

SCIENTIFIC APPARATUS AND LABORATORY METHODS

AN APPLICATION OF THE CONTROL CHART METHOD TO THE ANALYSIS OF FISHERIES DATA

In a paper now in press as a Bulletin of the U. S. Fish and Wildlife Service¹ the writer has discussed the downward trend of the catch of Columbia River Chinook salmon since 1920 and has stated that the decline is doubtless an indication that the runs of this species are seriously depleted. Recently the same data have been studied by means of the control chart method and the results show so clearly that the productivity has dropped to a new and much lower level that it has seemed worth while to present a brief note amplifying the discussion in the bulletin.

The statistical analysis, or control chart, as developed by Shewhart,^{2,3} Deming,³ Simon⁴ and others, has been applied chiefly to the control of quality of manufactured products but the same methods can be used in the analysis of other types of data, especially those involving time series. This application to the annual catch of Chinook salmon illustrates the value of the method in the field of fisheries biology.

Fundamentally the method has much in common with the analysis of variance and, in its more common application, involves systematic observations of a selected character and continuous analysis of the variations. It provides a convenient and rapid way of discovering the presence of heterogeneity in data, the causes of which, on further study, may be identified. The processes involved may then be controlled in the direction of the elimination of causes of undesired variability or, conversely, in the direction of the development of the causes behind an improvement. Ingenious tables facilitate the computations involved and the simple graphs used present the results in such a way that they may be readily extended, promptly analyzed and interpreted.^{5,6,7}

Fig. 1 presents a series of graphs resulting from the application of this method to the analysis of the annual catch of Chinook salmon in the Columbia River

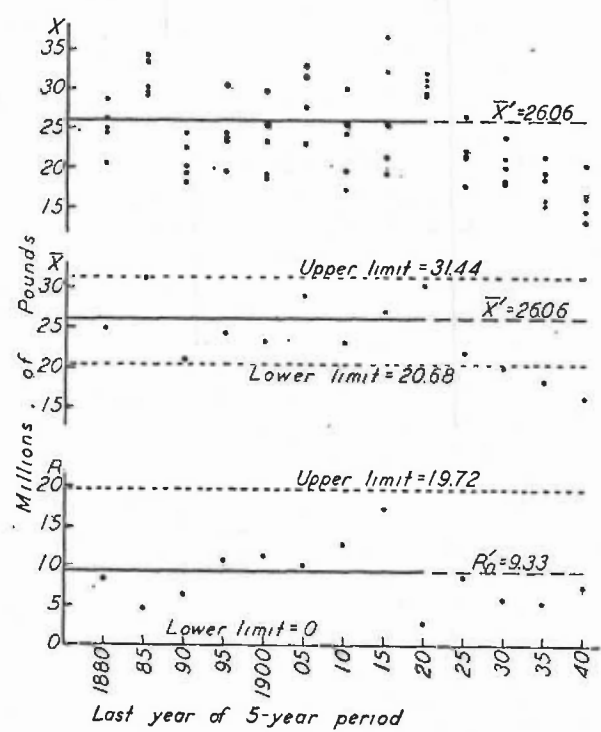


FIG. 1. Annual catch of Chinook salmon, Columbia River, 1876-1940. Analysis by control chart methods using the years 1876-1920 as standard.

from 1876 to 1940 (except for 1901, for which no data are available). The data are in pounds (estimated from pack data) and have been taken chiefly from Craig and Hacker⁸ and from the Yearbooks of the Pacific Fisherman. The years have been grouped by 5's, making 13 groups which may be considered as consecutive samples. The ordinates in Fig. 1 correspond to these 5-year periods and the points on these ordinates show (1) the catch of each year in the period (X); (2) the mean annual catch for the period (\bar{X}); and (3) the range of the annual catches within each 5-year period (R).

Previous inspection of the data, particularly of the 5-year averages, had shown that the period since 1920 had been marked by a constantly reduced catch and, for this reason, the period from 1876 to 1920 was taken as the standard with which the catch for the years since 1920 was to be compared. The average catch during the 45 years from 1876 to 1920 was 26.06 million pounds, which is shown as the central, horizontal line in the X and \bar{X} panels (labeled \bar{X}). The average range of the catches during each 5-year period was 9.33 million pounds and is shown as the

⁸ Joseph A. Craig and Robert L. Hacker, *Bulletin, U. S. Bureau of Fisheries*, No. 32, 1940.

