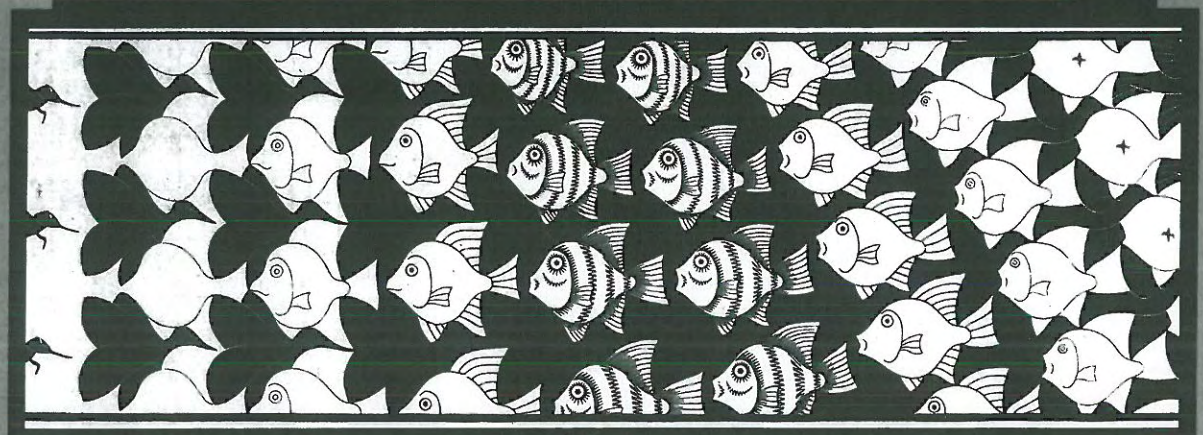
Handbook of Meta-analysis in Ecology and Evolution



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Summary: "Meta-analysis is a powerful statistical methodology for synthesizing research evidence across independent studies. This is the first comprehensive handbook of meta-analysis written specifically for ecologists and evolutionary biologists, and it provides an invaluable introduction for beginners as well as an up-to-date guide for experienced meta-analysts. The chapters, written by renowned experts, walk readers through every step of meta-analysis, from problem formulation to the presentation of the results. The handbook identifies both the advantages of using meta-analysis for research synthesis and the potential pitfalls and limitations of meta-analysis (including when it should not be used). Different approaches to carrying out a meta-analysis are described, and include moment and least-square, maximum likelihood, and Bayesian approaches, all illustrated using worked examples based on real biological datasets. This one-of-a-kind resource is uniquely tailored to the biological sciences, and will provide an invaluable text for practitioners from graduate students and senior scientists to policymakers in conservation and environmental management. Walks you through every step of carrying out a meta-analysis in ecology and evolutionary biology, from problem formulation to result presentation Brings together experts from a broad range of fields Shows how to avoid, minimize, or resolve pitfalls such as missing data, publication bias, varying data quality, nonindependence of observations, and phylogenetic dependencies among species Helps you choose the right software Draws on numerous examples based on real biological datasets "— Provided by publisher.
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PREFACE

YOU ARE HOLDING IN your hands the first handbook of meta-analysis specifically written for ecologists and evolutionary biologists. While meta-analysis has a longer history in disciplines like the medical and social sciences, it was introduced to ecology and evolution only in the early 1990s (Järvinen 1991, Gurevitch et al. 1992) and is still coming of age in these fields. However, despite this relatively short history, several hundreds of meta-analyses in ecology and evolution have already been published, and Gurevitch et al. (2001) concluded that at the turn of the twenty-first century meta-analysis had begun to have a substantial impact on the way data are summarized in these disciplines. They suggested that incorporation of meta-analysis as a routine and familiar approach will fundamentally change the nature of ecology and evolutionary biology.

Several factors contributed to the growth of meta-analysis in ecology and evolution. First, accumulation of an enormous amount of published and unpublished research has made the traditional narrative approach to comprehensive research synthesis increasingly unfeasible. Second, the importance of research synthesis in ecology and evolution is now particularly high because of the growing pressure on researchers to provide accurate quantitative assessments, predictions, and practical solutions to pressing environmental issues (e.g., biodiversity losses, biotic responses to global climate change). Third, sophisticated methods for meta-analysis have been developing in medicine and the social sciences since the late 1970s, and thus ecologists and evolutionary biologists could adapt these methods without starting from the very beginning.

