Scientific Method for Ecological Research

Scientists tend to take the thought processes that drive their research for granted, often learning them indirectly by observing first their supervisors and then their colleagues. This book emphasizes the advantages of being explicit about these thought processes and aims to help those undertaking ecological research to develop a critical attitude to approaching a scientific problem and constructing a procedure for assessment. The outcome is a text that provides a framework for understanding methodological issues and assists with the effective definition and planning of research. As such, it is a unique resource for anyone embarking on their research career. It also provides a valuable source of information for those more experienced researchers who are seeking to strengthen the methodology underlying their studies or who have an interest in the analysis of research methods in ecology.

DAVID FORD is a Professor in the College of Forest Resources at the University of Washington, USA. His teaching spans courses such as Scientific Method, Ecological Modeling, Spatial Processes in Ecology, and Ecology of Managed Forest Ecosystems.

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E. David Ford

College of Forest Resources, University of Washington

CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK
40 West 20th Street, New York, NY 10011-4211, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
Ruiz do Alarcón 13, 28014 Madrid, Spain
Dock House, The Waterfront, Cape Town 8001, South Africa
http://www.cambridge.org

First published 2000
Reprinted 2001, 2002

Printed in the United Kingdom at the University Press, Cambridge

Typeset in Garamond 11/13pt [VN]

A catalogue record for this book is available from the British Library

Library of Congress Cataloguing-in-Publication Data
Ford, E. D. (Edward David)
Scientific method for ecological research/E. David Ford.
p. cm.
Includes bibliographical references and indexes.
ISBN 0 521 66005 X (hardcover)
1. Ecology – Research – Methodology. 2. Science – Methodology.
I. Title.
QH541.2.F66 2000
577′.07′2 – dc21 99-30065 CIP

ISBN 0 521 66005 X hardback
ISBN 0 521 66973 1 paperback

For Rosemary

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Preface

My motivation for writing this book was to provide a text for new researchers in ecology, giving a framework for understanding methodological issues, and helping them to define and plan research. In the late 1980s I started teaching a graduate course in research methods at the University of Washington. My faculty colleagues were concerned that students were having difficulty writing research plans. At the same time statistical consultants were spending much time asking students to clarify their study objectives and logic of investigation before statistical advice could be given. Discussions with colleagues at other universities suggested that these were not unusual circumstances.

Problems with ecology and its methods are also encountered by established researchers and there have been substantial criticisms of the subject and its research methods. Concern has been expressed that there has been a lack of progress in ecology, that no general theory has emerged, that ecological concepts are inadequate, and that ecologists fail to test their theories (Chapter 16). While some of this criticism may be justified, the students' needs required me to look beyond it and seek ways of being constructive. This has required making two distinctions that are fundamental to the way this book is written.

The first distinction is between methods of *reasoning* such as how we use logic, construct a hypothesis and develop a theory, and techniques of *investigation*, such as an experiment, or a survey, or constructing a simulation model. Much of this book is about methods of reasoning for ecological research and how they can best be used with particular techniques of investigation. Analysis of methods of reasoning leads to answers to the question "How can we make scientific inference in ecology?" Ecologists have tended to define and answer this question in terms of what they actually do in their work rather than the processes of reasoning they use.

The second distinction is between different types of concept we use in ecology. For some concepts we make measurements or observations but others can be defined only through abstract reasoning in the process of theory construction. Difficulties with this latter type of concept arise in even the most practical problems. For example, I have taught a number of students involved in *restoration* ecology, sometimes applied to *wetlands*. Neither of these concepts have definitions that are simple, general and easy to apply consistently to all particular cases. Government agencies who want *restoration* may fund research to show how it could be done, but may not define precisely what is required, or may define only certain aspects. Researchers writing grant or contract proposals for this work must communicate with these agencies on the agencies' own terms and may set practical objectives and suggest methods that are considered to be successful in other circumstances. Difficulties in defining precisely what would constitute *restoration* of a different *wetland* in new particular instances may become apparent only during detailed research planning.

It is because of our difficulties with definitions, and so with the relationship between general ecological theory and particular instances, that we have to be precise about the methods of reasoning we use and how we make scientific inference. Some ecologists have taken refuge from difficulties about method by emphasizing the values of particular techniques of investigation, e.g., experiments are the key to successful research because they can be used to test hypotheses, or in criteria about data, e.g., questions must be asked that can be answered with a significant *P* value. Such emphases and repeated application of a particular research technique or approach can be a solution for the individual scientist working in an established research program (see Chapter 11). But they imply that only certain types of question can be tackled. Faced with a class of graduate students, all with interesting but different types of research, I found a more comprehensive approach was necessary.