¹ Willis H. Rich, "The Salmon Runs of the Columbia River in 1938." Contribution No. 7, Department of Research, Fish Commission of Oregon.
² W. A. Shewhart, "Economic Control of Quality of Manufactured Product." D. Van Nostrand Co., 1931.
³ W. A. Shewhart, "Statistical Method from the Viewpoint of Quality Control." Edited by W. Edwards Deming. The Graduate School, Department of Agriculture, Washington, 1939.
⁴ Leslie E. Simon, "An Engineers Manual of Statistical Methods." John Wiley and Sons, 1941.
⁵ "Guide for Quality Control, Z1.1-1941," American Standards Association.
⁶ "Control Chart Method of Analyzing Data, Z1.2-1941," American Standards Association.
⁷ "Control Chart Method of Controlling Quality during Production, Z1.3-1942," American Standards Association.

central line in the R panel (labeled R'_n). The upper and lower limits as shown in the \bar{X} and R panels are the limits set by adding to and subtracting from the mean values of these statistics (\bar{X}' and R'_n) three times an estimate of their standard deviations. The estimation of these limits has been made from tables given in reference 7 for determining the "control limits" from the ranges. Assuming that the values of \bar{X} and R are normally distributed, the probability of an individual value falling outside these limits solely as a result of sampling error would be only about .003.

It is apparent from the figure that there has been no significant change in the variability within 5-year periods—the points in the R panel cluster well within the limits. This is true even of the last four periods. In the case of the mean values, however (panel \bar{X}), the points for the last three periods are all below the lower limit and that for the period immediately preceding (including the years 1921–1925) is not far above the lower limit. The obvious interpretation is that the mean catches for at least the past three 5-year periods are significantly different from those of the period 1876–1920. If such a series of points outside the "control limits" were observed during the course of producing a manufactured product it would be taken as clear indication that something had gone wrong with the process and that things were getting rapidly worse. Even a single point outside the limits would be viewed with suspicion and an investigation started. There seems to be no reason to make a different interpretation of the data bearing on the runs of Columbia River Chinook salmon.

If such a control chart of the production of Chinook salmon on the Columbia River could have been presented in 1930 it would have shown that the 5-year period ending with that year was "out of control" and this should have been taken as a warning that something was wrong with the production process. As a result investigations could have been started to determine the causes of the reduced productivity and measures taken that might have prevented or at least delayed the progressive depletion that followed. As a matter of fact the need for such action was not felt because the true situation was not generally recognized. The catches had been small for a few years, it is true, but there had been poor years before and fishermen, cannerymen and fisheries administrators alike took counsel of their hopes and looked forward to a return of the better catches that had prevailed so long. An occasional biologist recognized the danger and as early as 1925 the writer made the following statements: "The pack . . . has remained practically stationary for a number of years during which time the intensity of fishing has been increased. . . . We may assume, therefore, that the present intensity of

fishing is too great and is resulting in a dangerous reduction of the reserve of breeding adults." And suggestions were offered for minimizing "the danger of seriously depleting the supply of fish before some indication of the imminence of such depletion has become apparent."⁹ In the light of present knowledge it would appear that a control chart of the sort now available would have given exactly the sort of information that was needed.

If such information had been available in 1930 and if the production of Chinook salmon had been a commercial venture under statistical control is it too much to think that something effective might have been done promptly toward maintaining production at a higher level? It seems altogether probable that the low average level of the catches in the 5-year period ending with 1930 would have been a "basis for action." The scientific management of fishery resources is not quite so simple as maintaining quality in a production line of a factory but the importance of maintaining productivity of biological natural resources is much greater on account of the serious losses that result from depletion and the long time required for rehabilitation of once depleted resources.

This control chart method of statistical analysis may well prove to be of rather general application in biology and particularly in the management of fishery and wildlife resources. It is concise, positive, easy to apply and points out variations due to heterogeneity of data promptly while there is still a chance that the causes are still operative and can be identified.

WILLIS H. RICH

FISH COMMISSION OF OREGON AND
STANFORD UNIVERSITY

⁹ Willis H. Rich, *Bulletin U. S. Bureau of Fisheries*, XII, 1925.

BOOKS RECEIVED

- ALLEN, GLOVER M. *Extinct and Vanishing Mammals of the Western Hemisphere*. Illustrated. Pp. xv + 620. American Committee for International Wild Life Protection.
- GLAUERT, H. *The Elements of Aerofoil and Airscrew Theory*. Illustrated. Pp. 228. Cambridge University Press and Macmillan. \$3.50.
- HUXLEY, JULIAN. *Evolution, The Modern Synthesis*. Pp. 645. Harper and Brothers. \$5.00.
- MIZWA, STEPHEN P. *Nicholas Copernicus, 1543–1943*. Illustrated. Pp. 88. The Kosciuszko Foundation.
- SMITH, EDWARD S., MEYER SALKOVER and HOWARD K. JUSTICE. *Analytic Geometry*. Illustrated. Pp. xii + 298. John Wiley and Sons. \$2.50.
- STUHLMAN, OTTO. *An Introduction to Biophysics*. Illustrated. Pp. 375. John Wiley and Sons. \$4.00.
- TWYMAN, F. *Prism and Lens Making*. A Text Book for Optical Glassworkers. Illustrated. Pp. 178. Adam Hilger, Ltd., London.
- U. S. Public Health Service. *The Anopheline Mosquitoes of the Caribbean Region*, by W. H. W. KOMP. National Institute of Health Bulletin No. 179. Illustrated. Pp. 195. U. S. Government Printing Office. 35¢.