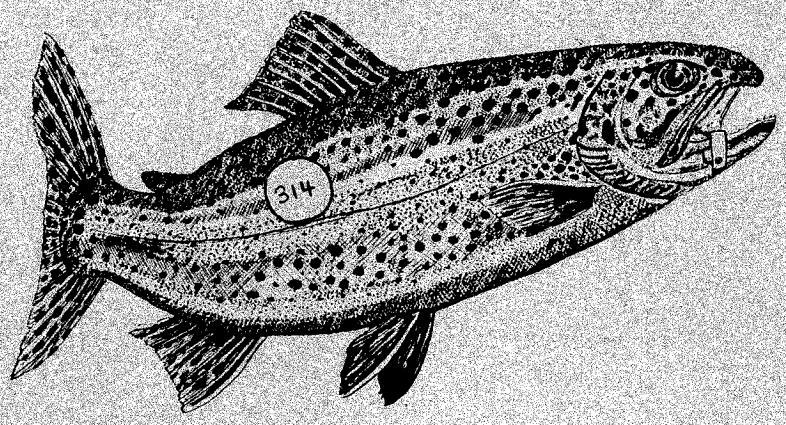
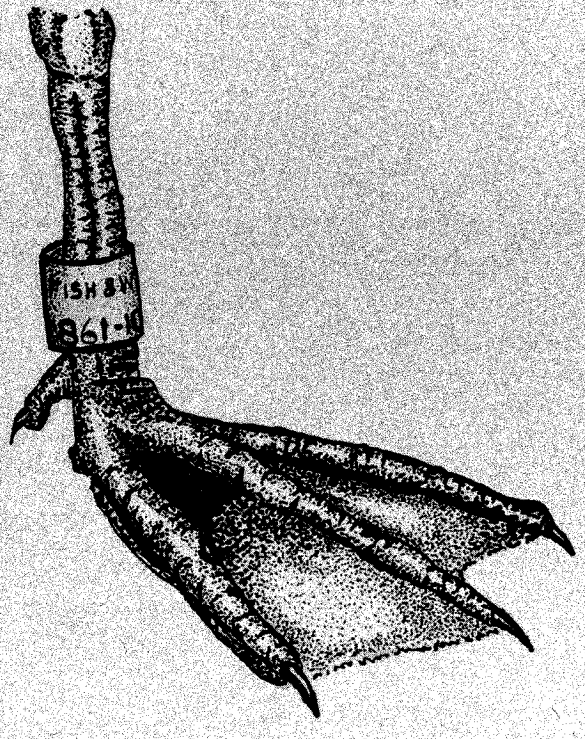
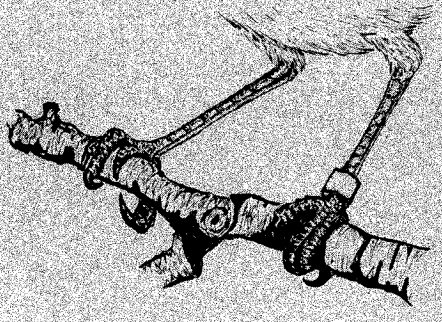
STATISTICAL INFERENCE FROM BAND RECOVERY DATA — A HANDBOOK

Second Edition



$$N_1 f_1 \qquad N_1 S_1 f_2 \quad N_2 f_2 \qquad N_1 S_1 S_2 f_3 \quad N_2 S_2 f_3 \quad N_3 f_3 \qquad N_1 S_1 S_2 S_3 f_4 \quad N_2 S_2 S_3 f_4 \quad N_3 S_3 f_4$$





$$\hat{f}_i = \frac{R_i C_i}{N_i T_i} \qquad , i = 1, \ldots, k$$

$$\tilde{S}_i = \left(\frac{R_i}{N_i} - \hat{f}_i\right) \Big/ \frac{N_{i+1}+1}{R_{i+1}+1} \qquad , i = 1, \ldots, k-1$$

$$\widehat{S_k \cdots S_{k+j-1} f_{k+j}} = \frac{R_k}{N_k} \frac{C_{k+j}}{T_k} \qquad , j = 1, \ldots, s.$$

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE / RESOURCE PUBLICATION 156

RESOURCE PUBLICATIONS

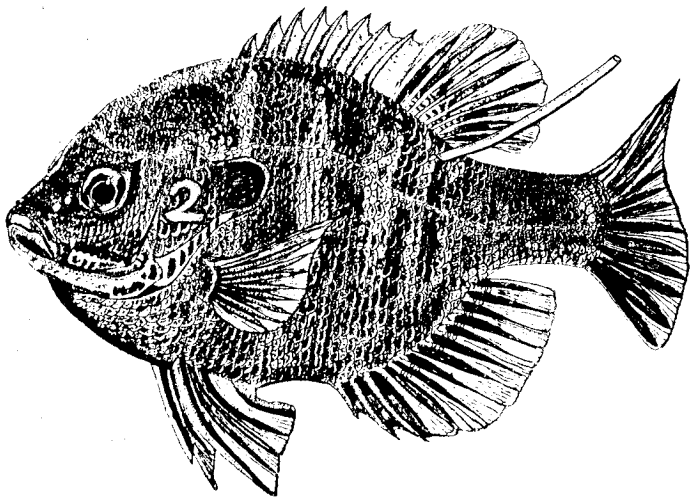
This publication of the Fish and Wildlife Service is one of a series of semitechnical or instructional materials dealing with investigations related to wildlife and fish. Each is published as a separate paper. The Service distributes a limited number of these reports for the use of Federal and State agencies and cooperators. A list of recent issues appears on inside back cover.

