Structural Equation Modeling and Natural Systems

This book presents an introduction to the methodology of structural equation modeling, illustrates its use, and goes on to argue that it has revolutionary implications for the study of natural systems. A major theme of this book is that we have, up to this point, attempted to study systems primarily using methods (such as the univariate model) that were designed only for considering individual processes. Understanding systems requires the capacity to examine simultaneous influences and responses. Structural equation modeling (SEM) has such capabilities. It also possesses many other traits that add strength to its utility as a means of making scientific progress. In light of the capabilities of SEM, it can be argued that much of ecological theory is currently locked in an immature state that impairs its relevance. It is further argued that the principles of SEM are capable of leading to the development and evaluation of multivariate theories of the sort vitally needed for the conservation of natural systems. Supplementary information can be found at the author's website, accessible via www.cambridge.org/9780521837422.

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CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo

Cambridge University Press
The Edinburgh Building, Cambridge CB2 2RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521837421

First published 2006

Printed in the United Kingdom at the University Press, Cambridge

A catalog record for this publication is available from the British Library

ISBN-13 978-0-521-83742-2 hardback
ISBN-10 0-521-83742-1 hardback

ISBN-13 978-0-521-54653-9 paperback
ISBN-10 0-521-54653-2 paperback

To my wife Peggy,
for her joyous spirit, wisdom, and laughter.

To my mother and my sister, Diane,
for a lifetime of love and support.

and

To Robert Wetzel, my Major Professor,
for his example of dedication to the pursuit of knowledge.

Contents

Preface

This book is about an approach to scientific research that seeks to look at the system instead of the individual processes. In this book I share with the reader my perspective on the study of complex relationships. The methodological framework I use in this enterprise is structural equation modeling. For many readers, this will be new and unfamiliar. Some of the new ideas relate to statistical methodology and some relate to research philosophy. For others already familiar with the topic, they will find contained in this volume some new examples and even some new approaches they might find useful. In my own personal experience, the approaches and methods described in this book have been very valuable to me as a scientist. It is my assessment that they have allowed me to develop deeper insights into the relationships between ecological pattern and process. Most importantly, they have given me a framework for studying ecological systems that helps me to avoid getting lost in the detail, without requiring me to ignore the very real complexities. It is my opinion, after some years of careful consideration, that potentially they represent the means to a revolutionary change in scientific inquiry; one that allows us to ask questions of interacting systems that we have not been able to ask before. These methods provide many new opportunities for science, I believe, and it is my hope that others will see their value as well.

It is important for the reader to keep in mind throughout this book the distinction between statistical procedures and the scientific enterprise. The application of structural equation modeling (SEM) to research questions embodies both elements, but the priorities of one do not necessarily match with those of the other. My approach to this book is from the perspective of a researcher, not a statistician. My treatment is not designed to satisfy the requirements of statisticians nor those interested in the mathematics. Rather, I strive to keep the focus on developing models that match the questions being addressed. Many treatments of statistical methods are prescriptive and based on protocols that have been

worked out on the basis of statistical requirements. While I could simply present SEM protocols for use by the natural scientist, I am of the opinion that protocols are commonly an impediment to the best use of statistical methods for research purposes (see also Abelson 1995). For this reason, my emphasis is on fundamental issues that provide the reader with the material to make their own decisions about how to apply statistical modeling to their particular research problems.

The general arena of studying complex relationships and the specifics of SEM is one where subject matter and statistical analysis intertwine to a greater degree than is customary for researchers or statisticians. What is distinctively different about the study of complex, multivariate relationships compared with univariate hypothesis testing is the degree to which the analyst has to know both the subtleties of the methods and the particulars of the system being studied. The goal of this book is to show why it can be worth the effort to develop and evaluate multivariate models, not just for statistical reasons, but because of the added scientific insights that can be gained. Those who apply these methods to their own data may find, as I have, that it is quite enjoyable. Hopefully the reasons for excitement will be evident as the reader explores the chapters ahead.

Acknowledgments

I have a great many people to thank for helping me along the way in this major venture. I thank Alan Crowden, Dominic Lewis, Emma Pearce, and Graham Bliss of Cambridge University Press for their support with this project. If this book is at all readable, it is because of the help of a great many individuals who provided numerous comments. I especially thank Glenn Guntenspergen, who not only read the whole volume in both first and last drafts, but who provided sage advice from beginning to end. To him, I owe the greatest debt of gratitude. I also wish to express special thanks to Sam Scheiner for many insightful suggestions on both content and presentation, as well as for advising me on the best way to present an illustration of SEM practice in the Appendix. I am appreciative of the USGS National Wetlands Research Center for their history of supporting the application of SEM to natural systems. Several examples in this book came from their studies.

Two of my comrades in the quest to introduce SEM to the natural sciences, Bill Shipley and Bruce Pugesek, both provided very helpful comments. It was Bill who convinced me that the first draft of this work was far too condensed to be useful to the student. The readers owe him a great debt of gratitude for the final structure of this book, which attempts to lead one gradually through the fundamentals of SEM in the beginning, in order to establish a base from which to jump into more advanced issues later. Bruce is especially to be thanked for introducing me to SEM and for working patiently with me through the initial learning process.

I am also thankful for the training and advice I received from some of the legendary figures in the development of structural equation modeling. My biggest debt of gratitude is to Ken Bollen, who saved me from several fundamental errors in the early development of many of my ideas. Ken possesses the rare combination of being brilliant, patient, and kind, which has been enormously helpful to me as I have struggled to make the statistical methodology fulfill my

research ambitions. I am also grateful to Karl Jöreskog and Dag Sörbom for their week-long workshop on SEM early in my learning and for answering my many pesky questions about all those complications about which instructors hope to avoid being asked. Bengt and Linda Muthén likewise shared lifetimes of experience with me in another week-long SEM workshop, again with tolerance for my questions about fringe methods and thorny problems. Others who helped me greatly through my involvement in their training classes include Bill Black (LSU), Adrian Tomer (Shippensburg University), Alex von Eye (Michigan State University), and most recently David Draper (University of California – Santa Cruz).

There are many other people who provided helpful comments on all or part of the book manuscript, including Jon Keeley, Diane Larson, Bruce McCune, Randy Mitchell, Craig Loehle, Dan Laughlin, Brett Gilbert, Kris Metzger, Gary Ervin, Evan Weiher, Tim Wootton, Janene Lichtenberg, Michael Johnson, Laura Gough, Wylie Barrow, Valerie Kelly, Chris Clark, Elsa Cleland, and Ed Rigdon. I apologize to any who I have left off the list, the process has gone on long enough to make it hard to keep track. To all who helped, Thank you!

Last and certainly not least are the people who have provided the encouragement and support in all those more personal ways that are essential to a great and productive life. My deepest gratitude to my loving wife Peggy, who has enhanced my quality of life in every way and who led me into a better life. To my Mother and my Sister Diane, I am unspeakably grateful for all the years of love and support. To Jeremy, Kris, Zach, Abi, Erica, Madison, Sophie, and Luke, your acceptance and love means more to me than you know. To Bob Wetzel, I am grateful for his encouragement over all these many years.