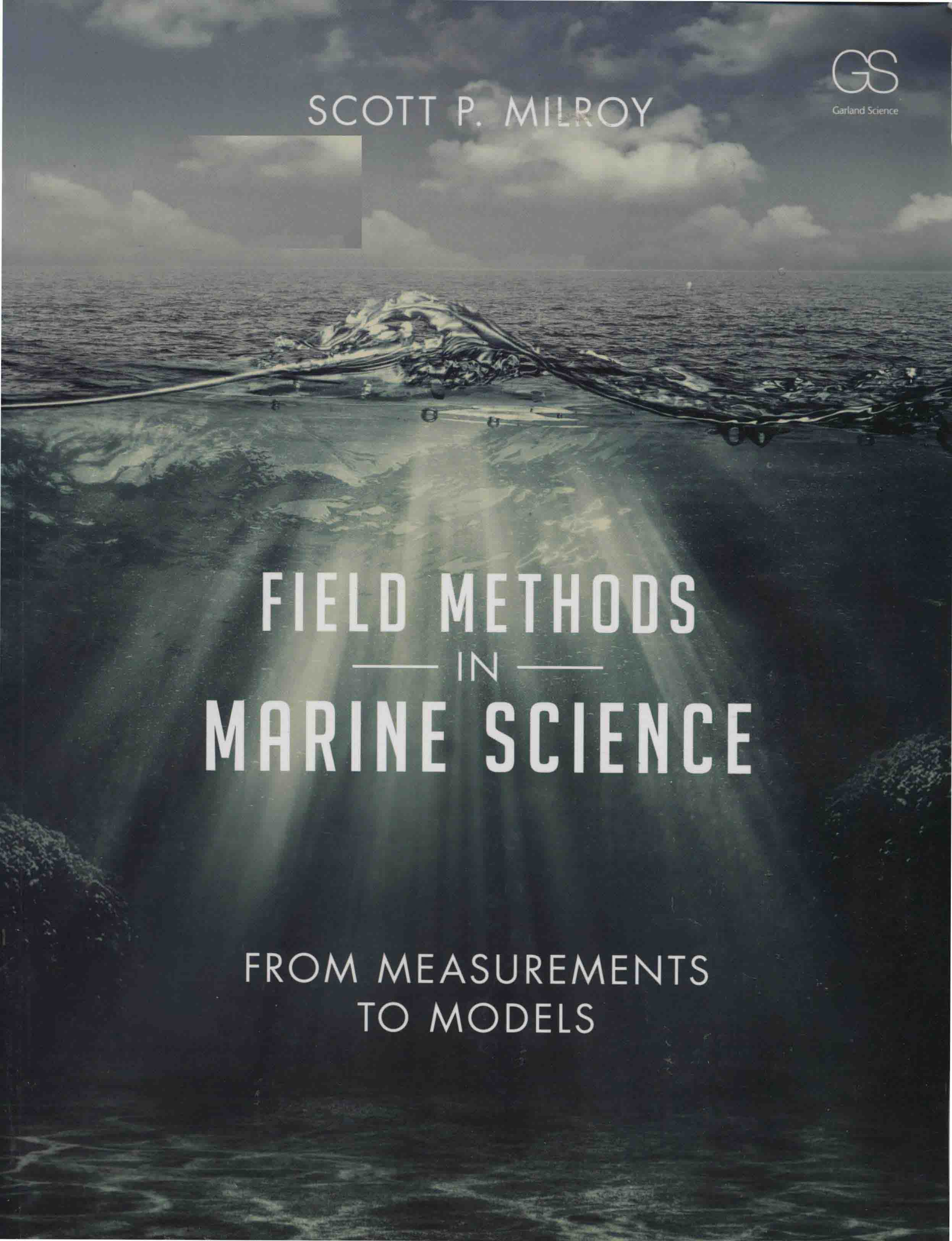
SCOTT P. MILROY

Garland Science

FIELD METHODS IN MARINE SCIENCE

FROM MEASUREMENTS TO MODELS



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Dr. Scott P. Milroy is the newly appointed Associate Chair for Undergraduate Programs on the Coast within the Department of Marine Science at the University of Southern Mississippi, where he also holds a tenured appointment as Associate Professor of Marine Science. He specializes in marine ecosystems modeling, with particular interests in biogeochemical cycling of nutrients, closed-system microcosms, coral reef ecology, ecological engineering, ecological feedback mechanisms, hydrologic optics, operational models of harmful algal blooms, ecosystem approaches to management, and the use of modeling approaches for evaluating ecosystem services and function. As a teaching and research faculty member in both the undergraduate and graduate schools of marine science, he currently teaches and has provided lectures for such courses as introductory oceanography, field methods in marine science, marine biology of the caribbean, special topics in marine science, marine environmental science, remote sensing of the oceans, ocean dynamics, and ecological modeling.

