

Spatial Analysis

A Guide for Ecologists

Second Edition

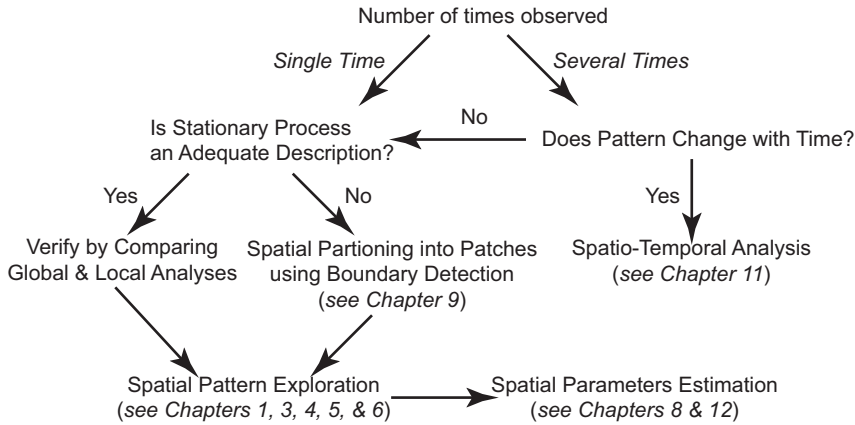
Nowadays, ecologists worldwide recognize the use of spatial analysis as essential. However, because of the fast-growing range of methods available, even an expert might occasionally find it challenging to choose the most appropriate one. Providing the ecological and statistical foundations needed to make the right decision, this second edition builds and expands upon the previous one by:

- encompassing the basic methods for spatial analysis, for both complete census and sample data;
- investigating updated treatments of spatial autocorrelation and spatio-temporal analysis;
- introducing detailed explanations of currently developing approaches, including spatial and spatio-temporal graph theory, scan statistics, fibre process analysis, and hierarchical Bayesian analysis;
- offering practical advice for specific circumstances, such as how to analyze forest Permanent Sample Plot data and how to proceed with transect data when portions of the data series are missing.

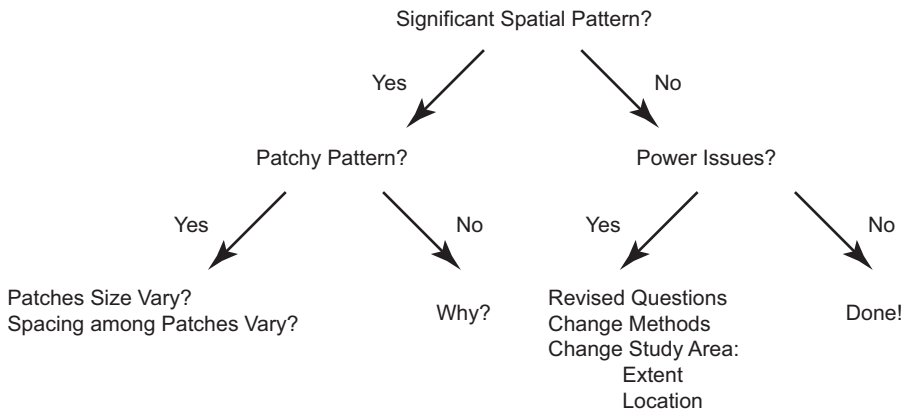
Written for graduate students, researchers, and professionals, this book will be a valuable source of reference for years to come.

Mark R. T. Dale is the Provost of the University of Northern British Columbia, and Professor in the Ecosystem Science and Management Program. His research concerns the effects of interactions between plants on the spatial relationships of plants of different species in a community and the effects of population processes on the development of spatial pattern in the vegetation, as during succession. One main focus of research in the past twenty years has been the analysis of spatial structure in plant communities.

Marie-Josée Fortin is Professor of Spatial Ecology in the Department of Ecology and Evolutionary Biology, University of Toronto. Her research focuses on the application of spatial ecology to fields of research such as conservation biology, ecotone detection, disturbance ecology, organismal dispersal, landscape genetics and functional connectivity of landscapes. She has been awarded the 2013 Distinguished Landscape Ecologist Award by the United States Chapter of the International Association for Landscape Ecology (US-IALE).



