Preface

The success of the first three editions of *Biometry* among teachers, students, and others who use biological statistics has encouraged us to prepare this extensively revised Fourth Edition.

We wrote and have now revised this book three times because we feel that there is a need for an up-to-date text aimed primarily at the academic biologist—a text that develops the subject from an elementary introduction up to the advanced methods necessary nowadays for biological research and for an understanding of the published literature. Personal inclination and the nature of the institutions at which we have taught cause us to address ourselves to general biologists, evolutionists, ecologists, geneticists, physiologists, and other biologists working largely on nonapplied subjects in universities, research institutes, and museums. Some of our presentation will deal with agricultural experimentation. More broadly, the statistical methods treated here are useful in many applied fields, including medicine and allied health sciences. Because it is a well-known pedagogical dictum that people learn best by familiar examples, we have endeavored to make our examples as pertinent as possible for our readers.

Much biological work is by its very nature experimental. This book, while furnishing ample directions for the analysis of experimental work, also stresses descriptive and analytical statistical study of biological phenomena. These powerful methods are often overlooked and sometimes, by implication, the validity of nonexperimental biological work is put in doubt. We think that descriptive, analytical, and experimental approaches are all of value, and we have tried to strike a balance among them. This approach will be appreciated by workers in applied fields such as the health sciences where ethical, financial, or other considerations may prevent free use of direct experimentation.

The readers we hope to interest are graduate students in biological departments who require a knowledge of biometry as part of their professional training and professional biologists in universities, museums, and research positions who for one reason or another did not receive biometric training during their student careers—that is, people who need to acquire this knowledge largely in an autodidactic way. This book has been designed to serve not only as a text to accompany a lecture course but also as a complete volume for self-study.

We aim to instill in our readers an ability to think through biological research problems in such a way as to grasp the essentials of the experimental or analytical setup, to know which types of statistical tests to apply in a given case, and to carry

out the computations required. A modicum of statistical theory has to be presented to introduce the subject matter, but once this is done, further knowledge of statistical theory is acquired as part of the learning process in solving statistical problems, rather than as a preamble to their solution. Because of limitations of time and in the mathematical preparation of most students, discussion of theory must be curtailed and some methods are presented almost entirely in "cookbook" style.

Over the years, we have found that students with very limited mathematical backgrounds can handle biometry excellently. There is remarkably little correlation between innate mathematical ability and capacity to understand the ordinary biometric methodologies. By contrast, in our experience a very high correlation exists between success in the biometry course and success in the chosen field of biological specialization. Teachers should encourage students who at the start have little confidence in their mathematical capabilities, because it does not apply to the study of applied statistics.

We must make our apologies to the mathematical statisticians who may chance on this volume. Compromises had to be made on occasion between precise definitions as required by mathematical statistics and formulations of theory that teaching experience has shown to be most easily understood by beginning classes. In judging our effort, allowance should be made for such changes and circumscriptions.

To make our book more useful to the autodidactic reader, we have employed a more direct and personal style than is customary in textbooks of this sort. No book can replace a dedicated and able teacher, but we have tried to make our written approach as similar as we can to our classroom manner.

Arrangement of This Book

Because this book deviates in several important ways from the customary statistics textbook, we would like to point out the differences so that the prospective reader may derive the maximum benefit from its use. Subject matter is arranged in chapters and sections, numbered by the conventional decimal numbering system: The number before the decimal point refers to the chapter, the number after the point to the section. Topics can be referred to in the table of contents as well as in the index. The tables are also numbered with the decimal system: The first number denotes the chapter, the second the number of the table within the chapter.

Certain special tables are designated "boxes" and are numbered as such, again using the decimal system. The boxes serve a double function. First, they illustrate computational methods for solving various types of biometric problems and can therefore be used as convenient patterns for computation. The boxes usually contain all the steps necessary—from the initial setup of the problem to the final result; hence to students familiar with the book, the boxes can serve as quick summary reminders of the technique. A second important use of the boxes relates to their origin as mimeographed sheets handed out in a biometry course at the University of Kansas. In the allowed lecture time, the instructor would not have been able to convey even as much as half the subject matter covered in the course (or in this book) if the material

contained in the sheets had to be put on the chalkboard. Asking the students to refer in class to their biometry sheets (now the boxes in this book) saved much time, and, incidentally, students were able to devote their attention to understanding the content of the sheets rather than to copying them. Instructors who employ this book as a text may wish to use the boxes in a similar manner.

Figures are numbered by the same decimal system as are the boxes. A similar numbering system is also used for (mathematical) expressions, and (homework) exercises.