An important role in the promotion of the quantitative approach to research synthesis in ecology has been played by the National Center for Ecological Analysis and Synthesis (NCEAS), established in Santa Barbara, California in 1995; the center has been funded by the United States National Science Foundation (Grant #EF-0553768), the University of California, Santa Barbara, and the State of California. The mission of NCEAS is to advance the state of ecological knowledge through the search for general patterns and principles, and to organize and synthesize ecological information in a manner useful to researchers, resource managers, and policy makers addressing important environmental issues. In 1996, a working group was created at NCEAS to help evaluate and guide the application of meta-analysis to ecological questions. A series of articles resulting from this workshop was published in a special feature issue of *Ecology* in 1999 (Gurevitch and Hedges 1999, Hedges et al. 1999, Osenberg et al. 1999). In late 2004, the National Evolutionary Synthesis Center (NESCent) was established in Durham, North Carolina, with the aim of promoting synthetic research in evolutionary biology. NESCent works in a manner similar to NCEAS by providing funding for working groups, postdoctoral researchers, and sabbatical fellows. Both NCEAS and NESCent have supported the development of quantitative research synthesis methods in ecology and evolution, as well as numerous applications of these methods to specific problems.

The work on this book was conducted as a part of the Meta-analysis in Ecology: Lessons, Challenges and Future Working Group supported by NCEAS. The working group consisted of 14 scientists from the United States, Canada, Australia, and the United Kingdom with expertise in statistics and/or meta-analysis application in ecology, evolutionary biology, medicine, and the social sciences. Four group meetings were held in Santa Barbara during 2006–2008. The topics to be covered were agreed on in the first meeting, and the remaining meetings were used to develop the individual book sections and chapters. The resulting handbook differs from the usual edited volume because it was a genuinely collaborative venture; the number of

participants was small, most contributed to more than one chapter, and the contributors worked closely together on the material. The working group format also resulted in all the contributors being more aware of the content of other chapters, which we hope has resulted in a more coherent treatment of the subject.

RATIONALE FOR THIS HANDBOOK

The decision to write a handbook on meta-analysis for ecologists and evolutionary biologists was prompted by several factors. First, meta-analytic techniques are either not covered or barely mentioned in the standard statistical books widely used by ecologists and evolutionary biologists (e.g., Sokal and Rohlf 1995, Quinn and Keough 2002) and are seldom included in the syllabi of standard statistical courses. Therefore, training in these techniques is not readily available to ecology and evolution students, and those ecologists and evolutionary biologists who have mastered meta-analysis are nearly all self-taught.

Second, although several reviews on meta-analysis in ecology and evolution have been published (Arnqvist and Wooster 1995a, Gurevitch et al. 2001, Hillebrand 2008, Stewart 2010, Harrison 2011), and software for ecological meta-analysis has been developed (Rosenberg et al. 2000), none of these publications describe in sufficient detail the entire procedure of conducting a meta-analysis from the problem formulation stage through data collection and analysis to the reporting of the results, nor do they address many of the issues and problems involved. On the other hand, the available handbooks on meta-analysis (Hedges and Olkin 1985, Lipsey and Wilson 2001, Borenstein et al. 2009, Cooper et al. 2009) are aimed at scientists from other disciplines (medicine and social sciences). As a result, they contain approaches, terminology, and examples that are unlikely to resonate with ecologists and evolutionary biologists.

Third, although the statistical issues and problems confronting meta-analysts in ecology and evolutionary biology share much in common with medicine and the social sciences, they also differ in important and substantive ways. For example, the dichotomous response variables that are common in medicine (e.g., dead/alive) are less frequent in ecology and evolutionary biology where continuous response variables prevail. Medicine and the social sciences seek to understand only a single species (*Homo sapiens*) whereas ecological and evolutionary meta-analyses usually strive to reveal patterns across many species. This introduces a number of issues, including the challenging problems of heterogeneity, and potential nonindependence among studies due to shared phylogeny. Most importantly, the types of questions asked and the data structure in meta-analyses in ecology and evolution differ from those in other fields. For example, meta-analyses in ecology and evolution typically are unconcerned with grand means, and are most concerned with the explanation of heterogeneity; meta-analyses in medicine tend to be much smaller and more narrowly focused, and the grand mean is the statistic of primary interest. For all these reasons, we felt that there was a compelling need for a handbook on meta-analysis aimed specifically at ecologists and evolutionary biologists.