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To my family, for all your love and support, and for teaching me that integrity and hard work are the keys to success, no matter what.

To my friends, mentors, and colleagues, your inspiration and good-natured competitiveness help me to stay sharp and to never become complacent.

To my students, for the honor of your trust in my tutelage, it is upon your shoulders that future generations shall stand, and it is from your minds that all that is knowable shall become known.

To my son Ricky, for your patience during all those long days (and nights) that I was not able to run around and play with you, daddy's coming! And boy do I owe your mom big-time.

Which brings me to my amazing wife Helen, for all the sacrifices you have made on my behalf, and for all the joy you bring into my life every single day, I did it all because of you.

Preface

In the marine sciences, the practice of our craft requires an interdisciplinary approach, where we must proficiently integrate the fields of biology, chemistry, geology, and physics, with simultaneous training in mathematics and computer science as well. And although some of us may prefer to pursue our scientific endeavors in the controlled environment of our laboratories, our pursuit of marine science (or, for that matter, any aquatic science) will invariably call us to the field, where the natural world rarely obliges our desire for experimental control. So we are challenged to grow our expertise in these multiple disciplines and conduct our science in nature's laboratory, a rather unforgiving place where only the most difficult and perplexing scientific questions remain.

Field Methods in Marine Science was written as an introductory text to serve as both a training manual and a trusted reference for marine science students and early-career professionals. The book provides the reader with the key conceptual linkages between the theory and practice of science, from the philosophy of the scientific method to practical advice on designing appropriate field experiments for hypothesis-testing and data analysis, and how to transition the reader's research "from measurements to models" and create numerical models as new investigative tools. Unlike many other titles, this text was designed to be broadly applicable to all of the major disciplines (biology, chemistry, geology, mathematics, physics) within the marine sciences, as the fundamentals of field methods and numerical modeling are ubiquitous throughout.

The text is organized into four distinct units: 1) First Principles, 2) Methods of Data Acquisition, 3) Methods of Data Analysis, and 4) Methods of Data Assimilation (Modeling). Each unit is designed as a self-contained plan of study, allowing instructors greater flexibility to select discrete units as they develop curriculum for their particular course. Units 1 and 2 (First Principles and Methods of Data Acquisition) are relevant to traditional field methods and could be taught as a single-semester course in field methods.

Unit 1 (First Principles) begins of course with Chapter 1, The Foundations of Scientific Inquiry, which provides a philosophical justification of the sciences and guides the reader through the stepwise process that forms the basis of all scientific inquiry: the scientific method. Chapter 2, Introduction to Statistical Inference, provides very practical advice and basic training in the clever (and proper) use of statistics to summarize data and to infer meaning from those data. Through the use of several clear examples, the reader is introduced to the methods by which scientific hypotheses can be tested and analyzed in terms of statistical significance.

Unit 2 (Methods of Data Acquisition) focuses on the development of the research prospectus (experimental design) and the proper execution of that experiment in the laboratory or in the field. Chapter 3, Experimental Design, starts with the very basic ingredients that must be included in virtually all lab or field experiments, and builds the reader's confidence by tackling the more subtle nuances of sampling effort and quantitative survey methods. Chapter 4, Oceanographic Variables, provides an overview of how to describe an ever-changing ocean in both time and space, and which essential measures should be most carefully considered, in terms of the biological, chemical, geological, or physical phenomena under investigation. Chapter 5, Common

Hydrologic Census Methods, presents the most commonly used methods for collecting data from the aquatic medium, when the body of water itself is the focus of inquiry. Chapter 6, Census Methods for Benthic Organisms, continues with the general quantitative survey methods first introduced in Chapter 3, but delivers more specific guidance (and more experimental design options) for census methods specifically designed for organisms living in or on the bottom. Not surprisingly, Chapter 7, Census Methods for Pelagic Organisms, shifts the attention to those census methods and data collection strategies best suited for those organisms either drifting or swimming in the water column.

Unit 3 (Methods of Data Analysis) returns to the realm of statistics and numerical analysis, where our understanding of the basics from Unit 1 and our data collection methods from Unit 2 are put to the test. In this unit, the reader is introduced to the most common single- and multivariate analysis methods, including the *t* test, one-way ANOVA, and various correlation and regression analyses. The contents of this unit could be taught either as a stand-alone data analysis course or as the second semester of a field methods sequence. Chapter 8, Introduction to Univariate Analysis, starts off with the fundamentals of statistical association, using the simplest case where two or more populations can be compared (and tested for significant differences) through the use of only a single variable. Chapter 9, Introduction to Multivariate Analysis, gently guides the reader into the more complex statistical methods used to explore the associative and causative relationships among populations, using several different variables at once.

