Preface

There has been rapid development of statistical theory, methods, and applications in recent years. Many leading universities and research institutions are initiating new and/or expanding existing interdisciplinary and integrative science programs. This book aims to showcase interdisciplinary and integrative approaches to environmental problem solving using statistical methods. Environmental science and management students, sustainability practitioners and professionals need guidance, and a synthesis of fundamental theory and applied modeling and application principles to better frame, understand, and assimilate highly specialized and technical congruent findings and insights that are emerging across scientific domains. This book addresses the need to connect theoretical understanding and real-world investigation. It bridges natural and social science context from a public science (i.e., broad, integrated, and interdisciplinary) perspective.

The term "real-world" in the title of this book refers to scientific assessment, modeling, and forecasting of "real" complex, adaptive ecosystems (i.e., the ocean/marine, coastal/ocean-land interface, or land/terrestrial-based forestry, agroecosystems, for example) integrated with human impacts and interactions. Our interactions with these systems vary from weak to strong, their boundaries change from open to closed, among other defining characteristics. By "real-world" I am contrasting such problems with problem solving and obtaining solutions and insights regarding more theoretical or more "idealized" or abstracted problems. "Real-world" problem solving recognizes the inherent interconnectivity, heterogeneity of ecosystems, and the ability of these systems to adapt. It aims to bridge the divide between our qualitative and quantitative understanding of more tractable solutions and defined problems to those that are more integrative, extended, and complex. This demands more of our current scientific theory, methodologies, and knowledge, to advance the frontier of science toward a future that is sustainable for both ourselves and the systems we depend on.

In *Complexity Theory for a Sustainable Future* (2008), J. Norberg and G. Cumming detail how advances in complexity theory, and understanding of complex adaptive ecosystems and socio-economic systems contribute new insights for adaptive management of these systems involving the concepts of resilience, scaling, asymmetries, self-organization, and regime shifts. Their book focuses on bridging the gap between theoretical and applied perspectives in the management of complex adaptive systems. While my book shares the same central aim to further the theoretical and applied understanding of complex dynamic systems, it expands on how statistics bridges this theory-data gap and showcases the real-world application of statistics to complexity, risk, and uncertainty.

The integrated approach, while at first may appear more heterogeneous and hybrid, has far more realistic assumptions, typically incorporates a broad set of uncertainties, provides greater methodological flexibility, and has a higher potential for inclusion in practical, operational, and industrial applications. Through my own interdisciplinary training, teaching, and public-good research, it became apparent to me that not enough emphasis and attention is being given to teaching or applying integrative problem solving in addressing environmental problems. Such integration requires more than just putting researchers or practitioners in a room together with a problem statement. It requires a sufficient appreciation, qualitative and quantitative understanding of ecosystems and knowledge of the wide variety of approaches, methods and datasets available for advancing a more holistic, interdisciplinary perspective and 'systems-level' understanding of environmental problems in terms of how we rely on and interact with ecosystems.

The broader motivation behind writing this book was to detail how statistical concepts, methodologies and applied insights are an essential requirement for translating sustainability concepts, principles, and frameworks into meaningful action. Scientific-based sustainability frameworks that go beyond broad concepts and generalities need to be devised, tested, and put into action. International and national institutions need to establish new sustainable metrics capable of integrating theoretical and applied knowledge and providing sufficient flexibility to refine them. These frameworks must be well-structured, salient, credible, and legitimate to adequately support and instill urgent action by better engaging organizations and citizens and helping them individually or collectively to respond - increasing societal adaptation capacity.

I see an urgent need to accelerate the application of statistics to ecosystems in providing enhanced methods and integrative technology-transfer solutions to address problems related to food, water, energy scarcity and climate change risks, vulnerability, impacts, and adaptation. Such problems include: pesticide transport and soil water contamination, greenhouse gas emissions, climate change impacts on crop production, crop growth and phenology dynamics, biofuel supply-chain modeling and energy supply risk assessment, remote sensing applications, and forecasting of extreme climatic events. The book highlights substantial, upcoming challenges linked with major aspects of modeling ecosystems that require further research.

This book is directed toward technical practitioners, scientific professionals, advisors and researchers, as well as upper undergraduate- and graduate-level students. It requires a fundamental grounding in theory and practice related to environmental science, and a basic level of understanding in building and applying quantitative methods for exploring data and quantitative modeling of spatial and temporal patterns and processes. Nonetheless, it provides an up-to-date reference to many significant scholarly and government literature references that provide a rich synthesis for those interested in further clarification, self-learning, and more in-depth investigation.

This book has many unique elements and features:

- It showcases the integrative, interdisciplinary scientific perspective

- It contains self-contained, state-of-the-art expositions of the core issues with extensive cross-referencing to help guide the reader through details and aspects in problem solving involving complex systems

- It connects the latest ecosystem concepts, hypotheses, and theories to applied understanding and insights

- It provides a synthesis and discussion of the latest context and knowledge of Earth system dynamics, resource depletion, and sustainability

- It includes relevant material and latest reported estimates, condensed from a broad set of regional, national, and international scientific and governmental reports

- It summarizes the current understanding and knowledge gaps related to major environmental problems and challenges, providing a foundation for putting statistics at the core of emerging sustainability science and industrial ecology

- It highlights applications involving a diverse range of data types, and the integration of new observational technology and platforms, such as satellite remote-sensing and wireless sensor networks

Chapters 1 and 2 provide a broad, integrated, perpective on sustainability and integrated risk, followed by a background and synthesis of the multi-scale changes and impacts taking place within ecosystems worldwide. Chapter 3 focuses on complex adaptive systems theory and alternative ways it can be useful in solving sustainability problems. Chapter 4 details many of the challenges in real-world problem solving and how geospatial approaches and statistical attributes of integrated risk can be statistically framed as an integrated stochastic sustainability control problem. Building on fundamentals detailed in the first three chapters, this chapter provides a synthesis of the latest measurement and analytical techniques, including research conducted by the author. Here, uncertainty arising from the strength of cumulative impacts and sensitivity between environmental, social, and economic trade-offs are key to obtaining robust solutions. Chapter 5 provides the future outlook in terms of statistical-based forecasting and the increasing use of artifical intelligence techniques in tracking and guiding our sustainable development.

Our sustainable future will require adaptive policy, science, and institutional arrangements, operational mechanisms, and sustainability tools. Such flexibility will enable us to track, integrate, and respond to environmental, economic, and societal risks more rapidly and comprehensively. I hope this book informs, motivates, and offers useful and meaningful theoretical and practical guidance, as part of a scientific evidence-based prescription for furthering global sustainable development.

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