Preface

The world in which we live is one of continuing change, which affects our environment, and the flora and fauna in it. Under the umbrella of "heterogeneity analysis," the understanding of changes locally and globally at short and longer terms, through accurate and precise quantification based on sound modeling, provides the basis for reliable predictions in space and time. Accordingly, I have written this book first of all as a dissertation on the theme of spatio-temporal heterogeneity. Loosely speaking, that includes "recognizing heterogeneity when it passes by" and being aware of the statistical approaches and tools available for its assessment, to be an informed user in due time. Definitively, I have not written a methods book. Instead, spatial or temporal heterogeneity comes first and the relevant analytical methods follow. Therefore, the concepts are introduced and discussed in words in the body of the text, the corresponding formulas and equations being distributed between the body of the text and appendices or tables.

Since Peter Whittle's (1951) *Hypothesis Testing in Time Series Analysis* and Bertil Matérn's (1960) *Spatial Variation*, numerous books on related topics have been published and each of them has its "raison d'être." One of the particularities of *Spatio-Temporal Heterogeneity: Concepts and Analyses* is that the treatment of heterogeneity analysis performed in it involves space and time taken separately or jointly, which ensures uniformity in notation and terminology throughout regardless of the framework. Two other consequences of this unifying approach are that (i) the material covered here replaces, in a sense, a number of sections in a number of books written for one or the other framework, and (ii) thanks to the CD-ROM with MATLAB® and SAS codes, analytical tools usually offered in different packages are made accessible in one place, together with computer programs not available elsewhere.

Biologists and environmentalists are often challenged on the ground of statistics, not due to lack of information or effort, but because matching a statistical method to the non-statistical question of interest can be a

subtle task. Things become even more complicated when the words and concepts used in statistics do not carry the same meanings for non-statisticians. This is the case in particular for the concepts of statistical heterogeneity and ecological heterogeneity, as emphasized in "Spatial heterogeneity against heteroscedasticity: an ecological paradigm vs. a statistical concept," by Pierre Dutilleul and Pierre Legendre, a Forum article published in *Oikos* in 1993. This is why one of my goals in writing this book was to marry the two points of view, by explaining to biologists and environmentalists what the parameters of statistical models exactly mean when they are used to measure heterogeneity in space and time. I also wanted to describe how to estimate these statistical parameters and assess the significance of estimates correctly.

Spatio-Temporal Heterogeneity: Concepts and Analyses responds to the need that biologists and environmentalists have to know more about the statistical analysis of spatio-temporal heterogeneity, but no book on this topic had been written for their audience. From the statistical perspective, the response, or stochastic process, can be modeled with the same fundamental equation or a variant, whether it is purely spatial, purely temporal, or spatio-temporal, without or with replication. This general model is applicable whether space and time are represented by quantitative indices or by levels of qualitative factors. From the biological and environmental perspectives, the model is directly related to the nature of the data, the sampling or experimental design, and the questions of spatial or temporal heterogeneity addressed in the study. Links are facilitated by the use of a cube with eight cells, defined by (i) the pattern serving as support for the heterogeneity analysis, (ii) the axis defining the domain of observation, and (iii) the potentially heterogeneous component of the stochastic process. The questions of interest in a given study will be linked to one or another cell of the cube, and will be assessed by one or several appropriate statistical methods. This way, questions regarding ecological heterogeneity will be defined in a sound statistical framework, and the ecologist will be brought to the statistics *a priori* instead of the statistics being brought to the ecology *a posteriori*.

With a volume providing a compendium that merges effectively the two perspectives on spatio-temporal heterogeneity, non-statisticians will find here a sufficient amount of information about the statistical analysis both in theory and in practice. The volume could serve as a primer, should more specialized statistical literature prove necessary. For their part, statisticians will see how some of their models for heterogeneity analysis in space and time may apply in the biological and environmental

contexts. From the sample data collected in those fields, they will be able to judge whether the assumptions of the analytical methods are satisfied or not. In *Spatio-Temporal Heterogeneity: Concepts and Analyses*, the reader will find a great variety of examples, in plant ecology and the earth and atmospheric sciences as well as in animal biology, forestry, and limnology, to name a few. These examples illustrate not only the application of statistical methods, with tables and figures, but also the biological or environmental motivation for the heterogeneity analysis, and finish with the interpretation of results. Focus is on clarity and precision – the two are not contradictory. Focus is also on simplicity because it is sometimes thought that, in the statistical sciences, it is easy to be complicated and difficult to be simple . . .

This book is intended to meet the needs of everyone planning to analyze some spatial or temporal aspect of ecological heterogeneity. It could be used by advanced undergraduate students in the life sciences and environmental engineering and by graduate students in ecology and environmetrics as well as in applied statistics. All that it takes to understand the main part of the material, with the exception of a few sections where a deeper treatment of the topic is performed, is a good introductory statistics course or book with a clear presentation of the concepts of mean, variance, and correlation, and a minimum mathematical background. The book could serve as a reference for researchers in the biological and environmental sciences and for statistical consultants, interested in learning the different types of spatio-temporal heterogeneity and the statistical models and methods appropriate for the analysis of each type. The book could be a source of inspiration for applied statisticians who may find in it ideas for the development of new methods of time series and spatial data analysis. Finally, parametric statisticians with interests in the analysis of spatial and temporal, univariate and multivariate stochastic processes will find useful material in specific chapters.

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