Because the emphasis in this book is on practical applications of statistics to biology, discussions of statistical theory are deliberately kept to a minimum. However, we feel that some exposure to statistical theory is a good idea for any biologist, so we have provided some in various places. Derivations are given for a number of formulas, but these are consigned to Appendix A, where they should be studied and reworked by the student. A new Appendix B has been added to provide an overview or review of matrix algebra. This is needed for an understanding of some of the material in Chapter 16.

In this book, we present what we consider the minimum statistical knowledge required currently for a PhD in the biological sciences. This material is of equal importance for basic research and for applications in areas such as medicine and allied health sciences. The most important topics treated are the simple distributions (binomial, Poisson, and normal), simple statistical tests (including nonparametric tests), analysis of variance through factorial analysis, analysis of frequencies, simple and multiple regression, and correlation. This is more material than is covered in most elementary texts, yet even this much is usually not sufficient to treat even the common problems of everyday biological research. To enable the reader to become acquainted with some advanced methods, we have therefore introduced at appropriate places throughout the book so-called signpost paragraphs, set in a smaller type and bordered by a gray bar to the left. Signpost paragraphs explain some of the advanced methods and their application and refer the reader to books and papers that we have found to be most useful in explaining a given technique in simple and instructive fashion. We hope that these signposted discussions will open up the wider field of statistics for the readers of this book and permit them at the very least to consult professional statisticians intelligently.

Homework exercises for students reading this book in connection with a biometry course (or studying on their own) are given at the end of each chapter. In keeping with our own convictions, these are largely real research problems. Some of them, therefore, require a fair amount of computation for their solution.

We have been dissatisfied with the customary placement of statistical tables at the end of textbooks of biometry and statistics. Users of these books and tables are constantly inconvenienced by having to turn back and forth between the text material on a certain method and the table necessary for hypothesis testing or for some other computational step. Occasionally, the tables are interspersed throughout a textbook at sites of their initial application; they are then difficult to locate, and turning back and forth in the book is not avoided. Constant users of statistics, therefore, generally

use one or more sets of statistical tables, not only because such handbooks usually contain more complete and diverse statistical tables than do the textbooks but also because it avoids the problem of constantly turning pages in the latter.

When we first planned this textbook, we thought we would eliminate statistical tables altogether, asking readers to furnish their own from those available or use probability values provided by statistical software. However, for pedagogical reasons, it was found desirable to refer to a standard set of tables, and we consequently undertook to furnish them, bound separately from the text. The forthcoming *Statistical Tables*, Fourth Edition (Rohlf and Sokal, W. H. Freeman and Company), are identified by boldface letters (for example, Statistical Table **A**).

When a textbook is published over a considerable span of time in several editions, some of the helpful work by former readers and reviewers lives on in later editions, having become part of the immanent (*pace* Kant) spirit of the book. It therefore behooves us to recall those early contributors here. They were Professor R. C. Lewontin (Harvard University), the late Professor K. R. Gabriel (University of Rochester), Dr. Michel Kabay (then of the Université de Moncton in New Brunswick, Canada), Professor F. J. Sonleitner (University of Oklahoma), Professor Theodore J. Crovello (then of the University of Notre Dame), Professor Albert J. Rowell (University of Kansas), Mrs. Barbara A. Thomson (then at Stony Brook University), and Mrs. Donna DiGiovanni (currently at Stony Brook University). All these persons, as well as many students in more than 59 biometry classes contributed comments on several versions of the text. Because not all suggestions were accepted, the reviewers named here cannot be held responsible for errors and other failings in the book.

Turning now to the Fourth Edition, we are greatly indebted to Professor Dean C. Adams of Iowa State University at Ames, Iowa, who in his capacity as "fact checker" fine combed the text and in the process found errors as well as unfortunately worded passages. Preparation of the Fourth Edition was greatly aided by the help of Leone Brown of our home institution, who converted ASCII text files from the Third Edition into formatted MS Word files that we could edit for the Fourth Edition. She also helped with a number of other tasks including the index.

We are obligated to the many generations of biometry students who have enabled us to try out our ideas for teaching biometry and whose responses and criticism have guided us in developing our course. It has been a never-ending source of satisfaction to see these students appropriate biometric techniques as their own and employ them actively in their researches.

RRS is deeply grateful to Dr. Philip Schulman and his colleagues of the Memorial Sloan-Kettering Cancer Center, whose skillful and dedicated care enabled him to complete this book.

To Julie we owe a continuing debt of gratitude for her forbearance during the long periods of gestation of four editions of this book. Janice gracefully survived her initiation to biometry book widowhood with the Fourth Edition. Authors as well as readers are indebted to both of these ladies for their support and encouragement during the several years of preparation of this edition.