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Foreword

Our environment and natural food resources are continually coming under threat so that the monitoring of population trends is essential today. Whaling is a good example. Here politics and conservation often clash, and over the years more and more restrictions have been applied through the efforts of the International Whaling Commission in an endeavour to save some of our whale species from extinction. Localized fisheries also need to be monitored and quotas set each year. In some countries, sports fishing and hunting are popular so that information is needed about the populations being exploited in order to determine such things as the duration of hunting season and bag limits. Methods of estimating animal abundance have been developing steadily since the 1940s but over the last 20 years activity in this area has intensified and the subject has begun to blossom. At the centre of this growth were two of the authors of this book, David Anderson and Kenneth Burnham, who have widely published in this field. The need for computers in this area was soon recognized and David and Ken were joined by Jeffrey Laake who, with his computing expertise, helped to develop suitable software packages for implementing some of the new techniques. In the 1980s Stephen Buckland entered the arena and began to make his presence felt. Among other contributions, he firmly established the role of Monte Carlo and bootstrapping techniques in population estimation where the unique role of the computer could be fully exploited. He also turned his attention to the difficult problem of monitoring marine mammals such as dolphins and whales. Many of the early methods of estimating animal abundance involved the tagging of animals. However, it has since been found that for such methods to be effective, large numbers of animals have to be tagged and high proportions of the population need to be caught on each sampling occasion. One area where such methods have been particularly successful is bird banding. However, for animals like the whale, these so-called capture-recapture methods are woefully inadequate and there has been a need for the development of alternative methods. 'Distance' methods, the subject of this book, based on animal distances from points or lines, provide such alternatives. In essence, one proceeds down a randomly chosen path called a line transect and measures or estimates the perpendicular distances from the line to the animals actually detected. Alternatively,

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one can choose a point instead and measure the radial distances of the animals detected. It is very appropriate that the leading exponents in this field have come together to produce an authoritative description on 'how to do it'. They bring with them many years of experience in this research area. This book is a must for all those involved in estimating animal abundance as the methods can be used for such a wide variety of animal species including birds and marine mammals. The methods also apply to clusters of animals such as schools of dolphins and to animal signs. The beauty of such methods lies in the fact that not every animal has to be seen when a population is investigated. At the heart of the methodology is a 'detectability' function which is estimated in some robust fashion from the distances to the animals actually seen. Many species are not always visible and may be detected by the sounds they make or by being flushed out into the open. Clearly animals can have widely different behaviour patterns so that different models will be needed for different situations. This book provides a tool box of such methods with a computer package which helps the researcher to select the right tool for each occasion. The authors have a reputation for being very thorough and, typically, they endeavour to cover every conceivable situation that might be encountered in the field. They bring to the book a practical as well as a head knowledge of the subject matter so that their book is well laced with real examples. One strength of their work is their chapter on experimental design, which looks at each aspect of setting up a 'distance' experiment. Sadly, aspects of design are often omitted from books on statistical ecology, usually because of the inherent difficulty of designing experiments. Such a chapter is refreshing. There are eight chapters in all, covering the basic concepts, background, and statistical theory, together with separate chapters on line and point transects, study design and field methods. A whole chapter is devoted to illustrative examples, which is most welcome, and there is a chapter looking at extensions and related work. This latter chapter, of perhaps less relevance to the practitioner, is important in that it highlights the fact that the subject is still developing. We welcome these additional insights from those who have spent so much time working in this topic. In conclusion I would like to congratulate the authors for all their hard work in bringing to the scientific community such a detailed and helpful book.

G. A. F. Seber
April 1992

Preface

This book is about the use of distance sampling to estimate the density or abundance of biological populations. Line and point transect sampling are the primary distance methods. Here, lines or points are surveyed in the field and the observer records a distance to those objects of interest that are detected. The sample data are the set of **distances** of detected objects and any relevant covariates; however, many objects may remain undetected during the course of the survey. Distance sampling provides a way to obtain reliable estimates of density of objects under fairly mild assumptions. Distance sampling is an extension of plot sampling methods where it is assumed that **all** objects within sample plots are counted.

The objects of interest are typically various vertebrate species, including those that exist in coveys or schools, or inanimate objects such as bird nests, mammal burrows or dead animals. The range of application is quite broad, includes a variety of surveys of terrestrial and aquatic species, and several innovative approaches are reviewed. Distance sampling often provides a practical, cost-effective class of methods for estimating population density. For objects distributed sparsely across large geographic areas, there are often no competing methods.

