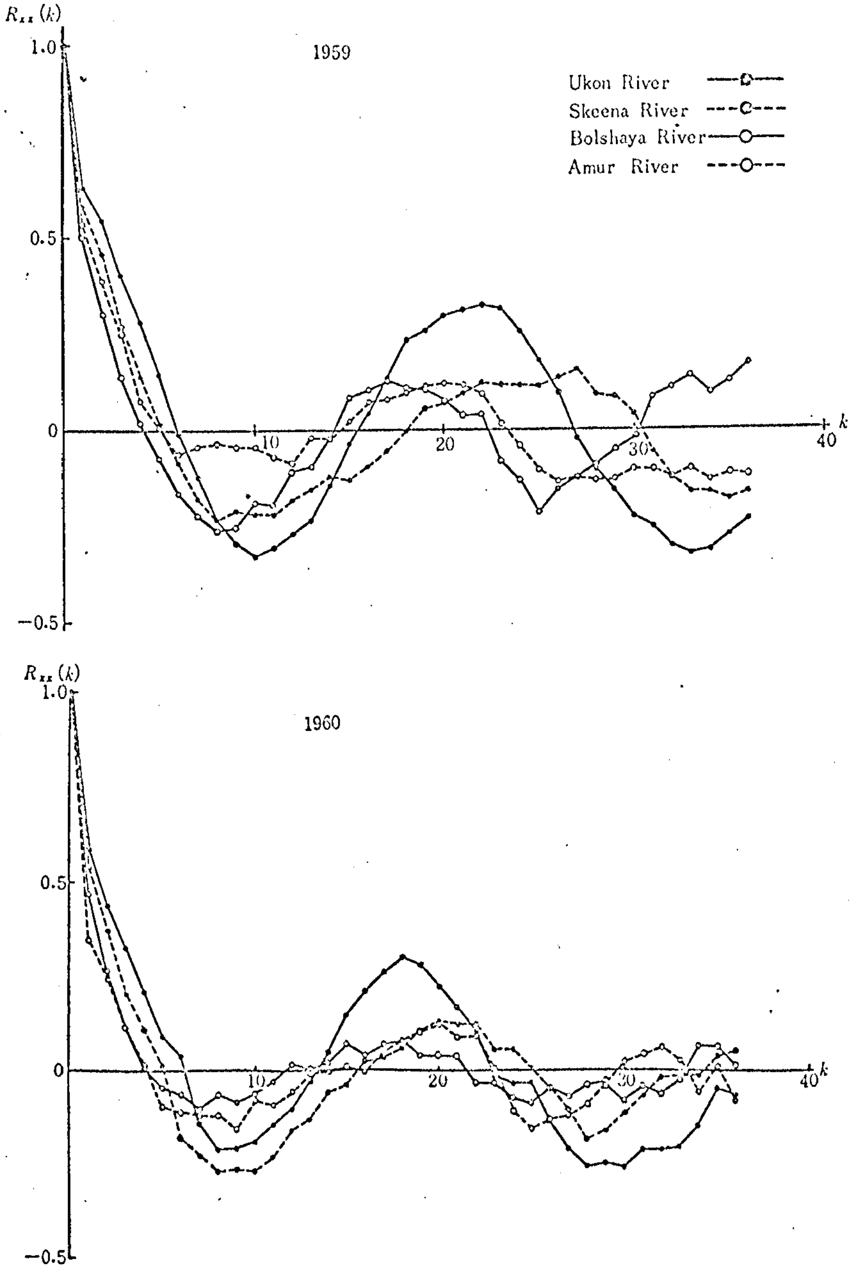

Fig. 4. Correlogram of the distance between ridges, $\cancel{\phi}_{xx}(k)$

R

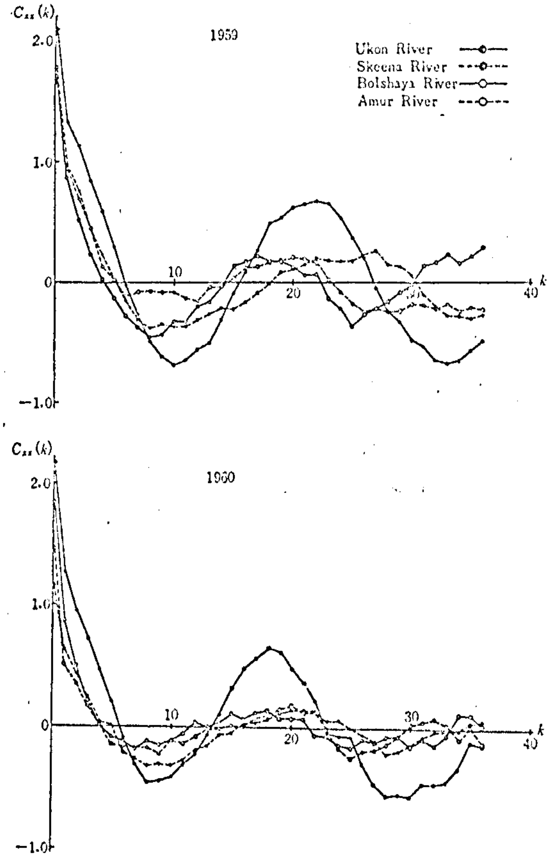

Fig. 5. Correlogram of the distance between ridges, $\cancel{R}_{xx}(k)$
C