Copies of this publication may be obtained from the Publications Unit, U.S. Fish and Wildlife Service, Washington, DC 20240 or may be purchased from the Government Printing Office, Superintendent of Documents, Washington, DC 20402 and National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161

Library of Congress Cataloging-in-Publication Data
Main entry under title:

Statistical inference from band recovery data.

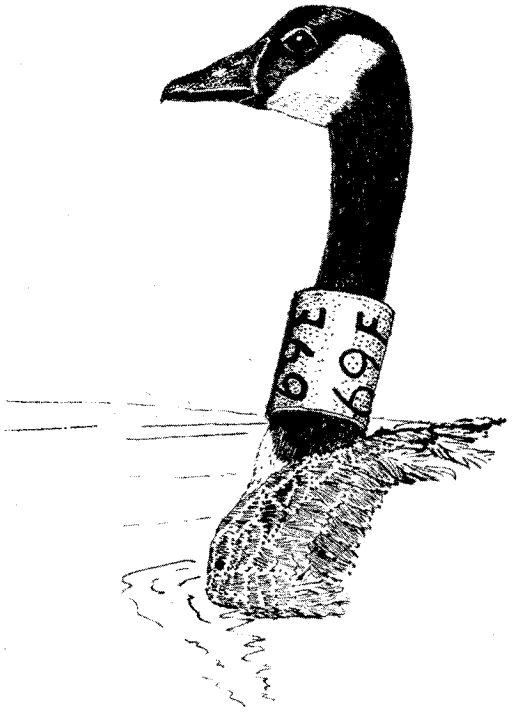
(Resource publication/United States Department of the Interior, Fish and Wildlife Service; no. 156)
Bibliography: p.
Supt. of Docs. no.: I 49.66:156
1. Bird-banding-Statistical methods. 2. Animal marking-Statistical methods. I. Brownie, Cavell. II. U.S. Fish and Wildlife Service. III. Series: Resource publication (U.S. Fish and Wildlife Service); no.156.
S914.A3 no. 156a 333.95'4'0973 s 85-600160
(QL677.5) (596'.0524'0723)



STATISTICAL INFERENCE FROM BAND RECOVERY DATA — A HANDBOOK

Second Edition

By Cavell Brownie
David R. Anderson
Kenneth P. Burnham
Douglas S. Robson



UNITED STATES
DEPARTMENT OF THE INTERIOR
Fish and Wildlife Service
Resource Publication No. 156
Washington, D.C. • 1985

Preface to the Second Edition

A second edition to *Statistical Inference from Band Recovery Data — A Handbook* was prompted by the exhaustion of the existing copies. Funds were sought for a second printing and plans were made to update certain sections. We believe this second edition will serve users for many years to come.

There has been relatively little new theory on the class of estimation and testing problems addressed in the *Handbook* since its publication in 1978. However, there have been significant developments in four areas. First, the assumptions have been investigated further and studies made on estimator robustness to partial failure of certain assumptions. These studies provide a firm setting for assessing the validity of estimates, and other inferences, from banding data. Second, various extensions have been developed to model survival rates as functions of auxillary information and thereby use banding data to explore population dynamic processes. Third, a large amount of new theory has been developed since 1978 on the analysis of multiple recapture data. This important subject was just entering a period of rapid development at the time Section 8.2 was written. Many of the new references added relate to these new developments. Fourth, many changes have been made to computer software. Programs ESTIMATE and BROWNIE have been written to be interactive and made to function on a host of microcomputers. In addition, two new, very general, programs allow the sophisticated user to fully explore arbitrarily complex models for the analysis of banding and recovery data.

The material in Chapters 1 - 5, 7, and 9 are little changed, but the developments listed above have led to rewritting material in Chapters 6 and 8. Chapter 6 has been rewritten to reflect the many changes in available computer software. Section 8.2 has been modified extensively to provide the reader insight into the recently developed methods for analyzing multiple recapture data (open population models for capture-recapture data). Sample size calculations described in Section 9.3 are now available in program ESTIMATE as an option. The *Bibliography* and *Other Literature Cited* sections have been merged and updated with the inclusion of 69 new references. New references are starred to allow the reader quick access to the new citations. Two minor errors have been corrected in Appendix A dealing with log-likelihood tests. Finally, we have added Appendix C to include 10 recent papers that are very important to the subject of banding data analysis. These are reproduced exactly as they appeared in various journals, including the original pagination. While those papers selected for reprinting reflect our personal judgement, we feel their inclusion provides a state-of-the-art Handbook. We believe the present theory has matured and stabilized and sophisticated computer algorithms now exist for easy application and analysis of almost all band recovery data.