Line and point transect sampling is well named because the important focus must be on accurate distance measurements of **all** objects near the line or point. It is the area near the line or point that is critical in nearly all aspects. Within this framework, many extensions and special cases are developed and illustrated.

The objective of this book is to provide a comprehensive treatment of distance sampling theory and application. Much work has been done on this subject since 1976. Development of fundamental new theory has diminished recently and it is timely to provide a state-of-the-art treatment of the information. Currently, there is no other book or monograph that provides a comprehensive synthesis of this material. A comprehensive computer software package, called **DISTANCE**, is also introduced.

This book covers the theory and application of distance sampling with emphasis on line and point transects. Specialized applications are noted briefly, such as trapping webs and cue counts. General considerations are given to the design of distance sampling surveys. Many examples

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are provided to illustrate the application of the theory. The book is written for both statisticians and biologists and this objective imposed a few obvious compromises.

The book contains eight chapters. Chapters 1 and 2 are introductory. Chapter 3 presents the general theory for both line and point transect sampling, including modelling, estimation, testing and inference. Chapters 4 and 5 provide insight into the application of the theory for line and point transects, respectively. These chapters are meant to stand alone, thus there is some duplication of the material. Extensions to the theory are given in Chapter 6, along with some new research directions. Chapter 7 provides material on the design of studies employing distance sampling. The emphasis here is on ways to assure that the key assumptions are met. Chapter 8 provides several comprehensive examples. Over 300 references to the published literature are listed.

The main concepts in this book are not complex; however, some of the statistical theory may be difficult for non-statisticians. We hope biologists will not be deterred by the quantitative theory chapter and hope that statisticians will understand that we are presenting methods intended to be useful and usable given all the practicalities a biologist faces in field sampling. We assume that the reader has some familiarity with basic statistical methods, including point and variance estimation. Knowledge of sampling theory would be useful, as would some acquaintance with numerical methods. Some experience with likelihood inference would be useful. The following guidelines are provided for a first reading of the book.

Everyone should read Chapters 1 and 2. While statisticians will want to study Chapters 3 and 6, Chapters 4 (line transects) and 5 (point transects) will be of more interest to biologists. Biologists should study Chapter 7 (design) in detail. Everyone might benefit from the illustrative examples and case studies in Chapter 8, where readers will find guidance on advanced applications involving several data sets.

Our interest in these subjects dates back to 1966 (DRA), 1974 (KPB), 1977 (JLL) and 1980 (STB). We have all contributed to the theory, been involved with field sampling, and had substantial interaction with the analysis of real sample data. Jointly, we have published around 50 papers in the literature on distance sampling. Computer software packages TRANSECT (now superseded) and DISTANCE have been the domain of JLL.

The contribution of Steve Buckland to this book was partially supported with funds from the Scottish Office Agriculture and Fisheries Department, through the Scottish Agricultural Statistics Service. David Anderson and Ken Burnham are grateful to the U.S. Fish and Wildlife Service for support and freedom in their research. Jeff Laake and the

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development of DISTANCE were funded by the Colorado Division of Wildlife and the U.S. National Marine Fisheries Service. Thomas Drummer, Eric Rexstad and Tore Schweder provided reviews of an early draft of this material and their help and support are gratefully acknowledged. David Bowden, Robert Parmenter and George Seber also provided review comments. Several biologists generously allowed us to use their research data as examples and in this regard we appreciate the contributions of Roger Bergstedt, Colin Bibby, Eric Bollinger, Graeme Coulson, Fritz Knopf and Robert Parmenter. We also gratefully acknowledge the following organizations for funding research to address the practical problems of distance sampling and for allowing us to use their data: the Inter-American Tropical Tuna Commission; the International Whaling Commission; the Marine Research Institute of Iceland; and the U.S. National Marine Fisheries Service. We have all benefited from the use of Les Robinette's data sets. David Carlile provided the photo of the DELTA II submersible, Fred Lindzey provided photos of aircraft used to survey pronghorn in Wyoming, and John Reinhardt allowed the use of a photo of the survey aircraft shown in Fig. 7.9. Tom Drummer and Charles Gates helped us with their software, SIZETRAN and LINE-TRAN, respectively. David Gilbert provided help with the Monte Vista duck nest data. Karen Cattnach carried out some of the analyses in the marine mammal examples and generated the corresponding figures. Finally, Barb Knopf's assistance in manuscript preparation and Eric Rexstad's help with many of the figures is appreciated.

We plan to continue our work and interest in distance sampling issues. We welcome comments and suggestions from those readers who share our interests.

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