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BIOLOGICAL MONOGRAPHS AND MANUALS

General Editor

F. A. E. CREW, Edinburgh

No. V

Statistical Methods for Research Workers

Statistical Methods for Research Workers

BY

R. A. FISHER, Sc.D., F.R.S.

D.Sc. (Ames, Harvard), LL.D. (Calcutta)

Formerly Fellow of Gonville and Caius College, Cambridge

Honorary Member, American Statistical Association

American Academy of Arts and Sciences

Galton Professor, University of London

EIGHTH EDITION—REVISED AND ENLARGED

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1941

BY THE SAME AUTHOR

THE GENETICAL THEORY OF NATURAL
SELECTION, 1930, Oxford University
Press.

THE DESIGN OF EXPERIMENTS, 1935,
1937, Oliver and Boyd, Edinburgh.

STATISTICAL TABLES (With F. Yates),
1938, Oliver and Boyd, Edinburgh.

EDITORS' PREFACE

THE increasing specialisation in biological inquiry has made it impossible for any one author to deal adequately with current advances in knowledge. It has become a matter of considerable difficulty for a research student to gain a correct idea of the present state of knowledge of a subject in which he himself is interested. To meet this situation the text-book is being supplemented by the monograph.

The aim of the present series is to provide authoritative accounts of what has been done in some of the diverse branches of biological investigation, and at the same time to give to those who have contributed notably to the development of a particular field of inquiry an opportunity of presenting the results of their researches, scattered throughout the scientific journals, in a more extended form, showing their relation to what has already been done and to problems that remain to be solved.

The present generation is witnessing "a return to the practice of older days when animal physiology was not yet divorced from morphology." Conspicuous progress is now being seen in the field of general physiology, of experimental biology, and in the application of biological principles to economic problems. Often the analysis of large masses of data by statistical methods is necessary, and the biological worker is continually encountering advanced statistical problems the adequate solutions of which

are not found in current statistical text-books. To meet these needs the present monograph was prepared, and the early call for the second and later editions indicates the success attained by the author in this project.

F. A. E. C.
D. W. C.

PREFACE TO FIRST EDITION

FOR several years the author has been working in somewhat intimate co-operation with a number of biological research departments ; the present book is in every sense the product of this circumstance. Daily contact with the statistical problems which present themselves to the laboratory worker has stimulated the purely mathematical researches upon which are based the methods here presented. Little experience is sufficient to show that the traditional machinery of statistical processes is wholly unsuited to the needs of practical research. Not only does it take a cannon to shoot a sparrow, but it misses the sparrow ! The elaborate mechanism built on the theory of infinitely large samples is not accurate enough for simple laboratory data. Only by systematically tackling small sample problems on their merits does it seem possible to apply accurate tests to practical data. Such at least has been the aim of this book.

I owe more than I can say to Mr W. S. Gosset, Mr E. Somerfield, and Miss W. A. Mackenzie, who have read the proofs and made many valuable suggestions. Many small but none the less troublesome errors have been removed ; I shall be grateful to readers who will notify me of any further errors and ambiguities they may detect.

ROTHAMSTED EXPERIMENTAL STATION

February 1925

PREFACE TO EIGHTH EDITION

THE demand, steadily increasing over a period of fully fifteen years, for a book designed originally to meet the technical needs of a much smaller public, has justified at least some of the innovations in its plan, which for a time aroused criticism. The author was impressed with the practical importance of many recent mathematical advances, which to others seemed to be merely academic refinements. He felt sure, too, that workers with research experience would appreciate a book which, without entering into the mathematical theory of statistical methods, should embody the latest results of that theory, presenting them in the form of practical procedures appropriate to those types of data with which research workers are actually concerned. The practical application of general theorems is a different art from their establishment by mathematical proof. It requires fully as deep an understanding of their meaning, and is, moreover, useful to many to whom the other is unnecessary. To carry out this plan considerable additions have had to be made with each new edition to illustrate extensions and improved procedures of established value.

In most cases the new methods actually simplify the handling of the data. The conservatism of some university courses in elementary statistics, in stereotyping unnecessary approximations and inappropriate conventions, still hinders many students in the use of

exact methods. In reading this book they should try to remember that departures from tradition have not been made capriciously, but only when they have been found to be definitely helpful.