We appreciate the efforts of Dr. Rollin D. Sparrowe and Richard S. Pospahala of the Office of Migratory Bird Management, U.S. Fish and Wildlife Service for authorizing the funds for the printing of this edition. We thank the editors of *Biometrics, Ecology, Journal of Animal Ecology, Journal of Field Ornithology,* and the *Journal of Wildlife Management* for permission to reprint the papers in Appendix C.

As we complete the second edition, Cavell Brownie has returned to the United States to a postion in the Department of Statistics at North Carolina State University, Raleigh, NC; David Anderson is the Unit Leader of the Colorado Cooperative Fish and Wildlife Research Unit at Colorado State University, after spending nine years in Utah; Ken Burnham left Colorado after eight years to take a position with the Agricultural Research Service and the Department of Statistics, North Carolina State University, in Raleigh NC; and Doug Robson has remained at Cornell University.

C. Brownie, D.R. Anderson,
K.P. Burnham, and D.S. Robson

June 1, 1985

Preface to the First Edition

This handbook presents a discussion of modern methods for the detailed analysis of certain types of marking studies of animal populations. The discussion and examples focus on bird banding studies, which are a common and important application and permit a consistent terminology. The estimation methods and statistical testing procedures presented here are potentially applicable to fish tagging experiments, entomological investigations, and studies of certain reptiles and amphibians. Bird banding studies, as these of game and nongame birds both migratory and resident, are perhaps the most extensive field of application. Indeed, probably over 40 million birds have been banded in North America alone.

The material presented here represents research done by the authors over a 4-year period. Interest in the specific subject was engendered by G. A. F. Seber's paper in *Biometrika* (1970). (Robson and Youngs had developed the same model independently while Seber's paper was in press.) At that time D. R. Anderson was studying population ecology of the mallard at Patuxent Wildlife Research Center and wanted to extend Seber's stochastic model to admit age-specificity. Subsequent contact with D. S. Robson and C. Brownie at the Cornell Biometrics Unit soon produced a contract funded by the U.S. Fish and Wildlife Service to explore the age-specific estimation problem.

This work led to the development of a series of models that we believe will be useful to many persons in years ahead. Under the initial contract, three new models (herein called H_1, H_2, and H_3) were developed for the analysis of age-dependent banding data. The contract was then extended and additional models were developed to allow further generalizations and new experimental situations. Eight of these models (H_1 through H_8) formed the basis for Brownie's Ph.D. dissertation in biometry written under Robson at Cornell University. K. P. Burnham's arrival at Patuxent during the contract work stimulated further thought and development particularly with regard to additional age-independent models and further testing procedures. Comprehensive computer programs were developed at Patuxent for the age-independent models and at Cornell for the age-dependent models.

With the analysis of 4 million mallard bandings in progress at Patuxent, we could still see the need for additional models. Five more models (M_0, M_2, M_3, H_{01} and H_{02}) were developed and incorporated into the existing computer programs. We began to consider other issues as well: additional statistical tests required, estimation of instantaneous mortality rates under various assumptions, the power of certain tests, statistical bias of estimators, geometric means of survival rates, estimators of band reporting rates, and sampling correlations between certain estimators.

Our efforts in this area have reached a convenient stopping point. The analysis procedures for the most common field experiments are now well developed. Still, there are several additional areas deserving attention. Most notable are the age-specific marking experiments of animal populations captured and released alive. Also, estimation and testing procedures for experiments involving both recovery information and data on live recaptures need to be developed and computer programs written to facilitate their use.

It is important for users of this handbook to know and understand the assumptions of a particular method, test, or model. The results are dependent, sometimes critically, upon the assumptions being made. Consequently, we have given considerable emphasis to these underlying assumptions. Furthermore, we present tests to assess the goodness of fit of each model to the data and tests between models. The assumptions and the procedures to statistically test these assumptions are as important as the estimation methods themselves.

The most useful results of our efforts are presented in this handbook, which we hope is a simple, easy-to-read primer. The subject of estimating parameters from marking experiments of animal populations is now very advanced. We have tried to simplify the presentation by employing a number of examples from real data. Of course, the availability of the computer programs alleviates many of the technical difficulties faced by biologists who use these methods. A guide to the mathematical theory underlying these methods is presented in two appendices.

The handbook is written on a level that should be understood by biologists who have taken two or three courses in applied statistics and a course in differential calculus. We have had to assume the reader is familiar with concepts such as random variables, estimators, sampling variances, confidence intervals, and chi-square test statistics. We make no apologies for these fundamental requirements.

As we complete work on this manuscript, C. Brownie has returned to Jamaica to live, D. R. Anderson has taken a position in Utah, K. P. Burnham has taken a position in Colorado, and D. S. Robson is heading for Australia on Sabbatical leave.

Cavell Brownie, David R. Anderson,
Kenneth P. Burnham, and Douglas S. Robson
June 1, 1976

Contents

Contents – Continued

Contents – Continued

Contents – Continued

Contents – Continued

List of Tables

List of Examples

List of Figures