This book deals first with problems as they are most usually encountered by beginning researchers and then progresses to wider issues in ecological research and the consequences of social systems on the research process. Section I presents techniques for conceptual and propositional analysis that can be used to define a research question, develop statements defining the investigations to be made, and specify how they will answer the question. Section I defines different properties that measurements can have and describes the range of experiments used in ecology and the types of question for which they are appropriate. Section I also defines the types of logic that scientists use, particularly when falsification is possible, the importance of causal arguments, and why contrasts are so important. The requirement for exploratory work to define an effective statistical hypothesis test is described and the distinction is made between statistical and scientific inference.

Research planning starts with analysis but it must also incorporate how a comprehensive assessment will be made of work to be done. This leads to Section II and defining scientific inference, particularly for the types of concept we use in ecology. The approach taken uses work from the philosophy of science that has focused on defining scientific explanation and its assessment through developing explanatory coherence. Section II describes how scientific inference is developed and refined by groups of scientists working in research programs.

This book defines a methodology for ecological research in terms of methods of reasoning and principles for applying them. The essential principle is continuous application of *just and effective criticism.* A consequence of depending upon criticism is that explicit account must be taken of social processes in research. These are discussed in Section III. Social studies of the research process have advanced remarkably but scientists are sometimes impatient with social analysis of their subject, or even angered if studies suggest that what may actually be going on does not meet their ideal. But the consequences of these findings, and the details they describe, illustrate how difficult it can be to achieve just and effective criticism. Because we depend upon abstract reasoning in ecology and can not assume that scientific questions can be resolved in a straightforward way by measurement, then we must be explicit about use of criticism. The result of Section III is a four-stage definition of the process of criticism.

Some experienced researchers have little patience with making a formal description of the research process, believing strongly that research is best taught by the student taking the role of apprentice in following their procedures and methods. After long practice, experienced researchers may find the logic of what to do next obvious and attempts to take a cautious and refining view of all the arguments can seem a waste of time, pedantic, or even threatening. However, when you are at the outset of research, some of the assumptions made by established researchers are not obvious and the process described here can be helpful. This book does not suggest that the close relationship between supervisor and student can be replaced. Far from it. Such a relationship is essential. However, it is important to be explicit about the difficulties that we all can have with ecological research.

In addition to being a text for new researchers this book, I hope, provides a reference for definitions of terms and components of the debate over method in ecology. As a subject develops and encounters new types of problem so too must its methods evolve. Some critics of ecology have been led by their criticism to suggest restrictions either in what the aims of the subject should be or in the techniques of investigation that should be used. The methodology of *Progressive Synthesis,* defined in Chapter 15, is not restrictive in either of these ways. However, it does require that researchers be explicit in how they define scientific inference and that they analyze carefully their ideals for what research should achieve and how those ideals influence research.

Acknowledgements

I am grateful to successive classes of students taking the course QERM521, whose diverse research problems have repeatedly challenged my ideas about ecological research. My special thanks are due to Ashley Steel and Denise Hawkins, who, when they were graduate students, allowed me access to their first thoughts about a research problem and have permitted me to publish these ideas and their development. This is courageous of them. As discussed in the book, the scientific world has conventions about how research must be presented that are not designed to illustrate how ideas develop. I am also grateful to Linda Brubaker, Bob Teskey, and David Janos for painstaking reviews of the use I made of their work, to Bruce Menge, Stephen Carpenter, and Bob Paine for helpful insights into the progress of their research, and Joshua Klayman and Paul Thagard for valuable comments on the use I made of their approaches to the analysis of science and its methods.

I particularly wish to thank David Chart of the Department of History and Philosophy of Science, Cambridge University, for his review of my use of ideas from philosophy of science. His detailed comments were always sympathetic to the purpose of the book and I hope my responses are adequate.

I am indebted to Carol Perry, both for her book on technical writing (Perry 1991), and for her extensive and repeated editing of Section I. Writing about how we can analyze problems is challenging and she consistently persuaded me towards accessible text.

I am most appreciative to colleagues at the University of Washington: to Bob Francis, John Skalski, and Bob Stickney for initial ideas and encouragement; to Jim Agee, Bob Edmonds, Tom Hinckley, Dave Petersen, Joel Reynolds, and Doug Sprugel for ideas and motivating comments; and to Ray Hilborn and Walt Dickoff for their positive and constructive comments during peer review. I wish to thank Peter Guttorp and the National Center for Research in Statistics and the Environment for support in writing Chapter 12.

Foundation work was done during a sabbatical at Harvard University and the University of Lancaster. I am grateful to David Foster and Peter Diggle, respectively, for their hospitality and to Harvard University for a Bullard Fellowship whilst I was there. At Harvard a reading group of Emery Boose, Jana Compton, David Janos, and Jason McLachlan kindly commented on the text. I am particularly grateful to Sally Hollis for her comments and suggestions on Chapter 8.

My thanks are due to Alan Crowden of Cambridge University Press for his perseverance, support at crucial times, and arranging for critical reviews, particular by Craig Loehle, who made many helpful suggestions, and two anonymous referees.

The support, encouragement, and tolerance of my wife Rosemary have been selfless and given so willingly and freely.