Especially in the order of presentation, the book bears traces of the state of the subject when it first appeared. More recent books have, rightly from the teacher's standpoint, introduced the analysis of variance earlier, and given it more space. They have thus carried further than I the process of abstracting from the field formerly embraced by the correlation coefficient, problems capable of a more direct approach. In excusing myself from the difficult task of a fundamental rearrangement, I may plead that it is a real value to understand the problems discussed by earlier writers, and to be able to translate them into the system of ideas in which they may be more simply or more comprehensively resolved.

With a class capable of mastering the whole book, I should now postpone the matter of Sections 30 to 40, dealing with correlation, until a further experience has been gained of the application of the Analysis of Variance, but should later give time to the ideas of correlation and partial correlation for their importance in understanding the literature of quantitative biology, which has been so largely influenced by them.

In the second edition the importance of providing a striking and detailed illustration of the principles of statistical estimation led to the addition of a ninth chapter. The subject had received only general discussion in the first edition, and, in spite of its practical importance, had not yet won sufficient attention from teachers to drive out of practice the

demonstrably defective procedures which were still unfortunately taught to students. The new chapter superseded Section 6 and Example 1 of the first edition; in the third edition it was enlarged by two new sections (57.1 and 57.2) illustrating further the applicability of the method of maximum likelihood, and of the quantitative evaluation of information. K. Mather's admirable book *The Measurement of Linkage in Heredity* illustrates the appropriate procedures for a wider variety of circumstances.

In Section 27 a general method of constructing the series of orthogonal polynomials was added to the third edition, in response to the need which is felt, with respect to some important classes of data, to use polynomials of higher degree than the fifth. Simple and direct algebraic proofs of the methods of Sections 28 and 28.1 have been published by Miss F. E. Allan.

In the fourth edition the Appendix to Chapter III, on technical notation, was entirely rewritten, since the inconveniences of the moment notation seemed by that time definitely to outweigh the advantages formerly conferred by its familiarity. The principal new matter in that edition was added in response to the increasing use of the analysis of covariance, which is explained in Section 49.1. Since several writers had found difficulty in applying the appropriate tests of significance to deviations from regression formulæ, this section was further enlarged in the fifth edition.

Other new sections in the fifth edition were 21.01, giving a correction for continuity recently introduced by F. Yates, and 21.02 giving the exact test of significance for 2×2 tables. Workers who are accustomed to handle regression equations with a large number

of variates will be interested in Section 29·1, which provides the relatively simple adjustments to be made when, at a late stage, it is decided that one or more of the variates used may with advantage be omitted. The possibility of doing this without laborious recalculations should encourage workers to make the list of independent variates included more comprehensive than has, in the past, been thought advisable.

Section 5, formerly occupied by an account of the tables available for testing significance, was given to a historical note on the principal contributors to the development of statistical reasoning.

In the sixth edition Example 15·1, Section 22, gave a new test of homogeneity for data with hierarchical subdivisions. Attention was also called to Working and Hotelling's formula for the sampling error of values estimated by regression, and in Section 29·2 to an extended use of successive summation in fitting polynomials.

I am indebted to Dr W. E. Deming for the extension of the Table of z to the 0·1 per cent. level of significance. Such high levels of significance are especially useful when the test we make is the most favourable out of a number which *a priori* might equally well have been chosen. Colcord and L. S. Deming have published a slightly fuller Table in the *Indian Journal of Statistics* (1936).

Two changes in the seventh edition may be mentioned. Section 27 has been expanded so as to give a fuller introduction to the theory of orthogonal polynomials, by way of orthogonal comparisons between observations, which most practical workers find easier to grasp. The arithmetical construction is simpler by this path, and the full generality of the

original treatment can be retained without very complicated algebraic expressions. A useful range of tables giving the serial values to the fifth degree is now available in *Statistical Tables*.

Section 49·2 has been added to give an outline of the important new subject of the use of multiple measurements to form the best discriminant functions of which they are capable. The tests of significance appropriate to this process have hitherto been somewhat obscure. The diversity of problems which yield to this method is very striking.

The sections of Chapter VIII, the Principles of Experimentation, which have always been too short to do justice to aspects of the subject other than the purely statistical, have since developed into an independent book, *The Design of Experiments* (Oliver and Boyd, 1935). The tables of this book, together with a number of others calculated for a variety of statistical purposes, with illustrations of their use, are now available under the title of *Statistical Tables* (Oliver and Boyd, 1938). Both of these publications relieve the present work of a claim for expansion in directions which threatened to obstruct its usefulness as a single course of study. The serious student should make sure that these volumes also are accessible to him.

It should be noted that numbers of sections, tables and examples have been unaltered by the insertion of fresh material, so that references to them, though not to pages, will be valid irrespective of the edition used.

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