In addition, the growing popularity of meta-analysis in the absence of proper training and guidelines results in highly variable standards for the application of meta-analysis to ecology and evolutionary biology; these standards fall short of those in other fields, such as medicine (Gates 2002, Roberts et al. 2006). Unfortunately, methodological shortcomings in some of the published ecological and evolutionary meta-analyses sometimes trigger criticism of the meta-analytic approach as a whole, and are used as an argument to resort to more primitive and statistically flawed methods of research synthesis, such as vote counting. There is clearly a considerable scope to improve the rigor of quantitative research synthesis in ecology and evolutionary biology, both by better educating ecologists and evolutionary biologists about available

methodological tools and by taking advantage of recent developments in meta-analysis in other disciplines.

This handbook is aimed at addressing the above problems. It should facilitate and promote the thoughtful and critical use of meta-analysis for research synthesis in ecology and evolutionary biology, and increase the scope of its application in these disciplines. This handbook should generally improve the robustness of meta-analysis in ecology and evolutionary biology. This book will, we hope, put powerful tools and concepts for research synthesis directly into the hands of those who need them, and make them available in one place.

THE INTENDED AUDIENCE

This handbook should be useful to anyone who is involved in conducting or interpreting meta-analyses in ecology or evolution; for example, researchers (ranging from graduate students to senior researchers), statisticians, and decision makers. In addition to academic scientists in the fields of ecology and evolutionary biology, we believe it will be useful to people in more applied areas, such as researchers in forestry, conservation, and other nonacademic areas. Furthermore, this book will be helpful to managers and policy makers who are not themselves conducting meta-analyses, but need to be able to evaluate and use information derived from published meta-analyses in their areas of interest. In addition to teaching meta-analytical techniques to beginning researchers, this handbook will also provide an up-to-date guide for more experienced meta-analysts by expanding the array of available techniques and by tackling some of the current problems in meta-analysis application to ecological data. Finally, the various chapters discuss and provide examples of the main applications of meta-analysis in ecology. This book will thus be ideal for both those who are new to meta-analysis, as well as those familiar with some of the techniques but who are interested in learning more about the background, assumptions, and additional methods in order to advance their own research.

LAYOUT OF THIS BOOK

The first section of this handbook defines the place of meta-analysis among the other methods of research synthesis (Chapter 1) and summarizes the process and procedure of meta-analysis in a nutshell (Chapter 2).

The second section describes the first steps in planning and initiating a meta-analysis, such as defining the problem and developing the protocol (Chapter 3), collecting data (Chapter 4), extracting and critically appraising the data (Chapter 5), and deciding on the metrics of effect size (Chapters 6 and 7).

The third section describes the main types of statistical models and approaches to statistical inference in meta-analysis (Chapter 8), including moment- and least squares-based approaches (Chapter 9), maximum likelihood methods (Chapter 10), and Bayesian analysis (Chapter 11). It also provides an overview of statistical software available for meta-analysis (Chapter 12).

The fourth section deals with specific statistical issues and problems in meta-analysis, including missing data (Chapter 13), publication bias (Chapter 14), and temporal changes in effect sizes (Chapter 15). Nonindependence is discussed when it is due to multiple measures per study (Chapter 16) or shared phylogeny (Chapter 17). In addition, this section covers meta-analysis of primary data (Chapter 18) and results from multisite experiments (Chapter 19).

The fifth section covers issues related to the interpretation and presentation of the results of meta-analysis. These include quality standards for meta-analysis (Chapter 20), graphical presentation of the results (Chapter 21), power statistics for meta-analysis (Chapter 22), and the

role of meta-analysis in interpreting scientific literature (Chapter 23) and in testing ecological and evolutionary theory (Chapter 24).

Finally, the last section of this book describes the contribution of meta-analysis in ecology and evolution by reviewing the history of the approach and comparing its progress in ecology and evolution with that in the medical and social sciences (Chapter 25). Its contribution is also described by discussing the application of meta-analysis to environmental management and conservation (Chapter 26) and by summarizing the current status of meta-analysis in ecology and evolution. Future challenges are also considered (Chapter 27). We have additionally included the section of frequently asked questions about meta-analysis.

BOOK DEDICATION AND ACKNOWLEDGMENTS

We dedicate this book to the memory of our friend and colleague Ransom Myers, who was an active and enthusiastic member of the NCEAS working group and played a key role in planning the statistical part of the book. Sadly, he did not live to see it completed. His untimely death has left an enormous void, and his wonderful personality and great passion for meta-analysis and conservation are sorely missed. This book is part of his legacy.

Working on this book as part of a highly interdisciplinary working group at NCEAS has been a wonderful, illuminating, and rewarding experience. We are very grateful to all the contributors for their cooperation and patience in putting up with the endless editorial comments, demands, and deadlines, and for their support and friendship. We also express our deepest thanks to the staff at NCEAS for their hospitality, technical assistance, and continuous supply of coffee and snacks.

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