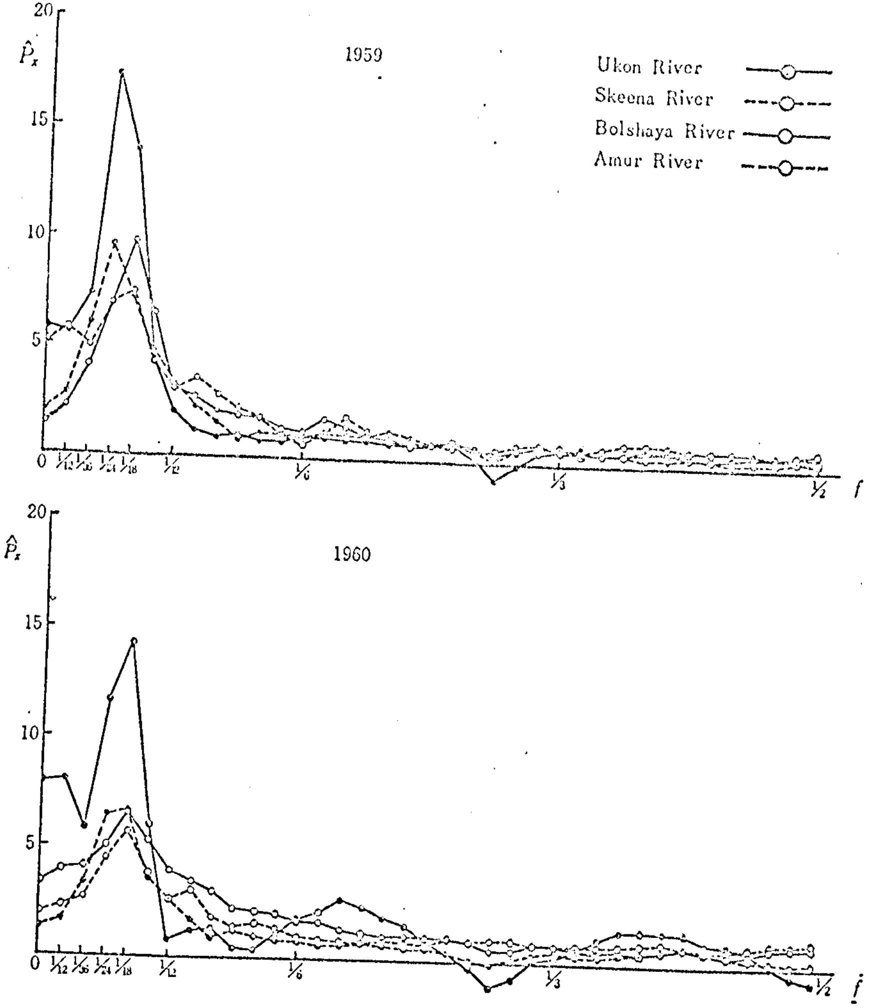

Fig. 6. Power spectra

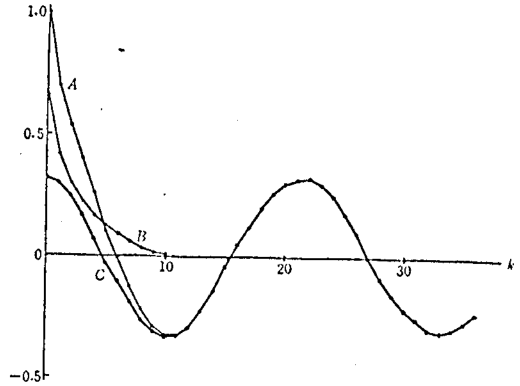

Fig. 7. Component of correlogram
A represents the correlogram of the distance between ridges, $R_{xx}(k)$;
B represents random component; C represents periodic component.