Unit 4 (Methods of Data Assimilation) represents the culmination of our research, where the data collected from the methods outlined in Unit 2 and the statistical relationships defined with the help of Unit 3 can now provide us with the tools to develop numerical models of the very phenomena we have been investigating. Since the chapters in this unit deal entirely with the basics of numerical modeling, Unit 4 can be used as a resource for an Introduction to Numerical Modeling course, or as a follow-up course (subsequent to the field methods sequence) designed to help students use data acquired through previous field or laboratory work to develop their own numerical models. Chapter 10, Fundamental Concepts in Modeling, leads the reader through an unintimidating prelude to numerical modeling, including a discussion of the fundamental elements to every numerical model, as well as a working example of how to take a conceptual map of complex dynamics (such as the nitrogen cycle) and translate each of its elements into a cohesive numerical model in the subsequent chapters. Chapter 11, Model Structure, includes an intuitive approach of how to define the spatial and temporal constraints of the model, how to populate the variables in our model with measurements we already have on hand (from our previous field research), and how our model can be used to interpolate values (using finite differencing as an example) when we are missing critical data. Chapter 12, Modeling Simple Dynamics, continues with the example of the nitrogen cycle (used in Chapters 10 and 11) and demonstrates to the reader how complex interrelationships can be systematically broken down into several constituent parts, where each can be solved as a much simpler model. Then in Chapter 13, Modeling Complex Dynamics, these simpler models are stitched back together following the conceptual model we first designed back in Chapter 10, thereby re-creating the complex dynamics we originally dissected to make our modeling tasks more manageable. Finally in Chapter 14, Modeling Large System Dynamics, the reader is introduced to the four most prevalent types of models used to model large system dynamics: hydrodynamic, biogeochemical, radiative transfer, and ecological models.

It is hoped that the content and organization of this text shall provide an opportunity for both instructor and student to bridge their gains in knowledge and skills across multiple semesters, and in so doing shall enable students to make use of research and study products acquired from their previous coursework.

The design of this text (as a plan of study) was specifically engineered to have significant implications for science students enrolled in field-based courses and those undertaking honors projects that require theses or directed or independent study. Of course, this text was also designed for the benefit of graduate level and early-career professional scientists, who may not require this text in an academic setting, but may find it to be a valuable tool for their professional development and training.

Acknowledgments

First and foremost, I would like to thank the hardworking folks at Garland Science who have quite literally made this work possible. Gina Almond, you were the first to envision what we could accomplish with this text, and you have my deepest gratitude for the opportunity. Louise Dawnay, little did you know what you were getting yourself into when you agreed to shepherd this book and its author. I am embarrassed to say that I missed just about every deadline I had agreed to meet, but your patience (and subtle impatience) were exactly what I needed to see this through. For a time, even Allie Bochicchio was there to spare you from the incessant cat-herding, and Allie did an incredible job of keeping me on task. Actually, let me extend that compliment to Natasha Wolfe as well, whose diligence and attention to detail during copyediting was uncanny. You ladies run a pretty amazing shop, and I'm honored that this text is a product of your excellence.

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Online Resources

Accessible from www.garlandscience.com, the Student and Instructor Resource Websites provide learning and teaching tools created for *Field Methods in Marine Science.* The Student Resource Site is open to everyone, and users have the option to register in order to use book-marking and note-taking tools. The Instructor Resource Site requires registration and access is available only to qualified instructors. To access the Instructor Site, please contact your local sales representative or email science@garland.com. Below is an overview of the resources available for this book. On the website, the resources may be browsed by individual chapters and there is a search engine. You can also access the resources available for other Garland Science titles.

For students and instructors

Three additional appendices complement the content in the book:

Appendix D. Exercises in Unit Conversion.
Appendix E. Oceanographic Sampling Equipment.
Appendix F. A Compendium of Routine Oceanographic Methodologies.

For instructors

Figures: The images from the book are available in two convenient forms: PowerPoint® and JPEG. They have been optimized for display on a computer.

PowerPoint is a registered trademark of Microsoft Corporation in the United States and/or other countries.

For students

Flashcards: Each chapter contains a set of flashcards that allow students to review key terms from the text.

Glossary: The complete glossary from the book can be searched and browsed as a whole or sorted by chapter.

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