Decision-Tree of the Spatial Analyses Presented in the Book



Key Questions to Ask while Analysing Spatial Ecological Data

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Mark R. T. Dale and Marie-Josée Fortin
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A Guide for Ecologists

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Mark R. T. Dale

University of Northern British Columbia

Marie-Josée Fortin

University of Toronto



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**To Phyllis, John and Martha
À Ian**

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Preface

Spatial analysis has been a rapidly growing field in ecology for the past decade (e.g. since Fortin & Dale 2005). This growth derives from at least three factors: (1) an awareness among ecologists that spatial structure is an essential component in ecological thinking; (2) the all-too-obvious alteration of landscapes around us at an increasing rate, requiring constant re-evaluation of their spatial heterogeneity; and (3) the ready availability of software to perform many types of spatial analyses. One major problem with the broad availability of spatial analysis software is that it is easy to use them incorrectly. Incorrect application arises because: (1) ecologists are not fully aware of the issues of spatial scales; (2) ecologists are only slowly realizing the full implications of the prevalence of spatial autocorrelation in their data, which are usually not independent and thus violate the assumptions of standard statistics; and (3) ecologists are aware of the importance of spatial structure in the systems they study, but they are not yet familiar with the many different ways that spatial structure can occur in those systems. In part, that is why we need to go beyond narrowly defined spatial statistics into the broader area of spatial analysis more generally. The purpose of this book is therefore to provide a bridge between the current understanding of the need for spatial analysis and the uncertainty of many ecologists on how to perform and interpret these kinds of analysis.

The motivation for this book is to introduce ecologists to a large array of methods available for spatial analysis. The scope of this book is quite broad, not as specialized as Dale (1999), which concentrates on the analysis of static spatial pattern and with more breadth

of coverage than Fortin & Dale (2005) by including topics not covered there (e.g. spatial aspects of diversity analysis). It is crafted as a reference book that could be used as a text in a course introducing ecology students to spatial analysis. The intent is that the book will help both those who do not know how to start dealing with spatial analysis in ecological studies, and those who have started but are unsure how to proceed. Each chapter is more or less self-contained but there are several threads that link them together, including the application of methods and their interpretation in addressing ecological questions. Our goal is to provide a broad overview of a wide range of well-established spatial methods, without much detail of the theoretical background or mathematical derivations (both are available elsewhere, in more specialized texts such as Cressie 1993). We hope that we provide sufficient detail for ecologists to apply and understand the methods. We do not cover all the methods that have ever appeared; we have been selective, but we have tried to go beyond what is readily available in the ecological literature, and to include references from fields such as geography, geology and epidemiology, where appropriate.

Most ecological questions are aimed at understanding the complexity of nature and how it works, by testing hypotheses about ecological processes, their context, and their interactions. This knowledge-building is based on observation, pattern detection, experimentation, and modelling. Hence for ecologists, pattern recognition is only one step in a series of steps to disentangle the complexities of natural systems. Thus, the ecological motivation for performing spatial analysis is to detect pattern, but that is only the beginning of answering bigger questions. Ecologists want to understand the process that generates the pattern. Geographers are like ecologists in that the description of the phenomenon is of interest, but not the final goal. Epidemiology is essentially applied ecology: looking for pattern to find the process. The classic example is John Snow's study in the 1850s that used the spatial pattern of disease incidence to determine that the Broad Street pump in London was the source of a cholera outbreak (cf. Haining 2003). Identifying the pattern leads to an understanding of the system that

gave rise to it. In ecology, however, many of the puzzles are of much greater complexity than tracing the source of disease. Consider the complexities of the processes that give rise to the spatial arrangement of 20 species of tree in a temperate forest... and then those for a tropical forest with hundreds of tree species... and then all the insects in the tropical forest...

This book stems from years of teaching by both authors in their respective universities. Also, it results from career-long learning and from collaborating with our mentors and colleagues: Barry Boots, Ferko Csillag, Geoffrey M. Jacquez, Pierre Legendre, Neal Oden, Chris Pielou, Robert Sokal, Tony Yarranton, NCEAS working groups including 'Integrating the Statistical Modeling of Spatial Data in Ecology', and many others.

We were fortunate to have several people helping along the way with all the details. We thank those who helped: creating the figures: Gillian Forbes, Aaron Hall, Patrick James, Stephanie Melles, Alexander Watts and Agnes Wong; editing the various versions of the text: Gillian Forbes, Stephanie Melles, Cheryl Smyth and Rebecca Torretti; carrying out the spatial analyses of the data: Pierre Legendre, Patrick James, Yuanyuan Liang, Stephanie Melles and Agnes Wong; with the field work: Ilka Bauer, Vernon Peters, Steve Kembel, Michael Simpson and Agnes Wong. Also, we were privileged to have access to excellent software packages, thanks to Mike Rosenberg (PASSaGE) and Geoffrey Jacquez (BoundarySeer and ClusterSeer by TerraSeer 2001). We thank the Ministry of Natural Resources of Ontario for providing landcover data, Natural Resources Canada for providing elevation data, the official sponsors of the OBBA (Bird Studies Canada, Canadian Wildlife Service, Federation of Ontario Naturalists, Ontario Field Ornithologists, and Ontario Ministry of Natural Resources) for supplying Atlas data.

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Mark R.T. Dale
Marie-Josée Fortin